BEYOND BEETLE

A Guide to Managing Lodgepole Pine Stands in Alberta After Mountain Pine Beetle Outbreak

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INTRODUCTION

Meet the Beyond Beetle team

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Mike Flannigan is one of the Principal Investigators on the project. He worked with Masters student Hugh Wallace on harvest treatments aimed at regenerating post-beetle stands and their implications for wildfire. Mike is a wildfire researcher and has been studying wildfires for over 40 years.

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Dr. Lieffers is one of the Principal Investigators on the project, focusing on natural regeneration of forests after mountain pine beetle outbreak and management options for facilitating regeneration. His research focuses on forest regeneration and management.

Julie Steinke, MSc.
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Shiyang (Violet) Zhao, PhD.
Shiyang (Violet) Zhao completed her PhD on the response of residual lodgepole pine trees after mountain pine beetle outbreak, including evaluating the implications of these findings for silviculture and forest management.

Lori Schroeder, MSc.
Lori Schroeder was a Research Assistant on the project focusing on natural regeneration of forests after mountain pine beetle outbreak. She studied the influence of understory vegetation on natural regeneration of pine.

Going "Beyond Beetle": the next chapter of the mountain pine beetle story

The mountain pine beetle (MPB) outbreak in Alberta, initiated by a major inflight of the beetle in 2006, has resulted in unprecedented loss of lodgepole pine forests across the landscape. Researchers and forest practitioners alike are familiar with the MPB story, but it has not yet reached its conclusion. A key question remains: what happens to lodgepole pine stands after outbreak?

To answer this question, the Beyond Beetle project was born. Our team **investigated the short- and long-term implications of MPB outbreaks for the future sustainability of lodgepole pine forests in Alberta.** Specifically, our team examined the following three questions:

- Will lodgepole pine forests come back naturally after MPB outbreak? Are there certain stand conditions that are better for natural regeneration than others?
- Why do some trees survive MPB outbreaks? Are these trees more susceptible to attacks by other insects afterwards?
- What management options can foresters use to stimulate regeneration of lodgepole pine? What sites should be prioritized for management?

Our team's goal is to arm forest managers and operators with the answers to these questions, ultimately empowering them to manage MPB-killed stands with evidence-based strategies and predictable outcomes. Through targeted silvicultural and harvest practices, forest managers can help reinvigorate these economically important forests in Alberta.

Purpose of this guide

The purpose of this guide is to provide a science-based look at how lodgepole pine forests are currently recovering after MPB outbreak, what management approaches are effective for stimulating regeneration of lodgepole pine, and what outcomes are expected from different approaches.

Throughout the guide, our team strives to provide suggestions and tools that will be helpful to forest managers without prescribing what companies must or must not do. Our team's approach is to inform and support decision-making on a site-by-site basis: what works for one situation may not work well for another, so we encourage foresters to apply our suggestions in context and to contact us (see Meet the Beyond Beetle team, pg. 1) if they have any questions.

Using this Guide

What is in the guide?

This guide summarizes the results of the Beyond Beetle team's research and puts these findings in context for forest managers.

The guide covers three key topics:

1. Letting Nature Run its Course: where can lodgepole pine recover on its own?
2. The Value of Residual Pine Trees: what makes surviving trees different from those that are killed?
3. Management Options: how can this knowledge be used to inform forest land management?

While the guide is focused on the findings of our team, additional context is provided from other research where appropriate. We conclude each section with management implications that put our findings in context to get down to the question: what do these results mean for managers and practitioners?

In the Management Options category, we provide **Decision-making diagrams** to help managers integrate site conditions into their management choices. These diagrams are designed to support decision-making based on site characteristics, as determined by on-the-ground or aerial site assessments (e.g., ecosite type, presence of advance regeneration).

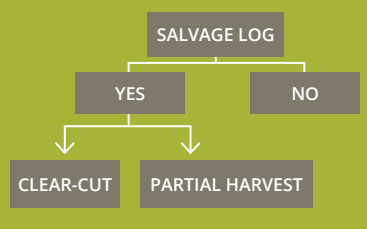
Who is this guide for?

This guide is intended for office and field use to aid forest managers in their decision-making related to managing MPB-killed stands in Alberta. **The pamphlet found at the end of this guide is printed on waterproof paper and intended for use in the field.**

How do I use this guide?

The guidance in this document can be integrated within the assessment and planning framework used by most forestry companies: performing an initial site assessment (i.e., desktop review and field assessment) and setting site-level management prescriptions accordingly.

To help planners make decisions specific to MPB during this process, our team has identified a list of key variables to consider during site assessment. Because the number of stands affected by MPB far exceeds the number of stands that can be logged in normal sequence, our team also provides a decision-making framework (below) to help guide a triage-based approach.

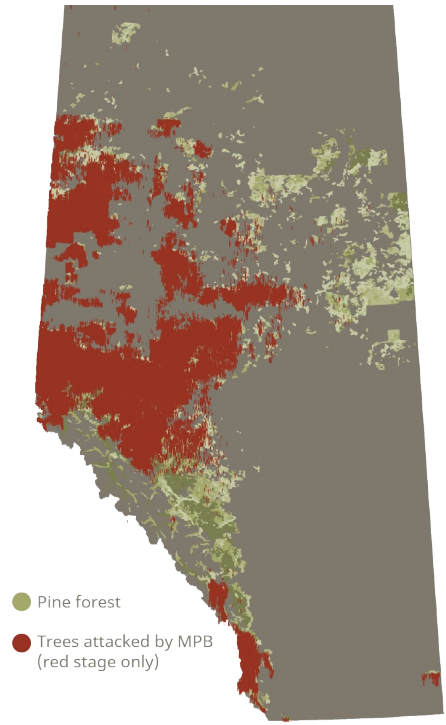
Key site-level variables from desktop review and field assessment:	Decision-making framework:
• Percent mortality due to MPB • Ecosite type • Density of advance regeneration (of lodgepole pine and other tree species)	

An Overview of Mountain Pine Beetle in Alberta

A challenge that's here to stay

Mountain pine beetle currently threatens several million hectares of pine forest in Alberta and is predicted to remain in the province for the foreseeable future. A substantial amount of mature lodgepole pine has been killed in B.C., serving as a reminder of the strong effects MPB can have on forest ecosystems and the forest industry.

