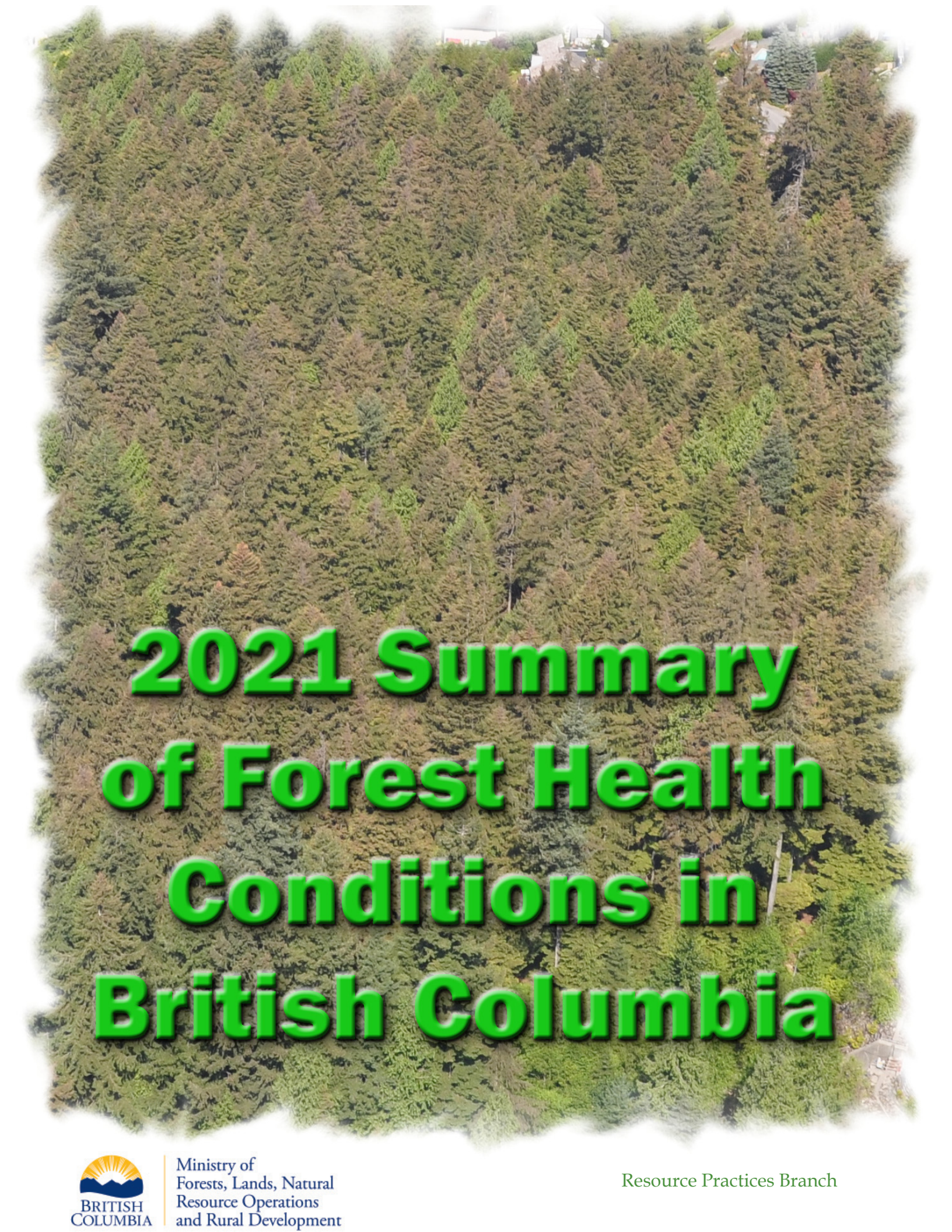

2021 Summary of Forest Health Conditions in British Columbia

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Front cover photo by Aaron Bigsby, western hemlock looper defoliation

2021 Summary of Forest Health Conditions In British Columbia

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Summary

The *2021 Summary of Forest Health Conditions in British Columbia* (BC) is a compendium of forest health damage collected during the 2021 BC Ministry of Forests, Lands, Natural Resource Operations and Rural Development (FLNRORD) aerial overview surveys (AOS). This data is augmented by additional forest health information such as ground surveys, insect trapping/tree beatings, lab investigations of damage samples, detailed helicopter surveys and ground reconnaissance observations from trained personnel.

The AOS are conducted by experienced surveyors mapping all visible, current forest damage from small planes. As much forested land as possible across BC is surveyed every year. In 2021 76% of the province was surveyed between July 6th and October 7th by 24 surveyors using ten aircraft companies. A total of 641 hours were logged over 129 days. This was the lowest coverage obtained since 2004, due to extensive rain and fog in the northwest and wildfire smoke with lack of aircraft availability/fuel issues in the rest of BC. At least 44 damaging agents affected a wide variety of commercial tree species of all ages, resulting in 6.3 million hectares (ha) of damage (including both mortality and partial tree/foliage damage) across the province. The AOS data is known to under-estimate some damaging agents, especially forest pathogens, as not all damage is visible at the height and time the AOS is flown.

Bark beetles continued to lead the damaging agents, with 3,206,471 ha of mortality. Western balsam bark beetle infestations were recorded at low intensity on 2,556,524 ha, mainly in northern BC where host trees are prevalent. Spruce beetle infestations declined in most regions to 470,668 ha, though several consecutive years of mortality have decimated many mature spruce stands, particularly in northwestern BC. Douglas-fir beetle damage increased slightly to 106,039 ha, with the majority of the attack continuing in Cariboo Region. Mountain pine beetle attack continued to decline to 73,238 ha of mainly low intensity mortality, in areas previously infested.

Observed defoliator damage of conifer and deciduous trees increased to 2 million hectares in 2021. Aspen leaf miner continued to be the main damaging agent with 1,327,856 ha recorded. Infestations in Northeast Region increased substantially, but declined in Skeena Region. Four budworms affected conifer species in specific regions of the province. Two-year cycle budworm was the most prevalent with 310,049 ha mapped, mainly in northern BC. Western spruce budworm defoliated 52,981 ha predominantly in Cariboo Region. Northeast Region sustained 36,449 ha of eastern spruce budworm attack, and western blackheaded budworm affected 217 ha in Haida Gwaii TSA. Large aspen tortrix damaged stands for the second consecutive year in northeastern BC, with 221,849 ha mapped. A western hemlock looper outbreak defoliated a record 51,093 ha in southern BC. A spray program utilizing *Bacillus thuringiensis* var. *kurstaki* (B.t.k.) was conducted on 50,173 ha in the BC interior to reduce western hemlock looper and western spruce budworm populations in high value stands.

Damage due to abiotic agents quadrupled since last year to over 1 million hectares. This was mailny due to wildfires, which burnt 863,630 ha mainly in the southern interior, where large interface fires consumed homes as well as trees. Early record breaking spring temperatures most likely contributed to substantial drought-damaged foliage, which affected 108,345 ha, mainly in southern BC. Flooding damage remained relatively consistent, with scattered mortality totalling 20,015 ha. Windthrow disturbances totalled 12,623 ha, with most (9,002 ha) occurring in Northeast Region. A total of 11,397 ha of yellow-cedar decline damage was mapped along BC's coastline. Damage due to a combination of agents following wildfires decreased to 11,000 ha, which was predominantly mapped mid province.

Needle diseases were the primary cause of observable disease damage, with 62,093 ha mapped in BC. Early AOS flights captured most of the 19,980 ha of lophodermella needle cast damage recorded mainly in Omineca Region. Dothistroma needle blight damage increased to 17,734 ha, with Skeena Region most affected. A further 3,379 ha of lodgepole pine needle damage observed mainly in Northeast Region was suspected to be caused by Dothistroma needle blight, but this couldn't be confirmed. Damage due to larch needle blight rose to 11,529 ha, chiefly located in Kootenay/ Boundary Region. White pine blister rust damage mainly occurred along the south coast of BC, affecting 4,288 ha.

Animal damage, primarily observed as scattered mortality in older trees, tripled to 3,699 ha, with the chief agent being black bear feeding.

Localized damage caused by other agents such as defoliators (satin moth, birch leafminer, balsam woolly adelgid, Douglas-fir tussock moth and forest tent caterpillar), diseases (large-spored Spruce-labrador tea rust, cottonwood leaf rust, Armillaria root disease and laminated root disease), abiotics (frost damage, snow/ice damage, slides, redbelt, drought caused mortality and aspen decline) and western pine beetle were noted in small, scattered disturbances as well. All damage recorded during the AOS is discussed by host tree species in the body of this report. Abstracts of some special projects, meetings, presentations and publications conducted by FLNRORD pathologists, entomologists and their associates are also included in the final sections of the report.

2021 Summary of Forest Health Conditions in British Columbia

Introduction

The diverse ecosystems of British Columbia (BC) are rich in complex forests that vary in structure, age and tree species. These forests are often damaged by a variety of diseases, insects, animals and abiotic factors that can vary greatly in area, intensity and location from year to year. Hence, an aerial overview survey (AOS) is conducted annually across the forested lands of BC to capture current damage in a timely and cost-effective way. All visible damage to commercial tree species is recorded by host, damaging agent, extent and severity. For the past 23 years the provincial government has been responsible for the AOS, currently under the BC Ministry of Forests, Lands, Natural Resource Operations and Rural Development (FLNRORD).

When the AOS is finished each year, the data is digitized, reviewed and collated. For this report, summaries are produced by Timber Supply Areas (TSAs, Figure 1). The exceptions are the Pacific and Cascadia TSAs that are small fragmented units within several larger TSAs, which are incorporated within the larger TSA units that surround them. TSAs are amalgamated into eight regions in BC: Skeena, Omineca and Northeast Regions cover northern BC; Cariboo, Kootenay/Boundary and Thompson/Okanagan are in the southern interior; West Coast and South Coast account for the south coast (Figure 1). In 2016, four coastal TSAs were merged/changed to create Great Bear Rainforest North and South TSAs. Since these TSAs are under special management constraints and the north TSA straddles two regions, they are considered an entity separate from the regions for this report.

Results in this report are discussed by individual damaging agents and grouped by host tree species. Some damage is not well captured by the AOS due to the elevation the survey is flown, the time period of the survey and/or the lack of aerial visibility. This includes a variety of diseases, low-intensity insect defoliation, very scattered or partial tree damage, very young tree damage or understorey damage. Information about these disturbances may be collected by other methods, such as helicopter surveys or ground assessments. This supplemental information is discussed in this report but since data collection methods are fundamentally different, it is not usually added to the AOS database. An exception is sometimes made to fill significant gaps in the survey coverage. Insect population information (including pheromone-baited traps, larval/egg surveys, and tree branch beatings) and ground observations may also be included.

Information obtained from the annual aerial overview survey is used by many interest groups including government agencies, industry, academia and the public for a variety of purposes. This includes input into government strategic objectives, guidance for management efforts related to forest health, as a source for research projects, contributions to national indicators for sustainable forest management (see Canada's National Forest Database: http://nfdp.ccfm.org/en/index.php), input into timber supply analyses, input into the National Forest Pest Strategy *Pest Strategy Information System* (www.ccfm.org/pdf/PestStrat_infosys_2012_en.pdf) and analyses relating to climate change and carbon accounting (i.e., estimating the success in meeting greenhouse gas emission reduction targets).

TSA Code	TSA Name
Cariboo Region	
TQU	Quesnel Timber Supply Area
TMH	100 Mile House Timber Supply Area
TWL	Williams Lake Timber Supply Area
Kootenay/Boundary Region	
TAR	Arrow Timber Supply Area
TBO	Boundary Timber Supply Area
TCB	Cranbrook Timber Supply Area
TGO	Golden Timber Supply Area
TIN	Invermere Timber Supply Area
TKL	Kootenay Lake Timber Supply Area
TRE	Revelstoke Timber Supply Area
Northeast Region	
TDC	Dawson Creek Timber Supply Area
TFN	Fort Nelson Timber Supply Area
TJO	Fort St. John Timber Supply Area
Omineca Region	
TMK	Mackenzie Timber Supply Area
TPG	Prince George Timber Supply Area
TRV	Robson Valley Timber Supply Area
Skeena Region	
TBU	Bulkley Timber Supply Area
TCA	Cassiar Timber Supply Area
TKI	Kispiox Timber Supply Area
TKM	Kalum Timber Supply Area
TLA	Lakes Timber Supply Area
TMO	Morice Timber Supply Area
TNA	Nass Timber Supply Area
TNC	North Coast Timber Supply Area
South Coast Region	
TFR	Fraser Timber Supply Area
TSC	Sunshine Coast Timber Supply Area
TSO	Soo Timber Supply Area
Thompson/Okanagan Region	
TKA	Kamloops Timber Supply Area
TLI	Lillooet Timber Supply Area
TME	Merritt Timber Supply Area
TOK	Okanagan Timber Supply Area
West Coast Region	
TAS	Arrowsmith Timber Supply Area
THG	Haida Gwaii Timber Supply Area
TKC	Kingcome Timber Supply Area
TMC	Mid Coast Timber Supply Area
TST	Strathcona Timber Supply Area

Figure 1. Map of British Columbia outlining Ministry of Forests, Lands and Natural Resource Operations and Rural Development Timber Supply Areas (TSAs) and Regional Boundaries.

Relevant forest health projects, presentations, workshops and publications conducted by FLNRORD pathologists, entomologists and their associates over the past year follow the damaging agent reporting section of this report. Not all forest health activities conducted by provincial staff or other agencies in the province are necessarily captured in this overview report. A more detailed annual report of forest health in the Southern Interior of BC and previous copies of this publication are also available at:
https://www2.gov.bc.ca/gov/content/industry/forestry/managing-our-forest-resources/forest-health/aerial-overview-surveys/summary-reports.

Methods

Aerial overview surveys are conducted in small (minimum four seats) high-wing configuration aircraft that are Ministry approved (Transport Canada licensed, approved maintenance schedule, appropriate insurance and experienced pilots). In addition to the pilot, two trained observers sit on opposite sides of the plane. The "primary surveyor" is usually seated in the front next to the pilot and is responsible for mapping out the right side of the aircraft, as well as general navigation and survey planning. The "second seat surveyor" sits in the back on the opposite side of the aircraft and is responsible for mapping out the left side of the aircraft. Total survey time is limited to 5-6 hours to ensure a quality product, though if necessary, ferry time can be added to this.

An additional trainee may map from the seat behind the primary surveyor. To become a second seat surveyor, an initial training course followed by a minimum of 15 hours of trainee mapping in varied forest types is required. To be considered a primary surveyor, one season of flying second seat (minimum 50 hours) is required. A minimum of two observers and a pilot survey each FLNRORD Region.

Current forest damage that is visible during the AOS is hand sketched on customized 1:100,000 scale maps (colour Landsat 8 satellite images with additional digital features such as contours, feature names, water bodies, roads, and some previous year's abiotic damage or bark beetle polygons). On flight completion, the information recorded on the individual working maps is combined and transferred to base maps, which are then manually digitized to capture the data spatially. Clear polyester film is used for these final composite maps. Various digital methods for capturing the data during flight have been tested over the past few years, but technology and database compatibility issues, along with the complexity of the survey in BC, have not resulted in adoption of a digital recording method to date.

Surveys are conducted when damage caused by the primary forest health factor(s) of concern for a given area are most visible, flight conditions permitting. Flight lines are recorded with recreational quality Global Positioning Satellite (GPS) receiver units. The resulting track files are collated and disseminated weekly to participants so coverage intensity and survey progress can be monitored. Depending on terrain and visibility, surveys are conducted between 700 to 1400 m above ground level. In relatively flat terrain, parallel lines are flown 7 to 14 km apart, depending on the intensity of mapping activity and visibility. For mountainous terrain, valley corridors are flown. Intensity of coverage in the mountains depends on visibility up side drainages, as stands are surveyed to the tree line. Aircraft speed ranges from 140 to 250 km/h, depending on mapping complexity and wind speed/direction.

All forested areas on the flight lines are observed for visible current damage, regardless of land ownership or tenure. The goal is to survey all BC forested land each year, weather and funding permitting. This goal can be difficult to obtain within the survey window, which is dependent on timing for optimum damage visibility (e.g. damaged needles/leaves may fade or drop off at different times, or snow may cover damage). Therefore, high priority areas are targeted first, followed by major drainages in lower priority areas. Areas not covered in a given year are given a higher priority the next year.

Tree mortality (caused by bark beetles, animal feeding, root diseases, and some abiotic factors) is identified primarily by the colour of the foliage. Only trees killed within the past year are mapped. Small clumps of up to 50 dead or dying trees are mapped as points (referred to as spot infestations) with an estimated number of dead trees noted. When digitized, spots of 1 to 30 trees are given a size of 0.25 ha, and 31 to 50 trees 0.5 ha with an intensity rating of severe, to capture the approximate area affected. Larger, more continuous areas of mortality are delineated as polygons and are assigned one of five severity rating classes based on the proportion of recently killed trees within the delineated area (Table 1).

Table 1. Severity rating classes used during aerial overview surveys for recording forest health damage that occurred over the past year.

Disturbance	Intensity Class	Description
Mortality (bark beetle, some abiotic, yellow cedar decline and animal damage)	Trace	<1% of the trees in the polygon recently killed.
	Light	1-10% of the trees in the polygon recently killed.
	Moderate	11-29% of the trees in the polygon recently killed.
	Severe	30-49% of the trees in the polygon recently killed.
	Very Severe	50%+ of the trees in the polygon recently killed.
Foliage Damage (defoliating insect, foliar disease and some abiotic)	Light	Some branch tip and crown damage, barely visible from the air.
	Moderate	Noticeably damaged foliage, a third of many trees severely damaged.
	Severe	Most trees sustaining more than 50% total foliage damage.
	Grey	Cumulative foliage damage resulting in mortality, recorded at end of damage agent cycle.
Aspen and birch declines	Light	Characterized by thin crowns and no individuals without visible foliage.
	Moderate	Thin crowns are accompanied by individuals devoid of foliage. Greater than an estimated 50% of individuals have some foliage.
	Severe	Crowns are very thin and greater than 50% of standing stems are devoid of foliage.

Trees with foliar damage (caused by insect feeding, foliage diseases and some abiotic factors) usually cover large areas and often all age classes of host trees are affected. Therefore, only polygons are used to map this type of damage. Severity rating classes are assigned based on the amount of foliage damaged during the past year on all host trees in the polygon. Three severity rating classes are used for foliar damage, with any cumulative damage that results in mortality recorded as grey once a damaging agent has run its course in a given area (Table 1).

Some exceptions are made to the "polygon only" rule for foliar damage. Venturia blight damage sometimes affects only a small clump of trees (most likely a single clone) within a stand of undamaged suitable hosts and can be recorded as a spot infestation. Occasionally, needle diseases (particularly in Kootenay/Boundary Region) severely affect host trees that are a very low component of the stand composition. This damage is sometimes recorded as spot damage. Aspen leaf miner damage that is visible from the air tends to have an "all or nothing" signature that has very little discernible tree-to-tree variation in damage. Additionally, in many areas, aspen occurs in mixed rather than pure stands. To most accurately record this damage, a standard was adopted in 2012 to record these disturbances in a manner similar to mortality, with severity ratings based on the percentage of the stand affected, rather than the intensity of the defoliation to the trees, although the defoliator categories of light, moderate and severe are used.

Cariboo south aerial overview survey crew

Aspen and birch decline (caused by a variety of combined damaging agents) are mapped as light, moderate or severe based on thinning crowns and mortality (Table 1).

If surveyors are uncertain from the aerial signature as to what damaging agent is causing a disturbance, then the damage is mapped by location and severity, tree species affected and as much detail as is known about the agent (e.g. foliar disease, defoliator, etc.) and aerial photos are taken. Local experts are then consulted and, if necessary, ground checks (if damage is accessible) are conducted with photos, samples and site data collected to determine the cause. Ground check information for 2021 is available at: https://www.for.gov.bc.ca/ftp/HFP/external/!publish/Aerial_Overview/2021/, under directory "Ground checks".

There are known limitations with the data collected during the aerial overview survey. Not all damage is visible: for example, needle cast damage often fades dramatically in intensity or the needles fall off before the AOS is conducted. Also, many damage agents that cause significant growth loss and tree defects do not generally produce an aerial signature that can be recorded by the AOS. Thus, damage by agents like mistletoe infections and gall rust are rarely detected during the AOS.

Care must also be taken in interpretation of the data. Area recorded as damaged by a certain forest health factor during past surveys cannot be added cumulatively, as new damage may be

recorded in all or a portion of the same area leading to double counting. Also, the relatively broad intensity classes and known errors of omission must be considered. For example, calculating accurate mortality volume is not possible since the actual number of trees killed (and consequently volume) is not precise. Spatial accuracy of the data can also be lower in areas without clearly visible geographic references and thus can be unreliable for directing site specific operational surveys and treatments.

Despite these survey limitations, FLNRORD Forest Analysis and Inventory Branch have used the overview survey data for example to estimate cumulative and projected volumes of pine killed by the mountain pine beetle, since the data is the most complete record of the outbreak's progress across the province. Similarly, the timber supply impacts of the current spruce and Douglas-fir beetle outbreaks will also be estimated. The annual survey data is also used by districts to estimate non-recoverable pest-caused losses for incorporation into timber supply reviews.

Forest Health Aerial Overview Survey Standards for British Columbia are available at: https://www2.gov.bc.ca/gov/content/industry/forestry/managing-our-forest-resources/forest-health/aerial-overview-surveys/methods.

Aerial Overview Survey 2021

The aerial overview surveys for 2021 commenced on July 6th and were halted on October 7th (Table 2). An unprecedented "heat dome" covered most of the province in late spring, with many high temperature records set. This led to a serious wildfire year that impeded the program significantly due to both a lack of available survey planes and heavy, extensive smoke. Only the Skeena Region was chiefly unaffected by wildfires, but rain and fog resulted in very few good flying days. Several logistical delays at the beginning of the season also hampered the surveys. Hence, the surveys went late this year but eventually had to be halted due to snow accumulating, which masks forest damage. Correspondingly, a total of 641 survey hours were logged, which was the lowest since 2004 and 76.3% of the landmass was flown, the lowest since 2008 (Figure 2: this is a gross estimate as it does not net out non-forested types, but the statistic is comparable year-to-year). Flights averaged 5 hours a day. A total of twenty-four surveyors and ten aircraft companies were involved with the program across the province. A large portion of the Skeena Region couldn't be surveyed, in particular most of the Cassiar TSA. In Omineca Region a portion of Mackenzie TSA wasn't surveyed due to challenging conditions in the mountains and the lack of a nearby fuel source this summer. The rest of the province was covered reasonably well.

Table 2. Flying hours and survey dates by region for the 2021 provincial aerial overview survey.

Regions	Flight hours	Days flown	Survey Dates
Cariboo	104.2	24	July 27th – Oct 8th
Thompson/Okanagan	49.0	11	July 16th – Sept 11th
Kootenay/Boundary	94.3	19	July 10th – Sept 16th
Omineca & Northeast	240.8	47	July 6th – Oct 7th
Skeena	70.5	14	July 11th – Sep 2nd
West & South Coast	82.3	14	July 12th – Sep 1st
Total	**641.1**	**129**	**July 6th – Oct 7th**

Figure 2. Flight paths flown while conducting the 2021 aerial overview survey. Approximately 76% of the province was surveyed this year.

Two survey training courses were held and mentoring flights were conducted with all new surveyors. Quality assurance flights were also completed throughout the province, with feedback provided to the surveyors to improve the quality and consistency of the survey. Covid-19 continued to be a challenge, so safety protocols developed for the program last year remained in place, and no infections occurred.

Composite maps were completed in a timely fashion and then were promptly scanned, geo-referenced and posted at: http://www.for.gov.bc.ca/ftp/HFP/external/!publish/Aerial_Overview/ for use by anyone needing quick access to the draft information. The final provincial summaries of the spatial and tabular data were available on the same site by February 25, 2022.

Despite less coverage of the forested land base this year, total forest damage increased provincially by 14% from 2020 to 6,327,709 ha (Table 3). Bark beetles continued to cause the most damage with 3,206,471 ha of mortality, down from 3,651,065 ha last year. Western balsam bark beetle infestations declined marginally for the fourth consecutive year to 2,556,524 ha, with almost all the damage rated as trace to light. Skeena Region sustained 1,177,766 ha of attack, followed by Omineca Region with 1,001,474 ha. Spruce beetle disturbances also declined (in all regions except Omineca and South Coast) to 470,668 ha. Attack continued to be most prevalent in Omineca Region with 319,260 ha delineated. Six consecutive years of significant attack in this region has resulted in very high cumulative mortality to many mature stands. Douglas-fir beetle damage increased slightly to 106,039 ha, exacerbated by increasing populations in trees weakened by record wildfires in 2017 and 2018. Cariboo Region continued to have the most damage at 81,934 ha mapped. Mountain pine beetle disturbances declined for the second consecutive year to 73,238 ha. Most of the mortality (88%) was trace to light, and occurred in the same general areas as in the past few years.

