Silviculture to Reduce Landscape and Stand Susceptibility to the Mountain Pine Beetle

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Abstract

The current landscape in western Canada includes an abundance of older pine stands that have matured without any active silviculture and are consequently very susceptible to mountain pine beetle outbreaks. The key to avoiding future damage is to focus long-term management of pine forests on relieving the conditions that facilitate landscape-level outbreaks. We present an overview of this management concept in three parts: a) landscape-level management of existing pine forests to reduce susceptibility to the development of epidemic outbreaks; b) stand-level management of future pine forests to reduce susceptibility to infestation; and, c) preliminary results of recent research examining the efficacy of spacing mature stands to prevent development of incipient outbreaks.

Introduction

The mountain pine beetle is a native insect in the pine stands of western North America. It causes little damage to forest resources at low population levels, but when populations build to an epidemic the losses are normally severe and occur at the landscape level. Where pine forest that has reached maturity without active silviculture predominates on the landscape, outbreaks last 10 years or more and kill most large-diameter pine trees on hundreds of square kilometres. When this happens, management for all forest resources is disrupted and effects on forest-dependant values and communities persist for decades. The current outbreak in central British Columbia (BC) is a good example of such a situation (Ebata 2004).

Historically, large mountain pine beetle outbreaks have been restricted by climate to a portion of the pine forests of western North America (Amman et al. 1977). However, recent analyses indicate that the suitable range for mountain pine beetle has expanded during a recent warming trend and future outbreaks are likely at higher elevations or more northerly latitudes than in the past (Carroll et al. 2004). Increasing mountain pine beetle activity is now becoming apparent in northern BC and on the eastern slopes of the Rocky Mountains in Alberta, and the potential for future expansion into hybrid and jack pine forests across Canada is questioned (Ono 2004). Lessons learned in areas historically subject to outbreaks may be applied in all these forests.

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The key to avoiding unacceptable damage by mountain pine beetle is a focus on long-term management of pine forests to alleviate those conditions that lead to outbreaks at landscape level (Safranyik et al. 1974). The objective of this paper is to present an overview of relevant management concepts, in three parts:

1) landscape-level management of present pine forests to reduce landscape susceptibility to development of epidemic outbreaks;
2) stand-level management of future pine forests to reduce stand susceptibility to development of incipient infestations; and,
3) preliminary results of a research study funded by the Government of Canada's Mountain Pine Beetle Inititative that examines the efficacy of spacing existing mature stands to reduce susceptibility to development of incipient infestations.

