Annotated Bibliography for the Mountain Pine Beetle Ecology Program

fRI Research Mountain Pine Beetle Ecology Program

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ACKNOWLEDGEMENT

The current Mountain Pine Beetle Ecology Program (MPBEP) had its early beginning in 2006 under the guise of the Foothills Model Forest – Mountain Pine Beetle Fire Ecology Program. As the threat of forest loss from the infestation of the mountain pine beetle and wildfire grew, it was evident that specific research was needed to provide science-based information to inform operational decision-making and policy development. Moreover, such information would significantly enhance regional preparedness for the challenges that laid ahead. In 2008, the Strategic Directions Committee of the Government of Alberta charged the MPBEP to act as a Science Information Forum to identify research needs, facilitate knowledge transfer and collaboration amongst researchers and managers, and inform the public. With steadfast support from the Government of Alberta and guidance from the Activity Team, the MPBEP successfully carried out its mandate.

In fulfilling its role as a Science Forum, the MPBEP identified four research themes embracing 29 critical priority questions. These critical questions guided the selection of projects awarded to universities and research agencies in British Columbia and Alberta. From 2006 to 2020, the MPBEP provided approximately $4.7 million in funding to support forty research projects.

The success of the many scientists engaged in the program is evident by the publications and reports listed in this bibliography, and the many presentations available for viewing on the fRI *Research* website. The program is also indebted to many support staff in Communications and Information Transfer, Accounting and Administration. I attempt to list all contributing individuals below with a deep sense of gratitude.

Activity Team Members

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- Dan Lux, Executive Director, Forest Stewardship & Trade
- Don Podlubny, Past Program Lead, Retired
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Lastly, I wish to thank Matthew Pyper and his highly talented staff at FUSE Consulting for their diligent effort in putting this Annotated Bibliography together, along with the able assistance of Fran Hanington, who painstakingly collated all the publications and reports presented in this report.

Keith M. McClain, Ph.D., R.P.F.
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Executive Summary

For over ten years, fRI Research and its partners has supported a range of research projects related to the mountain pine beetle in Alberta through the Mountain Pine Beetle Project (MPBEP). To bring this body of work together, an annotated bibliography was created to present project results in a format that is both accessible and useful to program partners. The 0.5-1-page project summaries highlight the key outcomes and implications of numerous peer-reviewed publications, final reports, and ongoing projects. This annotated bibliography is intended to be used as a tool for information transfer between program partners and help inform future research and management initiatives.

In addition to the annotated bibliography, a series of key messages were generated based on the information synthesized.

Summary of Key Messages

General

- MPB reached unprecedented outbreak levels in Alberta in 2006, by in large, due to more favorable climatic conditions in regions they historically were unable to persist in. This sparked a need for more research to understand the ability of MPB to survive and thrive in novel habitats and identify strategies to manage MPB spread and mitigate the impacts of beetle-killed forests.

MPB Biology

- The likelihood of MPB's survival throughout winter is different for each life stage. Only larvae can survive an average winter in Alberta, whereas eggs and pupae likely will not survive winter anywhere in Canada. Although adult beetles will survive a mild winter, they will not survive an average winter.
- Burned stands are likely a barrier to MPB colonization and do not promote outbreaks, likely due to the presence of competing bark and ambrosia beetles.
- MPB maintains population levels through different colonization patterns where different rates of pheromones are produced depending on their flight distance.

MPB Management

- To date, efforts to slow the spread of MPB have been reasonably successful. Control efforts can be optimized by improving the detection efficacy of green-attack trees and by applying treatments (i.e., single-tree cut-and-burn) more aggressively, and at the leading edge of expansion where beetle populations are still low.
- Since fire does not cause low-density populations of MPB to outbreak, prescribed burning should still be used as a general forest management technique in lodgepole pine forests with low-density populations of MPB.
- Various monitoring tools (i.e., pheromone and host volatile baits) have been assessed for monitoring MPB. Overall, monitoring should focus on the most susceptible stands to endemic MPB. To monitor low-density MPB in its eastern limit, researchers recommend a combination of standard MPB bait plus myrcene deployed in groups of four baited trees, spaced 50 m apart in a square formation, at 12 km intervals. Monitoring (trapping activities) should focus on the first half of the flight period. If the area has a low MPB population

density, use high-release rates of trans-verbenol, and use high-release rates of trans-verbenol if the area has a low MPB population density.

The Likelihood of Persistence in Novel Pine Forests

- Jack pine forests in Alberta are unlikely to support a persistent endemic MPB population. However, lodgepole pine in Alberta are at least as suitable to endemic MPB populations as lodgepole pine forests in British Columbia (BC) that have historically been exposed to MPB. MPB control and management strategies should focus on lodgepole pine stands while continuing to monitor MPB populations in Alberta and Saskatchewan's jack pine boreal forests. However, there are many uncertain factors that drive population shifts and even minor changes in climate or forest condition may trigger an outbreak and continued spread.

Impacts to Stand Hydrology

- Only modest changes in hydrology have been observed in red-attack stands, but researchers anticipate larger effects into the grey-attack stage. These early changes in hydrology could pave the way for more serious impacts on stand ecology into the future and will likely be magnified by different intensities of MPB attack in certain regions of Alberta. Another study found that a low-severity (~25% kill) stand is unlikely to impact stand water balance, but more severe attacks will likely generate more runoff across the region, especially with more precipitation.

Modelling Tools

- A range of resources (models and tools) have been or are being developed to project the impacts and spread of MPB. Specific to forest managers, an Enhanced Decision Support tool was developed and projects stand growth attributes 100 years post attack and wood quality metrics 10 years post-attack. Other tools such as MPBSpread and Spatial Discrete Event Simulation (SpaDES) capture MPB growth and spread over a range of management scenarios. Furthermore, detailed instructions on how to georeference Mountain Legacy Project photos have been documented. This may provide an opportunity for land managers to measure changes in forest susceptibility to MPB along the east slopes of the Rocky Mountains.

Dynamics of Natural and Managed Lodgepole Pine Stands Following MPB

- Long-term monitoring of forests following earlier MPB outbreak that occurred in Waterton Lakes, revealed that forests have been surprisingly resilient to varying intensities of MPB attack. The post-attack forests are more diverse and no longer dominated by pine. Other studies have supported these findings by observing and projecting more mixed-species forests and uneven-aged stands post-attack.
- Without management, lodgepole pine is unlikely to regenerate naturally within 50 years following high severity MPB attack on most site types. The availability of favorable seedbeds and the composition of non-pine vegetation will impact the ability of lodgepole pine to regenerate post-attack.
- There is no one-size-fits-all approach to regenerating MPB attacked stands. In most cases, significant silviculture intervention is needed, but management should be flexible and site-specific. Managers must take into account the severity of the attack (percentage of trees killed by MPB), original stand composition, and the natural disturbance pattern. Flexible management strategies like an "irregular shelter-wood" approach that accommodates variable regeneration periods and uneven stand structure might be beneficial.

- MPB attack also influences the belowground community in lodgepole pine stands by increasing nutrient (nitrogen) cycling and reducing natural defenses and growth (by altering the beneficial fungi community). The fungal community is also more sensitive to human disturbance (i.e., clearcutting and salvage logging) than natural disturbance (i.e., MPB attack and wildfire). Researchers identified a need for further investigation into the use of soil inoculation to re-establish beneficial fungi at salvage logged sites.

Climate Impacts

- Impacts of MPB to stand dynamics, forest hydrology, species at risk, and wildfire risk may be amplified by climate change. Under a range of future climate scenarios, MPB is likely to become more of an issue.
- In the future, the availability of climatically suitable MPB habitat is expected to rapidly increase regardless of the climate change scenario. In anticipation of an increasingly warmer climate, it is recommended that aggressive short-term indirect management strategies be used to reduce the susceptibility of the landscape. This could include techniques similar to the current "Healthy Pine Strategy" where the highest-risk pine-dominant stands are harvested sooner to reduce susceptibility to MPB.

Optimizing Timber Resources in MPB-killed Stands

- Similar to BC forests, wood quality declines the most within one to two years following MPB attack and is affected by checking and fungi. Although MPB-killed trees stay standing until c. 8-10years post-attack, they develop checking 2-3years post-attack. Therefore, infected trees should be harvested within 1-2 years post-attack. They should be harvested earlier if there are blue-stain fungi that can fully develop within the first year of the attack.

Impacts to Species at Risk

- MPB can alter food supply and favorable habitat for species at risk such as Grizzly Bears and Woodland Caribou. Grizzly Bears and Caribou select for different habitats and respond differently to MPB disturbance and MPB management. Woodland caribou showed a preference for mature uncut pine stands, and avoided disturbed (i.e., MPB infested and managed) habitat. In contrast, grizzly bears showed habitat preference for these disturbed stands and avoided mature pine. Where caribou and MPB overlap, a single-tree cut-and-burn control program is recommended to balance MPB spread management and negative impacts to caribou habitat.

Social and Economic Impacts

- The social and economic impacts of MPB on forest-based communities requires more investigation. So far, the research shows that the public's perception of MPB infestation and management are different than land manager perceptions and depend on the affected region. There is a need for context-specific management and communication strategies that consider these different ecological and socioeconomic factors. There are also opportunities for relationship-building between land managers and the public to improve communication and grow trust, such as workshops and tours of treated areas while discussing the benefits and uncertainties of different management strategies and including other experts.

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Introduction

In 2007, fRI Research implemented the MPBEP to support research on mountain pine beetle (MPB) in Alberta. Since then, the MPBEP program has facilitated numerous research initiatives to better understand the biology of the mountain pine beetle, impacts to forest ecosystems, and the effectiveness of different management strategies. This document was created to summarize key findings from these research projects in the form of an annotated bibliography. The goal is to facilitate information transfer between partners of the MPBEP, and to make the core findings and results of the program more accessible.

Methods

All materials related to projects funded through the MPBEP were reviewed, and 0.5—1 page summaries were developed for each peer-reviewed article and the most recent reports. Where these documents were unavailable, fRI Research Quick Notes were summarized to describe the research project. Each summary provides a concise and accessible synthesis of the documents highlighting key outcomes and implications. The summaries are grouped by fRI Research project and contain hyperlinks to for access to related documents.

Annotated Bibliography

Hydrology

Steinke, S., McIntosh, C. S., Schroeder, L., and Macdonald, S. E. 2020. Understory vegetation responses to simulated mountain pine beetle attack and salvage logging in grey attack stage lodgepole pine stands. Forest and Ecology, 475: 118373. [URL]

Document Type: Peer-reviewed

Key Messages:

- In a region where MPB is a new form of disturbance and management issue, understanding the impacts on future forest succession and understory diversity is critical.
- This study aimed to quantify and compare understory vegetation responses during the grey-phase of MPB attack and salvage harvesting in novel MPB habitat.
- Changes to the understory were more dramatic in higher mortality stands, thus post-MPB attack management and rehabilitation should prioritize forests with high-mortality kill.

Approach:

- Understory responses to simulated MPB attack and salvage logging were monitored through a field experiment near Robb, AB.
- Four disturbance treatments were applied across twelve plots (1.2–2.2 ha each): control (untreated/no disturbance), simulated MPB attack (50% and 100% kill - simulated using glyphosate injection) and salvage logging.
- Data were collected for above- and below-ground components for one pre-treatment year. Post-treatment data were collected annually for seven years as the treated stands transitioned into an early grey-attack phase.

Key Findings and Implications:

- Understory vegetation showed some resilience to moderate MPB attack and mortality, but higher levels of canopy kill could cause strong changes to understory vegetation which may have long-term implications for future forest recovery.
- There were limited changes to understory **vegetation cover**:
    - Immediate post-treatment changes in vegetation were only observed in the salvage logging treatment. Total vegetation cover declined in the short term but began returning to pre-treatment levels after five to seven years.
    - Grass cover increased with high-mortality MPB attack and salvage logging, and remained high seven years post-treatment. This effect was particularly strong in the salvage logged stands and may have caused other species to be outcompeted.
- Changes in **vegetation composition** increased with treatment severity and were most dramatic in salvage logged stands. Treatment types were characterized by different indicator species:
    - Shade-obligate feather mosses were indicators of control stands.
    - Shade-tolerant species were more abundant in the 50% attack treatment.
    - Shade-intolerant/early successional species (including lodgepole pine) were most abundant in salvage logged stands.
- By seven years post-treatment, there was evidence that plant communities were starting to return to pre-treatment levels of composition.
- Unexpectedly, soil moisture and nutrients did not increase over time in the higher-severity treatments. This may be because surviving plants increased their uptake.

- Due to the release of residual or shade-intolerant species in higher mortality (especially salvage logged) stands, lodgepole pine regeneration might be hindered by competition (e.g., with grasses), altering the successional pathway of the forest.
- The results point towards more dramatic effects to vegetation (e.g., increased grass cover that may compete with lodgepole pine seedlings) with increased treatment severity, **post-MPB attack management and rehabilitation should prioritize forests with high-mortality kill.**
- Potential techniques to manage the impacts of MPB attacks could include harvesting, planting or seeding, mechanical site preparation, and vegetation control to reduce competing grasses.
    - Salvage logging can facilitate pine cone dispersal, create good microsites for regeneration, and open up the canopy to more light, which could be an effective post-MPB attack management strategy to promote pine regeneration.
    - Because salvage logging had the greatest impact on canopy cover and understory environment/vegetation, the understory will likely be very different from undisturbed or MPB attacked stands. The potential long-term and/or cumulative effects of MPB and salvage logging are still unknown.
    - If shade tolerant species begin to dominate the canopy, fire might be required to reset the forest to post-MPB attack conditions.
- The long-term impacts of MPB attack and post-attack salvage logging on lodgepole pine forests in Alberta are still unknown. Longer-term studies on MPB effect would be beneficial (i.e., the transition from gray attack to when dead trees fall down).

McIntosh, A.C.S., and Macdonald, S.E., 2013. Potential for lodgepole pine regeneration after mountain pine beetle attack in newly invaded Alberta stands. Forest Ecology and Management 295, 11-19. [URL]

Document Type: Peer-Reviewed

Core Messages:

- As mountain pine beetle (MPB) range expansion occurs, there is uncertainty around how, and if, MPB attacks influence the successional future of pine forests.
- This study seeks to evaluate how lodgepole pine forest regeneration is impacted by varying levels of simulated MPB attack, and the role of salvage harvesting in promoting regeneration.
- A lack of favorable seedbeds for lodgepole pine regeneration limited regeneration. If the goal is to restock stands with lodgepole pine after MPB attack, **"significant silviculture management"** is likely needed.

