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Risk assessment of the threat of mountain pine beetle *to Canada's boreal and eastern pine forests*

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Summary

RISK ASSESSMENT OF THE BEETLE THREAT IN 2007

In 2007, alarming levels of tree mortality caused by the mountain pine beetle north (MPB) and east of its historical range in British Columbia prompted the Canadian Forest Service to conduct an emergency risk assessment of the potential threat of this insect to Canada's boreal and eastern pine forests.

That assessment determined the threat to be real and imminent (Nealis and Peter, 2008). Few apparent biological impediments to range expansion existed, and primary geographic barriers that previously defined the range of this insect had either moderated (weather) or already been breached (Rocky Mountains). Furthermore, unlike earlier incursions of mountain pine beetle into the southern prairies, this new invasion east of the Continental Divide was found to be farther north through near-continuous forest linking western lodgepole pine to boreal jack pine forests.

These conclusions focused additional questions of risk including vulnerability of boreal and eastern pine species to attack, expected survival of the insect in novel climates, likely rates and directions of spread, and ecological and socio-economic impacts.

As it turned out, this was just the beginning. The outbreak in British Columbia continued to increase after 2007 and the area of attacked and killed trees in Alberta expanded. Greater investments were made in surveys and stand-level interventions, especially in Alberta. Rapid change in the status of the beetle, together with newly gained information, led to a demand for a reassessment of the threat posed to boreal and eastern pine forests by the beetle.

REASSESSMENT OF THE THREAT IN 2010

The reassessment in 2010 found that many of the predictions made in 2007 have come true. Mountain pine beetle continues to expand both its geographic and host range. It is persisting in areas once thought to be climatically unsuitable, and is finding and attacking even sparse clusters of trees. The beetle is now reproducing in jack pine, a transcontinental pine species of the boreal forest. In addition to the potential impacts of this to forestry, an increase in tree mortality could exacerbate the already high fire risk characteristic of pine forest types.

Prediction of future rates of spread is greatly complicated by the continuing possibility of long-distance dispersal of beetles from existing outbreaks. However, refinements in other predictive tools, especially climate-suitability models, have improved our ability to map areas of future relative risk, likely pathways of range expansion, and areas where intervention may result in the greatest pay-offs. The rapid availability of diverse survey and research results and improved communications among professionals—both enabled by the risk analysis process—offer jurisdictions new possibilities for evidence-based, adaptive policy decisions. Given that the risk assessment process is now sufficiently mature, scientifically informed analysis of response options is more feasible than ever.

Introduction

The mountain pine beetle (*Dendroctonus ponderosae* Hopkins) is the most destructive pest of mature pine forests in western North America (Safranyik et al., 2010). Periodic outbreaks cause widespread tree mortality, especially to lodgepole pine (*Pinus contorta* Dougl. ex Loud. var. *latifolia* Engelm.) in British Columbia, although most species of *Pinus* challenged by the mountain pine beetle (MPB) have proved to be adequate hosts.

The recent outbreak first became apparent in British Columbia in the late 1990s. By 2011, more than 700 million m^3 of trees over 18.1 million ha of pine forests had been killed. This represented approximately 50% of the total merchantable pine volume in the province.[1]

A significant result of this current outbreak is the rapid ecological range expansion of MPB into forested areas north and east of the insect's historical range. This fast expansion is considered to be the result of the above-canopy dispersal of adult beetles from high-density populations in source areas within the historical range into susceptible forests previously undisturbed by MPB because of unsuitable climate. This development is especially significant in that a major geographic barrier, the Rocky Mountains, has been breached. Mild winters have favoured brood survival in these new areas, and ongoing recruitment of beetles from neighbouring areas of infestation has contributed to the persistence of populations.

A similar range extension was observed in the 1970s when dispersing MPB established populations in the Cypress Hills of southeastern Alberta and southwestern Saskatchewan where populations now persist (Safranyik et al., 2010). The current situation, however, is novel in that the newly infested forests in the north are not isolated pine stands within a large prairie region (as in southern Alberta), but rather are part of a contiguous forest stretching eastward and northward across Canada. Consequently, pine trees throughout the entire northern forest are at potential risk of undergoing new ecological disturbance from the effects of MPB.

INITIAL ASSESSMENTS OF THE PROBLEM

In 2007, the Canadian Forest Service completed an emergency risk assessment addressing the threat of MPB to Canada's boreal and eastern pine forests (Nealis and Peter, 2008). The conclusion was that few biological impediments existed to the range expansion of MPB into these new forests so long as weather conditions permitted brood survival. Although climate and forest conditions were considered less suitable in these new areas than in the historical range, the assessment determined that MPB populations would persist indefinitely and continue to expand their range, with a high potential for significantly affecting forests not previously disturbed by MPB. In 2005, Alberta began an annual program to detect and eliminate MPB populations along the presumed leading edge in hopes of reducing further spread. Mass dispersal of adult beetles in 2006 and again in 2009, however, resulted in spread exceeding expectations. Annual tree mortality increased along the foothills and eastward through the forest zone where lodgepole pine and jack pine (*Pinus banksiana* Lamb.) hybridize.

[1] for.gov.bc.ca/hfp/mountain_pine_beetle/Updated-Beetle-Facts_May2012.pdf (accessed October 2013).

In 2011, genetic evidence confirmed that MPB was successfully attacking and producing broods in pure jack pine, the dominant pine species of the boreal forest (Cullingham et al., 2011). The ecological bridge to eastern pine forests had been established.

THE RISK REASSESSMENT UNDERTAKEN IN 2010

These rapid changes in the distribution of MPB, together with the significant investments made by forest managers in response, resulted in the Canadian Council of Forest Ministers (CCFM) requesting a reassessment of the threat via the National Forest Pest Strategy (NFPS).

The reassessment began with a meeting between provincial and federal experts from the CFS in Edmonton in September 2010. A descriptive update with current status was identified as a priority. Additional analyses were to be added where opportunities presented themselves. Critical areas in need of reassessment included dispersal and the ecological relationships influencing MPB survival and reproduction at the tree level in the expanded range. Change in the risk of fire due to beetle-killed trees was identified as a factor of key public interest.

Three workshops were organized to address these critical issues: 1) dispersal and spread of MPB; 2) associated fire risk; and 3) reassessment of current and future status (see Appendix 1 for participants at all workshops). Summaries of the 2010 Edmonton meeting and first two workshops were submitted to the NFPS Working Group in April 2011 for communication to the CCFM.

This report summarizes the findings of the reassessment. In all cases, participants had the opportunity to review and comment on these reports. None of this could have been accomplished without their generous and frank provision of expert knowledge.

The same reporting format used in the original assessment (Nealis and Peter, 2008) is employed here: a pertinent affirmative statement of fact is given, accompanied by associated evidence and uncertainty. Where appropriate, the original statement or a slightly modified version is used again to facilitate consideration of change in assessment. Uncertainty is a weighting factor indicating confidence in the statement and highlighting information needs.

This reassessment focuses on new scientific evidence only. A reassessment of socio-economic impacts has not been undertaken. For additional information, readers should consult the original risk assessment (Nealis and Peter, 2008).

Dispersal and patterns of range expansion

MPB HAS ENTERED INTO, AND IS SUCCESSFULLY REPRODUCING IN, A NEW ECOLOGICAL RANGE, BOTH GEOGRAPHICALLY AND IN TERMS OF HOST-RANGE EXPANSION.

EVIDENCE

- Successful brood production has been confirmed in jack pine east of Lesser Slave Lake, Alberta (Fig. 1) (Cullingham et al., 2011).
- MPB presence has been observed from extensive direct surveys, including: i) Heli-GPS (GPS-guided reconnaissance by helicopter point records); ii) aerial overview surveys (fixed-wing with

manual delineation); and iii) digital aerial photography with selected ground confirmation of dead pine trees associated with MPB attack. Observations have been made:

» as far east as Marten Hills (100 km east of Slave Lake) (Fig. 2); and
» north in British Columbia to within 80 km of the Yukon Territory border and, most recently, in the Northwest Territories (Figs. 2 and 3).[2]

- MPB has attacked pine trees baited with an aggregation pheromone (variable blend of *trans*-verbenol and *exo*-brevicomin) as far east as Lac La Biche, approximately 120 km from the Saskatchewan border (Fig. 2).

