A STRATEGIC APPROACH TO SLOW THE SPREAD OF MOUNTAIN PINE BEETLE ACROSS CANADA

Prepared for the Forest Pest Working Group of the Canadian Council of Forest Ministers

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Executive Summary

From 1995 to 2015 British Columbia (BC) witnessed the largest mountain pine beetle (MPB) outbreak ever recorded. Over 18.3 million hectares were infested, resulting in a loss of 731 million cubic meters, or 54% of the province's merchantable pine volume, and significant losses to ecological forest values. A reduction of $57 billion in the province's GDP and a $90 billion decline in economic welfare are estimated between 2009 and 2054 (present value). This outbreak also saw the beetle's eastern geoclimatic barrier breached in 2006 and 2009, providing for the spread and establishment into pine forests that have not coevolved with MPB in Alberta, both in lodgepole and jack pine. Since 2004, the Government of Alberta has spent $456 million managing the eastern spread of MPB, and has removed approximately 1.43 million infested trees. Saskatchewan has also contributed almost $4.5 million since 2011 for the management of MPB along the invasion front in Alberta to reduce or eliminate the risk of eastward spread. Given the northern spread of MPB beyond its historical range, Yukon and the Northwest Territories have also completed risk analyses and implemented monitoring plans along their borders with British Columbia and Alberta.

This document presents a strategic approach meant to inform management actions and practices to help contain and limit the eastward spread of MPB. It was prepared in response to a request from the Canadian Council of Forest Ministers Forest Pest Working Group for information about options to slow the spread following a risk assessment (2014) which found that while forests east of Saskatchewan may be less climatically suitable to MPB, their susceptibility to infestations increases. The invasion frontal region as it currently exists between Alberta and Saskatchewan, not only has low climatic suitability for MPB but also represents a bottleneck in pine forest susceptibility and connectivity; which could be suitable for containment.

The strategic containment approach described is based on research and field observations which have shown that early, sustained, and aggressive actions are effective in containing and limiting MPB spread in absence of immigration events. As such removing infested trees when beetle populations are low is akin to addressing spot fires before they coalesce, whereby control of small, potentially feeder populations is central to slowing the spread. The approach is informed by recent research findings and lessons learned from British Columbia and Alberta.

The success of this strategic containment approach is contingent upon continued aggressive management efforts by the province of Alberta. The approach described is consistent with ongoing collaborative management efforts by the Spread Management Action Collaborative (SMAC) between Alberta and Saskatchewan on the eastern invasion front in Alberta. The approach adheres to adaptive management principles which ensure continuous improvement through iterative evaluation and adaption of actions as new information becomes available.

Foreword

This document was prepared as a follow-up to the risk assessment completed by Canadian Council of Forest Ministers (CCFM) Forest Pest Working Group (FPWG) in 2014, and in response to a request from the FPWG for information about options to slow the spread. This document presents a strategic containment approach meant to inform management actions and practices to help contain and limit the eastward spread. Collaborative multi-jurisdictional management actions, which apply the principles and theory outlined in this document, should be considered to help realize that goal.

The organization and contents of this document are aimed at a variety of audiences. **Part I** Introduces the strategic approach and is suited to all audiences. **Part II** provides the more technical aspects of the approach and is well suited to forest pest specialists and managers developing and implementing response plans. **Part III** describes some of the economic challenges and realities of MPB management and is suited to all readers. **Part IV** describes the science behind MPB spread control and is suited to those readers who have an interest in or knowledge of the science of MPB management.

A glossary of terms has also been provided.

Part I: The Approach: Background, Rationale, Overview, and Lessons Learned

Background

This document was prepared as a follow-up to the MPB risk assessment (Nealis and Cooke 2014) completed for the Canadian Council of Forest Ministers (CCFM) Forest Pest Working Group (FPWG), and in response to a request from the FPWG for information about options to slow the eastward spread into boreal forests. This document is meant to build on the collaborative work being conducted by the governments of Alberta and Saskatchewan under the MPB Spread Management Action Collaborative (SMAC).

Rationale

The most recent MPB outbreak in British Columbia, from 1995 to 2015, was the largest recorded with over 18.3 million hectares infested resulting in a loss of approximately 731 million cubic meters, or 54% of the province's merchantable pine volume, and significant losses to habitat and other resource values. This outbreak also saw the beetle's geoclimatic barrier breached in 2006 and 2009, providing for the establishment and spread in novel habitats in Alberta; both in lodgepole and jack pine (Bleiker et al. 2014; Cullingham et al. 2010). Novel habitats refer to landscapes where MPB has not historically occurred, and the pine within these landscapes are referred to as "naïve" hosts because they have not co-evolved with MPB. Since 2004, Alberta has spent $456 million managing MPB in novel habitats and has controlled approximately 1.43 million infested trees. Collaborative efforts between the governments of Alberta and Saskatchewan, advanced by SMAC, have led to contributions by the Government of Saskatchewan of almost $4.5 million since 2011. This funding focuses on the management of MPB at the front end of the leading edge zone in Alberta, herein referred to as the invasion front, to reduce or further eliminate the risk of eastward spread. Given the northern spread of MPB beyond its historical range, Yukon and the Northwest Territories (NWT) have also completed pest risk analyses and implemented monitoring plans along their borders with British Columbia and Alberta.

The Spread Management Action Collaborative (SMAC)

The SMAC is the result of an inter-provincial Memorandum of Agreement (MOA) signed in 2012 between Alberta (AB) and Saskatchewan (SK) to formalize a joint strategy to control the spread of MPB eastward into the Canadian boreal forest. This initiative enables coordinated evaluation of the strategic, operational and tactical plans for MPB control activities that are undertaken annually in areas of mutual interest in high-risk areas in northeastern Alberta. Control operations at the front end of the invasion's leading edge have been funded through the agreement from 2011 to 2013. The MOA was renewed for a further 3 years with the term expiring March 2017. The MOA includes provisions to incorporate additional partnerships in the future.

The effects of mountain pine beetle continue to be a significant concern in western Canada, with concomitant concern in non-infested jurisdictions regarding the potential for spread and establishment. Since MPB breached the geoclimatic barrier there has been heightened awareness of the potential impacts to novel forests north and east of the Rocky Mountains, including lodgepole pine, jack pine, and lodgepole pine/jack pine hybrid forests. Recent research has shown that these naïve trees are suitable hosts and are less resistant and more attractive to MPB, such that low pine volumes and poor host forest connectivity may not be as much of a constraint to eastward movement (Burke and Carroll 2016, Clark et al. 2014). A risk assessment completed for the CCFM in 2014 found that while forests east of Saskatchewan may be less climatically suitable to MPB, their susceptibility to infestations increases. (Nealis and Cooke 2014).

Why is MPB Spread an Issue?
Mountain pine beetle, an invasive native pest, poses a threat to boreal and eastern pine forests and the ecosystem services they provide. Over the last few years, the eastward movement of MPB across Alberta has been slow, a function of poor climate suitability, poor pine connectivity over a heterogeneous landscape, and management actions. This biogeoclimatic "bottleneck" presents the ideal time and opportunity to contain MPB. While the threat to eastern Canada is not imminent, the best opportunity for maintaining a lower rate of spread is now.

The costs of acting early are only a fraction of those associated with the management of wide-scale infestations and the associated impacts to socioeconomic and ecological values such as carbon, critical habitats, recreational and cultural values, and other ecosystem services. The negative impacts of continued eastward spread of MPB on the flow of goods and services from the boreal forest would be widespread, severe and long lasting. An analysis conducted for the CCFM FPWG in 2009 found that the average cost, if just one invasive pest becomes established in Canada over the next twenty years, would be on the order of $34 million annually. Authors estimated that a cooperative approach to managing MPB would yield annualized benefits of $14 million (Nelson et al. 2009).

The potential costs of not acting early are high. Estimates from BC of the economic impact alone, where the short-term benefits that followed from increased harvesting levels are now resulting in dropping Annual Allowable Cuts, is a $57 billion reduction in GDP and a $90 billion decline in economic welfare, measured over the period 2009-2054 (all in present value terms) (Corbett et al. 2015).

Current Status and Recent Trends

In British Columbia, MPB damage has declined significantly, to below 178,000 ha in 2016 from a peak of 10 million ha in 2007, thereby reducing or eliminating the potential for large long-distance beetle dispersal events into Alberta as seen in 2006 and 2009. In Alberta, overwinter mortality survey results showed MPB survival was higher in 2016 than in the previous two winters. This was likely the result of a mild winter and unusually warm spring. With this continuing trend of beetle overwintering success throughout much of their current range, it is very unlikely that populations will naturally decline in the foreseeable future.

In the northern boreal forest, no further detections have been noted along the Yukon/BC and NWT/AB borders since the positive detection along the NWT/AB border in 2014. Similarly, populations have retracted in northern BC, with the nearest spot infestation within 150 km of the Yukon border. In 2016 in Alberta, positive sites were detected east of 2015 detections, including inside the Cold Lake Air

Weapons Range (CLAWR) (Figure 1). Positive sites indicate presence of MPB and not necessarily successfully attacked trees. Historically, climate on the eastern invasion front has led to low recruitment rates and therefore has not been conducive to population growth (Figure 2). However, there are always exceptions to the rule as witnessed in 2016 (Figure 3), the year following El Niño. It is these exceptions which could lead to eruptive populations given the right conditions as described in **Part IV**.

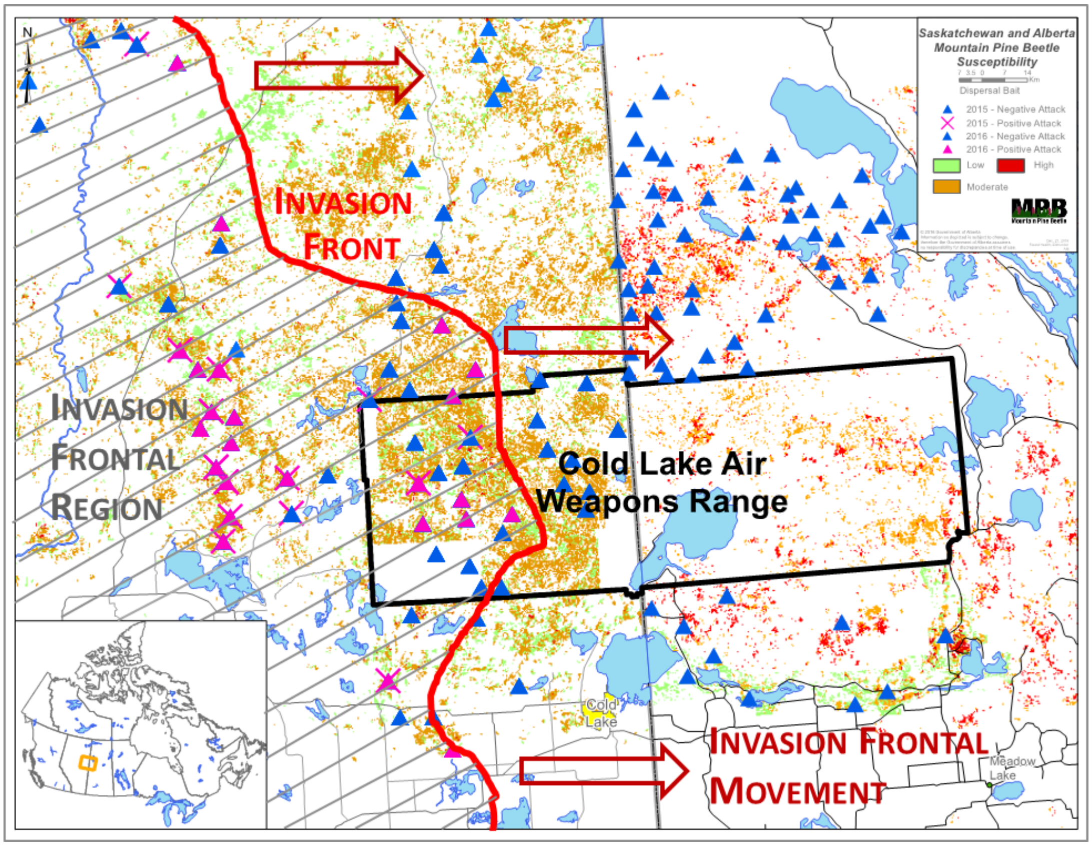

Figure 1. Current status of MPB incidence based on beetle detections in 2015 and 2016 at tree-baited dispersal sites along the invasion front in Alberta and Saskatchewan.

