REGIONAL DISTRICT OF CENTRAL KOOTENAY
MEADOW CREEK AND PINE RIDGE
MOSQUITO CONTROL PROGRAM
2021 YEAR-END REPORT

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Executive Summary

Morrow BioScience Ltd. (MBL) has now completed the 21st consecutive year as mosquito control contractor for Meadow Creek and Pine Ridge within the Regional District of Central Kootenay (RDCK). The 2021 season concludes the 4th year of a 5-year contract. Mosquito development site knowledge has been acquired in low and high-water years and through early and late freshet seasons. The mosquito control program reduces floodwater and snowmelt mosquito abundance within Meadow Creek and Pine Ridge. Most control activity takes place along the north side of Kootenay Lake, Pine Ridge, along the Duncan River, Meadow Creek, and the Marblehead area.

In April, immediately preceding the mosquito season, the snowpack in the West Kootenay Basin and Upper Columbia basin was 100 and 108 percent of normal, respectively. A regional warming trend in mid-April within the Basins led to low-elevation snowmelt. Secondary warming stints at the in mid-May and late-May/early-June triggered the melting of the rest of the mid-elevation and some high-elevation snowpack. Much of this snowmelt was likely attenuated by the Duncan Dam. This melting event resulted in the Kootenay Lake peak on 5 June at 532.602 m. The late June record-breaking heat experienced throughout much of the province resulted in the quick and complete depletion of all remaining snow. This heat event also led to the Duncan River peak (7 July; 2.914 m). Regional precipitation accumulation was lower than average from April – July and, thus, likely did not measurably augment regional river levels during their peaks. August precipitation accumulation was higher-than-average and may have contributed to local container mosquito development. Due to lower River and Lake levels in 2021 than in 2020, mosquito egg abundance was not compounded and led to moderate hatching events in 2021. No known sites were missed in 2021. One new site was added in Meadow Creek. No calls or emails were received with regard to the Meadow Creek and Pine Ridge mosquito control program in 2021. No human cases of West Nile virus or Zika virus were reported by the BCCDC in 2021.

Between 19 May and 8 July, a total of approximately 607 hectares was treated by ground and helicopter within Meadow Creek and Pine Ridge. This total is approximately 125 ha lower than the total of hectares treated in 2020. Treatment efficacy was assessed as high. One aerial events targeted floodwater mosquito development sites associated with the Kootenay Lake and Duncan River flood plains. A real-time monitoring and treatment data dashboard was provided to the RDCK program manager. The dashboard enables the program manager to view up-to-date treatment information and ensure quality control.

Communications with residents remains a priority for MBL. Although no interviews specific to the Meadow Creek and Pine Ridge mosquito control program were requested in 2021, on 13 May a virtual town hall was held for in-program residents. Information dispensed included a summary of 2020 mosquito control efforts, discussion of the snowpack and projection for 2021, and personal protective tips. Additionally, a media release was published on various local websites and social media platforms on 7 June, following approval by RDCK program managers. The reach of social media posts

continues to increase annually, meaning that more residents around Meadow Creek and Pine Ridge are aware of mosquito abatement efforts.

Season Highlights

- The average snowpack in the West Kootenay Basin was 100 percent of normal on 1 April, immediately preceding the onset of the mosquito season.
- The Upper Columbia Basin was 108 percent of normal on 1 April.
- A region-wide warming event within both basins prompted considerable low and mid-elevation snow melt conditions in mid and late-May/early-June, leading to the local peak in Kootenay Lake.
- The heat dome effect that was in place over much of the province in late June led to the depletion of all residual high-elevation snowpack in associated basins, resulting in the local peak of the Duncan River.
- The peak of Kootenay Lake (Queens Bay gauge) occurred on 5 June at 532.602 m.
- The official peak for the Duncan River (Below Lardeau River gauge) occurred on 7 July; 2.914 m.
- The 2021 peaks were lower than those of 2020, resulting in lack of compounded number of floodwater mosquito eggs triggered to hatch.
- One aerial campaigns was required to treat floodwater mosquito development habitat on 9 June.
- Total Aquabac® ground treatments in Meadow Creek were 634 kg (158 ha). Ground treatments were high in Meadow Creek due to the large-scale ground treatment on 8 July, made necessary because helicopters were preoccupied with fire control efforts.
- Total Aquabac® ground treatments in Pine Ridge were 11 kg (2.7 ha).
- Total Aquabac® aerial treatments were 1,783 kg (446 ha).
- No concern calls or emails were received by the MBL Mosquito Hotline or the RDCK Hotline in 2021.
- MBL's real-time data management and mapping portal provided RDCK program managers with improved ability to target areas and gave quality control assurance for clients.
- Education outreach pamphlets and media releases might have a greater audience if posted at the community bulletin board in Meadow Creek and submitted to the Penny Wise.

Introduction

Morrow BioScience Ltd. (MBL) is the longest-operating mosquito control firm in British Columbia, having conducted mosquito control in this province for nearly four decades. MBL has been the mosquito control providers for Meadow Creek and Pine Ridge within the Regional District of Central Kootenay (RDCK) since 2000. In 2018, MBL started a renewed five (5) year contract; this season – 2021 – is the fourth year of the contract.

The considerable mosquito habitat, program reach, and interannual regional river and lake peak variations, and influence of the Duncan Dam makes the Meadow Creek and Pine Ridge mosquito control program complex. However, throughout over two decades, MBL staff has acquired thorough knowledge of the program regarding site locations and effective treatment timing. In addition to the knowledge base, numerous improvements have been made to the program since its inception, including: intensive site survey along Duncan River and Kootenay Lake floodplains, identification of new mosquito development sites, the addition of a real-time data collection and review portal, increased public engagement both through social media and in-person events, and improved environmental awareness through annual carbon offset purchases. MBL's goal is to continue to provide effective mosquito control to the Meadow Creek and Pine Ridge residents, while remaining socially and environmentally responsible.

Carbon Offsets

The spatial reach of the Meadow Creek and Pine Ridge mosquito control program is such that driving is an inevitable requirement. The accumulated mileage over the course of 2021 was approximately 9,700 km (ground transportation only).

As an estimation, the driving requirements for this program result in the production of approximately 2.22 tonnes of CO_2 emissions. To offset this addition of CO_2 to the environment, MBL has committed to purchasing carbon offsets. To fulfill this commitment, carbon offsets are purchased through the West Kootenay EcoSociety[1]. When the carbon offsets are purchased, a proof of purchase and certificate from the offset provider will be delivered to the RDCK.

Methodology

The primary targets of the Meadow Creek and Pine Ridge mosquito control program are floodwater mosquito larvae. Unlike container mosquitoes (e.g., *Culex pipiens*), female floodwater mosquitoes (e.g., *Aedes vexans*, *Ae. sticticus*) deposit their eggs on damp substrate. Within the Meadow Creek, floodwater mosquito development sites primarily exist along the flooding corridors of the Duncan River (below the Lardeau River) and Kootenay Lake, including associated seepage sites. Within Pine Ridge, mosquito development sites primarily exist within sloughs and snowmelt sites. When water floods

[1] https://www.ecosociety.ca

these sites, due to the freshet and/or significant localized precipitation, the result is large-scale floodwater mosquito egg hatching (Image 1). If numerous seasons have passed between high-water years, then high river levels may trigger a compounded number of mosquito eggs to hatch.

The secondary target of the Meadow Creek and Pine Ridge mosquito program is snowmelt mosquitoes. Snowmelt mosquitoes hatch early in the spring (i.e., March – early May) within the area. Snowmelt mosquito habitat consists of smaller depressions in the landscape where snowmelt mosquito eggs were laid the previous summer. The smaller depressions collect water in the fall and freeze. Just as the site begins to thaw, snowmelt mosquito eggs hatch. These species typically hatch early to ensure their development habitat remains wet from hatching to emergence and also to reduce inter-species habitat competition as they develop (Clements 1992). Certain snowmelt mosquito species begin to hatch at a water temperature of approximately 4°C and can complete development to adult emergence at 10°C (Clements 1992). Snowmelt mosquito development sites are mainly located along the mountain benches within Meadow Creek.

Image 1. Standard dip (350 ml) from mosquito development site showing 3rd instar mosquito larvae (2021)

MBL field technicians begin monitoring all known mosquito development sites within Meadow Creek and Pine Ridge early in the spring as ambient temperatures began to cause localized snowmelt. Monitoring is increased and extended to floodwater mosquito development sites with the rising local Duncan River and Kootenay Lake levels in the spring. Mosquito development sites are adaptively managed, meaning that the regional river and lake levels and local temperatures largely dictate how frequently sites are visited, as opposed to a prescribed monitoring schedule. At the height of the mosquito season, MBL staff may monitor highly productive sites multiple times a week. Adaptive management techniques allow MBL staff to most accurately time treatments, if necessary. Prescribed monitoring methods increase the risk of missing optimal treatment windows due to accelerated mosquito development rates with rising temperatures (Read and Moon 1996). Hence, as regional river and lake levels and ambient temperatures begin to rise consistently, monitoring efforts increase.

Larval mosquitoes in sufficient number (i.e., >4/dip) are treated by ground applications of the microbial larvicide product Aquabac®. This product has the active ingredient *Bacillus thuringiensis israelensis* (Bti), which is carried in a corncob formulation. The mode of action for Bti inherently includes a high degree of species selectivity. Receptors within the mid-gut region of the mosquito larvae are specific to the toxin proteins that are produced alongside each bacterial spore. After the mosquito larvae ingest the toxin protein, it causes considerable damage to the larval gut wall and quickly results in death (Boisvert and Boisvert 2000).