Because the beetle is so widespread and so damaging, most Alberta forestry companies will need to contend with MPB on their tenures in the long-term. Currently, forestry companies mainly respond to MPB-killed stands by salvage logging them. However, it is likely not practical or economical to salvage log all stands: in B.C., the complete salvage logging of partially killed stands has likely contributed to the closure of several sawmills that no longer have a sustainable local timber supply. Clear-cutting may also have negative impacts on other forest values which are important to account for, such as forest diversity and soil health. To ensure that Alberta's forestry industry and forest ecosystems can co-exist and thrive alongside MPB in the long-term, new approaches and sustainable management methods are needed.



Distribution of red-attack stage trees surveyed by the province from 2006-2018; main inflights of the beetle occurred in 2006 and 2009. During these annual surveys grey-attack trees are not recorded and fieldwork is limited to a prioritized survey area. Data provided courtesy of Alberta Agriculture and Forestry.

A new disturbance for a fire-adapted species

Lodgepole pine has a long history of evolving alongside wildfire in Alberta. As a result, this species has several key adaptations to fire:

- **Serotiny:** cones open and release seeds in response to high temperatures produced by fire
- **Shade-intolerance:** seedlings grow best in open, sunny conditions after much of the canopy has burned away

In contrast, lodgepole pine in Alberta has had very limited historical contact with MPB, meaning it has had few chances to co-evolve and adapt to the beetle.

Despite this fact, trees are equipped with some tools to fend off beetle attacks: mainly, they defend themselves by producing toxic resins. Even with the damage caused by MPB, **some trees still survive during high intensity MPB attacks.** These survivors, or 'residual trees', are easily identified by their green colour among a vast canopy of red and grey trees.

The trees that die due to attack go through several stages associated with changing needle colour. While needles are still green the tree is actively defending itself, indicated by large globs of resin on the bark that emerge a few days after the attack. Within a year of attack the needles of dead trees turn yellow, orange, and then red. Finally, the needles drop off about 2-4 years after attack, at which point trees appear 'grey' with no needles

During the green-attack stage, trees are actively defending themselves by producing toxic resins. During yellow- and red-attack stages, the trees are dead and undergoing the process of dropping their needles.

Letting Nature Run its Course: The Potential for Natural Regeneration of Pine

One of the first questions tackled by the Beyond Beetle research team was: where is natural regeneration expected to occur? This critical information lets managers know where lodgepole pine can start to recover on its own and helps to prioritize areas for management intervention. The following represent the core findings from this stage of the research.

Sites will not meet stocking density without management

Our team surveyed lodgepole-dominated stands 6-10 years after MPB outbreak across a diverse range of sites (i.e., ecosite types, natural subregions) in west-central Alberta. In order to focus our work where the findings would be most applicable, we studied high mortality (>50%) stands. We complemented this fieldwork with a desktop analysis of a province-wide government dataset, which examined a wider range of ecosites and subregions containing pine and the full range of mortality levels (0-100%).

We found that no sites had an adequate number of pine seedlings to indicate they will reach full stocking density. This result means that **all lodgepole pine stands affected by MPB will require some level of management if managers wish to see the stand come back as dominantly lodgepole pine** (Box 1).

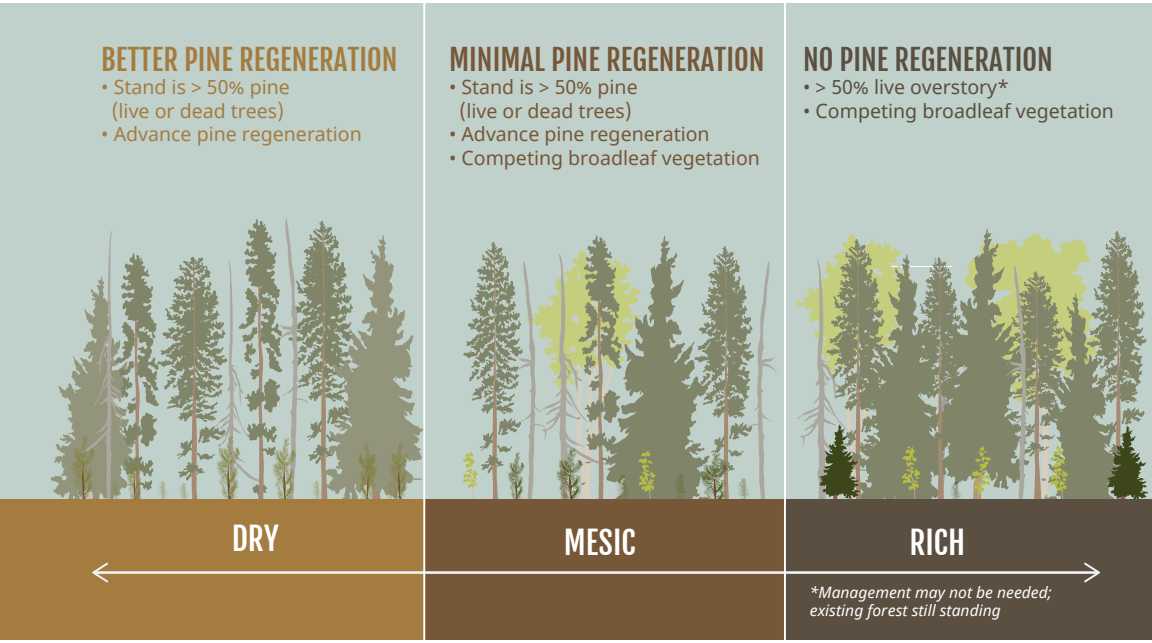
Box 1: The Opportunity for Something New