Approach:

- Lodgepole pine regeneration was evaluated in response to simulated MPB attack and salvage logging through a field experiment near Robb, AB.
- Four disturbance treatments were applied across twelve plots (1.2–2.2 ha each): control (untreated/no disturbance), simulated MPB attack (50% and 100% kill, simulated using glyphosate injection) and salvage logging.
- Lodgepole pine recruitment was also tested by sowing seeds on five different seedbed types (moss, shallow organic, deep organic, decayed wood, and mineral soil).

Key Findings and Implications:

- The overall lack of advance regeneration and natural regeneration in simulated post-MPB attack stands may limit re-establishment of pine forests on these sites in the short term.
- Overall tree recruitment was low across all treatment types. Mineral soil and decayed wood seedbed types facilitated the highest tree recruitment rates, but were scarce among all sites. Tree recruitment rates in mineral soil and decayed wood increased with disturbance (control → MPB attack → salvage logged).
    - Modest forest floor disturbance might be needed to create favorable seedbeds for lodgepole pine following salvage logging and minimal tree recruitment may be expected from unmanaged/unharvested stands.
- Spring-sown seeds had higher recruitment rates than seeds sown in the fall. A spring seeding strategy is likely to produce higher recruitment in artificially seeded sites.
- Long-term monitoring of lodgepole pine recruitment and seedling survival is needed to better predict future successional pathways of MPB-infested forest. Monitoring should be conducted as the trees transition from gray-attack to fallen.

Silins, U., Macdonald, E., Pina, P. McIntosh, A., and Presant, P., 2012. Early effects of mountain pine beetle red attack on hydrology and vegetation responses in Alberta lodgepole pine forests (Final Report for the Foothills Research Institute 1-36). University of Alberta.

Document Type: Final Report

Key Messages:

- The expansion of MPB into western Alberta is expected to impact hydrology and vegetation dynamics in lodgepole pine forests, and this could have significant implications for forested landscapes.
- This study investigated how early stages of MPB attack (green to red phases) affect the processes underlying hydrologic and vegetation dynamics in western Alberta.
- Only modest changes in hydrology were observed during the research trial. These early changes in hydrology could pave the way for more serious impacts on stand ecology into the future and will likely be magnified by different intensities of MPB attack in certain regions of Alberta.

Approach:

- Hydrology, vegetation and below-ground components (e.g., organic matter decomposition rates, microbial community characteristics, soil nutrient status) were monitored in response to simulated MPB attack and salvage logging through a field experiment near Robb, AB.
- Four disturbance treatments were applied among twelve plots (1.2–2.2 ha each): untreated control, simulated MPB attack (50% and 100% kill, using glyphosate injection) and salvage logging.

Key Findings and Implications to Date:

- Simulated MPB attack did not affect rainfall interception, but had a strong effect on transpiration rates. Transpiration **decreased** in 100% attacked stands, but **increased** in 50% attacked stands. Surviving trees in partially attacked stands may compensate for reduced water uptake of dying trees, buffering attacked stands from major changes in water inputs.
- Field-based calibration was used to generate a model to evaluate the hydrological impacts of MPB attack across Alberta. Results showed that modest MPB attacks (i.e., ~25% attack) are unlikely to change stand water balance, but **more severe attacks will likely generate more runoff across the region, especially with more precipitation**.
- No significant differences in understory plant community were observed in MPB treatment stands. The only significant differences were in salvage logged stands, where total understory plant cover was lower after harvesting. As needles drop in the coming years (transition to 'grey attack'), the understory community is expected to change in all treated stands.
- Since early changes in hydrology could drive larger changes in stand ecology into the future, these effects should be monitored for more years to come*.

***Research plots and water balance instrumentation have been maintained, and site conditions continue to be monitored. The research team anticipates an opportunity to study more dramatic changes into the future as the stands transition to a grey attack phase.*

Decision Support Tools (DST)

FORCORP Solutions Inc. 2013. Enhanced Mountain Pine Beetle Decision Support Tool Application Development. Report prepared for Foothills Growth and Yield Association.

Document type: Report

Core Messages:

- The Foothills Growth and Yield Association (FGYA) is working to develop a decision support tool for forest management in areas affected by MPB which incorporates baseline data, projections and expertise from research partners and decision-makers.
- The decision support tool is a web-based application to assist forest planners in predicting how different levels of MPB attack and silviculture treatments will affect forest stands and timber supply.
- This report describes the development of the **Enhanced** decision support tool application aimed to meet the needs of proposed improvements to the existing 2010 decision support tool by members of the Foothills Growth and Yield Association.

Proposed improvements to the 2010 Decision Support Tool:

- As suggested by the Foothills Growth and Yield Association, a proposed improvement to the 2010 decision support tool model should incorporate an additional level of MPB attack (75%), account for the presence of Balsam fir understories, and provide greater user-control over projection starting conditions for overstory/understory mean density.

Key Elements of the Enhanced Decision Support Tool:

- After users define a simulation scenario, the application will report stand growth projections including standard mensuration stand growth attributes for 100 years and post-MPB wood quality metrics for 10 years post-attack. Users can:
    - Quantify the impacts of different levels of lodgepole pine mortality that leave varying residual structures of live trees following MPB attack,
    - Quantify the impact of different regeneration assumptions following varying degrees of MPB attack, and
    - Identify and project differences in secondary structure and regeneration observed or hypothesized in different stand types (ecosites).

Limitations and Recommended Revisions:

- Four issues with GYPSY projections were identified through developing the tool, and the following revisions are recommended:
    - When compared with data provided by the Foothills Growth and Yield Association, GYPSY inaccurately models very early (>10 years) density trends of lodgepole pine regeneration. A revision that includes reasonable estimates of these early densities will help managers compare their observations of early stand development with the model's projection. Thus, they can see if their early stands are on their way to achieving stand development that was projected by the model.
    - Balsam fir is a potentially important cohort of lodgepole pine stands and should be included as its own group instead of combined with white spruce. This may be difficult to achieve because of data limitations, which should be considered in future monitoring.
    - The model currently uses an un-validated version of GYPSY layer 3 by AESRD. Validating this layer will help the decision support tool's current stand projections and increase acceptance.
    - The spatial version of GYPSY was unable to directly model the spatial implications of partial MPB-attack and salvage on future stand development. As a result, this project uses the non-spatial version of GYPSY instead.

Alfaro, R., Axelson, J., and Hawkes, B. 2009. The Dendroecology and Stand Dynamics of a Selection of Permanent Sample Plots, Alberta. Decision Support for Forest Management in a Mountain Pine Beetle Environment. Final report.

Document Type: Final report

Core Messages:

- Dendroecology can help describe a forest's life history. This information can then be used to generate growth and yield models to predict future stand composition in response to different disturbance intensities.
- This project aims to reconstruct the disturbance history and stand dynamics of 15 lodgepole pine dominant sites in the Lower and Upper Foothills regions of Alberta.
- The information collected from this study can be used by future researchers to better understand the ecology of the region and develop flexible decision support and growth models that reflect changes in disturbance patterns.

Approach:

- 15 permanent sample plots (PSPs) were selected for tree-ring analysis to reconstruct stand histories at two sites in the Lower and Upper foothills of Alberta.
- Over 1300 field samples (tree cores, snag and understory disc samples, and coarse woody debris) were collected during the summer and winter of 2008 to reconstruct the stand histories.

Key Findings and Implications:

- Fire played an important role in initiating the canopy in the studied stands, which have maintained an even-aged structure.
- Growth releases were observed in the dendroecological records and these were likely triggered by subsequent disturbances that were not severe enough to cause high canopy mortality, but likely reduced competition within the stands. For one site, a landscape-wide growth release may have been caused by a low severity ground fire (recorded in 1924) or a forest pest outbreak (like MPB).
- A strong relationship was also found between the Annual Pacific Decadal and Oscillation (PDO) and tree growth. The cool-phase of PDO appeared to negatively affect tree growth, thus lasting below-average growth is likely caused by climate and not by stand disturbance.
- The researchers suggest that comparing Alberta stands to stands in BC could potentially map the future of a MPB environment. For instance, disrupting the fire cycle (i.e., through fire suppression and exclusion) has increased the complexity of forest stands. Thus, dynamic growth and yield models that simulate different intensities of beetle disturbance are needed to fully understand the potential effect where MPB is a new form of disturbance.
- In-depth stand reconstructions can work as a guide for modelers in their efforts to simulate lodgepole pine stands in the Northern Foothills of Alberta.

Understandings of MPB in Alberta

S. Romanowski. 2009. Mountain Pine Beetle Media Analysis: Articles Published from 2000-2008 in Alberta Newspapers. Report published for the Foothills Research Institute.

Document Type: Report

Core Messages:

- Many individuals rely on the media (e.g., newspaper articles) to interpret science and relay information on community issues. However, the media can shape and reflect public perceptions which may not always align with expert knowledge.
- This report aimed to gain insight into public messaging about MPB in newspapers in Alberta as part of the broader 'public understandings' study. Specifically, what messages were communicated, when these messages emerged, and the expressed concerns about MPB management in AB.
- Alberta residents were exposed through the media to many messages and issues related to MPB presence, potential impacts, and management strategies. Both residents and land managers expressed distrust of the media, and the provincial government was a more trusted source of information.

Approach:

- A media analysis of newspaper articles distributed from 2000-2008 in western Alberta was conducted to identify, code, and categorize patterns in messages related to MPB.
- Ten main themes were identified that broadly focused on how MPB was portrayed in the media, the role of management and public messaging strategies, and opinions/concerns that emerged.

The Emergence of MPB in the Media:

- From 2000-2005, there was no major reporting on MPB in Alberta. Newspaper articles mainly focused on the impacts of the MPB outbreak in British Columbia (BC) including the tensions that resulted from BC's management approach, notably the impacts to forestry-based communities.
- Starting in 2006, MPB emerged more prominently in newspapers as an issue in Alberta. Coverage focused on rapid population growth, potential management strategies, and the concerns that arose (mainly from environmental groups and concerned citizens).
- From 2006-2008, as the number of infested trees increased, so did the media coverage.

Key Findings and Implications:

- Newspapers mainly focused on presenting factual information from expert sources and management agencies such as Parks Canada and the Government of Alberta. The main messages reflected issues related to MPB biology and ecology, and management strategies.
- In general, MPB was presented in a negative light and the main issues and reasons for the divergence from historical outbreak levels were explored. Indirectly, MPB was reported as an additional problem to broader issues of climate change (milder winters contributing to the outbreak) and forestry.
- Articles reflected that both the Provincial Government and Parks Canada see MPB as having significant consequences in Alberta, emphasizing that careful management is required to prevent the spread of MPB across Canada.
- Funding for MPB management was the main topic that related to the government's management goals. Key government messages focused on bringing awareness to the public, informing them on how to reduce spread, and directing them to other information sources. The main management strategies that were communicated included surveying, pheromones (i.e., verbenone), fire suppression and prescribed burns, logging and clearcutting, and selective cut/burn and heli-logging.
- Environmental groups and citizens (residents and business owners) were the main groups who expressed concerns related to the government's general approach and proposed management

strategies. In general, they were wary about prescribed burns, critical of logging, and concerned about impacts on wildlife and tourism. There was a specific concern that funding should be used to address bigger-picture concerns (i.e., climate change, land management, and fire management), rather than to only support logging.

- The analysis brought these concerns to light and provided insight into how these groups prioritize environmental, aesthetic, and economic factors. Overall, a broader understanding of local stakeholder knowledge, perception, opinions, and preferences of MPB is a **key element** in informing natural resource management and communication strategies.

McFarlane, B.L., Parkins, J., and Watson, D.O.T. December, 2010. Public and Expert Understandings of Mountain Pine Beetle in Alberta. Final Report on Survey Results Submitted to the Foothills Research Institute, Hinton, AB.

Document Type: Final Report

Core Messages:

- A key ingredient to effective natural resource management decision making is public acceptance. Without public acceptance, decision making and execution of management plans can be hindered. In the context of MPB in western Alberta, it is important to understand public perceptions and attitudes towards MPB, especially in regions most affected by MPB.
- The goal of this study is to help understand the public's response to MPB spread and proposed management strategies in Alberta, and to help guide resource managers and decision-makers on the most effective approach to communication strategies and management plans.
- Public perceptions of MPB infestation and management are often different than those of land managers and depend on the affected region. There is a need for context-specific management and communication strategies that consider these different ecological and socioeconomic factors.

Approach:

- There were three main components of this study (conducted in 2009) which included a media analysis [previous summary], a survey of residents in regions most directly affected by MPB, and a survey of land managers (experts and decision-makers).
- Survey questions focused on how respondents perceive risk and general attitudes towards MPB, management options, and current responses to MPB management. They also evaluated sources of MPB information and gathered demographic data.

Key Findings and Implications:

- Communication and management strategies should be context-specific and address the concerns of each region. The public is likely to be more accepting of responses that are tailored to their needs and concerns, rather than a generalized management approach.
- Land managers should be aware of how their perceptions are different from the public. Survey results show that land managers are more focused on traditional forest management concerns (i.e., fire and economic impacts) which will likely influence their approach to communication and MPB management. Though the public also sees these factors as important, they have additional concerns (i.e., loss of scenic quality and wildlife habitat, etc.) that should be taken into consideration.
- Most respondents see the government as the most trusted source of information, and the researchers see an opportunity for the provincial government to communicate and engage directly with the public about MPB management.
- The researchers also see opportunities for relationship-building between land managers and the public to improve communication and grow trust. A few ways this could be achieved are through community events (e.g., workshops) and tours of treated areas while discussing the benefits and uncertainties of different management strategies and including other experts.
- There is currently a sense of urgency about MPB infestation that is likely contributing to public acceptance of proposed interventions. As this sense of urgency decreases over time, the public may be less open to different management strategies, which must be accounted for in future public messaging.
- This study also has more broad implications if MPB were to spread into the boreal and affect forested communities. More needs to be understood about how the public views different management strategies related to MPB across a wide geographic area, taking into account how they differ from land managers. Recognizing these elements will enable management authorities to develop communication and management strategies that address local needs and are adaptive to changing MPB conditions.