As the season progresses and more mosquito development sites become flooded, it becomes increasingly difficult to treat sites by ground due to inaccessibility and concurrent site activation. At this point, a helicopter is used to conduct aerial treatments. Aerial campaigns use the same pesticide as ground applications, although sometimes with a higher application rate to permeate canopy cover in high-water years. High water years may require 2-day aerial treatment campaigns, due mostly to the level of flooding involvement associated with the Duncan River and Kootenay Lake foreshore sites.

It is important to time treatments according to the correct stage of larval development (i.e., 3rd and 4th instar). If treatments are applied too early, the larvae will not have advanced to their highest feeding rate yet and if applied too late, the larvae molt into pupae (i.e., non-feeding stage). Both circumstances may result in the development of adult mosquitoes. Additionally, by waiting until mosquito larvae are in the 3rd and early 4th instar stages, early instar larvae are available as food sources within the ecosystem.

Environmental Conditions

The three primary environmental conditions that affect Duncan River (River) and Kootenay Lake (Lake) levels throughout the mosquito season (i.e., April – August) are: 1) ambient temperature in the West Kootenay Basin and Upper Columbia Basin, contributing to the River and Lake, 2) snowpack in the West Kootenay Basin and Upper Columbia Basin, and 3) local precipitation. Local ambient temperature is also of interest due primarily to the effect local ambient temperature can have on mosquito egg hatching and development rates. As such, all noted conditions are tracked throughout the season.

Snowpack

Floodwater mosquito abundance within Meadow Creek is primarily governed by regional Duncan River (Below Lardeau River gauge; 08NH118) and Kootenay Lake (Queens Bay gauge; 08NH064) water levels. In turn, the water levels of those systems are largely determined by the freshet released from the West Kootenay Basin and, to a lesser degree, the Upper Columbia Basin. When snowpack exceeds 100 percent of normal, higher-than-average Duncan River and Kootenay Lake levels are expected during the mosquito season. Duncan Dam freshet attenuation dampens and alters the normal Duncan River level trend.

The West Kootenay Basin was 100 percent of normal and the Upper Columbia Basin was 108 percent of normal at the start of the mosquito monitoring season[2]. Both basins received additional snow in the early half of April. The augmentation of the snowpack at that time resulted in peak Snow Water Equivalent (SWE) values for numerous areas of both basins in early April. A ridge of high-pressure settled over much of the province from 14-18 April and led to unseasonably warm ambient temperatures and some low-elevation snowmelt toward the end of the month[3].

The weather in May was generally stable and the West Kootenay and Upper Columbia Basin snowpack depletion began in mid-May. Continued warm weather in early June resulted in the further depletion of all middle-elevation and some high-elevation snow within both basins. A brief stint of cool weather slowed the regional snowmelt in mid-June. The 15 June Snow Survey and Water Supply Bulletin note that the average snowpack within the West Kootenay Basin and Upper Columbia Basin was 78 and 133 percent of normal, respectively[4]. The River Forecast Centre suggested cautious interpretation of the reported percentage. However, the considerably high 'percent of normal' snowpack remaining as of 15 June in the Upper Columbia Basin reflected the rarity of late-season snowpack persistence. Record-setting heat was recorded for much of the province in late June. The heat dome effect resulted in the quick and complete depletion of all high-elevation snow in both basins by late June.

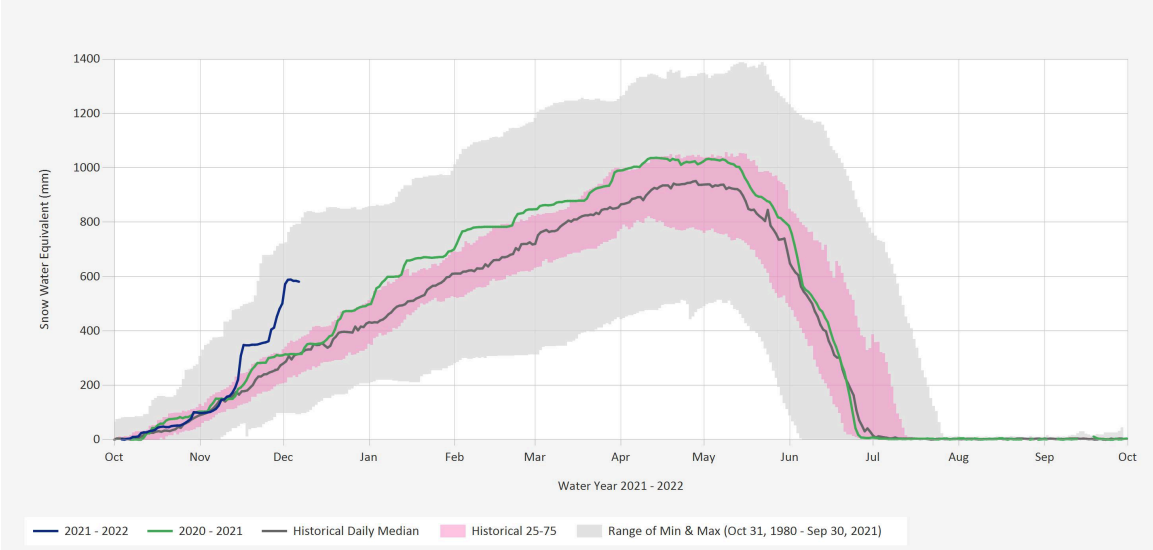

Figure 1. Snow Water Equivalent (SWE; mm) data from the East Creek snow survey (station ID: 2D08P) within the West Kootenay Basin (2020-2021 data represented by green line).

The East Creek snow survey station (ID: 2D08P) is upstream of the program purview (Figure 1). It serves as a representative site for the regional snowmelt trajectory. The Snow Survey data show a brief melting stint occurred toward the end of April[5]. It also shows the

[2] https://www2.gov.bc.ca/assets/gov/environment/air-land-water/water/river-forecast/2021_apr1.pdf
[3] https://www2.gov.bc.ca/assets/gov/environment/air-land-water/water/river-forecast/2021_may1.pdf
[4] https://www2.gov.bc.ca/assets/gov/environment/air-land-water/water/river-forecast/2021_june15.pdf
[5] https://www2.gov.bc.ca/gov/content/environment/air-land-water/water/water-science-data/water-data-tools/snow-survey-data

first measurable melting trend in mid-May, with the lower and middle-elevation SWE dropping significantly. The data show the impact of the heat dome in late June, resulting in the depletion of the East Creek station's snowpack by the end of June (Figure 1). Other snow survey stations throughout the West Kootenay and Upper Columbia Basin show similar trends[6]. Thus, by early July any fluctuations in the regional Duncan River and Kootenay Lake levels were likely not due to regional snowmelt contributions.

Local Precipitation

Extensive temporally and spatially-concentrated precipitation accumulation may elevate regional Duncan River levels. Local precipitation can also temporarily augment seepage site levels, where floodwater mosquito development habitat is located. Tracking local precipitation accumulation can aid MBL field staff in determining when mosquito sites become active and how long sites may require management. The Nelson Rixen Creek weather station (ID: 114EMDM) provides weather information allowing for interannual comparison of environmental conditions. This comparison facilitates some level of prediction regarding larval mosquito hatching and treatment timing requirements. When more than average precipitation is received within peak hatching months, seepage site levels may be higher or sustained for longer. Both scenarios may lead to additional floodwater mosquito egg hatches.

Precipitation accumulation recorded at the Nelson Rixen Creek weather station from April through July was lower than average (Figure 2). This is consistent with the frequent high-pressure weather systems noted within the province during that period. Precipitation accumulation received in those months ranged from 21-43 mm lower than the monthly averages (Figure 2). Given the relatively low amount of local precipitation during the height of the freshet, it is unlikely that precipitation augmented the Duncan River and Kootenay Lake levels or associated seepage sites in those months. Operationally, the relatively low amount of local precipitation received during the height of the freshet season meant that MBL staff did not have additional site areas to monitor beyond those created by the freshet.

[6] https://governmentofbc.maps.arcgis.com/apps/webappviewer/index.html?id=c15768bf73494f5da04b1aac6793bd2e

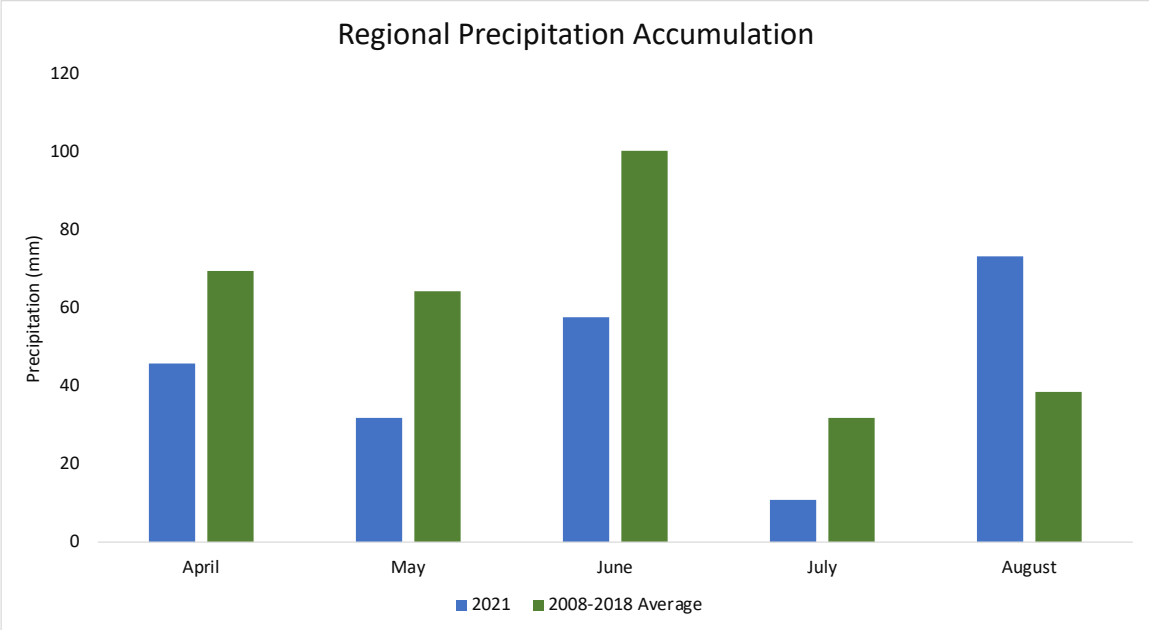

Figure 2. Precipitation values (rainfall and snow accumulation; mm) recorded at the Nelson Rixen weather gauge (ID: 114EMDM) for 01 April – 31 August 2021 (blue) and average station precipitation values (2008-2018; green).