*While we saw very low levels of pine seedling re-establishment on MPB-killed sites, **this is not to say that the forest lacked resilience**: our team found that other species filled in the gaps left behind, especially birch, aspen, and spruce (black and/or white). A recent long-term study at Waterton Lakes National Park also showed that lodgepole pine-dominated stands followed multiple different recovery trajectories after MPB outbreak (Axelson et al., 2018; https://doi.org/10.1139/cjfr-2018-0161). While the species composition of these forests shifted away from lodgepole pine, the overall species diversity of the stands increased and their susceptibility to MPB decreased over time. MPB-killed lodgepole pine stands may, therefore, represent an opportunity to increase the diversity of forest types on the landscape if some stands are left to regenerate as something new.*

Rich/moist sites should be prioritized for management actions

When it comes to managing MPB-killed sites, resources may be limited and it might not be possible to individually assess and rehabilitate each stand. To help managers decide how to prioritize their efforts, our research team determined which site characteristics were associated with better natural pine regeneration. These sites may not need to be managed as closely as those with very little natural regeneration.

Where lodgepole pine did come back, **our team found that it regenerated better on poor and medium quality (dry and mesic) sites.** These sites had less competing vegetation, making it easier for pine seedlings to establish. On high quality (rich/moist) sites, large amounts of competing vegetation and shady conditions made it nearly impossible for pine seedlings to establish. Overall, **our team found that competing vegetation was the primary factor that limited establishment of pine seedlings.**



Under what conditions will lodgepole pine regenerate? *This diagram depicts a few scenarios that foresters will likely encounter in the field. Pine regeneration was somewhat better in drier conditions and on sites with a more open canopy. It is important to note that even under the best-case scenario, natural regeneration of pine is not expected to meet stocking density.*

Our study's results suggest that poor and medium quality sites will have enough seedlings to retain some pine in these forests; however, such sites are uncommon on the landscape. This means that **most sites under consideration by forest managers (rich/moist sites) will experience almost no natural regeneration of lodgepole pine.** This observation matches with on-the-ground perspectives we have heard from operational foresters and suggests that pine stands on **rich/moist sites should be prioritized for management, if a return to lodgepole pine is desired.** On the other hand, such sites were also more likely to have advance regeneration of other species, such as broadleaf and spruce. Transitioning the stand to a different forest type is therefore also a viable management option.

The intensity and type of management to be used on sites affected by MPB can be narrowed down by performing a site assessment (see the **Field Pamphlet** at the back of this guide) and considering the guidance offered in our **Decision-making diagrams** (pg. 16). For example, we found that using mixing as a site preparation technique after partial harvesting will improve natural regeneration of pine seedlings on medium quality sites.

Management implications

- As there will likely be a limit to how many stands can be salvage logged, resources to manage sites may be more efficiently prioritized by leaving some sites to return naturally, especially if they have experienced low mortality or have advance regeneration.
- **Pure pine stands on rich/moist sites with high MPB-caused mortality should be prioritized for management,** as these sites will experience virtually no natural regeneration of pine. However, such sites will usually support advance regeneration of other tree species (e.g., aspen or spruce), meaning a **transition to a different forest type may be a viable strategy.**
- Because competing vegetation can overtake a site quickly (within 5 years), it is important to **expedite on-the-ground operations once a management decision is made.**

Survivors Are Worth Keeping: The Value of Residual Pine Trees

While it is extremely valuable to know where we can expect to find pine regeneration, our team also wanted to know more about the remaining mature pine left alive after an outbreak: what is the value of these surviving ('residual') pine trees? More specifically, we sought to determine if these trees are susceptible to future attacks by MPB or other insects (i.e., secondary attacks) and whether surviving trees possessed distinct characteristics compared to beetle-killed trees.

Surviving green trees have unique characteristics and should be preserved

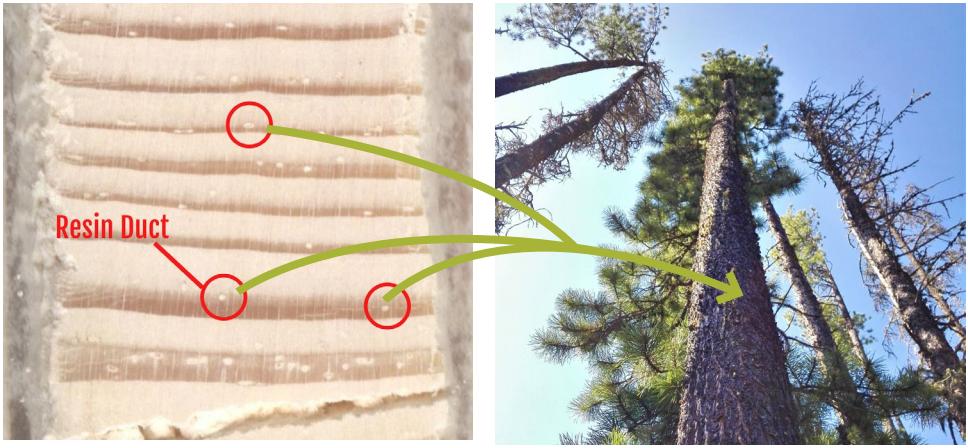
When managing an MPB-killed stand, a question that foresters are likely to ask themselves is: which trees should be harvested, and which should be left behind? To help respond to this question, our research team looked at what makes the surviving trees biologically different from those that are killed. This information can be used to help managers weigh biological values when making harvesting decisions.