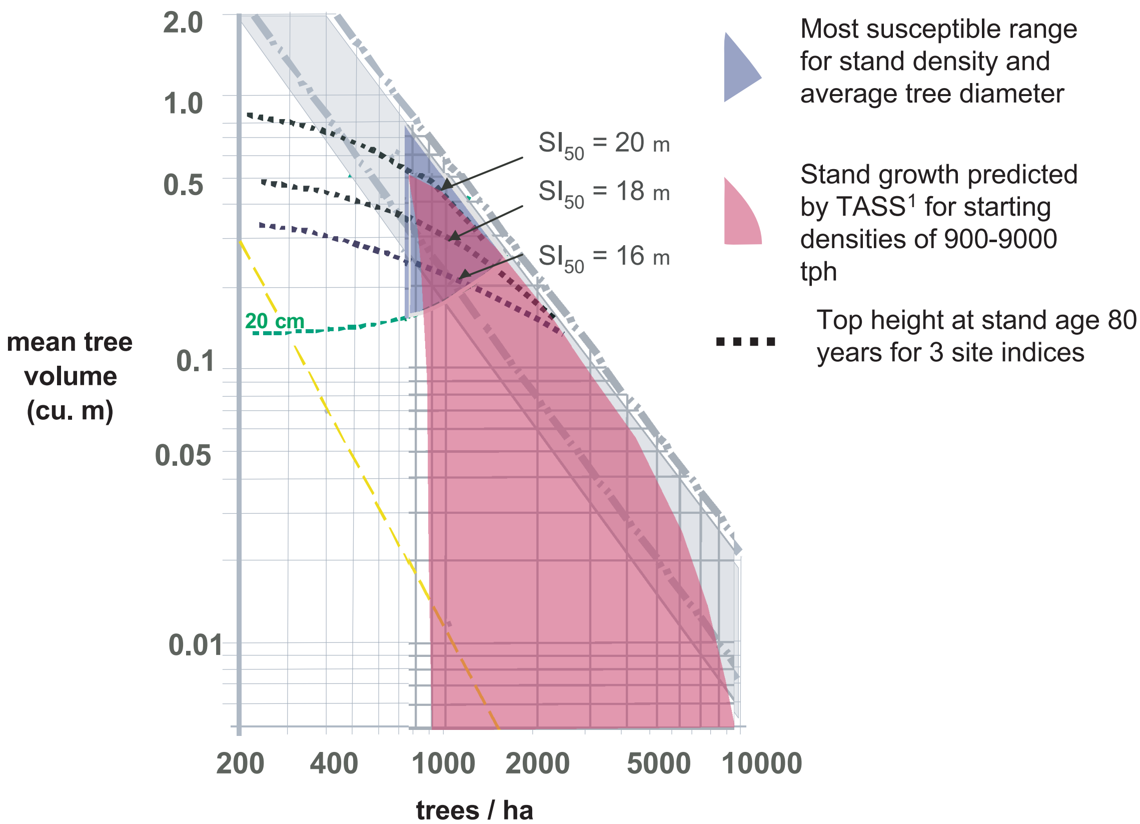
Landscape-Level Management

Management to reduce landscape susceptibility is based on knowledge of the basic biology and outbreak epidemiology of the mountain pine beetle, and their relationship with stand dynamics of lodgepole pine and its distribution on the current landscape. Carroll and Safranyik (2004) reviewed the biological basis for stand susceptibility and Safranyik (2004) reviewed the outbreak cycle. Stand characteristics usually associated with mountain pine beetle outbreaks in natural stands include stand age (more than 80 years at breast height), average tree diameter (greater than 20 cm) and stand density (750 to 1500 trees/ha) (Hopping and Beall 1948; Safranyik et al. 1974; Cole and Cahill 1976; Shore and Safranyik 1992). Age is associated with the effects of declining tree vigour on individual tree resistance to the blue-stain fungus carried by attacking beetles (Safranyik et al. 1975). Diameter is associated with the food and space requirements needed to support brood development for expanding populations (Cole and Amman 1969; Amman 1972). Stand density affects tree vigour and within-stand microclimate which influence success of bark beetle dispersal, attack or brood development (Bartos and Amman 1980). Growth modelling (Fig. 1) indicates that unmanaged natural-origin stands, which start at any density between 900 and 9,000 trees/ha at breast height age on land with typical site indices, will follow growth trajectories to a susceptible density and average diameter within 80 to 100 years (Farnden 1996). In the pine forests of western Canada, examining the age-class distribution of pine-leading stands in an area is a simple way of assessing the proportion of area carrying susceptible stands (Fig. 2).

Susceptibility of the Current Landscape

The susceptibility of any landscape unit to an epidemic outbreak depends on the amount of area in susceptible stands, how they are spatially arranged and how easy they are to access for direct control of incipient infestations. The current landscape in western Canada is very susceptible. Widespread natural and human-caused fire during early settlement followed by fire suppression and low utilization of lodgepole pine timber until fairly recently, resulted in accumulation of mature and overmature lodgepole pine forest in the BC interior and along the east slopes of the Rocky Mountains. In BC, the area of lodgepole pine greater than 80 years of age has increased from about 2.5 million ha in 1910 to more than 8 million ha in 1990 (Taylor and Carroll 2004). Most of this area is found in large swaths at mid-elevation in mountain valleys or on the large interior plateaus. It is this concentration of contiguous susceptible pine stands on large areas that make expansion of unchecked incipient infestations to landscape-level outbreaks highly likely, through a combination of local population growth and long-term dispersal, and underscores the need to bring the current landscape under active management to prevent future epidemic outbreaks.

Three main conditions must be satisfied before a landscape-level outbreak will occur. Several years of suitable weather (mild winters and warm, dry summers) are required to allow population growth to the point where large trees can be successfully attacked and small patch "incipient" infestations develop



[1] B.C. Ministry of Forests - Tree and Stand Simulator Model
www.for.gov.bc.ca/hre/gymodels/TASS/model.htm

Figure 1. Stand Density Management Diagram for natural-origin lodgepole pine, illustrating how all stands starting at breast height age from densities between 900 to 9000 trees/ha become susceptible to mountain pine beetle outbreaks within 80 to 100 years.