Considerable and above-average precipitation was recorded in August (Figure 2). The majority of precipitation was received in the latter half of August. At that point, precipitation was of little consequence to the regional river and lake levels and associated mosquito development sites because the univoltine floodwater mosquito species had already hatched and/or floodwater mosquito development habitat had been reduced. However, it's possible that precipitation received in August did create habitat for container mosquito hatching. Thus, adult mosquito presence toward the end of the season was likely due to container mosquito hatches, not floodwater mosquito species in most areas.

Local Ambient Temperature

From April through August, local ambient temperature fluctuations can affect mosquito egg hatching, larval development rates, and adult dispersal rates. In the early portion of the season, ambient temperatures strongly influence sites that are shallow, relatively stagnant, and land-locked, such as snowmelt sites. Often, the most productive snowmelt sites are ephemeral (Becker et al. 2010). Snowmelt mosquitoes are able to hatch under relatively cool temperature conditions. Floodwater mosquitoes require warmer temperatures and reduced dissolved oxygen content as environmental triggers for hatching. As such, ambient temperature and associate dissolved oxygen levels help dictate earlier season (e.g., April/May) snowmelt mosquito egg hatching events and later season (e.g., May/June/July) floodwater mosquito egg hatching events (Mohammad and Chadee 2011).

Ambient temperature, both locally and within the contributing snow basins, is an important variable to track. Local ambient temperature fluctuations from April through August can affect mosquito egg hatching, larval development rates, adult dispersal, and adult survival in the Meadow Creek and Pine Ridge region. Ambient temperature within the West

Kootenay Basin and Upper Columbia Basin dictates the commencement and often the intensity of the freshet.

West Kootenay and Upper Columbia Basin Temperatures

Ambient temperatures for April were generally normal within the West Kootenay Basin and Upper Columbia Basin. The 1 May Snow Survey and Water Supply Bulletin[7] noted that temperatures averaged between -2ºC to +2ºC for the month. This normal range was recorded despite the ridge of high pressure from 14-18 April that resulted in low-elevation and some middle-elevation snowmelt.

Ambient temperatures in May within both basins were considered slightly above normal in comparison to monthly averages[8]. Warming and cooling events both occurred during the month. Notable warming stints took place in mid and late-May/early June, resulting in melting events in both basins. The late-May/early-June melting event ultimately led to the seasonal peak levels for Kootenay Lake in early-June.

Weather within much of the province during the first week of June was dominated by a high-pressure system[9]. The following low-pressure system present slowed the high elevations snowmelt within both basins. However, a strong high-pressure ridge was in place over most of the province in the latter half of June. The heat dome effect resulted in the shattering of many high-temperature records within the province and led to the depletion of high-elevation snowpack within the West Kootenay Basin and Upper Columbia Basin. The pulse of water from that melting event led to the official peak in the regional Duncan River in early July. Temperature data are consistent with 2021 automated snow station data depicting snowmelt points correlating with regional ambient temperature spikes[10].

Local Temperatures

If the ground proximate to the Duncan River and the Kootenay Lake contains floodwater mosquito eggs and if hatching conditions are present (i.e., low dissolved oxygen, higher ambient temperatures), then floodwater mosquito egg hatching will commence (Mohammad and Chadee 2011). Thus, local ambient temperature is a predictive tool when gauging floodwater egg hatch commencement. Local ambient temperature data are acquired from the Nelson Rixen Creek weather station (ID: 114EMDM)

To illustrate the effect of ambient temperature on mosquito developmental benchmarks, Trpis and Horsfall (1969) exposed submerged eggs of a regionally common floodwater mosquito species, *Aedes sticticus*, to various constant air temperatures and recorded

[7] https://www2.gov.bc.ca/assets/gov/environment/air-land-water/water/river-forecast/2021_may1.pdf
[8] https://www2.gov.bc.ca/assets/gov/environment/air-land-water/water/river-forecast/2021_june1.pdf
[9] https://www2.gov.bc.ca/assets/gov/environment/air-land-water/water/river-forecast/2021_june15.pdf
[10] https://www2.gov.bc.ca/gov/content/environment/air-land-water/water/water-science-data/water-data-tools/snow-survey-data/automated-snow-weather-station-data

hatching success. Results revealed that eggs began to hatch at 8°C, although larval development was slow and survivorship was low. Eggs held at 21°C provided the optimal temperature, of the five temperatures tested, for hatching and larval development (Figure 3). While *Ae. sticticus* is not the sole floodwater species present in Meadow Creek and Pine Ridge, it is frequently caught in regional adult mosquito traps and serves as a representative species for control purposes.

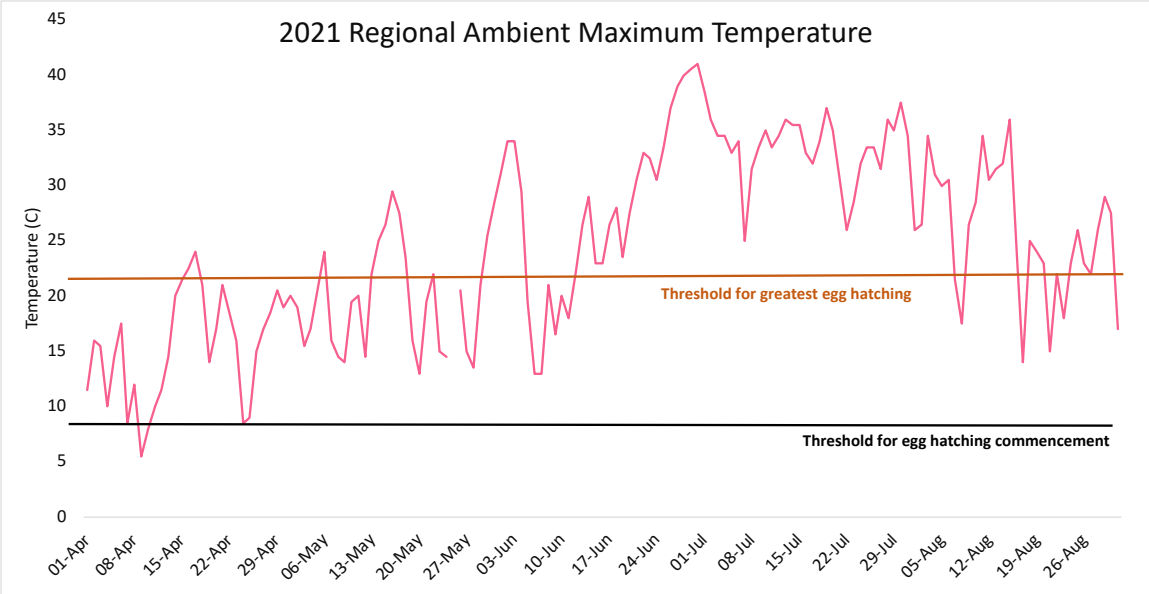

Figure 3. Maximum daily ambient temperatures (C) as recorded at the Nelson Rixen Weather Station (ID: 114EMDM) 01 April – 31 August 2021. Lower black line illustrates threshold at which *Ae. sticticus* eggs can commence hatching; upper orange line illustrates threshold at which most *Ae. sticticus* eggs hatch.

Snowmelt mosquito eggs hatch earlier than floodwater mosquito eggs. Certain snowmelt mosquito species begin to hatch at a water temperature of approximately 4°C and can complete development to adult emergence at 10°C (Kardatzke 1979, Clements 1992). Thus, snowmelt mosquito eggs laid along the mountain bench area were triggered to hatch in April as sites began to show initial melting (Figure 3). Of note, Figure 3 shows ambient temperature, not water temperature. The delay in realized water temperature is likely a few days in relatively small, shallow sites, such as the majority of snowmelt-influenced sites found in along the mountain benches in Meadow Creek.

April ambient temperatures were also sufficient to trigger floodwater mosquito egg hatching events if the eggs were exposed to flooding conditions (Figure 3). The displayed daily maximum ambient temperature thresholds are meant to conservatively depict the earliest point at which mosquito egg hatching may occur. Mosquito egg development at that time of the season would have likely been slow and hatching success low. While temperatures in mid-April briefly surpassed the threshold for a high rate of mosquito egg hatching and survivorship, the regional river and lake levels were low and, thus, most floodwater mosquito eggs were likely not exposed to water.