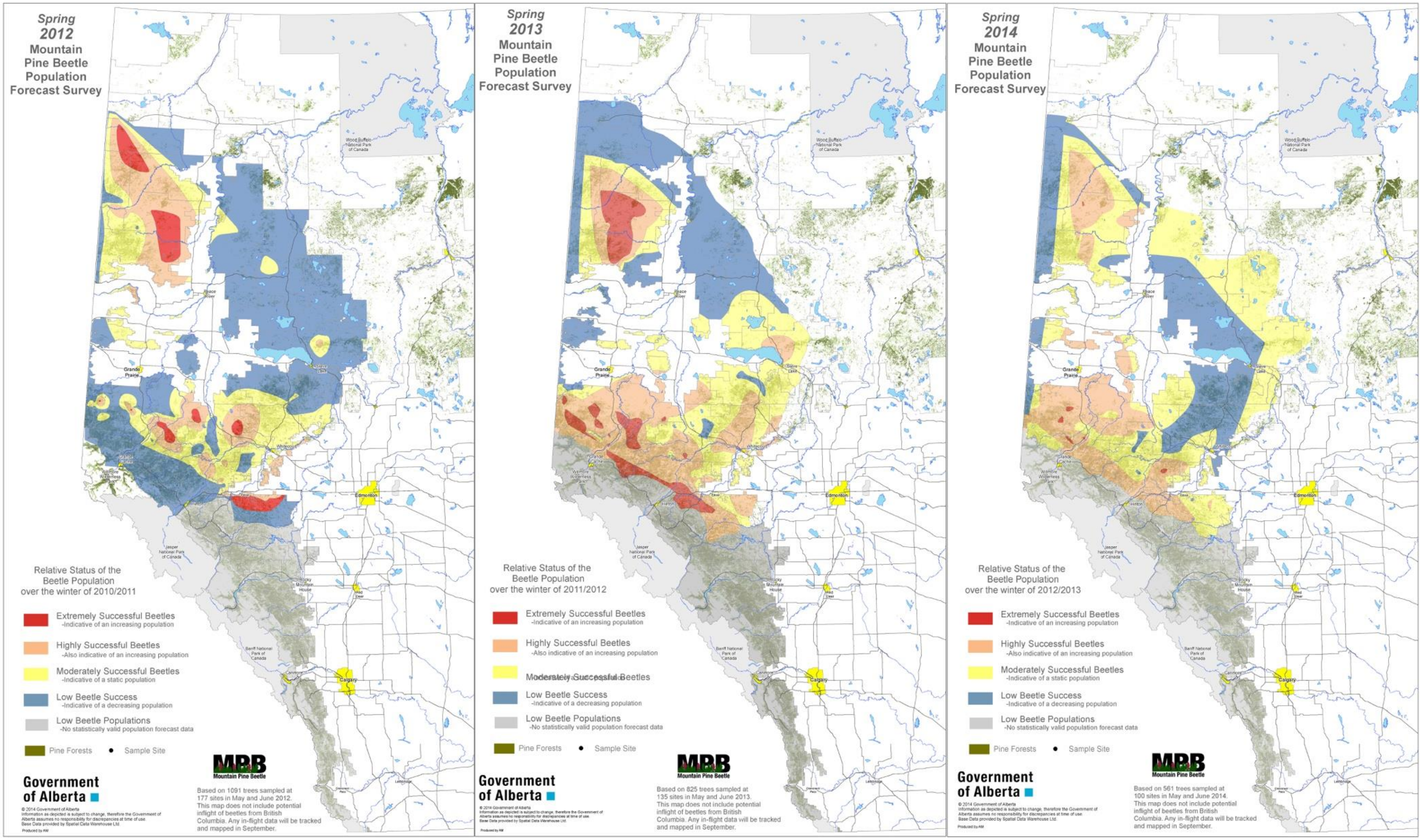

Figure 2. MPB overwintering success in Alberta based on extrapolation of point data collected from sampling sites between 2012-2014. General trend has been for low growth rates (R) on the eastern leading edge, or invasion front. Note also the low pine forest connectivity and potential bottleneck on the leading edge. Trend is similar for 2015.

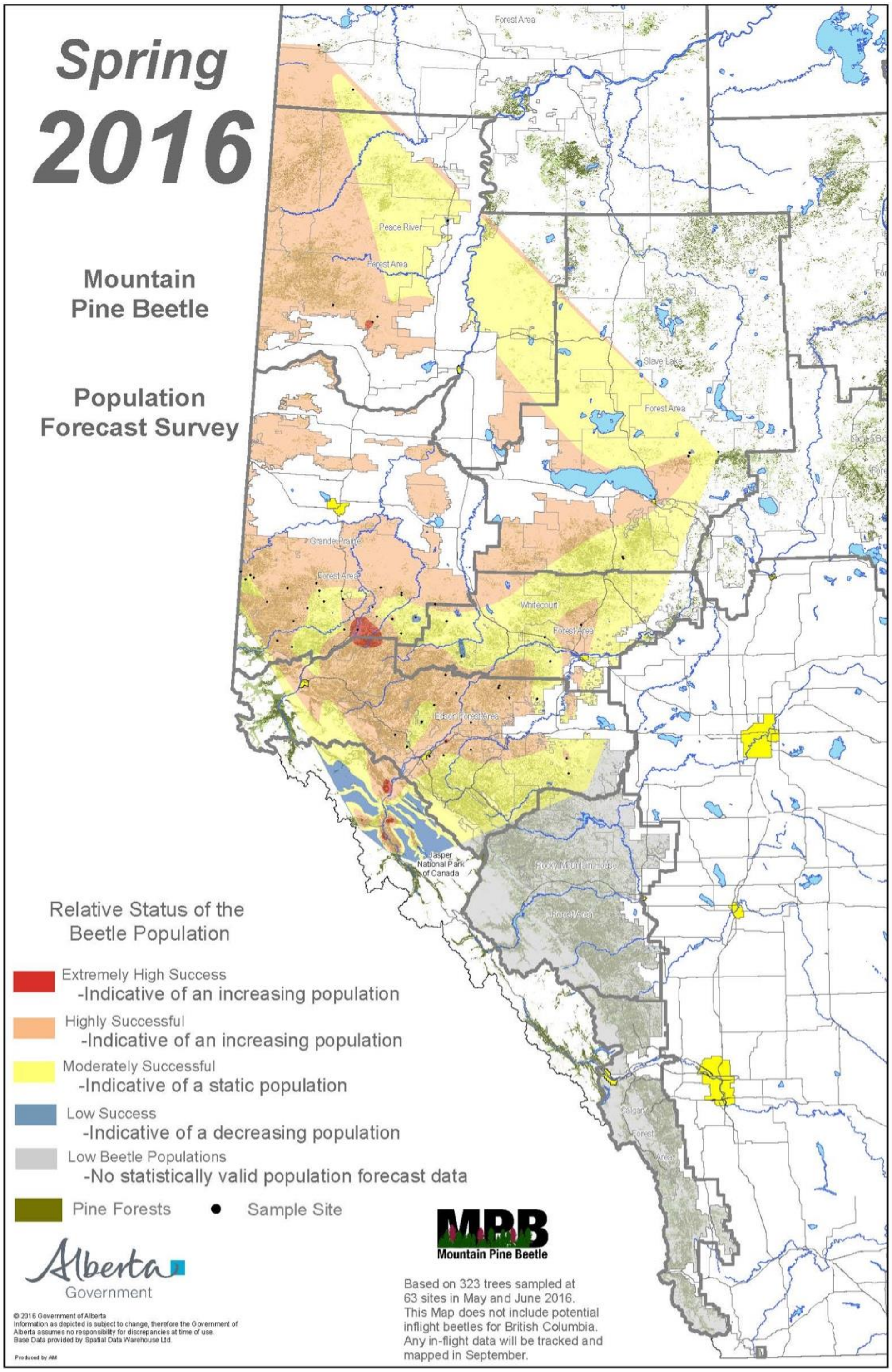

Figure 3. MPB overwintering success in Alberta based on extrapolation of point data collected from sampling sites in 2016. Note how much of the low success (blue) areas from previous years has changed to moderate to high (yellow to tan) success.

Overview of the Proposed Strategic Containment Approach

Long-range containment informed by an adaptive population management framework could help slow the spread of MPB across Canada. The proposed approach draws upon the theory of MPB management based on new science findings, some of which are pertinent to novel habitats. The approach also takes into consideration the collective experience and knowledge surrounding MPB management in British Columbia and Alberta. Incorporating these findings into an adaptive population management framework is key to help slow the spread of MPB across Canada, as it considers observed behavior of MPB in novel habitats, both in terms of establishment and spread, efficacy of management activities to date, and recognition of stress factors influencing population growth. Communicating all aspects of an MPB containment program is also key as it helps to increase awareness and garner support for management activities.

The proposed containment approach consists of 4 management zones: monitoring, eradication, suppression and adaptation. Boundaries are reviewed annually and adjusted based on MPB status and predisposing factors.

The strategic approach is intentionally non-prescriptive, but rather provides forest managers with a framework to formulate their own decisions. As such, there are no absolute treatment thresholds suggested, based on the notion that relative treatment thresholds are more adaptive. Treatment, in terms of a response tactic for MPB, refers to the removal of infested trees before adult beetles fly to attack new trees. MPB containment involves a wide range of possible tactical responses based on population status across the infested area. It is expected that ongoing risk assessments will inform appropriate operational responses. The proposed containment approach includes four response zones covering the range of conditions and objectives encountered with an eruptive invasive population, and include proposed actions to monitor, eradicate, suppress and adapt (Figure 4).

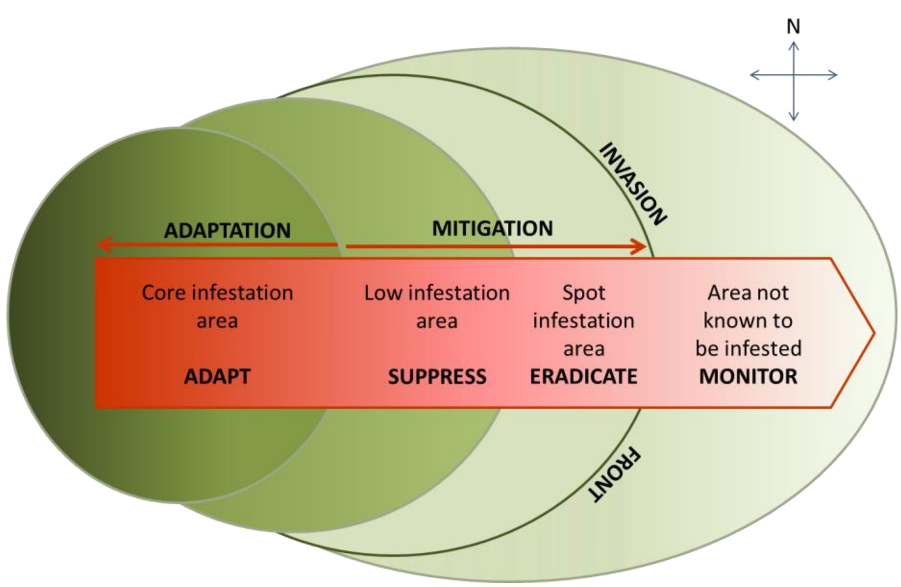

Figure 4. Conceptual representation of long-range containment management zones.

