BRITISH COLUMBIA

Ministry of Forests, Lands, Natural Resource Operations and Rural Development

2021 Overview of Forest Health Conditions in Southern British Columbia

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INTRODUCTION

This report summarizes the results of the 2021 Aerial Overview Surveys, forest health operations, and research projects conducted in the southern interior of British Columbia. The aerial overview survey is performed annually by the B.C. Ministry of Forests, Lands, Natural Resource Operations and Rural Development and details forest damage due to bark beetles, defoliators, and other visible forest health factors, such as foliar diseases and abiotic damage. Surveys were carried out using the standardized Provincial Aerial Overview Survey protocols (*http://www2.gov.bc.ca/gov/content/environment/research-monitoring-reporting/monitoring/aerial-overview-surveys/methods*). Polygons are used to record larger areas of continuous damage and are assigned severity ratings as described in Table 1. Spots are used to record small, discrete groups of affected trees.

The 2021 surveys were completed between July 10th and October 8th. Due to the number and severity of wildfires in the southern interior, particularly in the Thompson Okanagan and Kootenay Boundary Regions, flying conditions were difficult because of smoky skies and no-fly zones due to fire fighting. Flights were shut down for 5-6 weeks in the Thompson Okanagan and Kootenay Boundary Regions and resumed in September when conditions improved. A total of 358.8 hours of fixed-wing aircraft flying time over 55 days were required to complete the surveys, which covered all areas within the Cariboo, Thompson Okanagan, and Kootenay Boundary Natural Resource Regions. These three Regions cover more than 25 million hectares, of which over 15 million hectares are forested.

The Aerial Overview mapping was conducted by trained contractors in the three Regions as follows:

Region	Start-end dates flown	Mappers	Aircraft	# days	Hours	Contractor company
CAR - south	Aug. 3 – 24	Barbara Zimonick Karen Baleshta	Cariboo Air Ltd., Cessna-182	13	104.0	Zimonick Enterprises
CAR - north	July 27 – Oct. 8	Nathan Atkinson Scott Baker	Cariboo Air Ltd., Cessna-182	11	90.6	Industrial Forestry Service Ltd
KBR	July 10 - Sep. 16	Neil Emery Adam O'Grady	Babin Air, Cessna-337	19	94.3	Nazca Consulting
TOR	July 16 - Sep. 11	Janice Hodge Kevin Buxton	Upper Valley Aviation Ltd., Cessna 182P (long range tanks)	12	69.9	JCH Forest Pest Mgmt.
Total				**55**	**358.8**	

White Rock Lake Fire, Okanagan TSA

AOS pilot with Janice Hodge & Kevin Buxton

Douglas-fir beetle, Kamloops TSA

Thirty-three damage agents were mapped during the 2021 surveys, affecting approximately 1,484,422 hectares over 14 TSAs, which is about 875,669 hectares more than was mapped in 2020, and represents a 2.4-fold increase. However, much of this increase was due to wildfires that affected over 695,992 hectares in the southern interior. The damage from other factors totaled 788,430 hectares, an increase of 180,000 hectares from 2020. Bark beetle infestations (western balsam bark beetle, Douglas-fir beetle, mountain pine beetle, spruce beetle, western pine beetle, fir engraver beetle) increased by 9,993 hectares to 323,697 hectares. Douglas-fir beetle and western balsam bark beetle both increased, by 14% and 6% respectively, while spruce beetle and mountain pine beetle decreased. Damage caused by insect defoliators doubled in 2021, affecting 334,283 hectares, mainly due to increases in western spruce budworm and deciduous defoliators such as aspen serpentine leafminer.

Abiotic damage was mapped on 806,466 hectares mainly due to the 2021 wildfires, drought and the heat dome. The severe 2021 drought and heat dome affected 96,429 hectares, with most damage manifesting as foliar damage (96,346 hectares), plus 84 hectares of drought mortality. Fire damage was mapped on 695,992 hectares, with 3,640 hectares of post-fire mortality. Aspen decline was mapped over 383 hectares, a slight increase from 2020.

Foliar disease levels declined from 31,311 hectares in 2020 to 19,745 hectares, largely due to fewer pine needle cast infections observed.

Table 1. Severity ratings used in the aerial overview surveys.

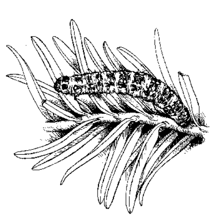
Disturbance Type	**Severity Class**	**Description**
Tree mortality	Trace	<1% of trees in the stand recently killed
(including bark beetles, abiotic factors, and animal damage)	Light	1-10% of trees in the stand recently killed
	Moderate	11-29% of trees in the stand recently killed
	Severe	30-49% of trees in the stand recently killed
	Very Severe	50%+ of trees in the stand recently killed
Defoliation*	Light	Some branch tip and upper crown defoliation, barely visible from the air.
(including defoliating insect and foliar disease damage)	Moderate	Thin foliage, top third of many trees severely defoliated, some completely stripped
	Severe	Bare branch tips and completely defoliated tops, most trees sustaining >50% total defoliation
Decline Syndromes	Light	Decline with no mortality - the first detectable stage, characterized by thin crowns and no individuals without visible foliage
	Moderate	Decline with light to moderate mortality - thin crowns are accompanied by individuals devoid of foliage. Greater than an estimated 50% of individuals have some foliage.
	Severe	Decline with heavy mortality - crowns are very thin and greater than 50% of standing stems are devoid of foliage.

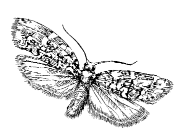
* Serpentine leafminer defoliation is rated according to the percentage of trees in the stand that are affected, based on tree mortality classes.

Table 2. Area affected (spots and patches) by damaging agents in the southern interior in 2021 by Timber Supply Area (TSA).

TSA and Damaging Agent	Area of infestation (hectares) Trace	Light	Moderate	Severe	Very Severe	Total
Douglas-fir beetle						
100 Mile House	2,536	189	92	36,953		39,769
Quesnel	73	50	125	73		322
Williams Lake	9,398	687		31,188		41,273
Arrow	2,677	1,745	127	1,164		5,713
Boundary	262	196	82	109		650
Cranbrook	454	588	117	205		1,365
Golden	77	379	65	174		694
Invermere	857	609	29	111		1,607
Kootenay Lake	844	878	41	280		2,043
Revelstoke	159	271		77		507
Kamloops	1,479	2,315	1,026	44	192	5,055
Lillooet	59	18	41			118
Merritt	68	69	27		10	173
Okanagan	236	291	164		50	741
Total	**19,178**	**8,286**	**1,935**	**70,379**	**252**	**100,029**
Spruce beetle						
Quesnel	434	51		79		563
Williams Lake	3,692	351	36	6,404		10,482
Arrow	13					13
Cranbrook	379	1,087	637	7	9	2,119
Golden	843	785	195	390		2,214
Invermere	515	151		721		1,387
Kootenay Lake	155	192	204	75		626
Kamloops	1,346	2,104	295	88		3,832
Lillooet	944	826	566	330		2,666
Total	**8,321**	**5,547**	**1,933**	**8,094**	**9**	**23,904**
Mountain pine beetle						
Williams Lake	3,457	963		30,037		34,457
Arrow	191	91		99		381
Boundary	22	61		28		110
Cranbrook	326	826	131	692		1,975
Golden	50	164		14		228
Invermere	991	1,873	215	964		4,042
Kootenay Lake	628	579	14	335		1,556
Lillooet	939	318	41	73		1,371
Merritt				34		34
Okanagan	13					13
Total	**6,616**	**4,875**	**401**	**32,276**	**0**	**44,167**

TSA and Damaging Agent	Area of infestation (hectares)					
	Trace	Light	Moderate	Severe	Very Severe	Total
Western balsam bark beetle						
100 Mile House				440		440
Quesnel	4,723	183	57	26,116		31,078
Williams Lake	3,407	152	277	39,888		43,725
Arrow	407	56		1,991		2,454
Boundary	10	66		237		312
Cranbrook	2,776	574		4,405		7,754
Golden	4,790	770		5,486		11,046
Invermere	3,388	794		5,968		10,150
Kootenay Lake	824			2,844		3,668
Revelstoke	196			2,252		2,448
Kamloops	355			20,127		20,482
Lillooet	1,110	5		7,615		8,731
Merritt	117	4		3,682		3,803
Okanagan	728	80		8,697		9,505
Total	**22,830**	**2,685**	**334**	**129,308**	**0**	**155,156**
Western spruce budworm						
100 Mile House	2,581	10,444				13,025
Williams Lake	1,996	27,013	8,384			37,392
Lillooet	315					315
Merritt	2,908	224				3,132
Okanagan	30					30
Total	**7,830**	**37,681**	**8,384**	**0**	**0**	**53,895**
Two-year cycle budworm						
100 Mile House		4,626				4,626
Arrow		50				50
Kootenay Lake	24					24
Kamloops	1,295	225				1,520
Merritt			9			9
Total	**1,319**	**4,900**	**9**	**0**	**0**	**6,228**
Douglas-fir tussock moth						
Williams Lake					121	121
Lillooet	9	6	79			94
Total	**9**	**6**	**79**	**0**	**121**	**215**





TSA and Damaging Agent	Area of infestation (hectares)					
	Trace	Light	Moderate	Severe	Very Severe	Total
Western hemlock looper						
Quesnel	269	63	25			357
Williams Lake	5,751	3,175	1,103		46	10,074
Arrow	1,181	954	194	26		2,354
Golden	774	636	99			1,509
Invermere	131					131
Kootenay Lake	715	256				971
Revelstoke	2,721	3,702	1,756	63		8,243
Kamloops	65					65
Okanagan	217	280				497
Total	**11,825**	**9,067**	**3,176**	**89**	**46**	**24,202**
Aspen serpentine leafminer						
100 Mile House	82,962	3,694	264			86,920
Quesnel	16,086	24,414	1,628			42,128
Williams Lake	64,865	4,605	521			69,990
Arrow	2,325	1,392				3,717
Boundary	361					361
Cranbrook	1,432	716				2,148
Golden	4,867	3,819				8,686
Invermere	373	780				1,153
Kootenay Lake	1,104	2,165	36			3,306
Revelstoke	1,460	586	53	236		2,334
Kamloops	14,834	9,372	1,351			25,558
Okanagan	719	775				1,493
Total	**191,388**	**52,317**	**3,853**	**236**	**0**	**247,794**
Birch leafminer (*Fenusa pusilla, Profenusa thomsoni, Lyonetia prunifoliella*)						
Arrow		15				15
Cranbrook	68	104				172
Kootenay Lake		20				20
Kamloops	29					29
Okanagan	195	508				702
Total	**291**	**647**	**0**	**0**	**0**	**938**

TSA and Damaging Agent	Area of infestation (hectares)					
	Trace	Light	Moderate	Severe	Very Severe	Total
Drought - general, foliage loss						
100 Mile House	247	472				718
Quesnel	39	162	142			343
Williams Lake	1,776	2,456	100			4,332
Arrow	203	1,024				1,227
Cranbrook	144	160				304
Golden	554	940	32			1,526
Invermere	38	219				257
Kootenay Lake	827	1,448	230	17		2,522
Revelstoke	6	50				56
Kamloops	10,547	23,934	2,557			37,039
Lillooet	113	14				127
Merritt	152	55				207
Okanagan	19,032	27,774	881			47,688
Total	**33,679**	**58,708**	**3,942**	**17**	**0**	**96,346**
Drought - mortality						
Williams Lake			76			76
Okanagan	8					8
Total	**8**	**0**	**76**	**0**	**0**	**84**
Pine needle cast						
Quesnel	220					220
Kamloops	676					676
Lillooet	26					26
Merritt	230					230
Okanagan	652	137				789
Total	**1,804**	**137**	**0**	**0**	**0**	**1,940**
Dothistroma needle blight						
100 Mile House	40	140				180
Quesnel	1,734	2,875	88			4,697
Williams Lake	614	215	24			852
Golden		24				24
Kamloops	308	470				778
Okanagan	46	102				147
Total	**2,742**	**3,825**	**112**	**0**	**0**	**6,678**
Aspen decline						
100 Mile House	36	13	15			65
Quesnel		12				12
Williams Lake	62	20	7			89
Kamloops		112				112
Lillooet		70	12			83
Merritt	22					22
Total	**120**	**228**	**35**	**0**	**0**	**383**

SOUTHERN INTERIOR OVERVIEW

MOUNTAIN PINE BEETLE, *DENDROCTONUS PONDEROSAE*

The area affected by mountain pine beetle declined by 4,358 hectares, to 44,167 hectares affected (Table 2; Figures 1 and 2). Mountain pine beetle was detected in 10 TSAs. No mountain pine beetle was mapped in the 100 Mile House, Quesnel, Revelstoke or Kamloops TSAs in 2021. A decline in area infested was recorded in all 10 TSAs (Table 2) except for Arrow and Cranbrook, where small increases were observed. Although the area infested in the Williams Lake TSA declined by 2,525 hectares in 2021, it still had the most active mountain pine beetle, at 34,457 hectares. Key areas of activity continued to be from Taseko Lake northwest to Chilko and Tatlayoko Lakes. Areas of increase in the Cranbrook TSA included Cranbrook Mountain, Wigwam River, Yahk Mountain, Caven Creek, and scattered spots throughout other mature pine types.

Many of the higher elevation infestations occurred in whitebark pine or mixed species stands.

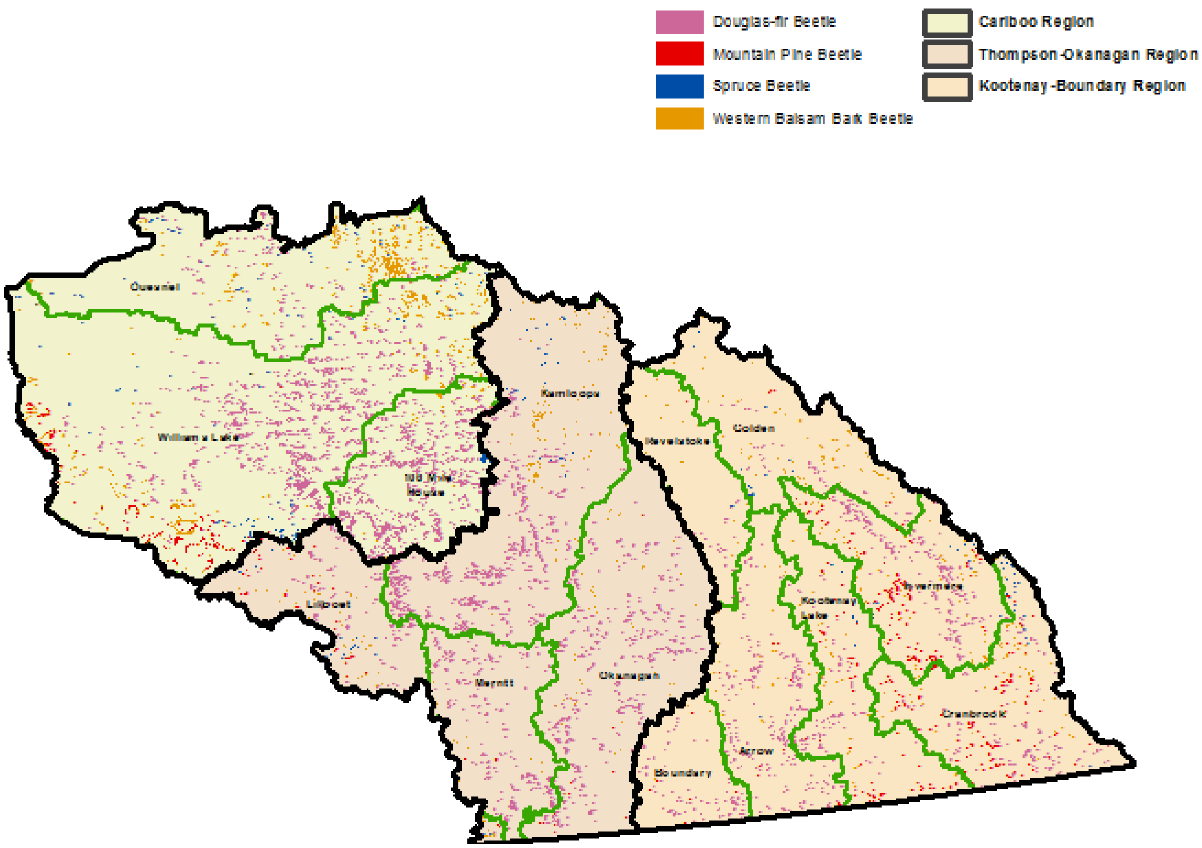
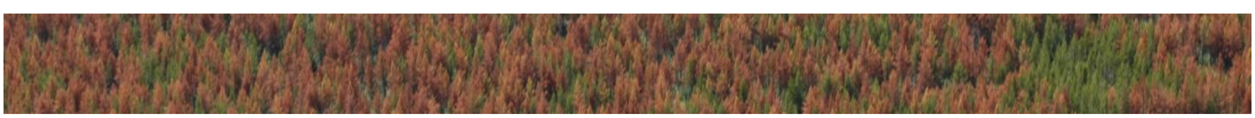


Figure 1. Timber Supply Areas and bark beetle infestations in the southern interior.



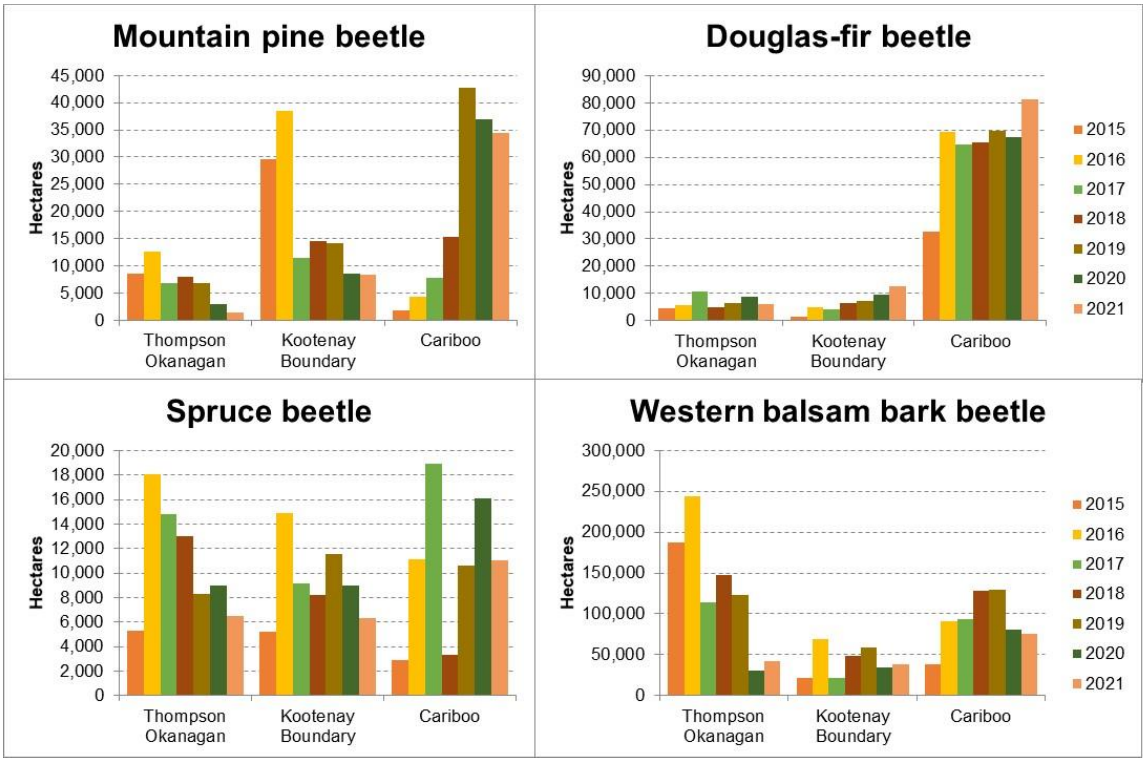
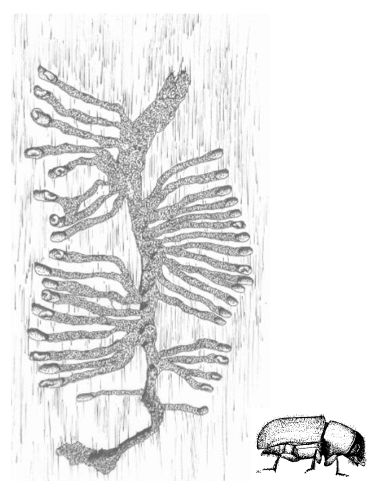


Figure 2. Area affected by major bark beetles in the southern interior of B.C. (Thompson Okanagan, Kootenay Boundary and Cariboo Regions) from 2015-2021.

DOUGLAS-FIR BEETLE, *DENDROCTONUS PSEUDOTSUGAE*

Douglas-fir beetle remained widespread across many areas of southern B.C., with 6 of 14 TSAs showing an increase in area attacked (Table 2, Figures 2 and 3). The most significant increase was observed in the 100 Mile House, Arrow, Cranbrook, and Kootenay Lake TSAs (Figure 3). In the 100 Mile House TSA, expansions were most significant in the south around Clinton, along the Bonaparte River, near Big Bar Creek, Big Bar Mountain, south of Big Bar Lake and near Canoe Creek. In the Williams Lake TSA, a decline in Douglas-fir beetle occurred near Williams Lake, but increased in Churn Creek and Empire Valley.

In the Arrow TSA, in the Kootenay Boundary Region, Douglas-fir beetle was scattered throughout particularly from New Denver, south to Silverton, Slocan and Salmo. In the Cranbrook TSA, Douglas-fir beetle activity increased in the Grasmere to Wigwam River area. In the Thompson Okanagan Region, Douglas-fir beetle populations were most active in the Kamloops TSA; however, there was a decrease of 1,033 hectares from 2020, with 5,055 hectares affected (Table 2; Figure 3). Much of this decline is most likely due to the fact that many of the active Douglas-fir beetle areas were affected by wildfires in 2021. In particular, the Sparks Lake and Tremont Creek Fires burned in areas where there was significant beetle activity mapped in 2020. These fires will present many trees and stands that will be highly susceptible to Douglas-fir beetle attack in 2022; therefore, detection and mitigation should be targeted in and near these burnt stands where hazard and risk are high.



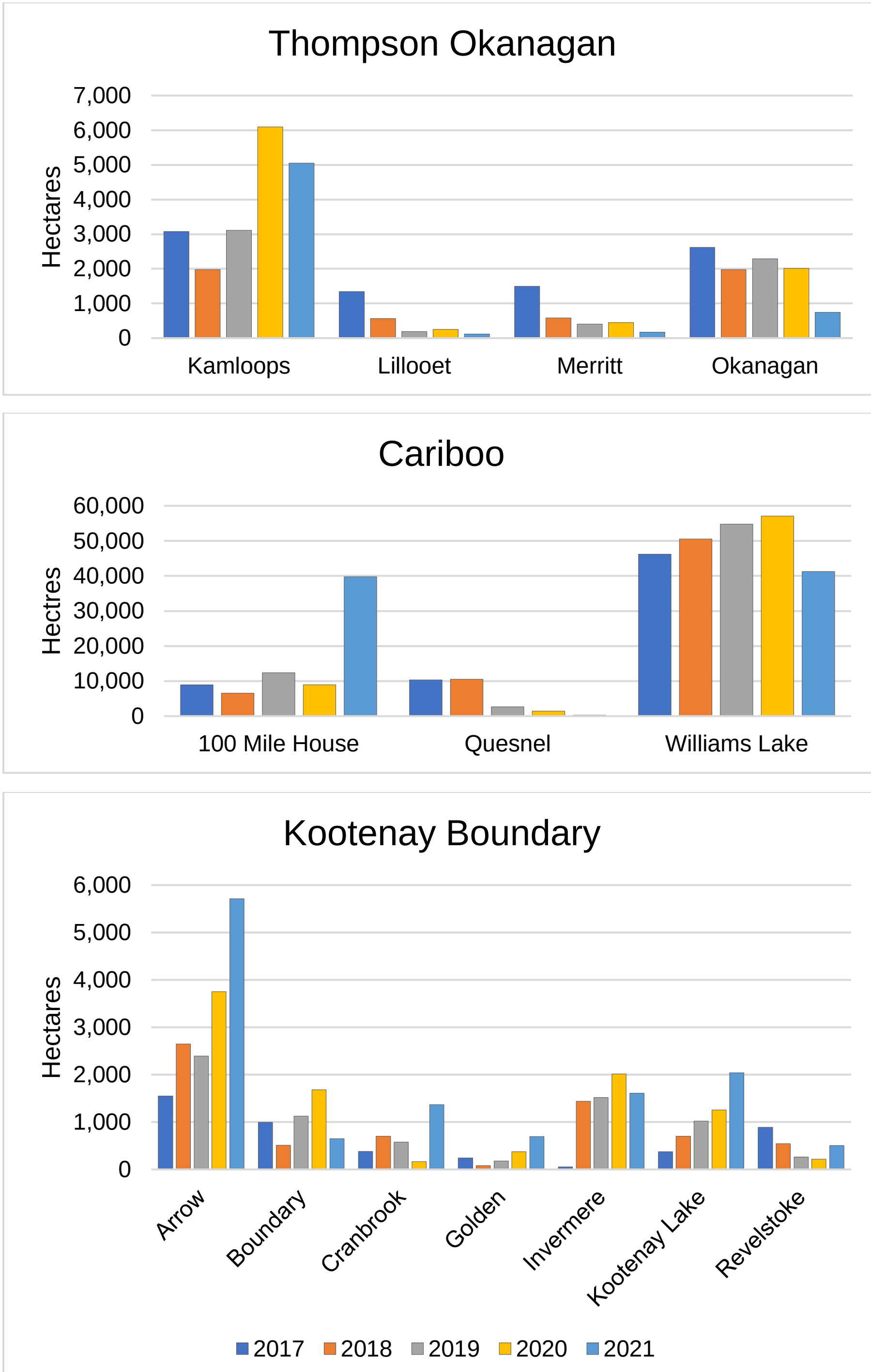
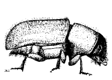
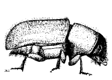
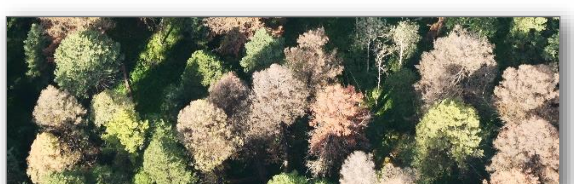
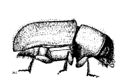


Figure 3. Hectares affected by Douglas-fir beetle in the southern interior 2017-2021, by TSA.