Local ambient temperatures in mid and late-May were relatively warmer and more favourable for larval development conditions of floodwater mosquitoes (Figure 3). Accordingly, floodwater mosquito hatching and larval development rates increased significantly within those months. Ambient temperature decreased around 7 June, slowing floodwater mosquito larval development. Ambient temperatures rebounded in mid-June and significantly increased in late June as the heat dome settled over most of the province. The heat dome facilitated further mosquito hatching and increased larval development rates. Because numerous floodwater development sites were at peak levels, the need to treat mosquito larvae in June and July was directly associated with ambient temperature.

Warmer-than-average ambient temperatures were documented from the latter half of June through mid-August. As regional river levels were also high within this timeframe, considerable mosquito eggs were exposed to ideal environmental hatching cues, resulting in the need for large-scale treatment events. By mid-August, the Duncan River and Kootenay Lake levels were receding and ambient temperature was no longer directly related to floodwater larval mosquito abundance and treatments.

As August progressed, localized annoyance due to container mosquito presence may have occurred. Container mosquito habitats near residential homes can be created throughout the summer whenever water presence is coupled with high ambient temperatures. MBL technicians regularly inform residents that adult container-bred mosquitoes can be reduced around homes by ensuring container mosquito environments are either free of water or refreshed frequently.

River and Lake Levels

Within the Meadow Creek area, floodwater mosquito development sites primarily exist along the flooding corridor of the Duncan River (Below Lardeau River gauge, ID: 08NH118) and Kootenay Lake (Queens Bay gauge, ID:08NH064), including associated seepage sites. The presence of cool water is a hatching cue and, thus, tracking regional river and lake levels provides predictive capabilities with regards to floodwater mosquito hatching and larval development.

The Duncan River levels increased in late April due to the first small pulse of the freshet from the West Kootenay Basin and, to a lesser extent, from the Upper Columbia Basin. Warming and cooling stints occurred throughout May, resulting in fluctuating freshet input to the regional River and Lake systems. A provincial warming trend in late-May and early-June led to the Kootenay Lake peak on 5 June at 532.602 m (Figure 4). The quick and complete depletion of West Kootenay Basin and Upper Columbia Basin snowpack in late-June/early-July led to the peak in the regional Duncan River on 7 July at 2.914 m (Figure 4).

Internally QA/QC'd Duncan Dam daily discharge data were not supplied by BCHydro in 2021. However, previous data show that there are usually two large discharges during the mosquito season. Typically, the Duncan Dam attenuates the freshet in the early part of the

season, has a discharge event in late-April/early May, attenuates the peak of the freshet, and has a final discharge event in late-July/early-August. If that same trend continued in 2021, the Duncan Dam likely had a discharge event in late April and the first week of August. It is unlikely that the peak of the Duncan River and Kootenay Lake were attributed to discharge events in 2021, based on the historical trend data and the data trendlines.

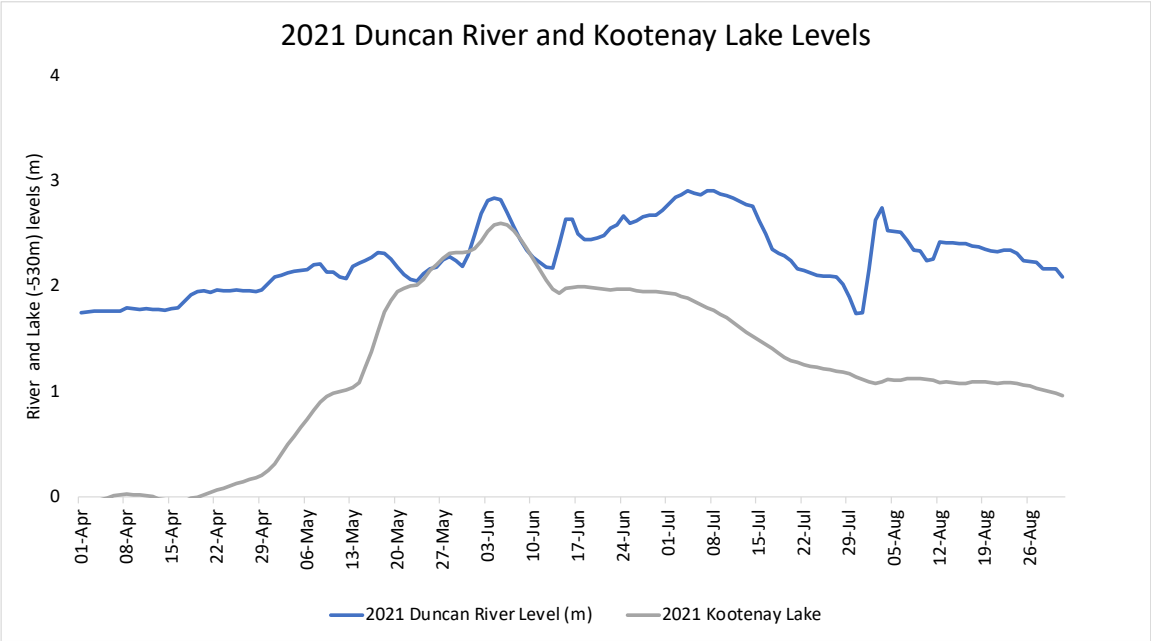

Figure 4. 2021 water levels (m) as recorded for the Duncan River (Below Lardeau gauge, 08NH118; Blue) and Kootenay Lake (Queens Bay gauge, 08NH064; grey). Note that 530 is subtracted from Kootenay Lake levels for ease of trend comparison.

Regional River and Lake peaks relative to those of recent seasons is a predictive variable that may help explain an associated year's larval abundance. If the current year's regional River or Lake levels far exceed those of preceding seasons, mosquito eggs laid between the high-water mark of both years could have remained dormant until current-year flood waters trigger their hatching. Figure 5 shows the Duncan River's levels since 2019. Figure 6 shows Kootenay Lake levels since 2019. While the 2021 season was considered a moderate-water year, the 2021 peak of the local Duncan River was 0.04 m lower than the 2020 peak, (Figure 5). The 2021 peak of the local Kootenay Lake was approximately 0.82 m lower than the 2020 peak (Figure 6). Given the relative peak water levels between 2020 and 2021, it is unlikely that the 2021 peak levels triggered dormant eggs to hatch. As such, an average larval abundance was noted in 2021.

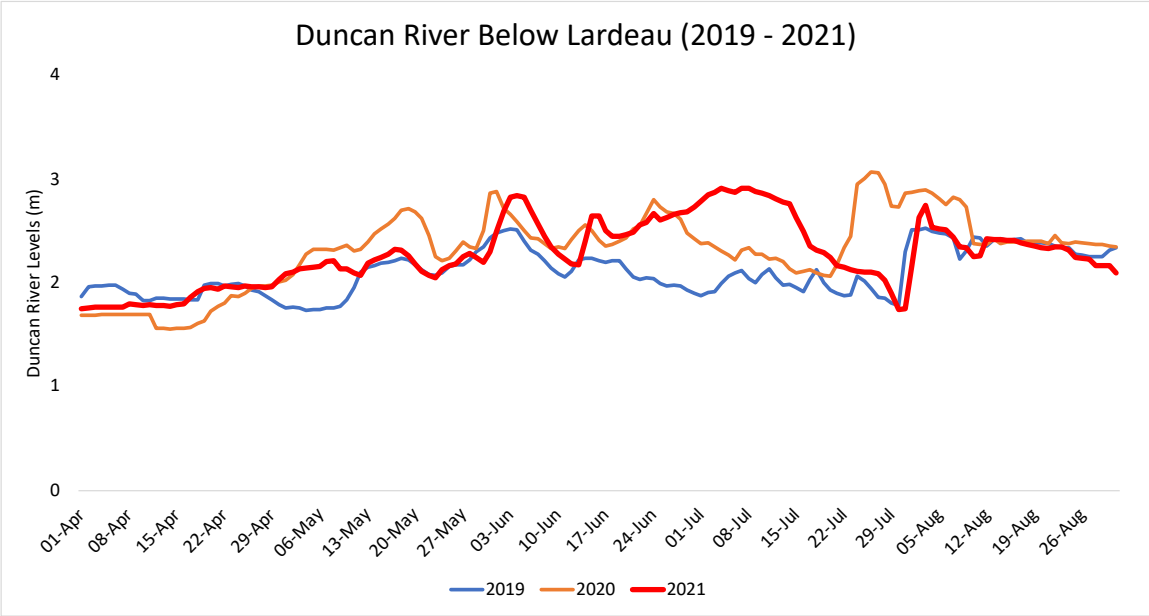

Figure 5. 2021 river levels (m) as recorded at the Duncan River (Below Lardeau gauge, 08NH118; red) with recent River levels, as reported by the River Forecast Centre (01 April – 31 August).

