Forest Health Annual Report

Peace River/High Level Forest Areas

2021

Alberta

Classification: Protected A

Executive Summary

The 2021 annual report provides an update on important factors affecting forest growth and mortality in the Peace River and High Level Forest Areas of northwest Alberta. The main goal is to highlight major insect, disease, and abiotic disturbances occurring throughout 2021.

Aerial survey observations indicate declines in regional mountain pine beetle populations for the fourth consecutive year. Populations have collapsed, and are now in an endemic phase. The immediate threat of further tree mortality from the mountain pine beetle is low.

Spruce beetle populations remain at endemic levels, limiting attack to weakened and dying trees only. Through aerial- and ground-based surveys, we found that while commonly present in mature white spruce stands, spruce beetles were not the primary cause of recent or elevated mortality.

In the High Level Forest Area, spruce budworm-caused defoliation decreased slightly from 2020 levels. It remained moderate in severity and limited to forests east of the town of High Level. Results from a field-based study estimating impacts to spruce health show that while on average just over 50 per cent of current-year growth was defoliated across the study area; top-kill, and mortality remained low.

The aspen serpentine leafminer contributed to an overall increase in area defoliated in the HLFA, while aspen defoliation in the PRFA was reduced in 2021. Aspen health in both forest areas has declined over the past decade as a result of the combined effects of prolonged drought and insect defoliation. Mortality peaked in 2020 with over 80,000 ha recorded, but reduced slightly in both area mapped and severity in 2021.

Notable forest diseases observed in 2021 include a localized outbreak of spruce needle rust north of Manning, as well as minor occurrences of pine needle cast throughout the region. Armillaria root disease remains a factor in balsam fir where mature stands have been affected by drought.

Abiotic factors caused significant mortality both in 2020 and 2021. Areas east of the Peace River affected by the blowdown event of August 2020 were accurately delineated through aerial surveying and satellite imagery interpretation. High amounts of precipitation over the past two years in the High Level Forest Area has caused significant flooding in many low-lying areas.

Effects of the unprecedented extreme heat event in June 2021 are yet to be determined, although reports from across western North America are not encouraging for indicators of forest health. Around the province and locally, early foliage drop in conifers, as well as scorching and wilting of deciduous foliage was observed.

Acknowledgements

The success of the Forest Health program relies on the dedication and support of many individuals. We wish to extend a sincere thank you to everyone that assisted the program in the Peace River and High Level Forest Areas during the 2021 season. This includes numerous individuals and sections within the Government of Alberta: Wildfire Prevention, Operations, Logistics, Dispatch, seasonal Wildfire staff, and Forest Management. Additionally, we wish to thank research project collaborators and staff with the Canadian Forest Service who have been very helpful and available to provide expert advice whenever needed. Thanks to the NAIT Boreal Research Institute for the opportunity to provide information to the public on important forest health issues through excellent event planning and delivery. A special thanks to industry partners and the public for reports on forest pest conditions, assistance with field programs and input on the Forest Health program.

We look forward to working with you in 2022!

For more information on the contents of this report, general forest health inquiries, or to report observations, please contact:

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Cover Photo: spruce budworm defoliation, High Level Forest Area

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Introduction

The broad goal of the forest health program in the Peace River and High Level Forest Areas (PR/HLFA) is to assess and manage impacts from biotic and abiotic forest health disturbance agents on public forest values. Operational aspects of the program, such as bark beetle control programs, are delivered at the regional level, while priority setting and program development is guided by provincial objectives and policies. These align with strategic plans for the ministry of Agriculture, Forestry and Rural Economic Development (AFRED) where forests resources are used sustainably and are resilient to wide scale threats.

The historical focus of the program has been on forest insects and diseases – specifically where populations are prone to periodic outbreaks that cause severe growth loss, canopy dieback and tree mortality. Efforts to understand and monitor the severity of impacts caused by damaging insect and disease agents (e.g. bark beetles) are required continually, and remain a large aspect of the forest health program. In addition to biotic forest disturbances, there is also a need to account for a wide variety of abiotic disturbance agents that are equally threatening to the forest. Factors such as severe weather events (e.g. high winds and extreme heat), fire, periods of drought, and long-term climate trends play a significant role in the regional forest disturbance regime. These factors are similarly recorded and evaluated annually to identify immediate risks and those that operate over longer time periods and predispose forests to other factors.

This annual update intends to provide accurate results of aerial and ground-based surveys of forest health disturbances caused by the following:

- **Biotic disturbance agents:**
    - ***Bark beetles***: mountain pine beetle, spruce beetle, eastern larch beetle, ips species, etc.
    - ***Defoliators***: forest tent caterpillar, bruce spanworm, aspen two-leaf tier, large aspen tortrix, aspen serpentine leafminer, spruce budworm, willow leafminer, etc.
    - ***Diseases***: armillaria root rot, lodgepole pine dwarf mistletoe, needle casts, leaf blights, etc.
    - ***Previously innocuous and alien invasive agents***: gypsy moth, Asian longhorned beetle, emerald ash borer, white pine blister rust, etc.
- **Abiotic disturbance agents:**
    - ***Severe weather events***: short-term events including high winds, hail, frost, snow damage, landslides, etc. The extreme heat event in 2021 is included due its magnitude and potential for impacts to forest health.
    - ***Other weather-related agents***: Short to mid-term, re-occurring weather anomalies resulting in drought, flooding, freeze-thaw cycles, winter desiccation, etc.
    - ***Fire***
    - ***Chemical***: air, soil, and water contamination.

1.0 Aerial Overview Survey

Aerial overview surveys delineate the extent and severity of disturbances caused by biotic and abiotic agents affecting provincial forests. Serving as the primary means of detection, they provide “coarse filter” observations that can trigger further examination of issues through detailed aerial and/or ground assessments.

During aerial overview surveys, forest disturbance is classified according to symptom (e.g. defoliation, mortality), tree species, agent type (e.g. forest tent caterpillar, flooding), and severity (i.e. percent crown affected; percent stems affected). Refer to Appendix 1 for the complete classification structure and types of agents included. Observers digitally sketch-map polygons of affected forest using computer tablets with GIS software and high-quality SPOT imagery (within last five years) displayed at a scale of 1:40,000 – 1:75,000.

Flight lines are pre-determined along lines of latitude or longitude, and adjusted depending on visibility, wind direction, terrain, forest cover type, presence or type of agent, and efficiency. Spacing of flight lines is approximately 10 km, but may decrease where significant issues are detected or more detailed mapping is needed, or increase where forest cover is marginal or unproductive. Ground speed maintained at 100-130 knots and altitude is 1500 to 2500 ft. above ground level. Surveys are conducted using a Cessna 206/210 fixed-wing aircraft based out of Peace River and High Level, with re-fueling locations in Manning, Rainbow Lake and Fort Vermilion.

2021 Aerial Overview Survey Summary

The PRFA was surveyed from July 5 to 8, 2021, requiring 25 hours of flight time. In the HLFA, we flew from July 19 to 26, for a total of 23 hours. Across both forest areas, we covered a distance of roughly 11,000 km. We avoided recent large wildfires, such as the Battle complex and Chuckegg Creek fires that burned in 2019. Additionally, we did not cover some large areas of less productive forest: Chinchaga Wildland Provincial Park along the western boundary of PRFA, Bistcho Lake area of northwest HLFA, and the Yates River/Caribou Mountains in northeast HLFA, for example. Otherwise, regional coverage of forested areas was reasonably thorough in both the green and white zones (Fig.1). Despite one postponement in the HLFA due to smoke, weather and visibility, conditions were suitable and consistent throughout the duration of the 2021 aerial overview survey.

A variety of forest health disturbances were recorded throughout the PR/HLFA in 2021, Figure 2 displays the major ones in terms of area affected. Aspen defoliation and mortality made up the majority of forest health-related disturbance in both forest areas. Dieback of willow was widespread and spruce defoliation from spruce budworm was common in the HLFA. Mortality in both spruce and mixed wood forests due to flooding was also a factor in the HLFA in 2021.

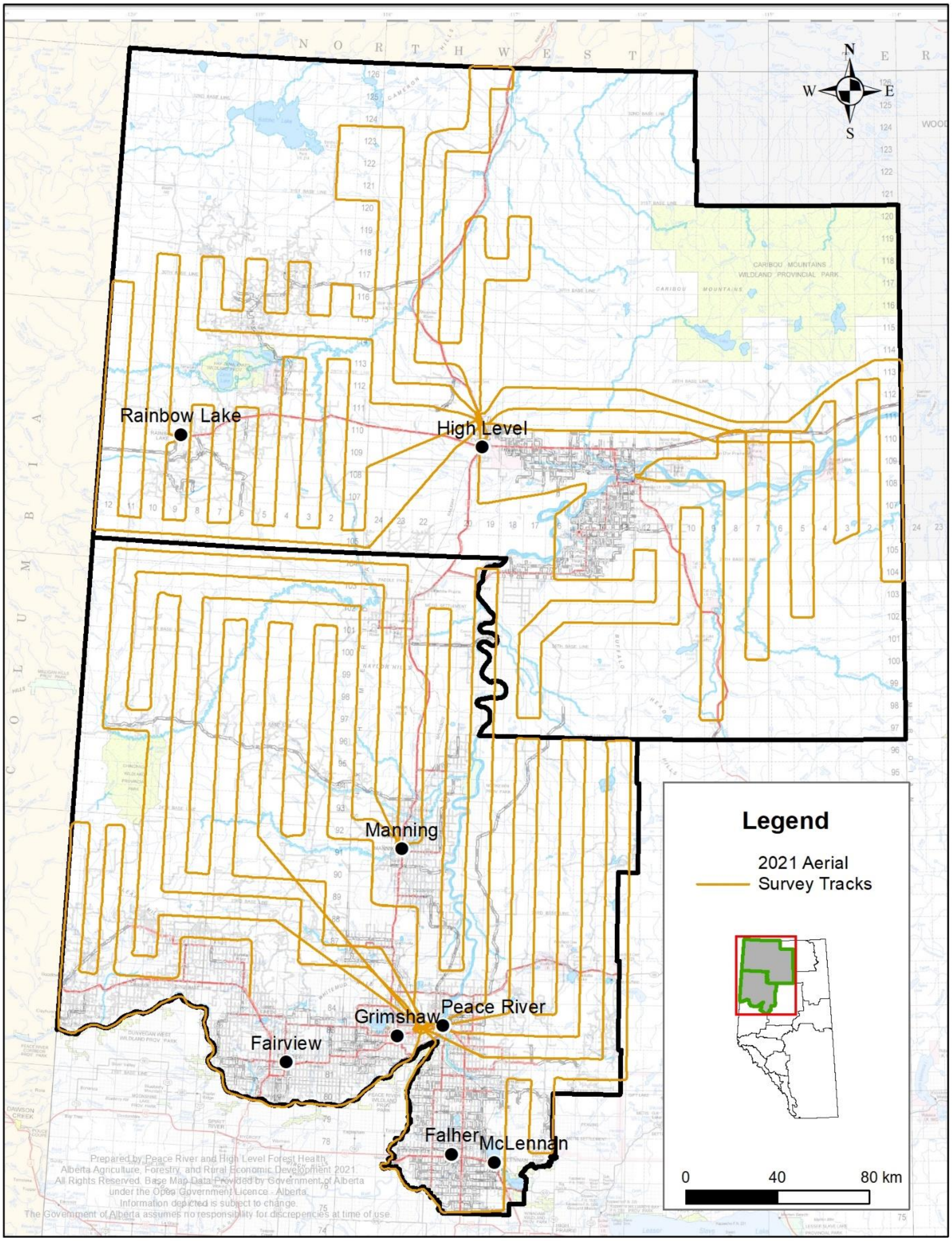

Figure 1. Aerial overview survey coverage in the Peace River and High Level Forest Areas, July 2021.