Fire MPB Project

Tabacaru, C.A., and Erbilgin, N. 2014. Competitors and natural enemies may cumulatively mediate *Dendroctonus ponderosae* colonizations of *Pinus* forests. Forest Ecology and Management, 337: 98-109. [URL]

Document Type: Peer-reviewed

Key Messages:

- A recent study showed that *Dendroctonus ponderosae* (MPB) colonization increased immediately post-fire but declined over the following four years in lodgepole pine forests in Alberta **[link]**.
- There is a need to understand the mechanism of MPB decline post-fire and evaluate if it is mediated by MPB's interactions with competing insects and natural enemies at the community level, after prescribed fire.
- In post-fire lodgepole pine forests, MPB colonization will likely be limited by interactions with the under-bark insect community.

Approach:

- The authors studied the community of insects that live under tree bark (specifically competitors, parasitoids and predators of bark beetles). This insect community was studied among three mature lodgepole pine forests located in the Rocky Mountains of Alberta. All three sites were previously exposed to MPB and part of a prescribed burn project in 2009.
- Researchers tracked how these insect communities changed over time and space, and whether they affected MPB colonization after prescribed fire. Under-bark insects were captured using passive (without bait) techniques.

Key Findings and Implications:

- MPB are regulated by competitors and natural enemies in lodgepole pine forests that exist at endemic (low population) levels.
- Both competitors and predators increased in abundance after prescribed fire (and continued to increase over time) and were responsible for driving community differences. As a result, MPB is likely to be outcompeted as early as one year post-fire. This might reduce colonization of MPB as it will not have enough time to build up its population in burned stands. This effect would be particularly strong in areas densely populated with under-bark insects.
- Local abundance and composition of insects likely affects post-fire communities. Distant individuals may be attracted by fire, but the local communities will likely have a stronger response to abrupt changes in habitat.
- Ultimately, longer-term data is needed to look at post-fire ecological trends.

Tabacaru, C.A., McPike, S.M., and Erbilgin, N. 2015. Fire-mediated interactions between a tree-killing bark beetle and its competitors. Forest Ecology and Management, 356: 262–272. [URL]

Document Type: Peer-reviewed

Key Messages:

- A previous study **[link]** found that MPB preferentially colonized burned lodgepole pine stands, where their populations spiked immediately post-fire but declined over three years.
- Because MPB population growth is regulated by other species of the under-bark beetle community, this study investigates how the bark and ambrosia beetle community (not including MPB) changes in response to prescribed fire, and if this can affect MPB colonization.
- In general, bark and ambrosia beetles were more attracted to burned stands and their populations were higher where MPB was present. This likely increased competition explaining why MPB populations did not achieve outbreak levels in burned stands.

Approach:

- MPB attacks on mature lodgepole pines were monitored over four years among three prescribed fire sites located in the Rocky Mountains of Alberta. All sites were burned in spring 2009.
- Bark and ambrosia beetle species were surveyed using passive (without attractant) traps and divided into four categories (ambrosia beetles and lower-, main-, and upper-stem bark beetles) to determine their abundance and species richness.

Key Findings and Implications:

- Generally, bark and ambrosia beetle abundance increased until at least two years post-fire in burned and non-burned stands. However, beetle abundances increased **earlier** in burned stands.
- This attraction to burned stands was likely in response to stress cues given off by fire-injured trees and pheromones released by early-colonizing under-bark beetles.
- Main-stem beetles in particular increased in both burned and non-burned stands. Since the beetles can potentially build up their populations in weakened (fire-stressed) trees and spread to neighboring healthy (non-burned) trees, post-fire conditions may provide the opportunity for certain species to outbreak. This is an opposite pattern to MPB, which in previous studies were found to decline or remain low in burned stands three years post-fire.
- In general, there were more bark and ambrosia beetles where MPB were present, likely because they were attracted to similar cues released by stressed hosts. Based on the results, the researchers propose that increased competition is a key interaction that negatively affects MPB colonization post-fire.

TABACARU, C.A., PARK, J., AND ERBILGIN, N. 2016. PRESCRIBED FIRE DOES NOT PROMOTE OUTBREAKS OF A PRIMARY BARK BEETLE AT LOW-DENSITY POPULATIONS. JOURNAL OF APPLIED ECOLOGY, 53: 222–232. [URL]

Document type: Peer-reviewed

Key Messages:

- Prescribed fires have been used to manage lodgepole pine forests, including to limit the amount of suitable hosts available to MPB. However, it is uncertain if MPB preferentially attack burned forests.
- This study examines if prescribed fires cause low-density populations of MPB to transition to outbreak levels. The potential mechanisms driving MPB's initial colonization of burned stands was also investigated.
- When MPB occur at low densities, fire does not appear to promote outbreaks. As a result, prescribed burning should still be used as a general forest management technique in lodgepole pine forests with low-density populations of MPB.

Approach:

- Study plots were selected within three previously established prescribed-fire sites with existing low-density populations. All sites were located in the Rocky Mountains of Alberta.
- Sites were burned in 2009 and MPB attacks were monitored for four years following the burn events.

Key Findings and Implications:

- Fire-injured trees were more susceptible to MPB attack than non-burned trees, and moderately burned trees had more attacks than lightly burned trees.
- Prescribed burning did increase the resources (phloem) available to the beetles, this did not lead to an outbreak. The burn only provided a short-availability of these resources and after three years, MPB attacks on trees in burned forests either decreased or remained low.
- A potential mechanism driving this decline is likely a decrease in resource **quantity** rather than resource **quality**:
    - The **quantity** of the more favorable trees (moderately-burned pines) rapidly declined in burned stands as they began to die off and emerging beetles were limited in their ability to find these hosts, causing the overall population to decrease.
    - The **quality** of resources (amount of nitrogen in the phloem of a tree) in burned stands was equal to or better than non-burned stands. Despite surviving trees having more nitrogen in their phloem, the number of surviving trees was likely too low to enable a population outbreak.
    - The **quantity** of the more favorable trees (moderately-burned pines) rapidly declined in burned stands and emerging beetles were limited in their ability to find these hosts causing the overall population to decrease.
- These findings emphasize the importance of longer-term studies. Had MPB populations only been monitored for one-year post-fire, the study may have incorrectly suggested that burned stands become population sources or provoke MPB outbreaks.
- Future studies should also investigate how burn size affects beetle colonization. Larger burns may cause beetles to disperse more broadly as they travel farther to reach hosts, which could have detrimental management effects by encouraging landscape spread of outbreaks. Additionally, MPB population size will directly affect colonization patterns after a forest fire. Future research should track "eruptive" levels of post-fire MPB attack over multiple years.

Oblique Photo Project

Stockdale, C., Clovis, P., and Louveks, K. September 22, 2010. Georeferencing the Mountain Legacy Project oblique photos to evaluate historical landscape change. Report Prepared for: Don Podlubny, Foothills Research Institute.

Document Type: Report

Core Messages:

- Historical photographs taken by the Mountain Legacy Project have revealed landscape-level changes (i.e., less diversity and more forest cover) along the east slope of the Rocky Mountains due to altered disturbance patterns and climate change.
- The ability to spatially analyze these images may provide the opportunity to land managers to measure changes in forest susceptibility to MPB since the early 1900s, thus informing future management practices.
- This report provides detailed instructions for georeferencing oblique photos taken by the Mountain Legacy Project using the freeware application, Corripio.

Approach:

- The Corripio application was selected to georeference oblique photos (provided by the Mountain Legacy Project) from five different survey areas for a test landscape. Images were combined with digital elevation models using two main inputs (the camera's point of view and the image's center point) using the Corripio application to create spatially referenced images that can be analyzed using GIS software.

Key Findings and Implications:

- Corripio is the most effective application for georeferencing images and can render a photo in under 5 min with a powerful computer. This method is very accurate and oblique photo points are within 37.7 m (standard error of 4.9 m) of their real locations. Relative distances and spatial extents (e.g., change in treeline and the size of cutblocks and meadows) within the images are accurate.
- The accuracy and precision of this method depend on the resolution of the input digital elevation model and precision of the point-of-view and center point locations. There will be more error with a larger field of view. The researchers recommend interpreting images before georeferencing them, as the latter reduces image quality.
- Accuracy can also be improved by manually adjusting the images (e.g., cropping, resizing, and scaling) prior to running them through the application.
- A GIS program with the ability to view 3D digital elevation models and perform viewshed analysis is required to create image inputs and analyze the georeferenced outputs. Steps for image interpretation and analysis are not covered in this report and will depend on the user's specific purposes for the image outputs.
- Further investigation of the potential of these photos to quantify landscape change and susceptibility (i.e., to MPB) could provide an opportunity to land managers for new types of decision support.

**The full report includes detailed instructions that can help the user replicate the process and the automation tools are available through fRI Research or by contacting the lead author.*

MPB Dynamics

Bleiker, K. P., Heron, R. J., Braithwaite, E. C., and Smith, G. D. 2013. Pre-emergence mating in the mass-attacking bark beetle, Dendroctonus ponderosae (Coleoptera: Curculionidae). The Canadian Entomologist, 145(1):12-19. [URL]

Document Type: Peer-reviewed

Core Messages:

- Before emerging from their natal trees, MPB may have the opportunity to mate with either siblings or neighbours. High rates of inbreeding during this period may have implications for population health.
- This study investigates mating that occurs before MPB emerges from their natal tree and the effects of delayed emergence on this process in northern Alberta.
- Late-emerging female beetles are more likely to have mated before leaving their host tree than early-emerging females. Delayed emergence does not have a significant effect on pre-emergence mating.

Approach:

- The mating status of female MPB was determined from two sites located in northern Alberta. Beetles were both collected in the field and through a laboratory experiment. In the lab, logs that had been naturally infested by MPB were subjected to two different temperature treatments: a constant 22°C (control) or 14°C for 350 hours, then increased to 18°C (delayed emergence).
- Researchers sampled beetles during both the early emergence and late emergence stages.

Key Findings and Implications:

- Later-emerging female beetles were more likely to mate in their host tree than early-emerging beetles. In logs held at 22°C in the lab, late-emerging females had mated two times more than early-emerging females. Late-emerging females may be more likely to encounter sexually mature males, whose numbers increase later in the emergence period.
- Delaying emergence in the lab (via keeping logs at 14°C then increasing them to 18°C after 350 hours) caused a surge in beetle emergence but did not have a significant effect on pre-emergence mating.
- Overall, the frequency of pre-emergence mating among female beetles observed in this study was low (3-12%) but was higher than observed in previous studies (1-2%).
- The relatively low rates of pre-emergence mating found in this study may help decrease the negative impacts of inbreeding that can reduce the overall health of the population. However, some pre-emergence mating before the beetles emerge from their host tree may be helpful when beetles disperse, and finding a mate becomes more difficult.

BLEIKER, K. P., O'BRIEN, M. R., SMITH, G. D., AND CARROLL, A. L. 2014. CHARACTERISTION OF ATTACKS MADE BY THE MOUNTAIN PINE BEETLE (COLEOPTERA: CURCULIONIDAE) DURING ITS ENDEMIC POPULATION PHASE. CANADIAN ENTOMOLOGY, 146: 271–284. [URL]

Document Type: Peer-reviewed

Core Messages:

- In general, MPB exists in an endemic phase, where populations are low and beetles typically colonize weakened trees and are regulated by host resistance (i.e., natural tree defenses). However, little is known about MPB attack behavior and offspring development at these low levels, which may have important implications for understanding outbreak triggers.
- This study investigates the life history and characteristics of MPB attack at the endemic level, including beetle attacks of weakened trees (as is typical of the endemic phase).
- Typically, the reproductive success of MPB at endemic levels is low. However, a high-quality host tree that has recently suffered abrupt stress could facilitate a rapid increase in MPB populations.

Approach:

- Eight trees were selected in 2009 for intensive sampling from two study sites in north-central Alberta, where areas of endemic MPB-attack were previously identified.
- Log-bolts were extracted from each tree and researchers recorded the height of the attack, total gallery length, and cardinal direction of attack. Egg gallery characteristics were also recorded to determine the reproductive status of female beetles (mated vs. unmated) that initiated attacks.

Key Findings and Implications:

- Egg galleries were more concentrated on the lower ~3 m of the bole, but they did not favour a particular aspect. During mass attacks, MPB typically favours cooler and shadier aspects, but the weakened trees they attack at endemic levels may already grow in shadier areas.
- The vast majority (99%) of galleries were created by **mated** female beetles. This finding indicates that MPB at endemic levels had ample mating opportunities and likely mated at the host, not natal trees. This is supported by Bleiker et al. (2013), where overall incidences of pre-emergence mating (i.e., at the natal tree) were low.
- Reproductive success was generally low as beetles rarely matured into pupae.
    - However, in one of the trees, egg galleries were three times the average length (25 cm) and with 123 pupae (60 eggs is the average for MPB). This tree was an example of a very favorable, but rare, host with little defenses and minimal competitors to MPB.
    - This finding reveals that under certain conditions an endemic population of MPB could rapidly grow in their host.
- Although low reproductive success is typical for MPB at low/endemic levels, a high-quality host that has recently suffered abrupt stress could cause high population growth rates. Understanding these factors is important to know what could trigger a transition of MPB from endemic to outbreak population levels.

Ecological Impacts

Axelson, J. N., Hawkes, B. C., van Akker, L., and Alfaro, R. 2018. Stand dynamics and the mountain pine beetle — 30 years of forest change in Waterton Lakes National Park, Alberta, Canada. Canadian Journal of Forest Research, 48: 1–12 (2018) [URL]

Document Type: Peer-reviewed

Core Messages:

- Little is known about long-term forest recovery in response to disturbance, but long-term monitoring can provide an opportunity to understand how stand dynamics shift over time. This is especially relevant in the context of MPB infestation because impacts to forest ecosystems from outbreaks (e.g., tree death and forest succession) are not evident in the short term.
- In the late 1970s, a MPB outbreak in Waterton Lakes National Parks caused varying levels of lodgepole pine death. This study investigates how this outbreak influenced stand dynamics over 30 years and where the future succession of these stands is headed.
- Over 30 years, the MPB outbreak caused forest stand composition and structure to become more diverse and varied, suggesting these stands have been resilient to this disturbance.

Approach:

- In 1981, the Canadian Forest Service and Parks Canada established 25 semi-permanent sample plots in five low-elevation stands in Waterton Lakes National Parks to monitor the impacts of the 1970s MPB outbreak. The stands and plots were re-measured in 2002 and 2010 to record overstory, fuel, and understory measurements.
- A susceptibility index (SI), which helps determine the likelihood of attack and tree death, was calculated for each stand. The 2010 MPB susceptibility and composition data were analyzed to determine the characteristics of the biological legacies left from the MPB attack.