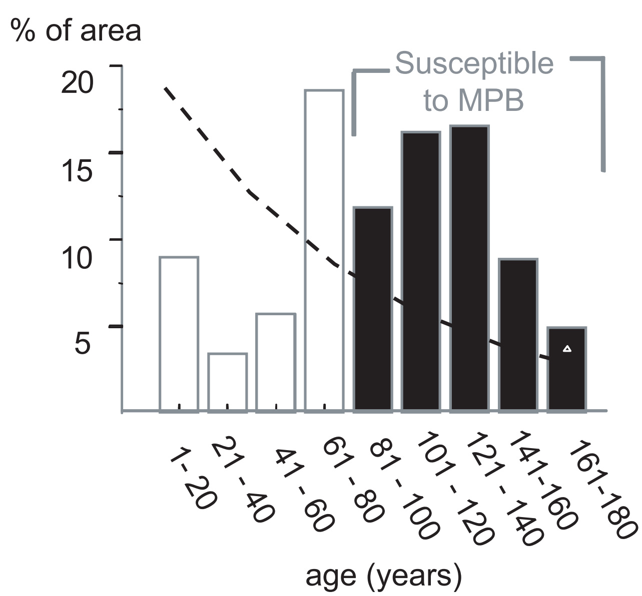


Figure 2. Age-class distribution of pine-leading stands in the SBS, SBPS, and MS biogeoclimatic zones of British Columbia. Dashed line indicates expected frequency distribution with a 100-year fire-return interval.

across the range where pine and mountain pine beetle occur together. At least some of these infestations must develop unchecked by weather or management action until they begin to export very high numbers of mountain pine beetles. Lastly, there must be an abundance of susceptible stands on the landscape to sustain these high populations. Periods of favourable weather occur from time to time throughout the range of mountain pine beetle and are not subject to management intervention. Shore and Safranyik (2004) discuss how timely and aggressive application of direct control to incipient infestations can slow or prevent transition to an outbreak at landscape level. In the current landscape, direct control will remain difficult and costly until the underlying cause (a concentrated abundance of susceptible pine on the landscape) is addressed.

Planned Stand Replacement

The primary action required to lower current landscape susceptibility is reduction of the amount and concentration of old pine stands, which can only be done through planned stand replacement. Fire and logging are the main tools available. Targets for the desired future age-class distribution will differ depending on land use emphases, but in any case a planner should aim at creating a landscape mosaic with less old pine, in smaller and more widely-separated parcels, where age-class, size and species mixes will not favour the development of large scale outbreaks. Two possible options for the pine component of a landscape unit are illustrated in Figure 3. One approximates the average age-class distribution expected in unmanaged landscapes with a natural wildfire return interval of 100 years (Taylor and Carroll 2004), which might be the desired condition for parkland or "wilderness", while the other illustrates a sustained yield for commercial timberland with most stands cycled on an 80-year rotation.

If there were no mountain pine beetle, adjusting the age-class distribution and redistributing it across the landscape in smaller patches would be relatively simple over time. Several decades of scheduled stand replacement based on a spatially-explicit inventory (through timber harvest or prescribed burning), and subsequent stand management to adjust density, growth rate or species composition would create the desired landscape condition. In the presence of mountain pine beetle the process is slightly more complex (Fig. 4). Harvest scheduling and access development must be flexible enough to incorporate direct control actions required to keep beetle populations low. A critical step is assessment of risk and susceptibility for existing stands (Shore and Safranyik 1992). High risk stands should be removed at the earliest logging chance, and access developed into areas of susceptible pine at lower risk so that they can be broken into smaller patch mosaics of diverse age, species, and tree size as opportunity allows. Consistent and thorough monitoring of the population status and location of mountain pine beetle is necessary for both risk and susceptibility rating, and for directing effective control activities during incipient infestations.

Stand-Level Management

Stand-level management can also play a significant role in reducing the probability of outbreak development if it is applied within a landscape-level plan to reduce the amount and concentration of old pine. This section of the paper will briefly discuss stand-level management options to reduce the current susceptibility of existing stands, and for planning and managing new stands to avoid future susceptibility.

Species Conversion

Many existing lodgepole pine stands will succeed to more shade tolerant species in the absence of a stand-replacing disturbance such as fire. In such cases, species conversion through pine removal from maturing mixed stands will accelerate succession to non-susceptible species, reducing the amount of susceptible forest while maintaining some mature forest cover for other values. Where appropriate and needed in the landscape plan, species conversion can also be achieved through preserving advanced regeneration of non-pine species during harvest, or by establishing alternative species after harvest.