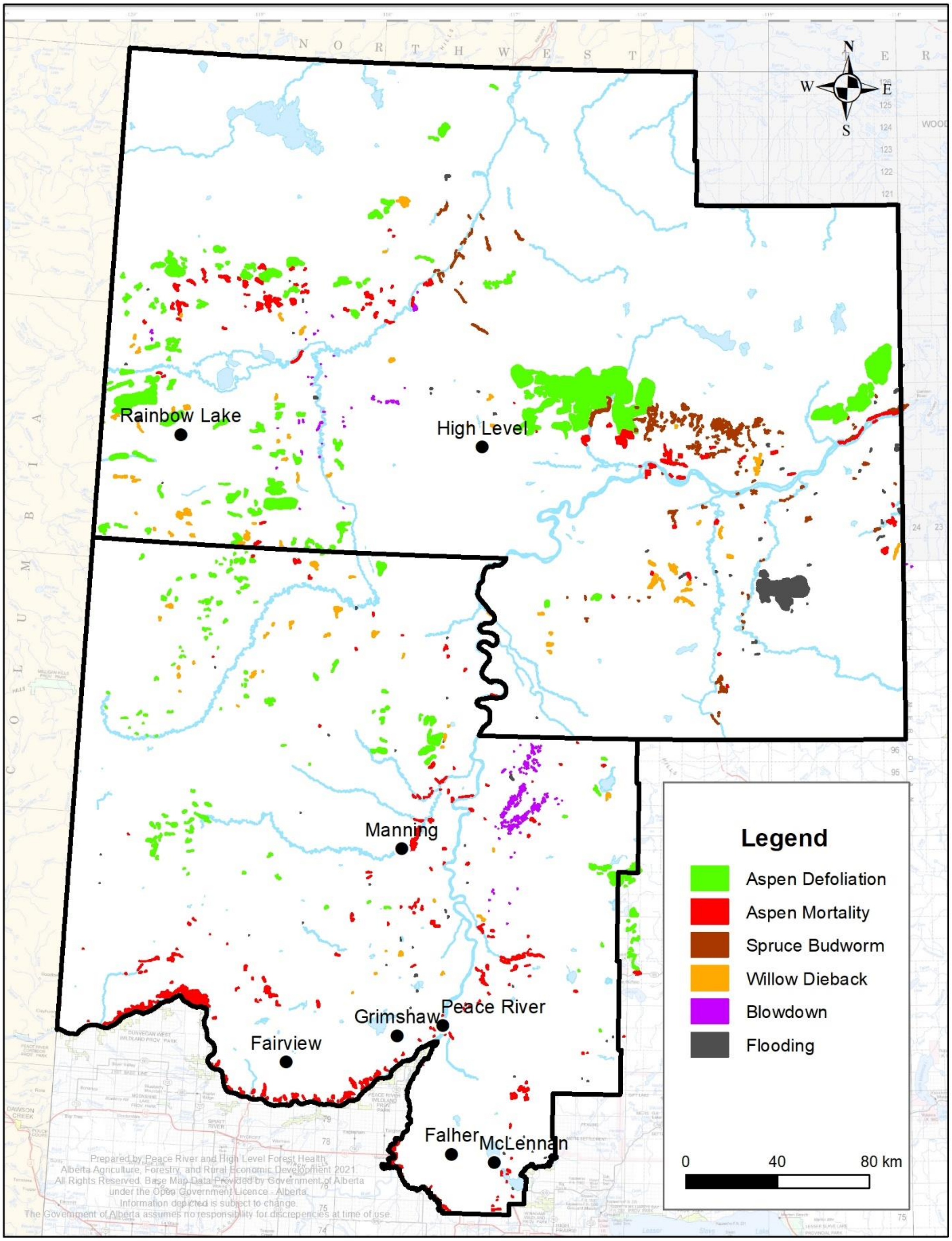

Figure 2. Major forest health disturbances in the Peace River and High Level Forest Areas, July 2021

2.0 Biotic Disturbance Agents

2.1 Bark Beetles

Bark beetles have the potential for rapid, exponential population growth under favourable forest and climatic conditions. When this occurs, they have the ability to overcome trees defenses and cause large-scale mortality in a short time period. For these reasons, they can create an immediate risk to forest values. Although a wide diversity of bark beetles occur in Alberta, this update only includes three major bark beetles in the PR/HLFA: mountain pine beetle, spruce beetle, and eastern larch beetle. Other bark beetle species such as *Ips spp.* and wood-boring insects are considered less capable of causing tree mortality and are not currently being monitored.

2.1.1 Mountain Pine Beetle | *Dendroctonus ponderosae*

Since the introduction of mountain pine beetle (MPB) into the PR/HLFA through massive inflight in 2006, and to a larger extent in 2009, large volumes of lodgepole and lodgepole/jack hybrid pine have been killed. Nearly all mature forests with a pine overstory component have been affected to some degree. MPB populations peaked in the region in 2009-12, stabilized in 2013-14, and have been steadily declining since.

In absence of a level 1 (cut and burn) MPB control program in the PR/HLFA, heli-gps surveys of red trees has not occurred for nearly a decade. We now use a more coarse approach during the aerial overview survey to classifying red trees on the landscape. As well, infested trees no longer occur with enough frequency in the PR/HLFA, even when considering remotely accessed sites, to support detailed ground surveys that more accurately measure population productivity. This includes r-value, green to red, and flight monitoring surveys that were used widely in the region during the outbreak.

"Hot spot" mapping is a MPB monitoring technique devised within PR/HLFA to identify areas where MPB populations remain active. This technique helps identify active MPB populations late in the outbreak as well as areas where they may be expected to persist. It is a coarse evaluation at the quarter township scale considering density and occurrence of red pine trees in townships where pine made up at least 20 per cent of the forest composition. Red tree observations in July represent trees killed by MPB during the previous summer.

Each township quadrant was assigned a hot-spot value as follows:

- **0**: no red trees observed
- **1**: 1-10 single red trees present, no clusters
- **2**: 1-5 clusters of up to five red trees
- **3**: 6-15 clusters, clusters enlarging to greater than five red trees
- **4**: greater than 15 clusters of trees, extensive coalescence of large clusters

Mountain Pine Beetle Status Update

In 2021, hot spot mapping for MPB took place during the aerial overview survey in July. Of the 877 township quadrants surveyed in 2021, 99 per cent had no red trees observed (value of 0), and 1 per cent had 1-10 red trees (value of 1; Fig. 3). Similar to 2020, MPB activity across the region declined drastically with mortality limited to single tree events. The distribution of pine trees with red or fading crowns was scattered in the region.

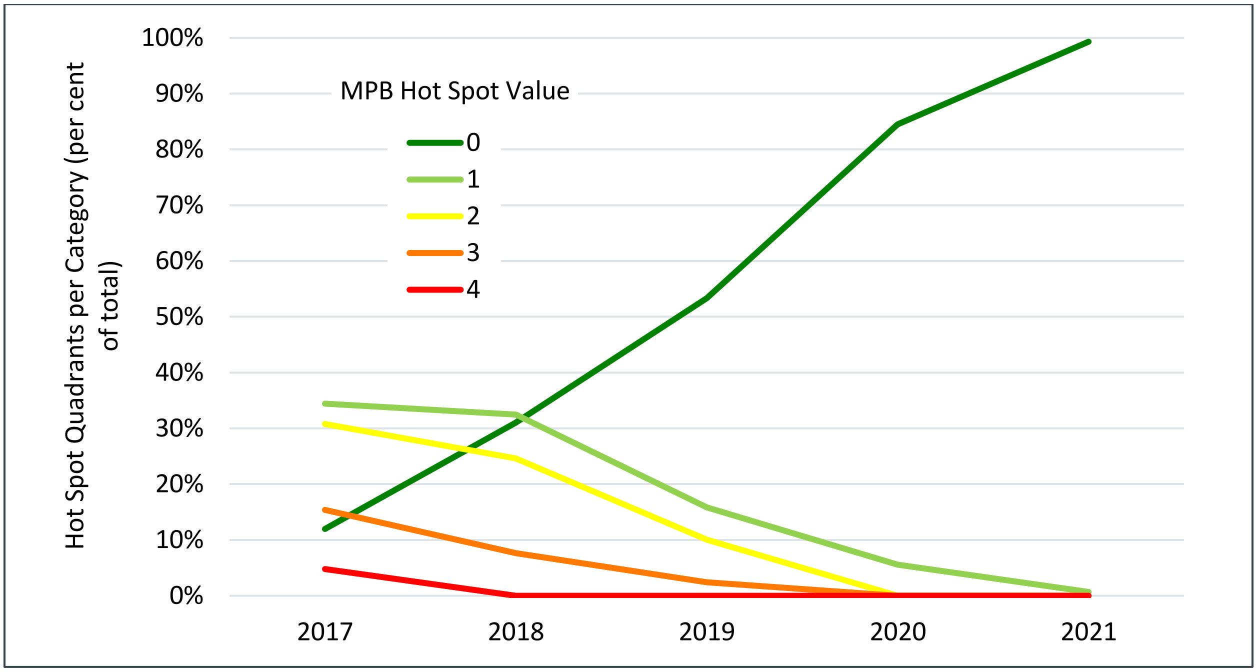

Figure 3. Proportion of total township quadrants (*n*=877) assigned a mountain pine beetle hot spot value from 2017-2021 in the Peace River and High Level Forest Areas.

With fewer than 20 pine trees with fading or red foliage observed in 2021, and the vast majority of pine forests exhibiting no MPB attack, MPB populations are considered collapsed in the PR/HLFA. Lack of suitable pine, increased chemical defense in surviving trees, recent cold winters, and a number of other factors make a sudden increase in MPB populations extremely unlikely in the near future. Further threat of inflight from BC or elsewhere is not a concern at this time.

The outlook for MPB now expands in temporal scale, with risk to forests no longer being immediate. As populations have shifted to an endemic phase, it will be interesting to see if they are able to persist in northwest Alberta. Susceptible pine will be monitored to detect future MPB population growth and dispersal baiting may be used to determine long-term presence in the region. Salvage harvest of grey-stage pine from the peak years of MPB attack (2009-12) remains an option while wood is of acceptable quality. A range of ecological consequences and trajectories occur in MPB-killed stands depending on whether they are replanted, burned, or left to regenerate without further disturbance. Opportunities to recover impacted pine ecosystems exist through integrating knowledge of MPB impacts, wildfire behavior and wildfire management strategies.

2.1.2 Spruce Beetle | *Dendroctonus rufipennis*

Considering the ongoing spruce beetle outbreak across vast portions of northeast British Columbia, there is a heightened awareness of spruce beetle populations in the PR/HLFA, and factors that both regulate and promote them. Although few reports of regional spruce beetle activity exist in historic records, it is clear that spruce beetles are ubiquitous in the region and prone to infrequent, isolated outbreaks. Population increases are most commonly linked to a buildup of hazard (e.g. over-mature forest) and damaging weather events (e.g. blowdown) that allow beetles a brief opportunity to increase production. As well, impacts of changing climate conditions may weaken spruce tree defenses, predisposing them to spruce beetles attack. Rather than the leading edge, wave-like scenario of MPB spread, spruce beetles have been known to build within stands, concurrently across broad areas, and move into surrounding stands at a comparatively slow rate.

In 1983, over 1,500 hectares of spruce in the Footner forest suffered a reported 70 per cent mortality from spruce beetles.

Spruce stands identified during the aerial overview survey containing elevated and/or recent mortality are prioritized for follow-up. A detailed aerial survey with either helicopter or remotely piloted aircraft system (RPAS) can then provide an estimate of the proportion of recent (last three years approx.) and old (more than three years previous) mortality and how it is distributed within the affected stand. If possible, a detailed ground survey is recommended to further confirm aerial classifications of severity and causal agents. Based on protocols developed by BC Ministry of Forests, Lands and Natural Resource Operations, *walkthrough surveys* provided initial estimates of the extent and severity of recent attacks. If recent damage from spruce beetles is estimated to be greater than five per cent of a stand, a transect, or *probe survey* can be established to gain a more accurate estimate of mortality. This systematic method gives a measure of population productivity by comparing the last three years of activity, and facilitates life cycle assessments in mass attacked trees.

Spruce Beetle Status Update

To provide a detailed stand-level assessment of recent damage caused by spruce beetles, ground-based surveys took place in the fall/winter of 2021-22. Although walkthrough surveys were completed, no probe transects were deemed necessary as recent mortality caused by spruce beetles was estimated to be less than 1per cent in all cases. Spruce beetles were commonly present in the surveyed stands (Fig. 4), but they did not play a primary factor in the majority of recently killed trees examined. In these stands, spruce beetles were behaving as expected in an endemic population phase, utilizing trees with weakened defense capabilities. No other obvious agents were associated, and it is assumed that mortality occurring at these sites, and others similar, is linked to factors such as age, aspect, and slope, that predispose them to climate-related stressors.

Figure 4. Adult spruce beetle, Notikewin tower road, Peace River Forest Area, May 2021.

Life cycle duration is a critical factor regulating spruce beetle populations across their range since they are capable of developing to maturity in either one or two years depending on environmental conditions. To become reproductively viable, unlike MPB, spruce beetles must overwinter for at least one season as adults (Fig. 5). Ground surveys performed in winter help determine life cycle duration based on the proportion of larvae to adults. With the sparse availability of mass-attacked spruce trees however, samples are difficult to obtain in the PR/HLFA. This was the case in 2021, where mass attacked trees facilitating life cycle sampling were too infrequent to draw conclusions from. Since development is related closely to temperature, sampling would need to be effective on an annual basis to get an indication of the temperature threshold that facilitates a shift in life cycle duration and the influence on populations.

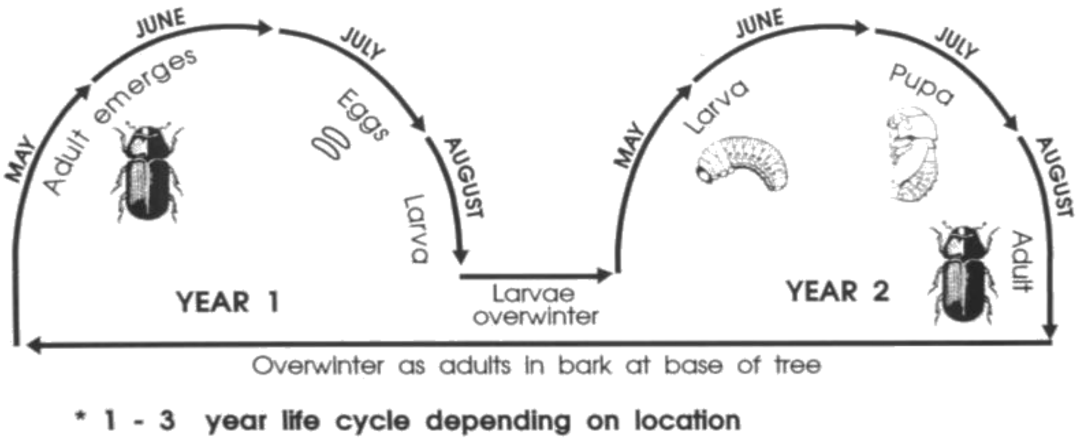

Figure 5. Diagram of typical two-year spruce beetle life cycle.