Key Findings and Implications:

- The researchers describe MPB as an “agent of transformation.” The 1970’s outbreak resulted in varying levels of lodgepole pine death, which caused variable stand structure and composition. Overall density, volume, and basal area of overstory trees decreased between 1982-2002. Canopy mortality, fallen trees, and regeneration (established and ongoing) have contributed to greater stand heterogeneity (variation in stand structures and composition).
- By 2010, the forests were no longer dominated by lodgepole pine. Non-pine conifers and broadleaf species were the main components of the understory and increased in density between 2002-2010.
- Shade-tolerant species were most prevalent in the highest-mortality stands, including moss and shrubs (i.e., thimbleberry), which are not suitable seedbeds for lodgepole pine regeneration. These changes in understory species composition suggest that stand succession is moving towards supporting more shade-tolerant species. However, based on the data that was collected from this study, the researchers cannot definitely state that the MPB outbreak accelerated these trajectories.
- Pre-outbreak understory conditions were not measured, and changes to the understory triggered by MPB are thus speculative. Establishment was likely limited immediately post-outbreak because MPB-infested trees can take decades to fall after they die. The understory species observed in 2002 were also likely present before the outbreak because trees grow slowly in this area.
- These low-elevation study stands were resilient to a highly variable (level of severity and tree mortality) MPB outbreak. Over time, most stands became less susceptible to MPB, especially where MPB had previously caused very high mortality (e.g., 93%) and killed more trees with the largest diameters. In contrast, in a stand with low levels (10%) of MPB-kill, lodgepole pines remained dominant and their susceptibility increased over time as the uninfested trees grew and matured.

- The mass and volume of coarse fuels (trees > 7 cm diameter) increased from 2002-2010 and was the highest c. 30 years after peak MPB activity and in stand stands with the highest MPB-kill. In contrast, fine fuels (trees ≤ 7 cm diameter) decreased. It is still unclear what this means for future fire probability.
- The future development of these post-MPB attacked stands will depend on future disturbances (i.e., fire), and the survival of saplings and small regeneration, which depend on climatic suitability. For example, the 2017 Kenow Fire caused a stand-replacing disturbance for two of the study stands which will reset their successional stages, helping early seral species like lodgepole pine and trembling aspen to develop. All study stands will continue to be monitored as the forest ecosystem evolves.

Post-MPB Shelf-Life

Lewis, K. and Thompson, D. 2011. Degradation of Wood in Standing Lodgepole Pine Killed by Mountain Pine Beetle. Wood and Fiber Science, 43(2): 130-142.

Document type: Peer-reviewed

Core Messages:

- Lodgepole pine is a commercially important species. Due to widespread MPB attack, decreases in wood supply are expected over the next few decades. These decreases can be mitigated by the efficient use of MPB-killed wood.
- This study examines the characteristics of MPB-killed wood and the variables that affect its quality and quantity.
- Wood quality declined the most within two years after MPB-caused death. After two years, changes were slower and more concentrated at the base of the tree.

Approach:

- MPB-killed trees were sampled over two years in three study areas in the central interior of British Columbia, including moist and dry subzones.
- Tree cookies were cut from the stem of each tree to quantify how wood characteristics changed over time and dendrochronology (tree-ring analysis) was used to determine when the trees were killed.

Key Findings and Implications:

- By the second year post-mortality, trees had substantially more cracks across their grain (i.e., checks) and over 70% of trees had checking. These checks deepened over time. Checks were more concentrated in the middle versus the bottom sections of trees, and are expected to increase the longer that dead trees stay standing. Increased wood breakage is predicted between two to six years after tree death.
    - Changes in wood moisture drove changes in wood properties. In general, wood moisture rapidly declined, then became stable two years after tree death.
    - Moisture was concentrated at the base of the tree, where it facilitated the development of saprot, a decay fungus, which continued to develop two years post-mortality.
- Blue-stain fungus spread deeper into faster-growing trees. It reached its maximum development within six to eight months following MPB attack, then declined over time after the trees died.
- Tree-fall rate is the most important factor to determine if dead wood can be used for biofuels or other wood fiber uses. The majority of trees fell eight years after they were killed by MPB. Once trees fell, there was a rapid increase in decay caused by saprot and cellulose loss at the base of the tree.
- **Trees should be harvested within one year after tree death** as wood quality declined most steeply one to two years after tree death. If the tree has been infected with blue-stain fungi, the window of opportunity is six to eight months. However, there could be up to a six-year harvesting window for smaller-diameter trees. Within these smaller trees, the depth and number of checks are likely to be less. Saprot development and wood-borer damage (i.e., blue-stain fungi spread) is also likely to be less in these smaller trees.
- Gathering information on how wood quality and quantity are affected by MPB-kill is important to optimize harvest strategies (timing and distribution). Understanding the rate at which MPB-killed trees fall is also important to plan for other non-timber values like wildlife habitat.

Lewis, K. J., and Hrinkevich, K. 2013. Post Mortality Rate of Wood Degradation and Tree Fall in Lodgepole Pine Trees Killed by Mountain Pine Beetle in the Foothills and Rocky Mountain Regions of Alberta. Final Report for the Foothills Research Institute.

Document Type: Report

Core Messages:

- Shelf-life (how long wood from a dead tree can be manufactured into wood products) is a key factor that should be considered in planning harvesting strategies to ensure the optimal use of MPB-infested forests.
- This study replicates research conducted in BC **[see previous summary]** to determine initial rates of wood degradation in pine trees killed by MPB.
- Overall, trees sampled in Alberta experienced similar trends to what was observed in BC: wood quality declined most steeply within one to two years after tree death. However, the Alberta trees dried faster and developed more checks within the first two years post-death, which was most pronounced in the mixedwood region.

Approach:

- Ten sites were sampled in Alberta's foothills region in 2011. Discs (tree cookies) were extracted at four different locations on the tree to determine moisture content, number and depth of checks (cracks across the wood grain often caused by drying), and depth of saprot decay.
- This was combined with data collected from a separately funded study where six sites were sampled in the province's Boreal Mixedwood region in 2010.
- 155 trees were sampled and tree-ring analysis was used to determine the year of tree death.

Key Findings and Implications:

- Similar to the BC sample sites, sapwood moisture content within the foothills and mixedwood samples rapidly declined within the first year following tree death. However, drying was faster in Alberta than in BC. Furthermore, the mixedwood samples dried faster than the foothills, likely because of lower total precipitation and colder winters in the mixedwood.
- The faster drying rates in the mixedwood samples likely caused the greater number and depth of checks than in the foothills. The Alberta trees had a similar proportion of trees that developed checks but had more checks per tree than in BC. This was likely driven by Alberta's drier climate. By three years post-death, nearly all Mixedwood trees had one or more checks at any of the four sample discs. This is in contrast to the foothills trees, where this point was not reached until seven years post-death.
- Surprisingly, saprot decay was most widespread in the mixedwood samples and almost non-existent in the foothills. Similar to BC, saprot in the foothills was concentrated at the bottom of trees that had been dead for five years. This was surprising as saprot thrives with more moisture, and the mixedwood trees dried the fastest.
- Although the time at which trees will fall is still unknown in Alberta, based on the similar rates of saprot development to BC trees, trees in Alberta's foothills are expected to have significant fall rates 8-10 years post-death. This process may be longer in the Mixedwood region, as saprot was less common than in the foothills.

Climate Project

Anderson, A., Carroll, A. L., Coops, N., Mahat, V., Roberta, D. R., Nielsen, S. E., and Stenhouse, G. B. April, 2013. Future of Alberta's Forests: Impacts of Climate and Landscape Change On Forest Resource. Report to Alberta Innovates.

Document Type: Report

Report Description:

- This report summarizes the contributions of five different research projects which quantify and project the impacts of climate change on forest condition and health in Alberta. The projects are specific to impacts to vegetation conditions, forest hydrology, insect infestation, and phenology.
- The first project developed climatic layers which served as the base for the other studies.
- The five projects and their findings are summarized below.

Project 1: Future Climate Change and Forest Condition

Contributing Author: Nicholas Coops

Core Messages:

- Modeling future climate change scenarios and disturbances can help characterize the landscape such that changes can be monitored and management strategies can be informed.
- This project aimed to generate layers using various disturbance, phenology, and climate inputs to develop a range of scenarios such that changes to three focal resources (water, plant phenology, and MPB) can be evaluated.
- This project provides the basis for the various studies that are included in this report.

Approach:

- A collection of climate layers were developed over Alberta and include past and future climatic conditions, as the base for the various studies in this section. Forest disturbance (fire and harvest) was mapped and analyzed using remote sensing data.
- Three future climate scenarios identified by the Intergovernmental Panel on Climate Change (IPCC) were used to help simulate conditions under a future projected climate. The three scenarios were:
    - A 'business-as-usual' (or high-emissions) scenario where future rates of greenhouse gas emissions are unchanged,
    - A low-emissions scenario where current emission rates are steady until mid-century (~2040), then decline to approximately half by the end of the century, and
    - A moderate-emissions scenario where the rate of emissions falls in between the two previous situations.

Key Findings and Implications:

- Lodgepole pine remains well-adapted to climate variability throughout most of Alberta. However, it was more vulnerable to climate variability on the eastern slopes of the Rocky Mountains in central Alberta.
- All team participants, Alberta Innovates, and fRI Research can request access to the combined GIS layers and simulations.

Project 2: Climate and Water

Contributing Authors: Vinod Mahat and Axel Anderson

Core Messages:

- The Oldman River supplies the majority of usable water to surrounding communities, and its headwaters originate in the Rocky Mountains, a very vulnerable region to climate change.

- The study evaluated the impacts of climate and the potential added effects of forest change (i.e., tree removal) to streamflow in the upper parts of the Oldman River in Southern Alberta.
- Climate change is likely to cause higher streamflow in the winter and spring, and lower streamflow in the summer.

Approach:

- Monthly climate averages from a global climate model (a model that projects future climates under different greenhouse gas emission scenarios; also known as general circulation models or GCM) were downscaled to produce daily climate averages. This was combined with two other models: a simple conceptual hydrological model and a stochastic weather generator to assess the impacts of climate and forest changes on streamflow in the Oldman River.
- The three climate change scenarios were used to incorporate the range of possible future climate conditions.

Key Findings and Implications:

- Seasonal streamflow patterns had the largest changes in response to climate change in the simulation. Increased temperatures likely caused higher winter and spring flows and lower summer flows in the model, which is consistent with other climate change studies that have been conducted in similar regions. Specifically, the GCM projects higher winter precipitation and lower summer precipitation, leading to up to 200% (9.3 mm) more winter streamflow in February and up to 63% (31.2 mm) less summer flow in June.
- The projected decrease in summer streamflows may have consequences to summer water availability since demand already exceeds the supply of usable water from the Oldman River.
- In both the reference and future periods, higher winter or early spring flow was observed after forest removal. This may be caused by faster snowmelt in the absence of trees.
- Certain hydrologic components (i.e., soil moisture, base flow, snow accumulation and ablation, evapotranspiration, etc.) were not validated in this study, which could influence the results of future streamflow simulations for climate change studies.

Project 3: Climate and Plant Phenology

Contributing Authors: David Roberts, Scott Nielsen and Gordon Stenhouse

Core Messages:

- A warming climate is expected to influence plant communities, with implications for species that rely on these plants as food sources and whose habitats depend on the availability of plant food communities (e.g., grizzly bears).
- The goal of this study is to assess how climate change may contribute to the vulnerability of grizzly bears based on changes to the plants they commonly eat.

Approach:

- Using field data and ecological niche models, the researchers projected how a warming climate may alter the habitat of 17 plant species that are key food sources for grizzly bears in the southern Rocky Mountains in Alberta and British Columbia.

Key Findings and Implications:

- Many species appear to increase their range with a warming climate. However, there are several key species of concern that are projected to lose large portions of their range, and should be considered at high risk:

    - The loss of habitat for alpine sweet vetch (*Hedysarum alpinum*) is of great concern to grizzly bears as it is an important root in the spring and autumn when other food options are not available.
    - Other species that are restricted to high elevations, such as crowberry (*Empetrum nigrum*) and grouseberry (*Vaccinium scoparium*), are also expected to experience habitat loss. It is uncertain whether the shifting habitat of these species will impact grizzly bears because other autumn fruit resources do not appear to have critical changes to their availability.
- There was a general trend of plant species moving towards higher elevations, which may cause potential human-wildlife conflicts for grizzly bears. Grizzly bears may become more vulnerable at lower elevations since the number of different plant species is projected to decrease by 50% in the summer or 25% in late summer to fall in many lower-elevation locations.
- To fully assess how climate change will affect the quality of grizzly bear habitat, future research should assess how the quality and abundance of food is affected by climate change

Project 4: The mountain pine beetle in novel pine forests: predicting impacts in a warming environment

Contributing Authors: Allan Carroll

Core Messages:

- In the face of climate change, it is important to understand how regions that were previously deemed unsuitable to MPB may be impacted by warming temperatures.
- This study projected the future distribution and abundance of climatically suitable and susceptible pines to MPB in the foothills region of Alberta, based on three different climate change scenarios.
- Although this region was historically deemed as unsuitable to MPB outbreak due to its cold winters, the amount of suitable and susceptible pine stands is projected to increase by the mid-century. In anticipation of a warming climate, there is a need for fast-acting management strategies that prioritize stands that are most favorable to MPB to mitigate the impacts of potential outbreaks in Alberta forests.

Approach:

- Researchers combined projections of climatic suitability with a stand susceptibility model for MPB that was based on empirical measures of beetle productivity in new MPB habitats. This combination projected the future quantity and distribution of suitable and susceptible pine stands for the Alberta foothills region based on the three climate change scenarios defined by the IPCC.

Key Findings and Implications:

- Although the foothills region contains many pine-dominated stands, **this region is currently unsuitable to MPB** due to its adverse weather conditions and is expected to limit MPB's ability to reach outbreak levels. Recent increases in average annual temperature have caused some lower-elevation stands in the eastern portion of the Foothills to be moderately suitable, but not optimal, MPB habitat. Thus, MPB is very unlikely to reach outbreak levels even if populations have already established in this region.
- In the future, the availability of climatically suitable MPB habitat is expected to rapidly increase regardless of the climate change scenario. By the end of the century, all scenarios will lead to at least moderately suitable habitat.
- It is cautioned that unless the IPCC low-emissions scenario is achieved, the vast majority of the region will be very susceptible to MPB in the near future. In both the business-as-usual and moderate-emissions IPCC scenarios, approximately 400,000 to 450,000 ha of pine will be at high risk of sustaining an MPB outbreak within the 2011-2040 time frame.
- In anticipation of an increasingly warmer climate, it is recommended that aggressive short-term indirect management strategies be used to reduce the susceptibility of the landscape. This could include

techniques similar to the current "healthy pine strategy" where the highest-risk pine-dominant stands are harvested sooner to reduce susceptibility to MPB.