Insect feeding resulting in foliage damage increased from 1,432,610 ha last year to 2,009,892 ha. Most of the deciduous damage continued to be caused by aspen leaf miner with 1,327,856 ha mapped. Defoliation increased ten-fold in Northeast Region to 469,229 ha, but declined by more than a third in Skeena Region to 406,682 ha. A large aspen tortrix outbreak which began northeast BC last year continued, with 221,849 ha mapped, primarily in Northeast Region. Intensity of damage declined substantially however. Both satin moth and birch leaf miner damage increased this year, to 3,884 ha and 1,229 ha, respectively.

Conifer defoliators continued to be led by two-year-cycle budworm damage with 310,049 ha mapped, primarily in northern BC, where the larvae are in the second year of their cycle. Western spruce budworm defoliation more than tripled since 2020 to 52,981 ha in southern BC. Most of the damage occurred in Cariboo Region in the Fraser River area. A treatment program with *Bacillus*

Table 3. Summary of hectares affected by forest damaging agents as detected in 2021 aerial overview survey in British Columbia.

Damaging Agent	Area Affected (ha)
Bark Beetles:	
Western balsam bark beetle	2,556,524
Spruce beetle	470,668
Douglas-fir beetle	106,039
Mountain pine beetle	73,238
Western pine beetle	1
Unknown bark beetle	1
Total Bark Beetles:	3,206,471
Defoliators:	
Aspen leaf miner	1,327,856
Two-year-cycle budworm	310,049
Large aspen tortrix	222,339
Western spruce budworm	52,981
Western hemlock looper	51,093
Eastern spruce budworm	36,449
Satin moth	3,884
Unknown defoliators	2,061
Birch leafminer	1,229
Balsam woolly adelgid	1,162
Douglas-fir tussock moth	489
Western blackheaded budworm	217
Forest tent caterpillar	51
Larch casebearer	33
Total Defoliators:	2,009,892
Animals:	
Bear	3,551
Deer	101
Hare	31
Porcupine	16
Total Animals:	3,699
Provincial Total Damage:	**6,327,709**

Damaging Agent	Area Affected (ha)
*Diseases:**	
Lophodermella needle cast	19,980
Dothistroma needle blight	17,734
Larch needle blight	11,529
Venturia blight	4,744
White pine blister rust	4,288
Unknown disease	3,379
Large-spored Spruce-labrador tea rust	276
Cottonwood leaf rust	75
Armillaria root disease	54
Laminated root disease	34
Total Diseases:	62,093
Abiotics:	
Wildfires	863,630
Drought (foliage)	108,345
Flooding	20,015
Windthrow	12,623
Yellow cedar decline	11,397
Post wildfire damage	11,000
Frost damage	6,874
Snow/Ice Damage	4,709
Slides	3,716
Redbelt	2,040
Drought (mortality)	558
Aspen decline	398
Unknown abiotic	251
Total Abiotics:	1,045,555

* Disease damage is greatly underestimated in aerial overview survey data

thuringiensis var. *kurstaki* (B.t.k.) was employed on 4,132 ha to control populations in Thompson/Okanagan Region. A western hemlock looper outbreak was in the third consecutive year in BC with a record 51,093 ha of damage delineated. South Coast, Kootenay/Boundary, Cariboo and Omineca Regions were most affected with all experiencing increased defoliation. A B.t.k. treatment program on 46,041 ha to control this defoliator was conducted in Cariboo, Thompson/Okanagan and Kootenay/Boundary Regions. An eastern spruce budworm outbreak in the Northeast Region affected stands for the fourth consecutive year, with 36,449 ha delineated in Fort Nelson TSA. Visible balsam woolly adelgid damage decreased to 1,162 ha, primarily noted in the coastal regions with minor disturbances in Thompson/Okanagan Region. Douglas-fir tussock moth damaged 94 ha in Lillooet TSA of Thompson/Okanagan Region in 2021. The outbreak in Cariboo Region has collapsed so mapping of mortality was conducted, resulting in 394 ha of very severe mortality along the Fraser River in Williams Lake TSA. Western black-headed budworm defoliation was observed on 217 ha in Haida Gwaii TSA of West Coast Region.

Abiotic damage increased four-fold in 2021 to 1,045,555 ha, due to a significant wildfire year with 863,630 ha burnt, predominantly in the southern interior. Over half the damage occurred in Thompson/Okanagan Region, with several very large interface fires that burnt homes as well as forests. Cariboo, Omineca and Kootenay/Boundary Region also sustained substantial wildfire damage, with heavy smoke causing delays to the AOS program. After record breaking early spring temperatures, drought caused foliage damage was noted to have affected 108,345 ha, mainly in southern BC. The damage became most obvious by late summer, so not all of it was captured by earlier surveys. Western redcedar was most affected, followed by Douglas-fir and lodgepole pine. Flooding damage was similar to the last few year with 20,015 ha of mortality recorded in small scattered disturbances throughout BC. Windthrow damaged 12,623 ha across the province with most (9,002 ha) occurring in Northeast Region. A large wind event in late June caused the majority of the damage, located in Fort St. John TSA. Yellow-cedar decline along BC's coastline has been steadily declining for five consecutive years, with 11,397 ha mapped in 2021. Post-wildfire damage declined to 11,000 ha, mainly delineated in Omineca, Cariboo and Skeena Regions. Frost kill of shoots and buds damaged a record 6,874 ha across BC. Snow and ice damage affected 4,708 ha, chiefly in Fort Nelson TSA of Northeast Region. Slide damage across the province accounted for 3,716 ha. Red belt damage rose substantially to 2,040 ha in Northeast Region, mainly in Fort Nelson TSA. Scattered mortality caused by drought affected 558 in the southern half of the province.

Damage caused by disease is known to be underestimated in the AOS, but the data collected is consistent. Disease damage observed in 2021 was less than half that last year, at 62,093 ha. Two pine needle diseases led the damage in 2021. Lophodermella needle cast affected 19,980 ha with the majority (14,471 ha) mapped in Omineca Region. The area where most of the damage was noted was flown early in the survey window, when damage is most visible. Dothistroma needle blight damage doubled over last year to 17,734 ha. Skeena Region sustained 7,677 ha of disturbances. Cariboo and Omineca Region were similarly affected, with 4,735 ha and 4,375 ha mapped, respectively. Larch needle blight also increased substantially, with 11,529 ha of damage observed, primarily in Kootenay/Boundary Region. Venturia blight disturbances in northern BC decreased to 4,744 ha, though some may have been missed due to earlier surveys in susceptible stands and wildfire smoke obscuring the signature. White pine blister rust damage covered 4,288 ha in 2021, chiefly along the south coast of BC. A needle disease affecting 3,379 ha mainly in Northeast Region couldn't be ground confirmed, but it is suspected to be Dothistroma needle blight.

Animal damage that was visible during the AOS (primarily scattered mortality to larger trees), tripled to 3,699 ha since 2020. Black bear feeding continued to cause the majority of the mortality, with 3,551 ha mapped, especially in Northeast Region. Sitka black-tailed deer damage of 101 ha was noted in Haida Gwaii TSA. Minor snowshoe hare and porcupine damage was mapped in northern BC, affecting 31 ha and 16 ha, respectively.

A few other disturbance agents were observed to have damaged trees across BC to a minor extent. Locations, extent, and intensity of damage by specific forest health factors are detailed in the following sections and summarized by host tree species.

Damaging Agents of Pines

Mountain pine beetle, *Dendroctonus ponderosae*

Mountain pine beetle infestations declined provincially for the second consecutive year to 73,238 ha (Figure 3). Damage decreased in all regions, with the exception of a minor increase in the Northeast Region. Intensity of mortality remained low, at 47,275 ha (65%) trace, 17,098 ha (23%) light, 7,874 ha (11%) moderate and 991 ha (1%) severe. The primary host was lodgepole pine though a higher percentage of stands with a component of whitebark pine (17%) were affected. In most cases whitebark pine is being attacked when multi-year infestations slowly move to higher elevation sites from active populations in lower elevation lodgepole pine sites.

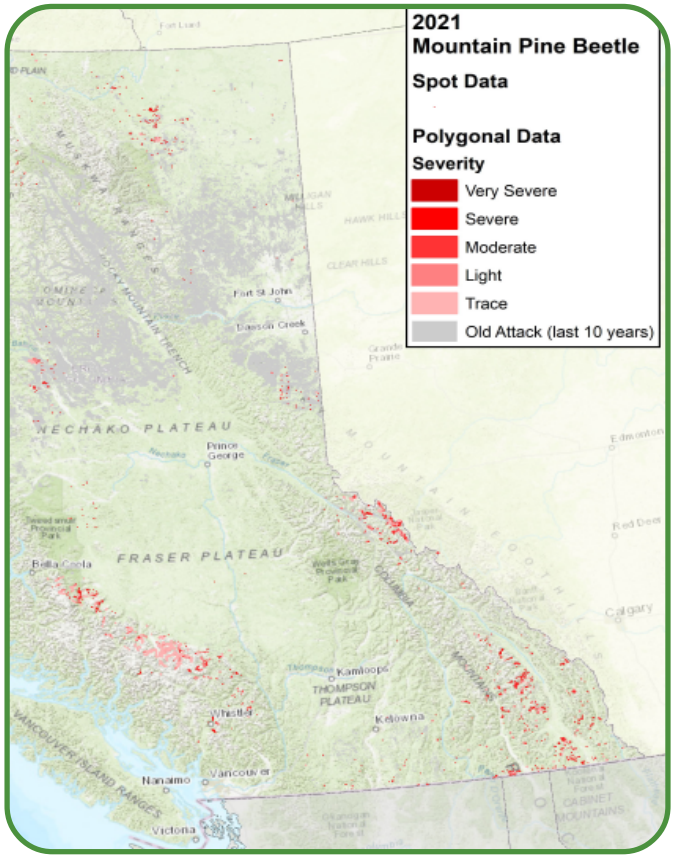


Figure 3. Current mountain pine beetle damage recorded by severity in BC for 2021 with old attack in grey.

All of the 35,530 ha of mountain pine beetle mortality mapped in Cariboo Region occurred in the western half of Williams Lake TSA. Most of the damage continued to be observed from Tatlayoko Lake to Taseko Lake, though some expansion occurred northwestward up to Charlotte Lake.

Attack in Omineca Region totalled 15,851 ha, of which most (15,702 ha) continued to occur in Robson Valley TSA. Infestations were observed in the same general areas as the last few years, primarily from Mount Robson south to Reunion Peak, though disturbance sizes continued to shrink. Mackenzie TSA sustained 145 ha of damage in one small disturbance north of Johia Peak and scattered spots. Only four spot infestations occurred in Prince George TSA.

Mountain pine beetle attack in Kootenay/Boundary Region totalled 7,912 ha in 2021. In general, infestations were small and widely scattered. Invermere TSA continued to be most affected with 4,101 ha delineated, chiefly in the western half of the TSA. Cranbrook TSA was the only TSA where infestations increased, to 1,679 ha. The regional entomologist noted that the attack was associated with smaller diameter stands affected by drought, and higher elevation whitebark pine stands. Kootenay Lake TSA sustained 1,481 ha of damage, and disturbances in other TSAs amounted to less than 400 ha per TSA.

Logdepole pine mortality in Cranbrook TSA due to mountain pine beetle and drought.

Mountain pine beetle disturbances of 4,442 ha were delineated in Great Bear Rainforest North TSA on the eastern boundary west of Charlotte Lake. The highest levels of mortality were observed from Knot Lakes north to Rainbow Lake.

Infestations in Skeena Region occurred in the same general areas as last year, totalling 4,034 ha. Most of the damage (3,839 ha) was observed in Bulkley TSA, primarily north of Fort Babine. Morice TSA infestations declined steeply to only 192 ha, mainly delineated south of Fort Babine. A large disturbance mapped north of Tochcha Lake in 2020 was not active this year, which accounted for the reduced damage. Only a few spot infestations were noted in other TSAs. Cold snaps in 2020 and 2021 in this region were suspected to have contributed to brood mortality.

Of the 3,350 ha damaged by mountain pine beetle in Northeast Region, most (2,977 ha) were delineated in Fort Nelson TSA, chiefly west of Fort Nelson. Dawson Creek TSA sustained 368 ha of attack, primarily around Tumbler Ridge. A total of 5 ha of spot infestations were widely scattered in Fort St. John TSA.

Thompson/Okanagan Region had 1,431 ha of attack with most of the activity (1,380 ha) occurring in the western half of Lillooet TSA. Minor infestations of 35 ha and 16 ha were noted in Merritt and Okanagan TSAs, respectively.

South Coast Region damage totalled 674 ha. Most of this (523 ha) was observed in Soo TSA, chiefly around the Whistler area. All of the 151 ha of attack delineated in Sunshine TSA was around Mount Raleigh in the north and only two spot infestations were mapped in Fraser TSA.

Mountain pine beetle damage covered 13 ha in West Coast Region. This was all mapped in Haida Gwaii TSA in one infestation on Moresby Island.

Pine needle cast, *Lophodermella concolor*

Pine needle cast damage becomes visible the spring after the needles have been infected. Moist conditions are ideal for infections, hence a dry season usually results in low damage the next year and visa versa. After a peak of 90,232 ha of pine needle cast damage in 2017, dry conditions resulted in minimal AOS damage observations for two years. The last two years have generally been wet and cool provincially however and mapped disturbances rose accordingly to 23,152 ha last year and 19,980 ha in 2021. Intensity of damage was rated 13,527 ha (68%) light, 5,937 ha (30%) moderate and 516 ha (2%) severe.

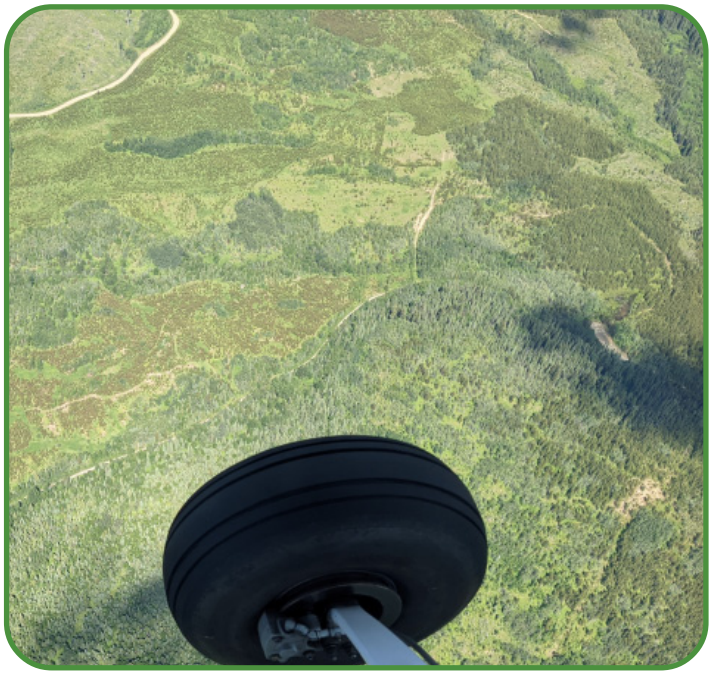
Omineca Region sustained the majority of the damage with 14,471 ha mapped. Several infection sites were ground checked with the disease confirmed from samples by the regional pathologist. Prince George TSA was most affected, with 14,282 ha delineated. This TSA was flown early in the AOS window, when the damage was most visible. Once new growth has fully flushed, this needle cast goes from a vibrant orange/red colour to barely or not visible from the height of the survey. Most of the damage was mapped northeast of Prince George to Takla Landing. A few scattered disturbances west of Mackenzie accounted for 189 ha in Mackenzie TSA.

Damage caused by pine needle cast in Skeena Region totalled 3,127 ha. Lakes TSA contained 1,713 ha north of Babine Lake, and Morice TSA sustained 1,414 ha in a few relatively large disturbances east of Tochcha Lake and north of Natowite Lake.

Thompson/Okanagan Region had 1,720 ha of pine needle cast damage mapped. Infections in Okanagan TSA occurred primarily mid TSA and accounted for 788 ha. Kamloops TSA had 676 ha noted north of Kamloops and Adams Lakes and east of Raft Mountain. Damage in Merritt TSA was 230 ha, located east of Douglas Lake and north of Cascade Recreation Area. Two polygons mapped south of Duffey Lake in Lillooet TSA totalled 26 ha.

Damage in Northeast Region was all located in Dawson Creek TSA, where 441 ha were mapped, scattered around the Tumbler Ridge area. Several of these disturbances were ground checked in a timely fashion and lophodermella needle cast was confirmed from collected samples by the regional pathologist. A total of 9,694 ha of damage with the same aerial signature was observed in this area last year, but collection of ground samples were too late for precise disease identification so it was called unknown foliage disease.

Three polygons west of Dragon Lake in Quesnel TSA of Cariboo Region accounted for 220 ha of damage.



Pine needle cast damage in Prince George TSA

Dothistroma needle blight, *Dothistroma septosporum*

Dothistroma needle blight damage increased dramatically for the second consecutive year, doubling since 2020 to 17,734 ha across the province. Intensity of infections increased as well, to 7,737 ha (44%) light, 8,399 ha (47%) moderate and 1,599 ha (9%) severe. Observed damage locations were almost entirely different than in 2020 though (Figure 4). This could be in part because stands that have been repeatedly infected have a much lower component of needles left to damage, hence the aerial signature is much weaker, compared to stands that are just newly infected (either because they are becoming a more susceptible age, or weather conditions haven't been conducive to infections in that area for a few years). Additionally, wildfires caused survey delays to timing that was not optimal to see this disease in some areas, and smoke resulted in reduced visibility for identification of the sometimes subtle aerial signature.

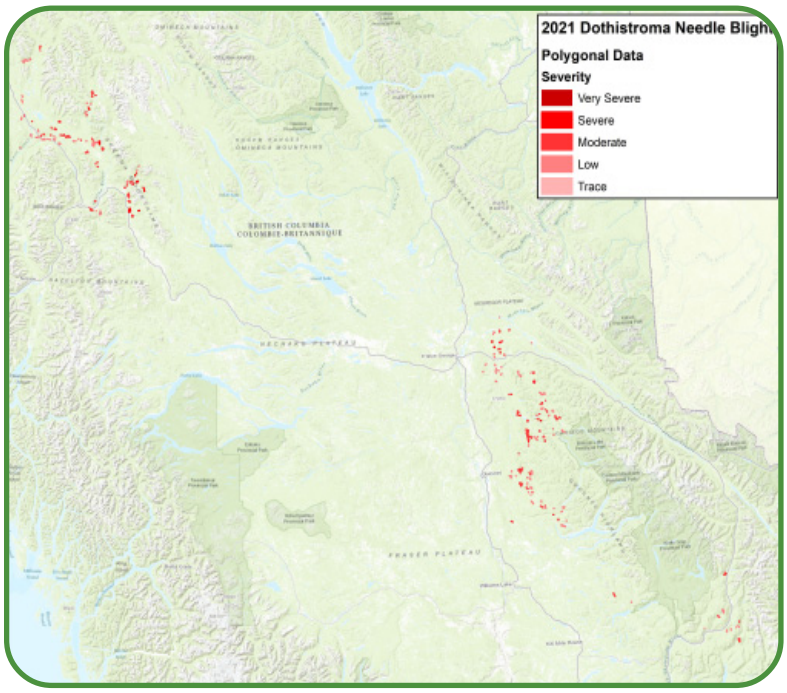


Figure 4. Dothistroma needle blight damage recorded by severity in regions with over 4,000 ha of damage for 2021.

Skeena Region sustained the majority of the damage this year with 7,677 ha mapped, compared to only 288 ha last year. Kispiox TSA had 5,794 ha of Dothistroma needle blight damage scattered throughout susceptible younger lodgepole pine stands. The 1,102 ha mapped in Nass TSA was more concentrated near Nass River. Infected stands in Bulkley TSA totalled 782 ha just east of Witset and Blunt Mountain. Although early weather conditions were unusually hot and dry in this region like the rest of the province, it was unique in that the weather turned rainy in later July through August, so the regional pathologist expects significant 2021 infections will result in high damage levels again next year.

Dothistroma needle blight damage in Quesnel TSA

Dothistroma needle blight damage decreased only slightly in Cariboo Region to 4,735 ha, though the location of mapped damage moved. Quesnel TSA sustained 3,703 ha of disturbances in the eastern half, with concentrations east of Crescent Lake and south of Wingdam. A total of 852 ha were recorded in Williams Lake TSA around the Likely area. The remaining 180 ha were delineated in 100 Mile House TSA north of Canim Lake.

All 4,375 ha mapped in Omineca Region occurred in Prince George TSA from Penny west to Prince George and down to the southern border of the TSA.

Dothistroma needle blight infections decreased from 2,315 ha in 2020 to 925 ha this year in Thompson/Okanagan Region. Kamloops TSA had 778 ha of damage around Blue River and Avola areas. Okanagan TSA had a few small, widely scattered disturbances totaling 147 ha.

Damage in Kootenay/Boundary Region declined to only 24 ha, defined in two small polygons on Bush Arm of Kinbasket Lake.

White pine blister rust, *Cronartium ribicola*

After an increase to 12,696 ha of white pine blister rust damage in BC last year, damage returned to 2019 levels with 4,288 ha infected. Hectares of damage often change substantially from year to year for this rust because most of the disturbances are assessed at trace intensity, which sometimes is better expressed as just spot disturbances in other years. Damage in 2021 was assessed as 3,668 ha (86%) trace, 389 ha (9%) light, 126 ha (3%) moderate and 104 ha (2%) severe. Significantly more spot disturbances were mapped this year, possibly because the visibility was very clear on the coast (where most of the damage was mapped) when the survey of infected stands was conducted, allowing identification of individual trees, even in young stands. Damage was noted in a mix of young and old stands.

West Coast Region sustained 3,377 ha of white pine blister rust damage, primarily along the east coast. Arrowsmith TSA was most affected, with 2,825 ha mapped, with concentrations noted from Nanaimo to Fanny Bay. North Island TSA had 552 ha of damage, mainly from Cumberland to Campbell River and a few disturbances along Highway 19 near Nimpkish.

White pine blister rust damage in South Coast Region totalled 799 ha. Sunshine Coast TSA had 468 ha of infected stands from Gibsons north to Ramsay Arm. Fraser TSA sustained 309 ha of damage, with the largest disturbances located south of Silvertip Mountain. Soo TSA had the remaining 22 ha of disturbances in this region.

A total of 77 ha of damage was noted in the south tip of Great Bear Rainforest South TSA.

Thompson/Okanagan Region continued to be the only interior region with white pine blister rust damage observed, with 35 ha mapped. Okanagan TSA was most affected with 33 ha noted east of Sicamous. A few spots scattered east of Avola in Kamloops TSA accounted for 2 ha of damage.

Scattered white pine blister rust damage in Arrowsmith TSA

Unknown lodgepole pine needle disease

All the unknown needle disease delineated in 2021 occurred in lodgepole pine stands, mainly in younger stands. A total of 3,379 ha were infected, with intensity of damage noted as 274 ha (8%) light, 3,092 ha (92%) moderate and 13 ha (<1%) severe.

Fort Nelson TSA in Northeast Region sustained the bulk of the damage, with 3,343 ha mapped northwest of Boiler Canyon near the Liard River. It was suspected from the aerial signature that the damage was Dothistroma needle blight, but this could not be ground confirmed. Okanagan TSA in Thompson/Okanagan Region had one disturbance of 24 ha noted west of Vernon. Two polygons totalling 24 ha were mapped along Lake Revelstoke north of Carnes Creek in Revelstoke TSA of the Kootenay/Boundary Region. These disturbances were also suspected to be caused by Dothistroma needle blight.

Damaging Agents of Douglas-fir

Douglas-fir beetle, *Dendroctonus pseudotsugae*

Douglas-fir beetle damage increased 7% since 2020 to 106,039 ha across BC (Figure 5). Intensity of mortality was assessed as 71,537 ha (68%) trace, 21,522 ha (20%) light, 9,194 ha (9%) moderate, 3,535 ha (3%) severe and 242 ha (<1%) very severe. Record wildfire damage in 2017 and 2018 that led to scorched, weakened trees and numerous constraints to management of attack most likely contributed to rising Douglas-fir beetle infestations. It is expected that the extensive 2021 wildfire damage in the southern interior may promote beetle populations to continue to build. Unlike last year when a generally cool wet spring resulted in delayed beetle flights and a delay in attacked tree colour change, the unusually hot early spring weather in most areas where Douglas-fir beetle infestations occurred generally resulted in more concentrated, earlier (hence more successful) flights this year.