Through survey efforts over the past five years and increased knowledge of regional spruce beetle populations, it is evident that spruce beetles remain in an endemic population phase – residing in ephemeral downed or stressed material. In this case, beetles are acting as secondary agents in the forest and their ability to mass-attack otherwise healthy trees is low. However, as spruce beetles are ubiquitously spread across the PR/HLFA, and climate may promote increased productivity, it is critical that changes in populations and resulting impacts are adequately monitored.

The stand- and landscape-level susceptibility of forests to spruce beetles is becoming more defined in the PR/HLFA through aerial and ground-based surveys. The application of a recently-developed stand susceptibility index (SSI) is also a useful aid in determining areas of high hazard. This knowledge is helpful in guiding future survey and assessment as well as forest management planning. Combining estimates of hazard with beetle population parameters will support a greater awareness of risk to regional forests.

2.1.3 Eastern Larch Beetle | *Dendroctonus simplex*

Another bark beetle in the genus Dendroctonus that carries potential for eruptive populations is the eastern larch beetle. They are native to the region and attack in a similar manner to MPB and spruce beetle, with a preference for mature trees that offer greater nutritional value, increased brood production, and protection against cold temperatures. Tamarack is relatively infrequent compared to other tree species in the PR/HLFA, and pure tamarack/tamarack-leading stands do not make up a large proportion of the forest composition. Since eastern larch beetles are limited to tamarack, they are likewise scattered in their distribution and constrained to a degree in their ability to reach outbreak levels. Perhaps owing to these challenges posed on the insect and the difficulty to detect beetle activity during aerial overview surveys, previous damage has not been extensive and few reports of disturbance from eastern larch beetle exist in the northwest.

Eastern Larch Beetle Status Update

One particular area of interest in terms of eastern larch beetle potential is the Machesis Lake area in the Forest Management Unit F11. Topography in this area of the HLFA is unique, consisting of wetland areas interspersed with mounds of coarse, sandy mineral soil deposits. The forest composition is also unique - wetlands are bordered by tamarack forests, while uplands consist of an aspen/jackpine mix (Fig. 6). In low-lying areas, organic soils occur, and where less saturated, tamarack stands become dense and pure, providing an opportunity for the persistence of eastern larch beetle.

During a ground survey in 2021, mature tamarack trees were found to be killed in the last five years by eastern larch beetles near the Machesis Lake municipal campsite. The full extent of damage is yet to be mapped since the area was largely avoided during aerial overview surveys in recent years because of the Chuckegg wildfire. While this fire burned over much of the forest cover in the area, the remaining live forests directly to the east of the fire may be at risk to eastern larch beetle attack and will be closely monitored in the future. In 2022, the goal is to determine the extent and severity of attack through aerial and ground survey methods similar to those used to monitor spruce beetle.

Figure 6. Example of forest composition in the Machesis Lake area, High Level Forest Area. Tamarack is distinguished in this photo as yellow-gold in colour. Photo taken October, 2018.

2.2 Defoliators

Defoliators of broadleaf and conifer trees reduce growth and can result in canopy dieback and mortality if damage is severe and prolonged. When occurring in times of reduced health from other factors, defoliation is particularly harmful. Insect defoliator populations are cyclical and eruptive at times across the PR/HLFA, resulting in broad-scale defoliation.

2.2.1 Spruce Budworm | *Choristoneura fumiferana*

Spruce budworm (SBW) populations in northwest Alberta have a long history of periodic outbreak. Records dating back to the early 1950's include high populations in the HLFA in the mid 1960's, and into the 70's. Most notable is the outbreak of the late 1990's - 2000's where significant impacts, including growth loss, top-kill (Fig. 7), and tree mortality to spruce health were observed in the region. While localized increases have been recorded in the Hawk Hills area of the PRFA, the vast majority of activity has been in the HLFA. On the west side of that region, SBW has persisted where dense spruce-dominant forests occur along the Chinchaga, Hay, and Steen Rivers. Southeast of High Level, roughly where the Muddy River and Senex Creek meet the Wabasca River, high SBW populations were observed concurrent with outbreaks on the west side.

Figure 7. Example of top-kill in white spruce caused by spruce budworm, John D'or Prairie area, High Level Forest Area, August 2021.

In addition to historical information on SBW population monitoring, biology, and phenology, a number of assessments have been carried out to quantify impacts on forest values in order to support timber management objectives. Not all of this information is publicly available or peer-reviewed. Results from past studies demonstrate variable levels of canopy dieback and tree mortality. However, some research did not clearly specify the duration and severity of defoliation prior to sampling. While information obtained has been accurate and valuable, there are uncertainties in basing current assessments of impacts on available historic information. Considering the dynamics of climate, pest, and forest conditions, it is important to re-evaluate impacts from SBW defoliation periodically.

Spruce Budworm Status Update

In 2021, defoliation caused by SBW was recorded in the HLFA during the aerial overview survey from July 19 to 26. A total of 21,900 ha of moderate (35 to 70 per cent crown affected) and 500 ha of severe (70 - 100 per cent crown affected) defoliation were mapped in 2021. This represents a slight decrease in area defoliated from 2020. The total area of spruce forest affected by SBW remains low relative to historic outbreak levels in the HLFA.

The extent of SBW defoliation was similar to 2020, with the majority occurring on the east side of the HLFA and Forest Management Unit (FMU) F26. New (i.e. first year) defoliation was recorded along the Wabasca at its confluence with South and North Senex Creeks. Defoliation was mapped in mature spruce along the Hay, Meander, Melvin, and Steen Rivers, and some nearby tributaries. Core historic areas west of the town of High Level remain largely unaffected as they have since 2018.

While the duration of SBW defoliation continues to increase in the active SBW area east of High Level, the majority of affected stands have been moderately defoliated for less than three years in a row as of 2021 (Fig. 8). Three to five years of consecutive defoliation have occurred in stands north of John D'or Prarie and Beaver Ranch Indian Reserve, and along the Ponton and Caribou Rivers (Fig. 9). In 2021, no stands had experienced SBW defoliation for greater than five years.

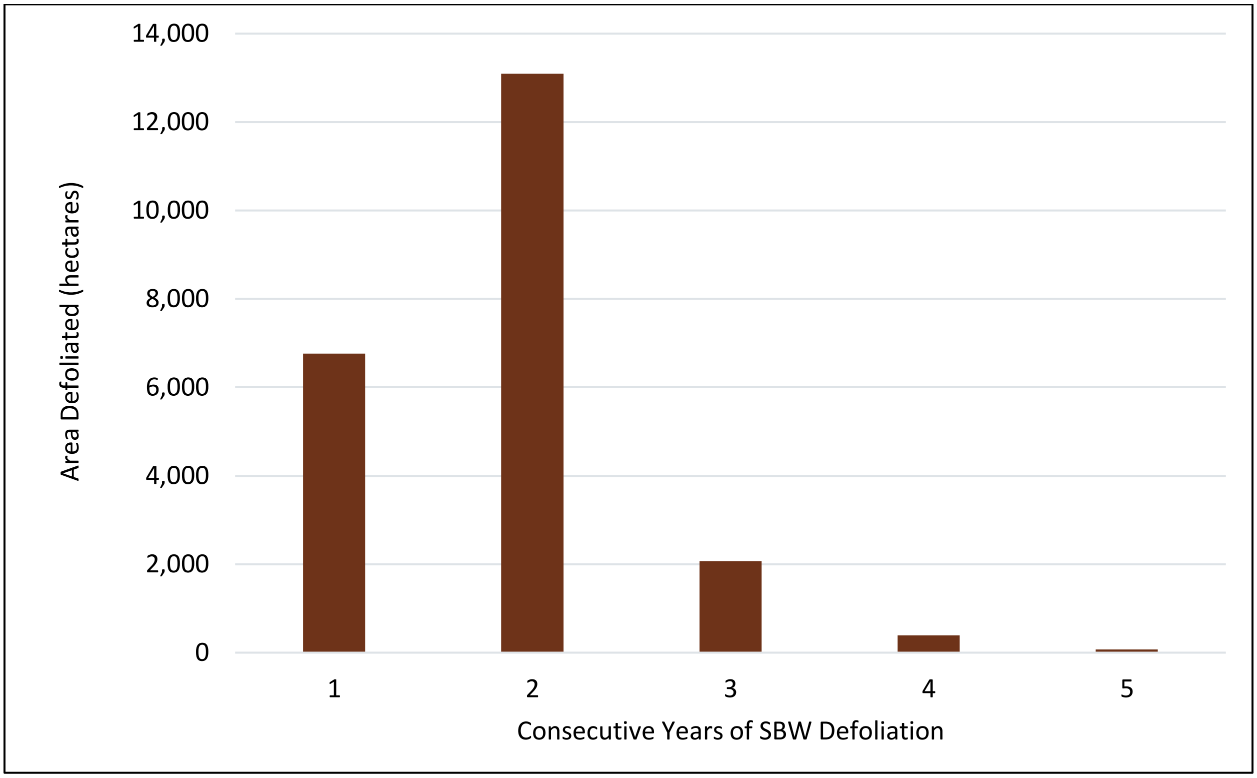

Figure 8. Area of spruce budworm defoliation per consecutive year category in the High Level Forest Area, current to 2021.

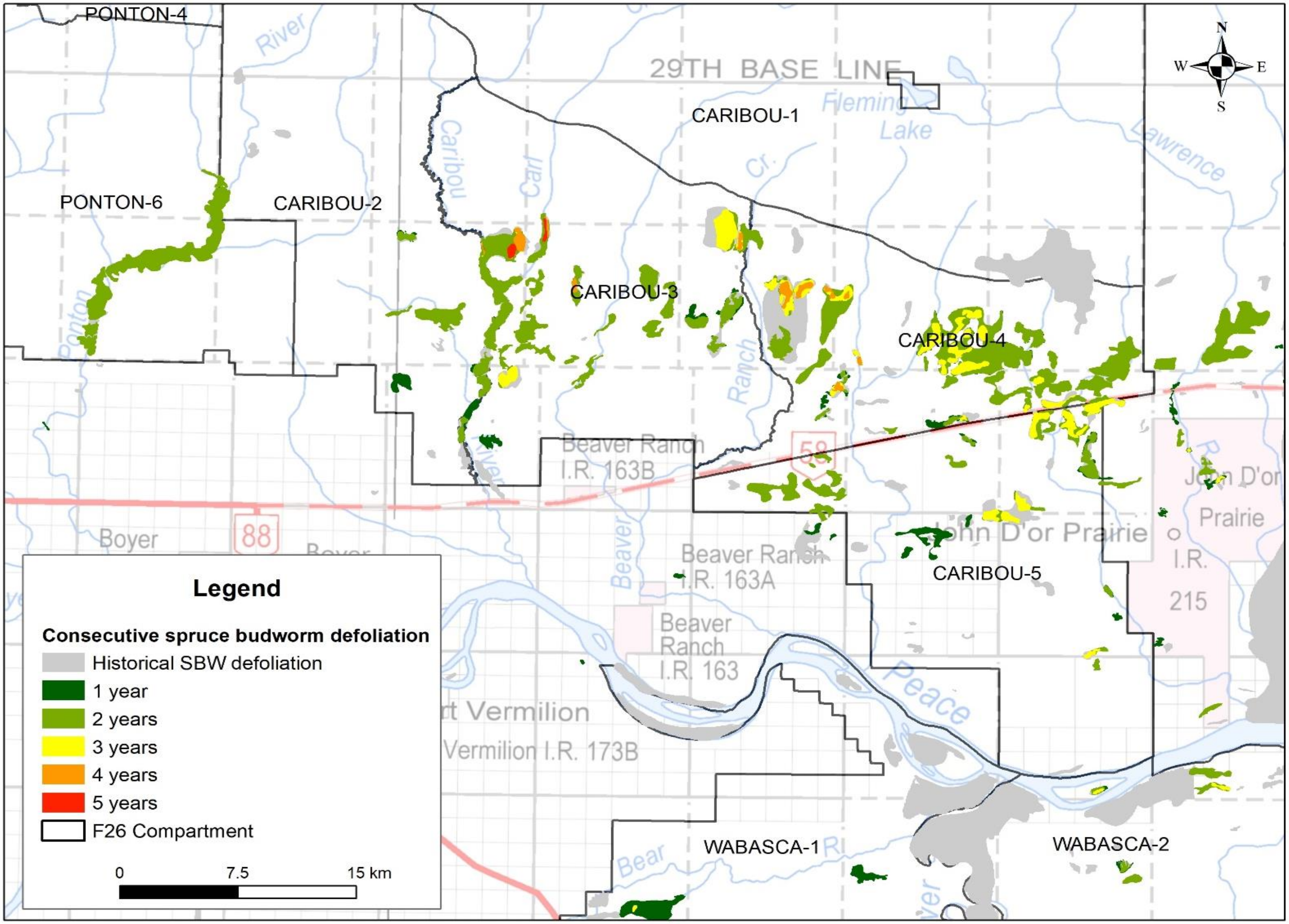

Figure 9. Cumulative years of spruce budworm caused defoliation (from 2021 backward) and historical defoliation in the last 10 years; Beaver Ranch/John D'or Prairie area, High Level Forest Area.

2.2.2 Spruce Budworm Impact Assessment 2021

To assess current impacts of SBW-caused defoliation on spruce health at the tree and stand-levels within FMU F26, a research collaboration was initiated with Tolko and AFRED in August of 2021. This study was supported by funds administered through the Forest Resource Improvement Program (FRIP) and aimed to provide information on the following factors related to spruce tree health:

1. Defoliation of current-year growth
2. Cumulative/total defoliation
3. Levels of canopy dieback (top-kill)
4. Levels of mortality
5. The influence of consecutive annual defoliation on above factors

Site selection criteria included stand age, species composition, density, slope, elevation, distance to access, and number of consecutive years of spruce budworm defoliation. Two variable-length transects were established at each site and included a minimum of 10 white spruce trees greater than 10 cm in diameter. Ocular assessments of percent of needles defoliated in both current and previous year's growth were completed over the top 40 per cent of each tree, representing the live crown. Also included was an estimate of percent top-kill and tree health status (i.e., dead or alive).