UNCERTAINTY

- Low to nil uncertainty for Heli-GPS, digital aerial photography and ground confirmations because of repeated observations over large area for several years by independent observers.

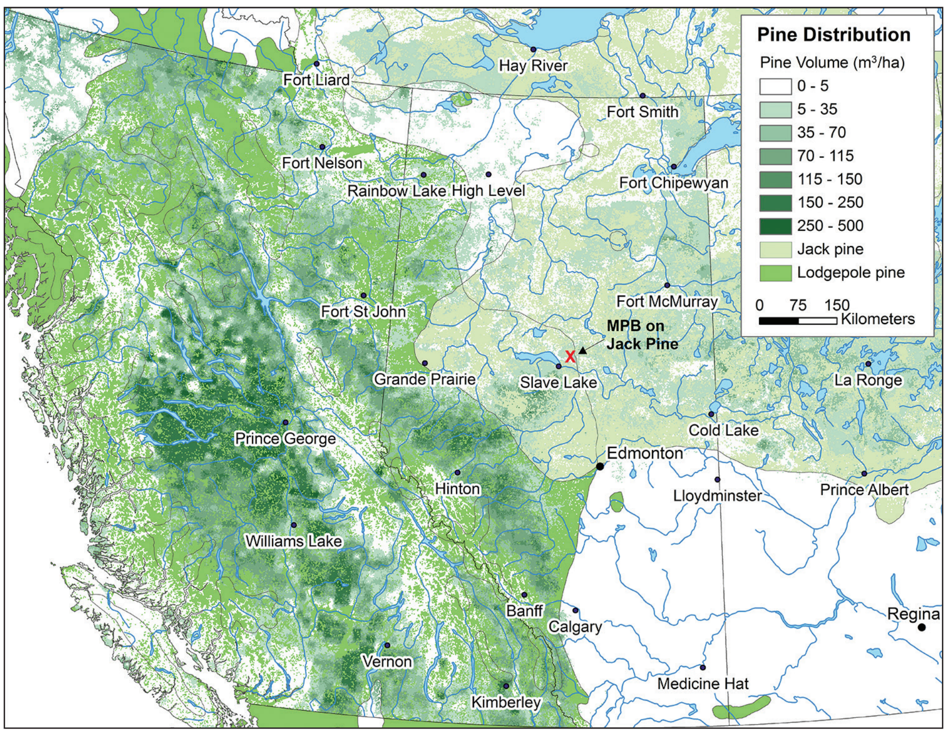


Figure 1. Volume (m^3/ha) of all pine species in western Canada. *Source:* Yemshanov et al. (2011). The approximate distributions of lodgepole and jack pines according to Little (1971) are shown, as well as the location of first confirmation of successful mountain pine beetle reproduction in jack pine. (Cullingham et al., 2011)

[2] norj.ca/2013/04/live-pine-beetle-larvae-found-in-nwt/ (accessed October 2013).

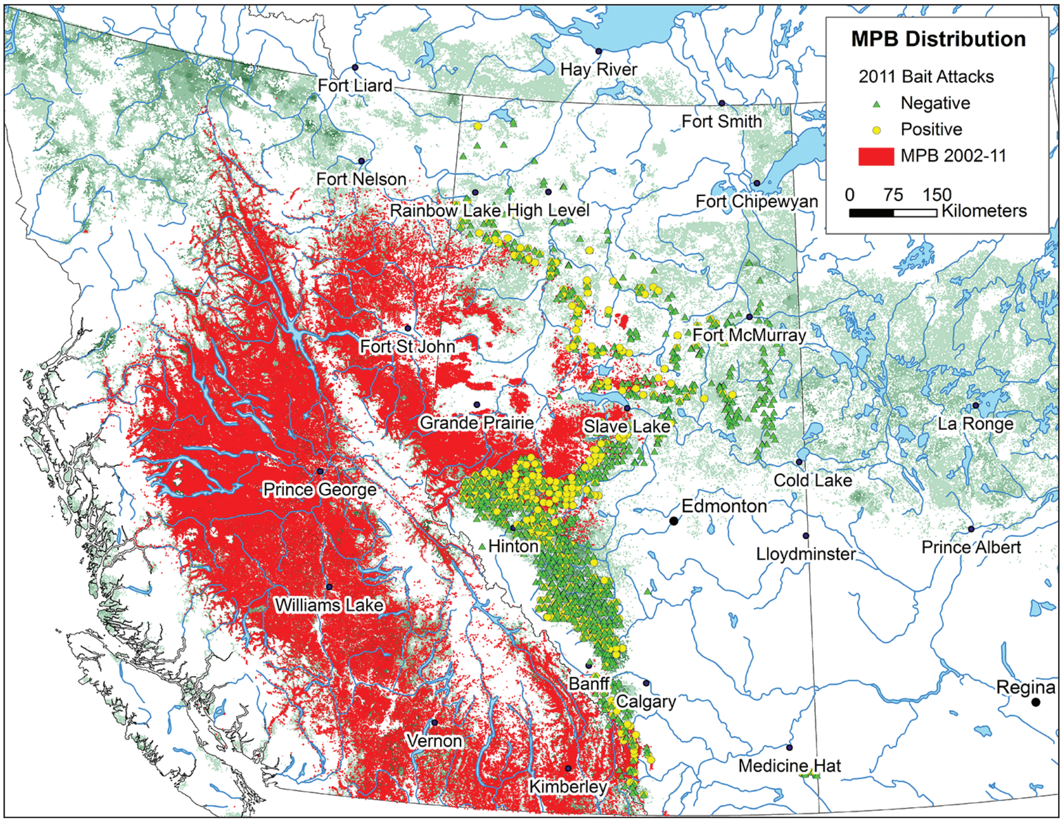


Figure 2. Distribution of trees killed by mountain pine beetle in western Canada 2002–2011 (red) and presence (yellow circle)/absence (green triangle) of MPB attack in 2011 on pheromone-baited trees in Alberta. Mountain pine beetles were also found at low population densities 150 km east of the Slave Lake region, where tree deaths are occurring in small clusters. *Source:* Alberta Sustainable Resource Development, Forest Health Division. Isolated populations of mountain pine beetle were found in the Northwest Territories in 2012 (M. Gravel, Manager, Forest Management Services, Northwest Terrritories).