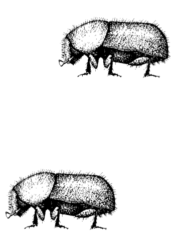
SPRUCE BEETLE, *DENDROCTONUS RUFIPENNIS*

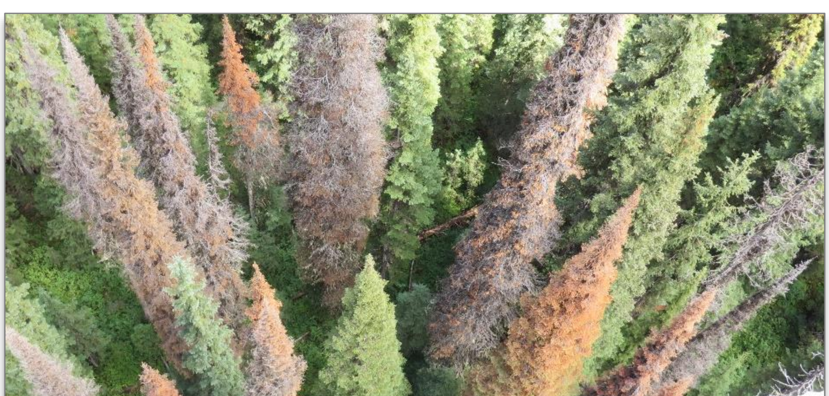
Spruce beetle was detected in 9 TSAs, down from 11 TSAs in 2020. The total area affected by spruce beetle decreased, from 34,078 hectares in 2020, to 23,904 hectares in 2021 (Table 2; Figure 2). The most significant declines were observed in the Quesnel, Williams Lake, Invermere, Kamloops and Lillooet TSAs. The decrease in area detected could in part reflect the two-year life cycle of this insect, with fewer trees being attacked in the 2nd year.

Old spruce beetle mortality in Kamloops TSA, Kostal Lake.

WESTERN BALSAM BARK BEETLE, *DRYOCOETES CONFUSUS*

In 2021, there was an increase of 9,891 hectares in area affected by western balsam bark beetle, for a total of 155,156 hectares across 14 TSAs. Eight TSAs recorded an increase in area attacked and 5 TSAs saw a slight decline (Table 2; Figure 2). The area affected in all TSAs remains less than what was recorded at its peak from 2015 through 2019 but is slowly increasing and could indicate the start of the next population pulse of this bark beetle. The highest levels of western balsam bark beetle activity were observed in the Williams Lake (43,725 ha), Quesnel (31,078 ha) and Kamloops (20,482 ha) TSAs.





Insect Defoliators, General

Methods used to monitor defoliator populations

There are several methods used to monitor or predict defoliator populations. Brief descriptions of the most regularly used methods are described below and more detailed information is provided within separate defoliator sections.

Methods include:

1. Aerial overview and detailed mapping of defoliation – provides the most current information on extent and severity of defoliation. Detailed aerial surveys are conducted when planning control programs.
2. Annual trapping with pheromones at permanent sample sites (PSPs) – provides trends in populations and can predict imminent defoliation. Trapping is conducted annually for Douglas-fir tussock moth and western hemlock looper.
3. Three-tree beatings – is an assessment of species richness and abundance. This is a technique conducted annually to collect defoliator larvae at permanent sample sites (often coupled with trapping). Three-tree beatings are conducted at Douglas-fir tussock moth and western hemlock looper PSPs throughout the southern interior and at an additional thirteen PSPs established in the East Kootenays to monitor western spruce budworm and other defoliating insects.
4. Egg mass surveys – conducted late summer or fall. These surveys provide an estimate of predicted defoliation (defoliator population) in the next season. Egg mass surveys are most often conducted for western spruce budworm and Douglas-fir tussock moth, and occasionally western hemlock looper, as part of the planning process for control programs.

In 2021, approximately 334,024 hectares of deciduous and coniferous forests were impacted by insect defoliators, doubling the area affected since 2020 (Figure 4). The increase was mostly due to a 2.5 to almost 3-fold increase in aspen serpentine leafminer in the Cariboo (199,038 ha) and Thompson Okanagan (27,051 ha) Regions, respectively, and a 5-fold increase in defoliation by western spruce budworm (50,417 ha) in the Cariboo Region.

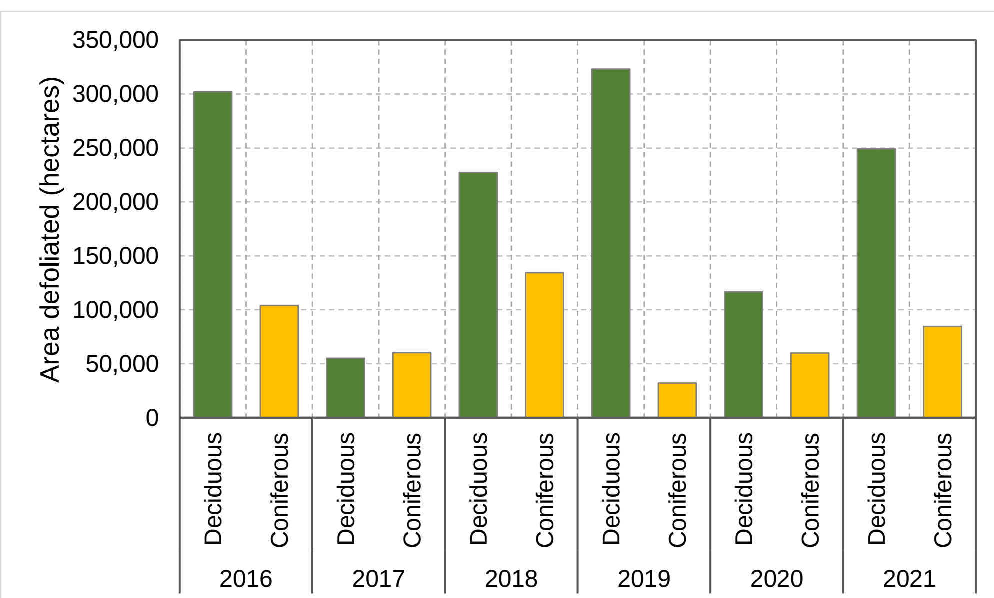


Figure 4. Area of deciduous and coniferous defoliation in the southern interior of B.C., 2016-2021.

Figure 5 illustrates the fluctuation in four major conifer defoliators in the southern interior from 2012 to 2021. In 2012, all four defoliators were active. Over the next several years, all but two-year cycle budworm declined. Western hemlock looper increased from 2019-2021, approximately 9 years since the last outbreak cycle. Western spruce budworm remains low compared to some past outbreak years but is slowly increasing within parts of its range.

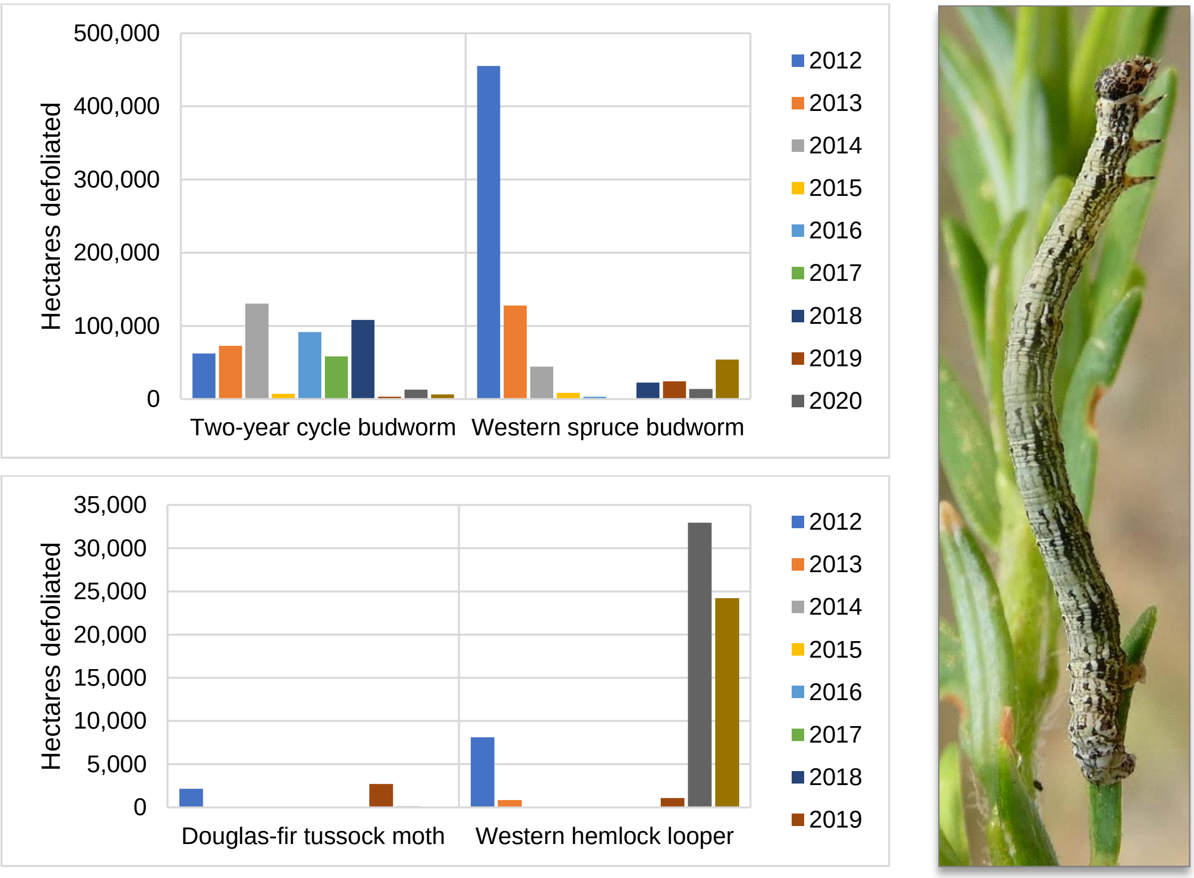


Figure 5. Hectares affected by four major conifer defoliators in the southern interior of B.C. (2012-2021).

Three species of deciduous defoliators were observed, with the **aspen serpentine leafminer** (*Phyllocnistis populiella*) being the most prevalent, affecting 247,794 hectares. Defoliation by the aspen serpentine leafminer increased by 132,362 hectares from 2020 to 2021, with the most significant increases of between 17,500 to 58,500 hectares recorded in the Kamloops, 100 Mile House and Williams Lake TSAs. Moderate increases of between 300 to 2,000 hectares of defoliation occurred in the Boundary, Golden, Kootenay Lake, Revelstoke and Okanagan TSAs. **Satin moth** (*Leucoma salicis*) defoliation remained low at 315 hectares mapped in the Thompson Okanagan Region. **Birch leafminers** (*Fenusa pusilla* and others) declined to 207 hectares in the Kootenay Boundary Region and increased slightly in the Thompson Okanagan Region to 731 hectares, for a total of 938 hectares affected in the southern interior.

Six species of coniferous defoliators were recorded, with **western spruce budworm** (*Choristoneura freemani*) affecting the largest area of southern interior forests. It affected 53,895 hectares, a five-fold increase over 2020, with most of the increase seen in the 100 Mile House TSA. **Two-year cycle**

budworm (*Choristoneura biennis*) was in its "off" year and was only observed defoliating 6,228 hectares, down from 12,800 hectares in 2020. **Western hemlock looper** (*Lambdina fiscellaria lugubrosa*) declined by 8,736 hectares to 24,202 hectares affected. The most significant declines were observed in the Williams Lake, Okanagan and Kootenay Lake TSAs. Much of this reduction in defoliation and lack of population growth of hemlock looper was due to the aerial control programs using *B.t.k.* in the Revelstoke, Okanagan and Kamloops TSAs. The heat dome, which occurred in June, also contributed to early instar larval mortality of both western hemlock looper and western false hemlock looper in Douglas-fir-dominated stands. The heat dome did not seem to affect insect populations as severely in hemlock-dominated stands in the Interior Cedar Hemlock (ICH) biogeoclimatic zone.

Aspen serpentine leafminer and western spruce budworm

The **larch casebearer** (*Coleophora laricella*) was observed in the Arrow (9 hectares) and Kootenay Lake TSAs (24 hectares) and the **balsam fir sawfly** (*Neodiprion abietis*) was mapped on 94 hectares in the Okanagan TSA.

Douglas-fir tussock moth (*Orgyia pseudotsugata*) remained low throughout the southern interior, with small, scattered spots of defoliation mapped in the Williams Lake and Lillooet TSAs for a total of 215 hectares.

WESTERN SPRUCE BUDWORM, *CHORISTONEURA FREEMANI*

Western spruce budworm defoliation of Douglas-fir was mapped in five TSAs in the south area in 2021 (Table 2) with a total of 53,895 hectares defoliated. Four of these TSAs (100 Mile House, Williams Lake, Lillooet, Merritt) also saw some defoliation in 2020. No defoliation was mapped in the Kamloops TSA in 2021, down from 1,088 hectares in 2020, and the Okanagan TSA had 30 hectares of new defoliation south of Kelowna in the Priest Creek area. The most significant increases occurred in the 100 Mile House and Williams Lake TSAs, with increases of 13,018 and 27,119 hectares respectively, since 2020. Western spruce budworm was very active in the southwest corner of the 100 Mile House TSA, into the Williams Lake TSA near Dog Creek, Canoe Creek and Onion Lake. In the Williams Lake TSA, budworm was active in the Meason Creek, Dog Creek to Jones Lake areas. Increases from 2020 were noted in the Doc English Gulch, Till Lake and Meldrum Creek areas near Williams Lake.

Budworm populations expanded slightly in the Merritt TSA, mainly in the south near Princeton, in the Asp Creek, China Creek, Hayes Creek, August Lake and along the Copper Mountain Road areas. A small population persists in the Mamit Lake area. A new and active area of budworm defoliation was mapped in the northeast portion of the Lillooet TSA in the Watson Bar area. More budworm was mapped north of Seton Lake near Shalalth.

The Thompson Okanagan Region sprayed 4,132 hectares of priority Douglas-fir stands in the Kamloops TSA with the biological insecticide Foray 48B (*Bacillus thuringiensis* var. *kurstaki*; P.C.P. No. 24977) to mitigate damage from western spruce budworm defoliation (Table 3; Figures 6 and 7). Two blocks were treated June 24th, 2021, with *B.t.k.* at 2.4 litres per hectare. Western Aerial Applications Ltd. conducted the aerial applications using one 315B Lama helicopter and one Hiller UH12ET helicopter, each equipped with four Beecomist 361A ultra low volume hydraulic sprayers. The spray operations were conducted from a staging site in the Criss Creek area, where the *B.t.k.*, mobile fuel trucks and loading crews were positioned. Spray conditions were optimal for these blocks but as June progressed the heat dome developed, and wildfires started to burn in the area. By the end of the summer, it was determined that the entire Criss Creek block had been burnt (3,825 hectares) by the Sparks Lake fire.

Lama doing spray swath over block and larval sampling.

Table 3. 2021 western spruce budworm spray blocks in the Kamloops TSA, Thompson Okanagan Region, showing the treated area, litres of *B.t.k.* applied, hectares subsequently burnt by wildfire, and date sprayed.

Location	Ha sprayed	Litres *B.t.k.*	Ha burned	Date sprayed
1. Deadman Creek	306	731	0	Jun. 24
2. Criss Creek	3,825	9,187	3,825	Jun. 24
Total	4,132	9,919	3,825	

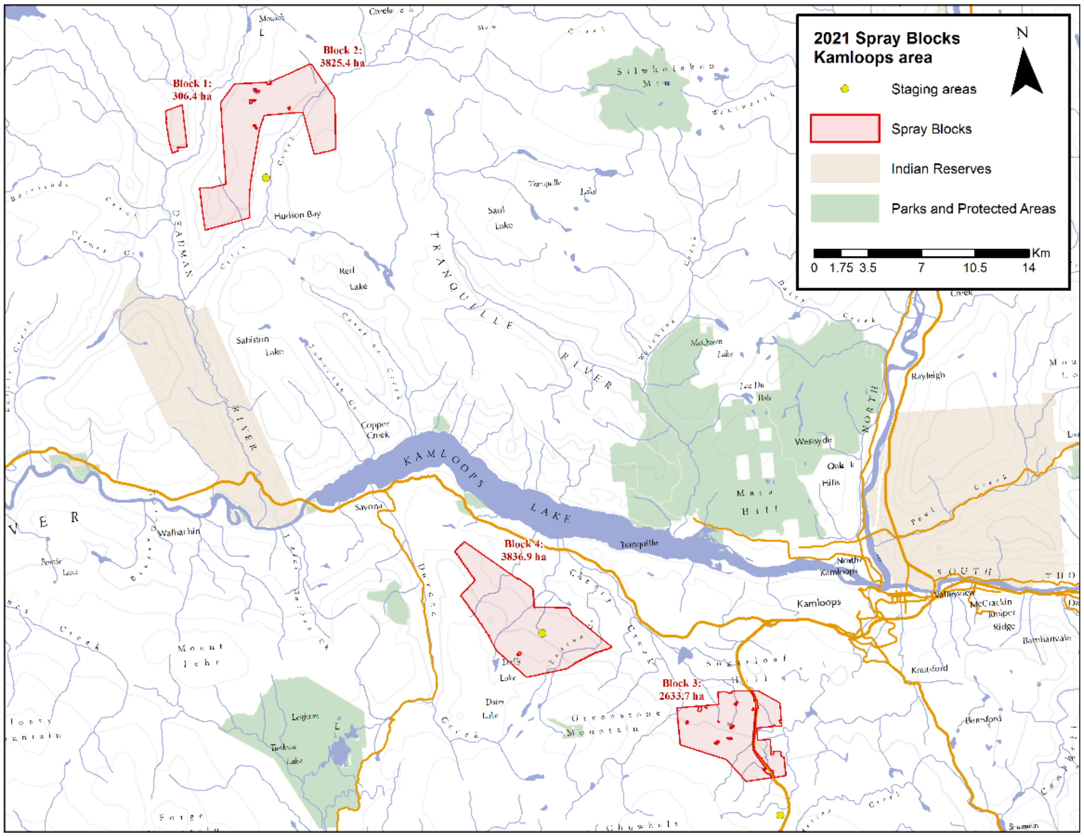


Figure 6. Western spruce budworm (Blocks 1 and 2) and western hemlock looper spray blocks (Blocks 3 and 4) in the Kamloops TSA, Thompson Okanagan Region.

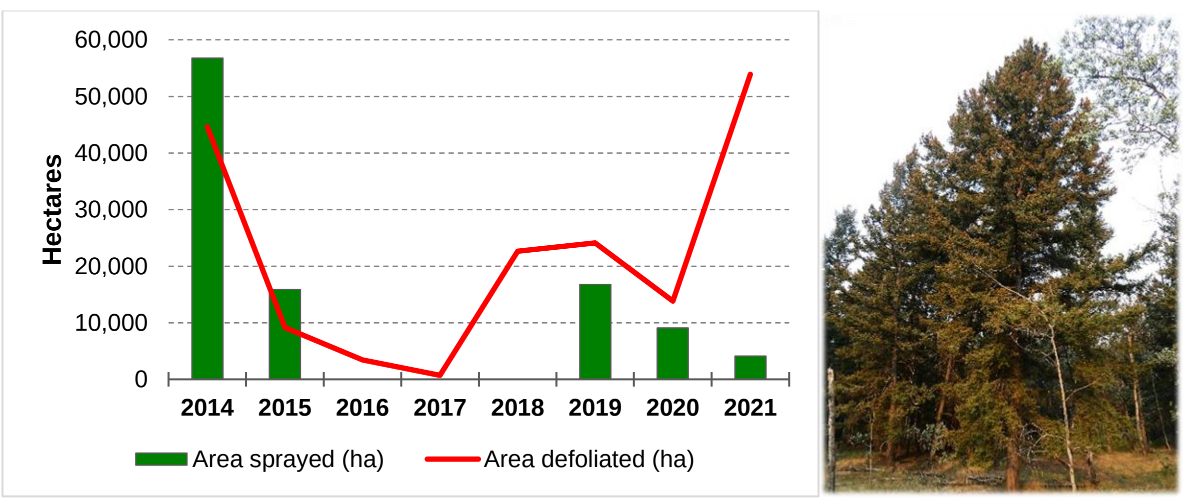


Figure 7. Area defoliated by western spruce budworm and area sprayed with *B.t.k.* in B.C. (2014-2021). 2021 data is only for the south area.

Efficacy assessment

Pre- and post-spray larval sampling was done within the Criss Creek block to determine larval density and treatment efficacy. No "control" sampling was conducted because there were no sites with comparable budworm populations outside the spray blocks. Pre-spray sampling was done the day before treatment, and the post-spray sample was done 7 days later. Budworm larval density at the pre-spray and post-spray sample times was 36.1 ± 6.4 and 2.1 ± 0.8 larvae/m^2 foliage, respectively. The majority of larvae were 4th or 5th instar at the time of the spray. The population was significantly reduced by the treatment (Figure 8).

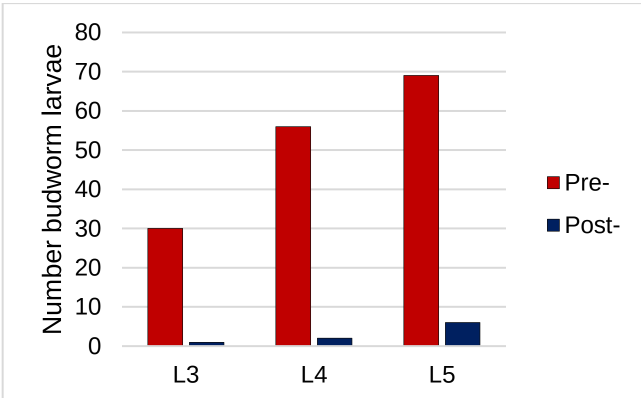


Figure 8. Number of western spruce budworm larvae, by life stage, at the pre- and post-spray sample times. L3=3rd instar; L4=4th instar; L5=5th instar.

Defoliation predictions for 2022

Fall egg mass sampling is conducted to predict defoliation in the following year and to determine whether stands will require treatment with *B.t.k.* Current, historic, and predicted defoliation are all considered when determining population trends and which areas are most at risk for continuing defoliation and damage. 321 sites were sampled throughout the south area, including Chilliwack (Table 4), for western spruce budworm egg masses. Egg mass sampling provides an estimate of the defoliation expected in 2022 based upon the density of egg masses found. Of all sites sampled, 71% predicted no defoliation in 2022 and 29% had predictions of light defoliation, very similar to the predictions in 2021. No sites predicted moderate or severe defoliation (Table 4). In the Thompson Okanagan Region, Kamloops and Merritt TSAs remain the key areas where budworm populations are active, with defoliation expected in 2022. Light defoliation is expected in Big Bar, Prospect Creek, Mamit Lake and in the Princeton area. Due to low egg mass counts and relatively few areas of defoliation noted in the 2021 aerial overview surveys, no *B.t.k.* treatment is planned for 2022 in the Thompson Okanagan Region.