In August 2021, 1,774 trees were sampled at 51 sites east of High Level. Of these, 57 per cent were within stands where defoliation was recorded for zero to two consecutive years during the aerial overview survey, and 43 per cent were in stands classified as defoliated for three or more years. Results indicate that while levels of both current-year and cumulative defoliation varied widely in sampled trees, there was no significant difference at the site level when considering the number of years of consecutive defoliation (Table 2). Top-kill and mortality levels were low, and likewise did not significantly change at sites defoliated for three or more years.

Table 2. Summary of results from spruce budworm impact assessment, August 2021. Sample size represents number of trees assessed within each consecutive defoliation category.

Spruce Health Factor	Number of years of consecutive SBW defoliation					
	0 (*n*=432)	**1** (*n*=215)	**2** (*n*=116)	**3** (*n*=545)	**4** (*n*=169)	**5** (*n*=55)
Current year defoliation (average)	61%	54%	55%	53%	47%	39%
Cumulative defoliation (average)	36%	34%	35%	28%	28%	21%
Canopy dieback (average)	0.7%	0.3%	1.6%	5.1%	1.9%	0%
Percent of trees alive	85%	90%	85%	86%	87%	85%

While SBW defoliation was common across the study area, the overall impacts on tree health at the time of sampling were relatively low. Based on previous information however, it is expected that impacts are delayed and likely to increase to some degree if SBW feeding continues into the future. The impact in terms of growth loss was not measured in this study.

Due to the difficulty of accurately determining the time of tree death without permanent sampling, estimates of mortality levels do not represent annual rates of mortality. Mortality data obtained in this study cannot be compared to background rates, or to a natural range of variability obtained through PSPs or other methods. Under investigation in this study was rather the effect of repeated SBW defoliation on spruce health within the study area. A full technical report on the 2021 spruce budworm impact assessment is available.

2.2.3 Aspen Defoliators

Based on aerial overview survey data, aspen defoliation roughly doubled over 2020 levels. A total of 234,000 ha were recorded in 2021 in the PR/HLFA. Aspen serpentine leafminer (*Phylloocnistis populiella*) accounted for 85 per cent of the area defoliated, while 15 per cent was attributed to a “complex” of multiple insects that feed on aspen leaves, generally causing greater damage. The overall area affected remains low in comparison to previous years (Fig. 10) when periodic forest tent caterpillar (*Malacosoma disstria*) outbreaks occurred. Aspen defoliation caused by the forest tent caterpillar was not detected during the aerial survey in 2021.

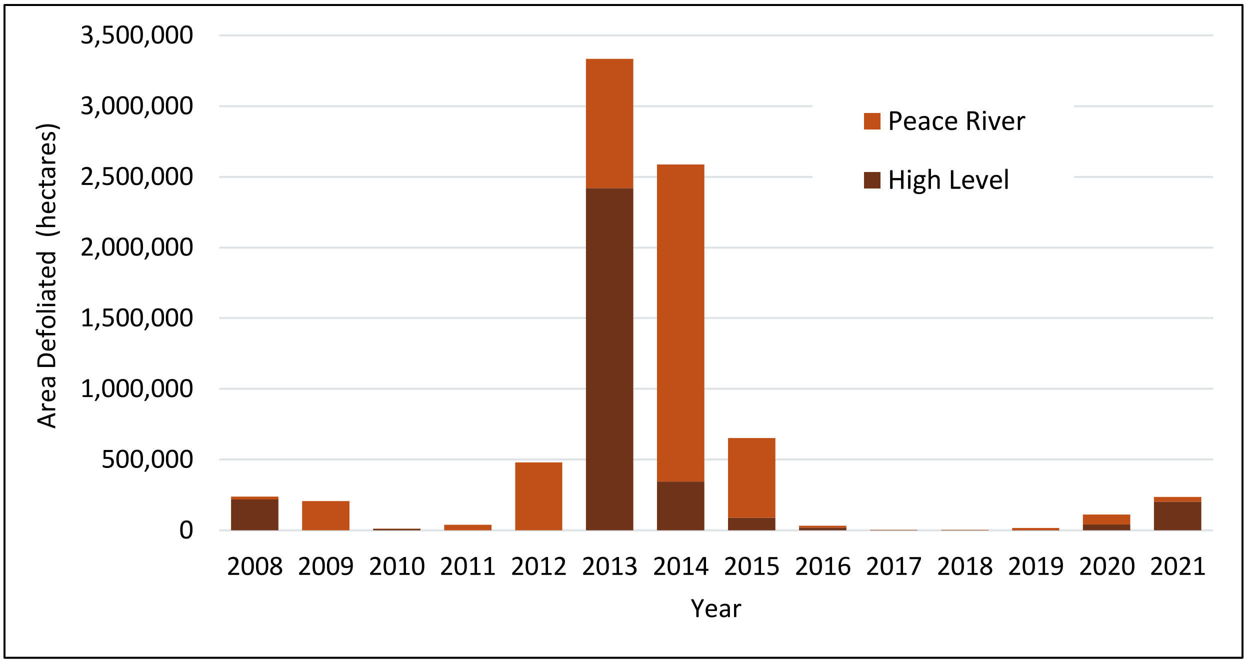

Figure 10. Area of recorded insect-caused aspen defoliation in the Peace River and High Level Forest Areas from 2012 to 2021.

Most of the recorded aspen defoliation in 2021 was in the HLFA where the aspen serpentine leafminer was widespread. While common in low abundance at most sites in both regions, severe infestations of this insect were limited to the HLFA. This insect, a moth with a wingspan of only five mm in its adult form, feeds as larvae between leaf surfaces, constructing a distinct serpentine-shaped mine (Fig. 11A). This gives a grey or white appearance to the foliage, which is conspicuous when looked at from a close distance on the ground, but only visible to aerial observers when damage is severe or on the high end of the moderate category (i.e., 60 to 70 per cent defoliation). As a result, nearly two-thirds of the defoliation from the leafminer was classified as severe. Small pockets of aspen serpentine leafminer have been recorded over the past five years and widespread outbreaks have been reported over the past decade in the Northwest Territories and Yukon. While photosynthesis is impaired, significant growth loss and damage to trees is expected to be low, based on supporting information. However, if climate and forest conditions extend the duration of outbreaks, impacts from the aspen serpentine leafminer may be significant.

In contrast to the HLFA, defoliation was reduced by about half in the PRFA to a total of 33,000 ha in 2021, the majority caused by multiple insects. Bruce spanworm (*Operophtera bruceata*), aspen two-leaf tier (*Enargia decolor*), and aspen leaf-roller (*Pseudexentera oregonana*) made up the complex of defoliator species observed from the air and found at ground survey locations across both forest areas. They were present in varying proportions with symptoms of the aspen two-leaf tier usually the most abundant on branch samples (Fig. 11B). Despite multiple defoliating insects found in the same aspen canopies, nearly all of the aerial observations of aspen defoliator complex were classified as moderate in severity with less than 70 per cent of foliage being affected. Individually, these agents are not known to cause significant impacts to aspen health due to the short duration of historic outbreaks and incomplete feeding. Damage to foliage from more than one agent can have a cumulative effect, reducing a tree's ability to defend and recover from attack. Reduced health of aspen forests from other factors makes them less resilient to the impacts of defoliating insects.

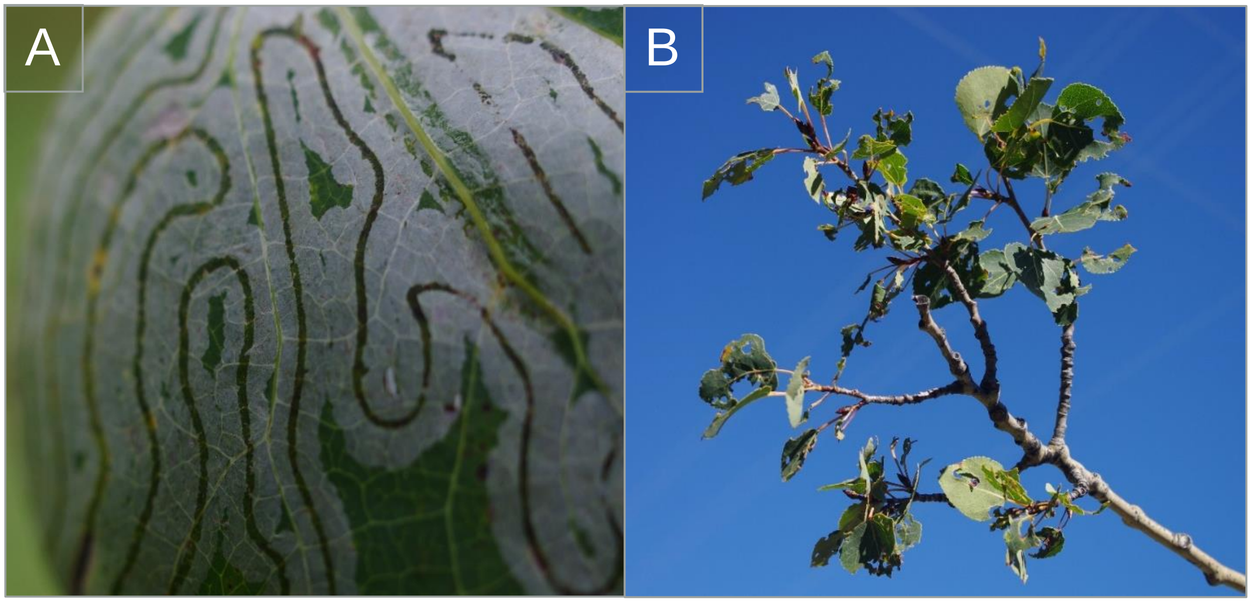

Figure 11. Examples of aspen defoliation caused by: A) aspen serpentine leafminer, Chinchaga forestry road; and B) multiple insects, near Twin Lakes, Peace River Forest Area, August 2021.

2.2.4 Willow Leafminer | *Micrurapteryx salicifoliella*

Following a prolonged period of foliar damage in willow species caused primarily by the willow leafminer, branch dieback has been widespread in the PR/HLFA. In total just over 20,000 ha of willow dieback was mapped in 2021. About 30 per cent of the willow in mapped polygons was affected in most cases, resulting in a grey appearance when viewed from an aircraft. Despite the large area affected, this is less than half of the dieback mapped in 2020. Ground surveys determined that leafminers were either not present in areas of dieback or found with very low frequency. This is the case for two consecutive years, indicating a potential collapse in leafminer populations. Recovery of willow is expected to be fairly rapid considering their growth form and ability to regrow from the base or roots. Impacts to wildlife are not known but it is expected that ungulate species that utilize browse as a portion of their diet, nesting songbirds, and insect communities, for example, have been affected.

2.3 Other Biotic Disturbance Agents

2.3.1 Sequoia Pitch Moth | *Synanthedon sequioa*

At the North Star pine and spruce clonal seed orchards, a sequoia pitch moth infestation is occurring with potential of significant loss to the orchard. Protection measures that were put in place in 2020 to reduce the population and damage at the site consisted of a grid-based network of traps baited with pheromones to lure male moths in search of a mate and prevent reproduction. These measures were also taken in 2021, with a total of 42 traps deployed in both the pine and spruce orchards. A subset of 12 traps were checked weekly to monitor flight period. No moths were captured in these traps at any point of the year. Less than ten pitch moths were incidentally detected in traps that were not part of weekly checks. Since this moth requires two years to complete its development, and no moths were captured in 2020, the cause of low catch rates in 2021 is not well understood. While lures have shown effectiveness in other areas (e.g., southern BC), it is possible that individuals in northwest Alberta do not respond to the lures as effectively. Climate may also have limited their emergence and flight again in 2021. A more detailed health assessment of pitch moth attack was completed in 2021 to help determine if new attacks are occurring and trees will be checked thoroughly in 2022.

2.3.2 Animal Damage

Forest damage caused by animals is very common and widespread in the PR/HLFA, but does not usually result in significant tree mortality. Several examples exist: woodpeckers, bears, beavers, porcupines, ungulates, rodents, snowshoe hares, and squirrels all can have a negative effect on tree health. Through feeding, climbing, rubbing, marking, and indirect damage (e.g. flooding due to beaver dams), they leave unique and diagnosable symptoms behind. No major animal damage was recorded in 2021.

2.4 Alien Invasive Forest Insect Species Monitoring

Alien invasive forest insects that are not currently found in the PR/HLFA have potential for introduction due to changing environmental or host conditions. Many of these insects are known to be particularly destructive in novel habitats where host tree species have not adapted to defend attack and native predators are not effective at regulating populations. No alien invasive forest insects were found or reported in the PR/HLFA in 2021.

2.4.1 LDD (Gypsy) Moth | *Lymantria dispar dispar*

The LDD moth, formerly referred to as gypsy moth, is a non-native defoliator of deciduous trees which is regulated by the Canadian Food Inspection Agency (CFIA) across Canada. Introduced to eastern North America on shipping materials in the 1860's, it has since expanded its range to the west. Annual surveys target the capture of adult male moths in areas where transport and occurrence is most likely, such as railway yards and provincial campsites.