Project 5: Environmental Stress and Susceptibility of Lodgepole Pine to Mountain Pine Beetle

Contributing Authors: Nicholas Coops

Core Messages:

- This study examined the connections between climate, tree species stress, and MPB infestation.

Approach:

- Stand-level measurements were combined with variables derived from detailed stand-level vegetation resource inventory datasets, weather data, and r-values (the ratio of surviving MPB offspring to parent attacks, previously measured by Alberta Environment and Sustainable Resources Development), to predict the size of an emerging MPB population.
- Climatic stresses on lodgepole pine were compared to the r-values, using 2005-2009 lodgepole pine species stress layers.

Key Findings and Implications:

- The ratio of surviving MPB offspring to parent attacks (r-value) increased with species stress. For example, MPB were the least abundant in regions where the trees experienced a suitable climate for all years between 2005-2009. Thus, lodgepole pine stands that are more stressed in their long-term geographic ranges attract more MPB.
- However, this relationship has a threshold. In stands with no stress or only one year of stress, the r-value rapidly decreases, meaning less beetle activity. If trees are stressed for more than two years, MPB populations are higher and remain at this rate regardless of additional stressful years.

Cold Tolerance

Bleiker, K. April, 2020. Cold tolerance of mountain pine beetle: implications for population dynamics and spread in Canada. Report submitted to the fRI Research, MPB Ecology Program.

Document Type: Report

Core Messages:

- In general, the larval phase is considered the most cold-tolerant MPB life stage, but little is known about the cold tolerance of other MPB life stages. The cold tolerance of MPB, and how cold tolerance changes in response to climatic conditions, have implications for the potential of MPB to survive very cold winters east of Alberta's Rocky Mountains
- Cold tolerance was experimentally assessed throughout different MPB life stages. These results can be used by both scientists and land managers to develop decision-support tools that evaluate the risks of MPB expansion in northern Alberta and Canada's boreal forest.
- The likelihood of MPB survival throughout winter is different for each life stage. Larvae can survive an average winter in Alberta, whereas eggs and pupae likely will not survive winter anywhere in Canada. Although adult beetles will survive a mild winter (similar to winter conditions in southern BC), they will not survive an average winter.

Approach:

- MPB were extracted from bolt samples cut from previously infested trees from field sites in north-central Alberta from 2014 to 2018. The cold tolerance of MPB in each life stage (egg, larval, pupal, and adult) was assessed by measuring the super-cooling point of individual insects (the temperature where internal ice forms within the beetle, causing death) that were acclimated under a variety of temperatures. Insects were exposed to different cold treatments for various lengths of time and their mortality rate was reported.

Key Findings and Implications:

- The average supercooling point for eggs, pupae, and adults ranged between -18°C and -21°C. An acclimation period improved adult MPB cold tolerance but did not affect egg or pupa cold tolerance.
- Larvae had higher cold tolerance than the other life stages, and it improved with acclimation. After an acclimation period at 0.5°C, 50% of the MPB population is expected to survive exposure to -34°C.
- Larvae reached their maximum cold tolerance after acclimating at cooler temperatures (0°C) for 60-70 days. However, they did not require a gradual temperature decline and were able to achieve cold-hardening at below-freezing temperatures. This finding suggests that cold tolerance can be achieved at a broad range of temperatures in the late fall.
- Cooler average daily temperatures will likely trigger cold-hardening rather than daily variation around these averages because daily temperature variations did not play a role in triggering cold-hardening.
- Larval cold tolerance rapidly decreased when they were exposed to warmer temperatures (e.g., 15°C or 22°C) for hours to days. Warm days in the spring could cause MPB to lose enough cold tolerance such that they would be more vulnerable to a cold snap. However, the temperature would have to be warm for long enough to significantly warm the wood surrounding MPB.

Bleiker, K. P., and Smith, G. D. 2019. Cold Tolerance of Mountain Pine Beetle (Coleoptera: Curculionidae) Pupae. Environmental Entomology, 48 (6): 1412-1417. [URL]

Document type: Peer-reviewed

Core Messages:

- This study is a component of a broader project [link] that examines the cold tolerance of MPB in its different life stages. Determining MPB cold tolerance can help understand and predict the potential for MPB outbreaks.
- This specific study evaluates MPB cold tolerance in the pupal stage.
- MPB pupae have similar cold tolerance to MPB eggs and are not well adapted to overwintering.

Approach:

- Five to ten short-logs (bolts) were cut from three pine trees in northern Alberta that were previously infested by MPB. MPB pupae were extracted and their cold tolerance was assessed by determining their supercooling points and survival status in the lab.
- The lowest lethal temperature for pupae was measured by determining supercooling points, the coldest temperature that the beetle can survive before freezing to death. Mortality was determined by brief exposure to cold temperatures and prolonged exposure to more moderate temperatures. Potential acclimation to cold temperatures was assessed with a chilling period.

Key Findings and Implications:

- A chilling period did not increase the pupae's cold tolerance. MPB pupae are not expected to survive winter in most regions of Canada.
- 50% of the pupae were killed at –19.3°C, which is only 1°C warmer than what was found for eggs in a previous study [link]. The average supercooling point for MPB pupae was –18.7°C.
- Many pupae died from prolonged exposure to warmer temperatures (0°C and –9°C) before reaching supercooling. This indicates that pupae suffer significant pre-freeze mortality, which can occur from membrane damage or disruption of their bodily functions.
- MPB appears to be more cold-tolerant than other pine beetle species (*Ips spp.* and *Dendroctonus frontalis Zimmermann*), which have an average super-cooling point of –12°C to –5°C.

BLEIKER, K. P., SMITH, G. D., HUMBLE, L. M. 2017. COLD TOLERANCE OF MOUNTAIN PINE BEETLE (COLEOPTERA: CURCULIONIDAE) EGGS FROM THE HISTORIC AND EXPANDED RANGES. PHYSIOLOGICAL ECOLOGY. ENVIRONMENTAL ENTOMOLOGY, 46(5), 2017, 1165–1170. [URL]

Document Type: Peer-reviewed

Core Messages:

- Mortality of MPB over the winter is expected to be a key factor that determines the beetle's range expansion in Canada.
- The goal of this study was to determine the cold tolerance of MPB in its historic range in southern British Columbia and its expanded range in north-central Alberta. The study also assessed whether eggs need to be chilled for an extended period to reach their maximum cold tolerance.
- A significant number of eggs died following brief exposure to very cold temperatures or prolonged exposure to somewhat cold temperatures (-7.7°C to 0.3°C). Eggs are unlikely to survive the winter in much of MPB's range.

Approach:

- Short-logs (bolts) were cut from MPB infested trees in southern BC and north-central AB. The cold tolerance of MPB eggs was determined by measuring the mortality rates and supercooling points (the temperature at which freeze-avoiding species die) after exposing the eggs to a range of cold treatments for different lengths of time.

Key Findings and Implications:

- Cold tolerance of MPB eggs was not affected by the population source or acclimation time. Egg mortality significantly increased with colder temperatures and longer exposure to cold temperatures. For example, 2.5-5 times more eggs died from a 2°C decrease in temperature from -19°C to -21°C.
- Eggs did not acclimate or increase their cold tolerance with a chilling period and suffered significant pre-freeze mortality. Based on the results, 50% of eggs can survive brief exposure to -20.5°C, but when eggs were stored at 0.3°C and -7.7°C for 59 days, 50% and 100% died respectively. This means that eggs are not well adapted to overwintering and are unlikely to survive winter throughout most of MPB's range.
- This information can be used to help model the climatic suitability of MPB and how a changing climate might affect seasonality and thus winter survival.
- It is recommended that to build a cold tolerance index for MPB, lower lethal temperatures and duration of exposure to sublethal temperatures must be included. These elements should also be incorporated into survival and population models.

Bleiker, K. P., and Régnière, J. 2014. Determining the instar of mountain pine beetle (Coleoptera: Curculionidae) larvae by the width of their head capsules. Canadian Entomology 146: 1–6. [URL]

Document type: Peer-reviewed

Core Messages:

- Identifying and differentiating larval instars (the development stages as larvae grow) can help determine the age distribution of MPB.
- The study aimed to define four different MPB larval instars using size classes derived from larval head-width measurements. The size thresholds provided by this study can help classify field-collected MPB larvae throughout most of the historic and expanded MPB range in western Canada.

Approach:

- Head-capsules from MPB larvae were collected from previously infested trees in southern British Columbia (BC), northwestern BC, and northern Alberta. Sampled tree species included lodgepole pine in BC and lodgepole-jack pine hybrids or backcrosses in Alberta. The width of larvae head capsules was measured, and the four instars were determined using a maximum likelihood approach.

Key Findings and Implications:

- The upper size threshold estimates for the four MPB instars based on head-capsule widths are:
    - Between instar 1 and 2: 0.552 mm
    - Between instar 2 and 3: 0.732 mm
    - Between instar 3 and 4: 1.037 mm
- Researchers can use these size thresholds to determine MPB larvae growth stages. This can be used to determine their age distributions, in lodgepole pine or lodgepole-jack pine hybrid stands, throughout most of MPB's range in BC and AB.
- This information can help build and improve decision-making tools that assess the climatic suitability of habitats and the potential of MPB to continue expanding its range.

Monitoring Tools

Klutsch, J. G., Cale, J. A., Whitehouse, C., Kanekar, S. S., and Erbilgin, N. 2017. Trap trees: An effective method for monitoring mountain pine beetle activities in novel habitats. Canadian Journal of Forest Research 47(10): 1432-1437. [URL]

Document Type: Peer-reviewed

Core Messages:

- Pheromone baits are an important tool for managing MPB. However, the effectiveness of trap trees to detect low-density MPB in new habitat is uncertain.
- This study examined the most effective deployment strategy for MPB baits by assessing different MPB bait combinations and different arrangements of baited trap trees. Monitoring of low-density MPB populations occurred in mature lodgepole pine forests in Alberta.
- The researchers recommend groups of four baited trees, spaced 50 m apart in a square formation, at 12 km intervals to monitor MPB in the eastern limit of its range.

Approach:

- This research occurred in two phases near Swan Hills and Whitecourt, Alberta. A first phase tested different bait combinations and determined that standard commercial MPB baits (trans-verbenol, exo-brevicomin, terpinolene) plus myrcene caught the most beetles.
- The bait combination was deployed to trees arranged in different densities and distances. Three different trap tree formations, all baited and with 50-m spacing, were tested: three trees in a triangle (similar to Alberta Agriculture and Forestry's current protocol), four in a square, and six in a rectangle. The formations were placed along a linear transect at 1, 4, and 8 km apart. Each combination was repeated three times at three different locations.
- The following field year (2016), the most successful formation (square) was tested again at two different distances (8 km and 12 km) to determine the most efficient and effective trap system.

Key Findings and Implications:

- Strong attractants, like standard MPB bait (exo brevicomin, trans-verbenol plus terpinolene) plus myrcene, can improve the success of a trap tree program. This bait combination resulted in over 90% of trees being attacked in the field, with 21% that were mass-attacked.
- The trap tees can successfully concentrate and contain a low-density population of MBP into a small area. This was most evident in the square formation, which had the highest proportion of mass-attacked trees and the fewest attacked nearby non-baited trees.
- Baited trees were effective in detecting both low and high MPB population densities. Most attacks on baited trees were assumed to arise mainly from MPB immigration from neighboring stands, thus it is possible that trees with **low attack density** reflect a **low overall MPB population density** and vice versa.
- A square trap tree configuration with 12 km spacing between groups was successful (i.e., very few nearby non-trap trees were attacked) and can be used to monitor MPB.
- All baited and nearby non-baited trees should be removed before the next generation of MPB emerges in the summer to reduce the risk of unintentionally increasing the population.

Dynamics Endemic MPB

Carroll, A. L., and Pokorny, S. W. 2020. Dynamics of endemic mountain pine beetle populations in novel habitats. The University of British Columbia, Faculty of Forestry. Department of Forest and Conservation Sciences. Final report for fRI Research project 246.16.

Document Type: Final Report

Core Messages:

- MPB mostly exists in an endemic phase where it is restricted to attacking weakened trees. The long-term persistence of endemic MPB in its expanded range depends on whether suitable hosts are available for low-density populations to persist.
- This study assessed the ability of endemic MPB to persist east of Alberta's Rocky Mountains by determining the susceptibility of mature pine trees to endemic MPB.
- Jack pine forests in Alberta are unlikely to support a persistent endemic MPB population. However, lodgepole pine in Alberta are at least as suitable to endemic MPB populations as lodgepole pine forests in British Columbia (BC) that have historically been exposed to MPB.

Approach:

- Endemic-susceptible trees were identified in 16 pine stands across eight locations from southern BC to east of the Rocky Mountains in Alberta. The stands were six lodgepole pine dominated stands from the historic MPB range in BC, four lodgepole pine stands that did not evolve with MPB, and six jack pine stands in Alberta.
- Endemic-susceptible trees were defined as any pine that was: 1) attacked by MPB within the last two years; or 2) occupied by other bark beetle species but had available phloem.

Key Findings and Implications:

- Jack pine stands had fewer endemic-susceptible trees (less than three per hectare), but lodgepole pine sites in Alberta and BC were relatively similar.
- Unlike jack pine, lodgepole pine stands are more dense and therefore can provide a steady supply of endemic-suitable hosts through self-thinning and higher inter-tree competition. Stand density index can be used by forest managers to predict the availability of endemic-suitable hosts for MPB.
- The presence of competitors (e.g., wood boring beetles) and predators (e.g., woodpeckers) can further reduce the ability for endemic MPB to persist in jack pine. Wood boring beetles were not found in lodgepole pine stands, but were present in almost 50% of endemic-suitable jack pine.
- The researchers anticipate that MPB will become locally extinct in jack pine forests, where fewer trees were endemic-susceptible. However, since Alberta's lodgepole pines can support the long-term persistence of **endemic** MPB, they could build up their populations to outbreak levels which could renew the eastward expansion.
- Mature pine stands (both lodgepole and jack pine) with a stand density index over 750 should be prioritized for MPB management (harvesting, thinning etc.), and younger pine stands should be managed to prevent their exceeding this density at maturity.