Table 4. Results of the fall 2021 western spruce budworm egg mass sampling in the southern interior. Number of sites indicating nil and light defoliation in 2022 is listed by TSA, with the average number of egg masses per 10m^2 foliage per tree (10 trees sampled per site) by TSA and the maximum number found at a site. Nil = 0; Light = 1-50 egg masses.

Region and	2022 predicted defoliation (No. sites)		Total	No. egg masses per 10m^2 foliage	
Outbreak Area	Nil	Light	# sites	Avg.	Max.
Cariboo					
100 Mile House	13	15	28	7.8	45
Williams Lake	41	18	59	2.9	20
Total	**54**	**33**	**87**	**4.5**	**45**
Kootenay Boundary					
Boundary	**10**	**8**	**18**	**3.1**	**56**
Thompson Okanagan					
Kamloops	79	27	106	5.3	49
Merritt	33	2	35	0.2	3
Okanagan	29		29	0.0	0
Princeton	5	22	27	13.4	37
Salmon Arm	3		3	0.0	0
Total	**149**	**51**	**200**	**4.7**	**49**
South Coast					
Chilliwack	**16**		**16**		
2021 Total	**229**	**92**	**321**		

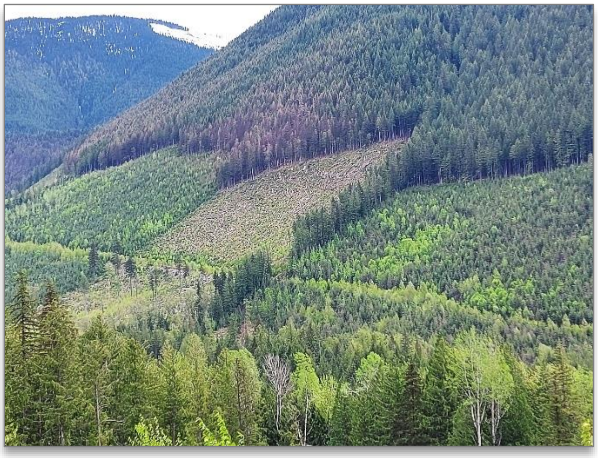
Eighteen sites were sampled in the Boundary TSA within the Kootenay Boundary Region. Fifty-six percent of the sites sampled yielded no egg masses (10 of 18 sites) and 8 sites fell into the light category (Table 4). Budworm populations remain low in this Region and no treatments are planned for 2022.

Eighty-seven sites in the Cariboo Region were sampled for egg masses in the fall of 2021. Fifty-four sites (62%) had no egg masses, 33 sites (38%) predicted light defoliation and no sites predicted moderate or severe defoliation in 2022. High priority sites which indicate an increase in budworm population will be treated with *B.t.k.* in 2022.

WESTERN HEMLOCK LOOPER, *LAMBDINA FISCELLARIA LUGUBROSA*

Western hemlock looper defoliation was mapped on 24,202 hectares in nine TSAs within the southern interior in 2021 (Table 2), up from seven TSAs in 2020. However, the area of defoliation decreased by 8,736 hectares, primarily in the Williams Lake and Okanagan TSAs, where the recorded defoliation decreased by 15,334 and 2,690 hectares, respectively. This decrease was largely due to targeted *B.t.k.* spray programs. 2021 was the second, and most likely final year in the outbreak cycle and we predict that very little new defoliation will occur in 2022. In 2020, there were also numerous sites in Interior Douglas-fir (IDF) stands in the Thompson Okanagan and Cariboo Regions with significant western hemlock looper and associated defoliator species causing localised damage. Many of the populations in the IDF crashed naturally in 2021; however, the Inks Lake population near Kamloops remained high, and therefore, a spray program targeted at this population was conducted. In the Cariboo Region, western hemlock looper populations in IDF stands also crashed and therefore all planned treatments in the IDF were cancelled. Most of the 2020 and 2021 defoliation in hemlock-dominated stands in the Cariboo Region was observed in the Quesnel Lake area.

In the Kootenay Boundary Region, defoliation by western hemlock looper increased from 4,339 hectares in 2020 to 13,209 hectares in 2021. Defoliation was widespread throughout the Revelstoke TSA, north and south of Revelstoke along the Columbia River drainage, and upper Arrow Lake.



Lower edge of block showing 2020 defoliation (prior to 2021 spray) and western hemlock looper larva.

2021 Spray Program

In 2021, a targeted *B.t.k.* spray program was conducted for western hemlock looper in all three Regions (Table 5). However, due to a natural population collapse and negative impacts from the heat dome, the IDF blocks in the Cariboo Region were cancelled, as well as two IDF blocks in the Thompson Okanagan Region (Table 5). All planned blocks in hemlock-dominated stands proceeded with *B.t.k.* treatment. A total of 16,956 hectares over 8 blocks were treated in the Okanagan TSA; 18,902 hectares over 9 blocks in the Williams Lake TSA; and 10,183 hectares over 25 blocks in the Revelstoke TSA, for a total of 46,041 hectares treated for western hemlock looper. (Table 5; Figures 9-11).

Table 5. Hectares sprayed with Foray 48B (*B.t.k.*) to mitigate damage from western hemlock looper and western spruce budworm (identified by asterisk*) defoliation in southern B.C. with hectares burnt in 2021 wildfires and date sprayed.

TSA	Location	Ha sprayed	Litres *B.t.k.*	Ha burned	Date sprayed
Thompson Okanagan Region					
Kamloops	3. Inks Lake	2,634	6,617	0	Jun. 25 & 28
	4. Duffy Lake	3,837	9,955	172	Jun. 28 & 29
Okanagan	7. N. Shuswap-1	1,968	4,851	0	Jul. 2
	8. N. Shuswap-2	1,627	4,042	0	Jul. 2
	9. Perry-1	1,251	3,029	216	Jul. 1-2
	10. Perry-2	461	1,109	0	Jun. 30-Jul. 1
	11. Crazy Creek	3,598	9,134	0	Jun. 30-Jul. 1
	12. Wap	1,581	3,826	307	Jun. 30-Jul. 1
Total		**16,956**	**42,563**	**695**	

TSA	Location	Ha sprayed	Litres B.t.k.	Ha burned	Date sprayed
Cariboo Region					
Williams Lake	1. Horsefly Peninsula	1,112	5,338		Jul. 7, 9
	2. Horsefly Bay	400	1,920		Jul. 7, 11
	3. Cariboo Island	84	403		Jul. 7
	4. Winkley Creek	4,112	19,738		Jul. 7, 8
	5. Lynx Peninsula	527	2,530		Jul. 7, 8
	7. Wasko Lake	1,006	4,829		Jul. 6, 8
	8. Jacques Lake	2,216	10,637		Jul. 6, 9, 10
	9. Hen Ingram	3,343	16,046		Jul. 5, 6, 9, 10
	10. Bouldery Creek	6,102	29,290		Jul. 5, 6, 10, 11
Total		**18,902**	**90,730**		
Kootenay Boundary Region					
Revelstoke	1	144	346		Jul. 3
	2	337	808		Jul. 3
	3	368	883		Jul. 3
	4	90	215		Jul. 3
	5	81	194		Jul. 3
	6	112	270		Jul. 3
	7	159	381		Jul. 3
	8	262	630		Jul. 3
	9	278	668		Jul. 3
	10	279	670		Jul. 3
	11	84	202		Jul. 3
	12	386	927		Jul. 2
	13	80	192		Jul. 3
	14	92	222		Jul. 4
	15	272	652		Jul. 5
	16	289	694		Jul. 6
	17	141	339		Jul. 3
	18	504	1,209		Jul. 2
	19	422	1,014		Jul. 1
	20	444	1,065		Jul. 1
	21	522	1,254		Jul. 1
	22	1,130	2,713		Jun. 29-30; Jul. 1
	23	987	2,368		Jun. 30-Jul. 1
	24	408	980		Jun. 29-30
	25	2,311	5,546		Jun. 28-30
Total		**10,183**	**24,439**		
South Area total		**46,041**	**157,731**	**695**	

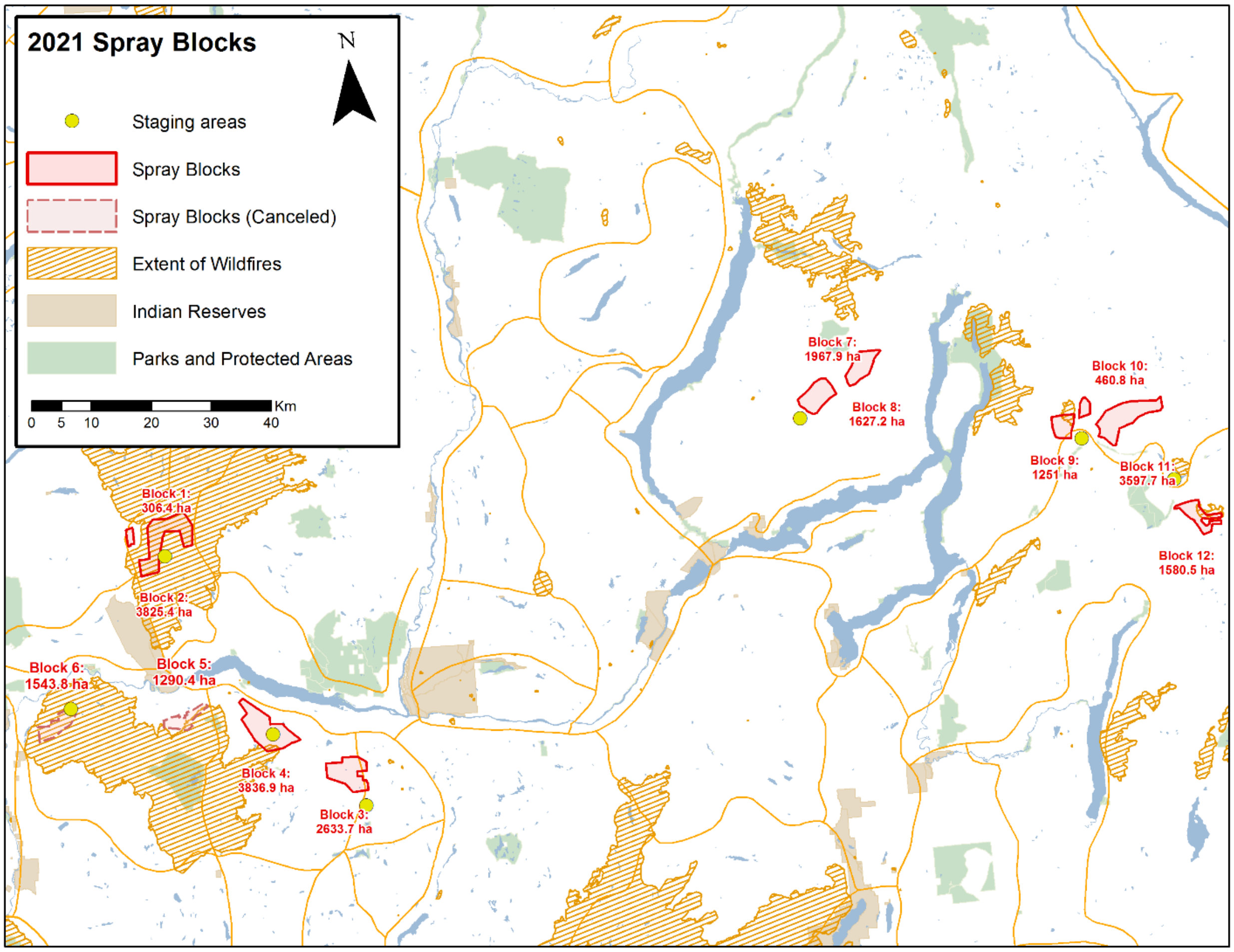
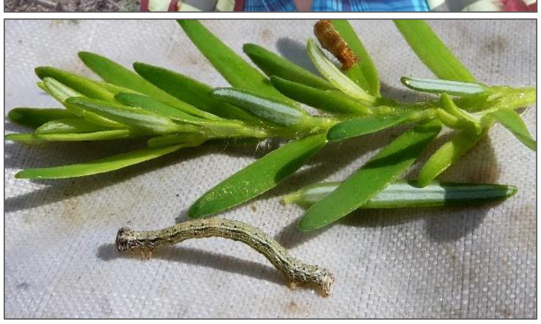


Figure 9. Western hemlock looper and western spruce budworm (Blocks 1, 2) spray blocks in the Thompson Okanagan Region, showing area burnt in 2021 wildfires.



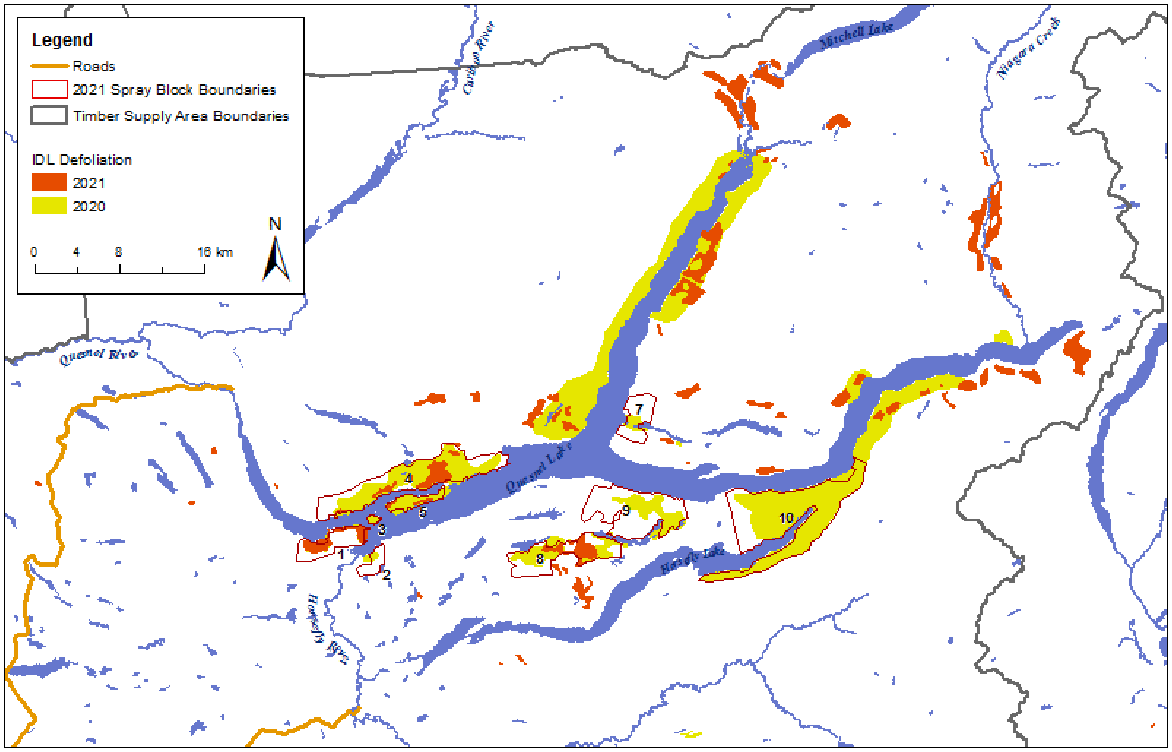


Figure 10. Western hemlock looper defoliation in the Quesnel Lake area, Williams Lake TSA, showing 2020 and 2021 defoliation, and areas sprayed in 2021 with *B.t.k.*

Hemlock foliage damaged by heat dome event, Perry River

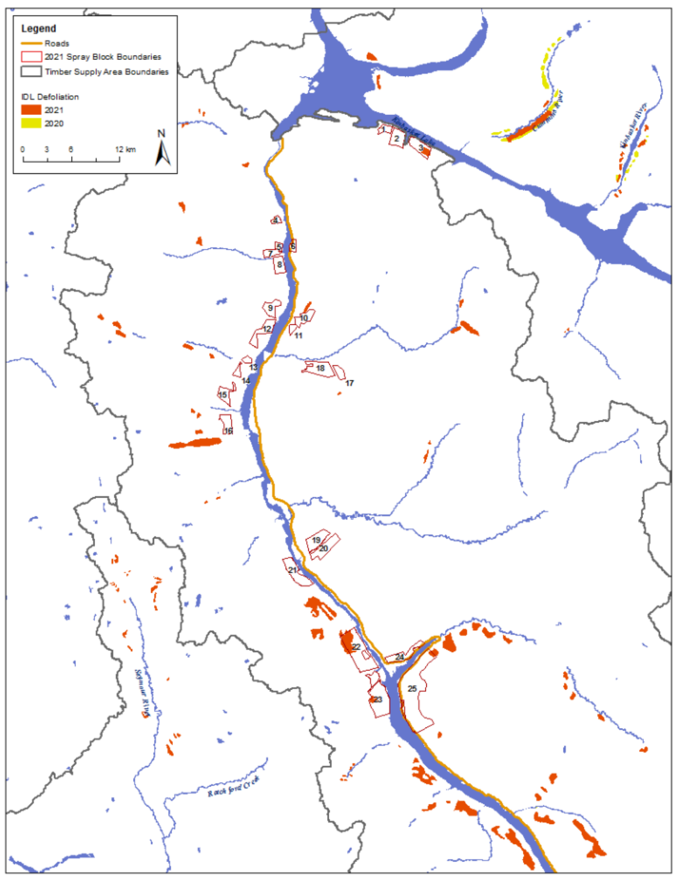


Figure 11. Western hemlock looper spray blocks in the Kootenay Boundary Region, showing 2020 and 2021 defoliation, and areas sprayed in 2021 with *B.t.k.*

Western Aerial Applications Ltd. conducted the aerial applications using one 315B Lama helicopter, two Hiller UH12ET helicopters, and one Jet Ranger 206B, each equipped with four Beecomist 361A ultra low volume hydraulic sprayers. The spray operations were conducted from numerous staging sites throughout the program area, where the *B.t.k.*, mobile fuel trucks and loading crews were positioned. Ground crews were positioned on site to monitor weather parameters before and during spray operations. Spray treatments occurred from June 5th through July 11th, 2021. Due to the heat dome event and continuing hot weather during the spray program, the morning spray window was often short. Some Lepidoptera larval mortality due to the heat dome was observed, primarily in IDF sites.

Treatment efficacy was measured. The Cariboo Region conducted pre- and post-spray sampling using the branch clipping method: two branches per tree were clipped from 10 trees per site and the average number of larvae per $10m^2$ foliage was calculated. The Thompson Okanagan and Kootenay Boundary Regions conducted branch beatings on up to 10 trees per site. When and where possible, both pre- and post-spray samples were collected in treated and control sites. However due to difficulty of access, timing of spray operations and difficulty finding comparable looper populations outside the treatment blocks, this was not possible in all areas.

The *B.t.k.* treatment was very successful. At the pre-spray sample time on the Inks Lake Block (treated June 25 and 28), there were several different Lepidoptera and sawfly species recorded, with the dominant species being western hemlock looper (238 larvae), western false hemlock looper (179 larvae) and 11 larvae of other species. *B.t.k.* does not affect sawflies. At the post-spray sample (1 week following treatment), no Lepidoptera larvae were found.

In the Okanagan and Revelstoke TSAs, western hemlock looper abundance was significantly reduced due to the spray treatment (Figure 12). Figure 13 shows the distribution of western hemlock looper instars at various sampling times in the Okanagan TSA. At the pre-spray sample, most larvae were 2nd or 3rd instar. By the third post-spray sample, very few larvae were collected in the treated blocks, and were mostly early instar (1st to 4th instar). These were probably too small or unhatched at the time of the spray. In the control block, the majority of larvae were late instar (4th to 6th instar). and significantly more were recorded than in the spray blocks.

Only a few patches of defoliation were mapped in 2021, in remote stands up the North Seymour River. No *B.t.k.* treatments are planned for 2022 in the Thompson Okanagan Region.

In the Cariboo Region, very few larvae were collected using the branch clipping method; however, populations were reduced successfully. There was 93% mortality in the 1st post-spray sample and 100% mortality in the 2nd and 3rd post-spray samples. It is unlikely there will be visible defoliation in any of the treatment blocks in 2022, and the outbreak will likely subside over the next year. No further treatments are planned during this outbreak cycle.

Spray morning in the Cariboo and Perry River staging site.

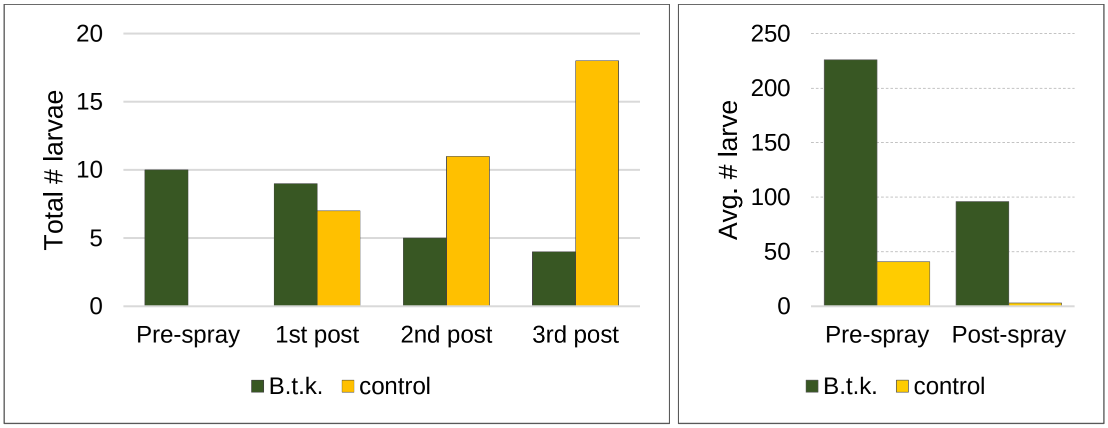


Figure 12. Number of live western hemlock looper larvae collected in tree beatings in *B.t.k.* treated and control blocks at pre- and post-spray sampling times in the Okanagan (total number of larvae) and Revelstoke (average number of larvae per site) TSAs.

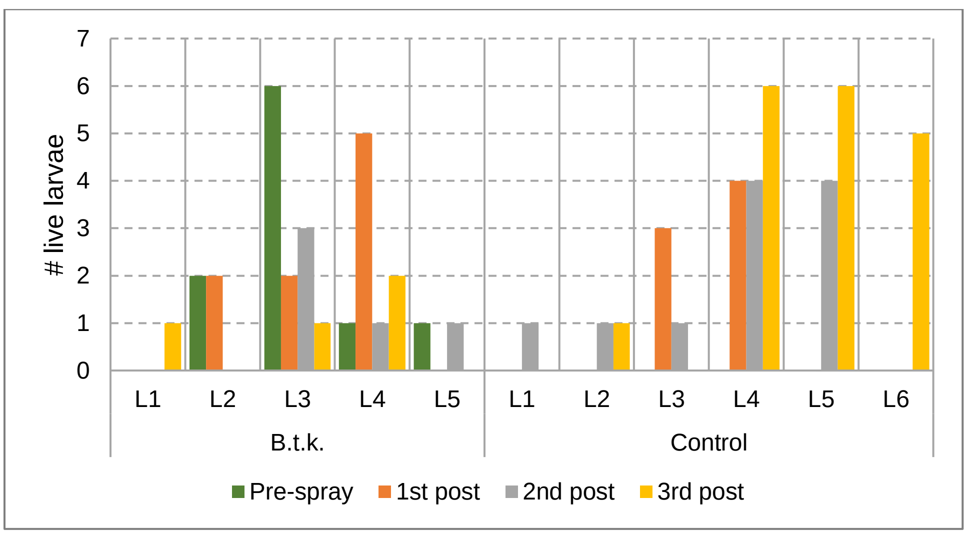


Figure 13. Number and stage of western hemlock looper larvae at pre- and post-spray sampling times. in *B.t.k.* treated and control blocks in the Okanagan TSA. L1-L5 refers to 1st through 5th instar.

		
Twolined larch sawfly, *Anoplonyx laricivorus*	Rusty tussock moth, *Orgyia antiqua*	Western hemlock looper, *Lambdina fiscellaria lugubrosa*
		
Yellow-lined forest looper, *Cladara limitaria*	Saddleback looper, *Ectropis crepuscularia*	Hemlock sawfly larva, *Neodiprion tsugae*
		
Balsam fir sawfly, *Neodiprion abietis*	Filament bearer, *Nematocampa resistaria*	Western false hemlock looper, *Nepytia freemani*

Trapping and three-tree beating

Western hemlock looper and associated defoliators are monitored annually at permanent sampling sites using a combination of three-tree beatings and/or moth trapping (six uni-traps placed per site) (Figure 14). Three-tree beatings and moth trapping were done at 16 sites in the Thompson Okanagan Region. In the Kootenay Boundary Region, three-tree beatings were done at 25 sites, while moth trapping was done at 10 of the sites. In the Cariboo Region, three-tree beatings were done at 10 sites, while moth trapping was done at 14 sites. Three-tree beatings were undertaken in early to mid-July at all sites and traps were placed at this time. A 60 cm x 90 cm drop cloth and a 2.5-meter pole were used to conduct the tree beatings. Traps were collected late September through early October 2021.