No LDD moths have been detected in the PR/HLFA since monitoring began in 2009, however epidemic populations of the insect are currently causing significant damage to broadleaf trees in eastern Canada and the United States. Since 2013, there have been repeated low numbers of LDD moth detections (i.e., two or less) in Alberta. Starting in 2019 however, trap catches have increased every year with the majority of individuals being caught in the City of Calgary. In 2021, eight traps had positive catches for a total of 11 adult moths identified as LDD. Edmonton, Jasper, and the Porcupine Hills also recorded a few LDD moths in traps. Trapping efforts have increased in these jurisdictions in response. If numbers continue to increase and evidence of reproduction exists, management actions to eradicate LDD moth must be taken. Actions are guided through the Alberta Critical Plant Pest Infestation Response, which defines a cooperative approach for provincial and federal government responsibilities.

LDD moth traps were deployed at six locations in PRFA area in 2021: Twin Lakes Provincial Recreation area, Manning grain elevator, Figure Eight Lake Provincial Recreation Area, Queen Elizabeth Provincial Park, CN rail yard near Grimshaw, and Falher rail yard. The time period for trapping was June 5 to September 26. No gypsy moths were captured. Data were submitted to the CFIA.

2.4.2 Other Alien Invasive Forest Insects

Emerald ash borer (*Agrilus planipennis*) is a small metallic wood-boring beetle native to eastern Asia and introduced to North America in the 1990's. This insect is closely related to the native bronze birch borer (*Agrilus anxious*) and bronze poplar borer (*Agrilus liragus*) and can cause severe mortality of ash trees, particularly in urban centers. Winnipeg, Manitoba is the closest known population of emerald ash borer to Alberta. A recent study using emerald ash borers sourced from Winnipeg revealed that these insects are very cold tolerant, with larvae surviving temperatures as low as -52°C. This suggests that Alberta would be climatically suitable for the highly invasive emerald ash borer.

Asian longhorn beetle (*Anoplophora glabripennis*) is a woodborer that has the potential to cause immense damage to deciduous tree species. In the past, damage has been limited to urban plantings of maple, ash and elm. Since the isolated case involving a single individual emerging from a pallet in an Edmonton warehouse in 2019, no other beetles have been detected in Alberta. Federal, Provincial, and Municipal agencies have worked to eradicate known occurrences of this insect within Canada, including the last known reproducing population in Ontario in 2013. After five years of no detection in urban areas, restrictions preventing the movement of firewood were lifted, because it appears the pest has been eradicated.

2.5 Forest Diseases

2.5.1 Spruce Needle Rust | *Chrysomyxa ledicola*

Spruce needle rust is a fungal pathogen that infects current year needles, resulting in discoloration and appearance of small dot-like fruiting structures (Fig. 12). Infected needles are likely to dry out and drop off. Infection can be severe, however it is reported that heavy infections seldom occur in successive years and that impacts to tree health are minimal and not widespread. Wet summers provide optimal conditions for the development and spread of fungal spores, which require the presence of Labrador Tea (*Ledum* Groenlandicum) as an alternate host. *Chrysomyxa ledicola* is limited to white spruce.

Spruce needle rust was frequently observed between Manning and Keg River, and reported along the Chinchaga Forestry Road in 2021. Only small areas were mapped during the aerial overview survey since it is difficult to detect from the air unless the infection is severe (greater that 70 per cent of crown affected). Ground assessments verified that most of the infection in the PRFA from spruce needle rust was classified as moderate. Spruce trees in the affected area will be monitored in 2022.

Figure 12. White spruce needles infected with spruce needle rust. Chinchaga Forestry Road, Peace River Forest Area, August 2021.

2.5.2 Armillaria Root Disease │ *Armillaria* spp.

Armillaria root disease, a fungal infection attacking the root collar, is normally an opportunistic pathogen that does not have the ability to cause tree death alone. It is known to thrive mainly in trees weakened or recently killed due to other factors. While mortality cannot be directly attributed to the disease, the links between drought, armillaria, and tree health are well supported.

Based on findings from ground surveys in the PR/HLFA, the presence of armillaria root disease is common in both aspen and fir stands exhibiting increased levels of mortality. It is likely that the effects from drought conditions contributed to a reduced ability of aspen and fir forests to defend the already present armillaria. In 2021, less area of both aspen and fir mortality was mapped than the previous two, suggesting that forests may be recovering after a lag in drought effects, and their ability to resist armillaria is improving.

2.5.3 Lodgepole Pine Dwarf Mistletoe │ *Arceuthobium americanum*

Lodgepole pine dwarf mistletoe is a parasitic flowering plant that causes severe deformities and growth loss in Lodgepole and Jack pine across their range. In northwest Alberta, the infectious plant is well established but limited in its range. There are two main occurrences in the PR/HLFA: a broad area within FMU F11 and surrounding areas, and a small area near the Whitemud/Peace River confluence.

In addition to infected pine stands east of La Crete, the F11 dwarf mistletoe infection covers a large area on the west side of the Peace River that extends to the northeast toward Rocky Lane. After aerial and ground surveys in 2018, lodgepole/jack hybrid pine the area appeared to be heavily infected (Fig. 13), indicating a long history of mistletoe presence in the area. Over 4,000 ha of infected stands burned in the 2019 Chuckegg wildfire however, reducing the amount of infected pine significantly. Although the fire was extraordinary in its size, rate of spread, and intensity, remnant patches remain. Unburned areas within the fire perimeter, those that may have burned at a lower intensity, and stands adjacent to the fire boundary consist of live pine that are infected with dwarf mistletoe. Slow spread from these unburned areas into the adjacent recovering forests is expected, but dependent a number of factors (e.g. forest conditions prior to fire, dwarf mistletoe infection severity, site characteristics, fire intensity, vegetation response, etc.) In areas where pine has been completely removed or burned, and the site has effectively been sanitized (i.e. live infected material removed), the planting of non-pine buffers would help to reduce the long-term impacts of dwarf mistletoe in the F11 area.

Figure 13. Lodgepole pine dwarf mistletoe infection, High Level Forest Area, 2018.

2.5.4 Pine Needle Cast

Pine needle cast broadly refers to early casting or death of needles and related symptoms caused by a group of fungal needle diseases. While there are many fungal species in this group, identifiable through microscopic analysis of spores and other minute symptoms and signs, two main types are widespread in the province of Alberta: *Lophodermella concolor* and *Elytroderma deformans.* Infection extent and severity of these disease agents across the landscape are influenced greatly by annual weather patterns, with cool, moist summer being favourable for the proliferation and spread of spores. As such, pine needle cast is variable in its occurrence on the landscape. Of the two main types, *Elytroderma deformans* (elytroderma needle cast) carries greater potential for damage as it is a systemic infection that once established, affects tree physiology for the life of the tree. Gradually, vigor, growth, and overall health can be reduced as a result. It is not known to cause tree mortality since heavy infections do not normally occur in successive years.

Elytroderma needle cast is a disease that infects pine trees for life.

A total of 1,805 ha of pine forest displaying symptoms of pine needle cast was recorded in 2021 in the PRFA. While the disease has been observed at low levels across the region, areas of moderate or severe infection are minimal. No pine needle cast was recorded in the HLFA in 2021.

2.5.5 Alien Invasive Forest Diseases

Diseases that have not evolved with native tree and shrub species are considered alien and can be invasive. Examples include: White pine blister rust (*Cronartium ribicola*) affecting native White and Limber pines in Alberta and across their range, and Septoria canker and leaf blight (*Septoria musiva*) which is causing damage in hybrid *Populus* plantations in British Columbia, but also has potential to infect native *Populus* species. No alien invasive forest diseases were found or reported in the PR/HLFA in 2021.
Dutch elm disease is a debilitating disease caused by a fungal pathogen (*Ophiostoma ulmi*). This disease is of particular interest in Alberta as Edmonton and Calgary are home to some of the largest populations of uninfected elm trees in North America, and urban plantings are common and highly valued across the province. This disease was introduced from Europe in the 1930’s and has now been detected as close as Saskatoon, SK. Currently transport of elm for firewood is banned, and pruning bans are in place throughout Alberta from April through September to limit the potential spread of fungal spores that are transported by bark beetles in a manner similar to MPB.

3.0 Abiotic Disturbance Agents

Abiotic forest disturbances are caused by severe weather events, temperature and precipitation anomalies from background levels, fire, chemical pollutants, and long-term climate trends. These factors vary in both their spatial and temporal occurrence, and likewise the immediacy of risk they pose on forests. Abiotic agents can be simple to diagnose (e.g. blowdown), or challenging because external symptoms may not be present. Furthermore, secondary agents such as woodborers can mask primary damage caused by abiotic factors.

3.1 Severe Weather Events

3.1.1 Blowdown

Severe wind events with winds exceeding 100 km/hr are uncommon in the PR/HLFA. When they do occur, some stands are susceptible to broken tops and severe blowdown depending on factors such as wind direction, site aspect and slope, forest composition, and soil characteristics. From an insect management aspect, unsalvaged blowdown, especially in conifer stands and surrounding intact stands, should be monitored over a few years after a wind event for bark beetle activity since populations are known to build in response blowdown events. Aspen forests are not known to face the same threat, as insects related to decomposition (i.e. secondary attack) are more limited to that role, and not normally capable of killing live trees.

In 2021, a total of 5,376 ha of blowdown was mapped, with 80 per cent occurring in the PRFA (Fig. 14). Most of the blowdown in the PRFA was due to a wind event in August 2020 that caused extensive damage in FMU P21. In the HLFA, blowdown happened in 2021 and was scattered with only a few locations of note: directly east of Tolko's Blue Angel satellite yard (approx. 100 ha), the west side of Negus 4 compartment (approx. 350 ha), and the east side of highway 35 at Meander River (approx. 240 ha). Nearly half of the blowdown in both areas was classified as very severe (50 per cent or more stems affected). Roughly 90 per cent of the damage took place in aspen dominant stands.

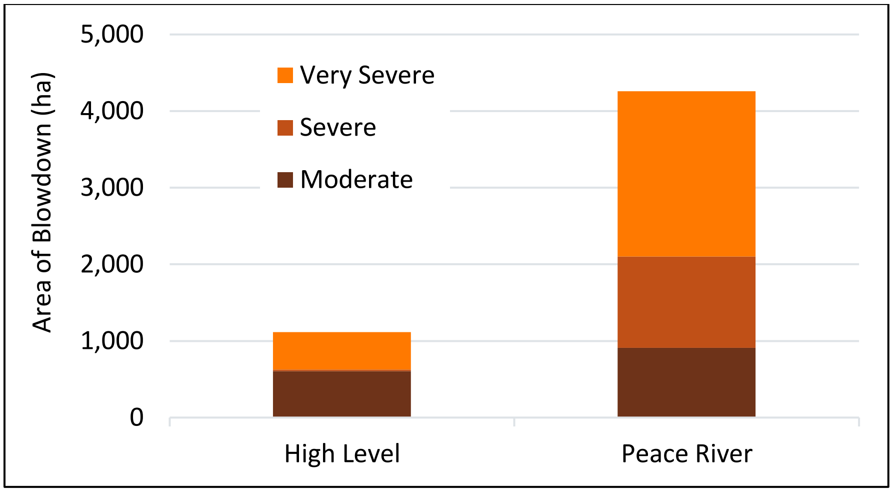

Figure 14. Area of blowdown by severity category in the Peace River/High Level Forest Areas, 2021.

A detailed classification of the 2020 blowdown in P21 was completed through interpretation of satellite imagery (SPOT6, RGB, 150 cm resolution, 2020 capture). The classification included a refinement of aerially mapped polygons as well as the inclusion of unmapped blowdown both within and beyond the 2020 search area. The total area of blowdown within P21 was 4,260 ha, including all forest types. This is a greater amount than what was originally mapped from a helicopter in September 2020. Over half of the damage was classified as very severe and the majority of blowdown took place in aspen stands. The extent did not change significantly, with the bulk of damage in the Keppler Creek (2,627 ha) and Cache Creek (1,242 ha) operating compartments (Fig. 15).