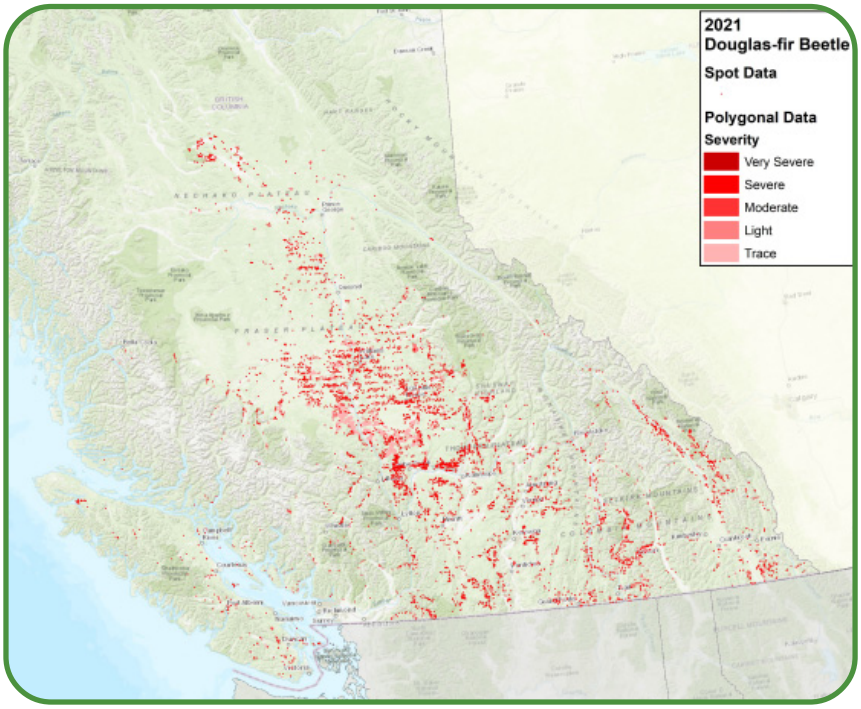


Figure 5. Douglas-fir beetle damage recorded by severity in BC for 2021.

Cariboo Region continued to sustain the highest damage with 81,934 ha delineated, more than three-quarters of the provincial disturbances. Douglas-fir beetle attack was widely dispersed and resulted in large low intensity polygons. For the past three years affected hectares has remained

high, but intensity of attack has been substantially lower than in 2017 and 2018 (Figure 6). Williams Lake TSA contained 41,575 ha of damage, down from down from 57,082 ha last year. Spot infestations were widely scattered, but polygon disturbances were primarily along the Fraser River and tributaries, as well as one large polygon adjacent to Tisdall Lake. Attack in 100 Mile House TSA totalled 39,984 ha with concentrations south of 93 Mile House and north of Canim Lake. This was a four-fold increase since 2020, most likely due to population increases from the 2018 wildfires, in particular the Elephant Hill wildfire. Quesnel TSA experienced small, widely scattered infestations totalling 375 ha.

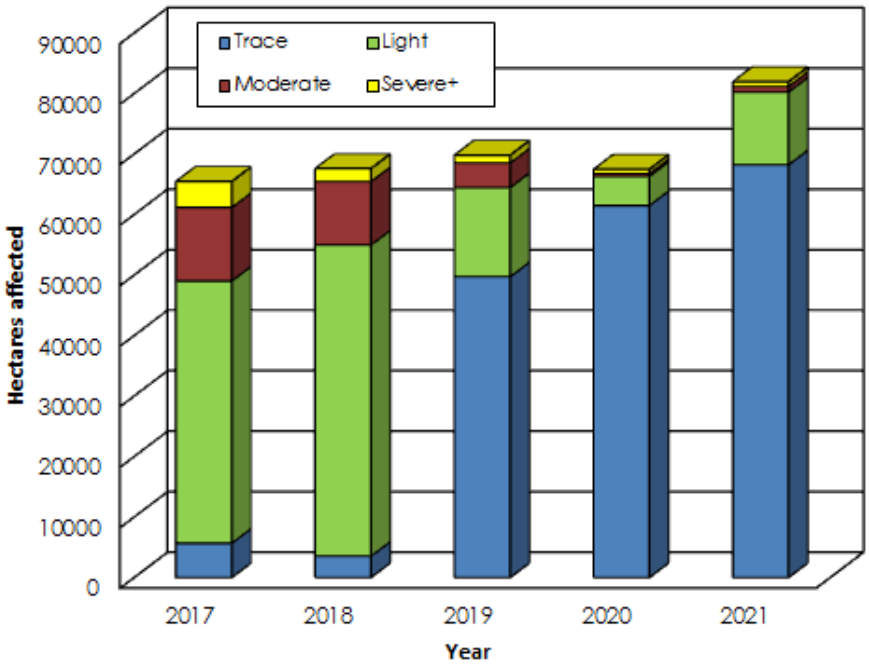


Figure 6. Douglas-fir beetle damage recorded by severity in Cariboo Region from 2017 to 2021.

Damage in Kootenay/Boundary Region rose by almost a quarter since 2020 to 12,831 ha. Douglas-fir beetle attack was highest in Arrow TSA with 5,791 ha delineated, chiefly on steep, dry slopes adjacent to Arrow and Slocan Lakes. Kootenay Lake TSA had 2,071 ha of damage mapped mainly from Balfour west to the TSA border. Infestations scattered at lower elevations in Invermere and Cranbrook TSAs accounted for 1,661 ha and 1,409 ha, respectively. Attack in the remaining TSAs was recorded at under 800 ha per TSA.

Douglas-fir beetle infestations covered 6,607 ha in Thompson/Okanagan Region, down from 8,798 ha last year. This decline may be in part due to many of the 2021 wildfires burning in areas of active Douglas-fir beetle. Kamloops TSA sustained most of the damage, with 5,270 ha delineated, mainly in the southern half of the TSA. Small, widely scattered infestations in Okanagan TSA totalled 914 ha. Merritt Lillooet TSAs experienced minimal attack, with 262 ha and 161 ha recorded, respectively.

Douglas-fir beetle frass

Virtually all of the 1,889 ha of Douglas-fir beetle damage noted in Omineca Region occurred in Prince George TSA (1,885 ha). Most of this was concentrated southwest of Prince George and around Stuart to Trembleur Lakes. Spot infestations in the north and south tips of Robson Valley TSA accounted for the four remaining hectares of attack.

Attack in South Coast Region more than tripled to 1,472 ha. Disturbances in Soo TSA totaled 817 ha, most of which were small and scattered with the exception of one large

polygon east of Mount Oswald. Most of the 632 ha of damage mapped in Fraser TSA was observed in the eastern half, in particular around Skagit Valley. The remaining 23 ha were noted in Sunshine TSA.

Infestations dropped sharply from 9,065 ha in 2020 to 857 ha in West Coast Region. This mainly occurred in the southern portion of Arrowsmith TSA, where several large trace mortality polygons from last year showed no new activity this year. A total of 768 ha were mapped in Arrowsmith TSA and 89 ha in North Island TSA.

Douglas-fir beetle attack in Great Bear Rainforest mainly occurred in Great Bear Rainforest North TSA, where 268 ha were delineated, chiefly south of Bella Coola. Seven spot infestations were noted in Great Bear Rainforest South TSA.

All 178 ha of damage mapped in Skeena Region occurred in Lakes TSA along Francois Lake.

Western spruce budworm, *Choristoneura occidentalis*

Western spruce budworm defoliation more than tripled since last year to 52,981 ha in 2021. Intensity of damage increased as well, to 6,853 ha (13%) light, 37,745 ha (71%) moderate and 8,384 ha (16) severe.

The bulk of the damage continued to be in Cariboo Region, with 49,374 ha affected. The majority was observed in Williams Lake TSA with 36,349 ha of defoliation delineated. All the severe damage in the province was mapped in this TSA. The remaining 13,025 ha of western spruce budworm defoliation in the region occurred in 100 Mile House TSA. All Cariboo Region damage was observed along the Fraser River and adjoining drainages, from Big Bar Mountain north to Williams Lake (Figure 7).

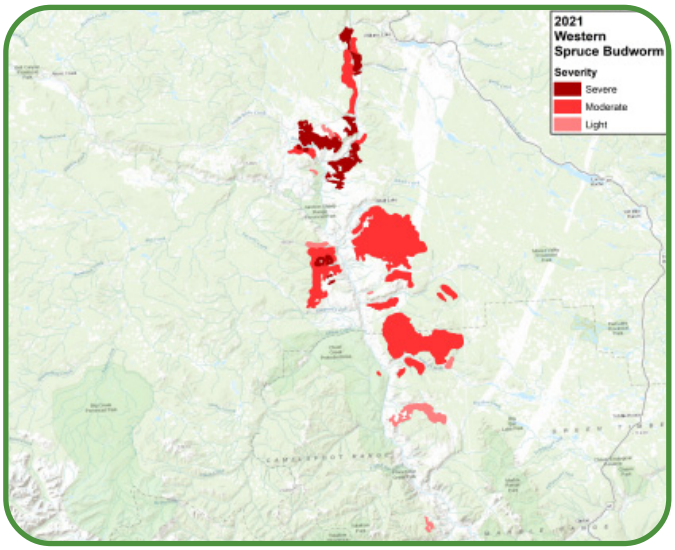


Figure 7. Western spruce budworm damage recorded in Cariboo Region by severity for 2021.

Thompson/Okanagan Region sustained 3,477 ha of western spruce budworm defoliation. Almost all (3,132 ha) occurred in Merritt TSA in the Princeton area. Lillooet TSA had 315 ha delineated north of Shalath and along West Pavilion Road near the Fraser River. Two polygons of damage totalling 30 ha were mapped south of Myra Canyon in Okanagan TSA.

The remaining damage in the province occurred in two small polygons totalling 129 ha west of D'Arcy in Soo TSA of the South Coast Region.

Western spruce budworm egg mass

Table 4. Summary of western spruce budworm defoliation predictions for 2022 based on 2021 egg mass survey results.

Region	TSA	Number of Sites by Defoliation Category			Total Sites
		Nil	Light	Moderate	
Cariboo	100 Mile House	12	13	1	26
	Williams Lake	42	24	3	69
Thompson/ Okanagan	Kamloops	79	27	0	106
	Merritt	38	24	0	62
	Okanagan	32	0	0	32
Kootenay/ Boundary	Boundary	8	10	0	18
	Total	**211**	**98**	**4**	**313**

Egg mass surveys were conducted in the fall of 2021 to predict spring 2022 defoliation, in and around stands with visible defoliation and in areas of historic defoliation in the southern interior (Table 4). As with the 2020 sampling, no sites had a prediction of severe defoliation. Moderate defoliation was predicted only in Cariboo Region, on Meadow Lake Road in 100 Mile House TSA and Joe's Lake Road, 2700 Road and Williams Lake Community Forest in Williams Lake TSA. The remaining sites had either light defoliation predicted, or nil (no egg masses found). Larvae collected in permanent three-tree beating sites (another reflection of population levels) were very low in 2021, possibly due to the extreme heat that was occurring at that time in the southern interior.

Western spruce budworm 6th instar larva

Western spruce budworm defoliation in Lillooet TSA

A spray program was conducted in the spring of 2021 in Thompson/Okanagan Region to control western spruce budworm populations in high value stands. The areas were successfully treated aerially by Western Aerial Applications Ltd. helicopters using *Bacillus thuringiensis* var. *kurstaki* (B.t.k.), formulation Foray 48B®. Treatment occurred in Kamloops TSA on June 24th on two blocks near Deadman and Criss Creeks, covering a total of 4,132 ha.

Douglas-fir tussock moth, *Orgyia pseudotsugata*

Douglas-fir tussock moth larva

The most recent Douglas-fir tussock moth outbreak in the southern interior of BC peaked in 2019 with 2,708 ha of damage. Observed 2020 defoliation was 130 ha, declining to 94 ha in 2021. However, the location of the 2021 damage was new, along the Fraser River in Lillooet TSA of Thompson/Okanagan Region. Intensity of defoliation was rated as 9 ha (10%) light, 6 ha (6%) moderate and 79 ha (84%) severe.

Douglas-fir tussock moth damage mapped in 2019 and 2020 in Cariboo Region along the Fraser River showed no new activity during the AOS in 2021 and ground surveys confirmed a collapse of the outbreak in this region. Hence, an assessment was made of the mortality resulting from the outbreak. A total of 394 ha of very severe mortality were delineated along the Fraser River in Williams Lake TSA. Defoliation noted in Thompson/Okanagan Region the past few years and to a lesser extent in the Kootenay/Boundary Region was not visible in 2021.

The moth populations are monitored in historical outbreak areas with pheromone-baited traps. The average trap catches are summarized in Table 5, but detailed results are available in the *2021 Overview of Forest Health Conditions in Southern British Columbia* Report. Average trap catches plummeted throughout the monitored areas in 2021, with less than 1 moth caught per site. An additional 14 temporary monitoring trap sites were monitored in the 2019 outbreak area of Williams Lake TSA, and these traps caught an average of 1 moth per trap. All of these catches indicate the end of this outbreak cycle.

Table 5. Average number of male Douglas-fir tussock moths caught per trap 2017 – 2021 in six trap clusters, by TSA and sub area, if applicable, with number of sites in brackets.

TSA	Average moth catch per site				
	2017	2018	2019	2020	2021
Kamloops (9)	6.7	8.8	13.7	15.9 (7)	0.10
Kamloops (West 11)	4.5	3.8	14.6	13.0 (13)	0.03
Okanagan (8)	7.1	14.4	8.6	8.4	0.47
Merritt (9)	8.8	26.0	18.2	15.6 (10)	0.15
Boundary (8)	1.3	2.3	5.0	5.7 (9)	0.30 (9)
100 Mile House (16)	2.4	1.8	5.3	0.7	0.01

Douglas-fir tussock moth populations and other defoliators of drybelt Douglas-fir are monitored by conducting three-tree beatings to collect larvae in historical outbreak areas. Larval catches were consistently low at these sites, which also indicates that populations are low. Similar to 2020, catches at these sites of false hemlock loopers and western hemlock loopers were higher than Douglas-fir tussock moths, which supports the observed outbreak cycle of these insects in both Douglas-fir and hemlock forests in the southern interior.

Laminated root disease, *Coniferiporia sulphurascens* (= *Phellinus sulphurascens*)

Laminated root disease mortality is prevalent in southern BC but is known to be under-estimated by the AOS due to the subtle signature it expresses at the height of the survey, combined with compounding forest health factors such as Douglas-fir beetle and drought. Often local ground knowledge is the main indicator of laminated root disease damage. Damage mapped in 2021 declined from 436 ha last year to only 34 ha in 2021. Intensity of mortality was assessed as 18 ha (53%) trace and 16 ha (47%) severe.

A total of 28 ha of damage was delineated in West Coast Region. Most of this (25 ha) occurred in Arrowsmith TSA, with one trace polygon west of Fanny Bay and the rest of the damage mapped in spots. North Island TSA had 3 ha of observable damage in scattered spots. The remaining 6 ha of laminated root disease damage was mapped in scattered spots in South Coast Region.

Damaging Agents of Spruce

Spruce beetle, *Dendroctonus rufipennis*

Spruce beetle infestations in BC decreased 10% from 2020 to 470,668 ha of damage (Figure 8). Attack declined in all regions except for South Coast and Omineca Regions. Severity of attack increased somewhat to 120,986 (26%) trace, 283,157 ha (60% light, 59,117 ha (12%) moderate, 7,344 ha (2%) severe and 65 ha (<1%) very severe. All regions continued to sustain some spruce beetle mortality.

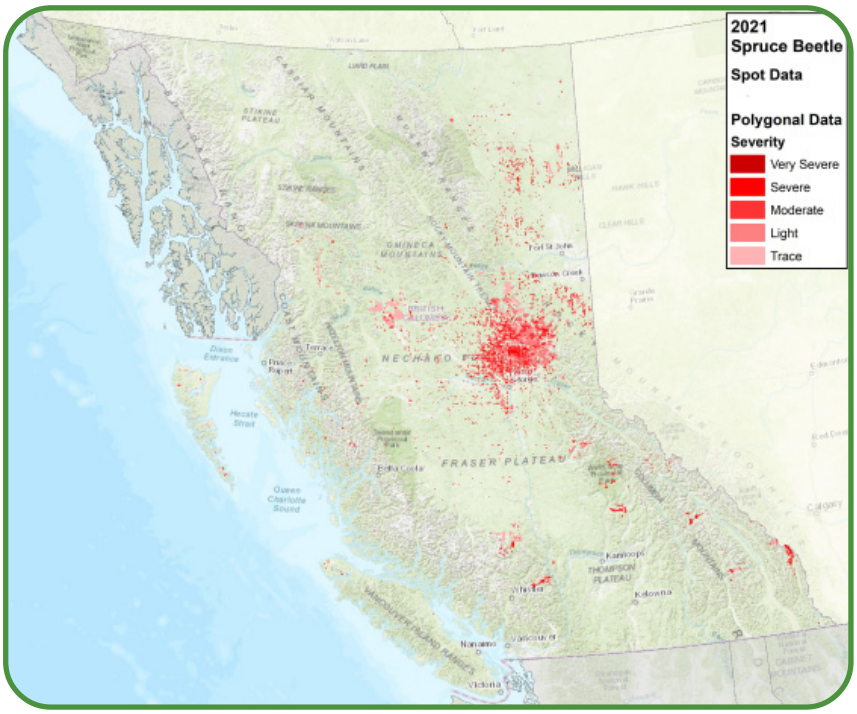


Figure 8. Spruce beetle damage recorded by severity in BC for 2021.

Omineca Region continued to have the highest level of attack in the province with 319,260 ha delineated. This represented two-thirds of the spruce beetle damage mapped in BC in 2021. Proportionally, intensity of attack remained low, at similar levels to the last four years (Figure 9). However, six consecutive years of damage over 200,000 ha per year, often within the same stands, has resulted in very high cumulative mortality in many mature stands. Prince George TSA continued to be most affected with 287,588 ha mapped, primarily in the north half of Prince George TSA. Younger trees are being attacked in areas where the mature spruce component is dead and/or populations are very high. However, an aerial survey of young (25 to 48 year old) spruce-leading stands chosen for fertilization in Prince George TSA was conducted in the summer to assess spruce beetle

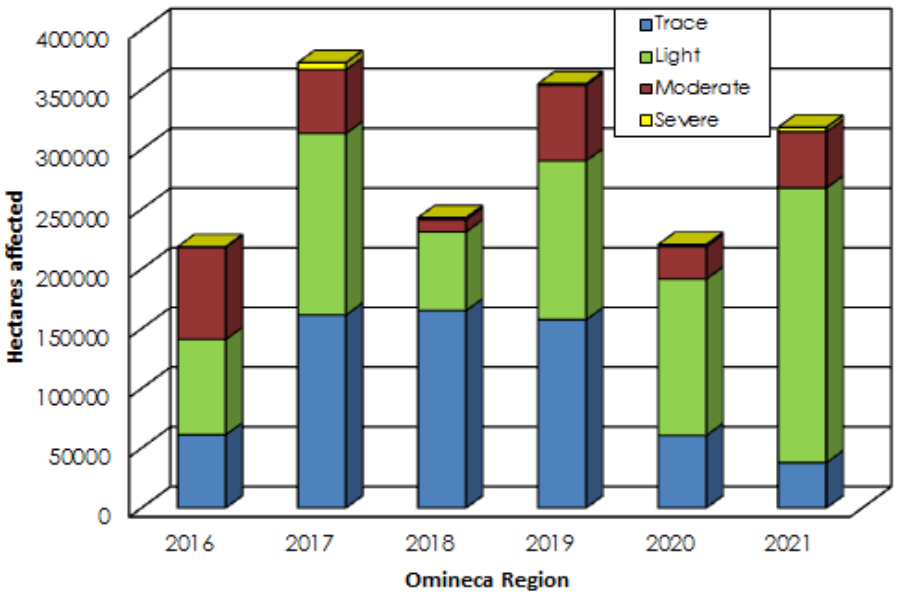
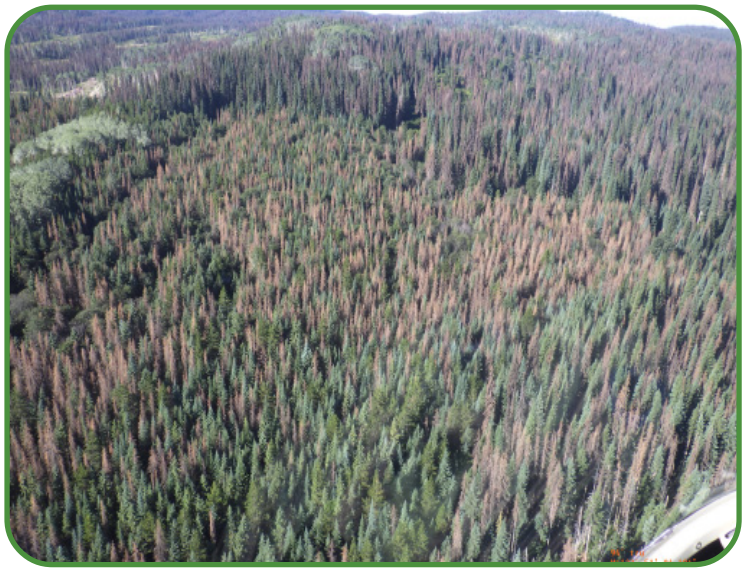


Figure 9. Spruce beetle damage recorded by severity in Omineca Region from 2016 to 2021,

mortality. Of these stands, trees under 40 years old showed no sign of mortality, though pockets of attack were noted in the 40 to 48 year old stands. The main infestation continued into the southern tip of Mackenzie TSA, where 30,892 ha were affected. Spruce beetle mortality in Robson Valley TSA remained low with 780 ha mapped, chiefly in the southern tip below Mount Blackman.

Spruce beetle damage in Northeast Region totalled 73,206 ha. Dawson Creek TSA was most affected, with 61,701 ha delineated, primarily along the western edge. Attack in Fort St. John TSA totalled 8,864 ha, principally in small, scattered infestations with a few larger polygons mapped near the northern edge. Fort Nelson TSA sustained 2,641 ha of attack scattered throughout the TSA, with one concentration of damage northwest of Tetsa River regional campground.



Previously fertilized 46 year old stand in Prince George TSA attacked by spruce beetle

Skeena Region attack declined to 51,918 ha, which was only a third of that mapped in 2020. Cold snaps in 2020 and 2021 may have led to a reduction in brood survival, but also one large infestation noted last year in the southern part of Cassiar TSA couldn't be flown this year. Morice TSA contained 29,946 ha of damage, chiefly in the northern tip. Attack in Bulkley TSA totalled 11,002 ha, mainly mapped just north of Fort Babine. Spruce beetle infestation in Kispiox TSA covered 6,683 ha, primarily as an extension of the Fort Babine infestation and around Swan Lake/Kispiox River Provincial Park. Nass TSA had 2,906 ha of damage, scattered around the northeastern portion of the TSA. All other TSAs in this region sustained less than 1,000 ha of attack per TSA.

Adult spruce beetle

Cariboo Region had 11,077 ha of spruce beetle damage mapped. Most (10,498 ha) was delineated in Williams Lake TSA, predominantly in the southern tip around the Big Creek Provincial Park area. Small, widely scattered infestations accounted for 579 ha in Quesnel TSA.

Spruce beetle attack in Thompson/ Okanagan Region covered 6,504 ha. Kamloops TSA sustained 3,835 ha of damage, primarily around Vavenby and in Wells Gray Provincial Park. The remaining 2,669 ha of damage was observed in Lillooet TSA, north of Stein Valley and around South Chilcotin Mountains Provincial Park.

Kootenay/Boundary Region had 6,371 ha of attack recorded in 2021. Golden TSA was most affected with 2,218 ha delineated, mainly around Glacier National Park and north of Mount Shackleton. Cranbrook TSA had similar levels of damage with 2,123 ha mapped chiefly in the Elk Valley area.

Spruce beetle mortality

Infestations in West Coast Region accounted for 1,856 ha of damage. Most (1,700 ha) was observed in Haida Gwaii TSA. This was a relatively large increase and though the aerial signature looked like spruce beetle, the attack was not ground confirmed. North Island TSA had 155 ha of attack, mainly northwest of Coal Harbour. Three spots of mortality were noted in Arrowsmith TSA.

Great Bear Rainforest North TSA had small, scattered spruce beetle infestations totalling 455 ha.

Only 22 ha of spruce beetle damage was mapped in South Coast Region, with all but a few spots recorded in Fraser TSA of Manning Park.