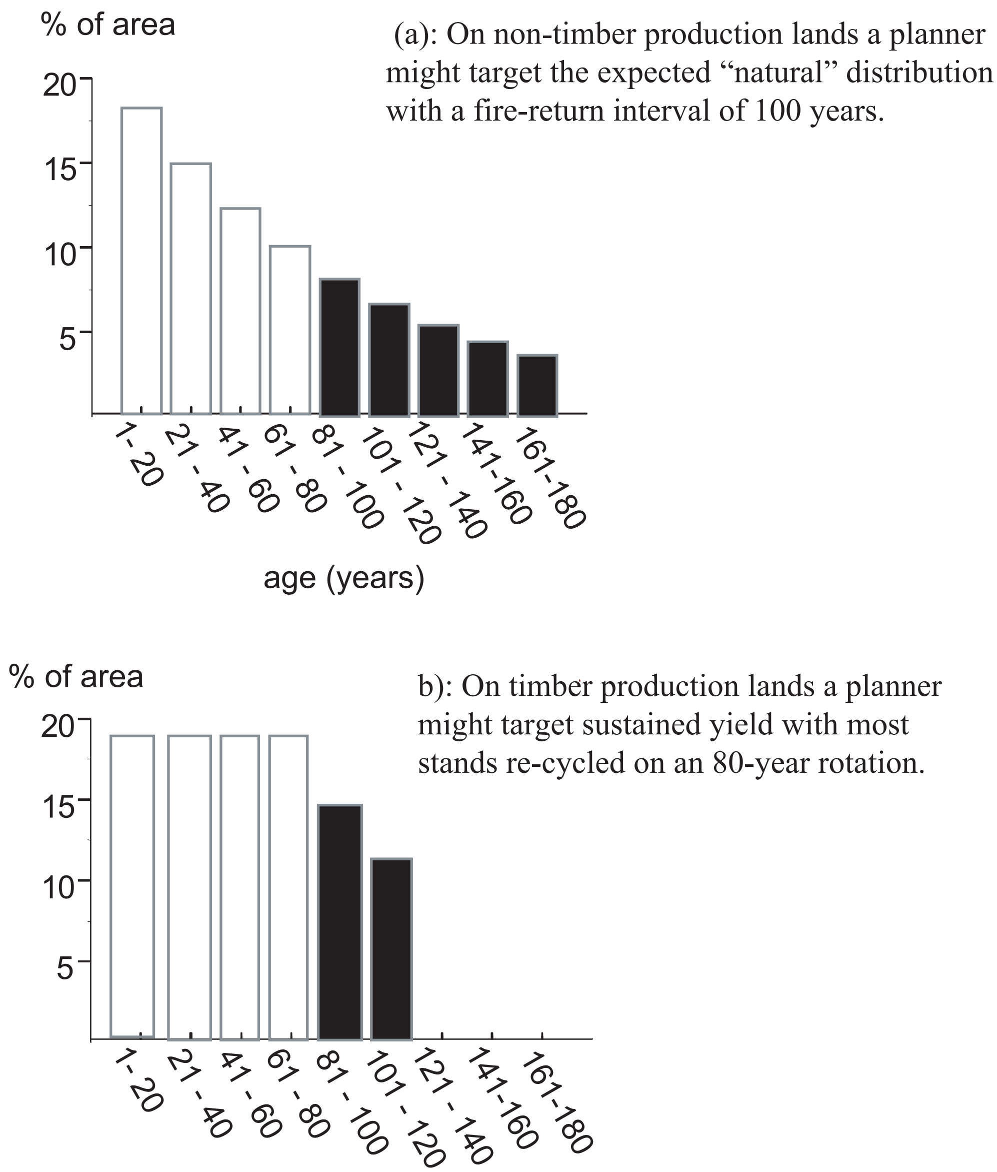


Figure 3. Two possible targets for the age-class distribution of pine stands in a landscape planning unit.

Access Development and Shorter Rotations

Most stands will regenerate to lodgepole pine after harvest or burning, and the question has been asked: "If we re-establish pine on areas affected by mountain pine beetle, are we simply setting the stage for another epidemic in 80-100 years?" It is important to remember that the current scale of mountain pine beetle damage is only possible because the landscape is poorly accessed (making direct control difficult) and most stands are overmature and largely unmanaged. Bringing the land under active management relieves both these conditions. Access development facilitates control of incipient infestations, while recycling stands on a rotation less than 100 years limits the possible level of damage by reducing the amount of susceptible pine at any given time.