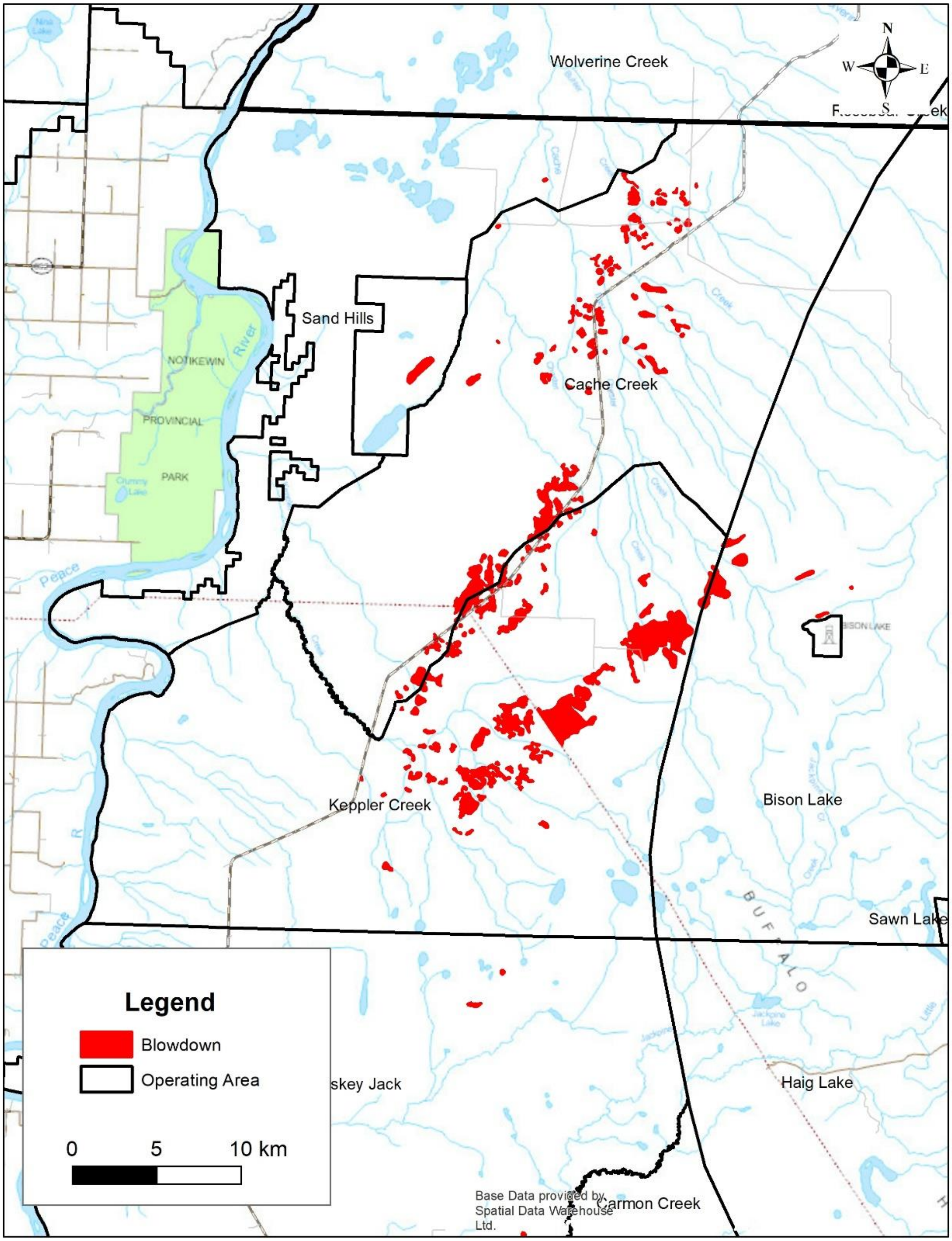

Figure 15. Areas of forest affected by blowdown in August 2020, Forest Management Unit P21, Peace River Forest Area.

3.1.2 Extreme Heat

Without question, the heat wave in the summer of 2021 was unprecedented across western Canada and northwestern United States. With prolonged daily maximum temperatures in the upper 30C's or more, and many local records being shattered, it was a significant anomaly from historic normals. The total number of days where the maximum daily temperature exceeded 30°C was also much higher than background rates in 2021 (Fig. 16).

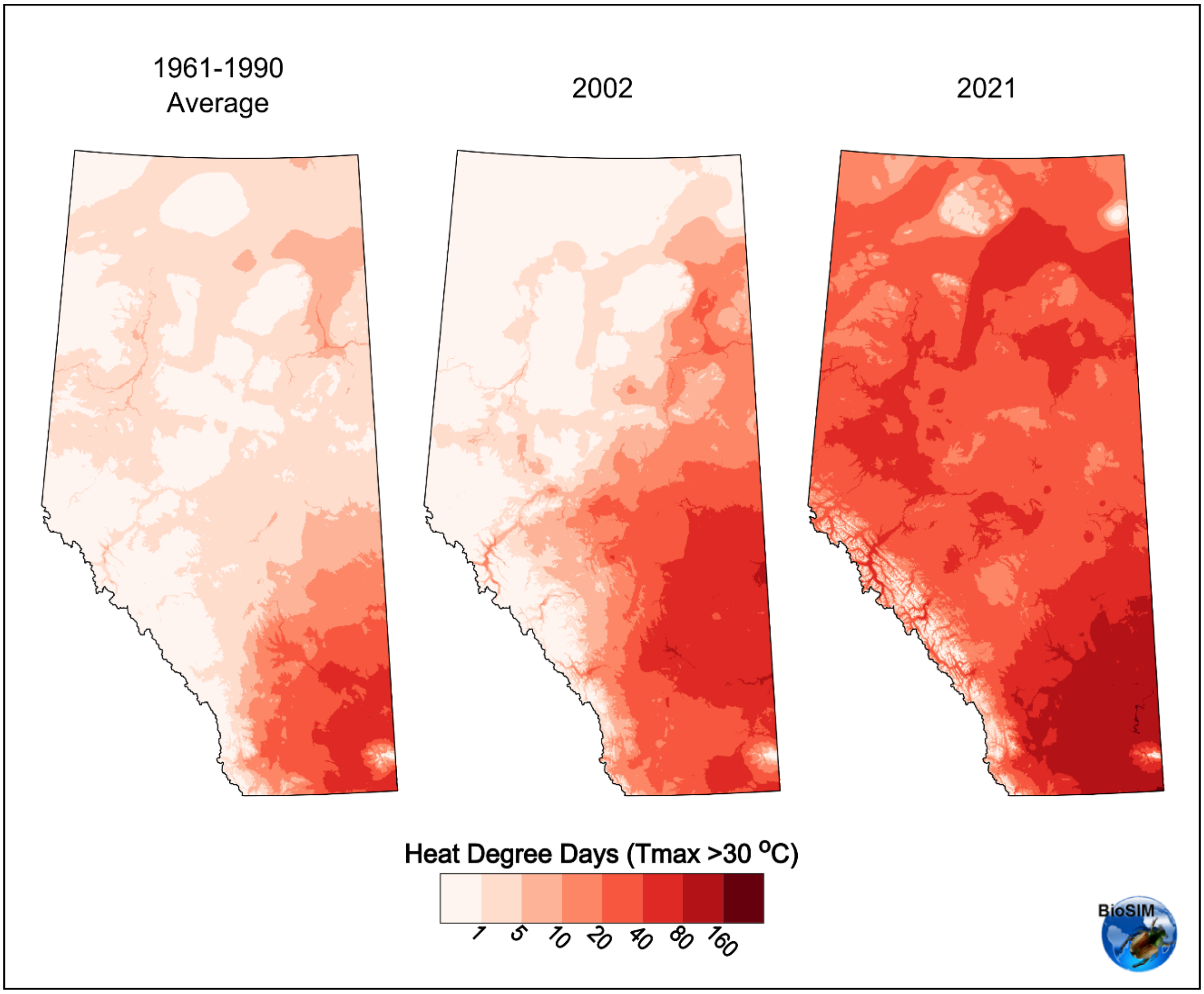

Figure 16. Comparison of heat degree days (maximum daily temperature exceeding 30°C): long-term average, 2002 (cool summer in northwest), and 2021, in Alberta. Figure provided by Canadian Forest Service.

The effects of this widespread extreme weather event on forest health are not well understood and may be delayed. While direct tree mortality has been reported in other jurisdictions, such as widespread severe juniper mortality across western USA, only minor symptoms of heat stress were observed in Alberta and the within the PR/HLFA in 2021. These included leaf scorch in deciduous and early needle drop in conifers, particularly in understory trees. It is expected that the full extent to the damage of trees will be more apparent over the next few years. Damage will be exacerbated when other agents, such as defoliators, are affecting tree health. Potential impacts from the late June-early July heat wave of 2021 will be monitored closely in the coming years.

3.2 Other Weather-Related Abiotic Agents

3.2.1 Drought

Approximately 61,000 ha of aspen mortality (above ground dieback) were mapped in 2021, a 28 per cent decrease from 2020. The spatial extent of mortality was similar to previous years. Dry, south-facing sites were affected most severely, including many areas along the valley of the Peace River west of the town of Peace River, as well as the Notikewin River valley. The vast majority of mapped mortality polygons overlap previous years and represent cumulative or ongoing mortality in stands that have suffered significant decline in the past four to five years (Fig. 17A).

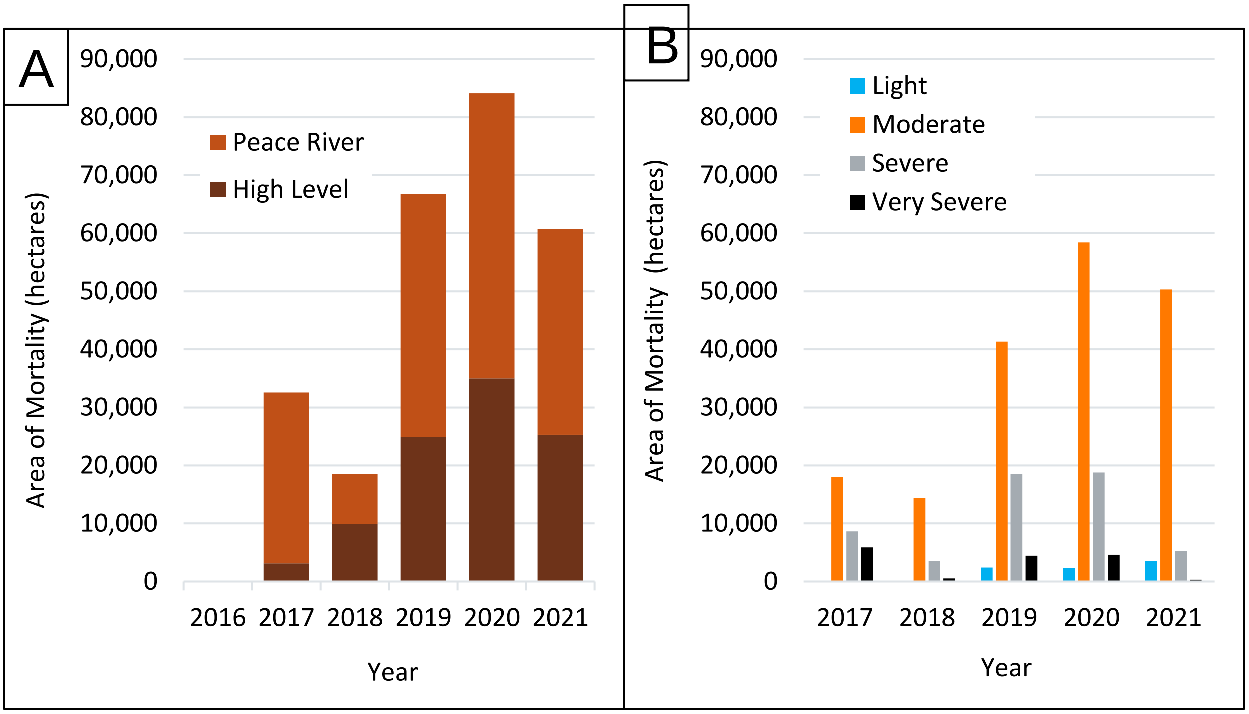

Figure 17. Aspen mortality in the Peace River and High Level Forest Areas: A) comparison of area mapped from 2016- 2021; and B) comparison of severity classification from 2017-2021.

In addition to less area mapped in the PR/HLFA in 2021, many of the affected areas showed a reduction in severity classification (Fig 17B). Only about 10 per cent of the aspen mortality was classified as either severe or very severe, compared to the same categories in 2019 and 2020 where they represented 28 per cent and 35 per cent of overall mortality, respectively. Evidence is demonstrating a lag in damage from the point that inciting factors (i.e., drought and insect defoliation) were at their peak, it is expected that aspen mortality will continue to subside over the next few years in areas that have received increased precipitation.

The large-scale mortality in regional and provincial aspen forests has occurred in stands that are predisposed to physiological stress from exposure to inciting drought and defoliation events over the past decade. When these two agents occur synchronously, such as in 2013 - 2015 in the PR/HLFA, the impact can be significant. The first and most severely impacted aspen stands were over-mature and found on dry, south facing slopes in the Peace River valley where the forest tent caterpillar outbreak took place. Incidence of wood boring insects, and other secondary and insects and diseases has increased greatly at these sites as well. While aspens mortality is attributed mainly to drought conditions, causal factors that interact to magnify their effects on aspen health are multiple and complex.

3.2.2 Flooding

Flooding was a significant disturbance factor in the HLFA in 2021. With increased precipitation in both 2020 and 2021, surface water was abundant. Areas of poor drainage as well as blocked watercourses were commonly flooded into surrounding forested areas. All forest cover types were subject to mortality from flooding in these areas, although spruce stands accounted for about 75 per cent of the total area damaged. This is not surprising given that spruce is often prevalent in riparian areas. Nearly 25,000 ha of flooded forest was mapped in 2021 during the aerial overview survey. Contributing to this high number are some large flood polygons that were mapped east of Tallcree and the Mikkwa River. This is a swampy lowland area with a low-density mix of white spruce, black spruce and tamarack.

3.2.3 Winter Desiccation

While conifer trees are dormant in winter, periods of above-freezing temperatures accompanied by wind, can result in winter desiccation. This phenomenon is a more serious threat in regions that experience regular chinook winds, but has caused damage locally in windrows and ornamental plantings where trees are often exposed. It’s likely that periods of drought reduce tree defenses, making foliage more susceptible to moisture loss. Reports from local residents in towns and on acreages are common, yet winter desiccation leading to discoloration and loss of needles in the spring/summer is not regularly encountered in broader crown forests.

No other damaging weather events occurred, to our knowledge, in 2021. This includes hail, frost, out-of-season heavy snowfall, tornados, and lightning. Research on freeze-thaw cycles has indicated that they may be a contributing factor to tree health declines, although the magnitude of impacts is not well understood in the PR/HLFA.

3.2.4 Weather Effects on Bark Beetle Populations

Bark beetles, including MPB and spruce beetle are often highly regulated by temperature. Summer temperatures govern development and emergence, while fall temperatures determine the onset of diapause. Finally, winter temperatures largely dictate survival.