Large-spored spruce-labrador tea rust, *Chrysomyxa ledicola*

A total of 276 ha of light large-spored spruce-labrador tea rust damage was mapped in Fort Nelson TSA of Northeast Region in 2021, down significantly from 10,281 ha in the same region last year. The damage was noted in 8 polygons clumped south of the Fort Nelson and Liard Rivers confluence. The surveyors noted it could also be due to a nutrient deficiency (not ground checked) but large-spored spruce-labrador tea rust has historically been a problem in this TSA (including last year) and the aerial signature looked like it was caused by this disease.

Eastern spruce budworm, *Choristoneura fumiferana*

An eastern spruce budworm outbreak began in 2018 in the Northeast Region, primarily along the Liard River in Fort Nelson TSA, with 35,753 ha of defoliation delineated. Observed damage declined substantially in 2019 and 2020, to 3,885 ha and 7,268 ha, respectively.

In 2021 however, the outbreak rebounded to 36,449 ha, with disturbances noted in similar locations as in 2018 in Fort Nelson TSA (Figure 10), along the Liard River and Beaver River on the Yukon border. Defoliation intensities increased as well, to 10,007 ha (28%) light, 21,584 ha (59%) moderate and 4,858 ha (13%) severe.

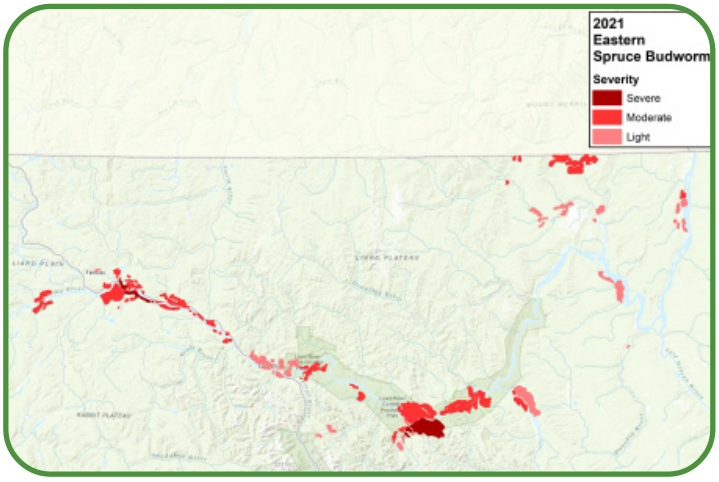


Figure 10. Eastern spruce budworm damage recorded by severity in Northeast Region for 2021.

Eastern spruce budworm defoliation in Fort Nelson TSA

Damaging Agents of True Fir

Western balsam bark beetle, *Dryocoetes confusus*

Western balsam bark beetle damage decreased slightly for the fourth consecutive year to 2,556,524 ha in BC (Figure 11). Intensity of mortality declined as well, to 2,231,876 ha trace (87%), 297,353 ha light (12%), 25,287 ha moderate (1%) and 2,008 ha severe (<1%). Infestations continued to be widespread throughout subalpine fir leading stands, with a minor percentage of amabilis fir attacked in South Coast Region. Attack decreased in all regions with the exception of the southern interior, where drought may have contributed to tree susceptibility.

Although infestations declined by 15% in Skeena Region, this region was still the most affected provincially with 1,177,766 ha of damage mapped. A total of 369,251 ha were infested throughout Morice TSA, with highest concentrations in the southwest. Attack in Bulkley TSA accounted for 215,106 ha, primarily north of Smithers to Fort Babine. All the damage in Nass TSA (203,886 ha) was noted in the northeastern half. Large scattered infestations in Kispiox TSA accounted for 202,503 ha. The 146,565 ha of damage observed in Lakes TSA was chiefly in the southwest and

north of Taltapin Lake. Attack mapped in Cassiar TSA dropped substantially to 31,992 ha but this was mainly due to a large northern portion of the TSA not being flown in 2021. The remaining 8,463 ha recorded in the region was in Kalum TSA on the eastern edge near Burnie Peak.

Omineca Region sustained 1,001,474 ha of western balsam bark beetle damage. Infestations in Prince George TSA totalled over half the attack with 571,024 ha. Mackenzie TSA had 333,352 ha of disturbances, primarily from the top end of Williston Lake southward. Over half of the higher intensity mortality (light and greater) occurred in this TSA in the Gauvreau Peak area. A total of 97,098 ha were impacted in Robson Valley TSA, in disturbances scattered throughout the TSA.

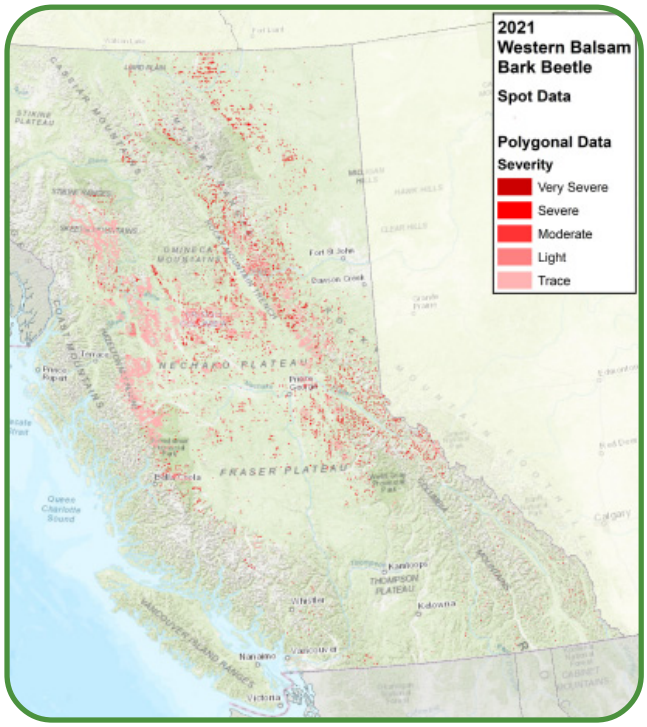


Figure 11. Western balsam bark beetle damage recorded by severity in BC for 2021.

Western balsam bark beetle attack affected 166,998 ha in Northeast Region. Disturbances mapped in Dawson Creek TSA totalled 116,104 ha, primarily noted along the western boundary. Fort Nelson TSA had 39,092 ha of damage observed, chiefly mid TSA. Infestations were small and scattered in Fort St. John TSA, accounting for 11,802 ha.

Cariboo Region had 76,410 ha of western balsam bark beetle damage mapped in 2021. Infestations of 44,824 ha were noted in Williams Lake TSA, primarily east of Likely and around Chilko Lake. Quesnel TSA sustained 31,136 ha of damage, of which most occurred east of Cottonwood. 100 Mile House TSA was minimally affected, with 449 ha delineated mainly north of Canim Lake.

Western balsam bark beetle caused mortality in Bulkley TSA

Great Bear Rainforest had 46,914 ha of attack, all of which except for 7 ha was mapped in Great Bear Rainforest North TSA. Of this, the majority of the damage was noted east of Bella Coola.

Infestations increased almost a third since last year in Thompson/Okanagan Region to 42,572 ha. Kamloops TSA sustained 20,502 ha of damage particularly north of Little Fort. Attack in Okanagan TSA accounted for 9,458 ha, delineated in small, scattered disturbances. Lillooet TSA had 8,734 ha of mortality dispersed throughout the western two-thirds of the TSA. Damage in Merritt TSA was concentrated along the western boundary and east of Princeton, with 3,878 ha mapped.

Overall damage by western balsam bark beetle increased in Kootenay/Boundary Region to 37,880 ha. Infestations were generally small and widely scattered. Golden and Invermere TSA were similarly affected, with 11,052 ha and 10,154 ha of mortality recorded, respectively. Attack in Cranbrook TSA totalled 7,763 ha with the majority of the damage located north of Sparwood. Kootenay Lake TSA had 3,675 ha impacted, particularly northwest of Kaslo. Infestations in Arrow and Revelstoke were similar, with 2,460 ha and 2,449 ha affected, respectively. The remaining 327 ha of damage was noted in Boundary TSA.

South Coast Region had 6,510 ha of western balsam bark beetle infestations in 2021. Most, 4,574 ha, was mapped in Fraser TSA, chiefly in the Manning Park area. Soo TSA sustained 1,447 ha of attack and Sunshine Coast TSA 489 ha.

Two-year-cycle budworm, *Choristoneura biennis*

Two-year-cycle budworm defoliation covered 310,049 ha provincially in 2021. Intensity of attack was assessed as 146,526 ha (47%) light, 159,158 ha (51%) moderate, and 4,365 ha (2%) severe. The majority of the damage occurred in the northern part of BC, where the larvae are in the second year of their cycle (Figure 12).

A total of 227,374 ha were affected in Skeena Region, which is a record since the province assumed responsibility for the AOS in 2001. Although damage was widespread, it was noted by the surveyors that it was still quite elevationally banded, not in the high alpine or the valley bottoms. Damage in Bulkley TSA accounted for 94,263 ha, all mapped northeast of Highway 16. In Morice TSA 90,099 ha of defoliation was recorded north of Topley. Disturbances totalling 29,305 ha in Kispiox TSA all occurred around Gunanoot Lake. Lakes TSA had 13,708 ha delineated north of Burns Lake.

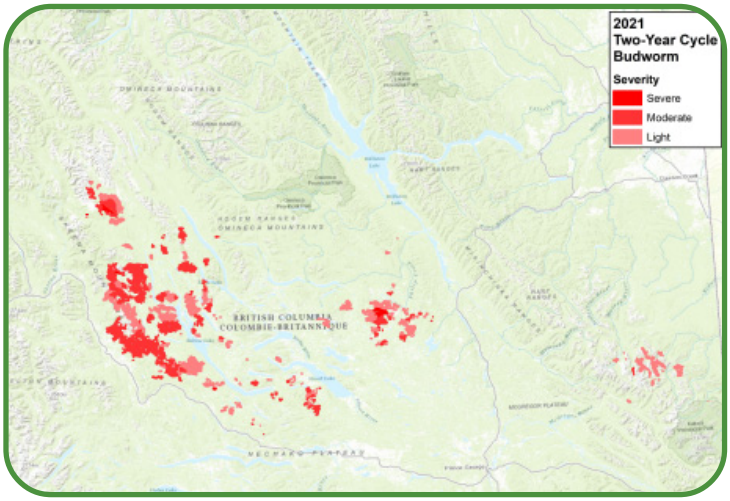


Figure 12. Two-year-cycle budworm damage recorded by severity in regions with greater than 5,000 ha of damage for 2021.

Two-year-cycle budworm defoliation is often highest provincially in odd numbered years in Omineca Region, but this year it was second with 60,892 ha affected. Prince George TSA sustained 50,953 ha of attack around Salmon and Takla Lakes. Damage in Mackenzie TSA was all in the Philips Lake area on the southern border, totalling 9,939 ha.

Disturbances of 15,548 ha in Northeast Region were all located in Dawson Creek TSA in the Wapiti Lake area.

Cariboo Region had 4,628 ha of moderately rated two-year-cycle budworm defoliation, all located southeast of Windy Mountain in 100 Mile House TSA. This infestation was ground checked, and it was determined that the two-year-cycle budworm defoliation aerial signature was exacerbated by bud frost damage.

Two-year-cycle budworm disturbances in Thompson/Okanagan Region totalled 1,534 ha, of which most (1,525 ha) was located in Kamloops TSA. Some was an extension of the Windy Mountain disturbance with a few other polygons delineated around Clearwater. Two small disturbances west of Stemwinder Provincial Park in Okanagan TSA accounted for the remaining 9 ha in the region.

Two-year-cycle budworm defoliation near Windy Mountain in 100 Mile House TSA

Kootenay/Boundary Region sustained 73 ha of visible attack. One disturbance of 50 ha was noted between Highway 6 and Mount Dundee in Arrow TSA, and one disturbance of 24 ha was located between Highway 6 and Red Mountain in Kootenay Lake TSA.
Pheromone trap monitoring continued this year in the Elk Valley of Cranbrook TSA, and though catches were down from last year (which was a mature larvae year) they still indicated a chronic issue in this area. The regional entomologist noted cumulative defoliation is extensive to both the mature and understory spruce and sub-alpine fir here, which has predisposed the mature spruce trees to extensive spruce beetle attacks.

Balsam Woolly Adelgid, *Adelges piceae*

After a record observed balsam woolly adelgid damage in 2020 of 5,159 ha (though almost all was of trace intensity) noted disturbances dropped to 1,162 ha in 2021. Intensity of recorded damage increased substantially however, to 681 ha (59%) trace, 418 ha (36%) light, 39 ha (3%) moderate and 24 ha severe (2%, all spot infestations). All disturbances were small and generally scattered.

For the first time since 2019 damage was highest in South Coast Region, with 464 ha mapped. Both Fraser and Sunshine TSAs sustained 209 ha of damage, with 47 ha delineated in Soo TSA.

Great Bear Rainforest had 352 ha of damage, most of which was observed in the south TSA (330 ha).

West Coast Region sustained 337 ha of balsam woolly adelgid damage in 2021. North Island TSA had 234 ha of damage located in the northern tip of the TSA and in one infestation adjacent to Gold Lake. Arrowsmith TSA contained 103 ha in one polygon at the north tip of Henderson Lake.

Balsam woolly adelgid damage continued to be low in Thompson/Okanagan Region, where only 8 ha were noted in Merritt TSA between Boston Bar and Kingsvale.

Damaging Agents of Hemlock

Western hemlock looper, *Lambdina fiscellaria lugubrosa*

2021 marked the third year of a western hemlock looper outbreak in BC. A total of 51,093 ha of current defoliation was mapped across the province (Figure 13), which is a record since the provincial government became responsible for the AOS in 2001. Intensity of damage subsided in the severe category but increased in moderate since 2020, with 30,736 ha (60%) light, 16,515 ha (32%) moderate and 3,842 ha (8%) severe. Ground checks continued to be conducted to confirm the causal agent in several areas. Defoliation was most common to hemlock, but western redcedar and Douglas-fir were also significantly damaged in some areas. To a lesser extent, true firs and spruce were affected.

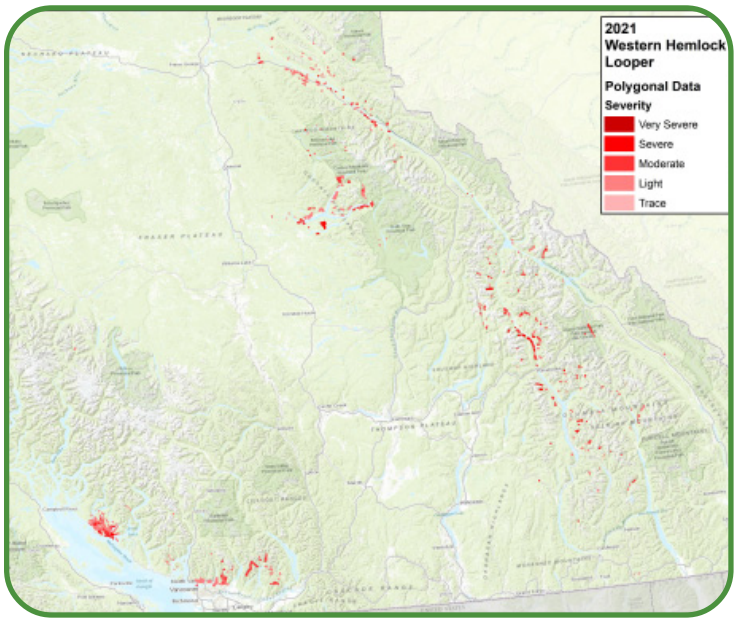


Figure 13. Western hemlock looper damage recorded by severity in BC for 2021.

Western hemlock looper defoliation doubled in South Coast Region since 2020 to 20,806 ha. In Sunshine Coast TSA, active infestations totalling 10,428 ha were concentrated around Powell River. Fraser TSA, where the outbreak was initiated, had 10,297 ha of damage from West Vancouver east to Chehalis Lake, where damage intensity was observed to be declining. Two small infestations amounting to 82 ha were noted in southern Soo TSA.

Western hemlock looper defoliation in Sunshine Coast TSA

Kootenay/Boundary Region sustained 13,209 ha of western hemlock looper defoliation in 2021, up from 4,339 ha last year. Infestations were smaller and more scattered than in South Coast Region, and wildfire smoke made intensity of damage difficult to determine in some areas. Revelstoke TSA was most affected, with 8,243 ha of defoliation mapped. The highest concentrations were noted along Lake Revelstoke. A total of 2,355 ha were delineated in Arrow TSA, primarily north of Selkirk Mountains. Golden TSA sustained 1,509 ha of damage, chiefly east of Rogers Pass and around Cummins Lakes Provincial Park. Infestations in Kootenay Lake TSA covered 971 ha, with concentrations east of Kaslo and along Big Climb Creek. The remaining 131 ha were in one polygon east of Harrogate in Invermere TSA.

Infestations in Cariboo Region declined 60% since 2020 to 10,432 ha. Almost all the attack (10,074 ha) was mapped in Williams Lake TSA in the Quesnel Lake area. Quesnel TSA sustained 357 ha of damage in small disturbances around the Bowron Lakes chain.

For the first time in this outbreak, western hemlock looper defoliation was mapped in Omineca Region, accounting for 6,088 ha of damage. Disturbances were highest in Prince George TSA, primarily from Purden Lake southeast along Highway 16. This damage continued along Highway 16 into Robson Valley TSA, where 1,897 ha were delineated.

Damage in Thompson Okanagan Region declined to 562 ha. Most of this (497 ha) was mapped in Okanagan TSA, chiefly in the northern tip around Upper Seymour River Provincial Park. The remaining 65 ha was observed in Kamloops TSA around Clearwater Lake.

Average western hemlock moth catches at permanent monitoring sites in the southern interior were variable in 2021 (Table 6). Average catches in Revelstoke TSA of Kootenay/Boundary Region continued to steadily increase to a high of 1,476 moths. Catches declined somewhat at two sites, but increased in nine, with highest catches at Begbie Creek, Pitt Creek Rec Site and Goldstream River. In Thompson/ Okanagan Region, catches in Kamloops TSA declined to 426 moths from a peak of 515 in 2020. In Okanagan TSA the decline was even greater, from 427 moths last year to only 79 in 2021. As per 2020, 15 additional sites were monitored along the Fraser River in Cariboo Region primarily for Douglas-fir tussock moth, but western hemlock looper moths were also caught. Average catches per trap were 137 last year, but declined to 21 in 2021.

Table 6. Average number of western hemlock looper male moths caught per trap at various FLNRORD monitoring sites (6-trap clusters per site), 2016 - 2021. Number of sites in brackets.

Year	TSA (# sites)		
	Kamloops (6)	Okanagan (10)	Revelstoke (11)
2016	1	10	2
2017	50	27	9
2018	120	184	68
2019	140	250	269
2020	515	427	1079
2021	426	79	1476

Another monitoring tool for defoliating insects is three-tree-beatings (3TB) to assess defoliator richness and abundance. These are conducted annually in the southern interior in traditional outbreak areas. Catches in Golden, Revelstoke and Arrow TSAs (at a total of 24 sites) in Kootenay/ Boundary Region declined slightly from a total of 492 last year to 475. Highest numbers were observed at Beaver River, Martha Creek and Pitt Creek Rec Site. Larvae caught in 16 western hemlock looper 3TB sites in Thompson/Okanagan Region declined from 109 last year to 30 in 2021, with no counts over 7 per site. Ten permanent sites around the Quesnel Lake area in Williams Lake TSA of Cariboo Region had greatly reduced numbers since 2020, from 249 larvae to only 10. It is suspected in general that populations were lower overall than they would have been, due to the record high temperatures that occurred across the southern interior in the spring and targeted spray programs in areas of highest population density.

A spray program was conducted in the spring of 2021 to control western hemlock looper infestations in high value stands. The areas were successfully treated aerially by Western Aerial Applications Ltd. helicopters using *Bacillus thuringiensis* var. *kurstaki* (B.t.k.), formulation Foray 48B®. Treatment

was a challenge as it occurred during record temperatures which impacted viable spray windows. Cariboo Region treated 9 blocks around Quesnel Lake from July 5th to 11th. A total of 18,902 ha were sprayed. In Thompson/Okanagan Region a total of 16,956 ha were treated from Jun 25th to July 2nd. Two blocks were located in Kamloops TSA near Inks and Duffy Lakes, and six additional blocks were in Okanagan TSA in North Shuswap, Perry River, Crazy Creek and 3-Valley Gap areas. Two additional areas planned for treatment were dropped due to a spring collapse in target insect population. Kootenay/Boundary Region treated 10,183 ha, over 25 blocks, from June 28th to July 3rd. The sites were all north of Revelstoke, along Revelstoke and Kinbasket Lakes in Revelstoke TSA.

Western hemlock looper larva

Western blackheaded budworm, *Acleris gloverana*

The last western blackheaded budworm outbreak peaked at 87,497 ha in 2010. Outbreaks by this budworm tend to be cyclical, starting in Haida Gwaii TSA of West Coast Region, then moving southward. In 2019, 370 ha of light defoliation was mapped in Haida Gwaii TSA, but nothing was observed in 2020. This year, 217 ha of damage occurred at the north and south tips of Graham Island in Haida Gwaii TSA on south facing slopes. The defoliation intensity was rated as 197 ha (91%) light, and 20 ha (9%) moderate.

Damaging Agents of Larch

Larch needle blight, *Hypodermella laricis*

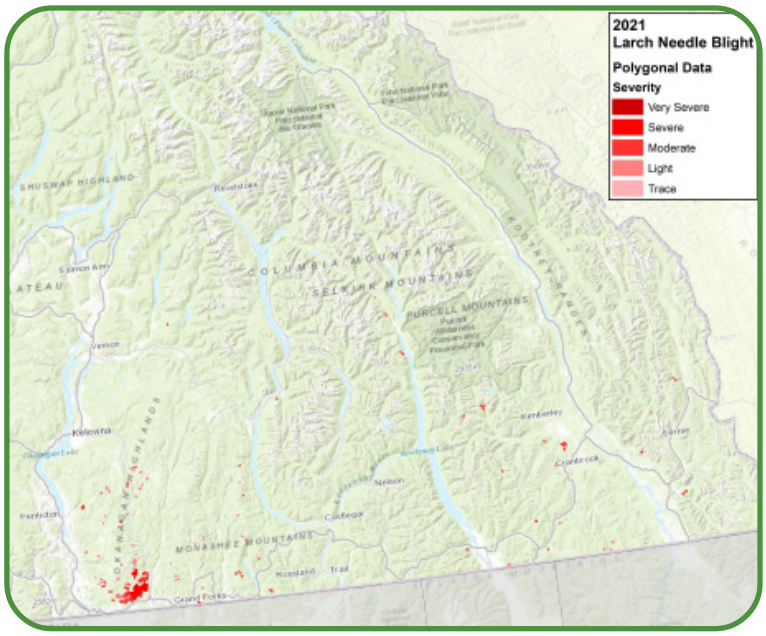


Figure 14. Larch needle blight damage recorded by severity in BC for 2021.

Larch needle blight infected 11,529 ha in 2021 (Figure 14), which was the highest level recorded since a peak of 31,330 ha in 2012, and up substantially from only 1,530 ha last year. Intensity of damage increased as well, with 18 ha (<1%) trace, 2,774 ha (24%) light, 4,388 ha (38%) moderate and 4,349 ha (38%) severe.

Larch needle blight historically causes the most damage in Kootenay/Boundary Region, and this trend continued in 2021 with a total of 10,847 ha mapped. Most of the damage (9,189 ha) was observed in Boundary TSA, primarily from Conkle Lake to Bridesville. A total of 1,043 ha of larch needle blight damage occurred in the western third of Cranbrook TSA, with

the largest disturbances northwest of Cranbrook. Smaller polygons, primarily north and south of Argenta, totalled 492 ha in Kootenay Lake TSA. Minor disturbances affected less than 70 ha in each of Arrow, Invermere and Golden TSAs. The damaging agent was ground confirmed in several areas.

In Thompson/Okanagan Region, 681 ha of scattered larch needle blight damage was mapped in the southeastern portion of Okanagan TSA.

Larch casebearer, *Coleophora laricella*

For the second consecutive year, larch casebearer defoliation was observed in Kootenay/Boundary Region. This is an introduced defoliator that has caused minor damage in the region since 1966, with a record 180 ha of damage mapped last year. In 2021, disturbances decreased in both size and intensity for a total of 33 ha of light defoliation. Damage was noted in the same general areas as 2020, when the damaging agent was ground confirmed.

Two polygons totalling 24 ha were mapped in Cranbrook TSA between Mount Irene and Highway 3. One additional polygon of 9 ha occurred in Arrow TSA north of Lost Mountain.