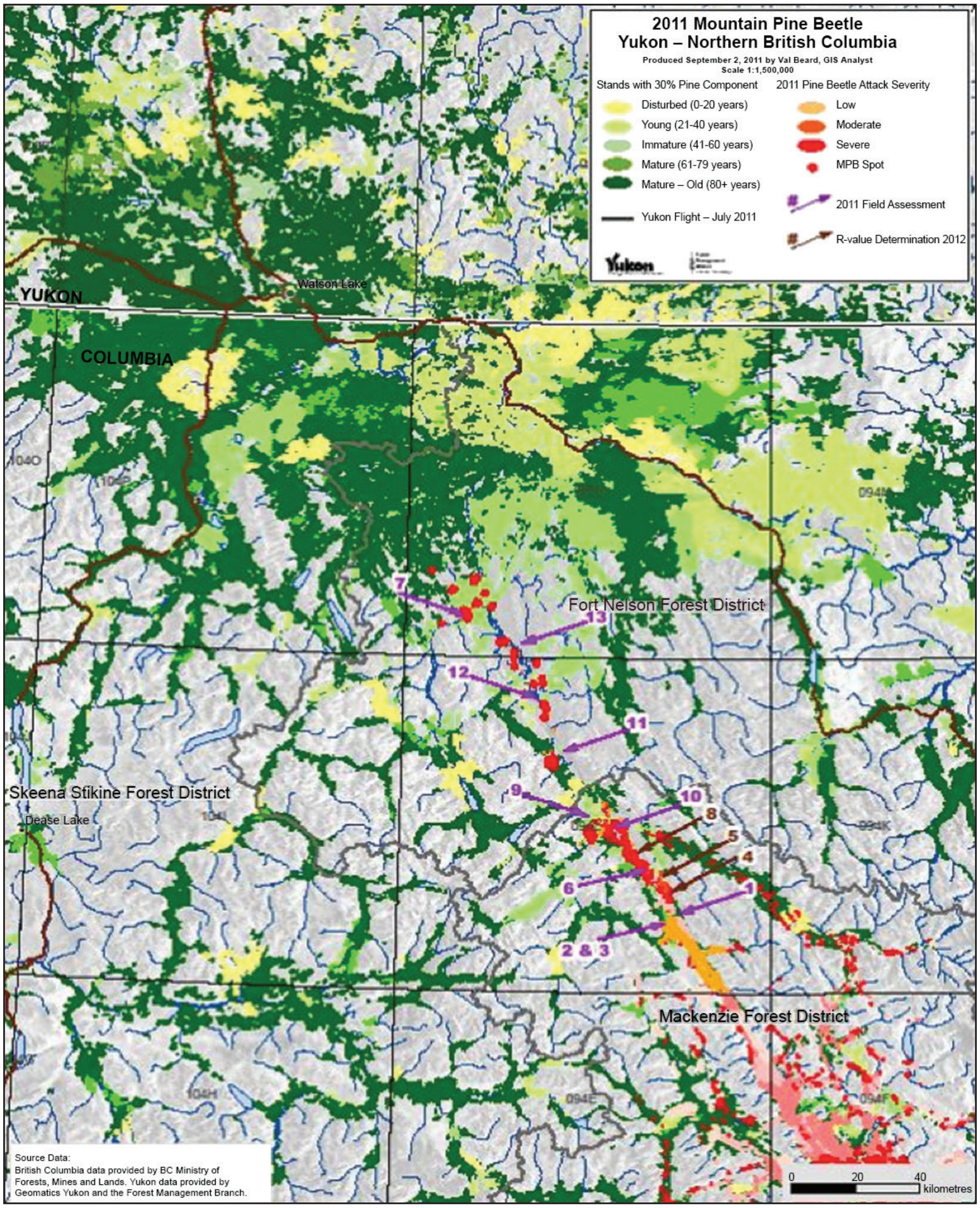


Figure 3. Locations of confirmed mountain pine beetle attacks in the Rocky Mountain Trench area of northern British Columbia. Note the large area of contiguous pine north of current locations of infestation. *Source:* Yukon Energy, Mines and Resources.

MONITORING IDENTIFIES THREE BOUNDARIES OR LEADING EDGES AND ASSOCIATED ZONES:

1) Red-attack[3] boundary—the geographic limit of beetle-killed trees;
2) Green-attack[4] boundary—the geographic limit of current-year attack; and
3) Beetle-boundary—the geographic limit of positive finds in baited trees irrespective of evidence of successful natural attack.

EVIDENCE

- MPB presence has been observed from extensive direct surveys (see *Evidence* on page 6).

UNCERTAINTY

- Low uncertainty for identifying red attacks with Heli-GPS and digital photography records, related to minor positional errors and extensive ground checks (Coggins et al., 2008).
- Moderate to high uncertainty in finding all red attacks with aerial overview surveys (Harris and Dawson 1979).
- Moderate uncertainty related to efficacy of baits and associated possibility of false negatives.
- Uncertainty overall is proportional to effort and consistency of surveys in space and time—that is:
  - Low to moderate uncertainty for Heli-GPS (Red-attack boundary) because these are readily detected with this survey method (Nelson et al., 2006a).
  - High uncertainty for detection of current-year attacks (Green-attack boundary) because these cannot be detected remotely (Wulder et al., 2009). The Green-attack boundary could lie anywhere between, or be the same as, the Red-attack and Beetle-boundaries.
  - Moderate to high uncertainty for bait trees (Beetle-boundary) because the range of attraction of the pheromone has not been established and the labour-intensive nature of the method limits spatial coverage.

3 "Red-attack" trees are those trees that have been colonized by beetles one, or sometimes two, years before the assessment. They are characterized by diagnostic red foliage.

4 "Green-attack" trees are those trees that have been colonized by beetles in the current year of assessment and for which symptomatic colour change may not yet be evident.

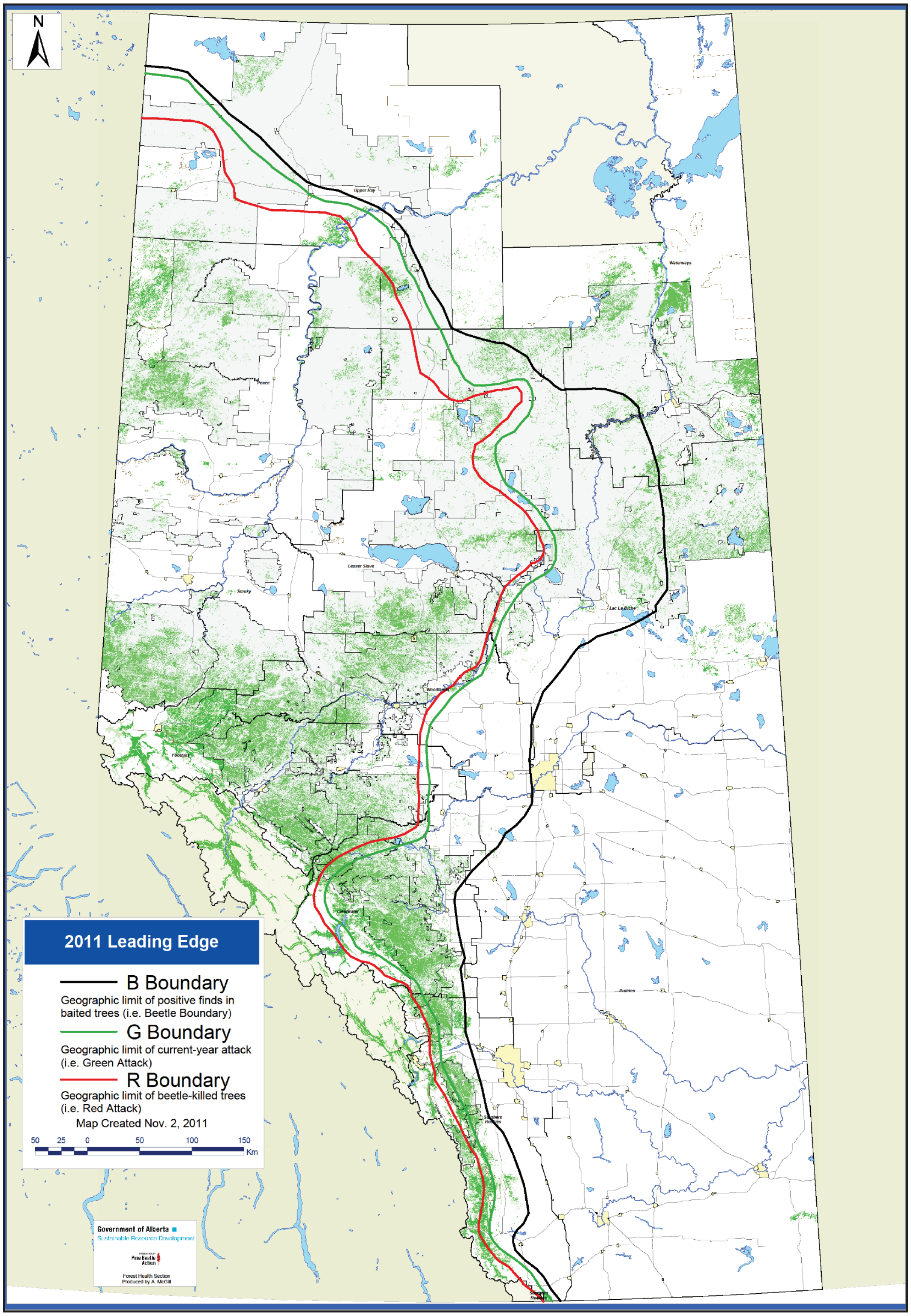


Figure 4. Approximate boundaries of leading edges of red-attack trees (R Boundary), green-attack trees (G Boundary) and Beetle attacks (B Boundary) in 2011. *Source:* M. Undershultz, Alberta Sustainable Resource Development, Alberta.