Stand Dynamics After MPB

Dempster, W. R., and Meredith, S. September, 2019. Stand Dynamics After Mountain Pine Beetle Attack. Forest Growth Organization of Western Canada. Final Technical Report.

Document Type: Final Report

Core Messages:

- After the 2006 MPB outbreak in western Alberta, permanent sample plots were established and reserved from harvesting to assess impacts to unmanaged lodgepole pine forests post-outbreak.
- This study assessed how stand structure, composition and dynamics changed 10 years following the 2006 MPB outbreak.
- Without intervention, lodgepole pine is unlikely to naturally regenerate within 50 years following high severity MPB attack on most site types. Sites containing non-pine species had higher (non-pine) regeneration. Flexible, site-specific management is recommended to promote post-outbreak regeneration.

Approach:

- 65 permanent sample plots in 17 stands were monitored to assess changes to stand structure and predict future stand development. Plots were re-measured at least once 6 — 10 years post-attack and compared with baseline measurement taken prior to the outbreak. Future stand development was projected using two different growth and yield models.

Key Findings and Implications:

- Ten years post-attack, stand volumes were less than 100 m^3 per hectare (20% less than pre-attack volumes). Conditions appeared unfavorable for lodgepole pine regeneration (i.e., lack of favorable seedbeds and more competing vegetation **[link to McIntosh and McDonald 2013]).**
- If less than 50% of lodgepole pine are attacked in a stand, very minor stand impacts are projected. With higher levels of attack severity (over 50%), total live softwood volume is projected to decrease.
- Natural regeneration outcomes varied and depended on site conditions and the presence of non-pine advanced growth. Similarly, attack severity and species composition varied within each of the study plots, resulting in a range of projected growth and yield outcomes.
- Without management intervention such as site preparation, seeding, and planting, lodgepole pine will unlikely regenerate within a timeframe that is consistent with forestry objectives.
- In high severity attack stands containing non-pine species (like white spruce or balsam fir) in the understory, the overstory will likely naturally recover with mostly non-pine species. **In highly impacted areas, management should focus on stands with high-severity attacks that do not have non-pine species in the understory.**
- Within the next 50 years, forests in the lower foothills are projected to have more diverse stand and forest structures (i.e., uneven-aged forests) due to variation in MPB attack intensities and tree species composition. An irregular shelter-wood approach to harvesting may be appropriate: it is flexible and can increase ecological diversity, retain the best trees for midterm timber supply requirements, and encourage regeneration and maintain forest cover.

Impacts Hydrology

Albrechtova, P., and Goodbrand, A. 2020. Impacts of Mountain Pine Beetle on Hydrology and Vegetative Redevelopment in Lodgepole Pine Forests of West-central Alberta, Phase II: Stand-level near Robb. fRI Research Quick Note.

Document Type: Quick Note

Core Messages:

- Forest cover loss can influence the amount of water that enters streams by altering stand hydrology. The effects of MPB kill on forest stand hydrology are less predictable than more immediate disturbances like forest harvesting or wildfire.
- This sub-project assessed hydrological responses to different severities of simulated MPB attack in mature lodgepole pine forests in the Foothills of Alberta.
- Salvage harvesting following MPB attack had a greater initial (<6 years) impact on stand hydrology than the grey phase of MPB attack. This impact moderated as the forest regenerated.

Approach:

- Three different severities of forest cover loss (50% MPB-kill, 100% MPB-kill, salvage logging and untreated control) were simulated in lodgepole pine stands near Robb, Alberta. **Refer to this project [link] for a more detailed description of the methods.**
- Stand-level micro-climate and hydrology (rainfall interception, transpiration, soil moisture, and groundwater) data were assessed to understand the impacts to stand-level hydrology as trees transition from their green- to grey-attack phases.

Key Findings and Implications:

- The treatments had little effect on air temperature and vapor pressure deficit, but they had higher wind speeds at the top of the canopy and more sunlight that reached the forest floor.
- Precipitation interception declined, and snow depth and persistence increased, with decreasing forest cover—i.e., the treated stands had more rain and snow reaching the ground and deeper, more persistent snow than the controls. However, the differences between 50% and 100% simulated MPB kill were slight.
- Soil moisture strongly increased in the 100% kill stands and decreased in the salvage harvest, but changes were less pronounced in the 50% kill stand. It is expected that soil moisture will increase with higher grey-attack intensity (i.e., more forest cover loss).
- Soil moisture in the 50% kill stand was not significantly different from the control, because the combined effects of interception loss, soil evaporation, and understory plant transpiration compensated for reduced evapotranspiration.
- Regeneration in the salvage logged stand six years post-harvest resulted in similar drainage to both of the MPB kill stands. Thus, impacts to stand hydrology will be greater in the short term for harvested stands (due to an abrupt loss in forest cover), but will become similar to MPB kill stands as the clear-cut regenerates.

Albrechtova, P., and Goodbrand, A. 2020. Impacts of MPB on Hydrology and Vegetative Redevelopment in Lodgepole Pine Forests of West-central Alberta, Phase II: Watershed-scale at Tri-Creeks. fRI Research Quick Note.

Document Type: Quick Note

Core Messages:

- The extent to which forest cover loss (i.e., from harvesting) influences streamflow depends on watershed characteristics like water storage capacity. Since most watersheds in the foothills contain harvestable forests, this region's streamflow may be particularly impacted by forest disturbance. However, unstable climate patterns may conceal changes to forest hydrology, making subsequent disturbance impacts difficult to assess.
- This study examines the effects of climate and different forest harvest levels on watershed-scale hydrology in three of the Tri-Creek watersheds in Alberta's foothills region.
- Despite over 60% of forest cover removal, Tri-Creek watersheds were more resilient to change caused by forest harvesting than expected.

Approach:

- Three sub-watersheds at the Tri Creeks experimental watershed (established in 1965) in Alberta's foothills region were chosen (control, 64% clear-cut with streamside timber removal, 52% clear-cut) to examine the effects of forest removal on the watershed. Statistical and hydrological modeling isolated the effects of forest harvest from climatic variability.

Key Findings and Implications:

- A shift from cool to warm phase of Pacific Decadal Oscillation (PDO) in 1977 caused warmer winters, more frequent and larger rainstorms, lower winter precipitation, and less snowpack in the Tri-Creeks watershed. Since then, there has been earlier snowmelt, a delayed rising limb period of spring freshet, and higher streamflow in the fall (the watershed's low flow period).
- In these watersheds, streamflow is influenced by how wet or dry the soil is before precipitation. In the control, large annual storage changes (1-33% of precipitation) caused variable runoff from year to year.
- Post-harvest, the amount of precipitation added and stored in the soil was variable and influenced the amount of runoff:
    - In the 52% clear-cut, changes to streamflow were similar to that of the controls, which resulted from a warmer PDO.
    - In contrast, the 64% clear-cut with streamside timber removal had earlier snowmelt with higher streamflow in the fall.
- Although harvesting increased water input to the watershed, subsurface conditions of the watershed may have buffered this effect by storing more water than expected. As a result, the watershed showed more resilience than expected to forest harvest. However, the amount of subsurface water storage may mask changes caused by forest disturbance.

Assessing Alberta Response Effectiveness

Cooke, B. J., Carroll, A. L. 2017. Predicting the risk of mountain pine beetle spread to eastern pine forests: Considering uncertainty in uncertain times. Forest Ecology and Management, 396: 11-25. [URL]

Document Type: Peer-reviewed

Core Messages:

- In 2006, MPB spread eastward from British Columbia (BC) to Alberta at unprecedented levels with an average rate of 80 km/yr. However, future rates of spread are uncertain due to the expansion of MPB into new habitats, unpredictable weather events, and management strategies.
- This study developed a complex model of MPB population dynamics that accounts for various factors that influence MPB population growth.
- The model highlights how minor changes in climate or forest condition may cause a rapid increase in MPB populations. Management strategies should be adaptive to account for unpredictability of future spread.

Approach:

- A synthetic framework model was constructed using inputs that take into account multiple internal and external factors that affect MPB population dynamics. These factors include those that are specific to distinct population phases of MPB (e.g., endemic or epidemic), climate, and ecosystem changes as a result of climate change.
- The model was analyzed under two different climatic conditions (warming and drying) and one forest scenario (increased ratio of unhealthy to healthy trees).

Key Findings and Implications:

- The model shows that even minor increases in warming or drying, or a slight increase of the ratio of healthy to unhealthy pines, can push MPB to a “tipping point” that triggers a population outbreak and rapid spread.
- It is likely that a similar combination of factors pushed MPB populations in BC to unprecedented outbreak levels in the late 1990s, and in the future will impact the rate at which MPB may spread into commercially important forests in Ontario.
- Unpredictable factors may also limit MPB expansion and outbreak. For instance, as MPB moves into the Boreal Plains, cooler temperatures may keep MPB at endemic levels where they remain at low population densities.
- Ultimately, the eastward spread of MPB will depend on whether, when, and where it transitions into an outbreak state. This is difficult to judge due to the many different factors that drive population shifts. The uncertainties surrounding these factors prevent the model from making absolute predictions of spread under natural conditions.
- In order to accurately assess the timing of an MPB outbreak, intensive monitoring over large areas is required.

Carroll, A., Seely, B., Welham., C., Nelson, H. March 10, 2017. Assessing the effectiveness of Alberta's forest management strategies against the MPB. The University of British Columbia Faculty of Forestry. Final Report for fRI Research project 246.18 parts 1 and 2.

Document Type: Final Report

Core Messages:

- Understanding the effectiveness of management strategies to date is critical for predicting their future effectiveness and identifying areas of improvement.
- This research assessed the efficacy of MPB control efforts to date in managing spread and infestation.
- Efforts to control the spread of MPB have had some success, and single tree cut and burn of infested trees is the most appropriate treatment for high priority stands. Treatment success can be increased by improving detection of infected trees (especially green-attack) and aggressively applying treatments with focus on small infestations (where beetle populations are still low).

Approach:

- This project evaluated MPB management in Alberta in two phases. Phase 1 assessed the effectiveness of direct control methods (single tree cut and burn) versus alternative strategies. Long-term data was used from Alberta Agriculture and Forestry and industrial partners to develop a model that predicts MPB productivity (number of offspring per attacking female beetle). Then, the efficacy of single tree removal to manage MPB was assessed by examining the intensity of MPB attacks in 1 km and 2 km zones of influence surrounding treated and untreated polygons.
- Phase 2 simulated the impacts of current control methods vs. alternative strategies, including a do-nothing approach, on reducing the spread of MPB. A model ("MPBSpread") was created using the Phase 1 outputs (MPB productivity model and control efficacy), clear-cutting data, and forest inventory data.

Key Findings and Implications:

- The MPB productivity model can accurately predict infestation size and rates of increase for individual populations, which can assist forest managers in targeting and prioritizing stands for direct control, thereby aligning with Alberta's Healthy Pine Strategy.
- The model revealed that probability of overwinter survival of larvae generally increased with tree diameter. Larvae survived mild winters (-35°C or warmer) in small diameter trees, but not in winters where temperatures were colder than -35°C.
- Burning and felling of infested trees (single tree cut and burn) can effectively limit local growth and spread of MPB **if** detection efficiency is improved, and treatments are aggressive and consistent from year to year while populations are still low. Treatments are most effective if applied to the leading edge.
    - The detection rate of newly infested (green-attack) trees within treated stands was ≤68%, and 32–46% of green-attack trees were undetected. At this detection rate, if MPB populations increase more than threefold annually, suppressing an outbreak will be nearly impossible.
    - Single tree cut and burn reduced MPB attack intensity immediately surrounding the parent attack tree (a 33% decrease within 1 km and 44% decrease within 2 km). However, when c. 8-10 trees are infested per km^2, single tree cut and burn is no longer effective.
    - When treatment rates are low, MPB from nearby untreated areas move into the treated zones of influence and limit the treatment's impact.
    - Current MPB control methods reduced the area colonized by MPB by 30% compared with a do-nothing approach in the 10-year simulation. However, no single control method was enough to stop the spread. Single tree cut-and-burn treatments were particularly sensitive to the effectiveness of early detection and treatment.
- Future research should focus on survey methods for on-the-ground detection of green-attack trees.

Rehabilitation Mycorrhiza

Cigan, P. W., Karst, J., Cahill, J. F., Sywenky, A. N., Pec, G. J., and Erbilgin, N. 2015. Influence of bark beetle outbreaks on nutrient cycling in native pine stands in western Canada. Plant and Soil, *390* (1-2), 29-47. [URL]

Document Type: Peer-reviewed

Core Messages:

- As MPB kills more trees, needle loss and root death may impact how nutrients are cycled through the forest. Understanding how MPB killed trees impact nutrient cycling may provide insight into vegetation dynamics and forest succession after an outbreak.
- This study tested the influence of MPB outbreak on nutrient cycling in lodgepole pine stands with no previous history of MPB.
- Nitrogen cycling in beetle-killed lodgepole pine stands increased, likely due in part to the rapid decline of key root functions including the production and release of organic acids (phenolics, released by plant matter like living roots). Changes in water and mineral uptake were also likely drivers.

Approach:

- Study plots were established in 11 lodgepole pine stands in west-central Alberta to test the effects of different levels of tree death and time since infestation (0-4 years) on the abiotic conditions and organic inputs (i.e., fallen needles) linked to nutrient cycling.
- The rate of pine needle litter and nutrient inputs, living root mass, supply-rates of plant-available nutrients, and concentration of mineral soil phenolics were measured during the pine's growing season (May to September).

Key Findings and Implications:

- MPB-killed stands had increased litter deposition (fallen needles), root death, soil moisture and mineral nutrient (ammonium and nitrate) supply with increasing tree mortality and time since death.
- Root mass declined by half post-MPB attack, which likely drove the increased mineral nitrogen supplied to the soil. Soil phenolics also declined by half, likely contributing to the increase in mineral nutrients through increased nitrogen mineralization and nitrification. Root loss also decreased plant demand for water and nutrients, thereby increasing soil moisture and nutrient availability.
- The effects of needle deposition on soil nutrient cycling will likely increase over time due to increased decomposition and mineralization rates. Although more soil nutrients might improve the growth rates of living and regenerating trees, additional monitoring may be needed to assess other potential barriers to seedling establishment.