Because pine trees mainly defend themselves by producing resin, our researchers studied the ducts in the trees' bark that produce, store and transfer this resin (called 'resin ducts') to see if there were differences in tree defenses between surviving and non-surviving trees.

Our research shows that surviving green trees had larger resin ducts compared to trees that died. This difference was consistent both before and after MPB outbreak, meaning that surviving green trees always produce larger resin ducts - even in advance of MPB outbreak**. These trees were pre-programmed to survive: they had unique qualities that allowed them to resist MPB colonization.**

These findings are supported by another study conducted at Beaverhead National Forest in Montana, which showed that surviving lodgepole pine trees were genetically unique from the general population (Six et al., 2018). The researchers studied a set of genes that are often linked to physical traits, finding that the structure and composition of these genes were significantly different in surviving trees.

Access the Beaverhead study:
https://bit.ly/2Gqp6Ua



Residual trees remain green after MPB attack. Our team's research shows that these surviving trees had larger resin ducts compared to the trees that were killed.

The key implication from this study may surprise some foresters. **Despite the economic value of salvaging live trees in a beetle-killed stand, these green trees hold distinct value in helping promote future stands that are resistant to MPB.** If all surviving trees are removed during salvage operations, the forest may lose the genetics of these key MPB-resistant trees.

Surviving trees have stronger defenses after outbreak

One widespread concern about pine stands is that they may become more susceptible to attacks by other insects after MPB outbreak, increasing the likelihood that they will die soon. Our research team found that **residual trees were still standing six years after the last MPB outbreak** and **they did not experience an unusually high rate of attacks by other insects after MPB**. In fact, these trees seemed to invest even more in defense: trees developed more resin ducts after MPB outbreak (Box 2).

Box 2: Growth after MPB: a trade-off with defenses

A hypothesis shared by many scientists is that trees surviving a major disturbance, especially one where most other trees don't survive, should experience benefits. With fewer other trees around, the survivors should experience less competition for resources, allowing them to suddenly grow much more quickly ("release growth"). Surprisingly, we did not see this happen immediately with lodgepole pine in Alberta: for the first five years post-attack, surviving trees invested their resources in producing more resin ducts, and only after that began to show evidence of increased growth. This result suggests that when trees are faced with a trade-off between investing resources in defense versus growth, in the context of MPB-attacked stands, investments in defense are prioritized.

Management implications

- **Retaining surviving green trees during harvest** (or retaining their cones as a seed source) **is important for the long-term sustainability of lodgepole pine stands**; this practice will:
  - » Allow trees with high MPB resistance to contribute seeds, and their genes, to the next generation of trees;
  - » Maintain structure and diversity in the forest canopy, as residual trees are unlikely to suffer from secondary attack by other insects.
- In the long-term, **a valuable practice would be to recruit residual trees carrying MPB resistance into breeding/tree improvement programs**. This strategy will ensure that nursery trees gain some resilience to MPB, which will add value and sustainability to tree-planting practices in the long run.

Management Options

Now that we have a clear understanding of some of the processes driving forest and tree responses to MPB outbreak, what can forest managers do to encourage the recovery of lodgepole pine on MPB-killed sites? Our research team evaluated three potential management options: partial harvest, clear-cutting, and site preparation.

We have complemented our findings from this work with novel approaches and methods tested by other researchers to give an overview of the options, summarized in the **Management toolkit** (pg. 12). This information has also been used to construct **Decision-making diagrams** (pg. 16) to support managers in deciding which options to pursue. The decision-making diagrams integrate information that can be collected during site assessments, allowing them to be used easily alongside the **Field Pamphlet** (insert at the back of this guide).

Management toolkit

Our team found that several silvicultural and harvest practices can be used to **facilitate natural regeneration of lodgepole pine**. Based on our research and the work of others, this species generally responds well to practices that:

- Open up the canopy: partial harvest, salvage logging, prescribed burn;
- Create favourable microsites: mixing, prescribed burn, leaving decayed wood onsite;
- Increase the number of trees/seeds available on site: tree-planting, cone-spreading by drag scarification.

While these tools provide options for future tree regeneration, management actions must consider other values and may be constrained by economics, logistics, policy, or regulations. To help put the pros and cons in perspective, our team has provided an efficient summary of each management option in the following toolkit.

HARVEST OPTIONS

Partial harvest of killed trees

PROS

- Best option for retaining MPB resistance in stand, by leaving residual trees standing
- Increases cone opening
- Machine corridors do not significantly increase fire risk

CONS

- More difficult logging to avoid living trees
- Opening up of canopy may cause increased competition from non-pine species
- Only improves pine regeneration when combined with mechanical site preparation (i.e., mixing)
- Current regeneration standards are limiting and make it difficult to perform partial harvest
- Retained trees may be susceptible to windfall

MITIGATING THE CONS:

Long-term sustainability of stand supported by MPB resistance may make up for short-term financial losses.