In the case of long-range containment, it is critical to stop founding populations on the invasion front from establishing and erupting. In this case, and assuming control budgets are small relative to the magnitude of the threat, the optimal allocation of control efforts is inversely proportional to the magnitude of threat. Currently, much of the control efforts by the Government of Alberta are in suppression of local populations in western Alberta where the risk and hazard are highest, whereas SMAC has focused on long-range containment on the invasion front in eastern Alberta where both populations and pine volumes are low.

Key Concepts

Importance of Early and Sustained Actions

A strategic containment approach for MPB, characterized by early, sustained and aggressive actions, has proven to be essential to slowing the spread, in absence of large immigration events. This has been shown repeatedly by the Government of Alberta's management actions as well as the Gypsy Moth Slow the Spread Program in the United States. The challenge for forest pest managers is in securing sufficient resources for invasion front management when the threat or risk is not fully expressed on the landscape. The concept of removing infested trees when populations are low is akin to addressing spot fires before they coalesce, whereby removal of small, potentially feeder populations is key to slowing the spread. This is particularly true for MPB in novel habitats as both the naïvety of pine trees and favorable weather conditions could lead to eruptive populations in one year. Given the potential for such eruptive behavior, risk removal (e.g. removal of infested trees when populations are low, at endemic to incipient-endemic levels), leads to the containment of existing populations and is a cost-effective option in both the short and long-term.

The Importance of Continued Action in Alberta

Since 2006, the Government of Alberta has successfully managed to slow the spread of MPB through sustained suppression of populations in the hind flank, and since 2011 through containment along the invasion front under the Alberta and Saskatchewan partnership implemented by the SMAC. The success of containment on the invasion front is contingent upon ongoing aggressive management actions by Alberta.

Understanding Factors Influencing Population Growth

This strategic containment approach requires an understanding of the factors that influence the transition from endemic to epidemic, or more precisely the eruptive threshold. The underlying principle is that the removal rate of infested trees must exceed the MPB population growth rate for management actions to be effective. Treatment efficacy is determined by the infestation density on the landscape. The most effective treatments occur when infestation density and population growth rates are low; the combination of these two factors also determines the level of program response. Indeed, understanding all the factors that influence eruptive thresholds helps forest pest managers make informed decisions regarding suitable strategies and tactics, identify winnable battles and in turn facilitate cost-effective decisions. These risk factors are more fully described in **Part IV**, the Science of MPB Spread Control.

The underlying principle of containment is that the removal rate of infested trees must exceed the MPB population growth rate for management actions to be effective, with success determined by infestation density on the landscape. The most effective treatments, and those that offer the best chance of success, occur when the populations are low and climate is poor.

Adaptive Management

Given the uncertainties associated with MPB in novel habitats, adaptive management is recommended to allow forest pest managers to make treatment decisions in consideration of all the factors which could affect MPB recruitment rates, rather than a prescriptive treatment threshold. Adaptive management also ensures that management efforts are evaluated and adjusted as required to fulfill management objectives, that uncertainties are identified and promoted as research needs, and the new research is evaluated and considered for incorporation in future response plans. Principles and approach are provided in Appendix 2to assist in that regard.

Management Insights Considering Science and Lessons Learned

A strategic containment approach should incorporate both science and lessons learned from British Columbia and Alberta, which include those pertaining to policy, planning and strategy, communications and collaboration, and MPB management itself, including resource issues or constraints. Appendix 1 summarizes these lessons and should serve as a valuable resource when managing MPB.

Lessons Learned

1. MPB can be managed using early, aggressive and sustained response actions when conditions are right, including the absence of immigration events.
2. MPB dynamics in novel habitats are such that small changes in environmental conditions could lead to eruptive populations.
3. Preliminary estimates of MPB ground survey detection rates of green attack in Alberta lodgepole pine are ~65% (Carroll et al. (2016).
4. Preliminary estimates by Carroll et al. (2016) of MPB single-tree control efforts in homogenous stands in western Alberta was shown to be moderately effective, e.g. 41% control. Efficacy: 1) varies from year to year depending on migration, 2) rises with smaller populations and in cooler climates, and 3) can be increased with increasing efforts at green attack detection and higher treatment levels.
5. Healthy forests where MPB seem manageable may switch to unmanageable when the trees become moisture-stressed.
6. If your control rate does not exceed your population growth rate you will slowly lose control and waste money. It is important to keep pace with growing populations, but know when to walk away.
7. Pay close attention to eruption and climatic thresholds, and base your damage tolerance thresholds on assets at risk, including downstream assets at risk.
8. Identify landscape bottlenecks, those with low climate suitability or connectivity. View these as battlegrounds to reduce populations to below eruptive thresholds or eliminate them entirely.
9. Emphasize the importance of early, aggressive and sustained detection and control efforts. Send clear and consistent messages including "If you're not early, you're too late".
10. Resolve legislative and land constraints in advance of MPB introduction and spread.
11. Securing funds is more attainable by clearly defining the values at risk and the benefits of investment. This can be more challenging for non-timber values due to lack of economic data.
12. Recognize that MPB life cycle does not coincide with government funding cycle.
13. Ensure data integrity via standard procedures, centralized data repository, and quality inspections.

Part II: Containment – MPB Management in Practice

Resource Allocation and Decision-Making

In British Columbia and Alberta, management zones with distinct treatment targets are used to help allocate resources and manage MPB. These zones are reviewed annually based on the ability to reach desired conditions given MPB status, funding, and resource availability. In the leading edge management zone of Alberta and in suppression beetle management units in BC, the target is removal of 80% of priority sites, whereas in the active holding zone the target is 50-80% removal. In Alberta, priority sites for treatment are determined by a decision support system (DSS) using a combination of number of potential green attacks, stand susceptibility index, and lastly (with minimal influence) stand connectivity. As a result, there are a higher number of infested trees addressed in the hind flank where the MPB, pine resources and connectivity are much higher than the heterogeneous landscape with fewer beetles and lower pine volumes on the invasion front. The SMAC program targets invasion-front populations when infestation level (X) and recruitment rates (R) are low, which vastly increases the chances of successful suppression and containment. As a result of the SMAC process, treatment thresholds have been lowered to address sites on the invasion front which are considered high risk by Saskatchewan.

Adaptive Management

The recent deviation in treatment thresholds and targets by SMAC on the invasion front shows how absolute targets may not be suitable for preventative spread control. Recall that for slowing the spread to be successful, the removal rate (P) must exceed the recruitment rate (R), and is most effective when infestation levels (X) are low. An adaptive, rather than prescriptive, decision-making process is therefore necessitated as it provides for recognition of the role of predisposing host stress factors regardless of homogeneity and connectivity, and resultant changes in MPB recruitment rates. Adaptive management principles and approach are provided in Appendix 2.

Population Management Framework

The challenge to managing any pest population is undertaking the right activities at the right time with sufficient effort to deliver a desired result, and measuring performance against that predicted result. Figure 5, from Carroll et al. (2016), illustrates how MPB may be managed using an integrated schedule of risk assessment, detection, control, and program evaluation. It tells us 'who, what, and when', and encompasses all aspects of a population management framework. This represents the framework which has been used by Alberta. Managing MPB within budget requires that careful attention be paid to its eruptive potential, in that small changes in environmental conditions could lead to large changes in population growth (R). This will help ensure that response thresholds are judiciously chosen and take into consideration all factors described in The Science of MPB Spread Control (Part IV).

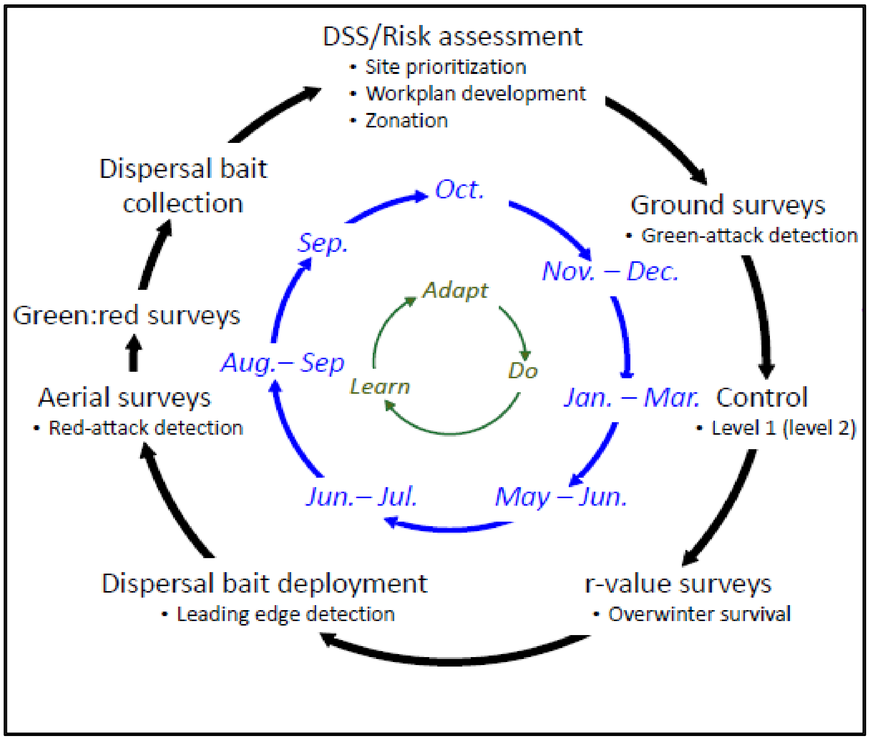

Figure 5. MPB population management framework as it relates to management activities and adaptive management.

Key Elements

Thirty-five key elements have been identified as factors influencing cost-effective MPB management decisions within a population management framework (PMF). These factors are drawn from existing models and new research findings and include those representing MPB biology, population status and risk, tree and stand characteristics, climatic variables, as well as socioeconomic aspects (Table 1). A PMF describes population risk and identifies where risk may be cost-effectively mitigated.

Table 1. The key elements of an adaptive population management framework and comparison to existing models.

	Existing Models		
Stand Characteristics	AB DSS	Shore and Safranyik 1992	MPB SELES
Percent pine (% by volume; % by area)	Y		Y
Stem age (years)	Y	Y	Y
Host basal area (m^2/ha)	Y	Y	Y
Height of tree (m)	Y		Y
Stand density (stems/ha)	Y	Y	Y
Merchantable volume xylem (m^3/ha)			Y
Phloem volume (m^3/ha)			
Diameter at breast height (DBH)			Y
Landscape connectivity (forest cover in some larger neighborhoods)	Y		
Beetle Populations			
Within-generation population growth rate (r value = emerging/entering ratio) – Rpred potential model from UBC			Y
Inter-annual change in infestation rate (ratio of green to red, G:R)	Y		Y
Number of red attacks (per cluster, per unit area)	Y		Y
MPB attack density (galleries/m^2)			
Height of mass attack (m)			
Measure of natural enemies			
Beetle Pressure			
Distance to source	Y	Y	Y
Size of source (potential green attacks, extrapolated across some neighborhoods)	Y	Y	Y
Short-distance dispersal factor			Y
Long-distance dispersal factor[1]			Y[7]
Dispersal mortality			Y
Integrative Indices of Climate Suitability			
Safranyik et al. (1975) - all season (S)			Y
Logan & Powell (2001) - summer seasonality (L)			
Regnière & Bentz (2009) - overwintering survival (R)			
Safranyik et al. (2010) - composite index (S*L*R)			
Regnière et al. (2015) - integrated index (MPB iMod)			
Geo-variables			
Aspect			
Elevation (m)	Y	Y	Y
Latitude		Y	Y
Longitude		Y	Y
Economic			
Return on investment (ROI)			
Transition point from mitigation to adaptation			
Cost-benefit analysis (CBA)			
Regional dynamic computable equilibrium (CGE)			
Social discount rate			
Valuation of ecosystem services at risk (timber, carbon, biodiversity, water purity, recreation)	Y		

[1] Long distance dispersal at a Timber Supply Area scale, e.g. 1 to 2 million hectares.