The average number of western hemlock looper moths caught per trap is trending downward in the Thompson Okanagan and Cariboo Regions, while there was a slight increase in the Kootenay Boundary Region (Table 6). In the Thompson Okanagan Region, average trap catch per site decreased significantly at 13 sites and increased at 3 sites, for an overall average of 209 moths per trap per site. In the Cariboo Region, the average of number of moths per trap was 22 moths, down significantly from an average of 137 moths in 2020 (Table 6). In the Kootenay Boundary Region, 7 sites saw an increase in average moth catch, while 3 sites declined, for an average of 1,476 moths per trap per site. The most notable increases were at sites along the Columbia River drainage, including near Martha Creek, Goldstream River, Bigmouth Creek, Carnes Creek, Begbie Creek and Pitt Creek (Table 6). In 2022, there should be a further decline in trap catches as the outbreak nears the end of its cycle.

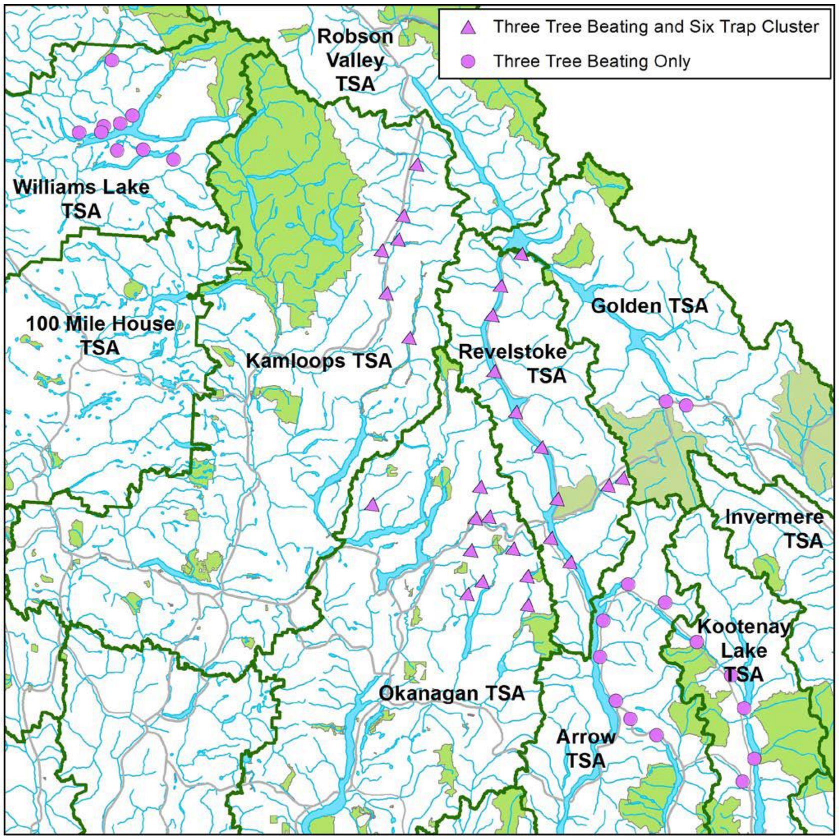


Figure 14. Locations of western hemlock looper permanent sampling sites in southern British Columbia.

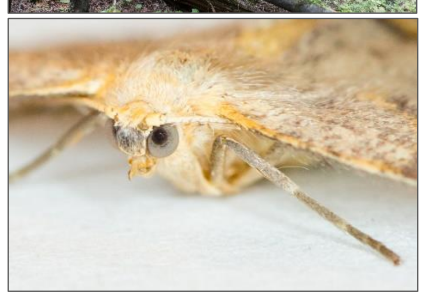


Table 6. Average number of western hemlock looper moths caught per six-trap cluster in the Thompson Okanagan, Kootenay Boundary and Cariboo Regions (2012-2021).

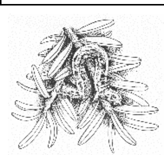
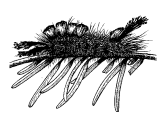
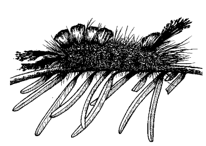
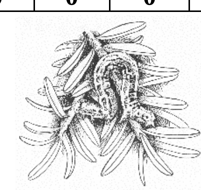
		Average moth catch per trap									
Site #	**Location**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**
Thompson Okanagan Region											
1	Serpentine River	26	3	2	6	1	9	18	38	448	541
2	Thunder River	79	6	7	34	2	34	146	107	489	266
3	Mud Lake	52	4	1	13	1	14	294	120	549	442
4	Murtle Lake	88	8	3	25	3	51	134	316	533	1,130
5	Finn Creek	35	5	2	13	0	14	43	237	356	37
7	Scotch Creek	705	44	11	20	4	34	311	222	844	108
8	Yard Creek	-	175	33	141	17	72	29	145	121	139
9	Crazy Creek	410	30	21	41	2	32	143	146	660	14
10	Perry River North	197	59	29	58	10	-	302	197	289	121
11	Three Valley Gap	240	53	21	50	8	55	234	291	314	68
12	Perry River South	410	70	29	33	8	30	156	233	128	99
13	Kingfisher Creek	732	80	43	55	27	50	241	211	260	51
14	Noisy Creek	450	117	106	107	12	47	128	178	88	19
15	Shuswap River	411	46	26	49	6	49	161	422	848	40
16	Greenbush Lake	1,530	83	20	23	11	81	140	515	724	138
17	Adams River/Tum Tum	501	12	8	41	0	39	84	119	716	142
	Average of sites	**391**	**50**	**22**	**44**	**7**	**41**	**160**	**219**	**460**	**209**
Kootenay-Boundary Region											
66	Sutherland Falls	222	40	21	2	1	-	72	235	1,195	1,234
72	Tangier FSR	390	110	23	19	1	19	98	56	196	67
73	Martha Creek	281	105	31	3	3	23	86	33	439	1,121
74	Goldstream River	597	137	23	2	3	42	55	257	1,631	2,213
75	Downie Creek	743	86	24	9	9	9	35	246	2,387	1,062
76	Bigmouth Creek	645	38	2	2	1	26	25	88	375	1,784
78	Carnes Creek	518	66	7	5	3	15	8	257	766	1,354
83	Begbie Creek	557	171	23	11	0	50	97	658	1,283	2,775
84	Pitt Creek Rec. Site	865	13	6	4	2	50	60	342	1,555	2,449
85	Kinbasket Lake	304	83	4	9	2	20	145	518	967	703
87	Jumping Creek	201	36	4	3	5	41	68	NA	-	n/a
	Average of sites	**484**	**80**	**15**	**6**	**3**	**29**	**68**	**269**	**1,079**	**1,476**
Cariboo Region											
	Average of 14 sites									**137**	**22**

In the Kootenay Boundary Region, western hemlock looper larvae were found in 83% of sites, down slightly from 2020 (96% of sites). The total number of larvae decreased very slightly from 492 in 2020 to 475 in 2021 (Table 7). The highest counts were at Beaver River, Pitt Creek Recreation Site and Martha Creek, ranging from 65 to 100 western hemlock looper larvae. There continued to be a wide assemblage of insects in the beatings, with sawflies being the most predominant. Sawflies increased in abundance more than two-fold over 2020. In the Thompson Okanagan Region, western hemlock looper larvae were found in 50% of sites, down from 88% of sites in 2020. The total number of western hemlock looper larvae recorded declined almost four-fold from 2020, with only 1 to 7 insects found at any individual site. The richness of insect diversity declined in the Thompson Okanagan samples and similar to the Kootenay Boundary, sawflies were the predominant insect, increasing from no sawflies in 2020 to 78 in 2021. Only two of 10 sites visited in the Cariboo Region had any western hemlock looper larvae and abundance at these sites was low (Table 7).

Table 7. Results from the 2021 three-tree beatings at permanent sample sites located in areas of historic western hemlock looper defoliation in the Kootenay Boundary, Thompson Okanagan and Cariboo Regions. The table shows the total number of specimens of the dominant insect species collected.

Site #	Location	Western Hemlock Looper (*Lambdina fiscellaria lugubrosa*)	Black-headed budworm (*Acleris gloverana*)	Sawflies (*Neodiprion, Anoplonyx*)	Green-striped forest looper (*Melanolophia imitata*)	Western False Hemlock Looper (*Nepytia*	Gray Forest Looper (*Caripeta divisata*)	Saddleback Looper (*Ectropis crepuscularia*)	Filament Bearer (*Nematocampa resistaria*)
Kootenay Boundary									
30	Keen Creek	1							
38	Hills	1							
58	Halfway River	11					2	1	
61	Box Lake	2	1		2				
62	Kuskanax Creek	2		2					
65	Shelter Bay Ferry	6		2					1
66	Sutherland Falls	50				2	1		1
69	Quartz Creek	12		25					
70	Gerrard	0							
71	Trout Lake	0		84					
72	Tangier FSR	0							
73	Martha Creek	82							
74	Goldstream River	32							
75	Downie Creek	22		2					
76	Bigmouth Creek	34		28					
78	Carnes Creek	12							
79	Lardeau FSR	0		2					
80	Meadow Creek	3							
81	Schroeder Creek	2		1					
82	Beaton	3		2					
83	Begbie Creek	33		11					
84	Pitt Creek Rec Site	65							
85	Kinbasket Lake	2		84					
86	Beaver River	100	4	70					
	Total insects	**475**	**5**	**313**	**2**	**2**	**3**	**1**	**2**

Site #	Location	Western Hemlock Looper (*Lambdina fiscellaria lugubrosa*)	Black-headed budworm (*Acleris gloverana*)	Sawflies (*Neodiprion, Anoplonyx*)	Green-striped forest looper (*Melanolophia imitata*)	Western False Hemlock Looper (*Nepytia freemani*)	Gray Forest Looper (*Caripeta divisata*)	Saddleback Looper (*Ectropis crepuscularia*)	Filament Bearer (*Nematocampa resistaria*)
Thompson Okanagan									
1	Serpentine-Lempriere	5		17					
2	Thunder River	3		4					
3	Mud Lake	5		3					
4	Murtle Lake Road	7		3					1
5	Finn Creek								
7	Scotch Creek								
8	Yard Creek Road	1		22					1
9	Crazy Creek Road								
10	Perry River North								
11	Three Valley Gap-Wap Creek								
12	Perry River South-Eagle River								
13	Kingfisher Cr. Road								
14	Noisy Creek-Kingfisher Creek	1							
15	Shuswap River	7		1					
16	Greenbush Lake			12	1				
17	Adams River/Tum-Tum	1		16					1
	Total insects	**30**	**0**	**78**	**1**	**0**	**0**	**0**	**3**
Cariboo	**Total insects (10 sites)**	**13**	**0**	**0**	**0**	**0**	**0**	**0**	**0**

DOUGLAS-FIR TUSSOCK MOTH

In 2019, the Douglas-fir tussock moth began its outbreak cycle in the southern interior, with numerous single-tree epizootics and patches of defoliation recorded for a total of 2,708 hectares. In 2020 and 2021, there was a dramatic decline in the total area of active tussock moth defoliation, most notably in the Williams Lake TSA, where only 121 hectares of defoliation was mapped in 2021, compared to 1,662 hectares in 2019. Active tussock moth defoliation was observed along both east and west sides of the Fraser River from north of the Chilcotin River to Dead Miners Creek and Ross Gulch. There were 94 hectares of defoliation mapped in the Lillooet TSA in 2021, where patches of defoliation were mapped along the Fraser River from Laluwissin Creek north to Texas Creek. No other active Douglas-fir tussock moth was observed in the southern interior in 2021, thus probably marking the end of this small outbreak cycle. The population collapse is most likely due to virus (nuclear polyhedrosis virus) infection and adverse climatic conditions, such as the 2021 heat dome.

Annual monitoring with six-trap clusters

The last Douglas-fir tussock moth outbreak collapsed in 2012. From 2012 through 2015, trap catches declined to very low levels until 2016, when a slight increase in the average number of male moths caught was observed in all Outbreak Areas. Outbreak periodicity varies by Outbreak Area (geographic location) and can range from 5 to over 40-year intervals between outbreaks. Typically, in the southern interior, we experience an outbreak in one or more of the Outbreak Areas every decade. When a consistent upward trend is found in a stand for 2 to 3 years (average over 10 moths per trap), or if an average of 25 moths or more per trap has been caught, ground surveys for egg masses are recommended and defoliation may occur the next summer. The current outbreak cycle began in 2019 and seems to have collapsed in 2021.

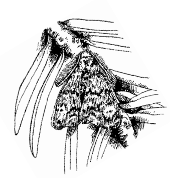
Douglas-fir tussock moth lures from three chemical companies were deployed in 6-trap clusters at each trapping site between 2016 and 2018, to compare the efficacy of the three lure types in attracting tussock moth and accurately predicting imminent outbreaks: Scotts® (Solida); WestGreen Global Technologies (ChemTica); and, Synergy Semiochemicals® (Figure 8). Scotts® is now no longer supplying the same lure, so only two lures have been used since 2019. All lures have a loading of 5µg pheromone. In 2021, two lines (one line per lure supplier) of 6 traps each were set at each trapping site in the Thompson Okanagan (39 sites) (Figure 15) and Cariboo (15 sites) Regions. The Kootenay Boundary Region had 9 trapping sites and used only the WestGreen Global Technologies (ChemTica) lure. There was some variation among average trap catches each year by the ChemTica and Synergy lures, but both were good at predicting defoliation events and/or increases in tussock moth population in the general area where traps were placed.

Overall, average trap catches were down significantly in all Outbreak Regions (Table 8). This mirrors the decrease in visible defoliation mapped in the 2021 aerial overview survey. Monitoring will continue but we do not expect to see much tussock moth activity in 2022 in the southern interior. A few rusty tussock moths and pine tussock moths were caught in traps at very low numbers.

Table 8. Average number of Douglas-fir tussock moths caught per 6-trap cluster in the Thompson Okanagan and Cariboo Regions (2016-2021). In the Thompson Okanagan and Cariboo Regions, lures from three suppliers (Scotts (Solida), ChemTica (WestGreen Global Technologies), and Synergy Semiochemicals) were compared in 2016-2019. In 2020-2021, the Thompson Okanagan and Cariboo Regions deployed WestGreen Global Technologies and Synergy lures.

		Average moth catch per site*					
Site	**Location**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**
Kamloops (KA)							
1	McLure	5.5	8.9	10.9	21.2	6.5	1.2
2	Heffley Creek	26.6	26.8	32.4	18.6	40.4	0.0
3	Inks Lake	0.1	0.1	0	0.2	0.0	0.0
4	Six Mile	3.4	3.8	9.9	23.1	32.3	0.0
9	Stump Lake	0	0.3	0.1	1.3	0.0	0.1
10	Monte Creek	3.8	6.4	7.8	20.1	30.3	0.0
11	Chase	1.7	0.3	3.4	5.9	2.0	0.3
48	Haywood-Farmer			9.6	20.3	2.6	0.1
49	Buse Lake			5.4	14.1	14.5	0.0
	Average of 9 sites	**5.9**	**6.7**	**8.8**	**13.7**	**14.3**	**0.2**

Site	Location	2016	2017	2018	2019	2020	2021
		Average moth catch per site*					
Okanagan (OK)							
12	Yankee Flats	3.2	0.5	2.3	1.2	2.4	0.0
13	Vernon		1.4	5.3	0.4	0.1	0.6
14	Wood Lake	7.6	17	41.3	17	31.2	4.3
15	June Springs	0.5	1.1	2	2.7	0.1	0.0
16	Summerland	0.7	0.9	0.3	1.6	0.1	0.1
17	Kaleden	4.9	6.2	4.4	7.5	12.1	0.0
18	Blue Lake	11.5	17.3	34.4	18.3	1.7	0.8
45	Glenmore	5.3	9	25.4	20.1	19.5	0.0
	Average of 8 sites	**4.8**	**7.1**	**14.4**	**8.6**	**8.4**	**0.9**
Similkameen (SIM)							
19	Stemwinder Park	8.6	8.2	29.8	-	18.1	1.7
32	Olalla	21.2	21.6	40.4	29.1	23.3	0.1
33	Red Bridge	8.8	7.4	9.3	9.4	10.9	0.0
38	Hwy 3 Bradshaw Creek	17.7	10.3	29.2	36.8	22.1	0.3
39	Hwy 3 Winters Creek	7.6	7.6	27.7	17.4	13.8	0.2
40	Hwy 3 Nickelplate Road	8.8	9.7	31.3	18.7	21.7	0.1
41	Stemwinder	11.4		34.2	26.5	13.0	0.5
42	11.8 km Old Hedley Rd	0.3	0.4	2	3.8	1.8	0.2
43	Pickard Creek Rec Site	5.5	6.8	31.6	14.5	20.2	0.0
44	5.7 km Old Hedley Rd	3.9	4.3	20.4	7.6	10.8	0.3
	Average of 10 sites	**9.5**	**8.8**	**26**	**18.2**	**15.6**	**0.3**
West Kamloops (WK)							
5	Battle Creek	0.3	0.7	0.9			
6	Barnes Lake	2.5	9.9	7.7	25.4	16.2	0.0
8	Pavilion	1.6	7.7	7.1	20.7	10.1	0.0
21	Spences Bridge	2.5	7.3	8.6	9.4	16.2	0.0
22	Veasy Lake	9.7	burnt	1.7	13.7		0.0
24	Veasy Lake	6.2	burnt	6.7	25	5.9	0.0
26	Venables Valley	0	1.4	0.2	4.6	39.8	0.0
27	Maiden Creek	0.2	1	1.6	6.6	1.3	0.0
28	Hwy. 99	2.2	6.1	9.2	28.6	2.4	0.0
31	Barnes Lake	0.6	2.1	0.8	9.1	14.5	0.5
46	Studhorse Road			2.2	11.2	2.4	0.1
47	Stinking Lake			0.3	6.8	0.5	0.0
	Average of 12 sites	**3.5**	**4.5**	**3.8**	**14.6**	**9.6**	**0.1**
Boundary (KT) (9 sites in 2021)		**0.6**	**1.3**	**2.3**	**5**	**5.7**	**0.3**
Cariboo (CAR) (15 sites in 2021)		**1.6**	**2.4**	**1.8**	**5**	**0.5**	**0.3**



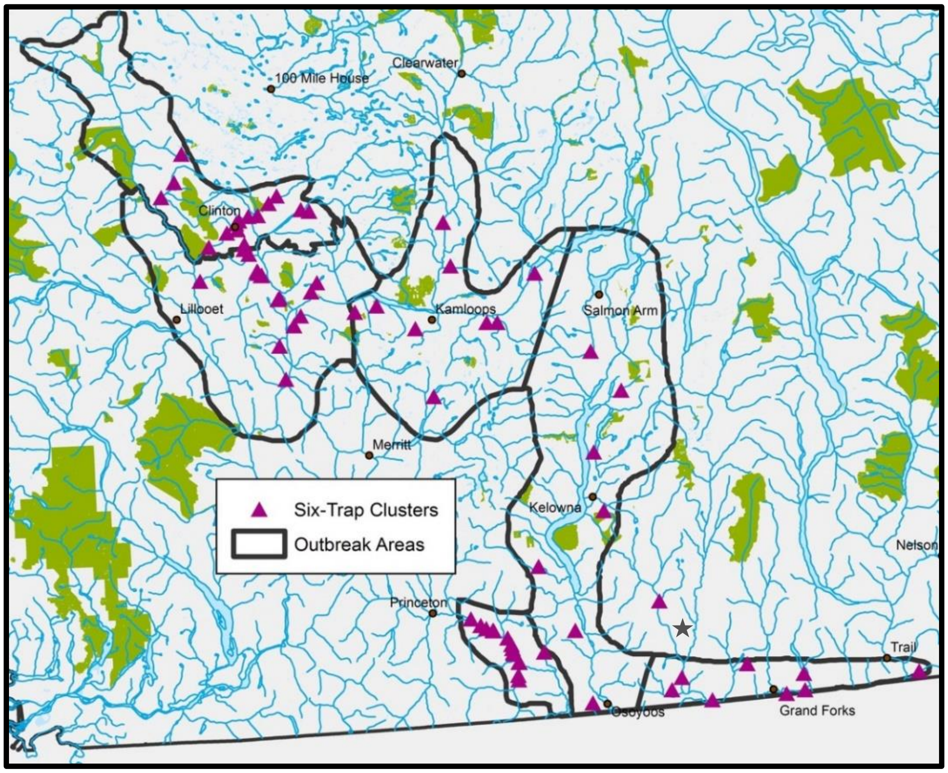


Figure 15. Location of Douglas-fir tussock moth 6-trap clusters throughout the southern interior.

Three-Tree Beatings

Three-tree beating is a procedure for sampling defoliating forest insect larvae, which involves beating the foliage of low hanging branches and collecting the fallen insects on a tarpaulin. Three-tree beating provides temporal and spatial information on the richness and diversity of defoliating insects and is conducted annually from mid-June to early July.

The three tree beatings were conducted during the 2021 heat dome, which likely negatively affected the survival of all defoliator species. Very few defoliators were recorded at any of the sample sites in 2021 (Table 9). Defoliator diversity was also down from 2020. The most predominant insects were western hemlock looper and false hemlock looper, which were found in relative abundance at the Inks Lake and Six Mile sites in the Kamloops Outbreak Region and Chase and Vernon sites in the Okanagan Outbreak Region. Very few Douglas-fir tussock moth larvae were found and most were inactive (stressed).

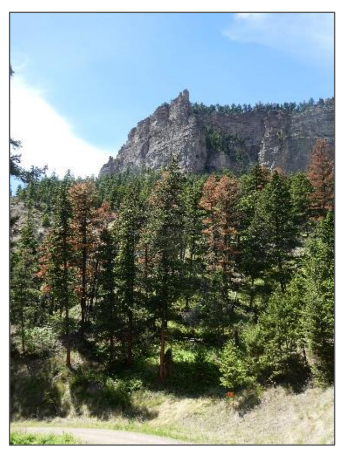
Table 9. Defoliators found in 2021 three-tree beatings in IDF forests within the Thompson Okanagan, Kootenay Boundary and Cariboo Outbreak Regions.

Outbreak Region	Douglas-fir tussock moth	Western spruce budworm	Sawflies	Green-striped forest looper	Western false hemlock looper	Western hemlock looper	Yellowlined forest looper	Saddleback looper	*Semiothisa unipunctaria*
Okanagan	0	0	0	9	14	12	0	0	0
Similkameen	0	0	0	0	0	0	0	0	0
Kamloops	0	0	4	2	37	29	0	2	0
West Kamloops	1	0	0	1	1	1	0	0	0
Kootenay Boundary	1	1	0	4	11	0	1	1	4
Cariboo	3	0	0	0	0	11	0	0	0
Total	**5**	**1**	**4**	**16**	**63**	**53**	**1**	**3**	**4**

Thompson Okanagan Region Summary

The Thompson Okanagan portion of the Aerial Overview Surveys was carried out between July 16th and Sept 11th, 2021. The surveys were completed in 69.9 hours, over 12 flight days. Due to the number and severity of wildfires in this Region, flying conditions were difficult, with smoky skies and no-fly zones because of firefighting. Flights were shut down for 5-6 weeks during the summer and only resumed once the fires had subsided. All surveys were conducted by Kevin Buxton (contractor) and Janice Hodge (JCH Forest Pest Management), and utilized a Cessna 182P operated by Upper Valley Aviation Ltd., of Chilliwack, B.C.

Kamloops TSA



Douglas-fir beetle was mapped on 5,055 hectares, down from 6,087 hectares in 2020. Much of this decline was due to wildfires burning in some of the most active bark beetle areas throughout the Sabiston and Criss Creek area (Sparks Lake Fire) and south of Kamloops Lake, impacted by the Tremont Creek Fire (Figure 16). Douglas-fir beetle populations that had built within the Elephant Hill Fire (2017) flew beyond the fire perimeter in 2019-2021 and infested many surrounding high hazard Douglas-fir stands. The Sparks Lake fire burned through the Sabiston Lake area where numerous patches of Douglas-fir beetle were mapped in 2020. West of this area, between the Sparks Lake Fire and eastern perimeter of the Elephant Hill Fire, many active patches of Douglas-fir beetle were observed near Tsotin, Stinking and Cultus Lakes. Expansions in area attacked occurred near Gallagher Lakes, Two Springs Creek, and Robertson Creek. Further south, large patches were mapped near Finney Lake and along Anderson Creek. Most of the active Douglas-fir beetle mapped south of Kamloops Lake near Barnes Creek was impacted by the 2021 Tremont Creek Fire.