BECK, J. L., CALE, J.A., RODRIGUEZ-RAMOS, J. C., KANEKAR, S. S., KARST, J., CAHILL, J. F., SIMARD, S. W., AND ERBILGIN, N. 2020. CHANGES IN SOIL FUNGAL COMMUNITIES FOLLOWING ANTHROPOGENIC DISTURBANCE ARE LINKED TO DECREASED LODGEPOLE PINE SEEDLING PERFORMANCE. JOURNAL OF APPLIED ECOLOGY, 00: 1-11. [URL]

Document Type: Peer-reviewed

Core Messages:

- Little is known about the impacts of disturbance events on fungal communities that affect pine establishment (mycorrhizae). This is especially important as salvage logging is becoming an increasingly common management strategy.
- This study investigates the relationship between different types of disturbance (logging, salvage logging, fire and MPB) with below-ground fungal communities and lodgepole pine seedling growth in western Alberta.
- Human disturbances had a stronger impact on fungal communities than natural disturbances, and soils from human disturbances had reduced seedling growth.

Approach:

- Lodgepole pine seedlings were grown in a greenhouse in soil samples collected from sites disturbed by fire, MBP-attack (minimum 24% kill), clear-cut logging, or salvage logging in west-central Alberta. Seedlings were also grown in soil from undisturbed control sites.
- Fungal communities in the soil samples, seedling height and biomass were compared.

Key Findings and Implications:

- Fungal communities from both logging treatments were different from the controls, while those from MPB-attack and burned stands were not. Salvage logging (following MPB attack) was most different from the control, suggesting that multiple subsequent disturbances impact the fungal community more than a single disturbance.
- Fungal communities in the burned and salvage logged treatments were different from each other.
- Seedling growth was unchanged in the fire and MPB samples and lower in both logging treatments. This suggests that seedlings are better adapted to the soil conditions that result from natural disturbances rather than human disturbance (i.e., logging).
- Seedlings grown in soil from salvage logging were smaller (34% less biomass) than seedlings grown in soil from the burned stand.
- Ultimately, human disturbance can impact future generations of pine seedling growth by altering their root-tip fungal communities. These effects appear to be most severe with salvage logging, which resulted in the largest changes to the root-fungal community and decreased seedling growth. As a result, land managers should consider how logging (clear-cut or salvage) may negatively impact pine regeneration through changes to the fungal community.
- More effort should be invested in looking into the long-term impacts of salvage logging and the use of soil inoculation to re-establish beneficial fungi at salvage logged sites.

KARST, J., ERBILGIN, N., PEC, G. J., CIGAN, P. W., NAJAR, A., SIMARD, S. W., AND CAHILL JR, J. F. 2015. ECTOMYCORRHIZAL FUNGI MEDIATE INDIRECT EFFECTS OF A BARK BEETLE OUTBREAK ON SECONDARY CHEMISTRY AND ESTABLISHMENT OF PINE SEEDLINGS. NEW PHYTOLOGIST, 208, 3: 904-914. [URL]

Document Type: Peer-reviewed

Core Messages:

- MPB attack has shifted stand conditions, including changes to the ectomycorrhizal fungi, a below-ground mutualist that benefits pine growth. However, the impacts of these changes on future generations of pine seedlings are unknown.
- This study investigates the influences on the altered ectomycorrhizal fungi community on lodgepole pine seedling secondary chemistry and survival in MPB-disturbed stands.
- Seedling secondary chemistry and growth are influenced by the disruption of ectomycorrhizal fungi post-MPB attack. Seedlings that were grown in soil containing fungi from MPB-killed stands had less mass with fewer defenses than those grown in soil from undisturbed sites.

Approach:

- Fungal inoculum and pine-needle litter was collected from 10 different locations within four mature lodgepole pine stands in west-central Alberta.
- Three fungal treatments were applied to the seedlings grown in a glasshouse: no-inoculation, inoculum from MPB-killed stands, and inoculum from undisturbed stands. Each treatment was further manipulated by three litter treatments (no litter, MPB-killed, undisturbed) and two light intensities (based on measurements taken from the forest stands). After 9.5 months, the presence of ectomycorrhizal fungi and secondary chemicals (defenses) were analyzed.
- The survival of sowed lodgepole pine seeds was also tracked over two growing seasons in the same stands where the soil and litter were collected**.**

Key Findings and Implications:

- Seedlings grown with fungi from MPB-killed stands decreased the amount of defense chemicals (monoterpenes) produced by the seedlings. However, seedlings grown with fungi from the disturbed stands still had many more monoterpenes than those grown with no fungi.
- In the field experiment, pine seedling survival was much lower in MPB-killed than undisturbed stands. Thus, changes to stand conditions (i.e., increased soil moisture, nitrate, litter **[link to nutrient cycling summary]** and altered fungal communities) may impact seedling survival.
- The effect of the fungi source on seedling mass depended on light intensity. Seedlings grown with fungi collected from MPB-killed stands had 22% less mass than seedlings grown with fungi from undisturbed stands, which only occurred under ambient light conditions. Seedlings grown without fungi grew the least regardless of the light intensity.
- Monoterpene production was higher in seedlings grown with fungi from un-disturbed stands regardless of light intensity.
- The results in this study show that changes to the composition of the fungal community and loss of ectomycorrhizal fungi in MPB-killed stands may reduce the defenses of establishing pines and future generations of seedlings.

KARST, J., BURNS, C., CALE, J. A., ANTUNES, P .M., WOODS, M., LAMIT, L. J., HOEKSEMA, J. D., ZABINSKI, C., GEHRING, C. A., LA FLÈCHE, M. AND RÚA, M. A. 2017. TREE SPECIES WITH LIMITED GEOGRAPHICAL RANGES SHOW EXTREME RESPONSES TO ECTOMYCORRHIZAE. GLOBAL ECOLOGY BIOGEOGRAPHY. 2018;1–10. [URL]

Document Type: Peer-reviewed

Core Messages:

- Although biotic factors (e.g., plant microbes) influence the geographical distribution of plant species, they are often overlooked when predicting their geographical distribution.
- This study used a large dataset of over 120 studies to investigate the relationship between ectomycorrhizal fungi and the range size of their tree hosts.
- Tree species with very strong relationships with ectomycorrhizal fungi have smaller ranges than trees with weaker relationships. Tree seedling growth may increase with exposure to new fungal communities.

Approach:

- Average seedling growth of 59 tree species was calculated using a dataset of 1275 observations from 126 studies that investigated seedling growth in response to ectomycorrhizal fungi.
- Overlap between tree and fungal ranges was determined using tree species distribution maps and geospatially referenced data from databases including ectomycorrhizal fungi.

Key Findings and Implications:

- Species with strong responses to ectomycorrhizal fungi (i.e., substantial positive or negative seedling growth responses to inoculation with mycorrhizae) had much smaller geographic ranges than species with average responses to ectomycorrhizal fungi. Species with average responses to the fungi still performed better than those grown without any fungi.
- Tree species with strong mutualistic relationships with ectomycorrhizal fungi had positive seedling growth responses to inoculation (40% increase on average). However, tree seedlings inoculated with fungi that do not occur within their geographic range had stronger positive growth responses than ones inoculated with fungi that naturally occur within the same geographic area.
- Tree seedlings may benefit from exposure to fungal communities they did not historically evolve with, or tree performance may increase with exposure to new fungal partners.
- It is important to incorporate and consider biotic interactions, especially within the microbial community, into tree distribution models since these relationships influence tree ranges.

Fellrath, E. G. 2019. Soil Fungi After Pine Beetle Outbreak: Diagnosis of Fungal Community Composition and Treatment of Outplanted Seedlings with Tailored Soil Inoculum. University of Alberta Department of Renewable Resources. Master's Thesis.

Document Type: Master's Thesis

Core Messages:

- Forest disturbance can shift the soil fungal community, which can potentially influence seedling performance. It is uncertain whether these effects on the fungal community change among soils with different nutrients and textures.
- This study assessed: 1) whether soil physical and chemical properties determine soil fungal community composition and function; and 2) whether lodgepole pine seedling performance (survival and height) is affected in MPB-disturbed stands by the addition of fungal treatments from different sources.
- Though forestry canopy disturbance may look relatively even post-MPB outbreak, there may be a lot of belowground variation that can influence forest succession. Planted seedling performance in MPB-killed sites was influenced by fungal composition but depended on the site's soil and chemical properties.

Approach:

- Study sites were established in lodgepole pine forests in western Alberta within a 125 km radius around Grande Prairie. Transects were established within each site to survey understory and overstory vegetation, and collect soil and fungal community samples.
- The fungal communities of lodgepole pine seedlings were manipulated with fungal treatments using soil collected from the study sites. Seedlings were inoculated with one of three treatments: soil without fungi, and soils with fungal communities from either MPB-killed stands or undisturbed stands. Inoculated seedlings were grown in controlled growth chambers for 17 weeks then outplanted to MPB-killed sites. After 14 months, their performance (height and survival) was assessed.

Key Findings and Implications:

- The composition and function of soil fungal communities following MPB disturbance were different depending on the physical and chemical soil properties where they were collected. Two main fungal groups (saprotrophic and ectomycorrhizal) were found in sites with loamy and sandy soils.
    - Across all sites, saprotrophic (wood-decaying) fungi had greater diversity than ectomycorrhizal fungi and are expected to increase as trees die. Saprotrophic fungi were more diverse in loamy soils.
    - Ectomycorrhizal (tree-root mutualist) fungi were also more diverse in loamy sites but are expected to decrease as trees die. Some species within the same genus showed opposing preferences, where some were more indicative of loamy soils, and others of sandy.
- After four months in the growth chamber, seedlings inoculated with soil containing fungal communities from MPB-killed forests were less likely to survive (18.8% probability) than the other treatments (inoculum from undisturbed sites and no inoculum, which were not statistically different from one another).
- After they were outplanted in MPB-killed stands, pine seedling height (but not survival) was affected by inoculation, but only in sandy sites. In these sites, seedlings grown with fungi from MPB-killed stands grew taller than those grown with the other fungal treatments. Since the seedlings were still in the field at the time of this analysis, direct or indirect influences of fungal inoculations and site variables on seedling survival may emerge once they are harvested.
- When evaluating the forest post-MPB outbreak, both above- and below-ground succession should be examined across sites with different soil and chemical properties and compared with paired mature undisturbed lodgepole pine stands. This can help reveal where, and to what degree, changes to the forest's successional pathways or resilience to disturbance may occur following MPB outbreak.

- Specifically, future research should examine the **long-term** succession of soil fungal communities in relation to physical and chemical soil properties, and the influence of fungal inoculation on outplanted seedling growth and survival. A deeper understanding of seedling responses to inoculation after being outplanted could help forest managers allocate and prioritize sites for post-disturbance management.

PEC, G. J., SIMARD, S. W., CAHILL, J. F., AND KARST, J. 2020. THE EFFECTS OF ECTOMYCORRHIZAL FUNGAL NETWORKS ON SEEDLING ESTABLISHMENT ARE CONTINGENT ON SPECIES AND SEVERITY OF OVERSTORY MORTALITY. MYCORRHIZA, 30: 173-183. [URL]

Document type: Peer-reviewed

Core Messages:

- It is uncertain whether, or how, MPB-caused tree mortality will affect below-ground interactions and influence seedling establishment. Understanding these effects will provide insight into how forests will develop post-MPB attack.
- The objective of this study is to assess the importance of ectomycorrhizal fungi networks, root presence, and bulk soil (soil that does not contain roots but might have some fungi) on lodgepole pine and white spruce seedling growth, nutrition, and survival (establishment) in response to varying levels of MPB-caused overstory kill.
- MPB-attacked forests shift the belowground processes that influence conifer seedling growth, but growth responses are species-dependent. After a large-scale MPB-outbreak, white spruce seedlings are more likely to establish than lodgepole pine, which could drive a species replacement in lodgepole-pine dominated forests.

Approach:

- In 11 forest stands covering a gradient of MPB-kill (0-89%) in the lower foothills of Alberta, treatments were applied to the base of lodgepole pine and white spruce seedlings to manipulate their contact with ectomycorrhizal fungi networks and other roots. The three treatments allowed the seedlings to access the mycorrhizae network but no roots, a fungal network and roots, or bulk soil only.

Key Findings and Implications:

- Lodgepole pine seedlings responded more strongly to the treatments and level of overstory kill than white spruce. Higher MPB-caused tree mortality reduced lodgepole pine's ability to establish fungal networks, which reduced seedling survival.
- In contrast, white spruce had high overall survival and six times the amount of seedlings in MPB-killed stands. The level of MPB-caused overstory kill did not change the relative influence of treatments (manipulated ectomycorrhizal fungi, roots, and bulk soils).
- Lodgepole pine seedlings with access to ectomycorrhizal networks had higher needle concentrations of nitrogen with higher overstory kill. In the presence of neighboring roots and bulk soil alone, nitrogen concentrations in lodgepole pine needles decreased as canopy mortality increased. These effects were not observed in white spruce.
- In both lodgepole pine and white spruce seedling needles, phosphorous concentrations were not affected by ectomycorrhizal networks and bulk soil. However, with the presence of neighboring roots, phosphorous concentrations decreased with higher overstory kill.
- Stands killed by MPB may better support white spruce recovery and not lodgepole pine. Following a large MPB attack where a large amount of the canopy is killed, white spruce may replace lodgepole pine as the dominant species in Alberta's forests. This means that the forest will be maintained, but with a different composition.

Persistence Extinction

Burke, J. L., and Carroll, A. L. January 6, 2020. Persistence of extinction? Quantifying the fate of invasive mountain pine beetles in eastern pine forests. The University of British Columbia. Faculty of Forestry. Final report for fRI Research project 246.25

Document Type: Final Report

Core Messages:

- The eastward expansion of MPB poses potential threats to eastern Canadian and US forests. However, these stands must first be able to support endemic populations of MPB.
- Since endemic MPB populations are regulated by competition, this research assesses natural enemies (other beetles and antagonistic fungi) of MPB in lodgepole pine and jack pine forests.
- MPB will likely persist long-term in lodgepole pine forests in western Alberta, but not in jack pine forests in central and eastern Alberta. MPB control and management strategies should focus on lodgepole pine stands while continuing to monitor MPB populations in Alberta and Saskatchewan's jack pine boreal forests.

Approach:

- Trees were girdled and monitored for 18 months in lodgepole pine (southern BC and western Alberta) and jack pine (north-central and eastern Alberta) forest within both native and novel MPB ranges. The trees were monitored for insect activity and damage, then destructively sampled to quantify woodboring, bark and ambrosia beetles, and associated fungi.
- Two lab experiments were conducted to evaluate competition between MPB and *Ips pini* (a strong competitor) and the interaction between MPB fungal associates and a one fungal antagonist (*O. minus*) under simulated pine chemical defenses.