THE OBSERVED RATE OF SPREAD OF MPB EAST OF THE ROCKIES HAS BEEN MOST RAPID NORTHWARD AND EASTWARD AND SLOWEST SOUTHWARD.

EVIDENCE

- MPB populations in northern British Columbia and Alberta began expanding rapidly in the mid-2000s, with spread proceeding both north through the Rocky Mountain Trench and east through Pine Pass into the Peace River region (Fig. 5). The first evidence of invasion into a new ecological zone came in 2006 with direct observations of beetle flights being made, followed by the appearance of red trees in central Alberta in 2007 (Nealis and Peter, 2008).
- The annual rate of spread north and east has varied considerably among years. During the five years 2002–2006, the eastern front advanced 62 km, while the northern front actually receded 155 km. In contrast, during the next five years, 2007–2011, the eastern front advanced an additional 413 km while the northern front advanced 420 km (Table 1).
- There are twice as many years (four) during which negative displacements (i.e., range retractions) were observed along the northern front as compared with along the eastern front. Range retraction occurred along both axes in 2002/2003 (Table 1).
- The annual rates of spread both north and east were exceptionally high in 2006 (red trees appearing in 2007) and 2009 (red trees appearing in 2010). Average annual frontal displacement was 163.2 km/year during those two years (Table 1, shaded columns) versus 5.4 km/yr during the other eight years (Table 1, non-shaded columns).
- Southward spread through Hinton, Alberta, has been relatively slow by comparison (Fig. 5) despite the abundance of susceptible pine in the region (Fig. 1).

UNCERTAINTY

- Moderate uncertainty but significantly less than in the previous assessment because sample size (i.e., the number of years of invasive spread) has doubled.
- Evidence of the eastern spread through Alberta is based on observation of "red" trees and the presence or absence of beetles.

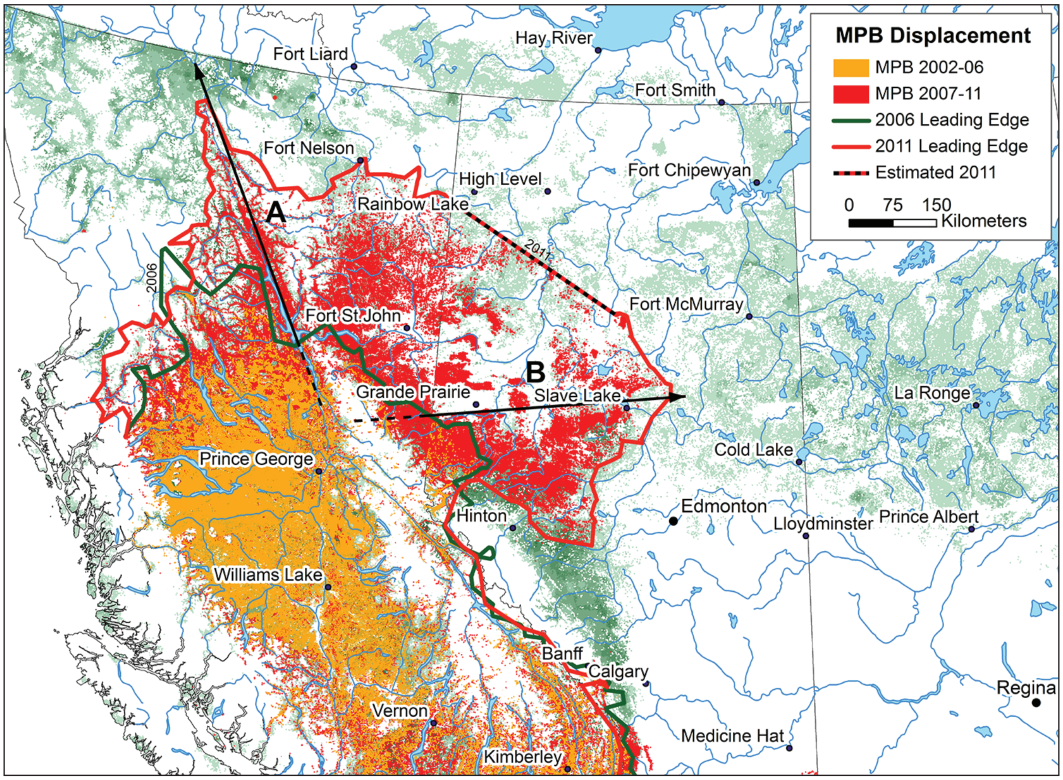


Figure 5. Distribution of trees killed by mountain pine beetle in western Canada between 2002 and 2006 (orange) and between 2007 and 2011 (red). Vectors indicate the general linear distance of spread north (A) and east (B) from the leading edge in 2006 (green) to the leading edge in 2011 (red). *Source:* R. Brett, Canadian Forest Service, Edmonton.

Table 1. Annual (km/yr) and net (km/5 yr) displacement of mountain pine beetle north and east from its historical range between 2001 and 2011. Shaded cells highlight exceptional events (see p.12).

	Annual displacement (km/yr)										**Net displacement (km/5 yr)**	
Year	2001/ 2002	2002/ 2003	2003/ 2004	2004/ 2005	2005/ 2006	2006/ 2007	2007/ 2008	2008/ 2009	2009/ 2010	2010/ 2011	2002/ 2006	2007/ 2011
North	37	-23	-187	124	-106	187	-15	38	150	60	**-155**	**420**
East	32	-108	86	-20	72	229	39	87*	38	20	**62**	**413**

* In these eastern plots, some trees (known as "early faders") were recorded in the same year as attack (i.e., 2009). Normally attack cannot be confirmed until the following year.

LONG-DISTANCE TRANSPORT OF MPB OCCURS WHEN ADULT BEETLES FLY ABOVE THE FOREST CANOPY, ASSISTED BY VERTICAL, CONVECTIVE LIFTING AND THEN HORIZONTAL ADVECTION ON PREVAILING WINDS. DISTANCES TRANSPORTED CAN EXCEED 100 KM DEPENDING ON METEOROLOGICAL CONDITIONS. SUCH LONG-DISTANCE DISPERSAL FROM HIGH-DENSITY SOURCE AREAS HAS SIGNIFICANTLY INFLUENCED RATES OF SPREAD NORTH AND EAST OF THE HISTORICAL RANGE.

EVIDENCE

- The dominant direction of the rapid range extensions occurring in 2006 and 2009 (Table 1) tended to be from infested, higher elevations toward low-lying areas. Three examples of this: i) northern spread through the Rocky Mountain Trench; ii) eastern spread through the pine corridor around Lesser Slave Lake; and iii) eastern and southern spread into south-central Alberta.
- An unusually high ratio of new attacks to previous attacks (170:1) was observed over a large area in 2009. Ratios greater than 10:1 are considered evidence of long-distance dispersal.
- Genetic studies indicate that MPB populations recently arrived in northern Alberta are closely related to populations in northern British Columbia, while populations in southern British Columbia and beyond reflect a pattern of genetic isolation-by-distance (James et al., 2011; Cullingham et al., 2012).