The largest cause of mortality in bark beetle populations in the PR/HLFA is cold temperatures. The timing, duration and spatial extent of cold temperatures are key in regulating populations since cold tolerance is a highly variable characteristic that changes throughout the year. During mid-winter, sustained temperatures of -35°C can result in 90 per cent mortality of MPB larvae. This threshold is significant as populations in an outbreak phase require at least 90 per cent wide scale mortality to stabilize populations, while populations that are declining are impacted to a greater extent by over-winter mortality. Cold tolerance is diminished in the late fall and early spring, and mass mortality may occur if temperatures are unseasonably cold at these times. Other factors at the tree level such as density of attack and bark thickness also play a role in winter survival.

The winter of 2020-21 experienced an extreme cold event, similar to the previous three winter seasons. The effect on what remains of regional MPB populations is expected to be significant. Figure 18 illustrates minimum daily temperatures recorded at a weather station at Fontas tower and in Manning, AB. During a one-week period in February, minimum daily temperatures in Manning averaged -39.6°C, dipping down to -43.5°C on February 6, 2021, while at a higher elevation at Fontas minimum temperatures averaged -34.3°C, reaching a low of only -37.5°C during the same period of time.

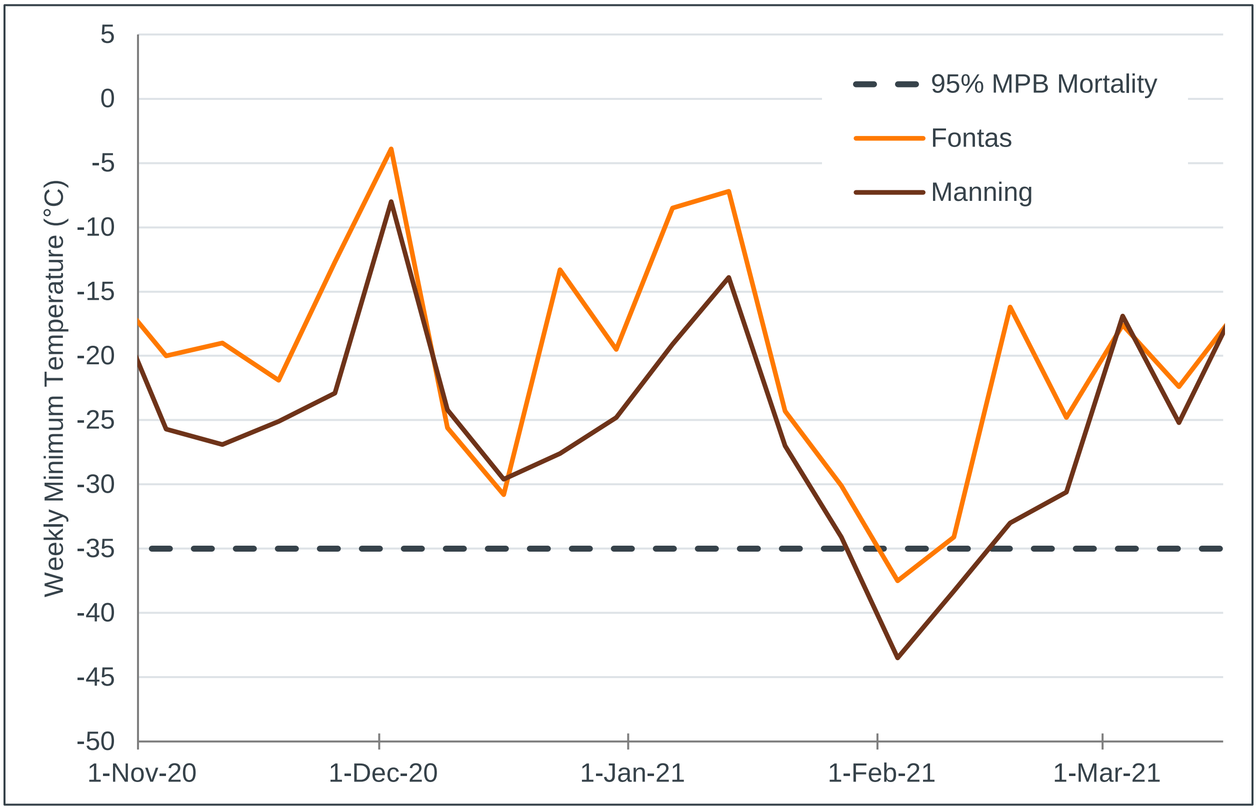

Figure 18. Weekly minimum temperatures at Fontas wildfire lookout tower and Manning weather stations and predicted mountain pine beetle mortality from November 1, 2020 to March 15, 2021 in the Peace River Forest Area. Data obtained from Alberta Climate Information Service.

Extreme heat on the other hand, can have a detrimental effect. Although MPB emergence initiates at temperatures above 16°C, studies have reported it as declining above 30°C. Flight periods also have an optimal temperature range and may be interrupted or severely restricted above 38°C. Since the heat event occurred in late June-early July, outside of the flight period for both MPB and spruce beetles, they may have evaded the heat to some extent under the bark. The influence on egg hatch, larval development, and voltism of spruce beetles is not well understood.

3.3 Fire

Wildfire has both a direct and indirect effect on insects and diseases and plays a large role in their occurrence in the PR/HLFA. Host mortality has obvious negative outcomes for insect and disease populations relying on live materials, but will conversely provide opportunities for secondary agents more adapted to survival in dying, freshly killed or decomposing material. Low-intensity fire with sub-lethal effects on trees can make them more susceptible to some insects and disease, however research is also finding that low-intensity fire can have a positive effect on induced defense capabilities in some trees. Fire disturbance reduces landscape-level susceptibility to agents associated with mature forests such as conifer bark beetles, while potentially increasing susceptibility to those that occur in younger-aged forests. Long-term establishment, abundance and distribution of forest insect and disease agents are uniquely affected by large scale wildfire regimes. In the exceptional fire season of 2019, nearly 6,000 ha of forest affected by epidemic insect populations, disease infection, or abiotic damage were burned over. The Chuckegg fire is expected to have a large influence on the occurrence of dwarf mistletoe in the HLFA (Fig. 19), but a minimal effect on spruce budworm populations.

2021 was a relatively minor year for wildfires in the PR/HLFA. About 2,500 ha burned in the HLFA, the vast majority of the total area attributed to a fire in the Caribou Mountains, west of Margaret and Eva Lakes. In the PRFA, only about 250 ha of forest was burned by wildfire with the largest covering 66 ha. There were no recently mapped forest health agents within fire boundaries in 2021.

Figure 19. Example of dwarf mistletoe-infected pine branch burned in the Chuckegg wildfire of 2019, FMU F11, High Level Forest Area.

3.4 Mid and Long Term Climate Impacts on Aspen Health

CIPHA Project Update 2021

Climate Impacts on the Productivity and Health of Aspen (CIPHA) is a long-term study that examines the interactions between climate, insects and diseases, and trembling aspen. At sampling plots across boreal and parkland regions of western Canada, health assessments are conducted annually, while basic tree mensuration and core sampling are repeated every five years. This study has effectively documented the lingering cumulative impact of severe defoliation and drought that the increased mortality is attributed to.

Health assessments were carried out in late July, 2021 at six plots within Notikewin Provincial Park. Data were submitted to the CFS. Annual mortality rates are stabilizing toward a normal level, down from the peak in 2016-17. The ratio of dead to live trees at the Notikewin plots increased dramatically over the past few years following the mortality event. Since the establishment of the plots in 2000, 67 per cent of trees have died. In 2018, we initiated additional sub-plots at the Notikewin node to assess aspen regeneration and changes in understory vegetation composition including all plant types. Since this is a long-term process, it will take some time to have sufficient data for analysis of these factors. Interestingly, 2020 data show an increase in the incidence of frost cracks (i.e. 30 per cent of trees), which occur when temperatures make a sudden and severe drop. Frost scars often allow the introduction of phloem-feeding and woodboring insects who themselves are vectors for disease such as cytospora canker (*Cytospora chrysosperma*).

3.5 Mid and Long Term Climate Impacts on Spruce Health

CIPHS Project Update 2021

The Climate Impacts on the Productivity and Health of Spruce (CIPHS) study was initiated in 2019 through a collaboration with the CFS. It is a long-term monitoring project that consists of a balanced system of forest health research plots in white spruce stands extending throughout the forested green zone. The objectives of this study are somewhat similar to the CIPHA project:

- Develop a targeted forest health monitoring system to assess climate-related changes in the productivity and health of Alberta's white spruce forests.
- Determine the impacts of drought, insects and diseases on historic, current and future productivity and health of Alberta's white spruce forests.
- Provide information and tools in support of forest management practices aimed at minimizing climate impacts on Alberta's white spruce forests
- Provide field-based knowledge for including a climate component in models of forest growth and yield, carbon uptake and wood fiber supply.

Additionally, this study will provide significant training opportunities to forest health and forest management staff alike and increase the identification and understanding of factors that affect health in white spruce.

A node (i.e. geographical area) within the CIPHS study consists of two stands within 40 km of each other and two variable area plots per stand. The minimum target for the number of nodes across the province is currently 15. In 2019, 10 nodes were established across Alberta, including three in the PRFA. In 2020, three additional nodes were added, including one near Watt Mountain in the HLFA. After the site selection and plot establishment phases are complete across the sampling network, ongoing monitoring will occur every three to five years. Health assessments have been completed at each stand with initial observations and agents being identified. Spruce budworm, spruce beetle, and red ring rot (*Phellinus pini*) are examples of agents recorded on spruce trees. No sampling was carried out in 2021.

3.6 2021 Climate Summary for PR/HLFA

Climate in the PR/HLFA is characterized by large seasonal and inter-annual variability in both temperature and precipitation. This was displayed in 2021 when both +40°C and -40°C were reported at some locations. Over a five-to-ten year period, precipitation, a limiting factor in the boreal forest, has varied widely, and the effects of both drought and flooding are being observed concurrently in some cases. Climate moisture indices (CMI) are used to demonstrate the combined effects of temperature and precipitation on forest health.

The following CMI figures are included:

- **Annual CMI** (Fig. 20): a representation of moisture related to tree health. Calculated as the difference between annual precipitation and potential evapotranspiration. This index is well-correlated with aspen productivity and health in the PR/HLFA with negative numbers linked to aspen decline. CMI is calculated from August 1, in the previous year (2020) to July 31, of the current year (2021) because this time period is most relevant to tree physiology, growth and health.
- **Short-term CMI trend (**Fig. 21): a comparison of historic background (1961-1990) CMI to past two years. Calculated over similar annual time period related to overall tree health.
- **Long-term CMI trend** (Fig. 22)**:** a comparison of historic background CMI to past three decadal average. Calculated over similar annual time period related to overall tree health.

Following a comparatively wet year in 2020, periods of low rainfall promoted localized drying conditions in the southern portions of the PRFA. Precipitation remained more consistent and near-normal across the northern half of the PRFA and the HLFA. As in 2020, significant moisture was observed in some areas of the HLFA and surface water was abundant. Effects from severe drought during portions of the last decade, such as aspen mortality, have lagged to some degree however in areas vulnerable to drought-effects despite recent moisture, most notably in the HLFA. After a variable winter of 2020-2021 with both colder and warmer than normal temperatures, spring was near-normal across the region. Record highs through the summer months are considered anomalies from background averages. The extreme heat event in the PR/HLFA was unprecedented, as described in the above sections of this report. No other significant events or weather trends were reported in 2021.

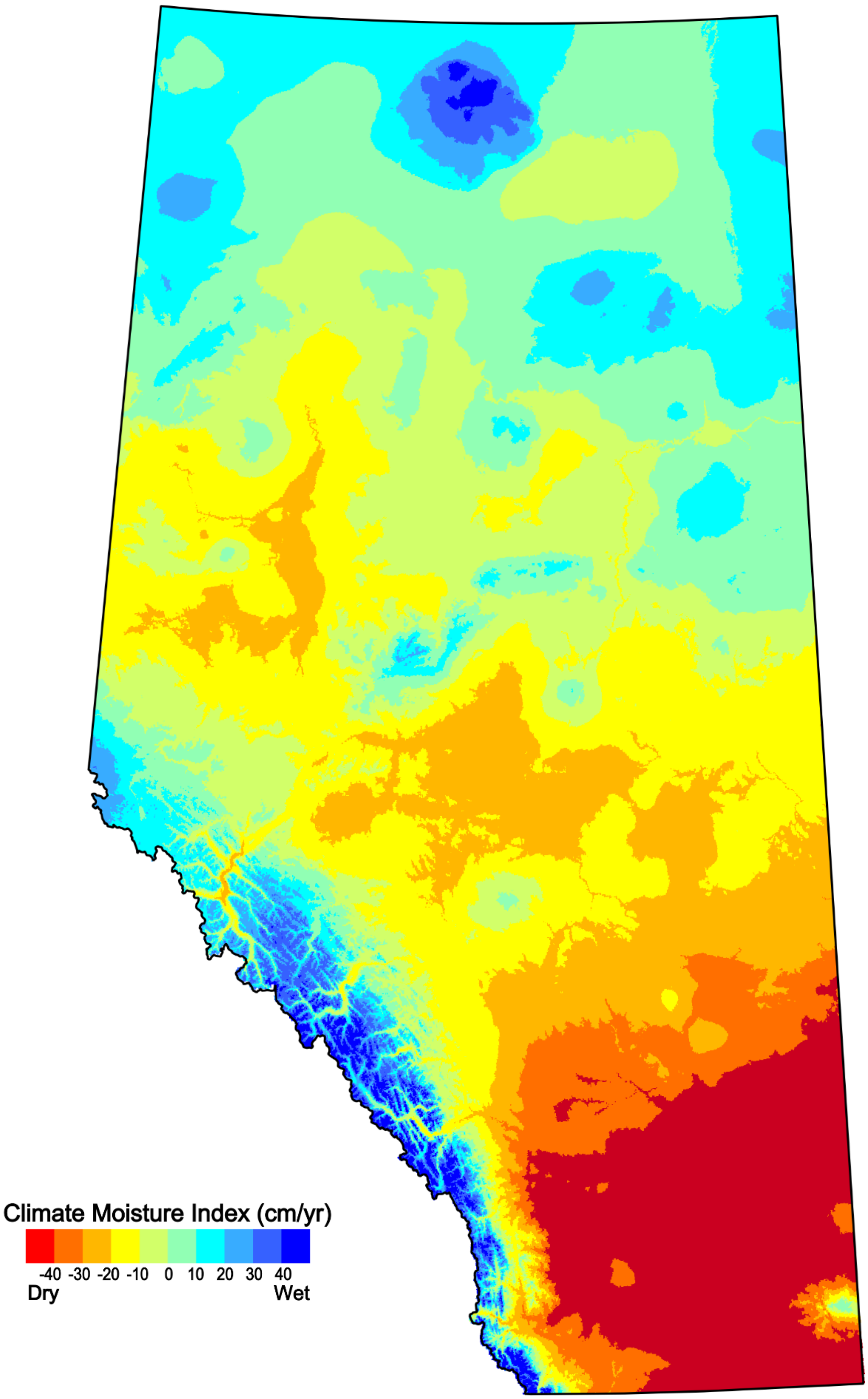

Figure 20. Climate moisture index in Alberta, August 1, 2020-July 31, 2021.