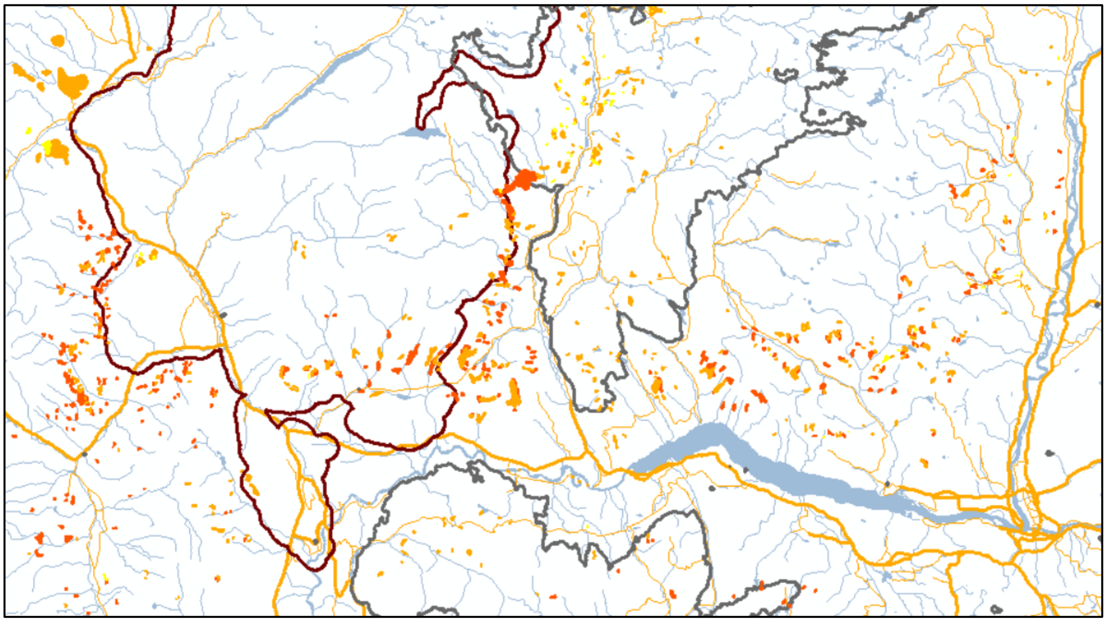


Figure 16. Douglas-fir beetle areas affected in 2020 (orange) and 2021 (dark orange) in and around the Elephant Hill Fire (dark red line) that burned in 2017 and Sparks Lake and Tremont Creek Fires (grey lines) that burned in 2021.

High intensity burn near Criss Creek and young stand burnt in Tremont Creek Fire.

Douglas-fir beetle built in the northern portion of the TSA, south of Clearwater on the east side of the North Thompson River, and west of Clearwater primarily on the north side of the North Thompson River. In the southern portion of the TSA, populations were noted north of Heffley Lake along Louis Creek; and most notably to the west of the Thompson River. Many patches of attack were mapped in the Lanes-Dairy Creek area; surrounding Pass Lake and Isobel Lake; along the Tranquille River drainage; and many sites north of Kamloops Lake. Many spots and patches were mapped from Sabiston Creek east to McQueen Lake.

Spruce beetle declined by 1,197 hectares, to 3,832 hectares affected. The most active populations were located west of Clearwater from Foghorn Creek to Burton Creek, south of the North Thompson River. **Western balsam bark beetle** increased from 11,794 hectares in 2020 to 20,482 hectares in 2021, an increase of 8,688 hectares. The main increases in population were in the Battle and Table Mountains areas, and near Granite Mountain and Dunn Peak. No **mountain pine beetle** was observed.

No **western spruce budworm** defoliation was mapped in the Kamloops TSA in 2021. The Criss Creek area where budworm was active in 2020 was treated with *B.t.k.* but was then burnt in the Sparks Lake Fire. **Two-year cycle budworm** was mapped on 1,520 hectares, down from 3,174 hectares in 2020. Defoliation was still detected near Granite Mountain and Liza Head Mountain in the northern portion of the TSA. 2021 is the "off" year in the two-year budworm cycle for this part of the province.

Aspen serpentine leafminer increased in 2021 throughout the east section of the Kamloops TSA on 25,558 hectares. Some key areas where this insect was active includes Pinantan to Niskonlith Lakes, Mad and Raft Rivers, Meadow Creek, Hemp Creek and along the west side of the North Thompson River. **Pine needle cast** was detected on 676 hectares between Rosseau Creek and Tranquille River, and along Moilliet Creek south of Raft River. Approximately 778 hectares of **Dothistroma needle blight** was mapped between the Mad and Adams River, and along May Creek. Small areas of damage caused by **satin moth** (125 ha), **western hemlock loope**r (65 ha), **forest tent caterpillar** (51 ha), **birch leafminers** (29 ha), **cottonwood leaf rust** (21 ha); **aspen decline** (112 ha); and miscellaneous abiotic influences was recorded.

Drought damage to foliage was mapped over 37,039 hectares, with the most damage detected in the ICH (63,150 ha) and IDF 14,485 ha) and 65% was light damage and 28% was trace. The Thompson Rivers District assessed 31 blocks for drought mortality and found 22 blocks had 5-30% seedling survival, 5 blocks had 40-60% survival, 2 had 90% survival and one block was destroyed by wildfire (near Adams Lake).

LILLOOET TSA

Damage was mapped on 109,438 hectares in the Lillooet TSA in the 2021 aerial overview survey. **Wildfire** impacted the most forested land, covering over 95,900 hectares. The area affected by **western balsam bark beetle** continued to decline, with active populations mapped on 8,731 hectares. Western balsam bark beetle was active in most high elevation subalpine fir sites in the Bridge River and Anderson Lake drainages, near Gott Creek, Devil's Lake and in the Stein River drainage. The other three major bark beetles also declined in 2021. **Mountain pine beetle** affected 1,371 hectares, primarily in the northwest portion of the TSA near Tyaughton Creek, Spruce Lake and Leckie Creek. Other small patches were recorded in the Stein River area and other mature lodgepole pine stands. **Spruce beetle**, mapped on 2,666 hectares, continued to kill small patches of spruce in the northwest area of the Lillooet TSA, including Leckie Creek, Slim Creek, upper Gun Creek, Tyaughton Creek, and Relay Creek. It was also detected in the Van Horlick to Cottonwood Creek area. **Douglas-fir beetle** affected 118 hectares near Intlpam Creek west of the Fraser River, along the

Yalakom River west, and east of Beaverdam Creek. Small patches of **western spruce budworm** (315 ha) remained active in the Watson Bar-Big Bar area. Other damage agents recorded include **Douglas-fir tussock moth** (94 ha), **aspen decline** (83 ha), **pine needle cast** (26 ha) and other miscellaneous abiotic influences.

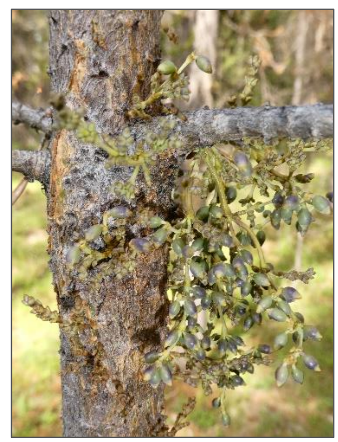
MERRITT TSA

A total of 83,577 hectares of damage was mapped in the Merritt TSA, of which 76,003 hectares was caused by abiotic damage agents (wildfire affected 75,533 ha) and 7,574 hectares by biotic factors. Three bark beetle species were active in small patches across the Merritt TSA, with a total of 4,010 hectares mapped, an increase of 1,420 hectares over 2020; mainly due to western balsam bark beetle. **Douglas-fir beetle** infestations were mapped on 173 hectares, a substantial decline from 2020. Small patches were detected near Missezula Lake and along the Similkameen River east of Princeton. **Western balsam bark beetle** covered 3,803 hectares, an increase of 1,730 hectares from 2020, with the most active populations near July Mountain, in the Arcat-McNulty-Finnegan Creek area, and near Dear Mountain south of the Tulameen River. **Mountain pine beetle** was observed in the Tulameen area between Sutter and Railroad Creeks, and near Britton Creek for a total of 34 hectares.

Western spruce budworm defoliation increased slightly in 2021, covering 3,132 hectares, up from 2,056 hectares in 2020. A small patch of defoliation was mapped near Mamit Lake and the defoliation around Princeton increased near Asp Creek, Red Creek and August Lake. A small patch of **satin moth** was still active in 2021, totaling 185 hectares near Rey Lake. **Pine needle cast** was mapped on 230 hectares near Frank Ward Creek.

Western spruce budworm defoliation, Mamit Lake

Dead budworm larva



Lodgepole pine dwarf mistletoe

Other damage recorded included **balsam woolly adelgid** (8 ha), **two year cycle budworm** (9 ha), **post-burn mortality** (222 ha), **aspen decline** (22 ha) and **drought damage** to foliage (207 ha).

OKANAGAN TSA

Abiotic damage agents caused 93% of the damage recorded during the 2021 aerial overview survey in the Okanagan TSA, with wildfires impacting 142,355 hectares and drought damage to foliage impacting an additional 47,696 hectares.

Douglas-fir beetle declined from 2,012 hectares affected in 2020 to just 741 hectares in 2021. Small patches were detected in the Mission-Belgo Creek area near Kelowna and off Beaver Lake Road. Populations declined significantly in the Lumby area, with only scattered patches detected in 2021. Small patches persisted in the Shuswap-Chase area. With all the Douglas-fir burnt in the 2021 wildfires, there could be substantial risk to further Douglas-fir beetle build-up in the next few years. MCH was again placed on high value trees in Herald Provincial Park to protect them from attack from Douglas-fir beetle.

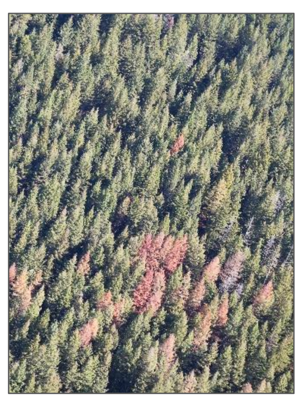
The area affected by **western balsam bark beetle** increased by 69% to 9,505 hectares of mostly severe attack, which is notable because typically this bark beetle manifests as trace or light pockets spread over the landscape. Most high elevation subalpine fir sites had some scattered attack. The most significant attack was recorded near Pukeashun and Mobley Mountains in the north Shuswap, near Sicamous Creek, SilverStar Mountain, and on the west side of Okanagan Lake from Trepanier Creek to Whiterocks Lake. **Mountain pine beetle** infestations remain very low, mapped on 13 hectares in the far south of the TSA, near Twin Buttes.

White Rock Lake fire

The most dominant insect defoliator of conifers in 2021 was **western hemlock looper**, affecting 497 hectares, down from over 3,000 hectares in 2020; largely due to a targeted spray program in the Shuswap and Crazy Creek areas. Most of the 2021 defoliation was mapped in remote areas at the north end of the Seymour River. This will probably be the last year of significant defoliation by this insect until its next outbreak cycle. **Aspen serpentine leafminer** and **birch leafminers** affected 1,493 and 702 hectares, respectively.

Most needle diseases were down from 2020, with **pine needle cast** affecting 789 hectares; **larch needle blight** affecting 681 hectares, and ***Dothistroma*** needle blight affecting 147 hectares.

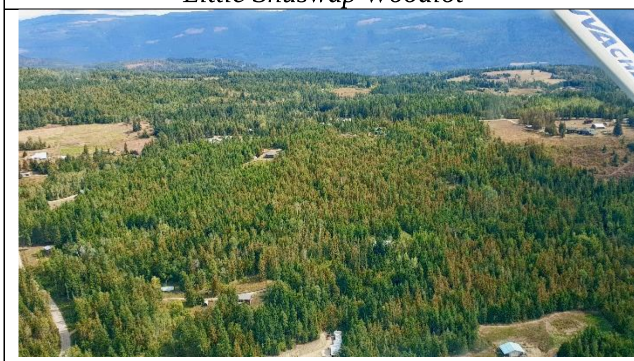
Larch needle blight, Mt. Baldy



Douglas-fir beetle

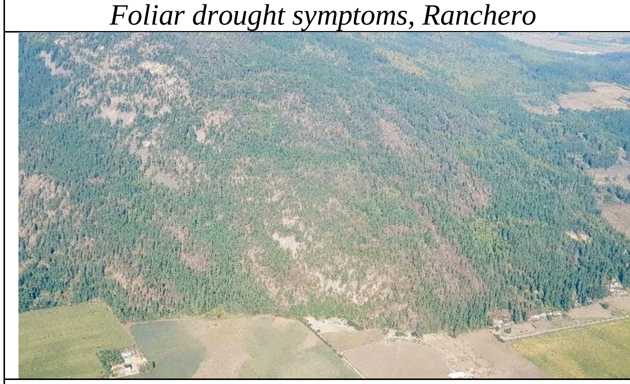
Little Shuswap Woodlot

Armillaria root disease, North Shuswap

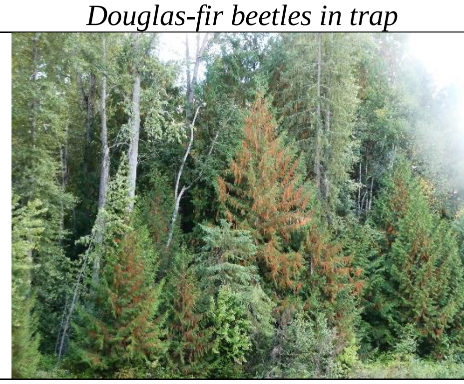


Foliar drought symptoms, Ranchero

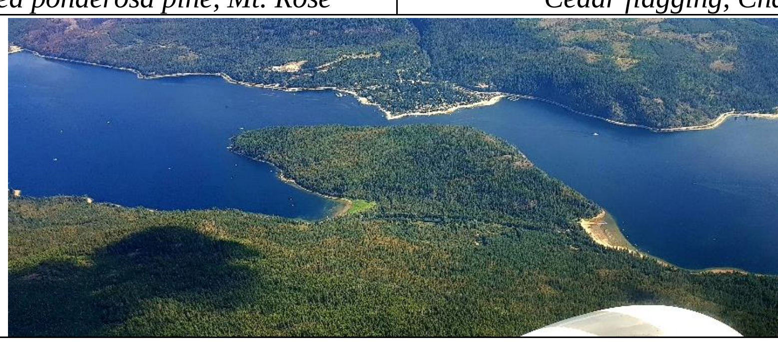
Douglas-fir beetles in trap



Drought affected ponderosa pine, Mt. Rose



Cedar flagging, Chase Creek



Cedar response to drought, Larch Hills

CARIBOO REGION SUMMARY

The Cariboo Region Aerial Overview Survey was completed between July 27th and October 8th and was also delayed by smoky skies and wildfires. The Cariboo Region was flown in two sections (north and south) by two separate contractor teams. The southern portion of the Region was surveyed by Barbara Zimonick and Karen Baleshta, and the northern portion by Nathan Atkinson and Scott Baker. Both teams used a Cessna 182 provided by Cariboo Air Ltd.

A total of 22 damage agents was recorded affecting 637,103 hectares of forest land. Table 11 lists the top ten damage agents (by hectares affected in 2021) in the Region. Biotic damage agents affected the most area, with aspen serpentine leafminer (199,038 ha), Douglas-fir beetle (81,364 ha) and western balsam bark beetle (75,243 ha) being the most predominant (Table 11). Wildfire (146,489 ha) and drought damage to foliage (5,393 ha) were the most dominant abiotic factors. Western spruce budworm increased to 50,417 hectares and mountain pine beetle remained static at 34,457 hectares affected.

Low levels of foliar disease were observed with *Dothistroma* needle blight and pine needle cast affecting 5,729 and 220 hectares, respectively.

Table 11. Top ten damage agents in 2021 in the Cariboo Region.

Pest	Hectares
Aspen serpentine leafminer	199,038
Fire	146,489
Douglas-fir beetle	81,364
Western balsam bark beetle	75,243
Western spruce budworm	50,417
Mountain pine beetle	34,457
Spruce beetle	11,046
Western hemlock looper	10,432
Dothistroma needle blight	5,729
Drought - foliage	5,393

100 MILE HOUSE TSA

Douglas-fir beetle saw a 78% increase over 2020 with 39,769 hectares affected. There were large build-ups of Douglas-fir beetle along the edge of the Elephant Hill Fire of 2017 from Clinton to Green Lake, with a few smaller patches still observed within the fire perimeter. West of Clinton, numerous patches were mapped from China Gulch to Big Bar Mountain, near White Lake and north of Mahood Lake. **Western balsam bark beetle** declined to just 440 hectares mapped in 2021. Small populations were recorded near Pavilion Mountain in the south of the TSA and in the northeast of the TSA. No **mountain pine beetle** or **spruce beetle** activity was recorded in the TSA.

Western spruce budworm continued to increase in the western edge of the TSA near China Gulch and Canoe Creek, affecting 13,025 50,417 hectares up from only 7 hectares detected in 2020. **Two-year cycle budworm** increased from 1,360 hectares in 2020 to 4,626 hectares mapped in 2021. **Aspen serpentine leafminer** was mapped on 86,920 hectares in 2021, a 3-fold increase over 2020. Large areas of defoliation were observed near 100 Mile House, Green Lake, Montana to Webb Lakes, the west side of Mahood Lake, and in the Eagle, Two Mile and Sprout Lakes area.

Other damage observed included 718 hectares of foliar damage from **drought**, 180 hectares of *Dothistroma* needle **blight** and 65 hectares of **aspen decline**.

Lodgepole pine terminal weevil attack

Douglas-fir beetle attack

QUESNEL TSA

Douglas-fir beetle saw a sharp decline from 2020 with only 322 hectares mapped east of Punshaw Lake at the far northern edge of the TSA. The area affected by **western balsam bark beetle** increased from 29,758 hectares in 2020 to 31,078 hectares in 2021. The largest area of infestation was near Trapline Creek, Swanson Creek and east of Blackwater River. **Spruce beetle** decreased four-fold in 2021 to 563 hectares affected in the Nazko-Snaking River area; Marcel Hills; and Baker Creek areas.

Insect defoliators were observed damaging 42,485 hectares in 2021 with **western hemlock looper** affecting 357 hectares and **aspen serpentine leafminer** affecting 42,128 hectares plus 19 hectares of unknown defoliation. Western hemlock looper was mapped in small patches in the Bowron River area, primarily near Harold Creek and Isaac Lake. The area affected by aspen serpentine leafminer remained unchanged from 2020 and was mapped throughout the central portion of the TSA along the Quesnel River.

Dothistroma needle blight was detected on 4,697 hectares near Willow River, Sovereign Mountain, Wingdam, and from sixteen Mile Lake to Swift River. Other damaging agents recorded in the TSA in 2021 included **pine needle cast** (220 ha), **wildfire** (12,385 ha), **post-fire mortality** (2,190 ha) **drought** damage to foliage (343 ha) and **aspen decline** (12 ha).

WILLIAMS LAKE TSA

Seventeen damage agents were recorded in the Williams Lake TSA in 2021, affecting 284,225 hectares. Bark beetles (129,938 ha) and defoliators (117,457 ha) were the predominant damage agents (Table 12). All four bark beetles declined in area affected. **Douglas-fir beetle** populations declined (Figure 17) for the first time in over 5 years, with 41,273 hectares affected, almost a 30% decrease since 2020. The most active outbreaks are in Little Gaspard Creek south to Empire Valley.

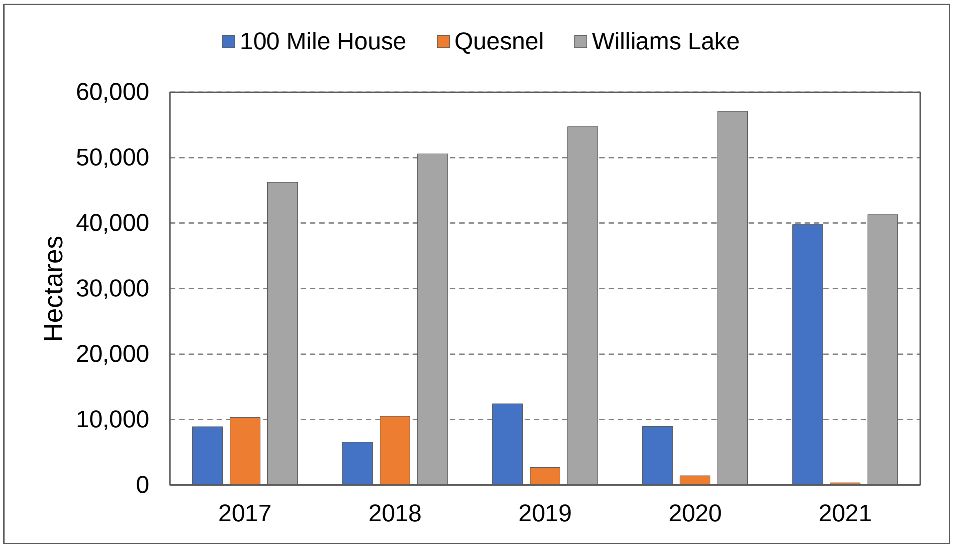
Spruce beetle decreased by 24 percent to 10,482 hectares mapped in 2021, with the largest populations located in the Dil Dil Plateau, Lone Valley and Buck Mountain in the southwest of the TSA, and near Welcome Mountain and Penfold Creek in the northeast. **Mountain pine beetle** infestations declined again in 2021 to 34,457 hectares, down from 36,982 hectares in 2020. The largest populations of mountain pine beetle were from Tatlayoko, Chilko and Taseko Lakes north to Bussel and Whitton Creeks. **Western balsam bark beetle** mortality declined from 49,836 hectares in 2020 to 43,725 hectares in 2021, but the majority of active patches were mapped as severe (39,888 ha; Table 2) which is not typical of this bark beetle.

The **aspen serpentine leafminer** increased 8-fold in 2021 to 69,990 hectares primarily in the Horsefly to Likely area. **Western spruce budworm** increased significantly in 2021, affecting 37,392 hectares, up from 10,274 hectares in 2020. Defoliation was mapped from Dog and Ward Creeks, Doc English Gulch, to Williams Lake. Egg mass sampling predicts light defoliation in 18 of 59 sites sampled and a targeted spray program with *B.t.k.* is planned for 2022. **Douglas-fir tussock moth** remained at very low levels in 2021, with 121 hectares affected. **Western hemlock looper** was recorded on 10,074 hectares down from 25,408 hectares in 2020. Much of this decline can be attributed to a targeted control program with *B.t.k.* (18,902 hectares sprayed) near Quesnel Lake. Most of the mapped 2021 defoliation was still in the Quesnel Lake area, but outside the spray blocks. Minimal defoliation is expected for 2022.

Wildfires affected 26,881 hectares in 2021 and **post-fire mortality** was mapped over 757 hectares. The severe **drought** conditions of 2021 caused foliar fade or loss over 4,332 hectares and **mortality** on 76 hectares. Drought was detected in the northeast portion of the TSA near Marguerite and Big Lakes, Hart Lake, Jacobie Lake, and between Snowshoe and French Snowshoe Creeks. There will likely be additional damage from drought manifested in 2022. **Dothistroma needle blight** affected 852 hectares in the Cedar Creek and Seller Creek areas. **Aspen decline** was detected on 89 hectares and **bear** damage affected 306 hectares in scattered patches from Horsefly Lake to Quesnel Lake.

Table 12. Top ten damage agents in 2021 in the Williams Lake TSA.

Pest	Total
Aspen serpentine leafminer	69,990
Western balsam bark beetle	43,725
Douglas-fir beetle	41,273
Western spruce budworm	37,392
Mountain pine beetle	34,457
Fire	26,881
Spruce beetle	10,482
Western hemlock looper	10,074
Drought - foliage	4,332
Flooding	3,416



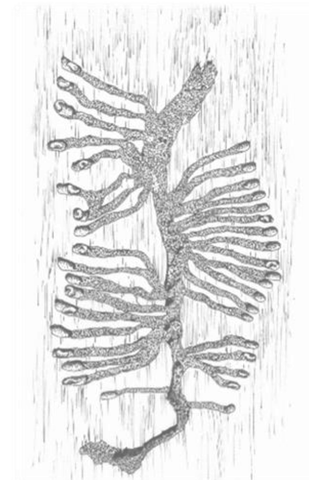


Figure 17. Hectares affected by Douglas-fir beetle in the 100 Mile House, Williams Lake and Quesnel TSAs (2017-2021).

Kootenay Boundary Region Summary

The Kootenay Boundary Region aerial surveys were completed between July 10th and September 16th, 2021, requiring 94.3 hours of flight time over 19 days. Weather conditions clear weather when flights were conducted but had a 5 week delay due to wildfires and smoke. All surveys were conducted by Neil Emery and Adam O'Grady of Nazca Consulting Ltd., using a Cessna 337 Skymaster operated by Babin Air.