UNCERTAINTY

- Detection of green attacks is difficult over vast, potential sink areas (Wulder et al., 2009).
- Not possible to unequivocally determine source of green attack in areas where local red-attacked trees have produced successful broods.
- Successful attack and brood production can occur without killing trees (i.e., new green attacks without local red attacks).

THE INFLUENCE OF LONG-DISTANCE TRANSPORT ON THE RATE OF SPREAD IS EXPECTED TO DECREASE POST-2011.

EVIDENCE

- High-density, source populations for long-distance dispersal are declining (Walton 2011).
- The farther that non-infested areas beyond the leading edge are from high-density, potential source populations, the less significant immigration events will become.

UNCERTAINTY

- Established beetle populations in the expanded range may become a source for migrants closer to non-infested areas. There are now more potential sources of migrants that determine risk of further range expansion on the leading edge of the boreal. According to the Shore-Safranyik (Shore and Safranyik, 1992) risk rating system, beetle pressure and the likelihood of infestation are a function of both size of the source population and its proximity to the target stand. Sources in British Columbia are large but not proximal to the leading edge; and new sources in Alberta are not yet as large but are proximal to the leading edge. Because the relative contribution of these two factors to risk is incompletely known, their influence on spread rates is uncertain.

SHORT- TO INTERMEDIATE-DISTANCE DISPERSAL—TYPICALLY LESS THAN 1 KM—OCCURS BELOW AND ABOVE THE CANOPY, WEAKLY ASSISTED BY AIR MOVEMENT, AND RESULTS IN MOVEMENT WITHIN OR BETWEEN ADJACENT STANDS. SUCH DISPERSAL WILL CONTINUE TO CONTRIBUTE TO RANGE EXPANSION.

EVIDENCE

- New infestations (green attack) occur typically in close proximity to the edge of previous infestations (red attack).
- Dispersal is normal behaviour for this species in seeking new, susceptible hosts (Safranyik et al., 1992).
- Spot infestations occasionally spawn new satellite clusters of attack (Borden 1993).

UNCERTAINTY

- The rate of short- and intermediate-distance dispersal is unpredictable from stand characteristics (Safranyik et al. 1992).
- Knowledge of dispersal behaviour is limited and rudimentary.

Relationship of spread to forest

HOST PINE STANDS IN THE BOREAL EAST OF THE ROCKY MOUNTAINS ARE SUBOPTIMAL FOR MPB, AS THESE STANDS HAVE LOWER PINE VOLUMES AND LOWER LANDSCAPE-SCALE CONNECTIVITY RELATIVE TO PINE STANDS IN BRITISH COLUMBIA. HOWEVER, AREAS OF CONTIGUOUS FOREST WITH RELATIVELY HIGH VOLUMES OF PINE EXIST IN THE WESTERN BOREAL, INTO SOUTHERN YUKON TERRITORY.

EVIDENCE

- Evidence that pine volumes and landscape-scale connectivity are lower in the boreal than in British Columbia was provided in the earlier emergency risk assessment (Nealis and Peter, 2008). See Figure 1 of this report.
- By contrast, the area of contiguous forest with relatively high volumes of lodgepole pine increases northward between the area of current infestation in the Rocky Mountain trench and northern BC, southern Yukon Territory (Fig. 3).

UNCERTAINTY

- Low uncertainty given the evidence of higher mean per capita brood production in naïve pines in the absence of certain weather factors (see *Relationship of spread to climate suitability* on p. 16).

DEGREE OF CONNECTIVITY OF SUSCEPTIBLE STANDS IN THE BOREAL APPEARS TO BE LESS OF A CONSTRAINT FOR MPB POPULATION GROWTH AND SPREAD THAN CONCLUDED IN THE PREVIOUS ASSESSMENT.

EVIDENCE

- The direction of spread in the northern boreal has not followed expected patterns of the MPB connectivity model (Riel et al., 2010). Notably:

- » the extent of the eastward and northward spread (toward Saskatchewan and Northwest Territories, respectively) has exceeded that of the southward spread (toward south-central Alberta).
  - » the eastward spread across disconnected forests of the Peace and Athabasca river valleys has been confirmed.

UNCERTAINTY

- High uncertainty arising from insufficiencies in the current model of forest susceptibility to MPB. The model relies on stand-level inputs (measurement and relationships) to calculate susceptibilities at landscape-level scales using forest inventory. These calculations are highly sensitive to input data containing different information (Nelson et al., 2006b), such as:
  - » wind direction, topography, and distance from source
  - » capability of long-distance dispersal and dispersal behaviour at edges (e.g., gap crossing)
  - » influence of weather and climate
  - » impact of management actions

Relationship of spread to climate suitability

MODELS OF CLIMATE SUITABILITY (NEALIS AND PETER, 2008; BENTZ ET AL., 2010) HAVE BEEN VALIDATED. MODEL OUTPUT SHOWS THAT RANGE EXPANSION IN THE PAST 15 YEARS HAS BEEN ASSOCIATED WITH WEATHER CONDITIONS FAVOURING SURVIVAL OF MPB IN WESTERN CANADA.

EVIDENCE

- A summer climate suitability model (Fig. 7 in Nealis and Peter, 2008) has been validated for MPB in Idaho (Powell and Bentz, 2009) and shows a strong positive trend from 1905 to 2010 in Canada (Fig. 6).
- Safranyik's (modified) model (Fig. 7 in Nealis and Peter 2008) has been validated for use in predicting range expansion (Safranyik et al., 2010), inasmuch as observations of successful attack and persistent populations are consistent with climatic suitability described by the model.
- Overwinter mortality (cold tolerance) predictions (Régnière and Bentz, 2007; Nealis and Peter, 2008) have been validated in Alberta (Cooke 2009) and British Columbia (Pellow et al., 2010).
- Preliminary research results in Alberta and British Columbia are consistent with overall model results in showing that local winter survival may be very low in the area of range expansion (Bleiker et al., 2011).
- Warmer winter weather since 1995 (compared with that in the previous normals period, 1961–1990) is associated with range expansion.
- Population rates of change during endemic periods in British Columbia are strongly related to annual weather variability (Sambaraju et al., 2012).
- The recent epidemic in British Columbia is strongly related to weather variability.

UNCERTAINTY

- Low to moderate uncertainty for future trends in climate in the boreal forest.
- Moderate to high uncertainty for predictions of location-specific weather—that is, climate suitability models have limits on spatial and temporal resolution, being more uncertain at finer scales.

- Low to moderate uncertainty related to interactions of local weather with local host condition.
- Moderate uncertainty related to physical versus physiological thermal scales. Physical thermal scales are direct meteorological measures of ambient temperature, whereas physiological thermal scales show transformation of physical scales to species-specific physiological scales (i.e., temperature-dependent development rates, critical maximum/minimum temperatures, etc.).