Key Findings and Implications:

- Jack pine were occupied more aggressively by natural enemies of MPB (woodboring beetles and *O. minus* fungi) than lodgepole pine stands. These results did not depend on the location and native and novel lodgepole pine stands experienced similar outcomes.
- Competition between MPB and *Ips pini* was similar in both lodgepole and jack pine, suggesting that low-density MPB invading jack pine will not have a competitive advantage over *Ips pini*.
- MPB's antagonistic fungi, *O. minus*, was more prevalent in jack pine than in lodgepole pine (novel or native) forests. This prevalence will further limit the establishment of MPB in jack pine forests, as it outcompetes and has broader temperature tolerances than the specialized fungal associates MPB requires to establish in a host tree.
- Jack pine forests are unlikely to support the long-term persistence of MPB. MPB populations immigrating from nearby lodgepole pine stands into boreal jack pine forests will likely be extirpated by competing beetle species and their associated fungi. However, it is still critical that jack pine forests continue to be monitored as changing conditions could alter factors limiting MPB in these regions.
- In contrast to jack pine, novel lodgepole pine in Alberta is very suitable for MPB. Aggressive control should be used to manage MPB and mitigate impacts to forest-based communities.

SpaDES

Chubaty, A. April, 2020. Simulating MPB spread management in Alberta and beyond using SpaDES. fRI Quick Note.

Document type: Quick Note

Core Messages:

- Spatial Discrete Event Simulation (SpaDES) is a new software tool that is being used within a multi-year project to simulate MPB spread across Alberta and in parts of Saskatchewan. This tool can be used to develop and run integrated data and simulation models, bring together various sources of expert knowledge, and can help inform decision-making.
- SpaDES has been successfully used in other projects led by the Canadian Forest Services and the team will continue to highlight more applications for the use of SpaDES.

Approach:

- The model in question combines historic MPB attacks, MPB climate suitability projections (under different climate change scenarios), and vegetation inventories to spatially capture two major parts of MPB outbreaks: eruptive population growth and spread.
- The main components of the model include MPB population growth and dispersal that are sensitive to climate, fire dynamics (ignition and spread), and different MPB management scenarios.
- SpaDES uses a modular framework, which means model components can be updated to include additional models (e.g., wind) or different models (e.g., fire and vegetation models that respond to climate change).

Assessing Community Resilience

Friberg, R., Gonzalès, R., Hanna. K., Parrott, L. 2016. Assessing Community Resilience to Mountain Pine Beetle Outbreaks in Alberta. Report.

Document Type: Report

Core Messages:

- The degree to which Alberta's forestry-based communities are economically and socially impacted by the eastward spread of MPB depends on their level of resilience.
- This research (currently underway) will assess the social and economic vulnerability and resilience of three forest-dependent communities in Alberta.
- The research will provide meaningful and user-friendly deliverables for Alberta's communities to assess their resilience and enhance current strategies for strengthening their resilience.

Approach:

- Hinton, Whitecourt-Blue Ridge, and Sundre were the three forest-dependent communities selected for the case study.
- Two main complementary approaches are used to address the objectives of the research.
    - A quantitative analysis of the factors that underpin resilience in these communities, using document reviews, interviews and focus groups.
    - A qualitative analysis of community resilience in the face of MPB (i.e., their capacity to anticipate and cope with MPB in their community) using stakeholder surveys and anonymous data.

Key Objectives and Implications:

- The project has two primary objectives:
    - Identify what resilience means and looks like within the context of each community.
    - Identify how this resilience can be enhanced, in these communities and other forest-based communities in Alberta.
- The findings of this research will provide meaningful and practical results. This will be achieved by actively involving community stakeholders in the research process and providing tangible results in the form of accessible summaries, reports, and presentations to provide a framework for developing and enhancing strategies to strengthen their resilience.

Monitoring Tools

Klutsch, J. G., Classens, G, Whitehouse, C., Cahill Jr., J. F., Erbilgin, N. Density-dependent responses of mountain pine beetle to its pheromones and host volatiles in naïve lodgepole pine stands. Forest Ecology and Management, 472: 118257 [URL]

Document type: Peer-reviewed

Core Message:

- It is unknown whether MPB population density impacts its attraction to certain synthetic lures (which are used to detect and monitor MPB) in novel lodgepole pine forests.
- This study assessed whether the attraction of MPB to pheromones and host-tree monoterpenes varies with local population density across the flight period.
- In the first half of their flight period, low density MPB flights were more attracted to baits with high-release rates of trans-verbenol and low release rates of other components. High-density MPB flights were more attracted to low-release rates of all bait components, but preferred a high-release rate of trans-verbenol later in the flight period. MPB population density and seasonality should be considered when selecting and deploying attractants for monitoring.

Approach:

- MPB traps baited with different lure combinations were established in mature lodgepole pine-dominated forests in north-central Alberta, near Swan Hills and Whitecourt. Three of the attractants (trans-verbenol, terpinolene, and myrcene) were released at different rates, and exo-brevicomin was released at a constant rate.
- Local MPB population densities were estimated using the previous year's aerial survey data from the Government of Alberta and categorized into either low or high MPB density areas.

Key Findings and Implications:

- Local MPB population density affected their attraction to different release rates of pheromone and host monoterpenes. These attraction patterns also shifted between the first and second flight periods. Based on these patterns, the following recommendations were developed for maximizing attractant effectiveness when MPB is below-outbreak levels:
    - Across all MPB population densities, low release rates of host tree monoterpenes are recommended. Higher release rates may indicate to MPB that host trees are well-defended and not worth colonizing.
    - MPB trapping efforts (for monitoring and detection) should focus on the first half of the flight period, when MPB has higher responses to trans-verbenol.
    - Standard commercially available attractant is recommended for sites with high population densities. At low population density sites, a combination of high release trans-verbenol plus standard host monoterpenes and exo-brevicomin should be used.
    - Below outbreak levels and during the first half (first three weeks) of the flight period, high-release rates of trans-verbenol is recommended for low MPB density sites. Low-release rates of trans-verbenol are suggested for high MPB density sites.
    - If operational control methods are desired when MPB population density is high enough, bait with a low release rate of trans-verbenol and standard host volatiles and exo-brevicomin can be used to concentrate MPB to a specific area for control.
- More research is needed to look at the mechanisms underlying these density-dependent responses to attractants.

Identification of Optimal Attack Density

Jones, K. L., Rajabzadeh, R., Ishangulyyeva, G., Erbilgin, N., Evenden, M. L. 2020. Mechanisms and Consequences of Flight Polyphenisms in an Outbreaking Bark Beetle Species. Journal of Experimental Biology 223(12). [URL]

Document Type: Peer-reviewed

Core Messages:

- MPB populations contain both long- and short-distance fliers. However, the impacts of flight variation on MPB host colonization and pheromone production are unknown.
- This study assessed: 1) the tradeoffs between energy spent on flying and MPB host tree colonization; and 2) the relationship between flight distance and MPB pheromone production.
- MPB maintain population levels through different colonization strategies. Energy lost to flying causes female MPB to produce more pheromones, which may help them to coordinate mass attacks, thus attracting more long-distance fliers. Understanding the difference in their flight patterns can help predict future spread.

Approach:

- Tree bolts were extracted from MPB-infested lodgepole pine from sites near Hinton and Slave Lake, AB. In a lab, emerging beetles from the bolts were collected and randomly assigned to a 23h flight period or 23h without flying (control). Both beetle groups were then given the opportunity to colonize (enter) lodgepole bolts. Pheromones were measured from beetles that successfully entered hosts.

Key Findings and Implications:

- Female MPB that lost less than 10% of their mass during flight were more likely to colonize a host than female beetles who lost more.
- Beetles that lost the most mass during flight colonized the fastest, indicating a trade-off between energy use during flight and which host a female MPB decides to colonize. Beetles with less energy left over from flying may quickly colonize a host regardless of its quality rather than flying farther to select a higher-quality host.
- Females that flew further and used more energy (lost more mass) produced more pheromones (trans-verbenol). By dispersing farther from their natal host, females may require more effective pheromone release to attract more beetles for a mass attack. Beetles that travel short distances would benefit less from producing strong pheromones.
- In contrast, male pheromone (exo-brevicomin) production was influenced by pre-flight mass and flight distance but not by mass (energy) lost while flying. Males that weighed more prior to flight produced more pheromones than lighter males. This could be influenced by the beetle's condition after it pupates, and by consequence, the quality of the host. Males that flew farther produced less pheromone once they reached a host.
- Silviculture techniques such as stand thinning could force beetles to fly further to find suitable hosts, which could impact their successful colonization.

Wildfire Spread and Risk

Stockdale, C. 2018. Mountain Pine Beetle Effects on Wildfire Rate of Spread and Landscape Fire Risk. fRI Quick Note.

Document Type: Quick Note

Core Messages:

- MPB outbreaks have the potential to increase landscape wildfire risk (likelihood of wildfire and its impacts). Addressing this issue depends on numerous variables linked to fire dynamics and potential effects of different MPB attack stages (i.e., red-attack, grey-attack, etc.). Wildfires have been observed to be larger, more intense and with a faster spread than before the large MPB outbreaks in British Columbia.
- This research is investigating how MPB-killed trees affect the rate of fire spread, the size of subsequent wildfires, and the relative likelihood and intensity of the fire (landscape burn probability).
- This research is ongoing and will be useful to those working in wildfire risk analysis and fire behavior prediction in areas affected by or susceptible to MPB.

Approach:

- This research looks at all fires that have occurred since 2001 in areas overlapping with MPB infestation in British Columbia.
- To answer how MPB-killed trees affect the rate of wildfire spread, satellite observations will be used to:
    - measure the rate of wildfire spread since 2001,
    - determine to what degree the stage of MPB-attack affects spread, and
    - compare how the spread might be different had MPB not infested the stands.
- To assess how MPB-killed trees affect the size of future fires, fire growth will be modeled by comparing spread rates of fires unaffected by MPB with rates that are affected by MPB.
- From this, a large number of fires can be modeled to determine how different stages of MPB-attack across a landscape will affect landscape-level fire risk.

Caribou Grizzly Bear Response

Larsen, T., S. Darlington, D. Wismer, G. Stenhouse, and L. Finnegan. 2020. Woodland caribou and grizzly bear response to mountain pine beetle attack and control in west-central Alberta. Final Technical Report prepared for the fRI Research Mountain Pine Beetle Ecology Program.

Document Type: Final Report

Core Messages:

- Little is known about how woodland caribou and grizzly bears respond to habitat disturbance caused by MPB, or management strategies related to MPB.
- This research examines how MPB infestation and related management strategies might alter food availability for woodland caribou and grizzly bears in west-central Alberta.
- Woodland caribou showed a preference for mature uncut pine stands, and avoided disturbed (i.e., MPB infested and managed) habitat. In contrast, grizzly bears showed habitat preference for these disturbed stands and avoided mature pine.

Approach:

- Habitat models were developed to assess changes in habitat value of mature uncut pine forest for woodland caribou and grizzly bears over two years post-MPB attack and management in west-central Alberta.
- These stands were mapped using forest inventory and habitat datasets within the ranges of the Narraway and Redrock-Prairie Creek caribou herds and grizzly bears within the Grande Cache, Swan Hills, Yellowhead, Clearwater, Livingstone, and Castle Bear Management Areas. Previously collected long-term location data were used to calculate how often, and when, these species frequented mature pine stands and how this compares to random locations.

Key Findings and Implications:

- Woodland caribou most commonly used mature uncut pine-dominated stands and avoided caribou habitat within 250 m of MPB attack and managed stands. The degree to which caribou selected these stands depended on the season (late or early winter), herd, and the model (scale of analysis).
- Grizzly bears typically avoided mature pine, especially pine-dominated stands (as opposed to mixedwoods), regardless of the season. Instead, they either responded neutrally or preferred habitat near disturbed stands (MPB attacked or harvested).
- The researchers suggest that disturbance (i.e., MPB infestation and its management) will increase favorable habitat for grizzly bears but not caribou. They recommend considering stand composition and seasonality in caribou range planning and ensuring a supply of mature pine-dominated stands, as older stands with more open canopies might be preferred by caribou due to higher lichen availability. Caribou avoided most stands attacked by MPB in early winter and selected them in late winter, which indicated a strong seasonal response to MPB disturbance.
- Overall, these models can guide forest management planning to support the recovery and conservation of these species-at-risk.

Nobert, B. R., Larsen, T. A., Pigeon, K. E., and Finnegan, L. 2020. Caribou in the cross-fire? Considering terrestrial lichen forage in the face of mountain pine beetle (Dendroctonus ponderosae) expansion. PLoS ONE 15(4): e0232248. [URL]

Document Type: Peer-reviewed

Core Messages:

- MPB management strategies like timber harvesting may indirectly impact species-at-risk (i.e., woodland caribou) habitat by altering food availability.
- This research evaluated the impacts of four different MPB management strategies on woodland caribou habitat (specifically, terrestrial lichen).
- In areas where woodland caribou and MPB overlap, a single-tree cut-and-burn strategy is recommended to balance caribou habitat recovery with MPB management.

Approach:

- Lichen cover was modelled in caribou ranges of west-central and northwestern Alberta under different forest conditions: timber harvested, wildfire burned, MPB single-tree cut-and-burn, MPB infested, and intact (undisturbed).
- Future lichen cover was then simulated in response to the four different management strategies: timber harvest, MPB single-tree cut-and-burn, burned, and MPB trees left as-is.
- Resource selection functions were used to test the ability of the models to predict caribou habitat based on the assumption that caribou select habitat with higher lichen cover.

Key Findings and Implications:

- MPB-killed trees left as-is and single-tree cut-and-burn management strategies did not significantly affect lichen cover. However, lichen is a slow-growing species and there were only data for an eight-year post-harvest period, meaning some longer-term effects may not have been detected. Although leaving MPB-killed trees standing might benefit caribou habitat, the risk of wildfire might increase as the dead trees become drier.
- Following timber harvest and fire, there was less lichen cover initially (lowest in the timber harvested stands) but it increased over time. In the west-central region, lichen cover recovered to undisturbed stand levels after 10 years post-timber harvest and after 20 years post-burn. Although timber harvesting or prescribed burning may preserve caribou food (lichen) supply over time, the researchers **do not recommend** this as a strategy due to their long-term effects on caribou populations by reducing available habitat and increasing predation risk.
- Where caribou and MPB overlap, a single-tree cut-and-burn control program is recommended to balance MPB spread management and negative impacts to caribou habitat.