Selkirk South: Arrow, Boundary, and Kootenay Lake TSAs

The four major **bark beetles** affected 17,525 hectares in the Arrow, Boundary and Kootenay Lakes TSAs in 2021, a 3,422 hectare increase over 2020. **Douglas-fir beetle** affected 8,405 hectares in the three TSAs, with 5,713 hectares mapped in the Arrow TSA, an increase of 1,959 hectares over 2020. A decline was seen in the Boundary TSA with only 650 hectares mapped in 2021. Patches of Douglas-fir beetle were active along the West Arm of Kootenay Lake, Slocan River, most side drainages of Lower Arrow Lake, near Whatshan Lake, Burton Creek and Rendell Creek.

Cumulatively, the area affected by **western balsam bark beetle** in the three TSAs increased to 6,434 hectares from 4,056 hectares in 2020. There were four times as many severe infestations (5,072 ha) as trace infestations (1,241 ha) mapped. Western balsam bark beetle was observed in most high elevation subalpine fir sites, with the most active populations noted near Cortiana Creek, Galloping Creek, Carpenter Creek, Keen Creek and Irvine Creek. **Spruce beetle** populations decreased again in the three TSAs to 639 hectares, with the Hamill Creek population being the most active. The area affected by **mountain pine beetle** remains static, with 2,047 hectares affected in 2021. Summit Peak, north of Bonanza Creek, Comb Mountain and Glacier Creek are the most active populations. Mountain pine beetle mortality continues in both lodgepole pine and whitebark pine stands.

Aspen serpentine leafminer activity continued to decline in 2021 with 7,384 hectares affected compared to 10,415 hectares in 2020. Defoliation was detected near New Denver, Meadow Creek, Kaslo River, Little Slocan River and Grohman Creek. **Western hemlock looper** was detected affecting 3,325 hectares in the Arrow and Kootenay Lakes TSAs, along Keen Creek and Kuskanax Creek to Halfway River. Small patches of **larch casebearer** (33 ha), **two year cycle budworm** (73 ha) and **birch** leafminers (35 ha), were also recorded.

Other damaging agents recorded include: **wildfire** (69,143 ha); **post-fire mortality** (83 ha); **larch needle blight** (9,578 ha); **bear damage** (92 ha); and **drought** damage to foliage (3,748 ha).

Selkirk North: Golden and Revelstoke TSAs

Douglas-fir beetle increased in both the Golden and Revelstoke TSAs, to 694 and 507 hectares, respectively. Active populations were mapped along Tonkawatla Creek, Drimmer Creek, Pingston Creek, Twin Butte and near Golden. **Mountain pine beetle** (228 ha) and **spruce beetle** (2,214 ha) were only mapped in the Golden TSA in 2021. Mountain pine beetle was detected near Valenciennes River and Mount Morrison. Spruce beetle was found in Casualty Creek and Mountain Creek areas. **Western balsam bark beetle** remained static in the Golden TSA (11,046 ha), but increased significantly in the Revelstoke TSA, from 402 hectares in 2020 to 2,448 hectares. Western balsam bark beetle remained active near Moonraker Peak, Ottertail River and Little Yoho River.

Western hemlock looper increased slightly in the Golden TSA to 1,509 hectares and increased very significantly in the Revelstoke TSA to 8,243 hectares from 74 hectares in 2020. Approximately 10,183 hectares of high priority Caribou habitat were sprayed with *B.t.k.* in Revelstoke TSA to mitigate damage from western hemlock looper. Defoliation was mapped along both sides of the Columbia River drainage, from Revelstoke north to Mica Creek, and along the Beaver River in the Golden TSA.

Other damage agents include: **aspen serpentine leafminer** (11,020 ha); **Dothistroma needle blight** (24 ha); **larch needle blight** (23 ha); **drought** damage to foliage (1,582 ha); **wildfire** (3,448 ha); windthrow (93 ha); and, **flooding** (87 ha).

Cranbrook and Invermere TSAs

The area affected by **Douglas-fir beetle** increased from 2,176 hectares in 2020 to 2,972 hectares in 2021, with almost a 2,000 hectare increase in the Cranbrook TSA and a slight decline in the Invermere TSA. Infestations were detected near Lake Koocanusa, Gold Creek, Grasmere and Inverted Ridge.

Mountain pine beetle infestations increased to 1,975 hectares in the Cranbrook TSA and declined slightly in the Invermere TSA, from 5,394 hectares in 2020 to 4,042 hectares in 2021. In the Invermere TSA, populations were active in the Thunder Creek, Toby Creek, Dutch Creek and Forster Creek areas. In the Cranbrook TSA, patches of attack were detected near Mount Baker, Moyie Mountain and Tepee Creek.

In 2021, **spruce beetle** attack declined in both TSAs, going from 5,922 hectares in 2020 to 3,507 hectares, with the largest decline occurring in the Invermere TSA. Spruce beetle was mapped near Elk River, Mount Bleasdale, Riverside Mountain, Mount Queen Mary and South Toby Creek.

Western balsam bark beetle declined to 17,904 hectares in the two TSAs combined, but increased in the Cranbrook TSA. It was detected in most high elevation sites along the western boundary of the Invermere TSA. In the Cranbrook TSA, it was scattered throughout subalpine fir forests, with the most notable infestations occurring from Sparwood to Profile Mountain.

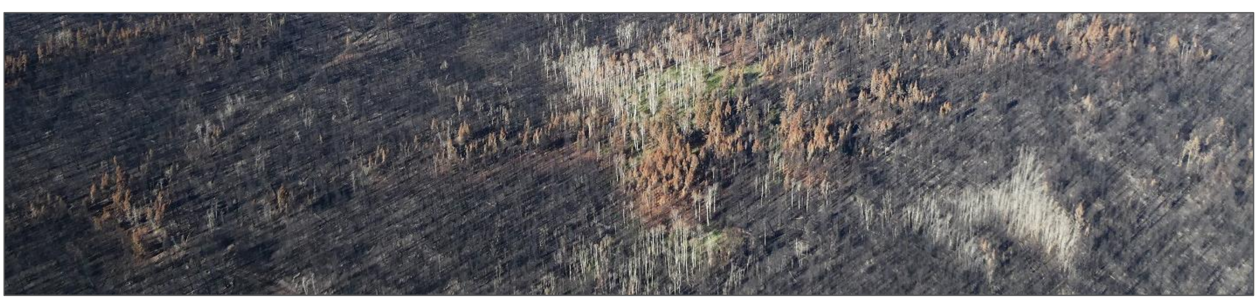
Defoliation from **aspen serpentine leafminer** declined to 3,300 hectares affected, from 8,291 hectares in 2020. The most active areas were near the Vermillion River, Cokato and Hartley Creek. **Drought** damage was mostly detected in plantations, affecting 561 hectares in Dibble Creek, Van Creek, Fenwick Creek and Alton Creek.

Western hemlock looper defoliation was mapped affecting 131 hectares near Harrogate. Other damage agents include: **birch leafminers** (172 ha); **larch needle blight** (745 ha); **wildfire** (4,988 ha); and, **windthrow** (23 ha).

The **black army cutworm** (*Actebia fennica*) monitoring program using pheromone traps was continued in 2021 at the Meachan and Doctor Creek sites (Table 13), where traps continued to catch high numbers of moths.

Table 13. Results from the 2018-2021 black army cutworm moth trapping program in the Kootenay Boundary Region.

Year and TSA	Location	# traps	Avg. 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	2	240
2021			
Cranbrook	Meachan	4	322
Invermere	Doctor Creek	9	433



OTHER CONTRIBUTIONS AND REPORTS

Calvin Jensen is the new Regional Forest Pathologist for the Thompson Okanagan Region. He started work in November 2021. Calvin has been working on becoming acquainted with forest pathology in British Columbia and the Thompson/Okanagan Region. He has been going through the records of past trials and experiments in the region to better understand the research that has been conducted. As well Calvin is writing a report about the current state of forest pathology knowledge in the southern interior. He is hoping to conduct fieldwork in the summer to study these historic operational trials, begin new projects, and settle more into his role as Regional Pathologist.

Spruce beetle repellency field trials- individual tree protection

Marnie Duthie-Holt, 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 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).

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 1). In addition, to providing individual tree protection, the repellents also provided protection to surrounding trees for upwards of 11 meters radius.

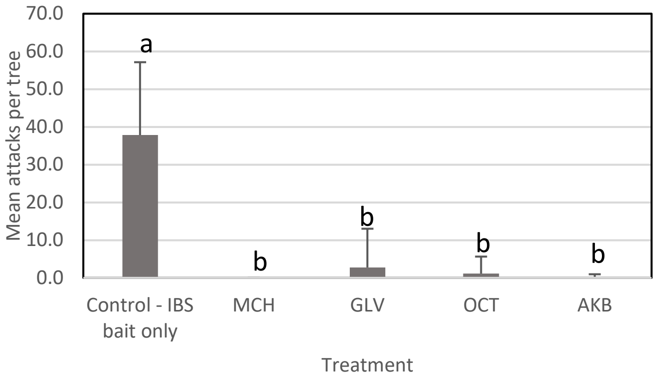


Figure 1. Spruce beetle attack by treatment.

A retrospective comparison of surveys for pest incidence in young lodgepole pine in the Cariboo Forest Region: forest structure and pest complexes

Lorraine Maclauchlan, Thompson Okanagan Region

Lodgepole pine forests occupy much of B.C.'s interior. Due to repeated large-scale mountain pine beetle (MPB) outbreaks in recent decades, there are many hundreds of thousands of hectares of regenerating pine forests today. Other disturbances, such as wildfire, have also contributed to extensive landscapes of young, relatively uniform forests. With today's changing climate, have the impacts of insects and disease on these young forests also changed?

As a follow-up to last year's retrospective analysis of pest incidence and occurrence in young lodgepole pine stands in the Okanagan, Merritt and Kamloops TSAs, a similar project was initiated in the Cariboo Forest Region, looking at possible changes in pest complexes and stand structure. Twenty-five years ago, forest health information, impact and occurrence, was not readily available for young forests (10-25 years), post free growing. Similar to other studies at the time, a forest inventory project was designed and implemented to measure and record insect, disease, mammal and abiotic issues in six ecosystems within the Cariboo Region. More than 1,830 surveys were conducted over a four-year period. A full report was produced (Westfall and Brooks 2001). In 2021, we conducted 91 surveys in similar aged stands, BEC, and geographical locations, to compare to those surveys conducted in the late 1990's. Pest abundance, occurrence and complexity, as well as forest structure were measured. The many stands which have regenerated from the most recent MPB outbreak in the 1990's-early 2000's are of a similar age to those which were measured in the first study. The survey for pest incidence (SPI) protocol was used to assess them (Joy and Maclauchlan 2000) (Table 1). This summary concentrates on pests of young pine. Other conifer and deciduous species have been removed from the data set when calculating pest incidence and occurrence. A full report is in preparation and will include pest impacts on all tree species.

Larvae of Pissodes schwarzi (left) and Pissodes terminalis (right)

Table 1. Number of SPI surveys conducted in 1996-99 and 2021 by TSA and BEC in the Cariboo Forest Region.

		Total number of surveys	
TSA	BEC	1996-99	2021
100 Mile House	ESSF	18	0
	IDF	273	13
	SBPS	166	9
	SBS	68	5
Quesnel	MS	39	3
	SBPS	293	13
	SBS	194	7
Williams Lake	ESSF	45	2
	ICH	42	3
	IDF	274	7
	MS	22	3
	SBPS	218	16
	SBS	186	10
		1838	91

Table 2 summarizes the general impact of forest health agents in lodgepole pine in six biogeoclimatic zones. In 1996-99, understory trees (layer 4) were not counted or assessed. For this reason, the 2021 surveys have been separated into layers 1-3 (L1-L3) and layer 4 (L4) to more easily compare stand characteristics and pest impacts between survey periods. The separation of the layers notwithstanding, it appears that the average density of young pine has increased substantially (See highlighted columns). General pest impact in terms of tree mortality and trees affected by damaging agents is also greater now (2021) than 25 years ago (1996-99) (see Dead and Affected columns).

Table 2. Percentage of lodgepole pine that is dead, live, clear or affected by one or more forest health agents, stand structure and average density (stems per hectare, sph) at both survey times.

1996-99 surveys			Percent (%) Pl				Avg. %		Avg. sph
BEC	N Surveys	Total N Pl	Dead	Live	Clear	Affected	Pl	other spp.	Pl
ESSF	63	3,161	0.5	99.5	52.2	47.3	76.6	23.4	1,607
ICH	42	2,126	0.1	99.9	70.5	29.4	60.1	39.9	2,307
IDF	545	36,430	0.6	99.4	17.1	82.3	82.5	17.5	3,321
MS	61	5,349	0.6	99.4	78.6	20.8	96.1	3.9	7,387
SBPS	691	49,041	3.3	96.7	38.4	58.3	87.2	12.8	3,610
SBS	448	29,408	2.8	97.2	40.8	56.4	79.5	20.5	3,848

2021 surveys			Percent (%) Pl (L1-L3)				Percent (%) of total trees			Avg. sph Pl	
BEC	N Surveys	Total L1-L3	Dead	Live	Clear	Affected	Pl (L1-L3)	Pl (L4)	other spp.	(L1-L3)	(L4)
ESSF	2	72	6.9	93.1	4.2	88.9	54.5	0.0	45.5	2,100	540
ICH	3	280	7.5	92.5	2.1	88.2	63.9	9.1	26.9	11,444	1,196
IDF	20	1,391	4.2	95.8	4.4	91.4	65.0	14.9	20.2	4,127	1,713
MS	6	618	2.1	97.9	17.5	80.4	69.1	19.7	11.2	7,328	2,681
SBPS	38	3,459	5.2	94.8	13.4	81.5	59.0	28.5	12.5	6,655	3,665
SBS	22	1,850	3.5	96.5	7.1	89.4	59.1	10.5	30.4	6,447	2,030

In the 1996-1999 study, the average number of pine pests identified per survey ranged from 3.7 in the MS zone to 6.8 in the SBS zone. These numbers increased substantially in 2021, with all BECs having an average of at least 7.5 pine pests per survey (Figure 1).

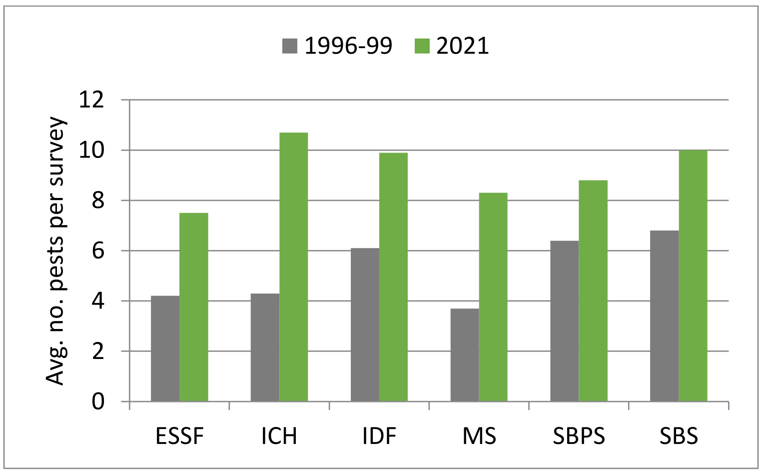


Figure 1. Average number of forest damage agents in lodgepole pine by BEC and sample year.

These increases in pest abundance and impact can be attributed to a number of factors including harvest and reforestation methods, stand structure and density, and changes in climate. Insects such as lodgepole terminal weevil are influenced by longer, warmer summers and milder winters, allowing higher survival of broods and shortened life cycles. Some of the rusts, such as western gall rust, could respond to more favorable spring conditions (e.g. precipitation events). Certainly, the average percent incidence of these forest health agents is dramatically higher in the more recent 2021 surveys (Figure 2).

Young lodgepole pine killed by Hylobius warreni

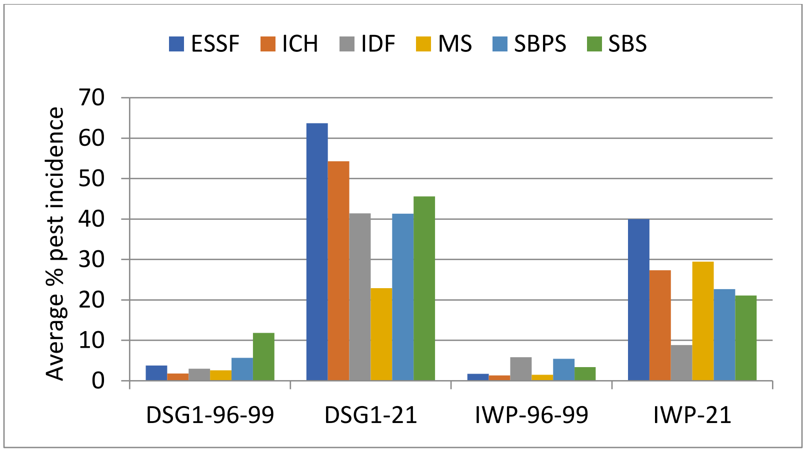
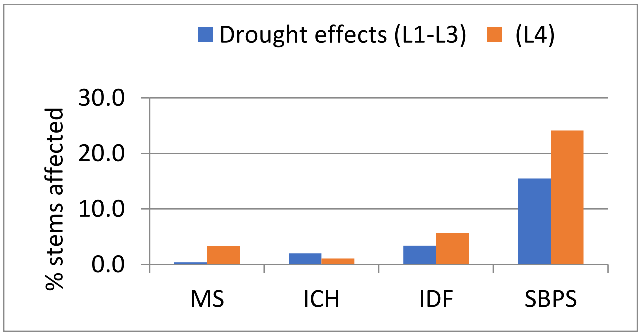


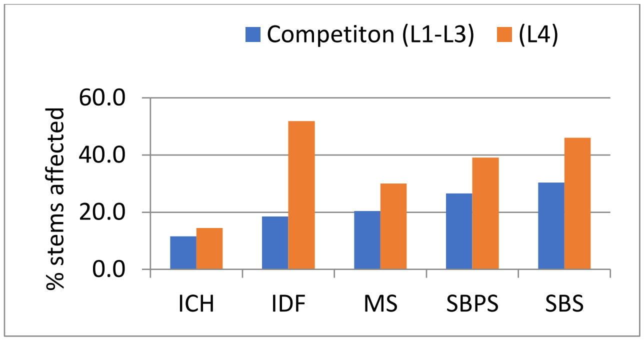
Figure 2. Differences in average percent incidence by survey for western gall rust (DSG) and lodgepole pine terminal weevil (IWP) between 1996-99 and 2021 in the Cariboo Forest Region.

Abiotic factors such as drought, hail, and snow press were also more prevalent in the recent surveys. In the 1996-99 surveys, the average cumulative damage from drought, hail, frost and snow press totalled 4.7% across all BEC. In 2021, this figure increased to 9.1%, with some BEC more affected by specific damage agents than were others. Drought damage was particularly noticeable in the drier ecosystems of the Cariboo in 2021. The increased incidence and damage caused by abiotic factors recorded the recent 2021 surveys is not surprising as evidenced by the unprecedented weather and climate events over the past two decades.

In the 1996-99 surveys, feeding by hare, comandra blister rust and Warren's root collar weevil were the most significant mortality-causing agents in young lodgepole pine, totalling 2.1% of all assessed trees. In 2021, deer browse and the three rusts, comandra, western gall and stalactiform blister rust, caused most mortality (6.3%). Other mortality agents included bear and Warren's root collar weevil; while competition had an impact on layer 4 understory trees. In total, 7.5% of the assessed L1-L3 lodgepole pine in 2021 were dead. No drought mortality was recorded. The effect of the 2021 heat dome in late June to early July and ensuing summer drought may manifest in the next few years.

Layer 4 trees are defined as regeneration, less than 1.3 m in height. A separate analysis was done for L4 lodgepole pine, which were only assessed in 2021. In general, the L4 understory suffered from the same pests as the older trees; however, they were particularly susceptible to drought damage, vegetation competition and deer browsing, with some biogeoclimatic zones more affected than others (Figure 3). The 2 surveys done in the ESSF had no lodgepole pine understory and were not included in the analysis.





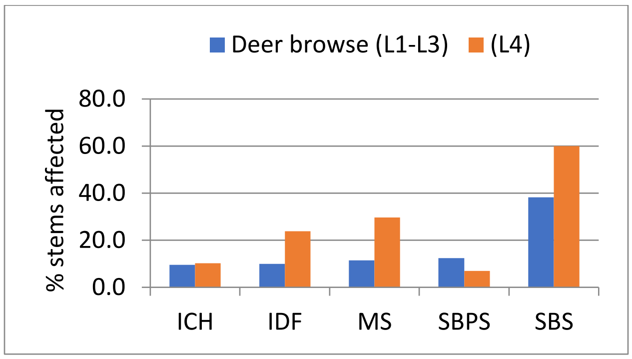


Figure 3. Comparison of drought damage, vegetation competition and deer browse on L1-L3 lodgepole pine and L4 lodgepole pine in the 2021 surveys for pest incidence, Cariboo Forest Region.

Results from our surveys of the incidence and impact of pests in young lodgepole pine stands 25 years ago and now has shown dramatic differences in both pest abundance, damage (e.g. tree mortality, infection, form) and stand characteristics. This clearly highlights that we must identify what harvest, regeneration and stand-tending practices might lead toward more resilient and healthy stands in the future. A full summary of this project will be available later in 2022.

Acknowledgements: I thank Rosanna M. Wijenberg for conducting the field assessments and Julie E. Brooks for assistance with data summary and report writing.

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Elephant Hill Fire and Forest Health

Lorraine Maclauchlan, Thompson Okanagan Region

Wildfire, drought (temperature driven moisture stress) and biotic agents (e.g. bark beetles) are important drivers of ecosystem dynamics. The Elephant Hill Fire (EHF) burnt through many Douglas-fir dominated stands leaving behind countless scorched, but very attractive hosts for Douglas-fir beetle, *Dendroctonus pseudotsugae* Hopkins (IBD). A severe drought event in the area further exacerbated the beetle situation, with tree mortality increasing across all age classes and species. This report summarizes the progression of Douglas-fir beetle attack before and after the EHF, within the area affected by the fire and outside the EHF perimeter from 2018-2021.

Background

In 2017, over 1,300 wildfires (42% of which were human caused) burned a record-breaking 1.2 million hectares (ha) (or 12,000 km^2) throughout the province (Nicholls and Ethier 2018). Following an 'unusually quiet' spring wildfire season, fire danger across many regions in B.C. rose significantly throughout June 2017. The Cariboo Region in the central interior experienced particularly hot and dry conditions. Then, between July 6 and 8, a series of widespread thunderstorms resulted in over 190 new wildfire starts, the majority concentrated in the Cariboo and in areas close to communities such as Williams Lake, 100 Mile House and Cache Creek. On July 6, what was soon to become known as the 'Elephant Hill wildfire' was first reported near the Village of Ashcroft and Ashcroft Indian Band's reserve. Within 24 hours, this fire grew to over 1,000 hectares in size and burned through Ashcroft's reserve. As it headed north over Elephant Hill Provincial Park, the fire destroyed 45 homes in the Boston Flats mobile home park and soon burned right to the edge of St̓uxwtéws (Bonaparte First Nations) 'Indian Reserve' 3. Over the following months, this wildfire continued to burn north throughout Bonaparte's and neighboring Secwépemc communities' territories, prompting the evacuations of the Villages of Cache Creek and Clinton (as well as multiple Secwépemc First Nations) and eventually burning close to 192,000 hectares – the third largest fire in the province that year (Dickson-Hoyle and John 2021).

The large landscape fires in 2017, 2018 and more recently in 2021, were exacerbated by many overlapping factors including climate change and annual weather conditions, forest structure and age, and the legacy of management practices. These varied and multi-layered issues must all be factored into decisions on where and how to best mitigate compounding factors such as the Douglas-fir beetle.

Landscape view of Elephant Hill Fire, 2017

Following the EHF a huge and collaborative effort was put toward wildfire recovery. However, it was soon realized that there were many definitions of what Wildfire Recovery looked like. Dickson-Hoyle and John (2021) wrote in the "Elephant Hill: Secwépemc leadership and lessons learned from the collective story of wildfire recovery: "Wildfire recovery is about more than healing the land – it's also about supporting community and economic recovery. This once again speaks to the connections and interdependence between Indigenous peoples, cultures, economies and their territories, and the distinction between physical rehabilitation and broader ecological, social and cultural recovery."

Given the complexities and challenges of 'recovering' such vast and differing impacts, joint wildfire recovery was narrowed down to focus on a defined set of relatively short-term activities (Dickson-Hoyle and John 2021).

These included fireguard rehabilitation, range recovery and timber salvage, and the associated activities of:

- Silviculture and reforestation;
- Douglas-fir beetle management;
- Access management;
- Archaeology; and,
- Managing impacts associated with the 2018 morel mushroom harvest.