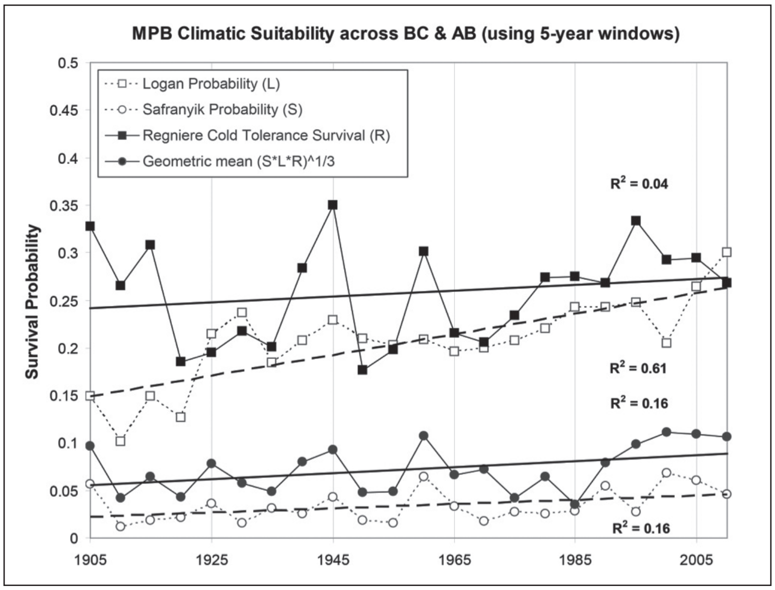


Figure 6. Long-term trends in four climatic suitability indices (mapped in Fig. 7 in Nealis and Peter, 2008). All indices show trends of increasing climatic suitability for mountain pine beetle. Note the strong, steady increase in summer climatic suitability (Logan Probability, open squares) and the repeated sequence of warm winters with improved survival since the mid-1980s (Régnière Cold Tolerance Survival, closed squares). A sharp increase in the former in the most recent five-year period compensated for a decrease in the latter, resulting in a sustained increase in the composite index of climatic suitability (closed circles).

CURRENT CLIMATE SUITABILITY DECREASES EAST OF SASKATCHEWAN, BUT THE SUSCEPTIBILITY OF THE FOREST INCREASES.

EVIDENCE

- Available climatic models and forest-cover data (Fig. 1) support this statement. Although the overall risk of severe outbreaks such as those observed in British Columbia is less in the boreal zone, the risk is now considerably greater than zero. Moreover, occupation of the boreal zone by the mountain pine beetle represents range expansion and establishes a potential pathway through which resident mountain pine beetle populations in the boreal plain may enter the pine forests of central and eastern Canada.

UNCERTAINTY

- Low uncertainty around the non-zero and potential threats to pine forests east of the current outbreaks.
- Moderate uncertainty as to the time scale over which the threat will develop.

Relationships between mountain pine beetle and its ecological associates

PER CAPITA BROOD PRODUCTION OF MPB IS GREATER AT ALL OBSERVED ATTACK DENSITIES IN NAÏVE PINES IN THE NEW RANGE. NAÏVE PINES ARE LODGEPOLE PINE TREES GROWING IN STANDS THAT HAVE NO HISTORICAL RECORD OF EXPOSURE TO MOUNTAIN PINE BEETLE. NAÏVE PINES ARE THEREFORE POTENTIALLY DIFFERENT THAN OTHERS IN THEIR CAPACITY TO RESIST ATTACK.

EVIDENCE

- Recent research has found brood production on naïve pines at low attack densities (Cudmore et al., 2010).

UNCERTAINTY

- Moderate uncertainty, as limited observations thus far could be associated with local factors affecting host defense (e.g., gene, site factors).
- Observations have been made in lodgepole pine only, and are required in jack pine.
- Relationships may change as a function of time. For example, the rate of natural enemy impacts may increase once populations establish and beetles select and kill those trees that are most resistant.

FUNGAL ASSOCIATES IN NEW RANGE (E.G., *LEPTOGRAPHIUM* SPP.) ARE WELL-ADAPTED TO BOREAL CLIMATE.

EVIDENCE

- The dominant blue-stain fungus associated with MPB in boreal forests of Alberta, *Leptographium*, is capable of surviving cold winters and thrives in jack pine.
- Laboratory studies show that *Leptographium* in jack pine significantly increases MPB fitness relative to the effects on the beetle from other dominant fungal associates.

UNCERTAINTY

- Moderate uncertainty, as details of interactions *in situ* have not been worked out.

THERE ARE NO MAJOR DIFFERENCES IN THE COMPETITORS OR NATURAL ENEMIES OF MPB IN THE JACK PINE AND LODGEPOLE PINE FORESTS OF CANADA.

EVIDENCE

- Major competitors of MPB thought to influence the transition from endemic to eruptive states (Safranyik and Carroll, 2006) appear common in boreal lodgepole and jack pine forests (Bright, 1976). Similarly the natural enemies (predators, pathogens and parasitoids) associated with MPB in lodgepole forests of British Columbia are common throughout the boreal zone (D. Langor, Canadian Forest Service, Edmonton, Alberta, pers. comm., August 2007).

UNCERTAINTY

- Low uncertainty about the similarity of the composition of the competitor-natural enemy faunas in lodgepole and jack pine forests. The expected qualitative nature of interactions in both forest types is comparable.
- Moderate uncertainty about the quantitative nature of these interactions as they pertain to MPB dynamics.

Impacts

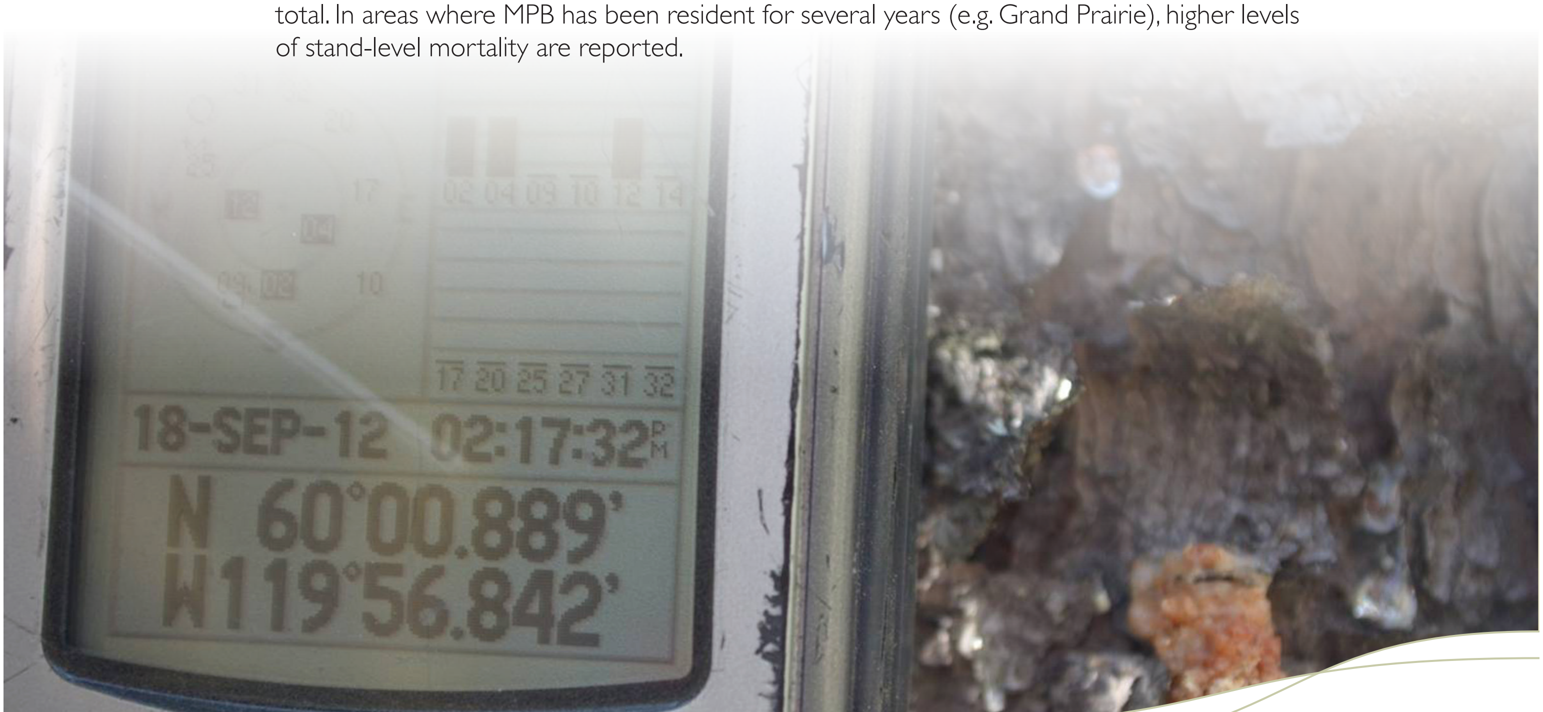
THE RISK TO ALL PINE FORESTS FROM MPB IS FINITE, BUT EXPECTED LOSSES IN THE BOREAL FORESTS OF ALBERTA, SASKATCHEWAN AND MANITOBA WILL BE LESS THAN THOSE EXPERIENCED IN BRITISH COLUMBIA AT ALL SCALES OTHER THAN THE TREE LEVEL. EVEN UNDER OUTBREAK CONDITIONS, AVERAGE STAND-LEVEL LOSSES IN THE BOREAL FOREST ARE UNLIKELY TO EXCEED 30% OF STEMS OR 40–60% OF STANDING VOLUME (NEALIS AND PETER, 2008, P. 16).