Management Zones

The proposed strategic containment approach would rely on a wide range of tactical responses based on population status across the infested area; basically, an assessment of risk informs the risk response.

A four-zone response model is the minimum required to cover the range of conditions and objectives that are encountered with an eruptive invasive population, and include monitoring, eradication, suppression and adaptation (Table 2). These zones recognize: 1) the eradication opportunity presented by climate and host constraints in the bottleneck between Alberta and Saskatchewan, 2) economies of scale, and 3) the potential for eruptive behavior given suitable conditions along the invasion front.

This approach is essentially what has been practiced by SMAC over the last few years on the invasion front between Alberta and Saskatchewan, while intensive monitoring ahead of the invasion front has been an integral part of the Alberta MPB management program since its inception, and continues into Saskatchewan. Similarly, Yukon and the Northwest Territories have implemented monitoring programs along their borders with British Columbia and Alberta.

Table 2. Proposed mountain pine beetle management zones (risk response) in relation to risk and ability to mitigate populations.

Risk Assessment (ability to mitigate)	Risk Response
Unnecessary	Monitoring
Possible	Eradication
Challenging	Suppression
Impossible	Adaptation

The following briefly describes the 4 management zones depicted in Figure 6, which shows the relationship between landscape infestation intensity (X) and MPB recruitment rates (R):

Monitoring (light green; endemic): Use of monitoring tactics in advance of the invasion front to detect new introductions.
Eradication (green; incipient-endemic): Use of suppression tactics in areas where MPB is established with low or minor levels of spread, e.g. endemic-incipient, to reduce levels to below eruptive thresholds.
Suppression (tan; incipient-epidemic): Use of suppression tactics to reduce spread into the eradication zone in areas with established and spreading populations, e.g. incipient-epidemic.
Adaptation (red; epidemic): Goal is to salvage wood, with no beetle management per se other than improving future forest resilience to MPB.

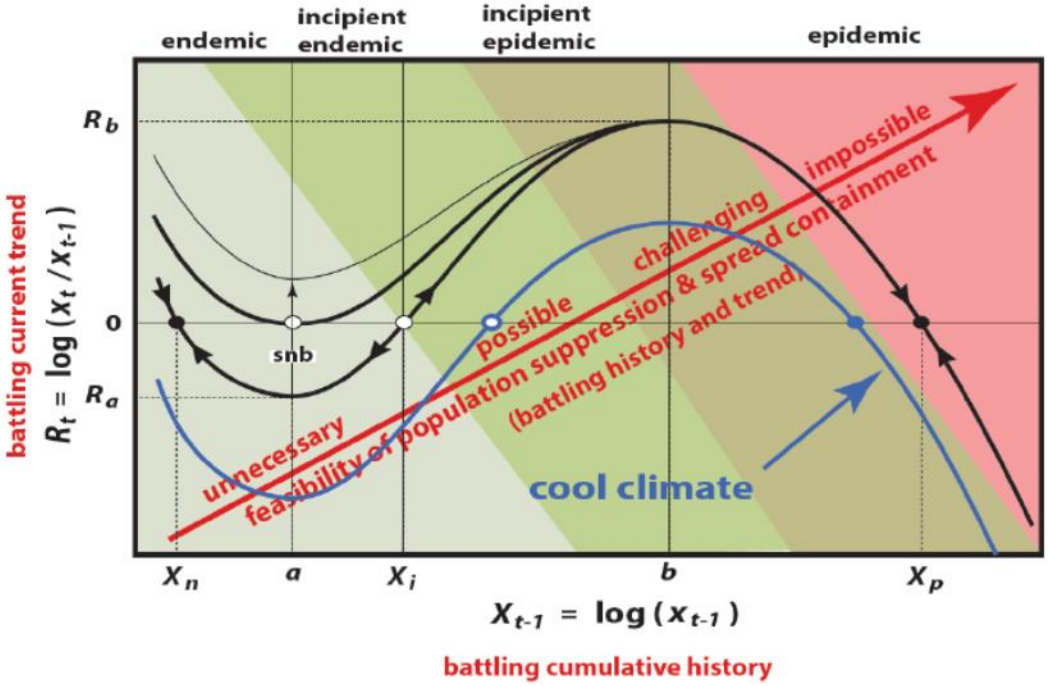

Figure 6. Relationship between landscape infestation density (*X*) and MPB recruitment rates (*R*) and the need to transition to different tactics as one proceeds across the invasion gradient of low *X* and low *R* to high *X* and high *R*. The abbreviation "snb" (saddle-node bifurcation) equates to an outbreak. The bifurcation leads to a discrete change in equilibrium state, and populations are released from their endemic state. Closed circles indicate stable equilibria. Open circles denote unstable equilibria. It's when the unstable and stable equilibrium points converge on one another that the two become one and then suddenly zero. At that point the process erupts, and the only stable equilibrium state is outbreak.

Zone boundaries should be reviewed annually, based on population status as described in Part IV, to help ensure that management tactics and levels align with population levels and the ability to achieve desired objectives; management efforts should be directed to winnable battles. Potential management zones based on current MPB status are depicted in Figure 7. When drawing zone boundaries, it is critical that both recruitment rates and infestation density are considered in order to avoid unnecessary battles, engage in winnable battles, and avoiding unwinnable (i.e. prohibitively costly) battles. In a cool climate (blue curve) a greater proportion of battles are winnable, as less effort is required to achieve a given objective (Figure 6).

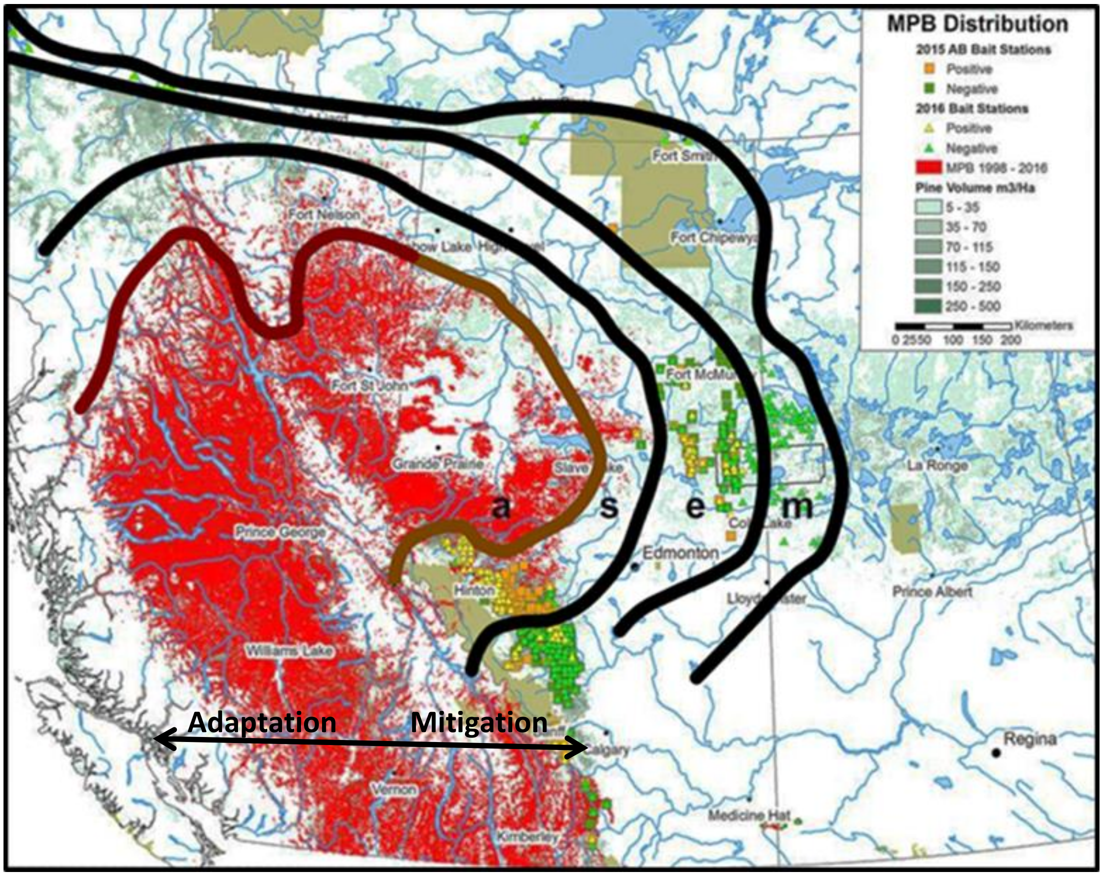

Figure 7. Potential containment management zone boundaries as a function of current MPB risk, and pine hazard and connectivity. Where m = monitoring zone, e = eradication zone, s=suppression zone, and a=adaptation zone.

Management Tools and Tactics

Management of MPB can be achieved through short-term beetle-focused strategies and tactics which aim to reduce or eliminate MPB populations, or long-term forest-based strategies and tactics which aim to reduce the susceptibility across the landscape (i.e. beetle management vs. host management). In British Columbia, where MPB is a native pest, the emphasis has been on short-term suppression of existing populations through aggressive treatment programs heavily augmented by direct sanitation harvesting by industry, and longer-term prevention strategies such as hazard reduction and modification of forest structure through creation of age- and species-class mosaics across the landscape. In Alberta, where MPB is viewed as an invasive native pest, initial management was aimed at eradication but shifted to suppression and prevention following the massive inflights of 2006 and 2009. Along the eastern leading edge, or invasion front, collaborative efforts between the Alberta and Saskatchewan governments via the SMAC focus on eradication of high-risk populations and extensive monitoring.

The selection of tactics should align with management zone objectives, which in this case are short-term tactics, given the containment objective. Selection of tactics will also be influenced by annual budget allocations. The population management framework (Figure 5) provides an overview of the planning and management cycle including survey types and timing. Forest pest managers are encouraged to contact jurisdictions currently dealing with MPB (British Columbia and Alberta) for more information on survey specifics, as they are the most up-to-date source for survey protocols, manuals and guidebooks, including those applying to quality control. Most of these are also available through the references section of the Pest Strategy Information System of the National Forest Information System, for registered members. Other information sources for monitoring and detection are Wulder et al. (2006), and Carroll et al. (2006) for direct control theory and practice.

Monitoring and Detection

Aerial surveys

Basic aerial surveys refer to aerial overview surveys conducted from fixed-wing aircraft and provide a coarse scale overview of infestations. It is the simplest and most cost-effective form of monitoring, but is *not* effective at low density populations on the invasion front, given the resolution of the surveys. MPB red attack is either recorded onto paper sketch maps, or onto a digital tablet. Predisposing agents such as drought, flooding or fire should also be mapped. In BC and in several other provinces, this aerial overview survey is a standard monitoring tool for all aerially detectable disturbance agents.

Enhanced aerial surveys refer to HeliGPS which more accurately captures locations of infestations for the purposes of ground assessments and are appropriate for suppression, eradication or monitoring zones.