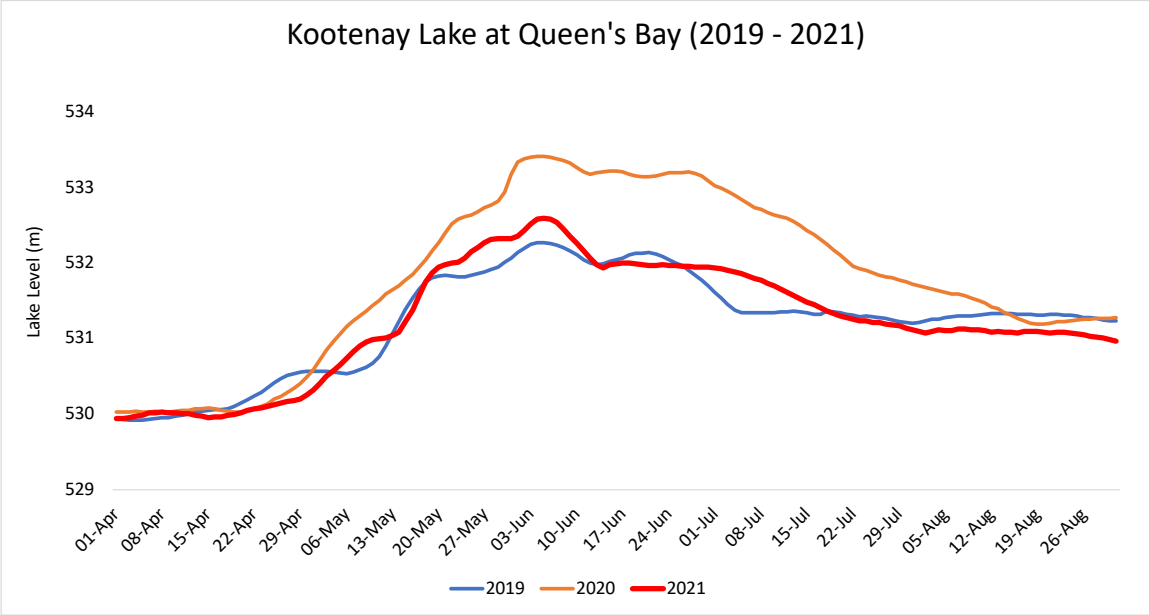

Figure 6. 2021 Kootenay Lake levels (m) as recorded at Queens Bay gauge (08NH064; red) with recent Lake levels, as reported by the River Forecast Centre (01 April – 31 August).

In the prime floodwater mosquito development period (i.e., April – June), both the Duncan River and Kootenay Lake rose at normal daily rates. When the water levels rise in this manner, floodwater mosquito eggs laid on substrates at various levels have optimal environmental hatching cues. When River and Lake levels rise at high rates in the early portion of the season, the typically cool, highly oxygenated water moving through the system makes it more challenging for mosquito eggs to hatch. In late-July, the Duncan River experienced a spike in water level. Although unverified, it is likely that this spike was due to discharge from the Duncan Dam (Figures 4, 5). This peak did not exceeded the initial peak. Thus, there was no additional mosquito larval activity.

By early July 2021, the West Kootenay Basin and Upper Columbia Basin were largely depleted of snow[11]. This depletion corresponds with a marked decline in both the Duncan River and Kootenay Lake water levels by mid-July (Figures 4, 5, 6). Duncan River levels decreased into August following the pulse of discharge from the Duncan Dam.

Larval Control

Monitoring within Meadow Creek and Pine Ridge began in late March, as snowmelt mosquito development sites first revealed signs of melting. Appendix I shows a map of average larval densities found throughout the 2021 season. Larval abundance is assessed in the field using a system of ranges (0, 1-4, 5-49, 50+) for early and late instar mosquito larvae. In order to transfer these data to a map (Appendix I), data are ultimately summarized and assigned to a hexbin representing an area of 21.65 ha.

Only wet sites were included in the analysis. An intensity value representing the relative number and life stage of the larvae are assigned to each single sample. For each sample, late instar larvae ranges are weighted more heavily than early instar larvae ranges to indicate targeted life stage and treatment urgency. In this way, each sample is assigned an intensity value from 0 to 1. All sample intensity values are then averaged by hexbin. Thus, each hexbin is also assigned an average intensity value from 0-1. The intensity value thresholds within Appendix I denoting 'low', 'moderate', 'high', and 'very high' were assigned based on biological significance and operational urgency. Consistently, the areas with highest recorded larval abundance amongst known sites are along the Duncan River, Meadow Creek, and Marblehead (Appendix I).

Hexbins are used to aggregate point data, making general data trends visible at large scales. The primary drawback and disclaimer to hexbin analysis is that generalizations must be made. In general, hexbins denoted as 'None Detected' (i.e. white) or 'Low' (i.e. light sandy colour) indicate the average sample contained < 5 larval mosquitoes per dip. In most cases, hexbins with a moderate frequency (0.2875 - 0.525 intensity value; light orange colour) or greater indicate those which had an average of > 5 mosquito larvae per dip. Hexbins can contain one or greater sample points, may contain sample points that lie directly on hexbin borders, or contain treatment area associated with a point that is officially housed within a neighbourng hexbin; each of these circumstances may create skewed results.

The first ground treatment in Meadow Creek occurred on 19 May (Figure 7). Treatments conducted in the early portion of the season took place at snowmelt sites. Treatments focused around the peak of the Duncan River and Kootenay Lake took place at floodwater-associated sites from late-May onward. The significant ground treatment that occurred on 8 July included the 90-Acre Swamp in Meadow Creek, upper Duncan Dam area, and the Marblehead region. Under normal circumstances an aerial would have been required to treat these large areas. However, all helicopters were occupied with fire control contracts during that time of the season, so MBL amassed a 5-person team to conduct the large-scale ground treatment. Ground treatments in Pine Ridge took place between 26 May and 2 June

[11] http://bcrfc.env.gov.bc.ca/data/asp/realtime/

(Figure 8). Ground treatments in Pine Ridge were associated with the ambient temperature spike in late-May/early-June.

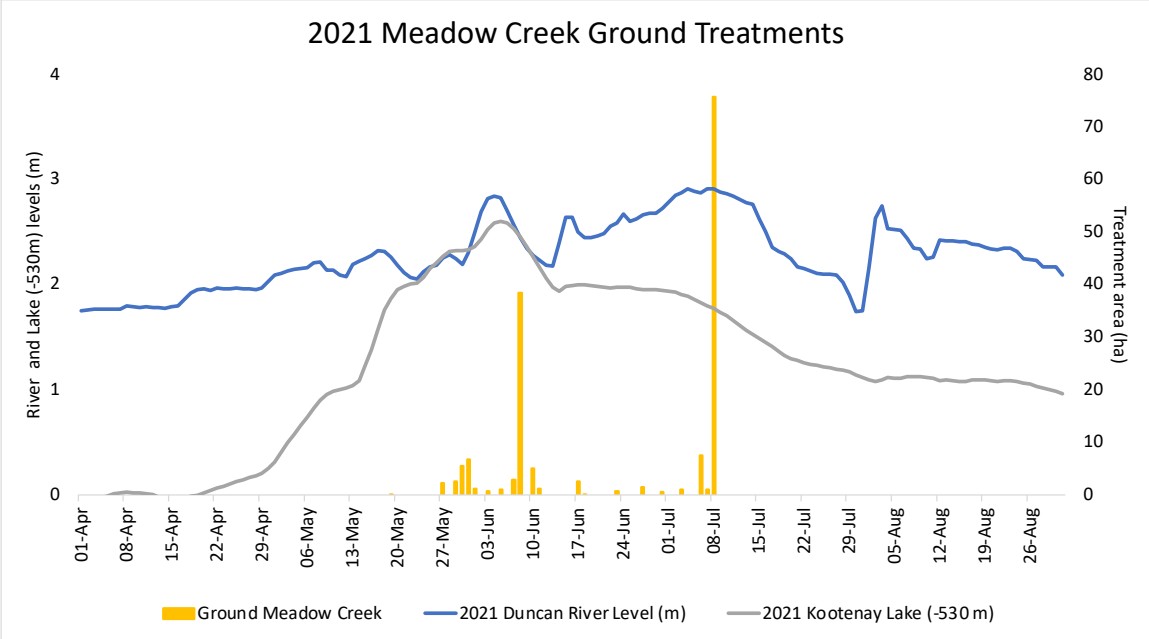

Figure 7. Duncan River levels (m; Below Lardeau gauge) and Kootenay Lake (m; Queens Bay gauge) with total mosquito development area treated by ground (ha) from 1 April – 31 August 2021 for Meadow Creek. Note ground treatments (ha) are recorded on the alternate y-axis.