Salvage log

PROS

- Proven effective technique for lodgepole pine regeneration if used alongside planting or drag scarification
- Inexpensive
- Maximize timber values

CONS

- Potential loss of MPB resistance
- May damage soil microbiota due to doubling up disturbances (MPB and harvest)
- Potential challenge with competition from other vegetation
- Not practical or economical for all stands, especially those with low mortality

MITIGATING THE CONS:

Cone-spreading and scarification can be used to maintain seed source from MPB-resistant trees. Site preparation or vegetation management may be effective to control competing vegetation.

SITE PREPARATION

Mounding

We tested this technique, but it did not have a strong positive effect on natural regeneration of pine.

Screefing

We tested this technique, but it did not have a strong positive effect on natural regeneration of pine.

Mixing

PROS

- Provides favourable microsites for pine
- Decreases competition with other vegetation in the short-term
- Increases pine seedling density

CONS

- May be too expensive/impractical to deploy machines on smaller sites
- May damage naturally regenerating pine and roots of advance growth

MITIGATING THE CONS:

Prioritize use of this treatment on rich/moist sites, which are likely to lack natural pine regeneration.

Drag scarification

PROS

- By keeping the seed source from residual trees on site, can retain MPB resistance while still harvesting these trees

CONS

- May be too expensive/impractical to deploy machines on smaller or partially harvested sites
- May damage naturally regenerating pine
- May not work on rich/moist sites with heavy competing vegetation
- Trees must be de-limbed stumpside (e.g., not at roadside) to ensure MPB resistance is retained

MITIGATING THE CONS:

Combine this treatment with clear-cutting on poor/medium sites.

OTHER MANAGEMENT OPTIONS

Regenerate as a different forest composition

PROS

- No financial resources required
- Retain MPB resistance
- Increase diversity of forest types across landscape

CONS

- Opportunity cost: no lodgepole pine harvest
- Run the risk that the site may not regenerate trees at all

MITIGATING THE CONS:

Prioritize this strategy for sites with low harvest value, low mortality, and that have established advance regeneration of other tree species. Sites with advance regeneration of other species (e.g., broadleaf, spruce, other conifers) are **more likely to regenerate trees.**

Tree planting

Option 1. Under standard practice, all trees are replaced.

PROS

- Common practice, quick and intuitive to implement
- Ensures a dominant lodgepole pine stand
- Could be used to transition to a new species

CONS

- Trees from nursery unlikely to carry any genetic resistance to MPB; stands regenerated to pine using this strategy alone are less likely to resist MPB in the future

MITIGATING THE CONS:

If tree-planting is planned to replace all trees on-site, combine with cone-spreading and scarification to retain MPB-resistant genes.

In the long-term, **a valuable practice would be to recruit MPB-resistant trees into breeding/tree improvement programs** so that nursery trees and forests become more resilient to MPB.

Option 2. Using in-fill planting, gaps are filled to increase densities within naturally regenerating stands.

PROS

- Can use to supplement sites with inadequate natural regeneration to ensure they reach stocking density

CONS

- Rich sites may need vegetation control to ensure survival of establishing pine

MITIGATING THE CONS:

Prioritize this strategy to supplement poor/dry sites that have some existing natural regeneration.

Prescribed burning

PROS

- Post-fire conditions are favourable for pine regeneration

CONS

- High risk option, potential to burn out of control
- Post-MPB stands often have higher fuel loads due to downed woody materials
- Unlikely to be implemented unless a government program/directive is initiated

MITIGATING THE CONS:

Combine with partial harvest: machine corridors can act as “barriers” to fire movement and help to decrease risk.

Decision-making diagrams

Step 1: Determine your site type.

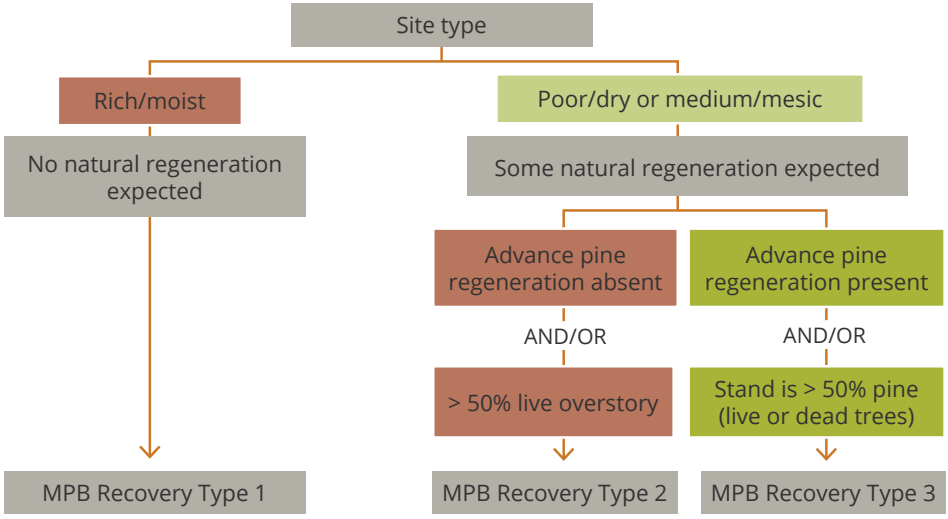
Look up your natural subregion using the rows, then match this with your site's ecosite letter in the columns. "NA" indicates this is not normally a pine site.