Damaging Agents of Cedar

Yellow-cedar decline

After a record 57,875 ha of yellow-cedar decline was recorded along BC's coastline in 2016, observed damage has been steadily declining with a total of 11,397 ha mapped in 2021 (Figure 15). Mortality intensity was assessed as 4,201 ha (37%) trace, 2,626 ha (32%) light, 1,375 ha (12%) moderate and 2,195 ha (16%) severe. Most of the identified damage occurred in small polygons or spots scattered along coastal inlets and islands.

Yellow-cedar decline was delineated on 7,802 ha in the Great Bear Rainforest. Most, (6,562 ha) was mapped in Great Bear Rainforest North. Damage in Great Bear Rainforest South totalled 1,240 ha.

After low amounts of damage was noted in Haida Gwaii TSA for the last two years, yellow-cedar decline rebounded to 2018 levels with 2,763 ha mapped.

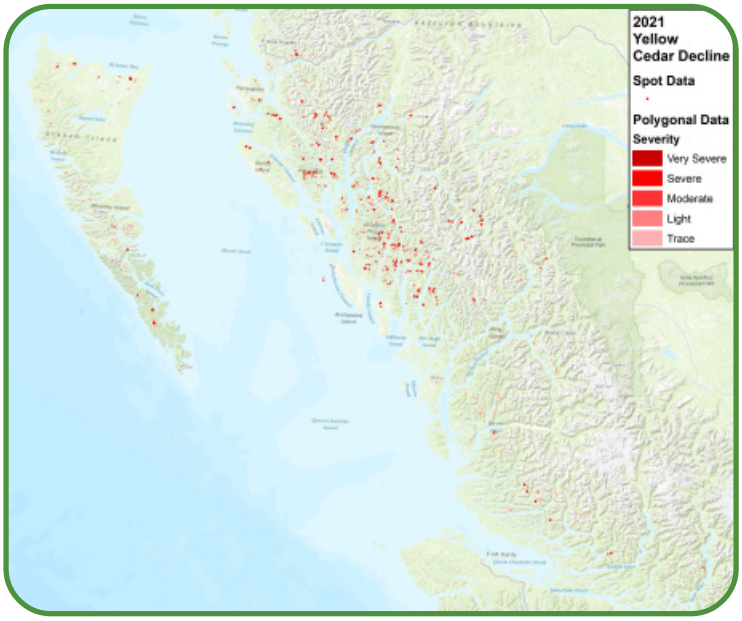


Figure 15. Yellow-cedar decline damage recorded by severity in BC for 2021.

Yellow cedar decline in Haida Gwaii TSA

All the damage in Skeena Region was located in the southern half of Kalum TSA with 716 ha delineated.

Sunshine Coast TSA in South Coast Region contained 117 ha of yellow-cedar decline along Bute Inlet.

Damaging Agents of Deciduous Trees

Aspen (serpentine) leaf miner, *Phyllocnistis populiella*

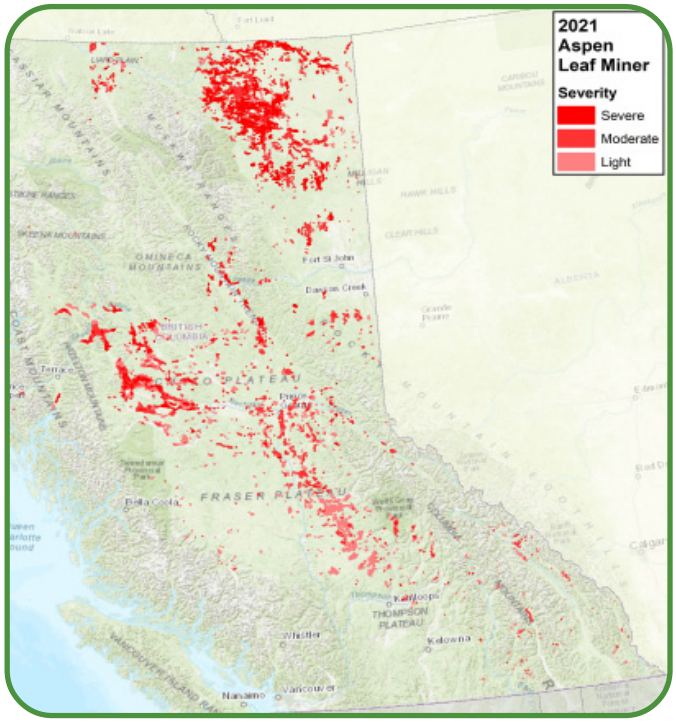


Figure 16. Aspen leaf miner damage recorded by severity in BC for 2021.

Aspen leaf miner infestations rebounded to 2019 levels, after a decline last year. A total of 1,327,856 ha were affected across BC in 2021 (Figure 16). Severity was assessed as 522,309 ha (39%) light, 475,814 ha (36%) moderate and 329,733 ha (25%) severe, which is a minor increase in intensity over last year. Trembling aspen continued to be the most affected host species, though 32% of the stands contained a minor component of damaged poplar.

The primary reason for the provincial damage increase was a ten-fold rise in aspen leaf miner defoliation in Northeast Region since 2020 to 469,229 ha. This was the highest level of damage recorded in this region since 2014. Fort Nelson TSA accounted for most of the increase, with 390,229 ha affected. Most of the disturbances were mapped mid TSA, and a large percentage of the moderate to severe damage noted in BC occurred in this TSA. Fort St. John TSA sustained 53,399 ha of attack, mainly mid TSA

north of Sikanni Chief Canyon and around Wonowon. Infestations in Dawson Creek TSA accounted for 25,600 ha of damage, mainly north of Tumbler Ridge.

Aspen leaf miner damage in Bulkley TSA

Defoliation in Skeena Region declined more than a third from 2020 to 406,682 ha. Morice TSA continued to be most affected, with 141,035 ha delineated, chiefly in the northern half. Damage occurred on 127,018 ha in Lakes TSA, with concentrations along Francois Lake and along the Highway 16 corridor. Infestations in Kispiox TSA totalled 80,525 ha, mainly located around the Hazelton area. A total of 51,479 ha were mapped in Bulkley TSA, with most of the damage southeast of Smithers. Cassiar and Kalum TSAs contained 4,227 ha and 2,189 ha of defoliation, respectively, with the remaining 209 ha located in Nass TSA.

Aspen leaf miner infestations in Omineca Region increased a quarter since last year to 203,425 ha. Most, (154,252 ha) was scattered throughout the southern two-thirds of Prince George TSA. Mackenzie TSA sustained 45,235 ha of damage in the southern third of the TSA. Defoliation in Robson Valley TSA totalled 3,938 ha, mainly along the Fraser River north of Dunster.

In Cariboo Region, defoliation rose 60% since last year to 199,038 ha. 100 Mile House TSA contained 86,920 ha of the damage, scattered primarily mid TSA. A total of 69,900 ha was mapped in Williams Lake TSA, with large disturbances mapped around the Horsefly area. Infestations in Quesnel TSA covered 42,128 ha, primarily mid TSA.

Thompson/Okanagan Region sustained 27,145 ha of aspen leaf miner defoliation, up three-fold since last year. Most (25,558 ha) was observed in Kamloops TSA, predominantly from Adams Lake north to Kostal Lake. Small scattered infestations accounted for 1,558 ha of damage in Okanagan TSA.

Aspen leaf miner damage

Damage in Kootenay/Boundary Region totalled 21,691 ha in 2021. Golden TSA was most affected with 8,686 ha delineated, mainly around the Blaeberry area. Scattered infestations in Arrow and Kootenay Lake TSAs accounted for 3,717 ha and 3,306 ha, respectively. Infestation levels in Revelstoke and Cranbrook TSAs were similar, with 2,334 ha and 2,148 ha noted, respectively. Most of the 1,140 ha mapped in Invermere TSA occurred northeast of Radium Hot Springs. The remaining 361 ha of attack occurred in Boundary TSA.

Large aspen tortrix, *Choristoneura conflictana*

An outbreak of large aspen tortrix began last year in the northeast of BC, with 277,057 ha affected. Defoliation continued in 2021 with 221,849 ha mapped. Intensity of damage decreased substantially however, to 194,445 ha (88%) light, 24,950 ha (11%) moderate and 2,944 ha (1%) severe. The bulk of the infestation moved northward as well, from the primary epicenter around Fort St John in 2020 to the center of Fort Nelson TSA this year (Figure 17). Aspen was the primary tree species affected, but some stands had a secondary component of cottonwood that was also defoliated.

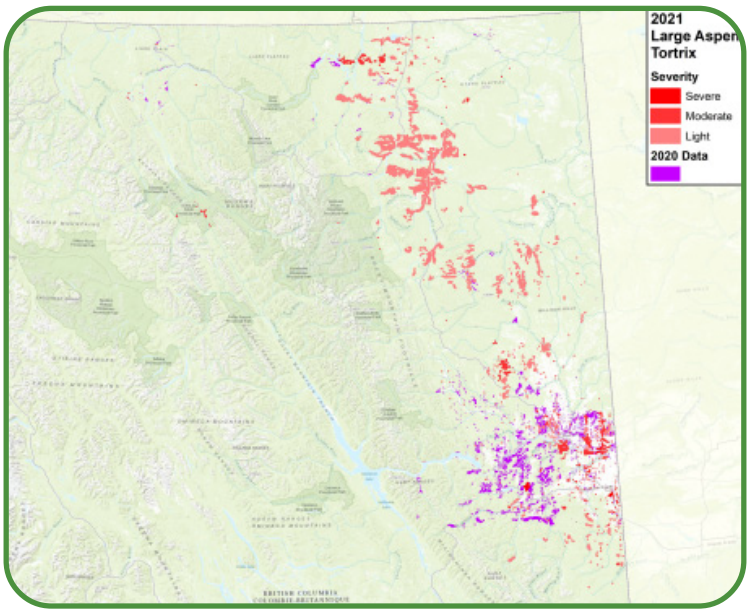


Figure 17. Large aspen tortrix damage recorded by severitiy in BC for 2020 and 2021.

The Northeast Region continued to sustain the bulk of the damage, with 221,849 ha attacked. Disturbances in Fort Nelson TSA totalled 139,986 ha, of which almost all were lightly defoliated except for a band of moderately affected polygons south of Maxhamish Lake. Fort St. John TSA contained 59,605 ha of large aspen tortrix attack in smaller, more scattered disturbances. Dawson Creek TSA was similarly affected, with 22,258 ha delineated. The majority of the moderately defoliated stands occurred on the border of these two TSAs south of Fort St. John.

All the attack in Omineca Region was observed in Mackenzie TSA. A total of 490 ha were damaged, primarily moderately. Most of the defoliation was mapped north of Kechika Peak.

Venturia blights, *Venturia* spp.

Mapped Venturia blight damage decreased almost 6-fold since 2020 to 4,744 ha. It was however noted to be widespread by the Skeena pathologist. It is suspected that infections were higher throughout northern BC than was captured, partially because the aerial signature isn't well expressed until later in the summer and may have been missed in early surveys, and partly due to wildfire smoke obscuring subtle signatures. Intensity of mapped damage was assessed as 1,081 ha (23%) light, 2,730 ha (57%) moderate and 933 ha (20%) severe. Trembling aspen was predominantly damaged, though some cottonwood was noted as a secondary species that was infected.

Skeena Region continued to be most affected, with 1,761 ha of damage observed. Kalum TSA contained 1,268 ha of Venturia blight caused disturbances north of Kitimat and along the Skeena river on the Great Bear Rainforest North TSA boundary. A total of 421 ha were delineated in Morice TSA west of Morrison Lake and south of Topley Landing. Bulkley and Cassiar TSAs were similarly affected, with 37 ha and 34 ha mapped, respectively. Last year a substantial amount of damage (7,882 ha) was mapped in Cassiar TSA which couldn't be flown this year, so disturbances may have been missed.

The Kalum TSA Venturia blight infections continued along Skeena River into Great Bear Rainforest North TSA, where 1,352 ha were affected.

Omineca Region sustained 1,069 ha of Venturia blight caused disturbances. Makenzie TSA had 850 ha of damage mapped in the northern tip. Damage totalled 219 ha in Prince George TSA just south of Bugle Lake.

Venturia needle blight damage in Northeast Region was mapped at 562 ha. Most of this (495 ha) occurred in Fort Nelson TSA in small, widely scattered disturbances. Fort St. John TSA had 54 ha of damage scattered around the southeast corner of the TSA. Disturbances in Dawson Creek TSA totalled 13 ha.

Satin moth, *Leucoma salicis*

A record 209,932 ha of satin moth damage occurred in 2018, followed by two years of declining defoliation. Infestations rebounded slightly in 2021 to 3,884 ha. Intensity of defoliation was rated as 1,023 ha (26%) light, 2,523 ha (65%) moderate and 337 ha (9%) severe.

The majority of the disturbances continued to be mapped in Prince George TSA of Omineca Region, where 3,569 ha were delineated. Scattered attack occurred from Prince George northwest to Stuart Lake.

Thompson/Okanagan Region had a total of 315 ha of satin moth defoliation. A few scattered infestations accounted for 185 ha in Merritt TSA. All 125 ha mapped in Kamloops TSA occurred east of Stump Lake. One 4 ha disturbance was noted in Okanagan TSA west of Summerland.

Birch leaf miner, *Lyonetia prunifoliella*

A peak in birch leaf miner damage occurred in 2019 with 10,242 ha affected provincially, followed by a large decline last year to only 520 ha. Defoliation increased in 2021 to 1,229 ha, though intensity of attack declined to 554 ha (45%) light and 675 ha (55%) moderate.

Thompson/Okanagan Region contained no birch leaf miner damage last year, but 731 ha were mapped in 2021. Most of this defoliation (703 ha) occurred in Okanagan TSA between Vernon and Falkland. One additional disturbance of 28 ha was identified in Kamloops TSA west of Niskonlith Lake.

Defoliation in Fort Nelson TSA of the Northeast Region totalled 291 ha. Infestations were noted along the Alberta border near the southern boundary of the TSA.

Kootenay/Boundary Region sustained 207 ha of birch leaf miner attack in 2021. Most of the damage occurred in Cranbrook TSA in small scattered polygons around the Kimberley area. One additional area of damage totalling 20 ha was observed in Kootenay Lake TSA south of Nelson.

Aspen decline

Aspen decline damage decreased provincially for the third consecutive year from a record 68,218 ha in 2018 to only 398 ha in 2021. Intensity of damage was assessed as 135 ha (34%) light, 228 ha (57%) moderate and 35 ha (9%) severe. As drought is a large factor in aspen decline, reduced damage may have been due to the two primarily wet, cool growing seasons in 2019 and 2020.

Thompson/Okanagan Region sustained 217 ha of aspen decline damage. Kamloops TSA had 112 ha of damage near Gold Peak and on Bonaparte Lake, Lillooet TSA 83 ha near Seton Portage and north of Pavilion, and Merritt TSA 22 ha west of Kingsvale.

Scattered small disturbances in Cariboo Region totalled 166 ha. Williams Lake TSA contained 89 ha, with concentrations east of 150 Mile House and north of Alexis Creek. A total of 65 ha were mapped in 100 Mile House TSA, and 12 ha in Quesnel TSA west of Marguerite.

The remaining 15 ha of aspen decline damage was observed in Dawson Creek TSA of the Northeast Forest Region.

Cottonwood leaf rust, *Melampsora occidentalis*

Cottonwood leaf rust moderately damaged 75 ha in the Thompson/Okanagan Region in 2021, down from 268 ha last year. Three disturbance polygons totalling 54 ha were noted south of Mabel Lake in Okanagan TSA, with the remaining 21 ha located north of Dunn Lake in Kamloops TSA.

Forest tent caterpillar, *Malacosoma disstria*

Forest tent caterpillar larva

A forest tent caterpillar outbreak in central BC peaked in 2014 at 711,297 ha, followed by two years of declining damage. No defoliation by this caterpillar was observed for the subsequent four years. In 2021 one disturbance of 51 ha was mapped in Kamloops TSA of the Thompson/Okanagan Region west of Murtle Lake. Defoliation was assessed as severe.

Damaging Agents of Multiple Host Species

Abiotic injury and associated forest health factors

Wildfire damage increased more than 40 fold provincially since 2020 to 863,630 ha, due to a record breaking spring heat spell followed by a primarily dry hot summer, particularly in the southern interior (Figure 18). This still didn't break the record set in 2018 of 1,351,837 ha burnt. Almost all the damage (99%) was rated as severe. All regions experienced some damage. Wildfire smoke caused significant work stoppages for the AOS this year.

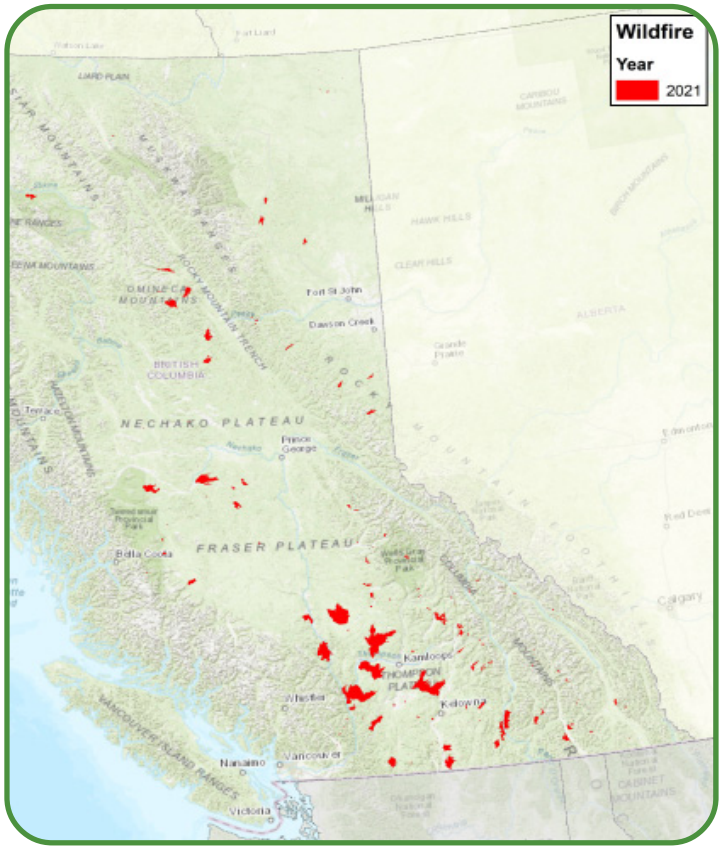


Figure 18. Wildfire damage recorded in BC for 2021.

Over half the wildfire damage occurred in Thompson/Okanagan Region, with 471,995 ha mapped. Several of the fires were very large and in interface settings, burning not only forests but homes as well. Kamloops TSA sustained 158,200 ha of damage, primarily in two large fires north and south of Savona. Okanagan TSA was severely affected as well, with 142,355 ha burnt, with the most serious damage done in one fire west of Vernon. Lillooet TSA sustained 95,908 ha of wildfire damage, chiefly in two large fires south of Spences Bridge (which burnt the town of Lytton) and west of Pavilion. Total area burnt in Merritt TSA was mapped at 75,533 ha.

Cariboo Region sustained 147,141 ha of wildfire damage, most of which (107,875 ha) occurred in 100 Mile House TSA. The largest fire of note happened northwest of Green Lake. Two mid-sized fires in Williams Lake TSA at Dog Creek and west of Sucker Lake accounted for most of the 26,881 ha burnt. Most of the 12,385 ha of damage in Quesnel TSA occurred in Kluskoil Lake and Bowron Lake Provincial Parks.

Wildfires burnt 101,237 ha in Omineca Region. Five fires on the west side of Williston Lake accounted for the majority of the 60,705 ha burnt in Mackenzie TSA. One large fire between Tatuk and Lucas Lakes in Prince George TSA was responsible for most of the 40,080 ha burnt. Robson Valley TSA had only small, scattered wildfires totalling 451 ha.

Kootenay/Boundary Region had 77,578 ha of wildfire damage in 2021. Most affected was Arrow TSA, with two large fires on Upper Arrow Lake and one east of Winlaw, with 44,538 ha damaged. A total of 16,265 ha were burnt in Kootenay Lake TSA, with two fires of note north and west of Sirdar. Wildfires in Boundary TSA consumed 8,340 ha, primarily in one fire west of Mount Faith.

Wildfire in Arrow TSA

Scattered wildfires in Cranbrook TSA burned 4,753 ha, with the largest located east of Wasa. Smaller, scattered fires affected less than 2,000 ha per TSA in the remaining TSAs in the region.

Wildfires consumed 29,034 ha in Northeast Region. A total of 14,082 ha were mapped in Dawson Creek TSA, chiefly in four scattered disturbances. Fort St. John TSA sustained 5,126 ha of damage, most of which occurred in two fires north and east of Pink Mountain. Small scattered wildfires in Fort Nelson TSA damaged 5,126 ha.

Skeena Region sustained 28,681 ha of wildfire damage. Lakes TSA was most affected, with 21,096 ha burnt. The main fire of note occurred south of Chief Louis Lake. Cassiar TSA had 7,494 ha damaged in one wildfire in Stikine River Provincial Park. All remaining TSAs had less than 90 ha burnt, respectively.

Wildfire damage in South Coast Region totalled 7,516 ha, of which most (7,465 ha) occurred in Fraser TSA. Of this, the largest fire of note occurred east of Falls Creek in the north tip. Remaining TSAs had less than 45 ha of damage, respectively.

Great Bear Rainforest has 315 ha of damage, with most (309 ha) burnt in the north TSA.

West Coast Region was the only region in BC where hectares burnt actually declined somewhat since last year, to 133 ha. Arrowsmith TSA had 93 ha of damage, North Island 38 ha, and the remaining 2 ha was noted in Haida Gwaii TSA.

Drought leading to excessive foliage damage affected a record 108,345 ha across BC in 2021. Intensity of damage was noted as 41,492 ha (38%) light, 62,315 ha (58%) moderate and 4,538 ha (4%) severe. It is suspected record high early temperatures in spring followed by a dry summer were the primary causes. In general, this damage became more obvious during the AOS as the season progressed, particularly in western redcedar stands. The height of visible damage was observed to be late summer. It should be noted that the AOS is a "snapshot in time" and it doesn't always reflect the full extent of certain damage. Disturbances were particularly prevalent in transition zones from dry to wet ecosystems, on south facing slopes, poor soils and microsite hummocks. Damage was most predominant in southern BC (Figure 19). Western redcedar was most affected, but substantial Douglas-fir and lodgepole pine damage was mapped as well, especially in younger stands. Affected to a

Douglas-fir foliage damaged by drought

lesser extent were ponderosa pine, western white pine, spruce and trembling aspen. Along the north edge of Cariboo Region to the south edge of Omineca Region, identification of causal agent in younger lodgepole pine stands was more difficult as further north a similar aerial signature tended to be the result of needle disease that developed from a wet growing season last year.

Over three-quarters of the drought caused foliage damage occurred in Thompson/ Okanagan Region, with 85,077 ha mapped. Most of the 47,688 ha recorded in Okanagan TSA occurred north of Armstrong and east of Cherryville. Kamloops TSA sustained 37,055 ha of damage, chiefly north of Chase. Small, scattered disturbances in Merritt and Lillooet TSAs accounted for 207 ha and 127 ha, respectively.

Kootenay/Boundary Region had a total of 5,892 ha of drought foliage damage. Kootenay Lake TSA was most affected, with 2,521 ha delineated, primarily north of Kootenay Bay. A total of 1,526 ha of small, widely scattered disturbances were mapped in Golden TSA. Arrow TSA had 1,227 ha of damage, primarily concentrated in the Trout Lake area. Most of the 304 ha observed in Cranbrook TSA were located east of Fort Steele. Invermere and Revelstoke TSAs contained minor damage of 257 ha and 56 ha, respectively.

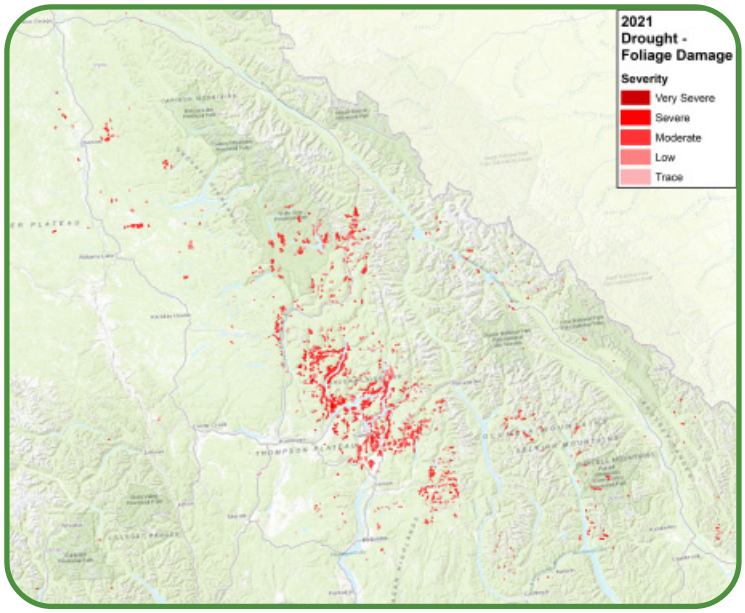


Figure 19. Foliage drought damage recorded by severity in regions sustaining over 5,000 ha of damage for 2021.