The document 'Post-natural disturbance forest retention guidance' was released from the Office of the Chief Forester in January 2018 (Nicholls and Ethier 2018), describing the retention planning required for landscape connectivity, interior forest and intact ecosystem attributes necessary for habitat, hydrologic function, and mid-term timber supply and to support recovery at stand and landscape scales.

However, additional guidance was needed on how to mitigate impacts from Douglas-fir beetle. Salvage logging is one of the most contentious aspects of post-fire recovery. Therefore, minimizing the number of green trees harvested in landscapes within and adjacent to the EHF while considering future damage from Douglas-fir beetle were key components in post-fire recovery considerations.

Blackened stand within EHF

Objectives

Data from the AOS were used to analyze the progress of Douglas-fir beetle populations leading up to the EHF in and adjacent to its boundary. Attack levels detected prior to the fire (2016) through to 2021 are described from a biological perspective. Several damage mitigation tactics are explored.

Results and Discussion

Douglas-fir beetle (IBD) was present at outbreak levels in numerous stands in Kamloops and 100 Mile House TSAs (Figures 1 and 2) prior to 2017, particularly in 100 Mile House TSA and within the perimeter of the eventual EHF (Figure 2). Prior to the EHF, there were sizable populations of IBD southwest of Clinton along Kelly and Porcupine Creeks in 100 Mile House TSA, and to the southeast along the Deadman River in Kamloops TSA.

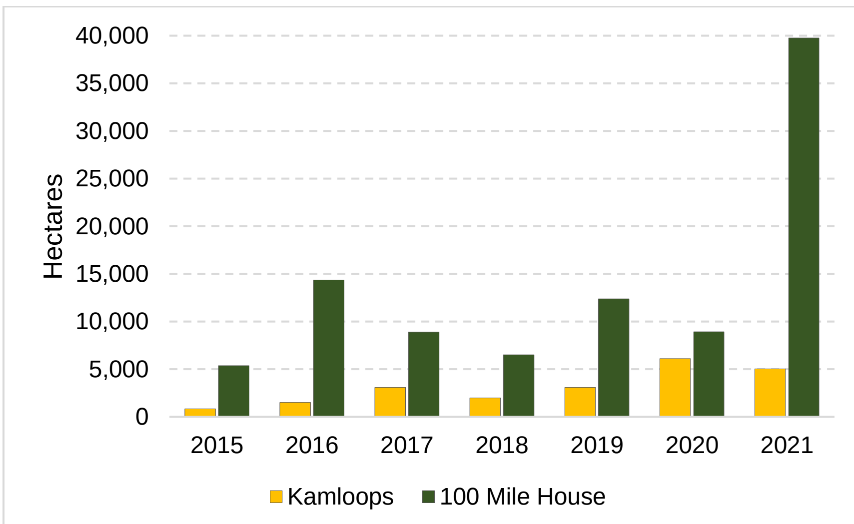


Figure 1. Hectares affected by Douglas-fir beetle in Kamloops and 100 Mile House TSAs (2015-2021).

As Figure 2 illustrates, there were substantial areas of high hazard sites both inside and outside the burned area. The fire burned from early July through the summer, after the main IBD flight and attack period had occurred. The main flight and attack period of IBD occurs in June (Figure 3), with a minor flight later in July. Therefore, some beetle populations within the fire perimeter were killed; however, many stands containing 2017 attack were only partially or lightly burned, leaving IBD populations inside the fire perimeter and in stands adjacent to the fire. Various beetle species will infest recently fire-killed trees that still have suitable phloem for survival and reproduction. IBD can have a significant influence on post-fire Douglas-fir mortality, killing trees that would otherwise survive fire. Post-fire tree mortality due to IBD is augmented when beetle populations are already present and active near a recent wildfire as was the case with the EHF.

IBD generally prefer Douglas-fir that:

- are over-mature (i.e. large trees, veterans)
- have fallen, been blown down in storms (recent windthrow) or felled during fire guard construction

- have been injured by fire or by machine damage
- are stressed (drought, defoliation, root disease, fire scorch)

When conducting ground surveys following a fire, care must be taken to distinguish IBD attack from other insects that infest fire-damaged trees. Bole symptoms include reddish boring dust that could be from IBD or white sawdust caused by ambrosia beetles. Crown symptoms are not reliable following wildfires: often beetles attack trees with blackened or red crowns. It is virtually impossible to distinguish post-fire mortality or IBD attack from the air in the first year or two-post fire. It was not until 2020 and 2021 that IBD attack within the fire perimeter was reliably mapped from the air.

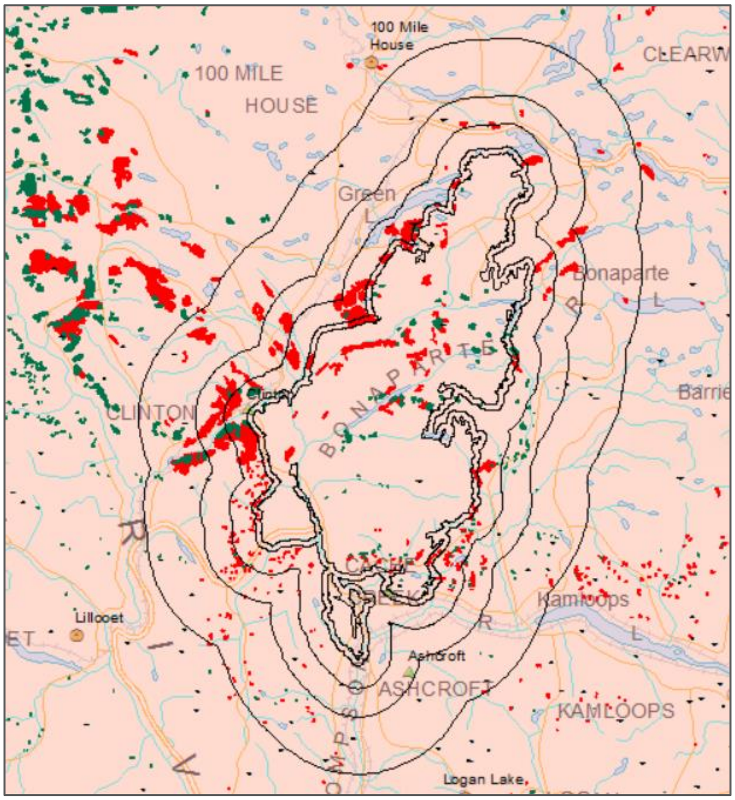


Figure 2. Map showing the perimeter of the EHF (innermost line) and 1 km, 5 km, 10 km and 20 km lines away from the EHF perimeter and IBD attack polygons for 2016 (green) and 2021 (red).

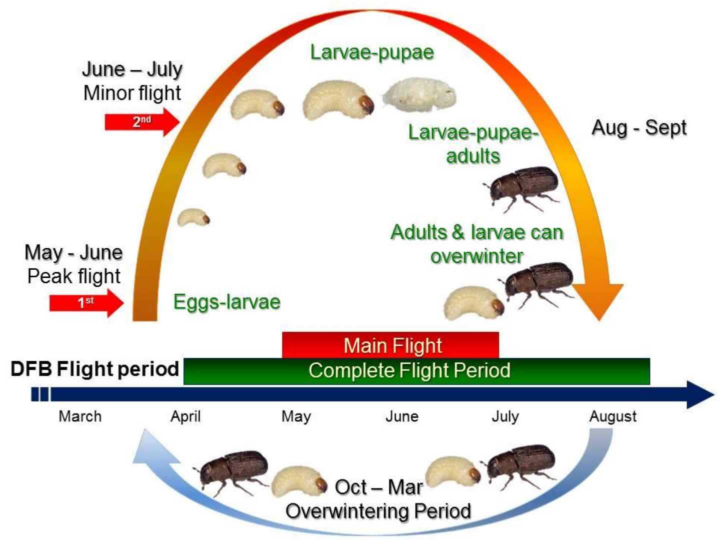


Figure 3. Life cycle of Douglas-fir beetle

From 2015 to 2016, IBD populations were increasing within the 5 km perimeter of the eventual EHF (Figure 4). IBD attack decreased within this perimeter area in 2018-2019 as many beetles moved into the fire itself to colonize susceptible fire-damaged trees. Then, in 2020 and 2021, there was a notable increase in beetle attack within that 5 km perimeter (Figure 4) because beetles that had attacked the fire-damaged trees were emerging and seeking live green hosts outside the fire perimeter. In 2020, mapped hectares of IBD attack were similar to those mapped in 2016, the most reliable estimate of beetle population prior to the EHF. By 2021, almost 5 times the area mapped in 2016 was recorded.

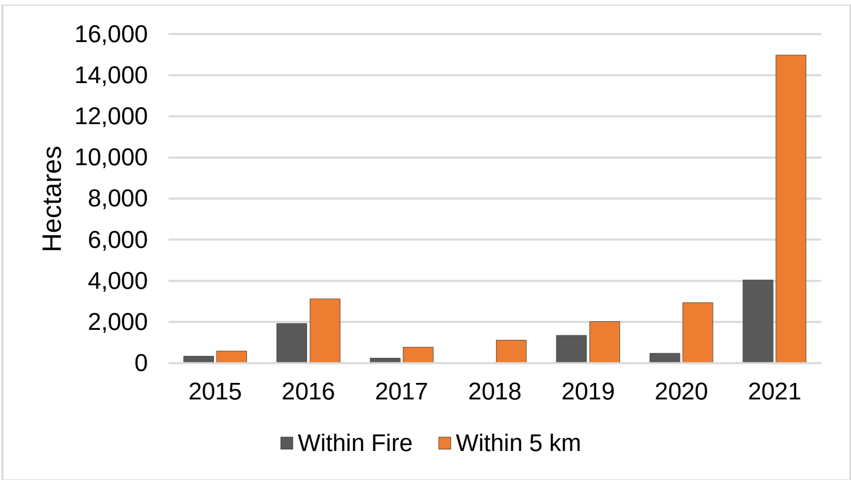


Figure 4. Hectares of Douglas-fir beetle attack within the Elephant Hill Fire and within a 5 km perimeter of the fire (2015-2021).

Figure 5 shows the hectares of IBD in expanding perimeters around the outside edge of the EHF before (2016) and after the fire. Starting in 2020 IBD attack started to noticeably increase around the EHF perimeter, particularly from 1 km out.

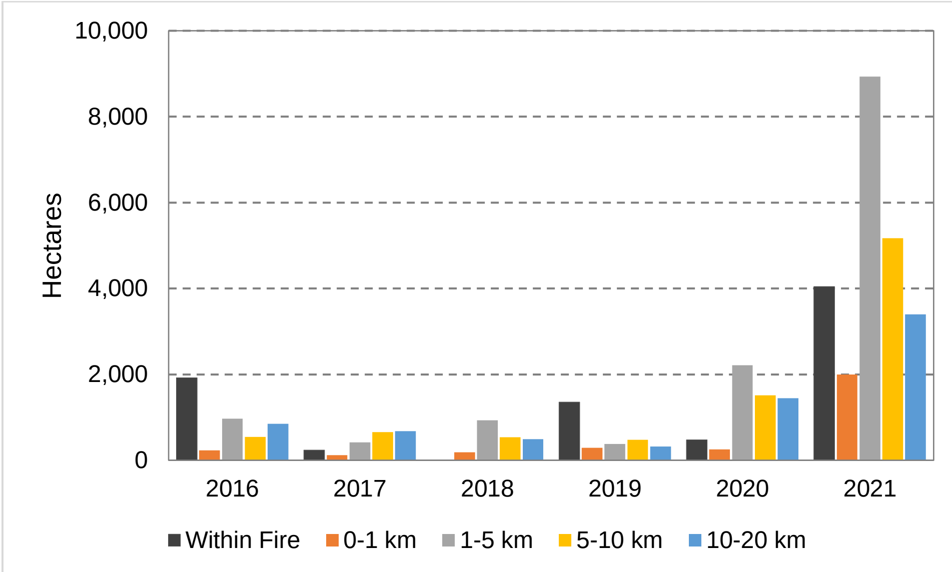


Figure 5. Hectares of Douglas-fir beetle attack within 1 km, 1-5 km, 5-10 km and 1-20 km of the Elephant Hill Fire perimeter (2016-2021).

In 2021, there were many fires in Douglas-fir dominated stands, where the same scenario may play out over the next few years. Of particular concern is the Sparks Lake Fire that burned very close to the EHF and has effectively "trapped" populations of IBD between these two fire perimeters (Figure 6).

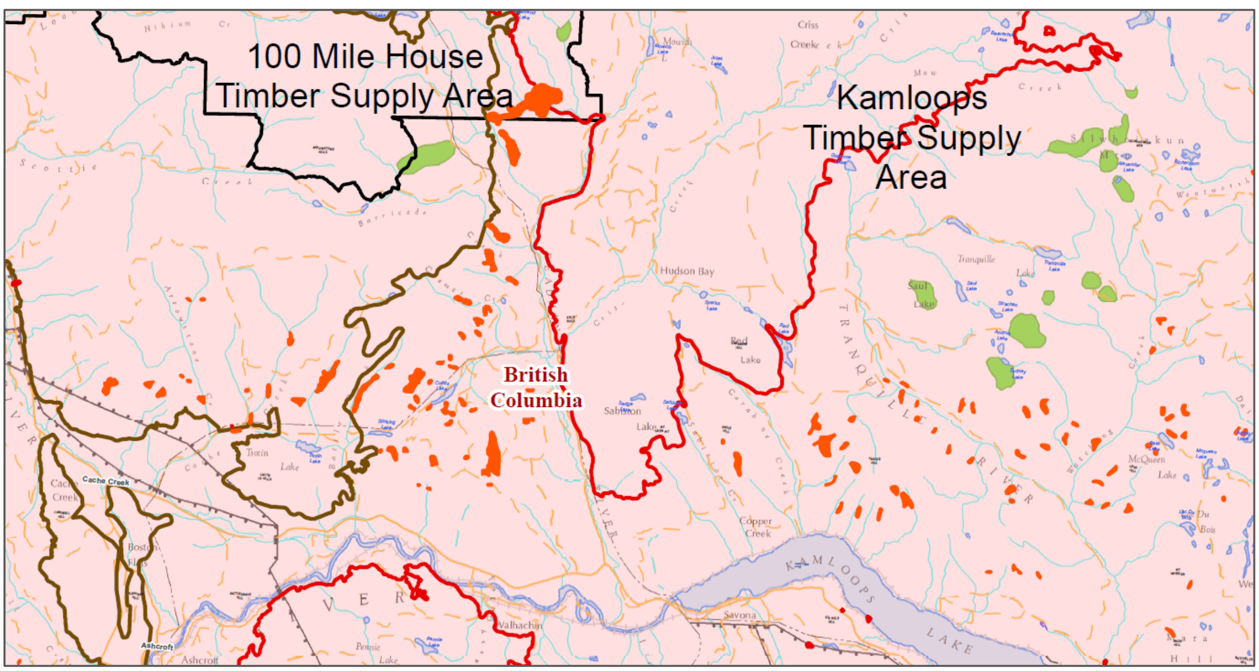
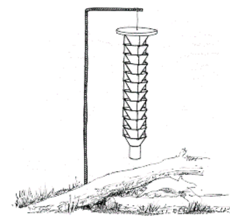


Figure 6. Elephant Hill Fire (brown line), 2021 fires (red lines) and 2021 mapped Douglas-fir beetle infestations (orange polygons).

There are many critical environmental, ecological, cultural and economic issues to consider when embarking on fire-recovery efforts. Proven tactics exist to reduce mortality from IBD post-fire; however, these tactics must be timely and targeted. Not all IBD populations should be managed. It is important to identify those that pose the highest risk to other identified values. Tactics that are very effective in containing and reducing localized IBD populations include:

- mass trapping using funnel trap clusters in severely burnt settings
- conventional trap trees in mixed-fire intensity settings
- targeted removal of infested trees



IBD mitigation must be considered when planning for all other fire-recovery activities.

References

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Retaining Whitebark Pine in Timber Harvests

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Jenny Berg, University of Victoria
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A gradual increase in harvest acreage above 1,800 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 1). 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 had ceased at all but a single harvest site.

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.

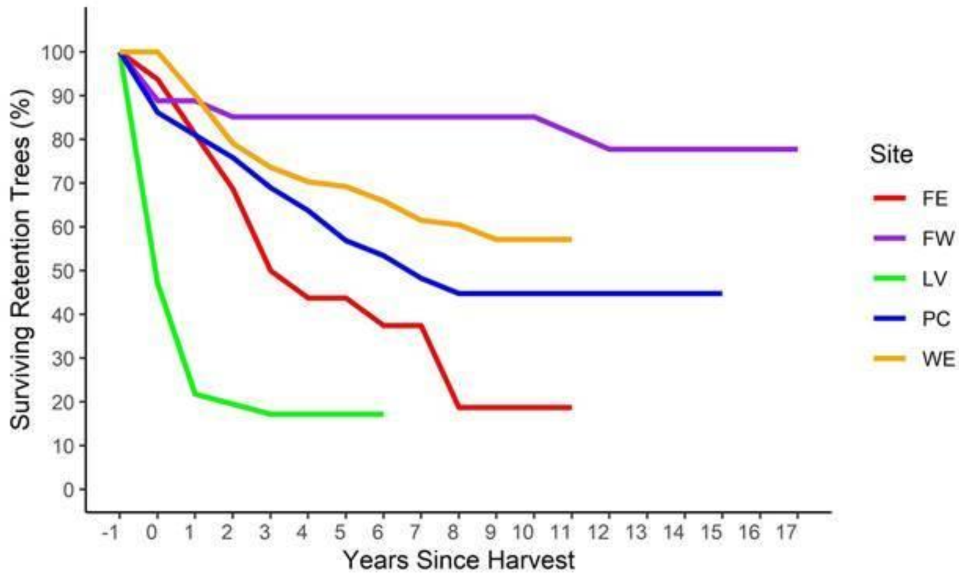

Figure 1. Post-harvest attrition of retained whitebark pine according to harvest site (FE: Findlay East; FW: Findlay West; LV: Lavington; PC: Paturages; WE: West Elk) (Murray et al. 2021).

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 2).

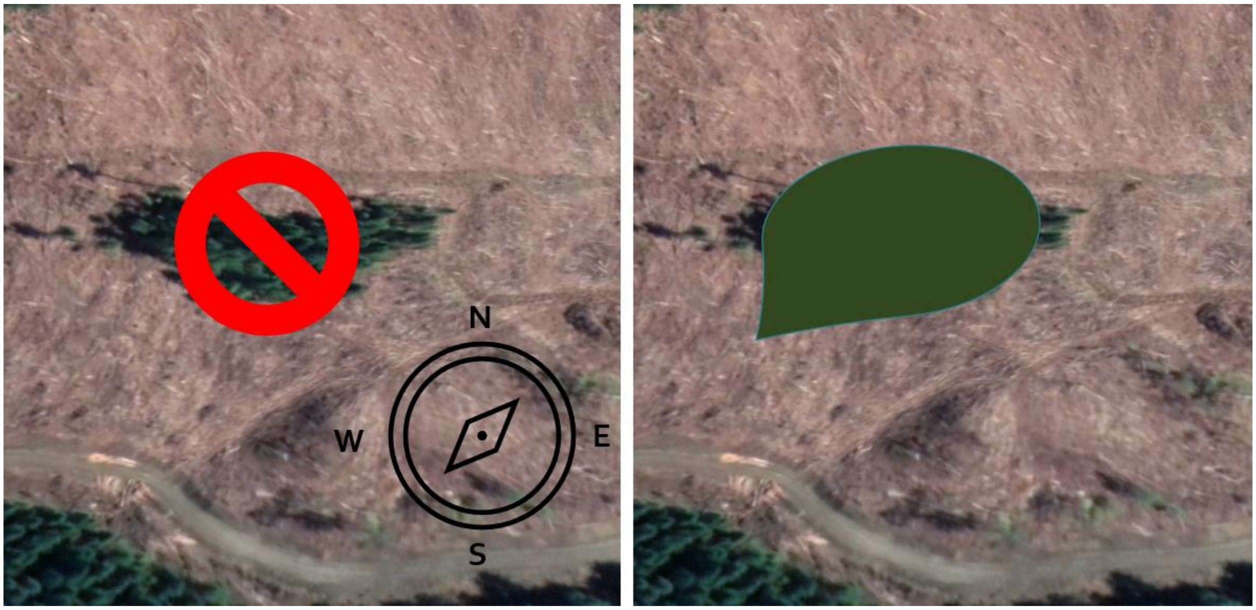

Figure 2. To reduce blowdown, ovate patches of retention can be oriented according to the predominant storm wind directions. In southeast BC, a southwest-to-northeast azimuth is recommended.

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 life link to the species' future.

Literature

Murray, M.P., Berg, J., and Huggard, D.J. 2021. Harvest retention survivorship of endangered whitebark pine trees. Forests. 12(6):654. doi:10.3390/f12060654

Lodgepole Pine Progeny Trial to test for relative susceptibility to Elytroderma Needle Cast 2021 Re-measurement Results

David Rusch, West Coast Region Forest Pathologist

Elytroderma needle cast is a foliar disease that can become systemic in infected trees and reinfect the needles even in years when weather conditions are not suitable for new needle infection from spores. If the infection becomes systemic in the tree leader, it can cause severe growth reduction or even tree death. If a high enough percentage of the trees in a stand are infected, this can affect overall stand growth.

A progeny trial to study the relative susceptibility of lodgepole pine families to elytroderma in the south Cariboo was set up in 2013. A total of 99 families were tested at three sites. Five orchard seedlots and several B+ families were tested. One of the sites subsequently burned up in 2017. The Fletcher Lake site (IDFdk4) first showed signs of infection in 2020. The trees were assessed for elytroderma in both 2020 and 2021 based on red foliage symptoms and signs of elytroderma fruiting bodies. The Dog Creek site

(IDFdk3) became infected for the first time in 2021. The trees at Dog Creek were assessed based on red needles in May and early June, prior to the emergence of fruiting bodies (late June/early July). Severity was measured at both sites using a modified Hawksworth dwarf mistletoe 6 point rating system (symptoms of elytroderma used in place of dwarf mistletoe brooms).

At the Dog Creek site, 15% of the trees showed symptoms of infection and the mean severity was 1.5. The Fletcher Lake site had an overall infection rate of 26% in 2020 and a mean severity of 1.9. In 2021, this increased to 32% incidence and a mean severity of 3.0. Although 57% of the trees infected in 2021 were also infected in 2020, some of the trees rated as healthy in 2021 were rated as infected in 2020 (28%). This suggests that some of the trees originally rated as infected based on the presence of red needles in 2020 were misdiagnosed, that infections did not become systemic (were confined to the needles), or that the systemically infected portions of the tree were killed or no longer showed visible symptoms of infection in 2022. Wirtz (1967) was able to demonstrate the presence of elytroderma in macroscopically asymptomatic needles and branches using microscopy. Detailed mapping of the location of elytroderma infections on branches of ponderosa pine over time using branch diagrams (Childs 1968) provide evidence for the "recovery" of infected twigs both with and without twig death and subsequent relapse of symptoms on some of the recovered twigs.

At the Fletcher Lake site, both elytroderma mean incidence (Figure 1) and severity (Figure 2) were higher in families originating from the colder BEC units (IDFdk4 and SBPSxc) relative to families from other warmer BEC units in the study. At the Dog Creek site, a similar trend was seen for elytroderma incidence (Figure 3), but disease severity was similar regardless of the BEC unit of origin (Figure 4). This could have important implications when selecting seed sources that are less susceptible to elytroderma in these colder BECs. It also suggests that elytroderma needle cast occurred with less frequency in these colder BEC units in the past. However, it should be noted that families originating from the SBPSxc also had lower mean rates of mortality from summer drought and winter desiccation at the Fletcher Lake site (Figure. 5). The Fletcher Lake site had sandy soil and a high percentage of course fragments. There was very little mortality at the Dog Creek site. Even within families originating from the same BEC unit, there was a fair amount of variation in terms of elytroderma incidence. The mean difference in incidence between the family with the lowest incidence and highest incidence for any given BEC unit at the Fletcher Lake site varied from 17.1-39.6 %. In 2020, tree height did not appear to be related to elytroderma incidence, which is good from a tree improvement perspective.