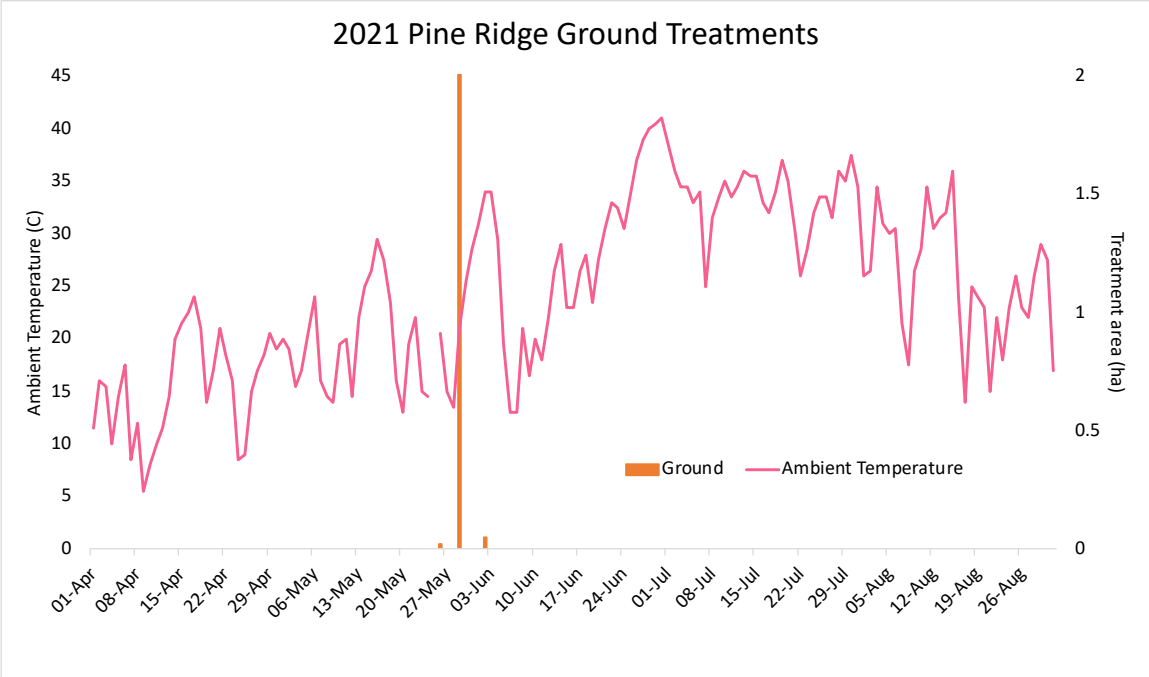

Figure 8. Daily high ambient temperature (C°; Nelson Rixen weather station) with total mosquito development area treated by ground (ha) from 1 April – 31 August 2021 for Pine Ridge. Note ground treatments (ha) are recorded on the alternate y-axis.

Relative to the 2020 season, mosquito habitat was reduced in 2021 due to moderate regional snowpack, leading to moderate Duncan River and Kootenay Lake levels. The peaks in the Duncan River and Kootenay Lake occurred during a period of high ambient temperatures which created ideal mosquito hatching environments. River and Lake levels started to recede in mid-July, although a late-season input of water in early August. Because all regional snow had been depleted and precipitation accumulation was not significant enough to cause water levels to increase as much as they did, it is likely that water was discharged from the Duncan Dam during that period. The late-season input did not cause the Duncan River to exceed the early July peak, however, so no new floodwater sites were activated along the River. The final ground treatment took place on 8 July (Figure 7; Table 1).

Table 1. 2021 treated area (ha) by method (i.e., ground vs. aerial) and month from April – August for Meadow Creek.

	April	May	June	July	August
Ground (ha)	0	17.0	56.1	341.2	0
Aerial (ha)	0	0	445.9	0	0
TOTAL	0	17.0	502.0	341.2	0

Treatments in Pine Ridge are relatively low in comparison to those required in Meadow Creek. The reduction in floodwater mosquito habitat and lower number of snowmelt mosquito development sites creates a reduced need for treatment. This season resulted in a

lower than normal treatment requirement due to the moderate regional snowpack (Table 2). No known sites were missed and no new sites were identified in Pine Ridge, although one new site was identified in Meadow Creek.

Table 2. 2021 treated area (ha) by method (i.e., ground vs. aerial) and month from April – August for Pine Ridge.

	April	May	June	July	August
Ground (ha)	0	2.64	0.05	0	0
Aerial (ha)	0	0	0	0	0
TOTAL	1.8	3.8	0	0	0

Appendix II is a map depicting where and how frequently treatments took place in 2021. In certain cases, hexbins denoted as 'Non-Detected' or 'Low' do have treatments associated with them (Appendix II). In these cases, treatments may have been triggered by the larval activity of a representative site. Typically, sites that are difficult to access may be associated with representative sites. When representative sites become active the other sites in the area have proven to also be active. Thus, sites with a previous designation of 'Non-Detected' or 'Low' may require a later treatment due to representative sites' activity level without the need to sample.

Ground treatments were applied at a rate of 4 kg/ha. In Meadow Creek a total of 158.4 ha was treated by ground, equating to a total of approximately 633.6 kg of Aquabac® used (Table 1). In Pine Ridge a total of 2.7 ha was treated by ground, equating to a total of 10.8 kg Aquabac® used (Table 2). Typically, sites only require one treatment per season unless additional mosquito larvae are pushed into the site due to the movement of water. If additional treatments at a site are required they occur at increased water levels, hence the treatment overlap is minimal.

One aerial campaign was required in 2021. The aerial campaign occurred on 9 June (Figure 9). Another aerial in early July was necessary, but due to the lack of helicopter availability, large-scale ground treatments were conducted instead on 8 July. The June aerial campaign was focused on floodwater sites immediately following the initial peak of the Duncan River and seasonal peak of Kootenay Lake. Only granular Aquabac® was used in 2021 during the aerial campaign. A total of 445.9 ha was treated by air, equating to a total of 1,783.6 kg of granular Aquabac® (Table 1; Figure 9). Efficacy assessments revealed >90 percent control; touch up treatments were conducted by ground around certain sites. No sites were missed in 2021. Appendix III shows more specific information about site, treatment timing, and extent of treatment.

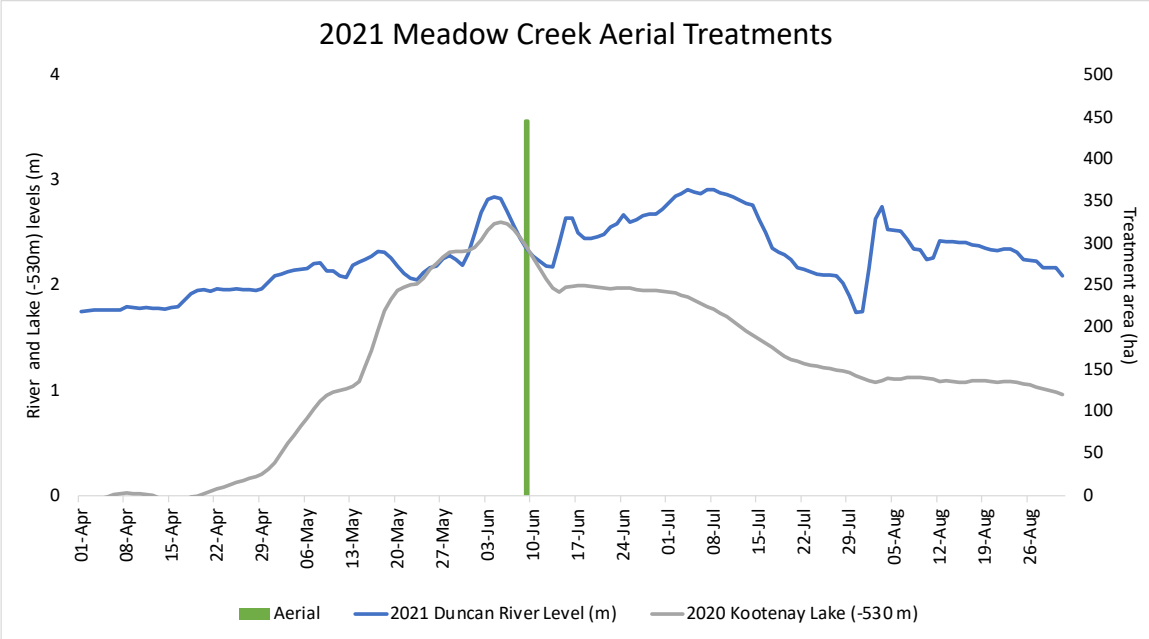

Figure 9. Aerial application events (green lines; ha) with Duncan River levels (blue line; m) and Kootenay Lake levels (grey line; m) from 1 April through 31 August 2021. Note treatment values (ha) are on the alternate y-axis.

Public Relations

Maintaining positive public relations remains a high priority for MBL. Public relations occur on several levels: in-person communication with members of the public, the mosquito hotline, presentations to staff and politicians, responding to e-mails, and continuing our social media presence. MBL continues to look for new areas to expand this aspect of our program and to improve our communication techniques.

Phone Calls and Emails

Meadow Creek and Pine Ridge residents have multiple venues to lodge calls or emails with MBL. MBL has a company-maintained Mosquito Hotline (877-986-3363) and email form, outlined prominently on the contact tab of the MBL website. Additionally, residents may interact with MBL staff through social media platforms. The RDCK has also established and maintains in-house lines for concerned residents, during and after business hours[12].

No calls or emails were received by the RDCK or MBL in 2021. The lack of concern calls and emails was likely due to the moderate-water year, low local precipitation accumulation, and that 2021 peak water levels were lower than those of 2020. When calls and emails are received, they are returned within 24 hours of receipt if contact information is provided. Often, follow-up visits are also made to residents.

[12] https://rdck.ca/EN/main/services/environmental-initiatives/mosquito-control-program.html

Direct Communications

Direct communication between MBL staff and the public can occur in many situations. The most common direct interfacing with the public occurs when technicians are in the field. While conducting site visits, MBL technicians are often asked questions by landowners or residents. These encounters provide an excellent opportunity for public relations. An important outcome of these interactions can be the identification of new sites.

Image 2. MBL education outreach pamphlet.

MBL contact information is disseminated when field technicians have direct communication with the public. Contact information for MBL includes the website address, an email, phone number, and social media sites (Twitter, Facebook). Additionally, MBL staff may provide residents with an outreach pamphlet (Image 2). The pamphlet includes information about the larval control product used, mosquito biology, and personal protective tips.