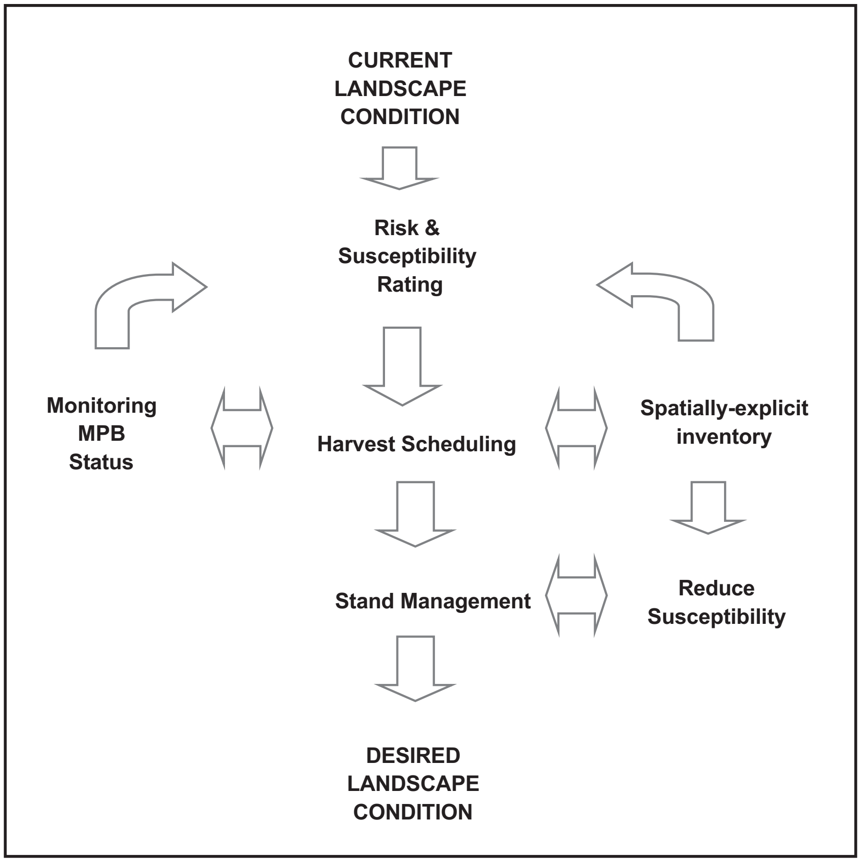


Figure 4. A simplified model for landscape management in pine-dominated operating areas.

Stand Hygiene

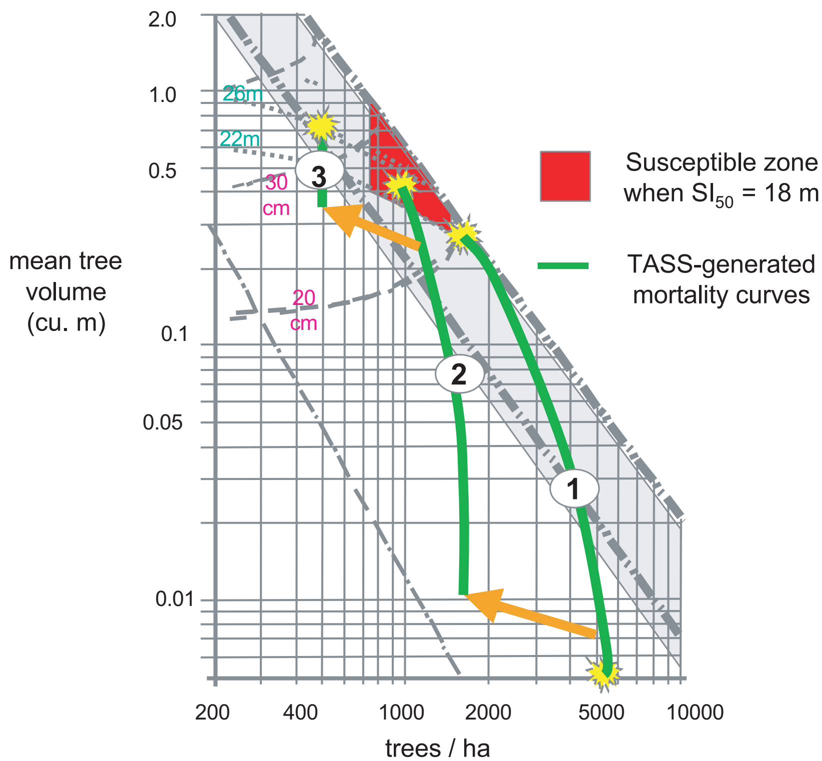
Endemic populations of mountain pine beetle generally require weakened or decadent trees for successful completion of their life cycle (Safranyik 2004). Removal of such trees during stand tending should limit potential for establishment and maintenance of endemic populations in stands managed for timber and reduce probability of incipient outbreaks when periods of weather favour population growth.