Western redcedar foliage damaged by drought

Foliage damage caused by drought affected 5,433 ha in West Coast Region. The surveyors noted that damage started being visible on the coast sooner than other regions. North Island TSA sustained 3,849 ha of damage, Arrowsmith TSA 1,552 ha and North Island TSA 33 ha. Anecdotally, big leaf maple (not a mapped species during the AOS) was observed to have leaf wilting and desiccation often beside affected young Douglas-fir trees.

Most of the 1,732 ha mapped in South Coast Region occurred in the southern half of Sunshine Coast TSA (1,392 ha). Fraser and Soo TSAs had minor damage accounting for 209 ha and 131 ha per TSA, respectively.

Great Bear Rainforest and Northeast Region had similar levels of damage with 1,495 ha and 1,480 ha mapped, respectively. All other regions had less than 300 ha of damage each.

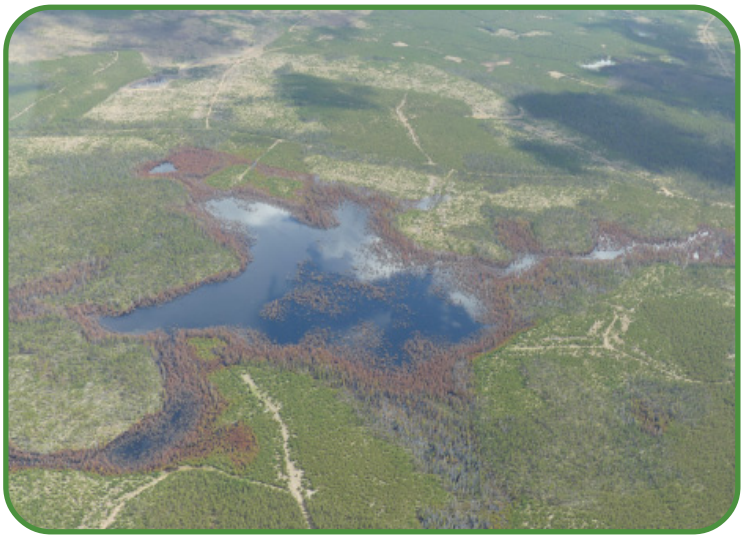
Drought damage leading to mortality (Drought Mortality) had a peak of 118,798 ha affected in 2018. Damage rapidly declined the last two years due to milder, moister growing seasons, but increased somewhat during the dry spring and summer of 2021 to 558 ha. Severity of mortality increased as well, to 26 ha (5%) trace, 358 ha (64%) light, 59 ha (10%) moderate and 115 ha (21%) severe.

Damage was highest in South Coast Region, with 457 ha of primarily western redcedar affected. Spot damage was widely scattered. Soo TSA sustained 290 ha of drought mortality, most of which was mapped in one disturbance adjacent to Pemberton Meadows. Fraser TSA had 117 ha of damage recorded with polygons noted near Harrison Lake and North Siwash Creek. Sunshine TSA had 49 ha of drought mortality, primarily in one disturbance south of Needle Peaks.

Mortality due to drought damage in Williams Lake TSA of the Cariboo Region totalled 76 ha. All the damage was to lodgepole pine located southeast of Eagle Lake. The damage wasn't ground checked this year, but in 2015 damage with a very similar aerial signature in the same area was ground checked and determined to be drought related, combined with significant lodgepole pine dwarf mistletoe infections. The soils in this area are very poor and a small rise in elevation can result in drought mortality. It was more extensive in 2015 but the damage this year occurred specifically on small hummocks. One spot of mortality was noted in 100 Mile TSA as well.

Arrowsmith TSA in West Coast Region sustained 18 ha of mortality primarily in the Gulf Islands, with the largest disturbance near Ruckle Provincial Park. One polygon of lodgepole pine damage affected 8 ha in Okanagan TSA in Kamloops/Okanagan Region. The disturbance was located north of Crescent Lake. A few spots of mortality were also recorded in Skeena Region and Great Bear Rainforest North TSA.

Flooding damage has been relatively stable for three years, with 20,015 ha recorded in 2021 across all regions in the province. Severity of mortality was assessed as 212 ha (1%) trace, 11,803 ha (59%) light, 2,938 ha (15%) moderate, 4,734 ha (24%) severe and 328 ha (1%) very severe. Disturbances continued to be very small and scattered throughout BC, with the exception of some larger damage polygons noted in Northeast Region. Spruce was the most affect tree species, followed by lodgepole pine, Douglas-fir and trembling aspen. A range of other conifers were also noted in minor amounts.



Flooding damage in Williams Lake TSA

Northeast Region continued to be the most affected with 14,094 ha of flooding damage mapped. A substantial number of the spruce affected polygons were noted to most likely contain spruce beetle as well, which is probable with the trees stressed by the flooding. Most of the areas were inaccessible and this couldn't be confirmed. Fort Nelson TSA contained 7,411 ha of damage, primarily in the eastern half. A total of 6,539 ha were mapped in Fort St. John TSA, mainly in the eastern third. Dawson Creek TSA had 145 ha of flood mortality.

Cariboo Region sustained 3,825 ha of flood damage. Most (3,432 ha) was situated in Williams Lake TSA, chiefly in the northern half. 100 Mile House TSA and Quesnel TSA had 341 ha and 52 ha of mortality observed, respectively.

Skeena Region had 568 ha of damage throughout the region, with no more than 230 ha per TSA. Most of the 520 ha of West Coast Region flooding occurred in Haida Gwaii TSA (381 ha) and North Island TSA (132 ha). Almost all of the 492 ha mapped in Omineca Region was noted in Prince George TSA (460 ha). The remaining regions had less than 200 ha of flood mortality per region.

Windthrow damaged 12,623 ha across the province in 2021, the highest damage recorded since 2005. Severity of disturbances was observed to be 407 ha (3%) trace, 917 ha (7%) light, 1,353 ha (11%) moderate, 4,638 ha (37%) severe and 5,307 (42%) very severe. Tree species most affected was spruce and trembling aspen. A variety of other conifer species were damaged to a minor extent. Northeast Region continued to sustain the most damage, with 9,002 ha delineated. Fort St. John TSA contained the majority of the disturbances, with 9,073 ha mapped. This damage was primarily caused by a large wind event in late June. A large concentration of polygons were mapped from Buick south to Charlie Lake and a band of disturbances ran northeast from Sikanni Chief Canyon to Hay River. Windthrow damage in West Coast Region totalled 2,473 ha, split between Haida Gwaii TSA (1,239 ha) and North Island TSA (1,234 ha). Omineca Region contained 504 ha of damage, with most (492 ha) located in Mackenzie TSA north of Mount Brewster. Similarly, Kootenay/Boundary Region was impacted by 499 ha of damage, chiefly noted on 368 ha in Arrow TSA. The remaining regions had less than 100 ha of damage per region.

Windthrow damage in Fort St. John TSA

Post-wildfire damage in 2021 decreased to 11,000 ha across BC from 89,064 ha last year. This decline was expected as wildfires were very low the last two years due to wet, cool conditions. Intensity of damage declined as well to 45 ha (<1%) trace, 6,248 ha (57%) light, 3,180 ha (29%) moderate and 1,528 ha (14%) severe. The leading tree species most affected continued to be lodgepole pine, followed by spruce, Douglas-fir, and a minor component of other conifer and deciduous trees. Most of the damage occurred in younger stands. All delineated polygons were small (generally under 100 ha).

Omineca Region had 3,788 ha of post-wildfire damage, of which most (3,745 ha) was located in Prince George TSA. Damage was concentrated mainly west of Fort Fraser. Robson Valley TSA sustained 41 ha of damage.

Cariboo Region had 2,956 ha delineated in 2021, with 2,191 ha located in the western half of Quesnel TSA, particularly around Tsibekuz Lake. Williams Lake TSA sustained 758 ha of widely scattered damage, with the remaining 7 ha noted in 100 Mile House TSA.

Post-wildfire damage in Skeena Region covered 2,614 ha. Damage noted in Lakes TSA totalled 1,905 ha, primarily east of Taltapin Lake and north of Cheslatta Lake. Morice TSA sustained 574 ha south of Nadina Mountain and 64 ha of damage was mapped in Kispiox TSA.

All remaining regions contained less than 650 ha of post-wildfire damage per region.

Frost kill of shoots and buds affected a record 6,874 ha across the province in 2021. Due in part to the subtle aerial signature, this damage is rarely recorded and has never been over 280 ha per year previously. Severity of damage was recorded as 6,248 ha (91%) light, 259 ha (5%) moderate and 267 ha (4%) severe. Subalpine fir, lodgepole pine and spruce were the affected tree species.

Frost damage totalled 4,628 ha southeast of Windy Mountain in 100 Mile House TSA of Cariboo Region. This damage was combined with two-year-cycle budworm defoliation, making it more visible aerially.

Frost damage

Small, widely scattered disturbances accounted for 1,375 ha in Northeast Region. Almost all (1,366 ha) were mapped in Fort Nelson TSA. Fort Saint John TSA had 8 ha of damage, and one spot disturbance was located in Dawson Creek TSA.

Thompson/Okanagan Region sustained 648 ha of frost damage, all in Kamloops TSA. One area was a continuation of the Cariboo Region disturbance, with the remaining damage mapped north of Moose Lake. This damage was also combined with two-year-cycle budworm defoliation.

All 223 ha recorded in Omineca Region was in the north tip of Mackenzie TSA. The remaining 1 ha in the province was noted in three spot disturbances in Cassiar TSA of Skeena Region.

Snow and Ice damage was further defined part way through 2021 to differentiate between breakage and press. The aerial signatures can be similar to windthrow, and local knowledge of storm events are sometimes the only way to tell them apart. In 2021 4,708 ha were delineated as snow and ice damage across BC. Intensity of the damage was significant, with 192 ha (4%) light, 1,608 ha (34%) moderate and 2,908 ha (62%) severe. Aspen was the primary tree species affected, with secondary lodgepole pine and spruce damage.

Of the damage, only 124 ha in Fort Nelson TSA of Northeast Region was noted to be breakage. The remaining disturbances in Northeast Region were substantial at 4,561 ha, of which the majority (4,518 ha) was mapped in the eastern half of Fort Nelson TSA in widely scattered, small disturbances. Fort St. John TSA sustained the remaining 43 ha in the region. In Omineca Region, 24 ha of damage was noted in Mackenzie TSA in the northern tip.

Slide damage almost doubled across BC since 2020 to 3,716 ha. Intensity of damage was determined to be 172 ha (5%) light, 109 ha (3%) moderate, 2,757 ha (74%) severe and 678 ha (18%) very severe. A wide variety of tree species were killed. Great Bear Rainforest sustained 1,209 ha of slide damage, with most (1,004 ha) in the north TSA: a series of slides on Clyak Creek accounted for a large percentage. South Coast Region had a total of 1,111 ha of damage mapped. Sunshine TSA had the majority with 1,099 ha, most of which was located in one large slide just west of Gunsight Peak. Total damage in West Coast Region was 914 ha of which 892 ha were scattered around Haida Gwaii TSA. Northeast Region sustained 377 ha, mainly in small widely scattered disturbances in Fort St. John TSA (203 ha) and Fort Nelson TSA (159 ha). Remaining regions in the province had less than 90 ha of slide damage per region.

Red belt damage affected 2,040 ha in Northeast Region in 2021, up from only 121 ha in the same region last year. Intensity of damage was assessed as 1,079 ha (53%) light, 688 ha (34%) moderate and 273 ha (13%) severe. Lodgepole pine was the most affected species, though subalpine fir and spruce were also substantially damaged. Fort Nelson TSA contained 2,025 ha of the damage scattered throughout the western half of the TSA. One disturbance of 15 ha was mapped in Fort St. John TSA west of Christina Falls.

Red belt damage in Fort Nelson TSA

Animal damage

Animal damage is known to be underestimated in the AOS data as it tends to be scattered and often occurs in younger trees, which are difficult to see from the height of the AOS. Only substantial feeding that causes top kill or mortality is detectable.

As noted in data comments, the causal animal isn't always obvious: in older trees porcupine vs. black bear is difficult and sometimes in younger stands black bear vs. hare is hard to tell, without ground checks or at least stand history (black bears in particular tend to feed for multiple years in the same young stands, and hare damage is more cyclical with population changes).

Black bear (*Ursus americanus*) damage quadrupled across BC since 2020 to 3,551 ha. Mortality intensity was rated as 92 ha (2%) trace, 2,509 ha (71%) light, 95 ha (3%) moderate and 855 ha (24%) severe. Young to intermediate aged trees were killed, with damage to the oldest possibly the result of porcupine rather than black bear. Lodgepole pine and spruce were most attacked in the interior, and western redcedar and Douglas-fir on the coast. Northeast Region continued to sustain the most damage, with 2,842 ha mapped. All but a few spots were mapped in Fort Nelson TSA spread over the western half. Cariboo Region had 373 ha of black bear mortality. Williams Lake TSA was most affected with 308 ha delineated east of Horsefly and along the northwest border. Attack in the northeast corner of 100 Mile House accounted for 60 ha of damage, and scattered spots covered 5 ha in Quesnel TSA. Attack in Omineca Region totalled 145 ha. Prince George TSA had 103 ha of widely scattered damage in the southern half, and the 42 ha mapped in

Mackenzie TSA primarily occurred in the north and south tips. All remaining regions had less than 100 ha of black bear damage per region.

Sitka black-tailed deer (*Odocoileus hemionus sikensis*) damage was mapped in four polygons southeast of Skidegate Lake in Haida Gwaii TSA of West Coast Region. The damage was rated as severe, and covered 101 ha. This introduced deer causes a significant browse problem for regenerating stands in Haida Gwaii.

Snowshoe hare (*Lepus americanus*) feeding damage is intermittently noted in northern BC when populations are large. Snowshoe hares usually only cause significant damage to very young trees, which isn't detectable during the AOS. However they can encircle the upper portion of the stem on intermediate aged trees if the snow sets up at a deep enough height. Damage peaked at 845 ha in 2018, with 136 ha recorded last year. It can be confused with bear or porcupine damage. In 2021 snowshoe hare damage was mapped on 31 ha in northern BC. Two spot disturbances were mapped in Prince George TSA of Omineca Region, but the rest of the damage was delineated in Morice TSA of Skeena Region. All this damage was observed south of Mount Morice in one lightly affected polygon and a few scattered spots.

Porcupine (*Erethizon dorsatum*) is often underestimated during the AOS, as feeding tends to be seen as very scattered individual trees with top kill, which is a subtle aerial signature. Mapped damage continued to be very low in 2021, with 16 ha noted across the province. Most (14 ha) were identified in Fort Nelson TSA of Northeast Region. One polygon of 7 ha southwest of Eskona Mountain was lightly affected, with the remaining 9 ha occurring in very scattered spots in the western half of the TSA. A few additional spot disturbances were noted in Cariboo and Omineca Regions.

Unknown defoliator damage

Damage due to unknown defoliators increased substantially this year to 2,061 ha. Intensity of damage was assessed as 1,580 ha (76%) light, 240 ha (12%) moderate and 240 ha (12%) severe. In most cases, ground checks of causal agent was not possible due to inaccessibility. Almost all the defoliation occurred in trembling aspen stands with a minor component of cottonwood, with just two exceptions.

Skeena Region sustained 1,171 ha of attack, of which most (1,144 ha) occurred in Cassiar TSA northeast of Tumeka Lake. One severely defoliated hemlock stand southeast of Lakelse Lake in Kalum TSA accounted for 27 ha. Defoliation in Northeast Region all occurred in Fort Nelson TSA in a cluster of stands south of Maxhamish Lake. A total of 464 ha were affected. Cariboo Region had 234 ha of unknown defoliator damage with the majority (215 ha) mapped in 100 Mile House TSA north of Mahood Lake. This infestation extended 26 ha into Kamloops TSA of Thompson/ Okanagan Region. The remaining 19 ha in Cariboo Region was mapped in Quesnel TSA east of Ten Mile Lake. Great Bear Rainforest North had one disturbance mapped just west of Bella Coola that accounted for 166 ha.

Armillaria root disease, *Armillaria ostoyae*

Armillaria root disease damage is known to be underestimated in the AOS due to the height flown and the subtle aerial signature of the disturbances, as well as confounding forest health factors such as drought and bark beetle. Mapped damage remained at a similar level to the last two years, with a total of 54 ha observed in coastal BC. Intensity of disturbances were rated higher however, with 13 ha (23%) trace, 29 ha (55%) light, 4 ha (7%) moderate and 8 ha (15%) severe. Amabilis fir was the most affected species this year.

Young Douglas-fir tree killed by Armillaria root disease next to old stumps

West Coast Region contained 48 ha of Armillaria root disease damage, most of which occurred in two disturbances near Splendor Mountain and two near Artlish Caves in North Island TSA, which with scattered spots totalled 43 ha. Spots of damage mapped in Arrowsmith TSA accounted for the remaining 3 ha in this region. Only a few scattered spots were observed in South Coast Region and Great Bear Rainforest South TSA.

Miscellaneous Damaging Agents

Poplar and willow borer (*Cryptorhynchus lapathi*)

Poplar and willow borer continued to damage deciduous trees and shrubs of all ages, particularly in Skeena Region where the range is noted to be expanding. There is ongoing concern that willow mortality could have negative implications for moose populations that rely on it for winter forage.

Bigleaf maple damage

Bigleaf maple damage, identified by red and chlorotic foliage, with some dieback, has been prevalent in South Coast Region over the past few years, especially in Salmon, Jervis and Narrows inlets. This trend continued in 2021. It was noted that Washington State in the USA has also been experiencing this damage. They have been investigating the cause, but nothing has been found to date.

Birch decline

Birch decline began to be obvious with drought occurrences in the late 1980's in southern BC. Since then, birch decline damage has moved steadily northward in the province as noted by the regional pathologist in Skeena Region.

Black army cutworm, *Actebia fennica*

Black army cutworm monitoring continued in Lakes and Morice 2018 wildfires in the summer of 2021. Overall trap catches indicate populations are now back to endemic levels.

Kootenay/Boundary Region has been monitoring black army cutworm in various locations since 2018. Trap catches continue to catch high numbers of moths as outlined below (Table 7).

Black army cutworm larvae defoliating a seedling

Table 7. Results from the 2018-2021 black army cutworm moth trapping program in the Kootenay/Boundary Region.

Year and TSA	Location	# traps	Average moths per trap
2018			
Cranbrook	Etna Creek	4	20
	Linklater	4	1
	Soowa	4	39
Invermere	White – Middle Fork	4	127
	White – North Fork	4	29
Revelstoke	RCFC	4	40
	Revelstoke	2	80
2019			
Cranbrook	Lost Dog	6	93
	Meachan	6	218
	Wickman	4	36
2020			
Cranbrook	Meachan	6	240
2021			
Cranbrook	Meachan	4	322
Invermere	Doctor Creek	9	433

Forest Health Projects

2021 drought event in the southern interior

Lorraine Maclauchlan, Forest Entomologist, Thompson/Okanagan Region

Background:
Drought, or temperature driven moisture stress, is an important driver of ecosystem dynamics and is predicted to increase in frequency and severity globally (Slette et al. 2019). The term "ecological drought" encompasses environmental consequences such as vegetation (forest) damage. The fundamental mechanisms underlying tree survival and mortality during drought remain poorly understood despite decades of research within the fields of forestry, pathology, entomology, and ecology. Drought, or more appropriately described as temperature driven moisture stress, can operate as a trigger that may ultimately lead to mortality in trees that are already under stress by other predisposing factors. Some of these predisposing factors include old age, poor site conditions, or planting condition, which may exacerbate subsequent stem and root damage by biotic agents. Several biotic agents have been recorded contributing to tree mortality or sublethal stem damage (e.g. form) with the most common being wood-boring insects and fungal pathogens.
Climatologists have grappled with defining drought (both conceptually and operationally) and have identified many types of drought:

- Meteorological Drought - When dry weather patterns dominate an area.
- Hydrological Drought - When low water supply becomes evident in the water system.
- Agricultural Drought - When crops become affected by drought.
- Socioeconomic Drought - When water supply from a regional water resources system cannot meet water demands.
- Ecological Drought - When vegetation is negatively impacted (stressed). This includes losses in plant growth, increases in fire and insect outbreaks, altered rates of carbon, nutrient, and water cycling, and local species extinctions.

McDowell et al. (2008) postulates three mutually non-exclusive mechanisms by which drought could lead to broad-scale forest mortality:

1. extreme drought and heat kill trees through cavitation of water columns within the xylem;
2. protracted water stress drives plant carbon deficits and metabolic limitations that lead to carbon starvation and reduced ability to defend against attack by biotic agents such as insects or fungi; and,
3. extended warmth during droughts can drive increased population abundance in these biotic agents, allowing them to overwhelm their already stressed tree hosts.

Annual weather conditions, particularly heat and moisture deficits, affect trees, landscapes, and biotic agents. Insect response to weather and host signals is often rapid and lethal.

Recent drought events:
Drought damage is mapped annually during the Aerial Overview Survey (AOS) as NDM (drought, mortality) or NDF (drought, foliage affected). Figure 20 shows the hectares of drought mapped

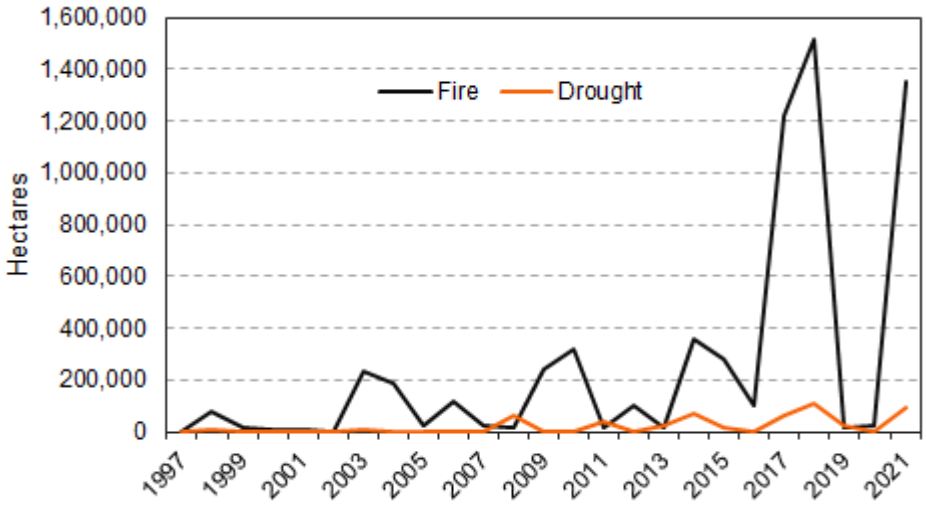


Figure 20. Hectares of wildfire and drought in BC (1997-2021).

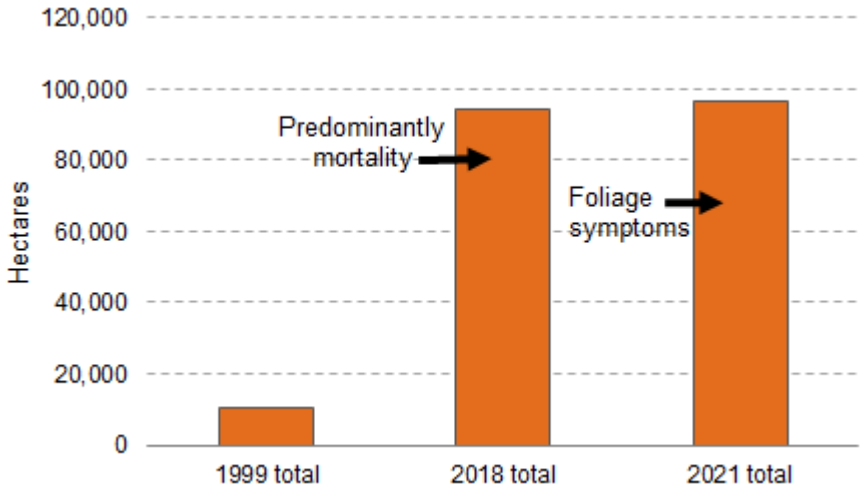


Figure 21. Drought damage detected in Aerial Overview Survey 1999, 2018 and 2021.

since 1997 compared with the hectares burnt by wildfires. The relationship between dry forest conditions, warmer than normal temperatures and hectares burnt is evident. In most years, drought damage was primarily manifested in foliar damage, but in 1998 (mapped in 1999) and 2017 (mapped in 2018), high levels of drought mortality occurred (Figure 21). Mortality typically manifests the year following the drought-heat event, so we may see areas of mortality in 2022 due to the 2021 drought. The late June to early July heat dome caused: scorching of some foliage (e.g. western hemlock on ICH sites); significant foliage drop on mature and young trees (e.g. Interior Douglas-fir (IDF) stands); and heat-killed early instar Lepidoptera larvae that were open feeding at the time of the extreme temperatures (e.g. western hemlock looper).