EVIDENCE

- Stand-level losses are a function of volume: lower stand volumes in boreal and eastern pine forests, at least in the Boreal Plain, should result in lower accumulated losses than are observed in higher volume stands in British Columbia and the Alberta foothills (Fig. 7).
- Stand-volumes in pine forests of ON, however, are relatively higher again.
- Estimates of losses in the Alberta foothills are lower than in British Columbia (approximately 5% to date), but rates of 90% have been observed in the boreal region.

UNCERTAINTY

- If beetles produce larger per capita broods (see *Relationship of spread to climate suitability* on p. 16) and/or survival is high in expanded range, within stand losses would increase.
- Losses are continuing in most infested stands in Alberta. We do not yet know the cumulative total. In areas where MPB has been resident for several years (e.g. Grand Prairie), higher levels of stand-level mortality are reported.



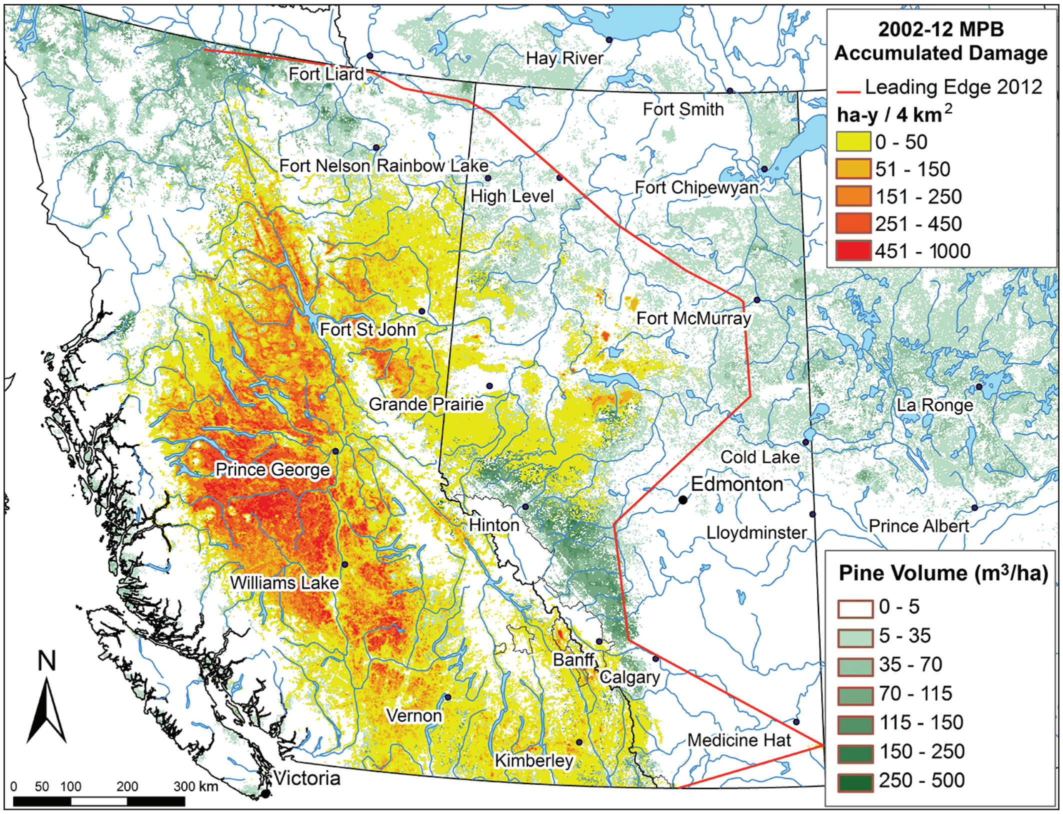


Figure 7. Accumulated damage by mountain pine beetle between 2002 and 2012, and the leading edge of distribution to 2012 based on areas surveyed annually. Because any one survey unit may be damaged year after year as beetles attack and kill new trees, adding up area damaged per year in severely damaged stands may exceed the actual area of the survey unit—a clear impossibility. A composite variable, the hectare-year (ha-y), corrects for this artifact of annual mapping of damage by area. One ha-y is 1 hectare damaged in one year (1 ha × 1 y). One hundred ha-y could be 100 ha damaged for one year (100 × 1) or 10 ha damaged for 10 years (10 ha × 10 y), etc. Calculations are per 4 km^2 (400 ha) units.

COMPARED WITH FORESTS IN THE BRITISH COLUMBIA INTERIOR, BOREAL FORESTS CONTAIN A HIGH PROPORTION OF LOWER-VOLUME STANDS ALREADY CLOSE TO THE MARGINS OF OPERABILITY FOR COMMERCIAL TIMBER HARVESTING. MPB-RELATED IMPACTS THEREFORE POSE A HIGH RISK TO THE OPERABILITY OF THESE STANDS.

EVIDENCE

- A high proportion of pine stands in boreal forest have stand volumes of less than 40 m^3/ha (Fig. 1).
- Many factors affect operability, but stands with lower volumes have, in general, have less capacity to absorb losses (volume and quality) while remaining operable.

UNCERTAINTY

- Moderate uncertainty because lower volumes are characteristic of the resource in the boreal zone, and flexibility in operability thresholds may exist.

COMMUNITIES ARE VULNERABLE TO THE SOCIOECONOMIC IMPACTS RESULTING FROM MPB. TIMBER SUPPLY IN SOME REGIONS MAY NOT HAVE THE CAPACITY TO ACCOMMODATE MPB-RELATED LOSSES. HOWEVER, THE CURRENT STATE OF OTHER INDUSTRIES (SUCH AS OIL AND GAS) RELATIVE TO THE FOREST SECTOR MAY IMPROVE THE ADAPTIVE CAPACITY OF SOME COMMUNITIES.

EVIDENCE

- Impacts, and therefore vulnerability, will vary. Extent of impacts will depend on realized rates of spread, with more rapid rates of spread increasing vulnerability.
- The degree of socioeconomic impact will depend on local reliance on the forest sector. Alternative employment opportunities may be abundant near the current (2011) leading edge in central Alberta, but considerably lower in the growing forest industry in Saskatchewan.

UNCERTAINTY

- Moderate to high uncertainty because the net impact depends on the timing and severity of the damage, and both of these are unknown.
- Economic impacts are uncertain even where impacts are already evident.

NON-TIMBER IMPACTS FROM MPB WILL BE GREATER IN THE BOREAL PLAIN THAN IN BRITISH COLUMBIA. FOREST MANAGEMENT INTERVENTIONS MAY COME INTO CONFLICT WITH NON-TIMBER VALUES.

EVIDENCE

- Boreal and eastern pine stands are a relatively rich source of non-timber revenue from tourism, recreation and trapping (Table 2 in Nealis and Peter, 2008).
- Hydrological impacts from reduction of pine overstory may be significant (BC Forest Practices Board, 2007).
- Negative impacts and salvage costs can be significant (Lindenmayer et al., 2004).