Ground surveys

Ground surveys complement aerial surveys and are generally undertaken to monitor presence/absence through baiting programs, forecast population trends, and identify new green attacks for the purposes of prioritizing management actions.

Dispersal baiting

Dispersal baiting is used to detect and monitor populations ahead of the invasion front using commercially available attractant pheromones stapled to a host tree. Alberta, Saskatchewan, Yukon and Northwest Territories employ this tactic on and ahead of the leading edge of the current infestation, and use consistent protocols to establish the network of tree bait sites. In Alberta and Saskatchewan, baited sites are distributed at one per township, and in the territories along southern highway corridors close to the northern limit of the MPB infestation. Baits are deployed prior to beetle flight in late June and surveyed and collected after beetle flight activity in September. All tree baits must be retrieved and accounted for at that time. The number of bait sites should not exceed the capacity to deal with the outcome, and the more accessible they are, the more feasible they are to monitor.

In Alberta, trees are considered successfully attacked if 40+ pitch tubes are noted on a tree, and live brood exists underneath the bark, however any beetle attack (even single) on the bait tree is considered "presence" of beetles in the area. Successfully attacked trees must be removed prior to beetle flight.

Mop-up

This form of monitoring generally consists of spot baiting in areas treated for MPB to monitor for the presence of any undetected MPB, or immigration from adjacent unmanaged lands. Similar to dispersal baiting, any successfully attacked trees must be removed prior to beetle flight.

Population trend forecasting

Spring r-value surveys

These surveys are conducted in early spring and record the number of offspring surviving per female from one generation to the next and provide an indication of population status, e.g. increasing, decreasing, or static. As these surveys are conducted in the early spring they could provide a better indication of population status than that of green:red surveys in the fall, as they take into account any overwinter mortality and predation. Furthermore, spring surveys also provide a better indication of 'real' productivity than green:red surveys as they do not factor in immigration.

Fall green:red surveys or green attack delineation

Following aerial surveys of red-attacked trees, surveys are conducted at red-attack sites to help determine population trends and possibility of immigration events. This is accomplished by determining the ratio of green attack in relation to red attack. Either strip surveys or 50 m concentric circles are used depending upon the levels of red attack, with strip surveys being more cost-effective in more heavily infested areas.

Mechanical or Semiochemical Control

Single tree or multiple tree removal

New green-attack trees identified during ground surveys in the fall must be removed prior to beetle flight the following year. This tactic, often referred to as single tree disposal, or STD, consists of felling infested trees and then either piling and burning, grinding, or debarking them.

Small Patch Harvesting

Small patch (snip and skid) harvesting is a viable option where feasible, e.g. close proximity to a mill or licensee already operating in the area. It is most often used when STD is not feasible or not likely to be efficacious due to size. Care must be taken to ensure that all green attacks are identified to avoid continued entries into the stand. This could result in a large opening which could have been more effectively dealt with through larger-scale harvesting.

Containment Baiting

If removal of green attack cannot be conducted prior to beetle flight for some reason, then consideration should be given to grid or spot baiting an area for the purposes of containing the emerging beetle population. Areas that are grid baited are generally candidates for small-scale or small patch harvesting, whereas spot baiting infested trees is used in areas where STD will be used for control.

Regulatory Controls

Wood movement and treatment regulations

Wood movement directives or regulations can be used to limit the likelihood of introduction of MPB via wood transportation or importation into and out of jurisdictions. These can apply to the movement or importation of raw pine logs into one jurisdiction from another or from other countries, or the movement, storage and processing of beetle-infested wood in an infested jurisdiction. Both Alberta and Saskatchewan have regulations regarding the importation, transport and storage of pine forest products within their own provinces.

Costs of MPB Management

Both Alberta and British Columbia have a very evolved MPB management program with dedicated forest health personnel to help support the MPB program, as well as a pool of experienced contractors. Alberta Agriculture and Forestry (AAF) relies on permanent and seasonal staff and contractors to perform various activities as part of the program. Costs associated with activities conducted as part of the AAF MPB management program fluctuate annually based on a variety of factors; however, funding trends emerge when viewed over the mid-to-long term. Figure 8 summarizes the costs of MPB management across all management zones in Alberta since 2009.

Direct population management activities, which consist of assessment surveys, detection of green attack surveys, Level 1 treatments (fall and burn, and some mechanical), and quality inspections account for 61% of the overall program costs. Of the four direct population management activities, Level 1 treatments account for 59%. Costs vary by level of infestation and in 2015 ranged from an average of \$12.3K/100 km^2 for light infestations to \$395.8K/100 km^2 for heavy infestations (Table 3).

Estimated Costs For the Invasion Front

Infestations on the invasion front will likely be 'light', but the costs may be higher than that indicated in Table 3 as most of the work to date in AB has generally been conducted in areas accessible by road or by sled. Helicopter access sites will be significantly more expensive given the cost of helicopters, and may be the reality in Yukon, NWT and Saskatchewan. The number of sites visited/day may also be lower given the reliance upon helicopters which may be hampered by weather, hence further increasing costs.

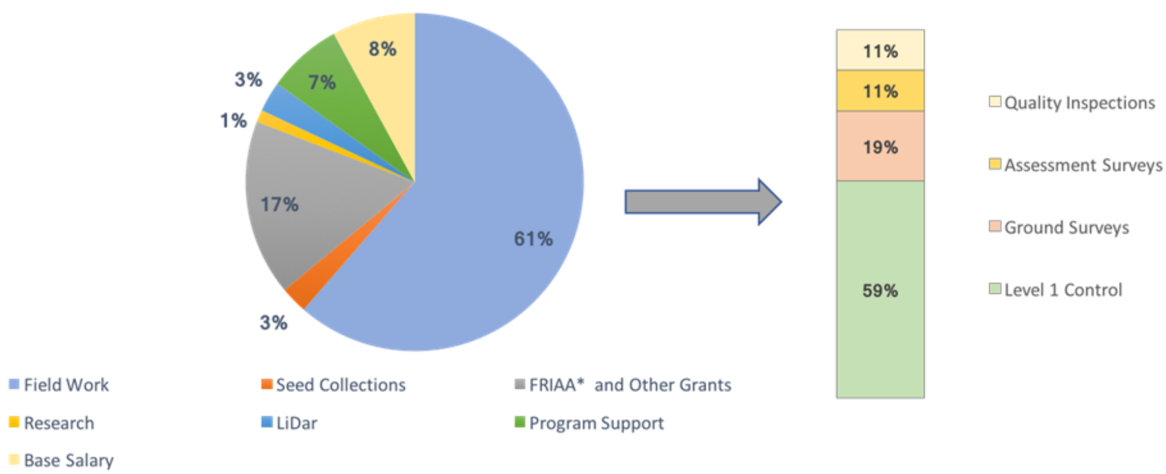

Figure 8. Distribution of MPB management costs since 2009 in Alberta (left), and breakdown of direct population management activities (right) to inspect (quality inspection), detect (assessment and ground surveys) and remove green attack (Level 1 control). *Forest Resource Improvement Association of Alberta

Table 3. Costs of MPB population management activities per 100 km^2 (10,000 hectares) in light and heavily infested townships in Alberta in 2015.

Level of Infestation	Average (\$)/Township	Range (\$)/Township
Light	12.3K	4.5K-17.8K
Heavy	395.7K	207K-580K

Part III: Management Challenges and Realities – An Economic Perspective

Costs

A number of reports have estimated the significant losses associated with introduced forest pests, where even a single article can report a range of estimates that vary by as much as two orders of magnitude. Colautti et al. (2006) estimate that the impact of non-indigenous pests and pathogens in Canada is between $187 million and $34.5 billion CAD per year. This wide range of estimates can be attributed to four factors: a dearth of data, and differences in scope, assumptions and methods (Holmes et al. 2009). Difficulties in estimation are magnified when the potential cost of a new pest and/or pathogen outbreak are considered because these differences are compounded by uncertainties about the likelihood of introduction, subsequent behavior and impacts. Even where there are known pests, the complex linkages between ecology, management and economic activity make such estimation difficult.

Estimating Benefits

Hottte and Nelson (2014) reported that several approaches have been devised to quantify the benefits of investing in preventing or managing the introduction of invasive pests. One is to develop bio-economic models of the pest in question and then simulate the effects of outbreak and spread. This may then be combined with simulating or modeling different management strategies to investigate the cost-effectiveness or benefit of investing in control strategies (e.g. Leung et al. 2002, investigating zebra mussels). There are also examples of models that look at the conditions under which investment in risk screening or control are warranted without identifying a specific pest (Keller et al. 2007; Moffit et al. 2008).

Other approaches involve using scenarios to develop estimates of the benefits from such approaches; one example is Nelson et al. (2009), which considered the economic impact of continued spread of MPB along with five other forest pests in Canada, in a report prepared for the CCFM FPWG. They found that the average cost over the next twenty years of just one invasive pest becoming established in Canada would be on the order of $34 million annually (where the overall costs of all five invasives becoming established exceeds $170 million per year). They estimated a cooperative approach to managing MPB, one of the six case studies, would yield annualized benefits of $14 million.

Early Intervention

One general result from the literature is that early investment in detection and eradication efforts can pay off, either in slowing the growth of the population (as well as damages and control costs associated with managing a larger population) or, where possible, reducing or eliminating the threat or population. The challenge in most such programs is an *ex ante* one: identifying what threats or risks different pests pose that *ex post* will subsequently turn out to have been the more serious. This is not the case for MPB. The potential risks are well understood, even if the potential costs have not yet been quantified. Estimates of the economic impact from BC, where the short-term benefits that followed from increased harvesting levels are now resulting in dropping AAC, are a $57 billion reduction in GDP and $90 billion decline in economic welfare, measured over the period 2009-2054 (all in present value terms) (Corbett et al. 2015).

Importance of Ecosystem Services

These estimates do not include non-market values, which some authors have suggested for other forest pests may easily exceed market impacts (Colautti et al. 2006; Holmes et al. 2009). In Canada, the potential impacts from continued eastward spread are MPB moving into areas where jack pine intermixes with several other susceptible pine species. The negative impacts on the flow of goods and services from the boreal forest would be widespread, severe and long lasting. In addition to direct economic costs, reduced water quality and non-timber products, and loss of critical habitats, are likely. Endangered woodland caribou, for example, prefer peatland areas containing black spruce (*Picea glauca*), larch (*Larix larcina*) and pine, and upland pine forests (ASRD 2010).

While the long-term benefits of investing in proactive strategies are clear, especially where the information exists (in the science, models, tools, and management expertise), the political challenge is that such strategies require up-front costs, and, where successful, the benefits are not visible or necessarily easily linked to earlier efforts. Much like other investments in public goods, such as preventive health or early childhood intervention strategies, the outcomes may be difficult to completely quantify but are no less significant or real.

Part IV: The Science of MPB Spread Control

Population Dynamics and Mountain Pine Beetle Management

A successful strategic approach to MPB management program must take into consideration population dynamics, and predisposing risk factors such as weather, climate, presence of secondary pests, and immigration. By better understanding the parameters that influence MPB population growth, forest pest managers are better equipped to identify winnable battles and strategies and tactics appropriate to population levels.

During the endemic stage, populations fail to establish because of insufficient adult beetle numbers to overcome a tree's defense mechanisms, a lack of host material, and/or unsuitable climate (Figure 10). Given suitable climatic conditions, adult beetles can successfully attack pine trees, populations become established during the endemic/incipient phases in the outbreak dynamic, and given availability of host material, have the potential to switch to the incipient/epidemic phases where populations grow, spread rapidly and erupt. Moisture stress and extreme cold weather are two predisposing climatic factors which affect population growth; moisture stress leads to decreased host resistance and extreme cold weather leads to higher mortality rates of overwintering beetles. Immigration via long distance dispersal can also positively affect recruitment rates, and hence increase the likelihood of establishment and spread. Containment involves keeping populations at stage (*ii*), and well away from stage (*iii*) where established populations erupt. Stage (*i*) endemic populations may go uncontrolled as conditions are not conducive to establishment, but do need to be monitored. Stage (*iv*) and Stage (v) populations are containable only in theory; in practice, they are beyond the point where control can be achieved within any reasonable budget.