Many weather records were broken in the summer of 2021 (From: Vanessa Foord):

- New national record: **49.6°C** Lytton
- **60** daily maximum records broken in one day
- Mean temperatures **15-20** °C above average
- At least **1 in 1,000** year event
- **>350** time more likely with climate change
- **3rd worse** fire season on record

Figure 22 illustrates the area affected by drought in 2018 and 2021 in the four most impacted biogeoclimatic zones (BECs). Other BECs were also affected, but to a very minor extent. The number of hectares affected in the IDF and ESSF was very similar in both years, although geographic locations varied between years (Figures 22 and 23). In the 2017 drought, the MS sustained the highest level of mortality (31,313 ha), whereas in the 2021 drought, most of the damage (foliar) was mapped in ICH stands (63,150 ha) (Figure 22).

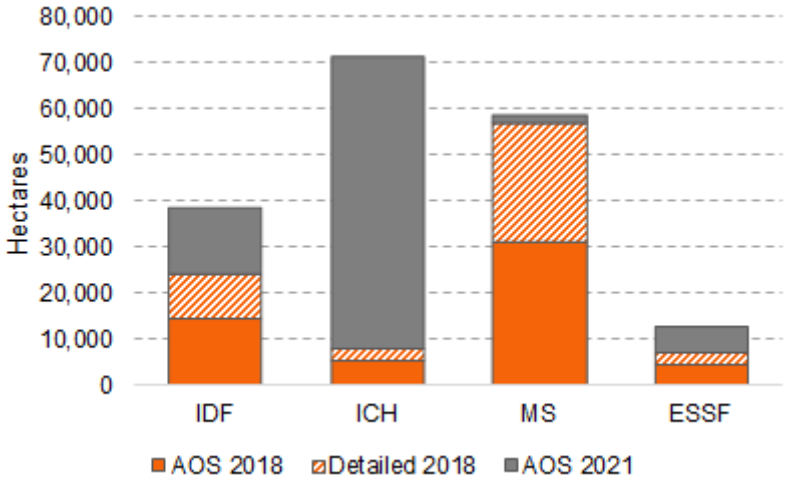


Figure 22. Hectares affected by drought in the Thompson/ Okanagan Region by biogeoclimatic zone in 2018 and 2021. Hectares affected were mapped during the Aerial Overview Survey and detailed flights (2018).

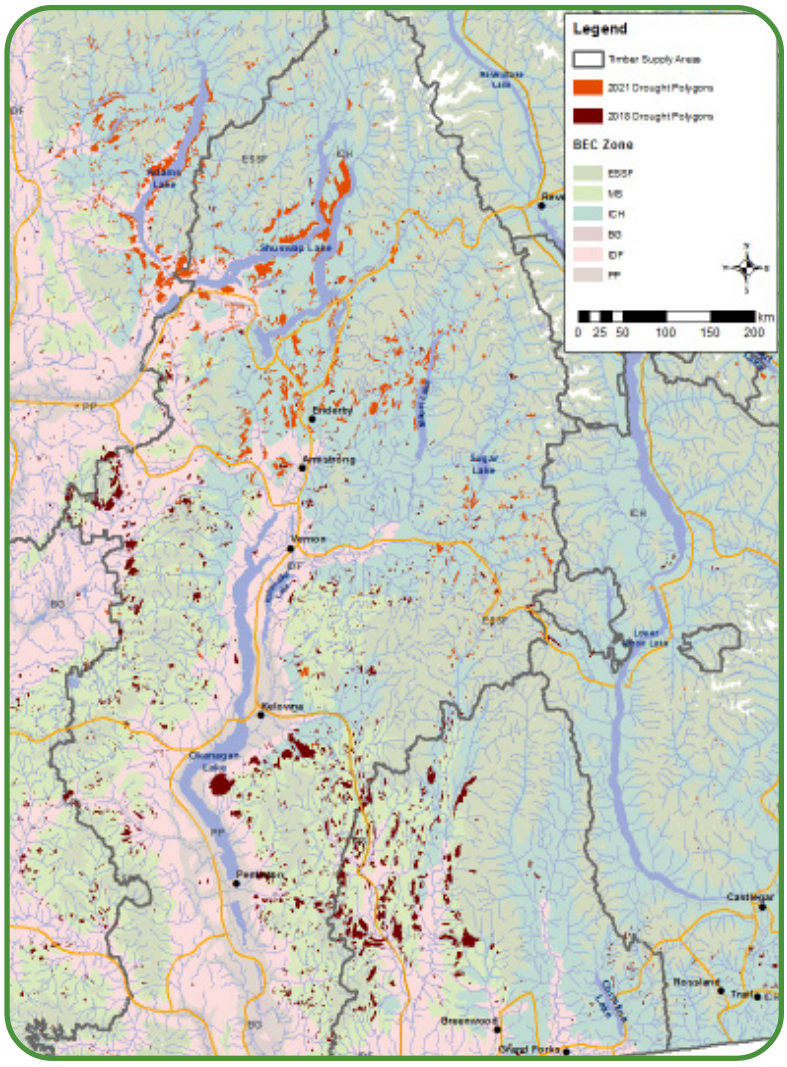


Figure 23. 2018 and 202 drought damage in the Thompson/ Okanagan Region.

Okanagan TSA was the most drought-impacted TSA in the southern interior in both 2018 and 2021 (Figure 24), with 45,267 and 47,688 hectares affected, respectively. The amount of drought damage in other TSAs varied greatly. Boundary TSA suffered over 25,000 hectares of drought damage (mainly mortality) in 2018, but no damage was detected in 2021. In Kamloops TSA, 3,270 hectares of damage (mortality) were recorded in 2018 compared to over 32,000 hectares of damage (foliar) in 2021 (Figure 24).

Tree mortality commonly involves multiple, interacting factors, ranging from cumulative climate stressors, stand composition and history, to insect pests and diseases. Temperature driven heat events can trigger population surges of certain bark beetles such as Douglas-fir beetle, western balsam bark beetle, mountain pine beetle, weevils, and many secondary bark beetles. Heat and moisture stress can increase plant (tree) attractiveness to insects by altering cues used to find hosts. When drought is coupled with heat events, (temperature driven moisture stress) it can cause:

- reduced translocation in trees, resulting in less resin pressure to repel bark beetle attack
- stunted growth adding to tree stress and reducing productivity
- earlier insect flights and attack periods
- insects could be physiologically active earlier in season and activity could be prolonged

The general health of stands and trees prior to drought events also plays a role in the severity of damage cause by these extreme weather events. Sub-lethal infections of stem rusts, dwarf mistletoe, Armillaria root disease and other biotic agents can increase vulnerability to

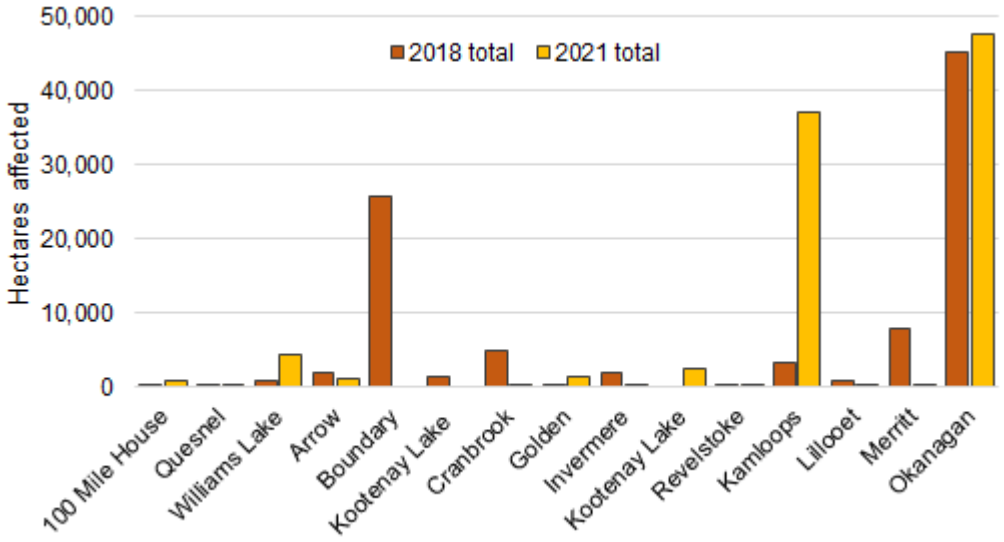


Figure 24. Comparison of drought damage mapped during the Aerial Overview Survey in 2018 and 2021 in affected TSAs in the southern interior.

drought and increase the probability of mortality. Longer, warmer growing seasons promotes successful insect development (e.g. spruce weevil) and influences other life history processes (flight, reproduction, development time, voltinism, symbiotic associations).

Key points to consider include:

- number and time interval of drought events (temperature driven moisture stress)
- severity of drought – duration, temperatures, precipitation
- forest composition, structure and density
- homogeneity of species, age, and genetic structure
- biogeoclimatic zone and geographic location
- predisposing agents can reduce tree resistance mechanisms against subcortical insects
- temperature exerts strong influences on life history processes of bark beetles

References:

McDowell, N., Pockman, W.T., Allen, C.D., Breshears, D.D., Cobb, N., Kolb, T., Plaut, J., Sperry, J., West, A., Williams, D.G., and Yepez, E.A. 2008. Mechanisms of plant survival and mortality during drought: why do some plants survive while others succumb to drought? New Phytologist 178(4): 719-739.

Slette, I.J., Post, A.K., Awad, M., Even, T., Punzalan, A., Williams, S., Smith, M.D., and Knapp, A.K. 2019. How ecologists define drought, and why we should do better. Global Change Biology 25: 3193–3200. doi:10.1111/gcb.14747

Spongy (Gypsy) moth, *Lymantria dispar*

Marnie Duthie-Holt, Acting Provincial Forest Entomologist

A total of 5 adult male *Lymantria dispar dispar* (LDD) moths were captured in 2 traps near Courtney in 2020 yielding a spray program of 187 hectares in the spring of 2021.

Positive trap catches in 2021 yielded a total of 184 LDD moths in 95 traps throughout BC (Table 8). As well, an additional two Asian Gypsy Moth (AGM) moths were detected in two separate traps

in the Township of Langley, BC approximately spaced two kilometers apart. A total of nine treatment areas have been identified for *Btk* sprays in 2022 including; Langley (AGM), View Royal, Lake Cowichan, Nanoose/Lantzville/Nanaimo on Vancouver Island and Burnaby, Coquitlam (ground spray), Mission, Surrey, and Chilliwack in the Lower Mainland and Fraser Valleys. All other identified positive trap catch areas will be monitored using delimitation trapping.

Table 8. Numbers of male spongy moths caught in pheromone traps throughout BC in 2021 and management recommendations.

Location	Male Spongy Moths Caught	Treatment
Vancouver Island/ Gulf Islands:		
Oak Bay	1	Delimitation trapping
Esquimalt	2	Delimitation trapping
Saanich	1	Delimitation trapping
Victoria	3	Delimitation trapping
View Royal	11	Aerial spray
Colwood	2	Delimitation trapping
Salt Spring Island	6	Delimitation trapping
Duncan	1	Delimitation trapping
Lake Cowichan	10	Aerial spray
Youbou	7	Delimitation trapping
Gabriola Island	1	Delimitation trapping
Nanoose/Lantzville/Nanaimo	22	Aerial spray
Qualicum Beach/Parksville	3	Delimitation trapping
Bowser	4	Delimitation trapping
Denman Island	1	Delimitation trapping
Courtenay/Comox	13	Delimitation trapping
Campbell River	1	Delimitation trapping
Sproat Lake	1	Delimitation trapping
Port Alberni	4	Delimitation trapping
Lower Mainland, Sunshine Coast and Fraser Valley:		
North Vancouver	1	Delimitation trapping
West Vancouver	2	Delimitation trapping
Burnaby	19	Aerial spray
Coquitlam	10	Ground spray
Maple Ridge	1	Delimitation trapping
Surrey	11	Aerial spray
Delta	2	Delimitation trapping
Harrison Mills	1	Delimitation trapping
Abbotsford	1	Delimitation trapping
Langley	6	Delimitation trapping
Chilliwack	9	Aerial spray
Madeira Park	3	Delimitation trapping
Sechelt	1	Delimitation trapping
Squamish	1	Delimitation trapping
Interior:		
Penticton	1	Delimitation trapping
Canoe	1	Delimitation trapping
Sicamous	2	Delimitation trapping
Revelstoke	1	Delimitation trapping
Eagle River Provincial Park	1	Delimitation trapping
Prince George	1	Delimitation trapping
Quesnel	2	Delimitation trapping
Barkerville	5	Delimitation trapping

- Where there's not enough information to clearly demonstrate that Lymantria moths are becoming established in a particular area (or not enough traps were set to effectively define a treatment boundary), ministry staff will re-evaluate those areas. A higher density of moth traps will be set the following summer to monitor moth populations.
- The 2021 total is over three times the annual average number of Lymantria moths caught in traps. This increase was expected, due to ongoing outbreaks in Ontario and Quebec over the last three years.
- Increases may also be due to the diversion of recreational vehicle drivers to the West Coast, due to the COVID-19 pandemic.
- Generally, the source of infestations is very difficult to determine.
- It is difficult to determine why there was an increase in moths last year, however the eastern provinces also experienced an increase in moth populations over the last several years. Moths may have been unknowingly transferred here on various personal and commercial vehicles and by people moving into the area.

Preliminary results from lodgepole pine progeny trials looking at elytroderma susceptibility in the Cariboo Resource Region

David Rusch, Forest Pathologist, Coast Regions

Elytroderma needle cast is a common needle disease affecting ponderosa and lodgepole pine that occurs throughout the range of these species in BC. In lodgepole pine stands throughout most of BC, mortality and growth impacts are normally restricted to young stands less than 15 years of age. In older stands, the disease results in large elongated knots and abnormal stem growth in the lower bole (Rusch 2020). However, on low productivity sites in the southern Cariboo, growth and mortality can persist in older stands (40+ years). Growth on impacted trees in the southern Cariboo can be half that of adjacent healthy trees and severe infection in the upper crown third can lead to death even in older trees. In 2013, a lodgepole pine progeny trial was established in the southern Cariboo to test susceptibility of lodgepole pine families to elytroderma. B plus seed from the Cariboo and some seed from parents previously rated for elytroderma stem cankers at the Prince George seed orchard (Wallis et al. 2010) were planted at one site in each of the IDFdk3, IDFdk4, and SBPSxc BEC units. Unfortunately, the SBPSxc site was burned up shortly after planting. Symptoms of eytroderma needle cast were first observed at the IDFdk4 site in 2020 and in the IDFdk3 site in 2021. The incidence and severity of elytroderma at the IDFdk3 site was relatively low in 2021 and the trees were growing better compared to the IDFdk4 site. At the IDFdk4 site, elytroderma severity and incidence were high in 2021 (32% and 3.3, respectively). The graph in Figure 25 appears to indicate that trees at the IDFdk4 site from families originating from the SBPSxc and IDFdk4 have a higher susceptibility to elytroderma needle cast than trees from warmer BEC units. These finding could have important implications for seed selection in the IDFdk4 (and potentially the adjacent SBPSxc) in areas with a high hazard for elytroderma needle cast. Some seed sources from the IDFdk3 are currently available for the SBPSxc and IDFdk4 under the current seed transfer guidelines for BC.

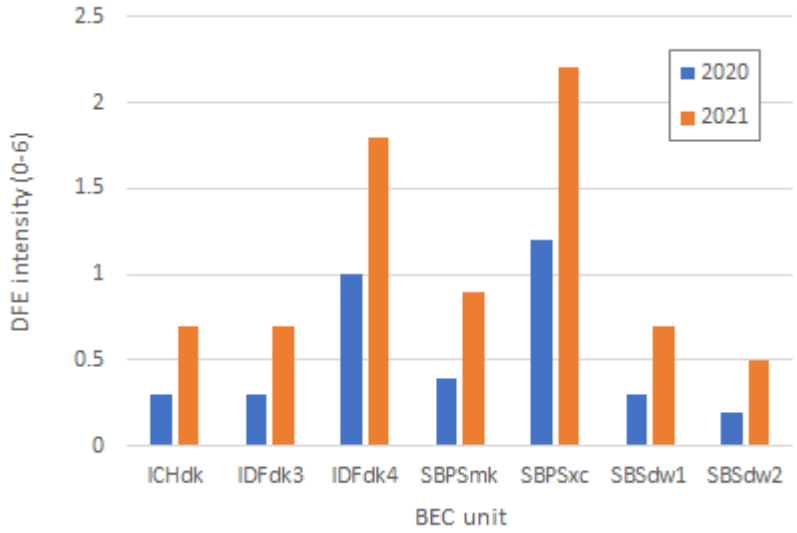


Figure 25. Elytroderma intensity (mean severity of infected trees x mean incidence) by BEC variant of seed origin at the IDFdk4 site. Severity is based on a Hawksworth 6-point severity rating system similar to that used for dwarf mistletoe. Incidence was based on the presence of red needles with or without fruiting bodies present.

References:
Rusch, D.R. 2020. Elytroderma needle cast on lodgepole pine in British Columbia. Prov. BC. Land Manag. Handb. 74.
Wallis, C.M, Reich, R.W., Lewis, K.J. & Huber, D.P.W. 2010. Lodgepole pine provenances differ in chemical defence capacities against foliage and stem diseases. Canadian Journal Forest Research 40:2333.

Retaining whitebark pine in timber harvests

Michael P. Murray, Forest Pathologist, Kootenay/Boundary Region
Jenny Berg, University of Victoria
David Huggard, Apophenia Consulting

Study:
A gradual increase in harvest acreage above 1800 m elevation began in 2008 in the Kootenay/ Boundary Region. The long-term retention of endangered mature whitebark pine trees can ensure that ecological values are better protected. Before this study, survivorship of whitebark pine retained within commercial harvests had not been examined. We investigated the fate of residual trees to infer some preliminary recommendations. Our objectives were to describe the temporal attrition of retained mature whitebark pine trees and to identify factors that likely promote survivorship during the critical initial post-harvest period.

We analyzed a total of 197 dead trees and 134 live trees at five separate harvest units. Mortality rates were highest immediately following harvests (Figure 26). At Lavington (LV) operators reported that most retained trees were blown over during a single powerful storm as they were completing harvest. A negative exponential trend characterized three harvest sites, where initial steep declines became increasingly moderated over time. By 9 years post-harvest, mortality ceased at all but a single harvest site.

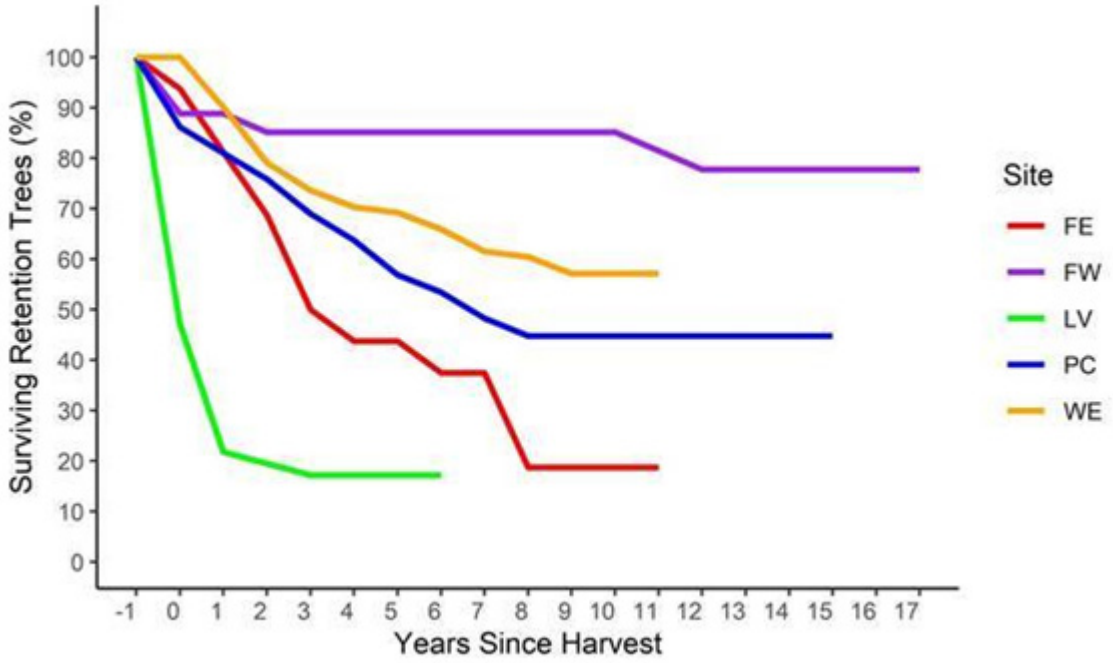


Figure 26. Post-harvest attrition of retained whitebark pine according to harvest site (FE: Findlay East; FW: Findlay West; LV: Lavington; PC: Paturages; WE: West Elk) (Murray et al. 2021).

The probability of mortality of retained whitebark pine trees is best explained by a combination of tree characteristics; slope/aspect, and the number of surrounding retained trees. We found a strong increase in survivorship, with greater tree crown length accompanied by decreasing tree height. Thus, the probability of post-harvest mortality was higher for taller trees with shorter crowns and lower for shorter trees with long crowns. In examining the importance of neighbor trees, a survivorship probability greater than 50% required a minimum of 7.5 retained neighbor trees with tree height radial distance. For trees that did not survive, we found the vast majority of downed stems oriented in a northeasterly direction from root collar to crown indicating the strongest winds experienced at the sites arrived from southwesterly directions. Interestingly, there were opposite effects depending on the tree lesion type (cankers vs. rodent wounding). Any rodent damage indicated higher survivorship. With one or more blister rust cankers, there would be less than a 50% chance of survival.

Our results suggest that most trees fell during storm conditions. We suggest that winter storms and approaching fronts of coastal low-pressure systems are the most significant drivers of blowdown for whitebark pine stands in the southern interior region. For at least one harvest site (Lavington), a majority of trees were blown over while alive. Although cankered mature trees can survive for decades, if *Cronartium ribicola* remains in the host, chronic stress may interfere with physiological mechanisms that contribute to windfirmness. Contrary to expectations, we found higher survival in trees damaged by rodents. Rodent damage may therefore indicate healthier trees that can adapt more quickly to post-harvest exposure. Our results are consistent with the vast majority of retention studies, indicating that higher retention levels favor positive survivorship rates. There are likely additional factors that favor retention survivorship that we did not examine. These may include pre-harvest stem density, soil (texture, depth, moisture), and rooting structure.

Management Implications:
For southeast British Columbia and the adjacent Kootenai Region of the USA, we recommend harvest practitioners carefully retain whitebark pine. To increase likelihood of survival, we recommend practitioners retain:

- A minimum of eight neighboring trees within the target tree's height radius.
- Trees with longer crown lengths and lower frequencies of disease cankers.
- Trees of average height.
- Ovate patches of retention oriented on a southwest-to-northeast azimuth (Figure 27).

Harvesters should consider moving any wood debris away from retained stems. During fire events, we suggest that retained trees be protected by clearing surface fuels away from their driplines, wrapping tree boles with resistant material, and conducting spot suppression. All healthy cone-bearing trees are potentially disease resistant, thus represent a lifelink to the species' future.

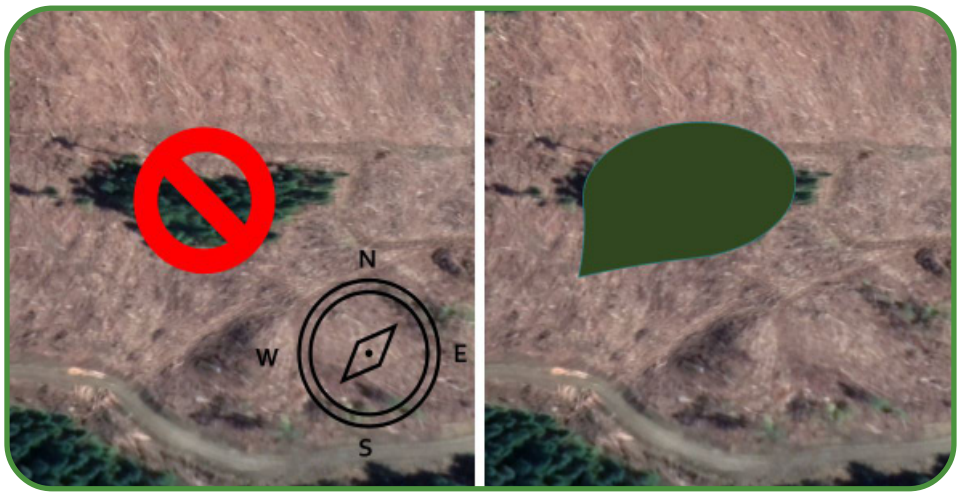


Figure 27. To reduce blowdown, ovate patches of retention can be oriented according to the predominant storm wind directions. In southeast BC, a southwest-to-northeast azimuth is recommended.