NATURAL SUBREGION	ECOSITE LETTER							
	a	b	c	d	e	f	g	h
Boreal Highlands	POOR	POOR	POOR	MEDIUM	RICH	NA	RICH	NA
Boreal Mixedwood	POOR	POOR	POOR	MEDIUM	RICH	RICH	RICH	NA
Lower Foothills	NA	POOR	POOR	POOR	MEDIUM	RICH	NA	RICH
Upper Foothills	NA	POOR	POOR	POOR	MEDIUM	RICH	NA	RICH
Subalpine	NA	POOR	POOR	POOR	NA	RICH	NA	NA

After you have identified your site type (poor, medium, or rich), proceed to step 2.

Step 2: Determine your Mountain Pine Beetle Recovery Type.

Follow the branch of the diagram with your site type to determine whether natural regeneration of lodgepole pine is expected and what your site's MPB Recovery Type is.



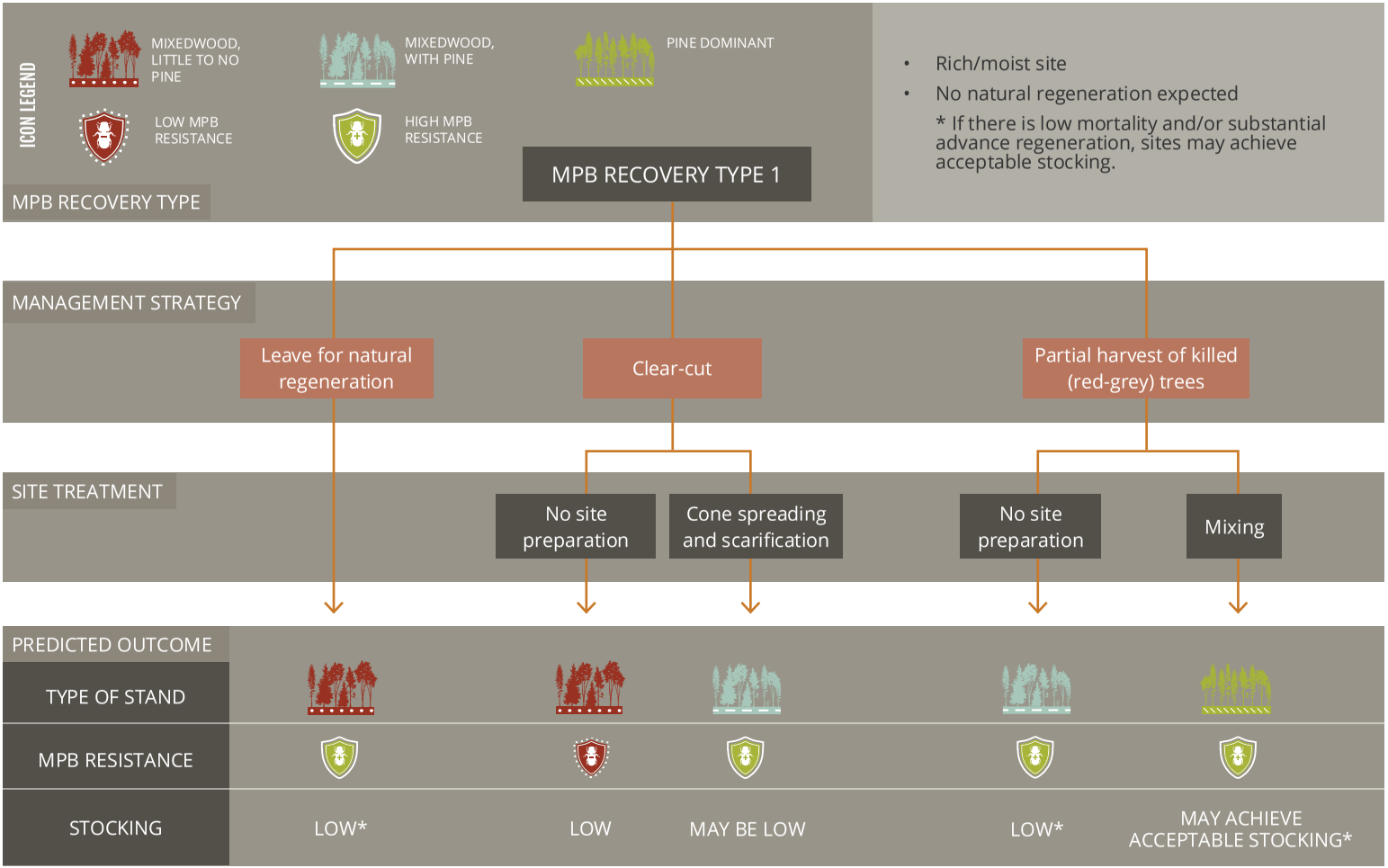
Once you have identified your MPB Recovery Type, proceed to step 3.