The ability to contain and slow the spread requires that the removal rate (spiral red line in Figure 11) exceeds the growth rate (R), with the growth rates determined by climate (as represented by different colors). For a slow-growing recruitment rate (green) labelled "cold", growth rates do not exceed removal rates, and the shift from control to endemic levels is achieved in three years. For a fast-growing recruitment schedule (orange) labelled "hot", growth rates exceed removal rates, and control to endemic is not possible. After three years of failed effort, the slow loss of control may start to become apparent. The unstable and stable thresholds depicted here are realistic in terms of being well-aligned with those illustrated in Figure 9. This scenario was built using a suppression rate of 2/3, which is realistic for low density MPB on the very leading edge of the invasion front (this rate is ~44% in western Alberta). If the control rate is higher than 2/3, then a pest manager can afford to be more aggressive in the severity of cases that can be controlled within budget.

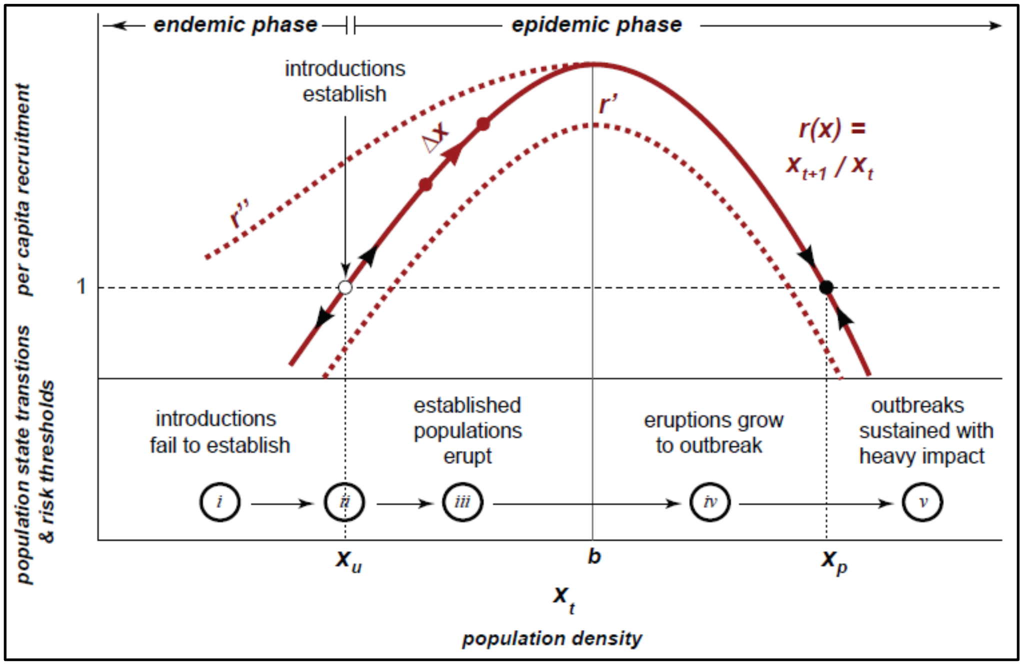

Figure 10. Population dynamics as a function of population density (X) and three different recruitment conditions (r), all of which affect the ability to control populations. Δx refers to the rise in population density resulting from immigration, r' indicates a drop in recruitment associated with heavy winter mortality in a cold winter or a cool climate, and r'' indicates a deflection caused by a loss of tree vigour under moisture stress, which makes low-density populations more prone to eruption.

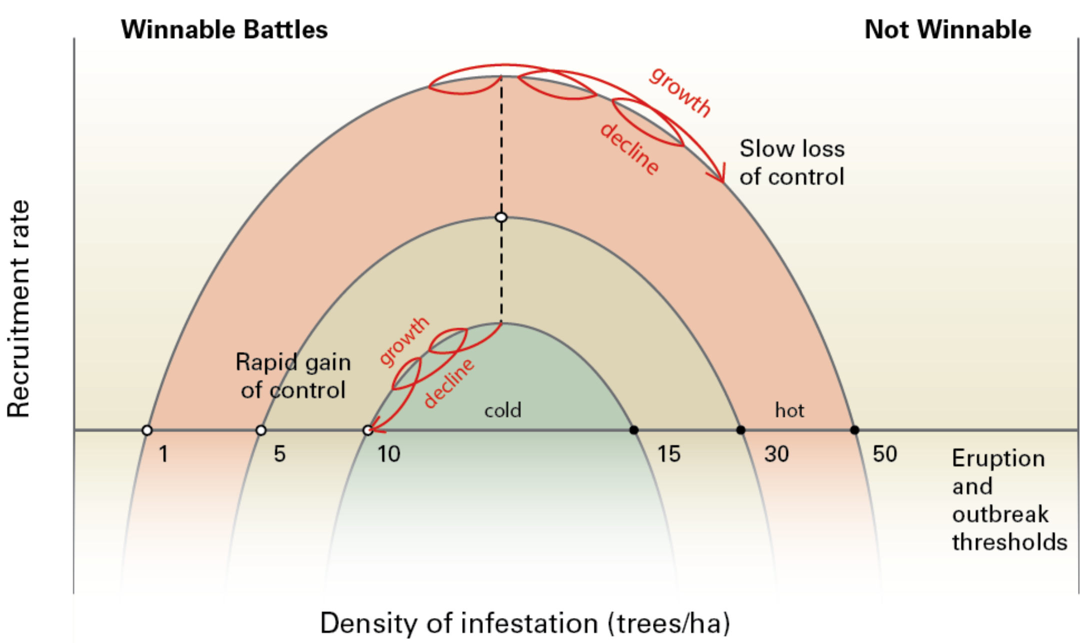

Figure 11. The ability to control MPB given three climate regimes (cold, normal, hot), and a fixed suppression rate of 2/3 (this rate is realistic for low density MPB on the very leading edge of the invasion front as this rate is ~44% in western Alberta).

Figures 10 and 11 illustrate why it is necessary to be judicious about which MPB battles one should be willing to take on, and realistic about one's expectations for program success. The difference between success and failure can be small, and the difference lies in biophysical parameters that are sometimes uncertain, such as the status of a population, or the suitability of a site's microclimate. For example, while Jasper National Park populations might have followed the slower schedule (r') in Figure 9 from the 1950s–1990s, the global climate has now warmed to the point that populations there are likely following a much faster recruitment schedule (solid red line), making populations there that much harder, or possibly unfeasible, to control.

Host Stress Factors and Management Implications: A Real-World Example in Experienced Habitat

The importance of climate, particularly moisture stress, cannot be overstated or disregarded as the eruptive thresholds from endemic to epidemic change quickly in response to lowered host resistance (Figure 12). Cooke et al. (2013) built a model derived from Boone et al. (2011) depicting the effect of host defense relaxation on an eruptive MPB growth process for lodgepole pine in experienced habitat in the southern interior of British Columbia. The model shows that in a healthy forest, with an unstable eruption threshold (*u*) of 4.0 trees per hectare, if the current population is larger than 7.2 trees per hectare, it is possible to force that population to endemic in a single year if the control rate is as low as 44% (Carroll et al. 2016). In an unhealthy, moisture-stressed forest it is roughly 10 times harder to suppress MPB populations to a given level. And because it is very hard to detect mass attacks when they are occurring at a rate of just one mass-attacked tree per 2.5 hectares (or one small attack cluster of four trees per 10 hectares), an intensive management campaign will need to be carried out for multiple years. Furthermore, for suppression to occur the growth rate (R) needs to be lower than the removal rate (P). That threshold population growth rate (R) is 1.8 based on a removal rate of 44%. For populations to be kept lower, they cannot be allowed to grow to or beyond their maximum rate, which occurs at 12.9 trees per hectare (the top of the inverted parabola).

Productivity (r) Model

Researchers at the University of British Columbia have recently developed an MPB productivity model using diameter at breast height (height and age as surrogates), temperature, and location (function of elevation and latitude) (Carroll et al. 2016). This model was tested on both experienced and novel habitat data with very good results. This model could complement management decisions regarding treatment priorities particularly in the invasion front, and inform dispersal bait deployment and aerial survey priorities.

Novel Habitat and Host Connectivity

Naïve hosts differ in many respects, including their decreased ability to defend themselves from MPB attacks (Cudmore et al. 2010). In the summer of 2009, MPB reached jack pine, a naïve host, in central Alberta, and started spreading through the mixed wood matrix of aspen and spruce of the boreal plains region (Figure 13).

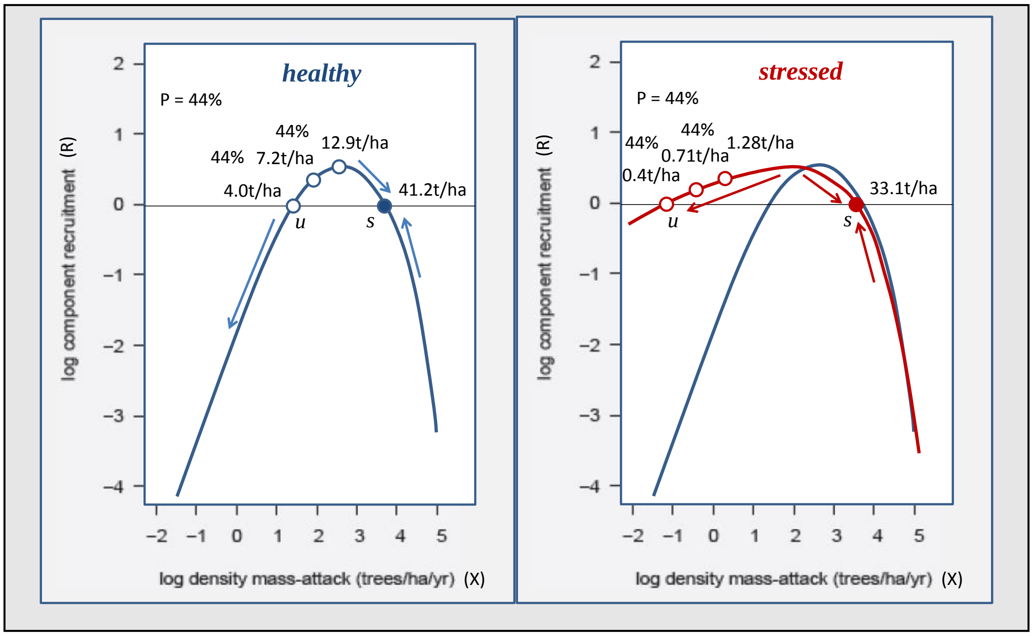

Figure 12. The effect of host defense relaxation on an eruptive mountain pine beetle growth process in experienced healthy and stressed forests in Southern BC, when only 44% annual rate of suppression is possible. The sequence of open circles above (*u*) indicates populations that are successively larger by 44%, the average rate of suppression indicated in a study by Carroll et al. (2016). An outbreak occurs when populations (of mass-attacked trees) grow past the unstable threshold (*u*, open circle), where upon they proceed to the upper threshold, (*s*, filled circle), which is stable. The outbreak peaks and starts to decline once populations reach the stable threshold (*s*).