Spruce bark beetle repellency field trials – individual tree protection

Marnie Duthie-Holt, Forest Entomologist, Kootenay/Boundary Region

Spruce beetle (*Dendroctonus rufipennis*) is the primary tree killer of mature spruce throughout North America. Climate change can also accelerate its life cycle increasing the frequency of one versus two-year life cycles. Currently, BC is experiencing higher-than-normal populations with significant impacts to timber and non-timber resources resulting in lasting social, cultural and economic impacts. Management for spruce beetle mitigation includes a variety of tactics, however repellent compounds have had variable

Mature trees killed by spruce beetle

Baiting spruce trees

Randomly, 25 trees in each treatment were baited with spruce beetle attractants and each of the four treatments also included the repellents to challenge the beetles. All four semiochemical combinations significantly reduced spruce beetle attack (See Figure 28). In addition, to providing individual tree protection the repellents also provided protection to surrounding trees for upwards of 11 meters radius. Additional work is required to test area protect and determine optimal spacing and dosages of the various repellents.

results in the past. The development of an effective biodegradable repellent is important for use in sensitive areas including riparian, residential settings, seed orchards, recreation areas, and other critically sensitive areas with limited mitigation options.

Individual tree protection field studies in southeastern BC (Elk Valley) were employed during the summer of 2021. Four novel semiochemicals were tested as spruce beetle repellents including.

1. **SPLAT**® (Specialized Pheromone & Lure Application Technology) **MCH** (3-methylcycolhex-2-en-1-one) commonly used repellent for Douglas-fir beetle
2. **SPLAT**® **MCH** plus **GLVs** (green leaf volatiles which smells like *cut grass* (*E*)-2-hexen-1-ol, and (*Z*)-2-hexen-1-ol)
3. **SPLAT**® **MCH** plus **OCT** (which smells like *mushrooms* - 1-octen-3-ol)
4. **SPLAT**® **MCH** plus **AKB** (acer kairomone blend which smells like *maple trees*- linalool + Beta-caryophyllene + Z-3-hexen-1-ol).

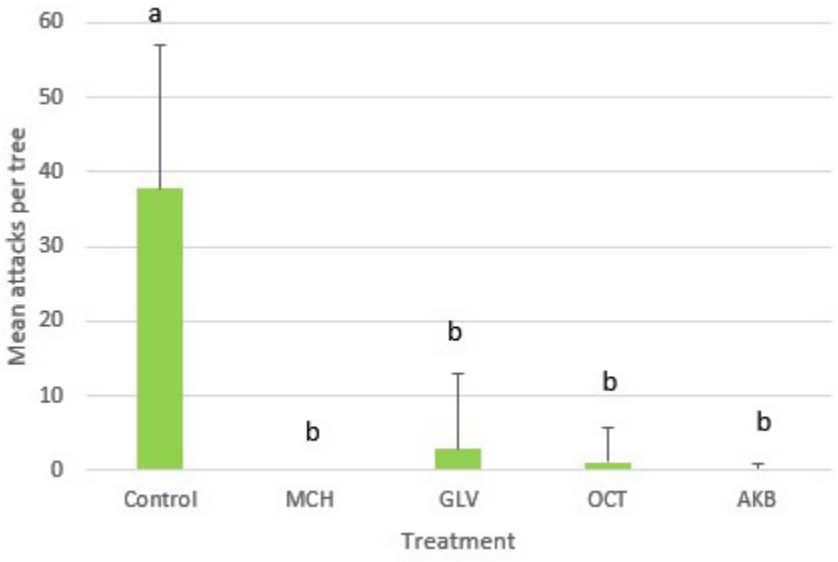


Figure 28. Spruce beetle attack by treatment.

The value of long-term, large-scale randomly located monitoring plots in BC's managed forests; The impact of biotic disturbance

Alex J Woods, Research Forest Pathologist, Skeena Region

Thirty, one hectare stem-mapped plots established in 1997 in randomly selected pine leading plantations aged 15-25 in the Lakes TSA, were re-assessed using a combination of drone technology and ground verification plots in early 2021. The ground plots consisted of 5 randomly located 3.99 m radius plots within each one-hectare plot. The original study published in 2000 involved running the stem mapped stands through TASS 2 and applying rules to forecast rate of decline of rust infected trees and forecast impact the loss of those trees would have. All 30 plots were flown with drones to create orthomosaics and digital elevation models that have been used to estimate both individual tree volumes and collective stand volume. Ground verification field plots were used to improve the accuracy of the tree height and diameter estimates. These ground plots indicated that about 11% of the current live pine volume in these mid-rotation stands would be culled based on licensee log specifications in the Lakes TSA due to large stem galls, forks, and live comandra infected trees that are expected to die soon. The large one-hectare plots clearly illustrate the extent of gaps in stocking caused primarily by comandra blister rust. TASS 3 forecasts based on the original stem maps are being projected to the current stand age and these are being compared to the drone based current volume estimates. These 30 plots provide a unique opportunity to check on the fundamental assumptions of managed stand growth forecasts.

Drone image of an example 3.99 m radius ground verification plot (left) and a photo taken in the same larger one ha plot showing trees killed by comandra rust (right) resulting in stocking gaps.

Forest Health Meetings/Workshops/ Presentations/Podcasts

Best fire management practices for endangered pines in the crown of the continent

Michael P. Murray, Forest Pathologist, Kootenay/Boundary Region

Venue: Symposium – Fire in the Crown of the Continent (sponsored by Crown Managers Partnership) March 22nd to March 26th, 2021.

Abstract:
Whitebark pine (*Pinus albicaulis*) and limber pine (*P. flexilis*) are ecologically important trees in western North America. Due to changing fire and insect regimes, introduced disease, and climate change, these species are federally listed, or proposed (limber) as endangered. They experience complex fire regimes which appear to be increasing in severity. As hot droughts become commonplace in the Crown, fire-induced mortality is a mounting concern. Management objectives should emphasize limiting mortality to healthy trees, reducing ladder fuels and competition from other tree species, and increasing post-fire regeneration.

Community of practices – Provincial forest health workshop

Venue: Virtual team meeting December 7th, 2021.

Abstract:
Participants were Branch, Region and District staff involved with forest health. Discussions included drought and post wildfire responses, forest hazard ratings, landscape level planning, old growth announcement and ramifications, proactive/reactive budget, Skeena's bark beetle data portal, and silviculture changes (briefing on stocking standards and rust resistance material.

Global plant health assessment: North America x forests (managed softwoods):

Alex J Woods, Research Forest Pathologist, Skeena Region

Venue:
Global Plant Health Assessment International Workshop, Toulouse School of Economics (TSE) Toulouse France, October 6, 2021 (presented virtually).

Abstract:
The Global Plant Health Assessment (GPHA), conducted under the aegis of the International Society for Plant Pathology (ISPP) aimed to provide a first-time ever overall assessment of plant health in the natural and human-made ecosystems of the world. Plant health was assessed through the

functions that plants ensure in ecosystems: "ecosystem services". The GPHA assessed plant health on the basis of published, science and factbased, expert evaluations. The event included three days of closed-session workshop on the 26 reports that are being assembled on the various Plant-Systems across the world.

My task was to coordinate a team that could provide a current snap-shot and future forecast of managed forest plantation health across North America. I drew on the following experts from the east and west of the US and Canada to produce a report on the health of North American managed softwood forests: Isabel Munck, Forest Health Protection, USDA Forest Service; Anna Leon, Weyerhaeuser Company; and, Tod Ramsfield, Natural Resources Canada, Northern Forestry Centre. I presented our report on North America x Forests (Managed softwoods) and was invited to be part of a panel discussion.

Is climate triggering changes in the epidemiology of Swiss needle cast on Douglas Fir?

Stefan Zeglen, Provincial Forest Health Officer, Office of the Chief Forester
Nicolas Feau, Research Scientist, Pacific Forestry Centre, Canadian Forest Service

Venue:
National Pest Forum, Ottawa, ON via virtual platform, December 9, 2021

Abstract:
Climate change is threatening the health of forest ecosystems through direct and indirect effects. The impacts of this change are already being observed on trees, with consequences such as reduction in growth, increased maladaptation and subsequent vulnerability to pest and pathogen attacks. Changes in climatic conditions has also been associated with severe epidemics caused by endemic and usually innocuous pathogens. One noticeable example being *Nothophaeocryptopus gaeumannii* an endophytic fungal associate of Douglas-fir in the coastal forests of the Pacific Northwest (PNW). The fungus is the agent responsible for Swiss Needle Cast (SNC), a disease-causing needle chlorosis and premature shedding. In recent decades, changing environmental conditions have coincided with periodic epidemics of SNC resulting in an average of 23% growth loss and up to 60% growth loss in severely impacted Douglas-fir stands. Using genomics and phenotyping approaches, we identified two major genetic lineages (lineages 1 and 2) of *N. gaeumannii,* with different environmental tolerance. We examined the presence of the two lineages at 37 sites in coastal British Columbia from 2017–2019 and in pre-epidemic herbarium specimens. In the contemporary samples, lineage 1 was found at all sites while lineage 2 was found at only six sites. By contrast, lineage 2 was more abundant in the pre-epidemic samples. Modeling of their distribution under future climatic conditions suggested that the current environmental tolerance range of lineage 1 should keep exceeding that of lineage 2. We expect lineage 1 to expand further inland, while lineage 2 will remain constrained to its current range on the coast. Our results indicate that lineage 1 might be the "lottery winner" in the climate change contest by becoming the dominant lineage in the PNW. We hypothesize that the higher adaptive plasticity of this lineage for temperature and humidity is facilitating its spread and fuelling the SNC epidemics under the current changing climate.

The legacy of managing mountain pine beetle in British Columbia: the science and the policy

Lorraine Maclauchlan, Forest Entomologist, Thompson/Okanagan Region

Venue: North American Forest Insect Work Conference, May 25-28, 2021, University of Minnesota. Held virtually.

Abstract:
The pine forests of British Columbia have experienced many large-scale mountain pine beetle (MPB) outbreaks that have resulted in mortality of hundreds of millions of trees over expansive areas of forest. In response to these landscape-level events, foresters and scientists have developed a suite of management strategies and tactics to mitigate the impacts of MPB. When major infestations of both spruce beetle and MPB erupted in central BC in the 1970s and 1980s this prompted the BC government to develop a coordinated response, resulting in the creation of the Pest Management Program (now Forest Health); and, so began the battle of the beetles in BC. When the last, and largest, MPB outbreak on record began to develop in north central British Columbia during the 1990s, federal and provincial governments once again looked to their top scientists for guidance to take on this monumental challenge. In this presentation I described intervention techniques used to control MPB, and BC's current strategies that incorporate new technology, modelling, harvesting and scientific insight. I also highlighted the never-ending challenges faced by forest mangers such as sheer physical scale, climate change and the biological, social and political intricacies. But the most pressing questions may be what have we learned and how will our future management of MPB differ?

Presentation at the 64th Forest Pest Management Forum, hosted by the Canadian Institute of Forestry

Harry Kope Provincial Forest Pathologist, Forest Science, Planning and Practices Branch

Venue: Held virtually through Zoom on December 7-9, 2021

Abstract:
The Forest Health program in British Columbia (BC) is the responsibility of regional and headquarters Forest Health specialists. Provincial scale forest health monitoring is captured through an annual aerial overview survey, as well, forest health updates from ground surveys conducted by the regional specialists. This report is a brief consolidation of information from data available for 2021.

Abiotic Factors

Heat Dome

An event in the form of a so-called Heat Dome (a heat inversion) occurred over much of British Columbia in late June 2021. This heat dome resulted in temperatures above 45C for at least 4 consecutive days. Such extreme heat is unusual and far beyond the gradual increase in heat normally experienced in the summer in BC. What immediate effects this had on forests and pests or what long term effects this will have, are not known.

Fire

From April 1, 2021 to Sept. 30, 2021, 1,610 wildfires burned 868,203 hectares in BC. In areas where fire damage does not result in mortality, surviving trees could be scarred which provide wound openings. Smoke particulates on leaves/needles can decrease photosynthesis and occlude stomata can result in pest susceptible stressed trees.

Yellow Cedar Decline

The symptoms of yellow cedar decline appear as tree crown thinning with eventual tree death. Research has shown that biotic factors are not the cause of the decline but rather the decline is related to regional climatic warming. Freezing damage to fine roots leads to drought-induced decline and death of yellow-cedars. Since 2006 when monitoring began, close to 400,000 hectares of yellow cedar have been damaged with over 14,000 hectares of forests affected in 2020 along the coast of BC and in Haida Gwaii.

Pathogens

Swiss Needle Cast

Swiss needle cast is a foliar disease of Douglas-fir. It causes trees to drop older foliage prematurely. Before the early 2000's the disease was only poorly documented in BC. Since that time the disease has become more obvious especially affecting young stands in coastal areas of BC. Increasing disease incidence into the future is likely due to changing weather patterns that have increased the amount of spring moisture during the infection window in some years.

Phytophthora

Phytophthora is a serious root and canker-causing disease of many tree species. The disease is favoured by abundant soil moisture in poorly drained areas. The disease can affect all ages of all species of trees. A specific instance of a phytophthora-like disease was documented as dying and dead mature and young western white pine trees at multiple seed orchards on the coast and in central BC. Common yet unexpected Phytophthora species were identified from sampled roots.

Septoria leaf and stem blight

It has long been recognized that the high selection pressure exerted through breeding, coupled with high productivity levels, have led hybrid poplars (Populus genus) to become vulnerable to multiple biotic agents. One such biotic agent, Septoria disease, was originally reported as an endemic pathogen in eastern North America causing leaf spots on poplar. In 2006, S. musiva, was found for the first time in British Columbia on hybrid Populus clones located in the upper Fraser Valley. And less than 10 years later it was found on hybrid poplar clones in the Okanagan Valley. The establishment of this pathogen in B.C. could threaten black cottonwood, a keystone species naturally occurring in riparian ecosystems.

Insects

Bark Beetle trends - mountain pine beetle affected hectares in BC have decreased, but the western balsam bark beetle affecting subalpine fir is increasing.

Some hectare data for 2020:

- Mountain pine beetle – 111,963 ha
- Spruce beetle - 525,270 ha
- Western balsam bark beetle – 2,900,000 ha
- Douglas-fir beetle – 98,496 ha

Health of Young stands Forum

The Forest Health group and the Canadian Forest Service held a Forum on "The Health of Young Stands" (HOYS) in November 2020. Young stands of all tree species continually occupy more of the BC land base. This forum presented information on pests affecting young stands, models to predict damage from pests, climate and drought impacts and potential implications for policy and decision makers.
(https://www2.gov.bc.ca/assets/gov/farming-natural-resources-and-industry/forestry/forest-health/news/agenda_abstracts_presenterbios_hoys_2020.pdf)

British Columbia Provincial forest health reports and resources:
https://www2.gov.bc.ca/gov/content/industry/forestry/managing-our-forest-resources/forest-health

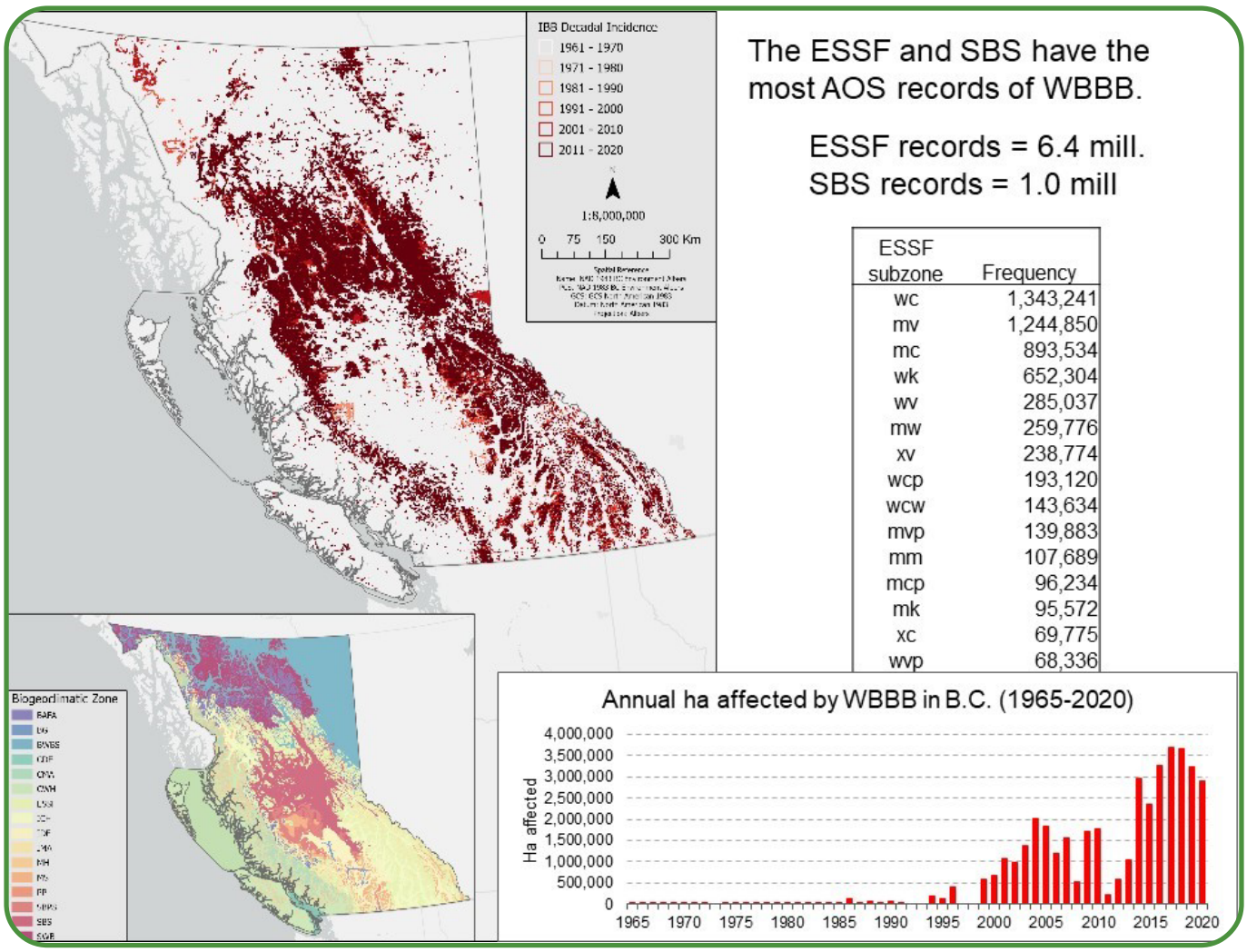
Presentation to initial meeting of the "Subalpine fir – western balsam bark beetle consortium"

Lorraine Maclauchlan, Forest Entomologist, Thompson/Okanagan Region

Venue: Held virtually

Abstract:
A diverse group of FLNRORD, University (UNBC, UBC) and Canadian Forest Service researchers make up this group that are all interested in expanding and promoting research on western balsam bark beetle.

Temperatures at high elevations, in the north and interior mountain ranges of B.C. have risen faster than the global average, particularly in winter. Drought years are more frequent and seasonal development time longer. During drought years subalpine fir is increasingly vulnerable to bark beetle attack, notably western balsam bark beetle, and less aggressive insects (e.g. *Pissodes striatulus*). I summarized my published work (10 refereed publications) on western balsam bark beetle and ongoing, long-term projects in the southern interior with plans to expand some of these projects into northern ecosystems.



Research Palooza's

Lorraine Maclauchlan, Forest Entomologist, Thompson/Okanagan Region

Venue: Held virtually

During March and April of 2021, the Thompson Okanagan Regional Research Team *virtually* toured each of the District Offices and gave updates to staff on current issues and research projects. I updated each District on planned spray programs and the status of other forest health issues in their District. I also updated them on the progress of my three primary research projects:

1. Managing mortality agents of subalpine fir: elucidation of stand and landscape-level response and impact of insects to erratic climate events.
2. Post-mountain pine beetle regeneration: density, pest incidence and impact and resilience of young lodgepole pine.
3. Managing for resilience in the IDF: management options to mitigate defoliator and bark beetle damage in unpredictable climate regimes.

Research Podcast: A Forest of Ideas – Episode 4 – Fear No Weevil

Lorraine Maclauchlan, Forest Entomologist, Thompson/Okanagan Region

- Concept: a conversation about forest health, those biological parts of a forest ecosystem we call "pests" and ultimately the potential big impact of little things that can explode into great abundance
- Integrated Pest Management – what is it, how does it contribute to the integrated forest management?
- Holistic forest management – the overwhelming 'dischordant harmony' of lifecycles, climatic cause and effect, and the complex interaction between the 'pests' we don't like and the 'hosts' we protect

Podcast: https://bcpublicservice.libsyn.com/website

Forest Health Publications

Bleiker, K.P., Brooks, J.E. (Eds.). 2021. Spruce Beetle A Synthesis of Biology, Ecology, and Management in Canada. Natural Resources Canada, Canadian Forest Service. https://cfs.nrcan.gc.ca/publications/download-pdf/40527

Comeau, V. M., L. D. Daniels and S. Zeglen. 2021. Climate induced yellow-cedar decline on the island archipelago of Haida Gwaii. Ecosphere 12(3) **https://doi.org/10.1002/ecs2.3427**.

Hennon, P.E., Frankel, S.J., Woods, A.J., Worrall, J.J., Ramsfield, T.D., Zambino, P.J., Shaw, D.C., Ritóková, G., Warwell, M.V., Norlander, D. and Mulvey, R.L., 2021. Applications of a conceptual framework to assess climate controls of forest tree diseases. Forest Pathology, 51(6), p.e12719. https://www.fs.fed.us/psw/publications/frankel/psw_2021_frankel001_hennon.pdf

Maclauchlan, L.E. and Brooks J.E. 2021. Comparison of two treatment regimes for managing western balsam bark beetle. Journal of Ecosystems and Management 21(1):1–11. http://jem.forrex.org/index.php/jem/article/view/611/523

Murray, M.P. 2021. Grizzly bears prune cone-producing branches on whitebark pine. Nutcracker Notes. 40:14.

Murray, M.P.; Berg, J.; Huggard, D.J. Harvest Retention Survivorship of Endangered Whitebark Pine Trees. Forests 2021, *12*, 654. https://doi.org/10.3390/f12060654

Murray, M.P.; and A. Leslie. 2021. Climate, radial growth, and mortality associated with conifer regeneration infected by root disease (*Armillaria ostoyae*). The Forestry Chronicle. 97(1):43-51. https://doi.org/10.5558/tfc2021-006

Murray, M.P., & Strong, W. 2021. Disease Screening for Endangered Whitebark Pine Ecosystem Recovery in Canada. Journal of Ecosystems and Management 21(1):1–7.

Zeglen, S. and Diprose, R.S. 2021. Efficacy of delayed entry low branch sanitation pruning in preventing mortality of western white pine infected with white pine blister rust, Canadian Journal of Plant Pathology 43: sup2, S358-S369, DOI: 10.1080/07060661.2021.1916602

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- Kootenay Lake Aviation
- Lakes District Air
- Talon Helicopters
- Trek Aerial Services

Photographs:

Aaron Bigsby (western hemlock looper defoliation)
Alex Woods (comandra blister rust affected stands)
Barbara Zimmonick (surveyors with plane, dothistroma infected stands, two-year-cycle budworm defoliation)
Erica Reid (yellow cedar decline)
Joan Westfall (various remaining)
Kevin Buxton (frost damage)
Keith Little (spruce beetle mortality in fertilized stand)
Lorraine Maclauchlan (Douglas-fir beetle frass, western spruce budworm larva, defoliation, and egg mass, Douglas-fir tussock moth larva, spruce beetle, western hemlock looper larva, aspen leafminer close-up, Armillaria root disease caused mortality)
Marnie Duthie-Holt (spruce beetle stand mortality, baiting spruce trees)
Michael Murray (Whitebark pine patch retention)
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Tom Foy (eastern spruce budworm defoliation, red belt damage)

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