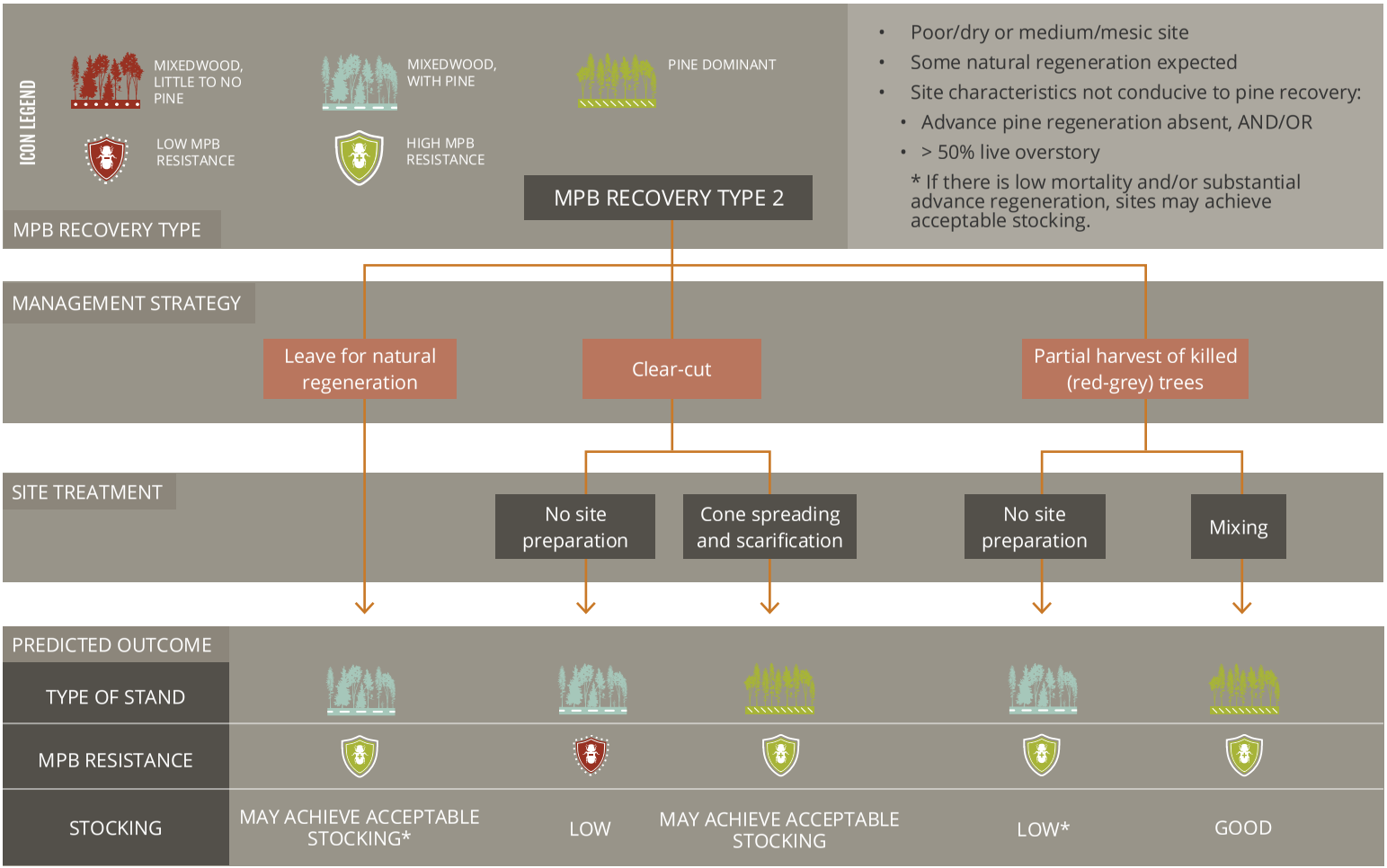
Step 3: Explore management options for your MPB Recovery Type.

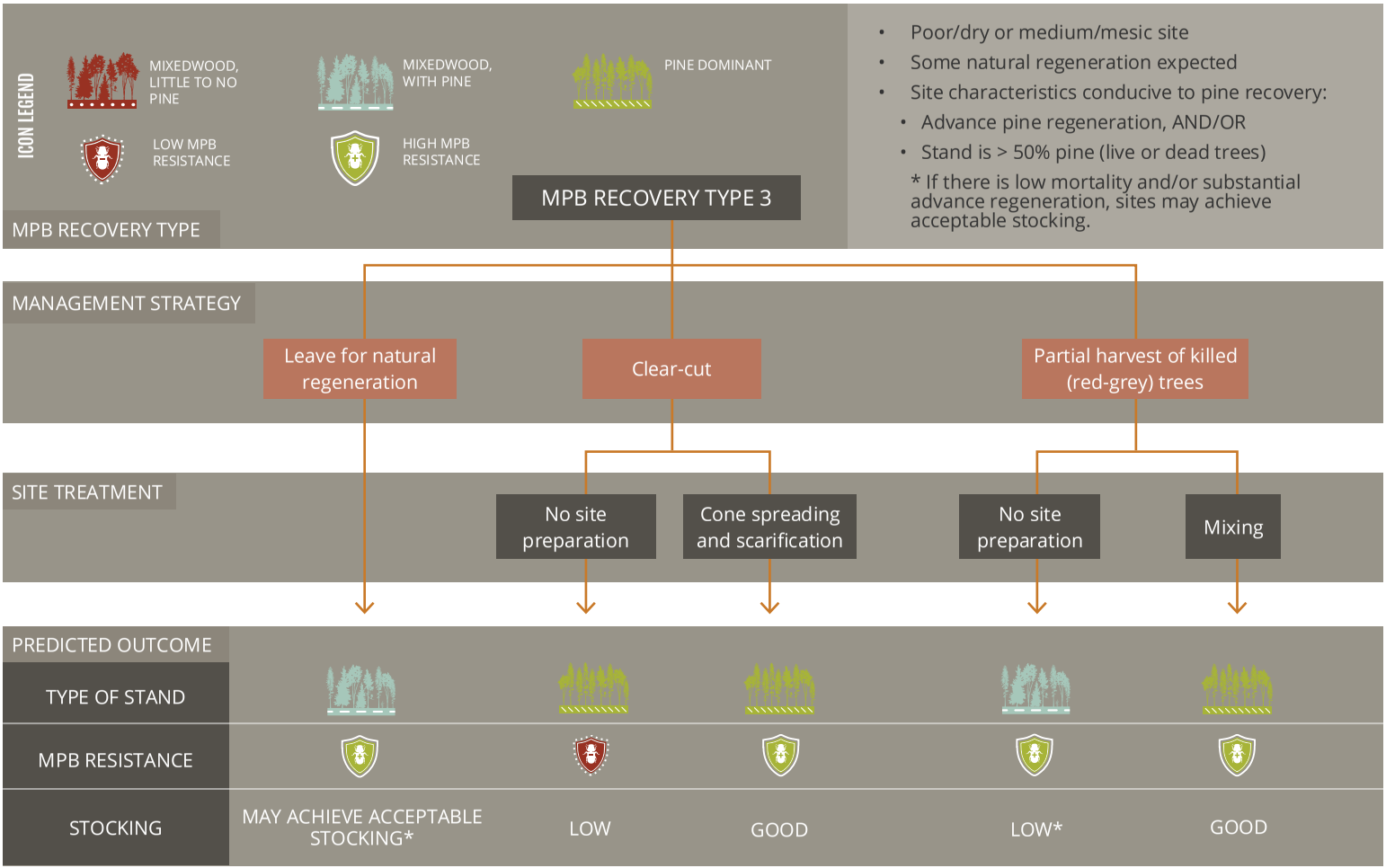
Proceed to the appropriate diagram for your MPB Recovery Type.