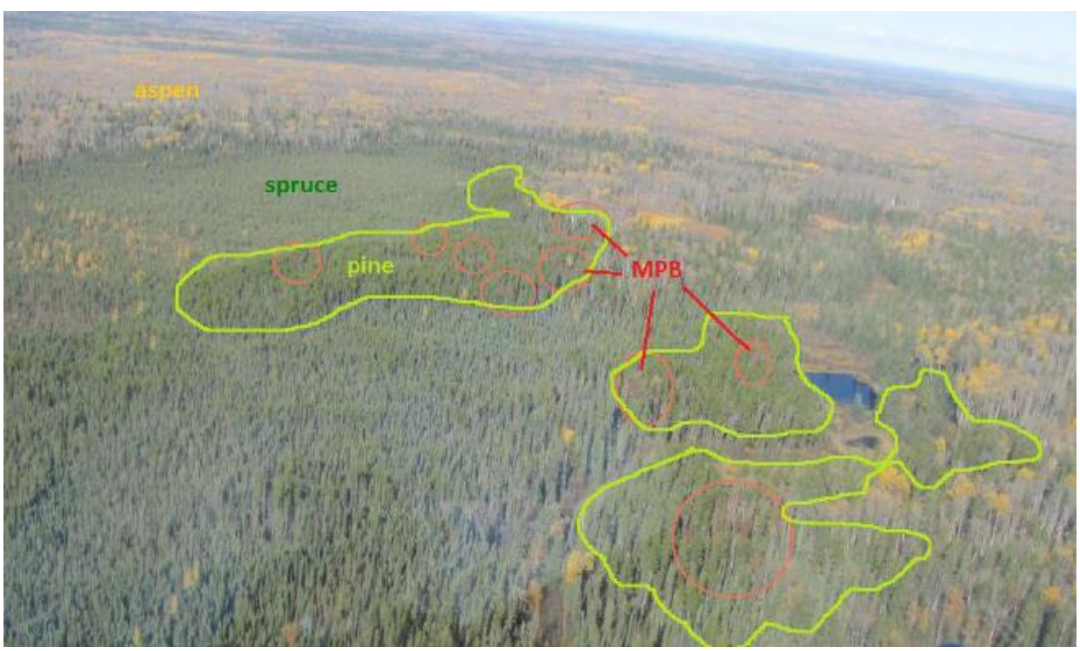

Figure 13. MPB in Marten Hills, East of Lesser Slave Lake. De novo clusters of fading trees East of Lesser Slave Lake indicate these populations were not endemic prior to their arrival, but were initiated by immigration.

Although there exists confidence that the form of MPB recruitment is like that shown in Figure 10, we still do not have sufficient data to confirm such is the case for jack pine in Alberta, because populations have thus far remained very low since MPB first arrived in jack pine in 2010. Over the last six years, MPB on the invasion front have frequently been failing to aggregate in sufficient numbers to overcome the establishment threshold. This situation could change at a moment's notice, as was the case in 2016 when changes were noted in both the Marten Hills and the Cold Lake Air Weapon Range (CLAWR). In the Marten Hills the number of attacked trees per site increased significantly from previous years, while Figure 2 demonstrates the first indication that MPB became established in the CLAWR. Positive dispersal baiting sites in the CLAWR were first noted in 2015 (pink X), and the number doubled in 2016 (pink triangles).

Treatment Efficacy

Recent analysis of Alberta's Level 1 treatments consisting of single or multiple tree removal, by Carroll et al. (2016) in western Alberta naïve pine has provided some valuable insight into the realities surrounding successful management of MPB.

Carroll et al. (2016) estimated that the rate of green attack detection via ground surveys of MPB red attack clusters in western Alberta lodgepole pine was 65% in years of low migration, and as low as 40% during years of high migration. They estimated that the overall rate of population suppression using Level 1 treatments was in the order of 41%. This was determined by assessing the number of new "green" (e.g. "child") attacks within 1 kilometer of "parent" source (polygons) which had been treated the previous year (Figure 14). They also showed, rather significantly, that the effective rate of population suppression depended on the size of the population being treated (Figure 15). Populations with lower-density attack are suppressed at a higher rate than landscapes with high-density attack, hence confirming the need for early detection and sustained control efforts, before populations reach eruptive thresholds.

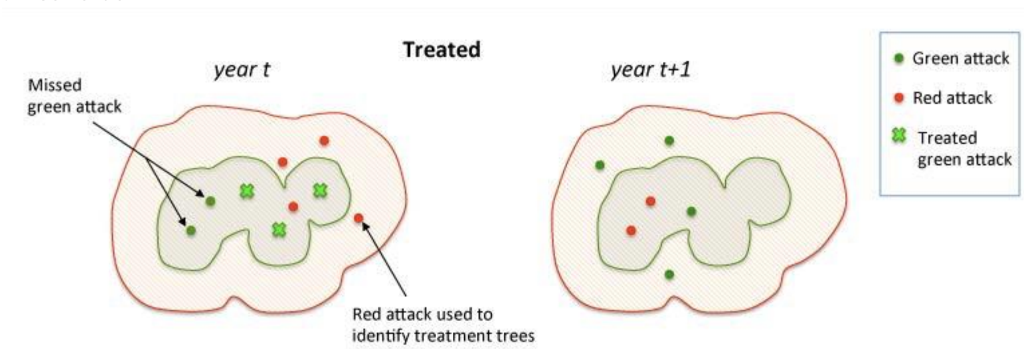

Figure 14. Depiction of Level 1 treatment efficacy as measured through the number of "child" or green attacks the year following treatment (year t+1) in a 1 kilometer zone of influence of the parent source polygons or year t treatment area.

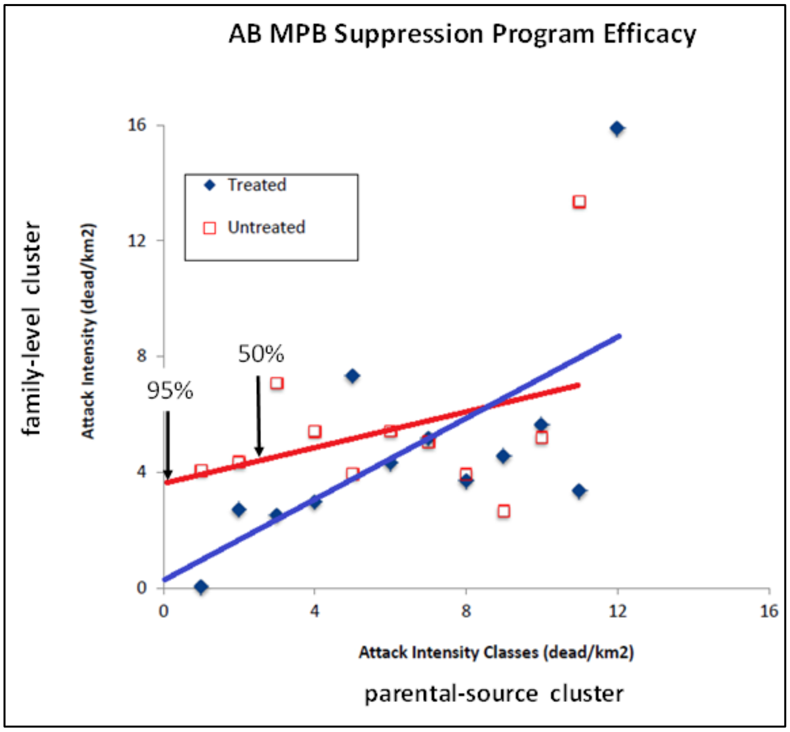

Figure 15. The effect of density of attacked trees in "parent" source clusters on density of attacked trees the following year in surrounding "family" clusters within 1 kilometer of "parent" clusters, in treated (blue) versus untreated (red) clusters.

Treatment Threshold Efficacy

In Alberta, management efforts are guided by a decision support system (DSS) which considers susceptibility (stand susceptibility index), a stand connectivity index, and the number of potential green attacks, with a lower treatment threshold in the leading edge zone (≥ 3 potential green attack trees), than the active holding zone (≥ 10 potential green attack trees). This treatment threshold in the leading edge zone has proven to be 91% effective in the Alberta application, where only 9% of the sites which were not managed experienced increases in MPB.

Glossary

Containment – A strategy designed to reduce the rate of spread of a nonindigenous species (Liebhold and Tobin, 2008).

Endemic – Insufficient beetle populations to overcome even a single large- diameter tree within a stand. Beetles in this population phase are restricted to low-quality host trees with little or no defensive capacity (Carroll and Safranyik, 2006).

Eradication – Management of MPB to endemic levels given the knowledge that small populations may fail to establish on well-defended trees (Boone et al. 2011).

Eruptive – The propensity to suddenly switch from a low-density stable state of existence (e.g. constrained to an endemic niche of suppressed trees inhabited by other bark beetle species) to a high-density state of existence (e.g. with a willingness and ability to attack and successfully colonize even vigorously defended host trees).

Establishment – Growth of a population to sufficient levels such that natural extinction is highly unlikely (Liebhold and Tobin, 2008).

Invasion Front – An invasion front is a generic term from invasion biology representing a moving line separating where a pest has been found versus where it is likely to occur in the future. In theory, the invasion front is represented by well-defined lines, however in practice the frontal location is uncertain as it must be determined from point samples. For convenience, "invasion front" in this document is frequently used as shorthand for the "invasion frontal region".

Invasion Frontal Region – The area where a pest occurs behind the invasion front that is actioned with mitigation efforts as part of containment.

Invasive – Insects and diseases that spread beyond their known usual range. "Invasive," refers to a shift from one ecosystem to another, not to shifts across national borders. So, even organisms that move into new ecosystems within the same country can be considered invasive if they extend beyond their usual geographic range. The spread of mountain pine beetle from British Columbia's lodgepole pine forests to Alberta's jack pine forests is an example of a native forest insect behaving invasively. (Natural Resources Canada, 2016)

Leading Edge (Zone) – Alberta's highest priority management zone. It includes areas where beetle populations threaten to spread eastward into the boreal forest. Infestation control is performed through aggressive Level 1 treatments and supplemented with Level 2 treatments where applicable. Level 1 treatments involve single or multiple tree removal from small infestation patches with follow-up debarking, burning or grinding to destroy the beetle broods. Level 2 treatment involves harvesting infested trees in patches that are considered too large for single or multiple tree treatment. (Alberta Sustainable Resource Development, 2007)

Native – Indigenous species that have existed in Canada for thousands of years. Outbreaks occur periodically. An example is the spruce budworm (Natural Resources Canada, 2016).

Risk –Risk is a function of stand susceptibility and beetle pressure. Beetle pressure is the magnitude of a mountain pine beetle population affecting a stand as determined by the number of currently infested trees and their proximity to the stand being assessed. Beetle pressure relates to the likelihood of a beetle population entering a given stand (Shore and Safranyik, 1992).

Suppression – A strategy characterized by aggressive direct control tactics to reduce populations to endemic levels within a few years (Carroll, Shore and Safranyik, 2006).

Susceptibility – The inherent characteristics or qualities of a stand of trees that affect its likelihood of attack and damage by MPB populations. Synonymous with the term 'hazard' (Shore and Safranyik, 1992).

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Appendix 1. Lessons Learned

Mountain Pine Beetle Management– Lessons Learned from British Columbia and Alberta

Background

To help realize this goal this strategic containment approach takes into consideration lessons learned from jurisdictions currently managing MPB (BC and Alberta), and is founded on the principles of pest risk analysis whereby scientific knowledge has been reviewed and incorporated. The following provides a summary of lessons learned from MPB management in BC and Alberta.