UNCERTAINTY

- Low uncertainty because of the known relative values of timber vs. non-timber values in the boreal region compared with those in British Columbia.

REGULATORY IMPACTS AND CHANGES TO FIBRE FLOW MAY RESULT FROM MPB ACTIVITY.

EVIDENCE

- In Alberta, stands killed by MPB are subject to a use-it-or-lose-it policy. Forest companies may have their cut redirected if they cannot keep pace with the infestation.
- The transportation infrastructure may not be able to accommodate harvesting response.
- As the transportation, storage and processing of beetle-infested logs become regulated, the costs of these activities will increase.

UNCERTAINTY

- Low uncertainty that there will be impacts, but the ultimate cost of those impacts is unknown.

Risk of fire

THE FREQUENCY OF WILDFIRES IN MPB-AFFECTED STANDS WILL REMAIN THE SAME OR INCREASE SLIGHTLY.

EVIDENCE

- Pine forests are among the most fire-prone forest types. Weather events, especially the frequency of lightning strikes, dominate the frequency of ignitions in pine forests. These are not associated with the effects of MPB.
- Successful ignitions may increase if trees downed because of MPB attack nurture ignitions in kindling caused by dry lightning, spotting from other fires and human activities.
- Coarse woody debris created by MPB-induced fall-down is very dry, even in normally moist sites.
- A disproportionate number of large-area fires have occurred in MPB-affected stands. While only 5% of recent fires in British Columbia occurred in MPB-affected stands, those fires accounted for more than 50% of the area burned.

UNCERTAINTY

- Future frequency of lightning strikes and human-caused ignitions is unknown.
- Observations from the Carrott Lake research site (near Vanderhoof, British Columbia) found no change in the probability of ignition in the early stage of MPB impacts (i.e., presence of red trees), but this may increase as dead, dry material accumulates.

INTENSITY OF FIRE INCREASES AS MPB-AFFECTED TREES DIE, AND IT REMAINS HIGH FOR SEVERAL YEARS.

EVIDENCE

- Recent observations indicate that fires during the red-tree phase are more intense.
- Crown fires in red-phase stands move and grow more rapidly.
- The rate of fire spread in standing, dead trees is slower than in living trees, but intensity is high because of the drier surface conditions resulting from very dry fuel loads.
- The pattern of fire spread is more unpredictable because high-intensity fires create more complex interactions between fuel and atmosphere.
- Moist sites affected by MPB regenerate understory quickly but also dry out quickly.

UNCERTAINTY

- Large fires in British Columbia often occur in pine-dominated stands anyway because pine forests are associated with dry, isolated regions.
- Existing fire process models do not account for changes in wind conditions associated with differences in the forest structure characteristic of the boreal, and so tend to underestimate rates of spread.
- Understanding fire behaviour is hampered by the need to combine observations that occur over broad scales from small, controlled fires to large wildfires.
- Translating MPB-induced change in the risk of fire from lodgepole pine in British Columbia and east slopes to boreal jack pine is tenuous. Jack pine has a higher fire return interval because

such stands have less understory development. These forests dry very quickly; and, in older stands with abundant reindeer moss, the hazard can be very high even in the absence of MPB.

THERE IS A TENDENCY FOR INCREASED RATE OF FIRE SPREAD THROUGH SPOT IGNITION IN MPB-AFFECTED STANDS.

EVIDENCE

- Bark slough and fall-down in MPB-killed trees contribute large woody debris that produces larger embers which can be widely transported by winds. Recent observations estimate transport distances of 3–5 km.
- Ignitions in MPB-affected stands occur more easily than in non-affected stands.

UNCERTAINTY

- Infrequent observations made so far.
- Unsuccessful ignitions are not well documented.

RAPIDLY SPREADING CROWN FIRES MAY BECOME MORE COMMON IN MPB-AFFECTED STANDS.

EVIDENCE

- Severely impacted stands create significant change in dry fuel loads within a very short period of time.
- Dried fine fuels (needles and twigs) remain on trees for several years.
- Regeneration creates potential for "ladder fuels."

UNCERTAINTY

- Depends to a great extent on context and climate. The risk is much reduced in mixed and sparse stands.

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Appendix 1

Workshops and Participants

1. KEY AREAS OF UNCERTAINTY (EDMONTON, 28 SEPTEMBER 2011)

Kathy Bleiker, Natural Resources Canada-Pacific Forestry Centre
Barry Cooke, Natural Resources Canada-Northern Forestry Centre
Tom Hutchinson, Alberta Sustainable Resource Development
David Langor, Natural Resources Canada-Northern Forestry Centre
Erica Lee, Alberta Sustainable Resource Development
Dan Lux, Alberta Sustainable Resource Development
Rory McIntosh, Saskatchewan Ministry of Environment
Vince Nealis, Natural Resources Canada-Pacific Forestry Centre
Tod Ramsfield, Natural Resources Canada-Northern Forestry Centre
Bill Riel, Natural Resources Canada-Pacific Forestry Centre
Steve Taylor, Natural Resources Canada-Pacific Forestry Centre
Mike Undershultz, Alberta Sustainable Resource Development

2. DISPERSAL AND SPREAD (VICTORIA, 23 FEBRUARY 2011)

Kathy Bleiker, Natural Resources Canada-Pacific Forestry Centre
Chris Bone, Natural Resources Canada-Pacific Forestry Centre
Elizabeth Campbell, Natural Resources Canada-Pacific Forestry Centre
Allan Carroll, Univ. British Columbia
Barry Cooke, Natural Resources Canada-Northern Forestry Centre
Andrew Fall, Gowlland Technologies Ltd.
Josie Hughes, University of Toronto
Vince Nealis, Natural Resources Canada-Pacific Forestry Centre
Bill Riel, Natural Resources Canada-Pacific Forestry Centre
Greg Smith, Natural Resources Canada-Pacific Forestry Centre

3. FIRE RISK (TELECONFERENCE, 6 APRIL 2011)

Rebecca Han, Alberta Sustainable Resource Development
Brad Hawkes, Natural Resources Canada-Pacific Forestry Centre
Dana Hicks, British Columbia Ministry of Forests, Lands, and Natural Resource Operations
Chris McGuinty, Alberta Sustainable Resource Development
Colleen Mooney, FPInnovations
Vince Nealis, Natural Resources Canada-Pacific Forestry Centre
Dan Perrakis, British Columbia Ministry of Forests, Lands, and Natural Resource Operations
Mike Pritchard, British Columbia Ministry of Forests, Lands, and Natural Resource Operations
Les Safranyik, Natural Resources Canada-Pacific Forestry Centre
Dave Schroeder, Alberta Sustainable Resource Development

4. RISK ASSESSMENT (VICTORIA, 18–19 OCTOBER 2011)

René Alfaro, Natural Resources Canada-Pacific Forestry Centre
Kathy Bleiker, Natural Resources Canada-Pacific Forestry Centre
Elizabeth Campbell, Natural Resources Canada-Pacific Forestry Centre
Allan Carroll, University of British Columbia
Barry Cooke, Natural Resources Canada-Northern Forestry Centre
Lyle Dinn, Yukon Energy, Mines and Resources
Tim Ebata, British Columbia Ministry of Forests, Lands, and Natural Resource Operations
Andrew Fall, Gowlland Technologies Ltd.
Jacques Gagnon, Natural Resources Canada-Headquarters
Janice Hodge, NFPS Technical Coordinator
Rob Legare, Yukon Energy, Mines and Resources
Eliot McIntire, Natural Resources Canada-Pacific Forestry Centre
Vince Nealis, Natural Resources Canada-Pacific Forestry Centre
Kevin Porter, Natural Resources Canada-Atlantic Forestry Centre
Bill Riel, Natural Resources Canada-Pacific Forestry Centre
Mike UnderShultz, Alberta Sustainable Resource Development
Joanne White, Natural Resources Canada-Pacific Forestry Centre