Density Management

Development of stand characteristics optimum for mountain pine beetle outbreaks coincides closely with "physiological maturity", which is defined by the point in stand development when current annual increment declines to below the mean annual increment (Safranyik et al. 1974). The onset of physiological maturity may be delayed by management actions that retain stand vigour, such as density management (Anhold and Long 1996). Density management can also be used to direct stand growth to meet specific product or timber supply objectives (Farnden 1996).

Figure 5 illustrates how two silvicultural entries to a fully-stocked, natural lodgepole stand starting at 5000 trees/ha at breast height on a site with SI_{50} = 18 m affects stand development. Without any treatment ("1" in Fig. 5), the stand would self-thin to about 1500 trees/ha by 80 years of age, just reaching average diameter where outbreaks typically develop. The stand could then be harvested, yielding 270 m^3 per ha of .25-m^3 average piece-size or, if beetle pressure is low, left to grow with regular monitoring of mountain pine beetle activity. If the same stand is pre-commercially thinned to 1600 trees/ha ("2" in Fig. 5), it develops to about 1100 trees/ha at age 80 and about 330 m^3 per ha, of larger average piece-size, which may be a more desirable logging chance if sawlogs are the product objective. If it is necessary or desirable to carry this stand to larger piece size or older age to meet some timber supply, habitat, or visual quality objective, a commercial thinning entry at about age 60 is an option. Removing approximately 100 m^3 of sawlog material would shift the growth trajectory away from conditions where outbreaks would ordinarily develop ("3" in Fig. 5), and yield about 350 m^3 per ha with large piece size at 100 years breast height age.

The above examples illustrate only three possibilities. When stands are brought under active management, there are many possible pathways for stand development that will lead to acceptable end products with reduced stand and landscape susceptibility to mountain pine beetle.



(Source of Stand Density Management Diagrams: Farnden 1996)

Figure 5. Stand Density Management Diagram for natural-origin lodgepole pine, with TASS-generated mortality curves illustrating how density management can lead to acceptable final products on 80-year rotation or maintain low susceptibility to mountain pine beetle on extended rotation.

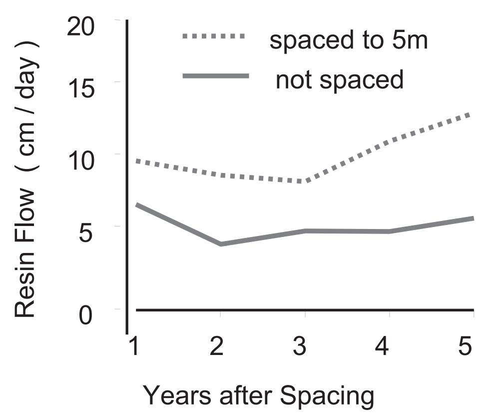
Spacing Mature Stands ("Beetle Proofing")

In most operating areas in western Canada, it is difficult to remove all stands with high susceptibility quickly without exceeding other constraints on harvest (e.g., timber supply, visual quality, habitat, etc.) and it is often important to hold some mature stands in the harvest queue while older stands are recycled. One tactic that has shown considerable promise is commercial thinning of some mature stands to a uniform inter-tree spacing at less than 600 trees/ha (also known as "beetle proofing"). The prescription requires thinning from below to enhance individual tree vigour, which increases ability to produce resins that are the primary defense against attack, and uniform spacing to create stand microclimate conditions (higher temperatures, light intensity, and within-stand winds) that negatively affect beetle dispersal, attack behaviour or survival (Bartos and Amman 1980; Amman and Logan 1988). To optimize these effects, stands must be opened to at least a 4-m inter-tree spacing (to increase wind penetration, light and temperature), with the largest, healthiest pine retained (for vigour and windfirmness) and damage to leave trees minimized to avoid stress. It is important to remember that it is increasing inter-tree spacing (not thinning to a target density or basal area) that achieves the microclimate objectives. This prescription, which takes mature stands down to between 400 and 625 trees/ha, usually removes enough volume of sufficient piece-size to ensure a commercially viable operation (Anon. 1999. *Case study in adaptive management: Beetle proofing lodgepole pine in southeastern British Columbia*. BC Min. For. Extension Note EN-039). The Canadian Forest Service has been studying "beetle proofing" for more than a decade and a few of our results are summarized in the following section.