Social Media

MBL maintains a presence on social media with a Facebook account (facebook.com/MorrowMosquito), Twitter account (@MorrowMosquito), and Instagram account (linked to Facebook) which are regularly updated. There are five goals for MBL's social media presence: 1) provide timely and up-to-date information regarding conditions pertinent to mosquito production, 2) relay MBL's current efforts to control mosquitoes, 3) inform the public about MBL's efforts at environmental sustainability, 4) provide the

community with opportunities to get involved with related public events, and 5) offer a platform for mosquito-related discussion amongst program residents and the MBL team. The number of MBL social media site followers increases annually.

MBL Website

The MBL website (**www.morrowbioscience.com**) was launched in 2015 and redesigned in 2021 (Image 3). This site was developed to allow clients and the public to have access to information about MBL's background, activities, outreach, and company. To further support residents in contract areas, the homepage includes visible tabs for resources and the contact information. The 'Contact' tab allows users to directly send a message to MBL. Additionally, there are links to MBL's Facebook account and Twitter feed, so residents have access to real-time updates on MBL's activities.

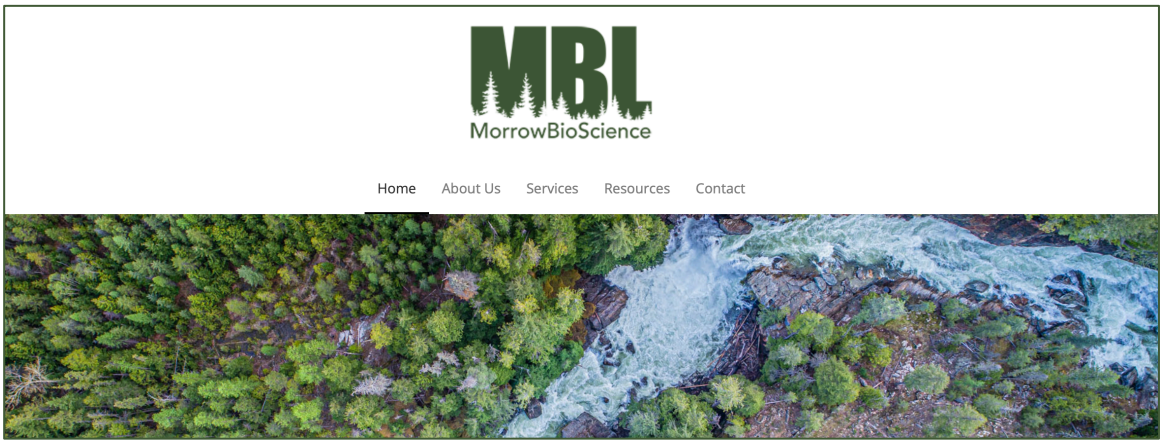

Image 3. Morrow BioScience Ltd. new homepage (www.morrowbioscience.com; April 2021)

Education Outreach

Given the continued provincial restrictions regarding large gatherings to reduce the spread of COVID-19, MBL relied on previously created virtually-available education outreach material instead of attending public events. As such, the MBL website (www.morrowbioscience.com) has highlighted two sets of FAQ documents focused on (1) mosquito biology and disease transmission and (2) the active ingredient used in control efforts (*Bacillus thuringiensis* var. *israelensis*). Both FAQ documents were provided to the RDCK program manager in April. Additionally, a blog dedicated specifically to mosquitoes and COVID-19 was published on the MBL website.

On 13 May, a virtual town hall was organized for Meadow Creek and Pine Ridge residents. MBL staff presented a summary of 2020 mosquito management efforts, challenges, and successes. The presentation also included a discussion about the early-season snowpack and larval mosquito abundance going into the 2021 season. Although attendance was not high, the presentation was well-received. Of note, the majority of residents were from Pine Ridge. Future advertising efforts should possibly target physical notification boards in Meadow Creek, as well as online advertising.

Following approval from the RDCK program manager, a media release was generated and distributed on the local LINKS network and Lardeau Valley Facebook page on 7 June. The media release included an update on general mosquito control activities occurring within the program purview. It also focused on tips to reduce mosquito breeding habitat around private properties and suggestions related to personal protective measures against mosquitoes. No additional interviews were requested in 2021.

West Nile virus Summary

Although floodwater mosquito species in Canada are not the main West Nile virus (WNv) vectors, it is important to remain current in regional mosquito-related diseases. Along with their partners, Health Canada compiles on-going provincially reported surveillance data of WNv cases in humans, animals, and mosquito pools between 1 January and 29 September. As of 12 October, no human case of WNv were reported to Health Canada from British Columbia[13]. Similarly, no horse or bird cases were reported from British Columbia within 2021. Of note, mosquito pool surveillance data are not reported to Health Canada from British Columbia and it is possible that other information was not reported by the BCCDC to Health Canada.

As Washington State and Idaho State share a border with British Columbia, it is important to follow WNv activity in those areas, as well. As of 17 October, there were three human cases of WNv reported in Washington State; all were acquired in-state within counties in the southern area of the state[14]. Additionally, 51 mosquito pools and 11 horses/other mammals tested positive for WNv. No birds tested positive for WNv in 2021. Of note, historically high temperatures experienced throughout the Pacific Northwest from June through August contributed to a greater number of degree days and translated to an increase in state-wide WNv activity.

As of 17 October, 11 human WNv cases were identified in Idaho[15]. Additionally, multiple mosquito pools and animals tested positive for WNv. All cases were identified within counties in the southern and southwestern portion of Idaho.

Zika Virus Summary

No information regarding Canadian Zika cases has been reported by the Public Health Agency of Canada for 2021. HealthLinkBC reports that no Zika cases have originated in Canada due to presumed lack of vector mosquito species[16]. There have been human Zika cases reported in Canada prior to 2021, although those were determined to have been acquired while traveling.

[13] https://www.canada.ca/en/public-health/services/publications/diseases-conditions/west-nile-virus-surveillance/2021/week-37-38-september-13-26.html
[14] http://www.doh.wa.gov/DataandStatisticalReports/DiseasesandChronicConditions/WestNileVirus
[15] https://www.cdc.gov/westnile/statsmaps/preliminarymapsdata2021/index.html
[16] https://www.healthlinkbc.ca/health-feature/zika-virus

According to Peach (2018), the primary Zika mosquito vectors (i.e., *Aedes aegypti*, *Ae. albopictus*) are not found in British Columbia. *Ae. albopictus* has been found on east coast, but tested negative for Zika. There is currently a low risk for Zika virus to circulate within British Columbia.

2022 Program Recommendations

A number of important issues must be addressed at the start of each season:

- Education outreach methods should be expanded to target Pine Ridge and Meadow Creek residents that are not on social media sites. Posting information on the bulletin board in Meadow Creek and the Pennywise might be viable options.

- Notify the Ministry of Environment of the RDCK intent to treat mosquitoes in 2022 under the RDCK Pest Management Plan. Notification should take place 2 months before the start of the season (the end of February at the latest).

- It is important to attach copies of all the mosquito development site maps with the Notice of Intent to Treat (NIT). NOTE: all sites have been re-mapped. This new data should be used to reprint maps for the purposes described above.

References

Becker N, Petric D, Zgomba M, Boase C, Madon MB, Dahl C, Kaiser A. (2010). Mosquitoes and Their Control. Springer-Verlag, Berlin Heidelberg. ISBM 978-3-540-92873-3

Boisvert M, Boisvert J. (2000). Effects of *Bacillus thuringiensis* var. *israelensis* on target and non-target organisms: A review of laboratory and field experiments. *Biocontrol Sci Tech* 10:517-561.

Ciota, A.T., A.C. Matacchiero, A.M. Kilpatrick, L.D. Kramer. (2014). The Effect of Temperature on Life History Traits of *Culex* Mosquitoes. *J Med Entomol*. 51(**1**): 55-62.

Clements, A. (1992). *Biology of Mosquitoes.* CAB International. https://beckassets.blob.core.windows.net/product/readingsample/457488/9783540928737_excerpt_001.pdf

Horsfall, W.R. (1956). Eggs of floodwater mosquitoes III (Diptera, Culicidae). Conditioning and hatching of *Aedes Vexans*. *Ann. Entomol. Soc. Am.* 49(1): 66-71.

Kardatzke, J.T. (1979). Hatching of eggs of snow-melt *Aedes* (Diptera: Culicidae). Ann. Entomol. Soc. Am. 72: 559-562.

Mohammad, A. and Chadee, DD. (2011). Effects of Different Temperature Regimes on the Development of *Aedes aegypti* (L.) (Diptera: Culicidae) Mosquitoes. *Acta Tropica* 119: 38-43.

Read, N.R. and Moon, R.D. (1996). Simulation of Development and Survival of *Aedes vexans* (Diptera: Culicidae) Larvae and Pupae. *Environ. Entomol.* 25(5): 1113-1121.

Trpis, M. and Horsfall, W.R. (1969). Development of *Aedes sticticus* (Meigen)) in Relation to Temperature, Diet, Density, Depth. Annals Zoologici Fennici, 6(2): 156-160.