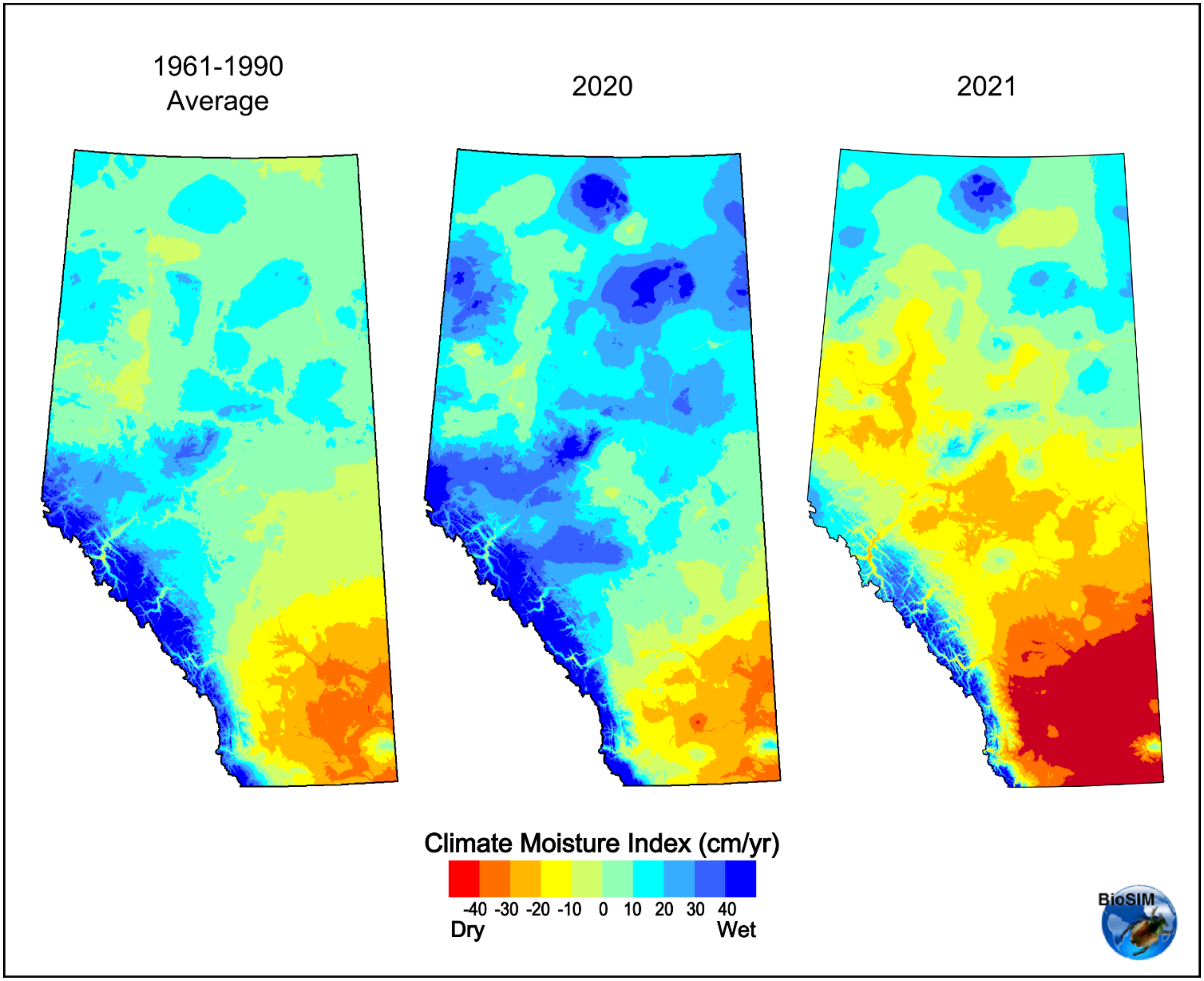

Figure 21. Long-term and past two-year comparison of average climate moisture index in Alberta. Figure provided by Canadian Forest Service.

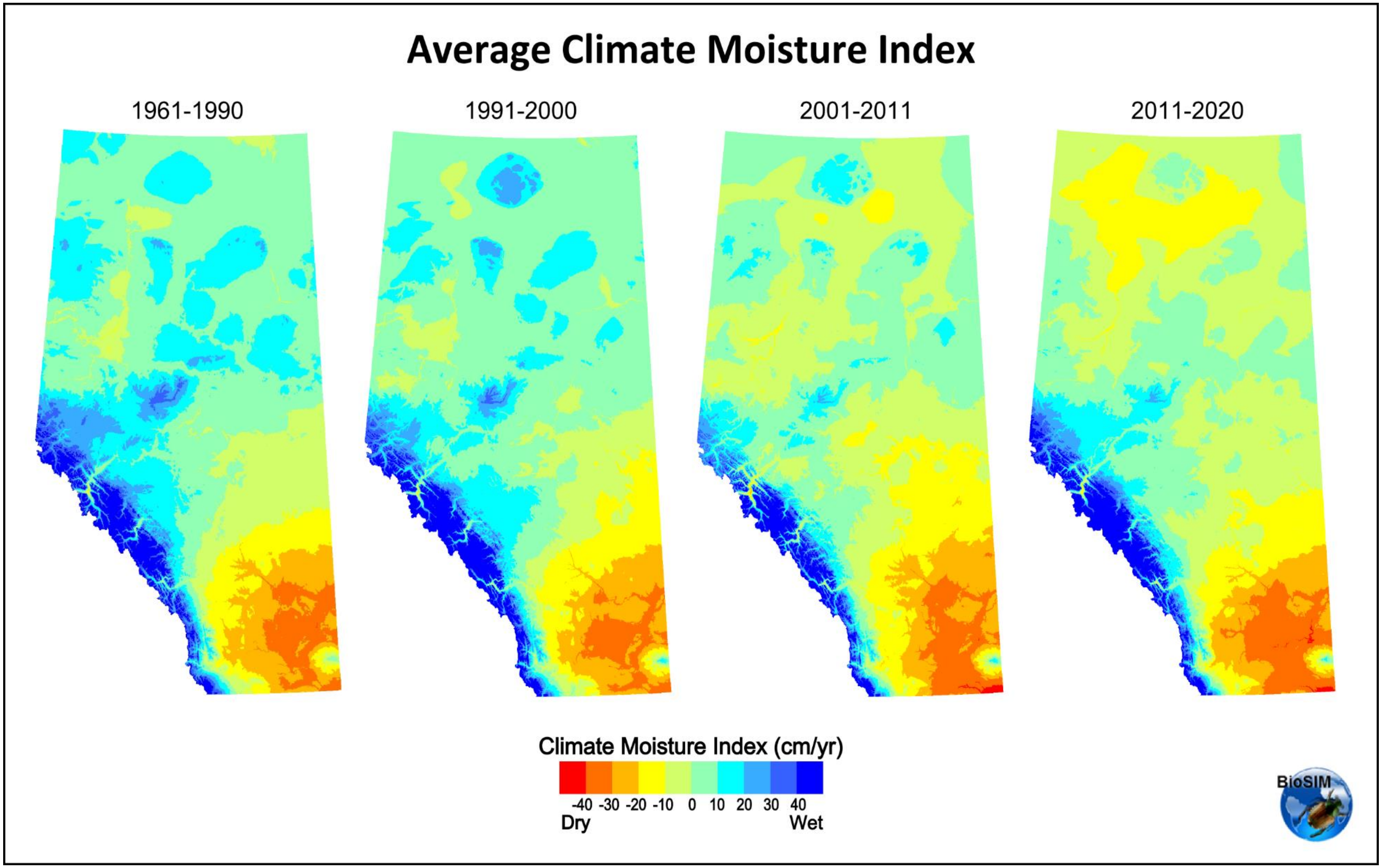

Figure 22. Long-term and past three decadal comparison of average climate moisture index in Alberta. Negative values represent unfavourable conditions for aspen health. Figure provided by Canadian Forest Service.

Appendix 1

Disturbance Polygon Classification Structure

Symptom	Tree Species	Agent	Severity
Defoliation	Aspen	Aspen serpentine leafminer Aspen twoleaf tier Bruce spanworm Forest tent caterpillar Large aspen tortrix Linden Looper Unknown	Moderate (35- 70 per cent crown affected) Severe (70 – 100 per cent crown affected)
	Birch	Unknown	
	Black spruce	Unknown	
	Pine	Jackpine budworm Lodgepole pine needle miner Unknown	
	Poplar	Aspen twoleaf tier Bruce spanworm Forest tent caterpillar Large aspen tortrix Linden Looper Unknown	
	Spruce	Jackpine budworm Spruce budworm Two-year budworm Western spruce budworm Unknown	
	Willow	Gray willow leaf beetle Willow leafminer Unknown	
Dieback	Aspen	Drought Hail Unknown	Moderate (35- 70 per cent crown affected) Severe (70 – 100 per cent crown affected)
	Birch	Drought Hail Unknown	
	Pine	Jackpine budworm Lodgepole pine needle miner Unknown	
	Poplar	Drought Hail Unknown	
	Spruce	Jackpine budworm Spruce budworm Two-year budworm Western spruce budworm Unknown	
	Willow	Gray willow leaf beetle Willow leafminer Unknown	
Foliar Damage	Aspen	Drought Frost Hail Unknown	Moderate (35- 70 per cent crown affected) Severe (70 – 100 per cent crown affected)
	Birch	Drought Frost Hail Unknown	
	Black spruce	Unknown	

Foliar Damage	Pine	Drought Frost Hail Lodgepole pine dwarf mistletoe Pine needle cast Redbelt/winter desiccation Unknown	Moderate (35- 70 per cent crown affected) Severe (70 – 100 per cent crown affected)
	Poplar	Drought Frost Hail Unknown	
	Spruce	Drought Frost Hail Redbelt/winter desiccation Spruce needle rust Unknown	
	Willow	Drought Frost Hail Unknown	
Mechanical	Aspen Birch Black Spruce Larch Mixed Poplar Pine Spruce	Animal Chemical Lightning Snow damage Windthrow/blowdown Unknown	Light (1-10 per cent stems affected) Moderate (11-29 per cent stems affected) Severe (30-49 per cent stems affected) Very severe (50 per cent+ stems affected)
Mortality	Aspen	Armillaria root disease Drought Flooding Hail Windthrow/blowdown Unknown	Light (1-10 per cent stems affected) Moderate (11-29 per cent stems affected) Severe (30-49 per cent stems affected) Very severe (50 per cent+ stems affected)
	Birch	Armillaria root disease Drought Flooding Hail Windthrow/blowdown Unknown	
	Black Spruce	Armillaria root disease Drought Flooding Hail Redbelt/winter desiccation Tomentosus root rot Windthrow/blowdown Unknown	
	Fir	Armillaria root disease Drought Douglas fir beetle Flooding Hail Redbelt/winter desiccation Tomentosus root rot Western balsam bark beetle Windthrow/blowdown Unknown	

Mortality	Larch	Armillaria root disease Drought Eastern Larch Beetle Flooding Hail Redbelt/winter desiccation Tomentosus root rot Windthrow/blowdown Unknown	Light (1-10 per cent stems affected) Moderate (11-29 per cent stems affected) Severe (30-49 per cent stems affected) Very severe (50 per cent+ stems affected)
	Mixed	Armillaria root disease Drought Flooding Hail Redbelt/winter desiccation Windthrow/blowdown Unknown	
	Poplar	Armillaria root disease Drought Flooding Hail Windthrow/blowdown Unknown	
	Pine	Armillaria root disease Drought Flooding Hail Mountain pine beetle Redbelt/winter desiccation Tomentosus root rot Windthrow/blowdown Unknown	
	Spruce	Armillaria root disease Drought Flooding Hail Redbelt/winter desiccation Tomentosus root rot Windthrow/blowdown Unknown	
	Willow	Flooding Gray willow leaf beetle Willow leafminer Unknown	