Recent Research on Spacing Mature Stands

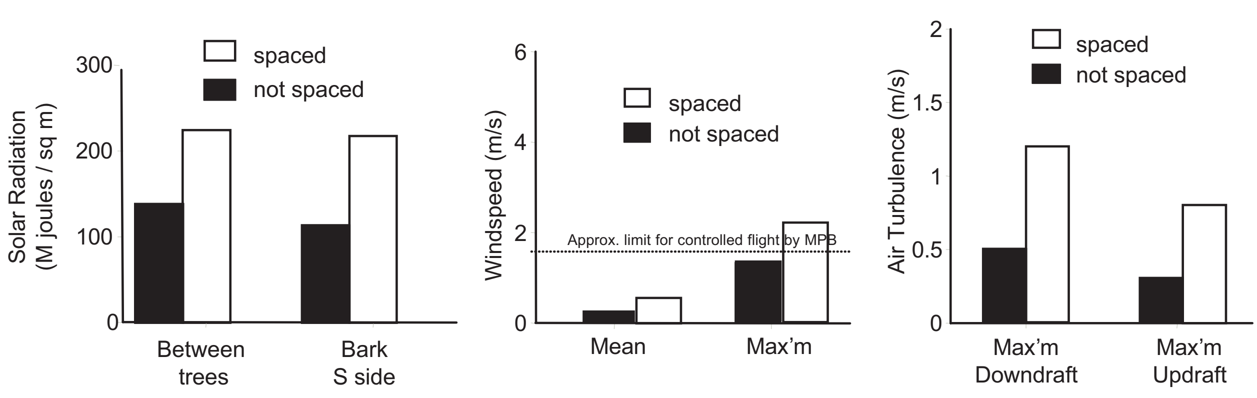
The "East Kootenay" Trial

Three levels of treatment (not treated, spaced to 4 m and spaced to 5 m) were applied to treatment units established in uniform, 90- to 110-year-old lodgepole stands at each of three sites in the East Kootenays between 1992 and 1993. Each treatment unit was instrumented to document within-stand microclimate and trees within each unit were monitored to document tree vigour. Results over the first decade since treatment suggest that the prescription achieves all the desired tree vigour (Fig. 6) and microclimate effects (Fig. 7). Until recently, these stands were not challenged by sufficient beetle pressure to directly evaluate whether these observed treatment effects impact bark beetle behaviour at a stand level.



(Source: Safranyik, Linton and Carroll, unpubl. data)

Figure 6. Comparison of resin production in response to wounding in spaced and unspaced stands from the East Kootenay Trial (mean of 10 trees/treatment on each of 3 sites).



(Source: Benton and Brown, unpublished data)

Figure 7. Comparison of 3 important within-stand microclimate parameters in spaced and unspaced stands from the East Kootenay Trial (5-year average on 3 sites for days in July and August when air temperature exceeds 18° C).

Table 1: Stand descriptions for five case studies of efficacy of "beetle proofing" to reduce incipient infestations of mountain pine beetle.

Location and Treatment Year	Prescribed Treatment	Area (ha)	Stand Density (trees/ha)	dbh (cm)	Age (years)
Cranbrook	No Treatment	3.9	1380	22.7	90
1992	Space to 4 m	5.3	443	25.3	90
	Space to 5 m	2.4	378	24.5	90
Parson	No Treatment 1	1.9	812	28.2	90
1993	No Treatment 2	1.7	1089	24.1	90
	Space to 4 m	2.9	386	22.3	110
	Space to 5 m	2.5	258	25.3	90
100 Mile House[a]	No Treatment	6.6	n/a	n/a	128
1994	Space to 4 m	7.7	549	22.1	124
Hall Lake	No Treatment	3.8	1169	22.3	109
1994	Thin to 500 tph	4.7	573	22.7	109
Quesnel	No Treatment	1.0	1300	21.5	83
1991	Space to 4 m	1.0	484	25.1	83

[a] Some data are not available (n/a) for 100 Mile House because the untreated control area was partially harvested to remove infested trees prior to the survey.

Five Case Studies of "Beetle Proofing"

This field season, we examined five existing side-by-side comparisons of "beetle proofed" and untreated stands[2] (including two of the East Kootenay Trial sites) established since 1991 to determine if changes in microclimate or tree vigour actually translate to a lowered frequency of mountain pine beetle activity at stand level (Fig. 8). Brief stand and treatment descriptions are listed in Table 1.