Keep in mind that the following management options, although not directly tested by the Beyond Beetle research team, might also be used to help improve outcomes for lodgepole pine:

- **Tree planting**
  - increase lodgepole pine or other species on site
  - lower probability of MPB resistance
- **Prescribed burning**
  - improve conditions for pine regeneration on site
  - potential risk of burning out of control


ICON LEGEND
MIXEDWOOD, LITTLE TO NO PINE
MIXEDWOOD, WITH PINE
PINE DOMINANT
LOW MPB RESISTANCE
HIGH MPB RESISTANCE
MPB RECOVERY TYPE
MPB RECOVERY TYPE 1
Rich/moist site
No natural regeneration expected
* If there is low mortality and/or substantial advance regeneration, sites may achieve acceptable stocking.
MANAGEMENT STRATEGY
Leave for natural regeneration
Clear-cut
Partial harvest of killed (red-grey) trees
SITE TREATMENT
No site preparation
Cone spreading and scarification
No site preparation
Mixing
PREDICTED OUTCOME
TYPE OF STAND
MPB RESISTANCE
STOCKING
LOW*
LOW
MAY BE LOW
LOW*
MAY ACHIEVE ACCEPTABLE STOCKING*


ICON LEGEND
MIXEDWOOD, LITTLE TO NO PINE
MIXEDWOOD, WITH PINE
PINE DOMINANT
LOW MPB RESISTANCE
HIGH MPB RESISTANCE
MPB RECOVERY TYPE
MPB RECOVERY TYPE 2
• Poor/dry or medium/mesic site
• Some natural regeneration expected
• Site characteristics not conducive to pine recovery:
• Advance pine regeneration absent, AND/OR
• > 50% live overstory
* If there is low mortality and/or substantial advance regeneration, sites may achieve acceptable stocking.
MANAGEMENT STRATEGY
Leave for natural regeneration
Clear-cut
Partial harvest of killed (red-grey) trees
SITE TREATMENT
No site preparation
Cone spreading and scarification
No site preparation
Mixing
PREDICTED OUTCOME
TYPE OF STAND
MPB RESISTANCE
STOCKING
MAY ACHIEVE ACCEPTABLE STOCKING*
LOW
MAY ACHIEVE ACCEPTABLE STOCKING
LOW*
GOOD


ICON LEGEND
MIXEDWOOD, LITTLE TO NO PINE
MIXEDWOOD, WITH PINE
PINE DOMINANT
LOW MPB RESISTANCE
HIGH MPB RESISTANCE
MPB RECOVERY TYPE
MPB RECOVERY TYPE 3
• Poor/dry or medium/mesic site
• Some natural regeneration expected
• Site characteristics conducive to pine recovery:
• Advance pine regeneration, AND/OR
• Stand is > 50% pine (live or dead trees)
* If there is low mortality and/or substantial advance regeneration, sites may achieve acceptable stocking.
MANAGEMENT STRATEGY
Leave for natural regeneration
Clear-cut
Partial harvest of killed (red-grey) trees
SITE TREATMENT
No site preparation
Cone spreading and scarification
No site preparation
Mixing
PREDICTED OUTCOME
TYPE OF STAND
MPB RESISTANCE
STOCKING
MAY ACHIEVE ACCEPTABLE STOCKING*
LOW
GOOD
LOW*
GOOD

Further Reading and Resources

- Axelson, J.N., Hawkes, B.C., van Akker, L., & Alfaro, R.I. 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. https://doi.org/10.1139/cjfr-2018-0161
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- **Beyond Beetle project virtual field tour: https://youtu.be/3O0AfUpViT0**

Photo Acknowledgements

Front and back cover: Koby Michaels

Mature mountain pine beetle (pg. 4): fRI Research

Pine tree attack stages and resin (pg. 5): Koby Michaels

Residual trees (pg. 10): Shiyang (Violet) Zhao

Resin ducts (pg. 10): Koby Michaels