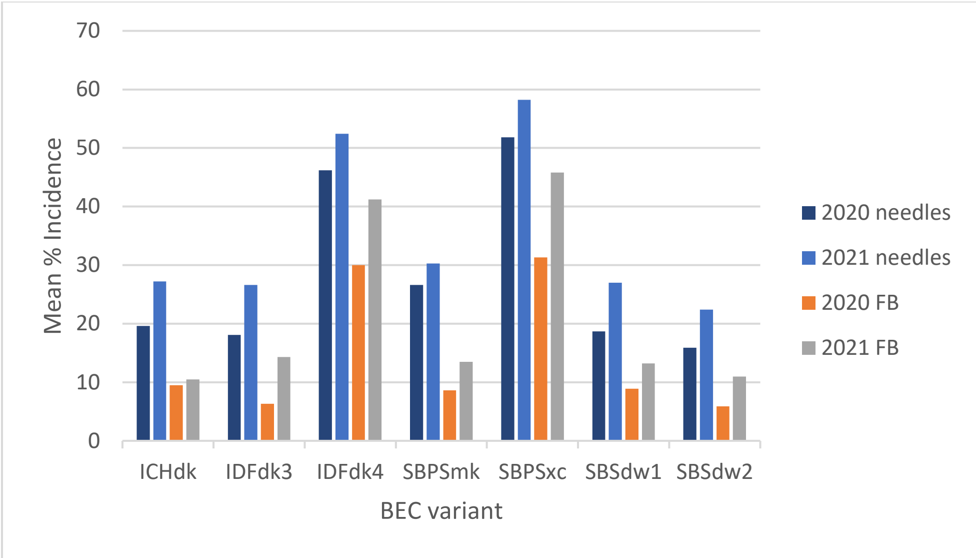

Figure 1. Mean elytroderma incidence based on red foliage and the presence of fruiting bodies (FB) by BEC unit at the Fletcher Lake site in 2020 and 2021.

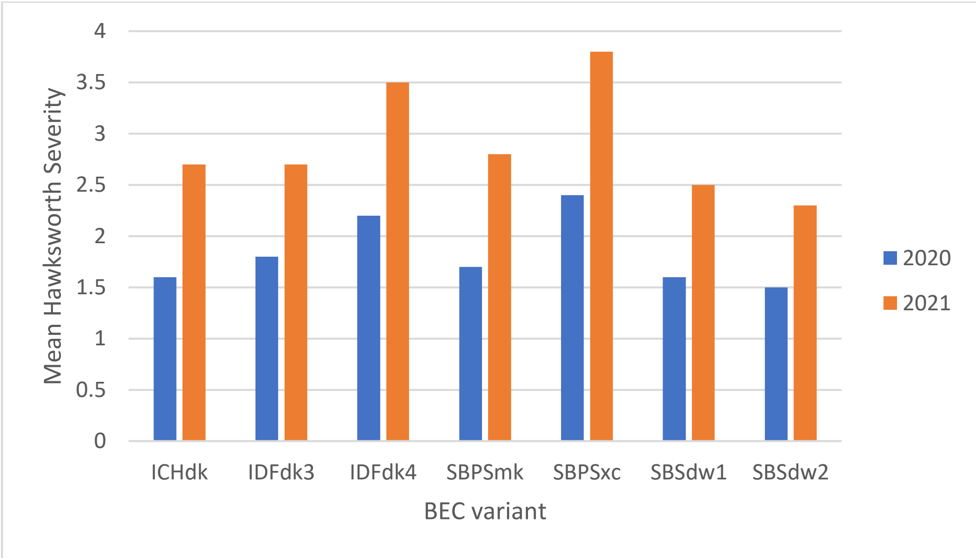

Figure 2. Mean elytroderma severity by BEC unit at the Fletcher Lake site in 2020 and 2021.

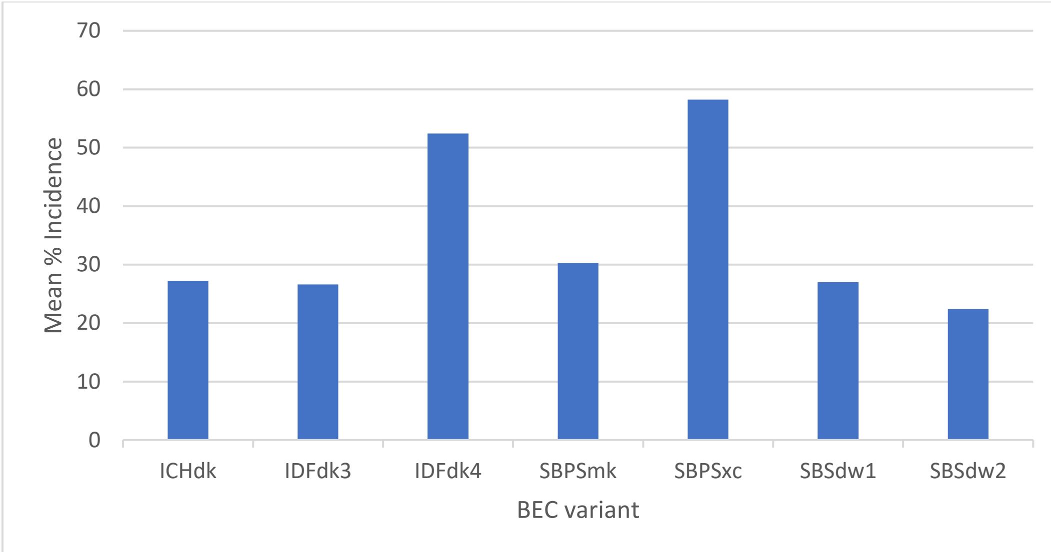

Figure 3. Mean elytroderma incidence by BEC unit of origin at the Dog Creek site, 2021.

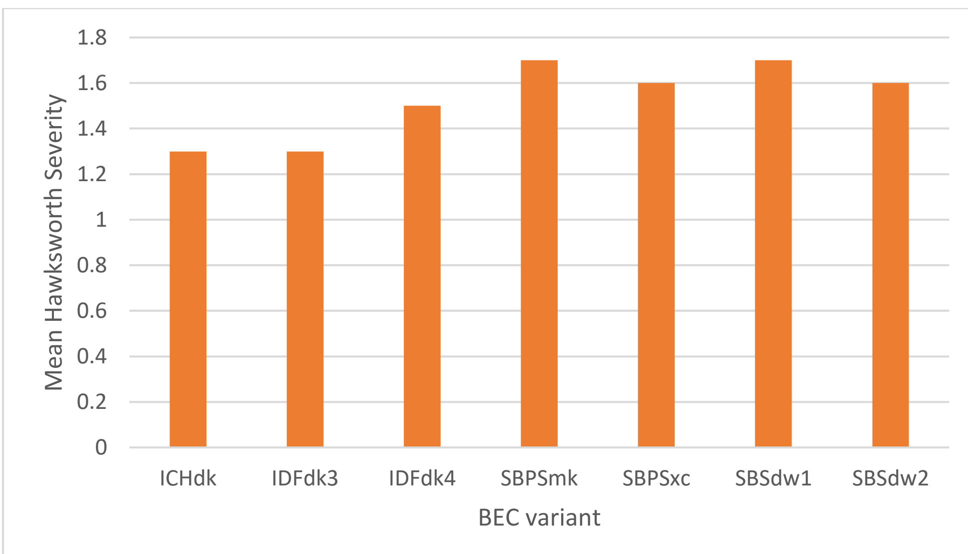

Figure 4. Mean elytroderma severity by BEC unit at the Dog Creek site, 2021.

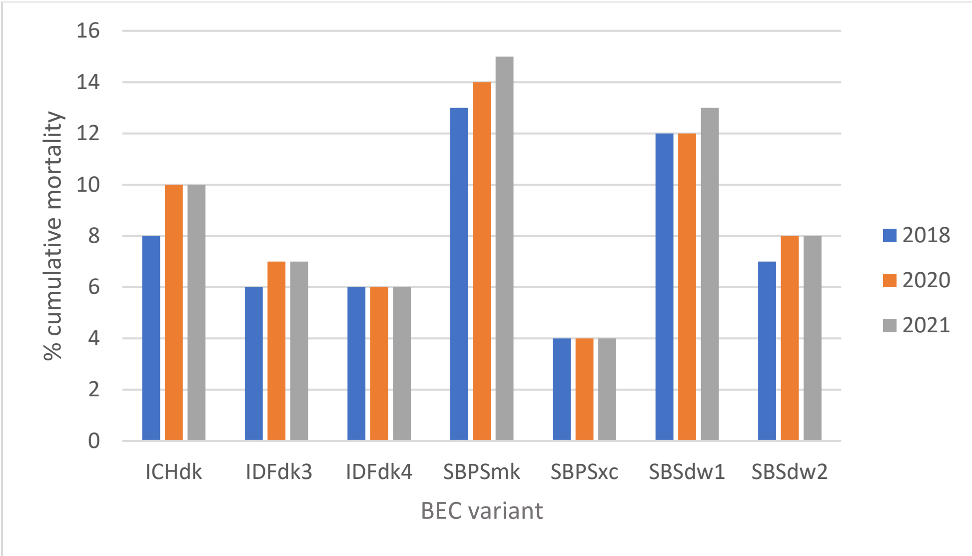

Figure 5. Non-elytroderma cumulative mortality at the Fletcher Lake site by BEC unit, 2018, 2020 and 2021.

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2021 drought event in the southern interior

Lorraine Maclauchlan

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 1 shows the hectares of drought mapped 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 2). 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).

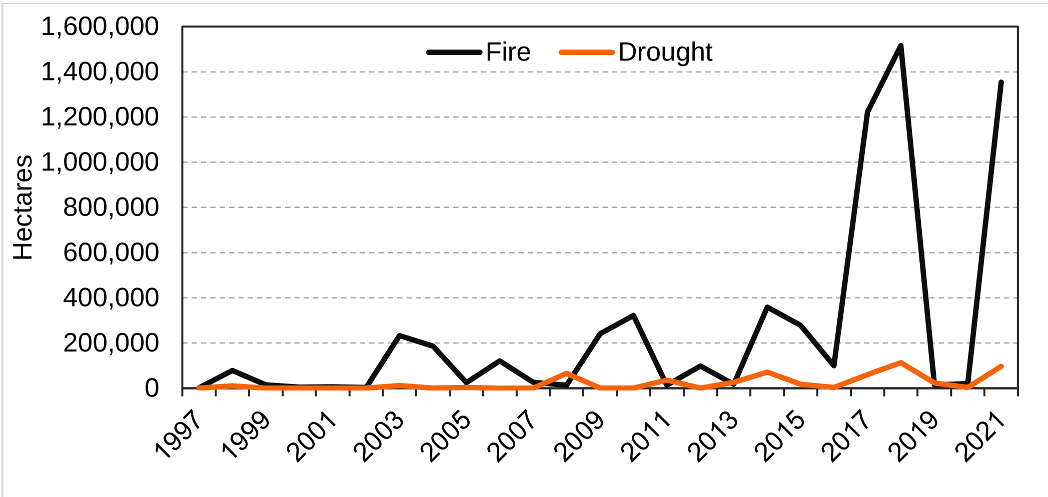

Figure 1. Hectares of wildfire and drought in B.C. (1997-2021).

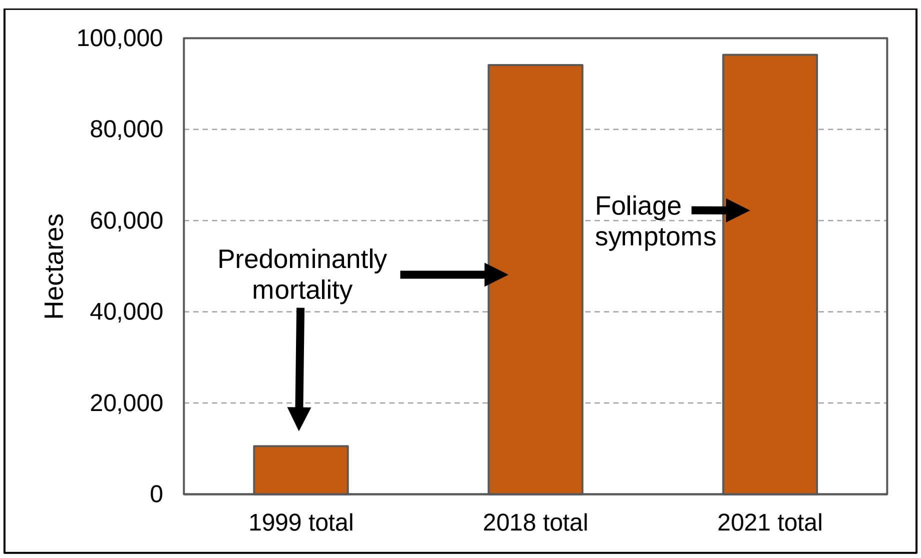

Figure 2. Drought damage detected in Aerial Overview Survey 1999, 2018 and 2021.

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 3 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 3 and 4). 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 3).

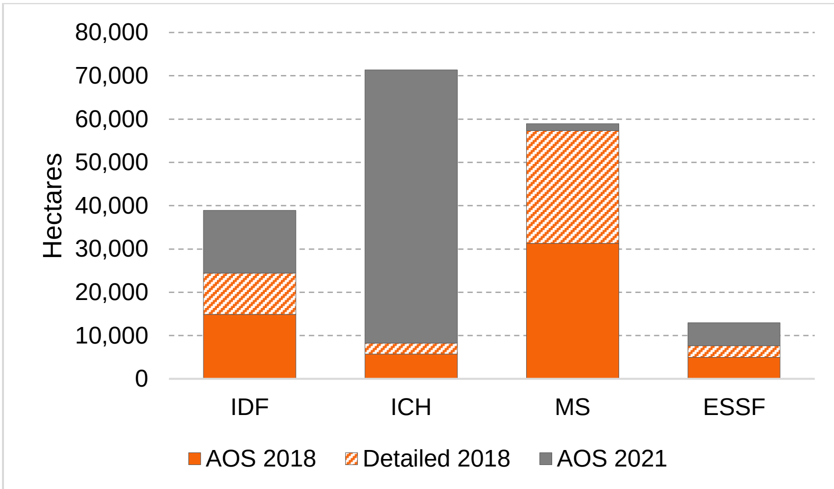

Figure 3. Hectares affected by drought in the Thompson Okanagan Region by biogeoclimatic zone in 2018 and 2021. Hectares affected were mapped during the Aerial Overview Survey (AOS) and detailed flights (2018).

Drought damage to cedar, Mount Ida, Okanagan TSA.

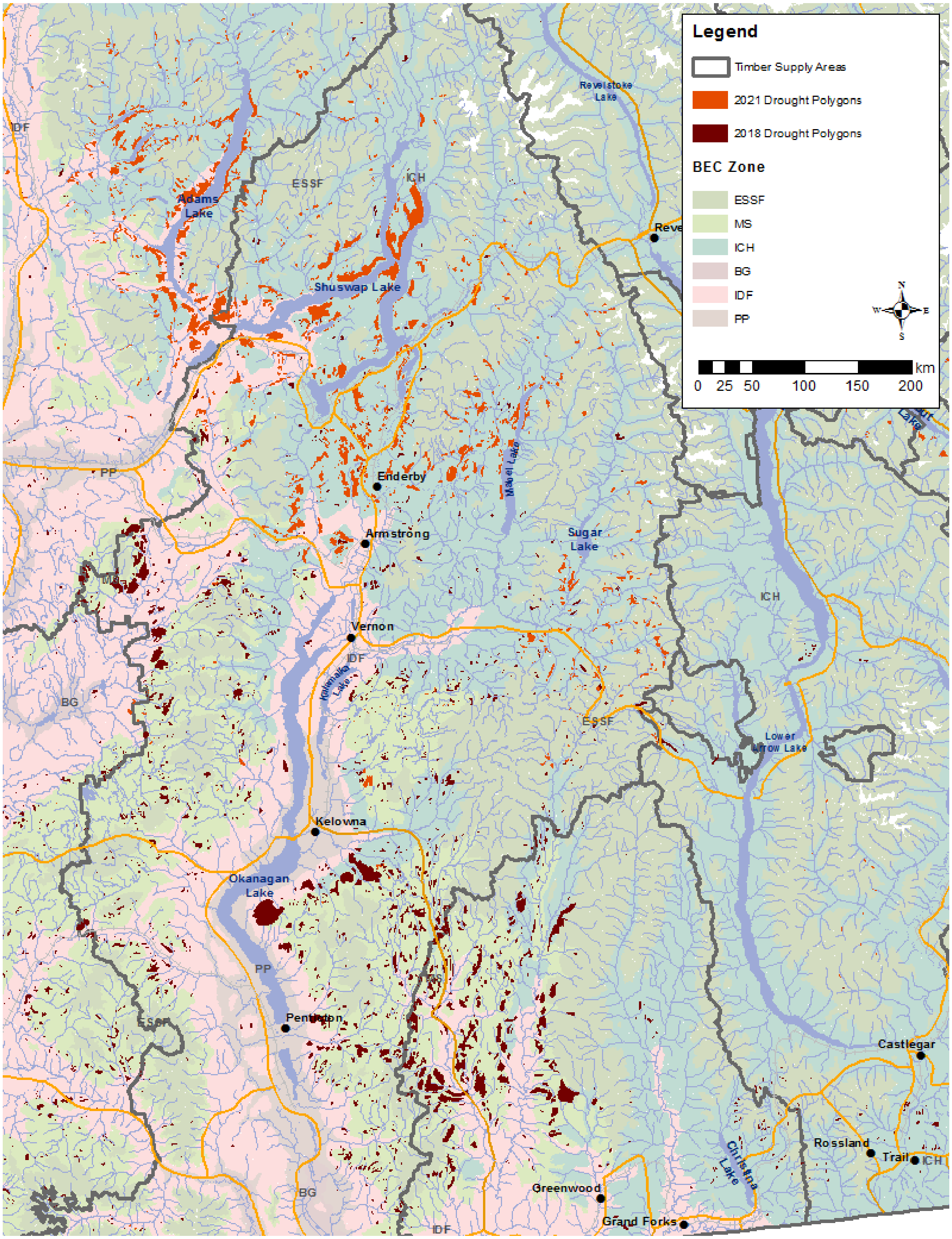

Figure 4. 2018 and 202 drought damage in the Thompson Okanagan Region.

Okanagan TSA was the most drought-impacted TSA in the southern interior in both 2018 and 2021 (Figure 5), 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 5).

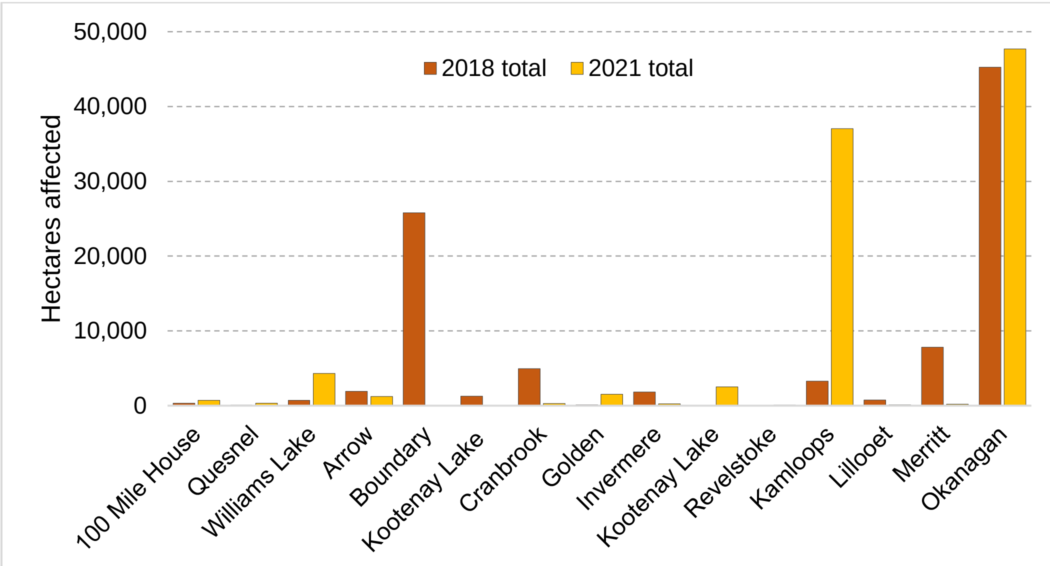

Figure 5. Comparison of drought damage mapped during the Aerial Overview Survey in 2018 and 2021 in affected TSAs in the southern interior.

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 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

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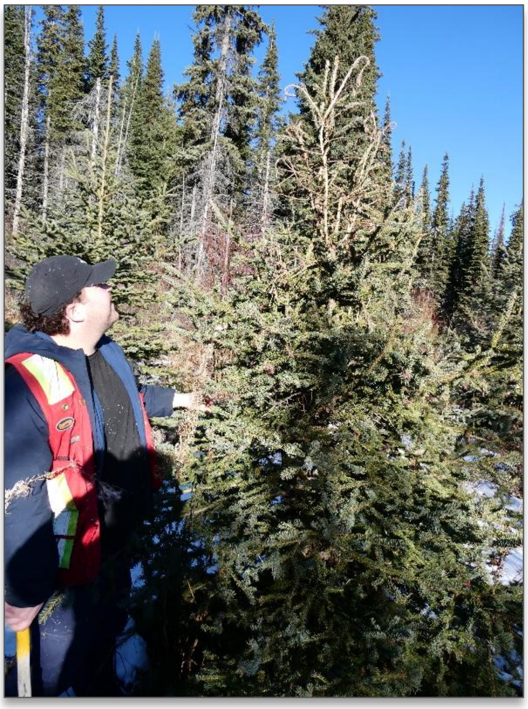
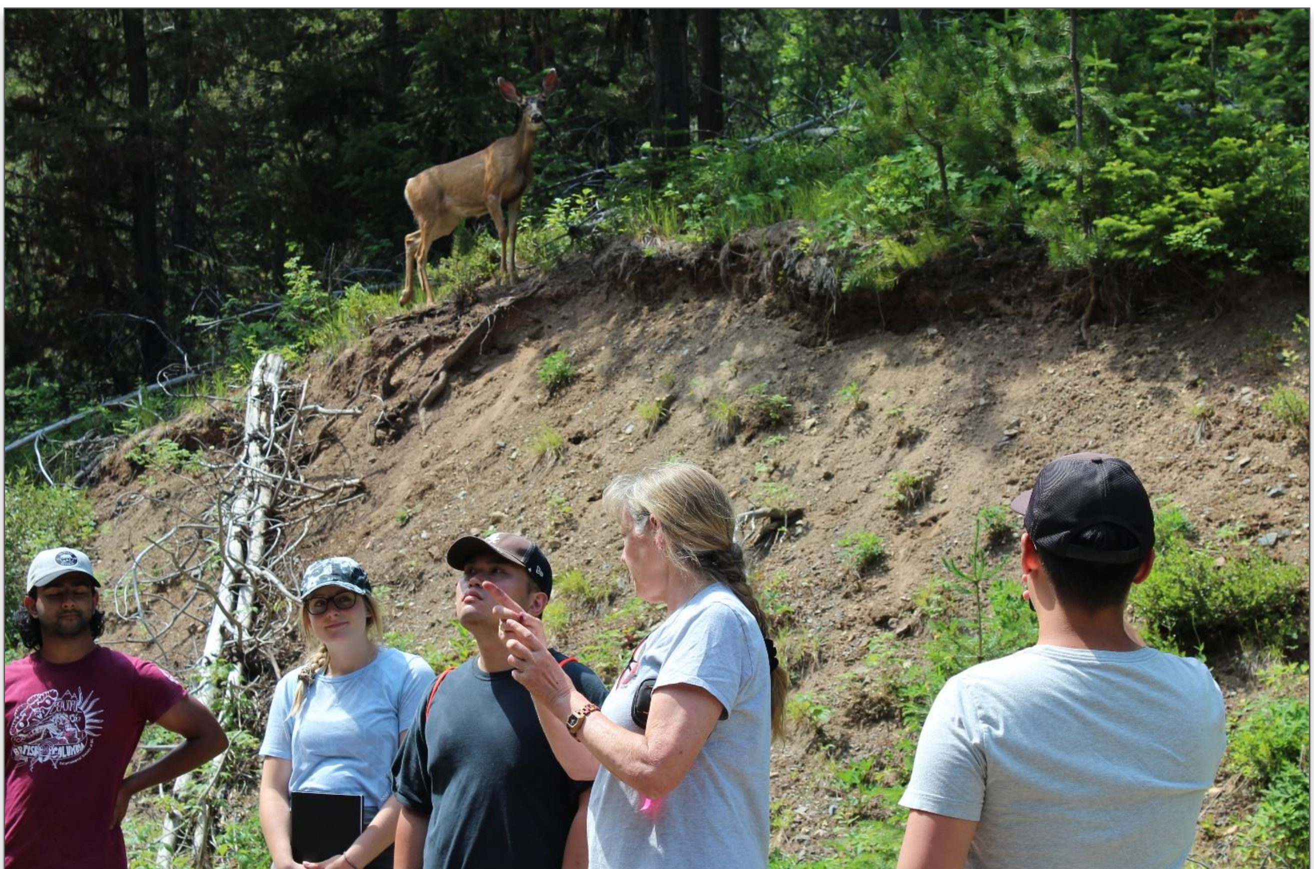
Drought damage to cedar, Mahood Lake, Kamloops TSA.





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