At each site, we laid out regular areas of known size in each treatment unit and systematically examined every living or dead tree over 10 cm in diameter at breast height for evidence of mountain pine beetle activity. The proportion and number of trees successfully attacked in each stand, attack density and ratio[3] of "green attack" to "red attack" are shown in Table 2. Density of attack and green:red attack ratio is lower in beetle-proofed treatment units than in untreated stands in every case; however, the magnitude of that difference reflects site-specific factors. The Quesnel site, which is located on the leading edge of the expanding epidemic outbreak described by Ebata (2004) has experienced extreme beetle pressure for the last 2 years. Beetle proofing is intended to prevent transition between endemic and incipient phases of the outbreak cycle, not to save stands during an epidemic. About 35% of all trees in each treatment unit have been attacked. In the untreated unit, this fraction includes more than 80% of all trees over 20 cm diameter at breast height (dbh) and attacks are now occurring in smaller diameter trees while about half of trees over 20 cm dbh have been attacked so far in the "beetle-proofed" unit. Although the green: red attack ratio is much lower than in the untreated stand, we expect this already unacceptable level of damage to worsen as large diameter pine in the surrounding area are killed and pressure on the "beetle-proofed" stand increases.

[2] Funding for this work was provided by the Risk Reduction Research Component of the Canadian Forest Service's Mountain Pine Beetle Initiative as part of a project titled "Expansion of "Beetle-Proofing" Research, and Operational Evaluation for Feedback and Adaptive Management."

Figure 8. Location of five case studies assessed for efficacy of "beetle proofing" in 2003.

The other four sites are more representative of the situation for which "beetle proofing" is intended. At Cranbrook, Parson, and 100 Mile House, the prescribed spacing treatment produced the intended result. Untreated stands in all three areas have developed incipient infestations that require direct control intervention, while the "beetle proofed" stands have not. The Hall Lake demonstration area is different in that the prescription called for thinning to 500 trees/ha, rather than spacing to a minimum inter-tree distance. The proportion and density of trees attacked in the untreated stand is three to four times higher than in the thinned area, but the green:red attack ratios are similar (1.8 and 1.4 respectively). Our methods of data collection did not allow testing the influence of density on attack frequency; however, our surveys indicated considerable variation in stand density (142 – 2059 trees/ha) within the thinned stand, and a somewhat higher mean than prescribed. When thinning to target densities, patches of higher density are often left to compensate for natural stand openings and removal of damaged trees along skid trails. These patches may still provide good microclimate for host selection and initiation of attack. It is important to remember that "beetle proofing" requires thinning to minimum inter-tree spacing to maximize the desired results.

Summary

The current landscape in western Canada, which includes an abundance of largely undeveloped older pine stands that have developed without active silviculture, is very susceptible to development of landscape-level outbreaks of mountain pine beetle. Planned stand replacement is required to create a landscape mosaic with less old pine in smaller and more widely separated parcels, where age-class, size and species mixes will not favour the development of large scale outbreaks. Opportunities for reducing future susceptibility of replacement stands include conversion to non-pine species, management on shorter rotations, density management to control stand growth and attention to stand hygiene. There are also limited opportunities for stand-level management of current stands, including pine removal from mixed stands and "beetle proofing" some mature stands to provide flexibility for integration of non-timber objectives on the timber harvest landbase.

[3] As used here, the "Green:Red Attack Ratio" is a ratio of the total number of trees attacked (whether successful or unsuccessful) in the most recent year to the total number of trees attacked in the preceding year. Some trees may have been attacked in both years.

Table 2: Mountain pine beetle activity since treatment at five case studies of "beetle proofing" to reduce incipient infestations of mountain pine beetle.

Location and Treatment Year	Prescribed Treatment	Proportion of Stand Attacked (%)	No. of Trees Attacked		Green:Red Attack Ratio
			Total	per ha	
Cranbrook	No Treatment	1.6	88	22	1.8
1992	Spaced to 4 m	0.5	12	2	0.3
	Spaced to 5 m	1.9	16	7	0.5
Parson	No Treatment 1	6.9	98	56	2.9
1993	No Treatment 2	1.4	24	15	0.3
	Spaced to 4 m	0.0	0	0	-
	Spaced to 5 m	0.4	1	0	-
100 Mile House[a]	No Treatment	n/a	433	67	n/a
1994	Spaced to 4 m	0	0	0	-
Hall Lake	No Treatment	13.5	579	158	1.8
1994	Thin to 500 tph	56.5	161	37	1.4
Quesnel	No Treatment	34.8	453	453	3.3
1991	Spaced to 4 m	34.5	167	167	1.2

[a] Data for the untreated control area at 100 Mile House are adapted from the pre-harvest survey undertaken by the Ministry of Forests.

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