Policy, Planning and Strategy

- Develop a comprehensive management program which could include higher-level strategies, action plans and identification of roles and responsibilities. Minister or Cabinet approval should be sought for both the program and associated documents to ensure that any changes to forest management practices are not challenged.
- Develop a business case for a management program based on science.
- Securing funds is more attainable by clearly defining the values at risk and the benefits of investment; this approach works best where the forest economy is a major economic driver and forest product markets are good.
    - Securing funding for non-timber values is more difficult due to the challenges presented by lack of sound economic data.
- Secure a long-term funding commitment if possible. Lulls in MPB populations should be viewed as an opportunity to aggressively manage small pockets rather than walking away.
- For the purposes of timber supply, ensure that realistic impacts are considered, with a range of scenarios from best- to worst-case scenarios.
    - Reliance upon worst-case scenarios may lead to industry capital investments that may not be sustainable in the long-term.
- Recognize that management objectives and timber supply projections may need to be reviewed and modified as MPB populations evolve, and are not necessarily in schedule with regular planning cycles.
    - Includes assessing whether MPB populations are behaving as models predicted – adjust timber supply reviews accordingly.
- Planning should be proactive and consideration given to the long term.
    - Identify program implementation and management issues and concerns at the onset and seek out ways to resolve these. This includes wildlife habitat and diversity, timber dues calculations, inoperable areas, reforestation requirements and responsibilities, water crossings, and legislative pest listing.
    - Identify and address information requirements for long-term forest management planning including seed source inventories, rehabilitation priorities, and desired future conditions.
        - A salvage strategy and rehabilitation strategy should be developed concurrently with an MPB strategy.

        - Make sure that management strategies today don't increase landscape level susceptibility in the long term.
- Develop appropriate policies or guidelines – e.g. Alberta developed the following policies:
        - Pesticide, bark beetle pheromone and biological control use guidelines for forest pest management
        - Forest pest management product development guidelines
        - Importation of conifer logs and forest products with bark attached
        - Mountain pine beetle log management
        - Mountain pine beetle level 2 harvest priorities and approval process
- Ensure that administrative tools and incentives for expedited harvesting are in place.
    - Ideally with the ability to direct licensees to harvest specific areas, or have the ability to harvest and sell small patches of infested timber outside government programs, or commit to supporting a small-scale salvage program.
- Land-use designations can hinder effective management of MPB (e.g. Parks Canada). These should be identified and addressed at the onset.
    - Alberta initiated a municipality granting program for detection, control and public awareness.
    - A similar program was initiated with industry – the Forest Resource Improvement Association of Alberta (FRIAA).
    - Alberta signed an MOU with Parks Canada making them responsible for MPB management in parks and protected areas. This allows them to conduct surveys and control activities in consultation with Parks Canada when developing control plans.

Communications and Collaboration

- Develop a communication strategy and establish working relationships and partnerships with other jurisdictions, stakeholders and researchers.
    - Continuous communications and collaboration must be maintained with the forest industry – this could be facilitated with some form of landscape-level steering or advisory committees.
    - Communication materials are key to consistent messaging; depending upon the magnitude of MPB populations, a communication specialist should be considered.
    - Communication efforts should not be limited to outreach but also internally within government to ensure a similar level of familiarity and education within.
    - Identify research agencies and potential funding sources and promote research needs annually if possible.
- Inter-jurisdictional collaboration has a multitude of benefits including resource and information sharing, and potentially improved suppression efforts due to funding contributions from concerned jurisdictions.
- Stakeholders should be engaged at the onset and educated as to the potential impacts of MPB through information sessions, summits, workshops, and committees.
    - Alberta hosted an MPB Summit which included MLAs, municipal leaders, First Nations representatives, adjacent jurisdictions, and the forest industry. The Summit included presentations by research scientists and MLAs who discussed real and

    potential MPB impacts. The Summit also included an aerial tour of devastated areas in BC.
    - Alberta formed a provincial MPB Advisory Committee to ensure that informed decisions were being made. The committee included research scientists and a variety of stakeholders. An MPB Mitigation Committee was also formed, consisting of government executives and forest woodland managers where information is shared and issues are brought forth and discussed.

MPB Management

- Establish landscape-level management boundaries or units to assist with the assignment of strategies and allocation of resources.
- Complete landscape-level susceptibility ratings and identify and address any gaps or shortcomings of inventory data.
- Use decision support tools and/or spread models to assist with MPB management where necessary.
- Develop a centralized database at the onset with standardized data collection protocols.
- Review program annually to: 1) ensure that management unit strategies and tactics are appropriate for MPB population levels, 2) new technologies are reviewed and considered, and 3) review and improve administrative processes if necessary.
- Adaptive management, whereby treatments and methodology are accessed for efficacy, should be part of an overall MPB program.
- Recognize that MPB life cycle does not coincide with government funding cycle; this will affect management efforts at the beginning of each fiscal year. Alternatively, explore means to circumvent this issue.
- Remain proactive and learn from experiences in other jurisdictions, e.g. identify your winnable battles.
- Maintain a commitment to landscape-level monitoring on managed forests for the following purposes regardless of MPB strategy to ensure that mortality is captured:
    - identification of wildfire risk, development of an effective rehabilitation program, determination of seed supplies and needs, timber supply reviews, and to provide insight into MPB behaviour.
- Maintain an integrated approach to forest management where possible.
- Protect permanent sample plots for a variety of reasons including post MPB-attack stand dynamics, and regeneration.
- Encourage industry activities that are above and beyond those required to meet forest management obligations, e.g. those which would have otherwise been the responsibility of the Crown.

Resources

- Central coordination may be required to effectively manage MPB.
    - Human and fiscal resources should coincide with MPB project demands.
    - Methodologies should be standardized.
    - Recognize the need for contractors for program delivery; provide training as required and monitor performance.

- Build a pool of qualified aerial survey and single tree treatment contractors, provide training where necessary, and ensure that quality assurance training and checks are built into a management program, with penalties for non-compliance.
    - Establish performance measures for all MPB surveys and review as operational goals change.

Appendix 2. Adaptive Management and Mountain Pine Beetle

Rationale

Given the uncertainty around MPB spread and impact in new forest ecosystems, there is a need to monitor and evaluate management strategies and tactics on an ongoing basis to determine if desired outcomes are being achieved, and if not, adjusting them accordingly. The 'learn by doing' principles of adaptive management are applied to address uncertainties, evaluate management practices and evaluate new evidence relevant to MPB management that can be incorporated into a containment strategy.

Purpose

The purpose of this document is to:

- Describe means to evaluate and learn from the effectiveness of management strategies and tactics applied for containment, and
- Describe means to adjust management strategies and tactics of containment based upon an evaluation of their efficacy or integration of new knowledge or tools.

Principles of Adaptive Management

Adaptive management is defined as a "process to assess our scientific models, assumptions and values, and an approach that emphasizes continuous improvement" (Adamowicz 2003)[1]. Uncertainty is acknowledged and learning from outcomes is valued, which allows continual improvement of management policies and practices (Figure 1). This iterative 'learn by doing' process is well suited to situations with uncertainty. The learning aspect of adaptive management comes from monitoring, evaluation and learning, which are key components to effectiveness evaluation. Evaluation determines whether management actions fulfill desired outcomes and are most often linked to objectives. Hence objectives play a critical role in evaluating performance, reducing uncertainty, and improving management over time (Williams 2011)[2].

There are two approaches to adaptive management: passive and active. Passive adaptive management employs the use of current best practices, whereas active adaptive management tests several practices and determines which is best suited to reach the desired outcome. The ability to reduce uncertainties is not optimal with the use of passive adaptive management, as it does so by chance, whereas in active adaptive management, actions are designed to reduce uncertainties.

[1] Adamowicz, W.L. ed., 2003. Towards sustainable management of the boreal forest (pp1-40). Ottawa: NRC Research Press.

[2] Williams, B.K. 2011. Adaptive management of natural resources – framework and issues. Journal of Environmental Management 92: 1346-1353.

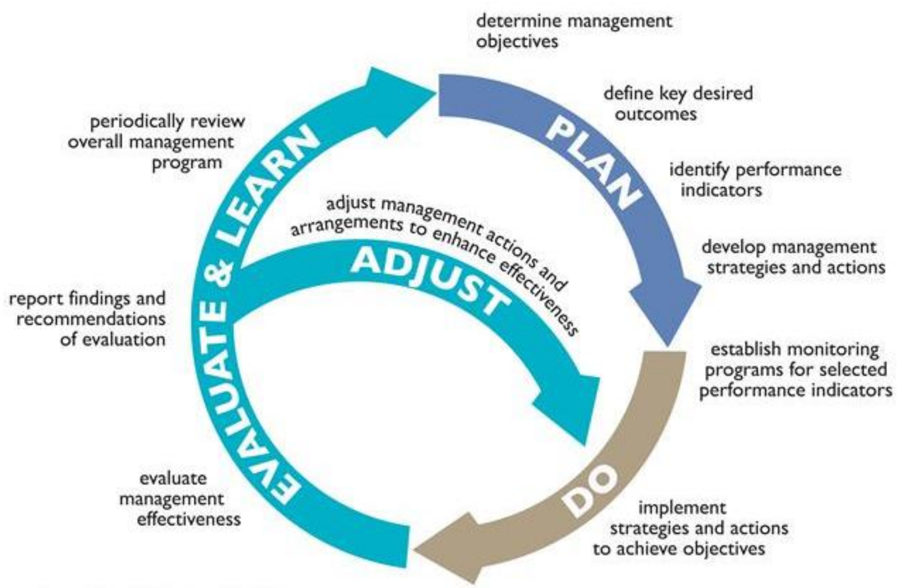

Figure 1. Steps involved in the adaptive management cycle.

Application of the Principles of Adaptive Management

Evaluate and Learn

Evaluation of Management Strategies and Actions

Monitoring consists of operational practices to assess MPB populations via ground and aerial surveys, while **evaluation** consists of assessing efficacy of management strategies and actions. For the most part, both are implicit to mountain pine beetle management, and hence already form part of jurisdictional forest pest management programs. The evaluation component is undertaken by forest managers informs adaptive management.

Proposed Approach to Evaluation

Implementation of containment actions can be described in annual work plans where management objectives are defined, and performance indicators and expected results (performance targets) identified. The following is an example of how this approach could be applied to the objectives of Alberta's leading edge management zone:

Objectives (Criteria): To reduce and maintain MPB populations and spread to an endemic level.
Performance Indicator: Green-attack tree removal of identified priority sites with surviving brood beetle.
Expected result: Removal of 80% or more of the green attack trees in identified priority sites with surviving beetle brood.

Using this example, the question of whether the expected result has been achieved is addressed. However, it will not identify whether the target is appropriate for the objective, or if the strategies and tactics that have been utilized suffice. One can employ adaptive management principles by asking the following questions:

1. Are expected results meeting management objectives?
2. Are current treatment thresholds sufficient to meet management objectives?
3. Are current monitoring efforts sufficient to meet management objectives?

Once specific objectives of containment actions are defined, indicators and expected results can be further defined by responsible forest managers for each of the four proposed management zones.

Adjust

Modifying Strategies and Tactics

If an evaluation of management actions indicates that objectives are not being met, then strategies and tactics must be reviewed and adjusted accordingly, to the extent possible. Evaluations may also reveal knowledge gaps which can in turn be promoted as research questions. responsible forest managers review evaluation outcomes and make recommendations regarding corrective actions.

Integration of New Research Findings

The majority of research being conducted by the MPB research community addresses uncertainties and jurisdictional priorities (Cooke 2015)[3] (the exception is research relating to economics, which was identified as a gap five years ago, and remains a gap in 2016). New findings, applicable to MPB management, are published or communicated via workshops or conferences. These findings can be incorporated into a containment approach as deemed appropriate by responsible forest managers.

[3] Cooke, B.J. 2015. NFPS MPB Strategic Research Gap Analysis: Summary of Research Priority Needs and Status. Canadian Council of Forest Ministers, Forest Pest Working Group. Unpublished paper. 24 p.