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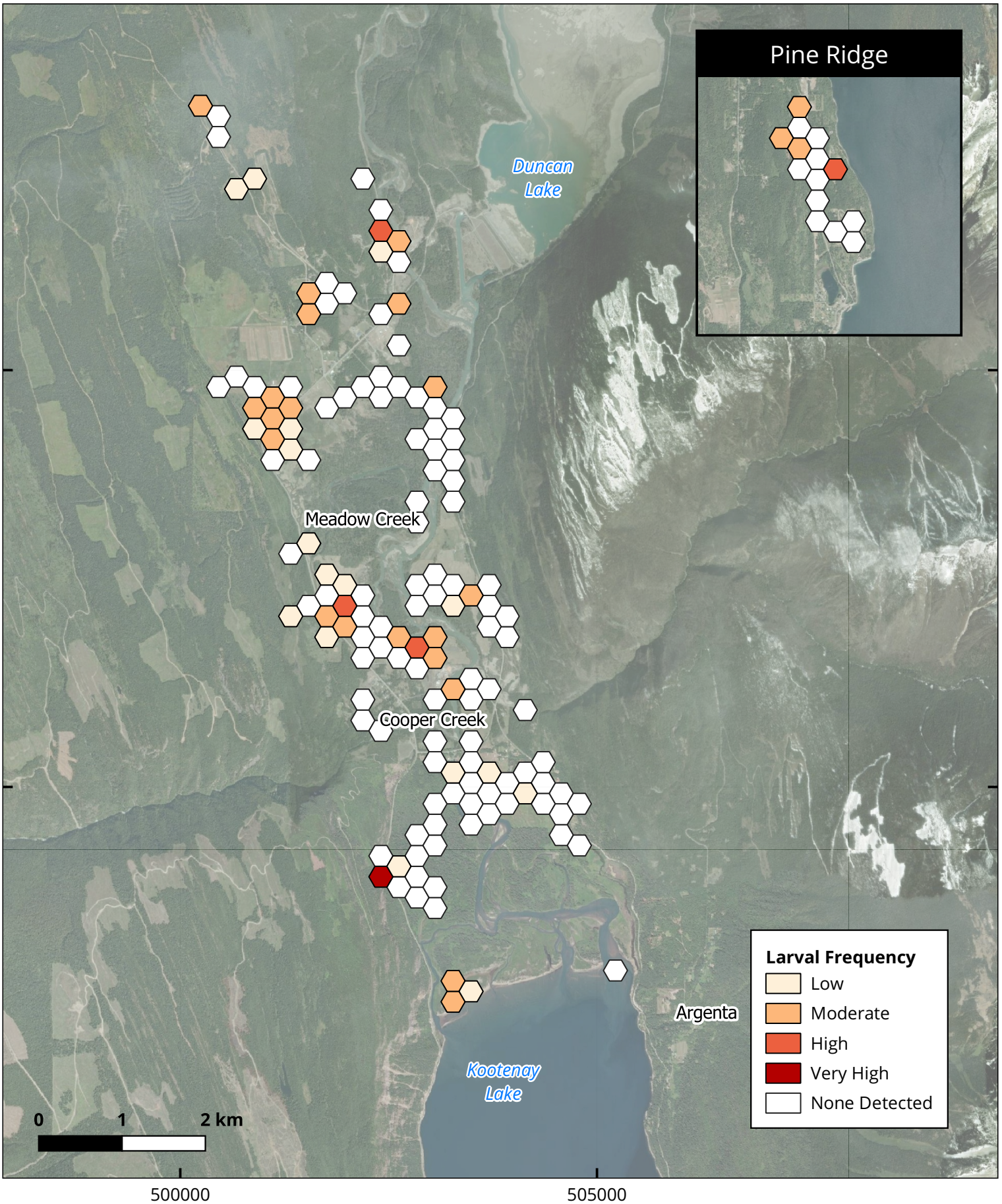
2021 Mosquito Larval Densities at Sample Locations

Appendix I

Morrow BioScience Ltd
PO Box 1013 Rossland, BC V0G 1Y0
gis@morrowbioscience.com 1(877)986-3363

Scale = 1 : 60,000 CRS = NAD83 UTM Zone 11N

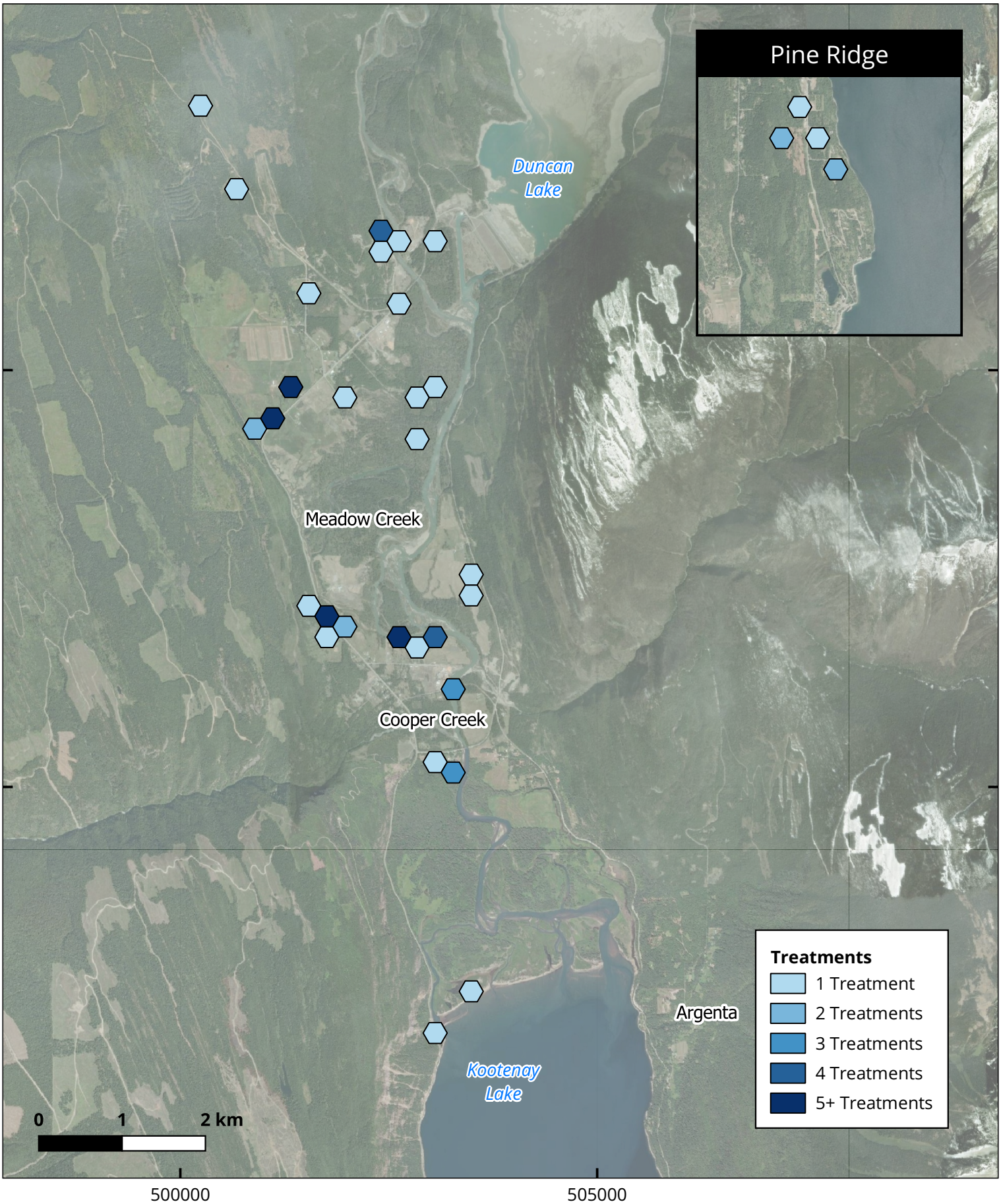


2021 Mosquito Larvicide Treatment Locations

Appendix II

Morrow BioScience Ltd
PO Box 1013 Rossland, BC V0G 1Y0
gis@morrowbioscience.com 1(877)986-3363

Scale = 1 : 60,000 CRS = NAD83 UTM Zone 11N



Appendix III A. 2021 ground treatment data (kg, ha) by day for Meadow Creek and Pine Ridge.

Meadow Creek

Treatment Date	Site Code	Site Name	Amount Treated (Kg)	Area Treated (Ha)
2021-05-19	7	Marblehead 2	0.05	0.01
2021-05-19	6	Marblehead 1	0.05	0.01
2021-05-27	6	Marblehead 1	5.00	1.25
2021-05-27	RDCK-MC-016	Halleran	4.00	1.00
2021-05-29	RDCK-MC-016	Halleran	10.00	2.50
2021-05-30	RDCK-MC-040	End of the lake	22.00	5.50
2021-05-31	RDCK-MC-016	Halleran	0.00	0.00
2021-05-31		Sonja’s channel	0.00	0.00
2021-05-31	RDCK-MC-016	Halleran	22.00	5.50
2021-05-31		Cooper creek rd ditch	0.00	0.00
2021-05-31	RDCK-MC-016	Halleran	0.00	0.00
2021-05-31	RDCK-PR-018		5.00	1.25
2021-06-01	RDCK-MC-012	Gravel Pit	5.00	1.25
2021-06-03	6	Marblehead 1	3.00	0.75
2021-06-05	RDCK-MC-054	Gravel pit	4.00	1.00
2021-06-07	RDCK-MC-007	Hamil Creek Park	4.00	1.00
2021-06-07	RDCK-MC-043	Tracy's	1.00	0.25
2021-06-07		Cooper creek rd ditch	3.00	0.75
2021-06-07	RDCK-MC-030	Fiona's	0.02	0.01
2021-06-07		Sonja’s channel	1.00	0.25
2021-06-07		Cooper creek rd ditch	0.50	0.13
2021-06-07		Cooper creek rd ditch	2.00	0.50
2021-06-07		Cooper creek rd ditch	0.20	0.05
2021-06-08	RDCK-MC-014	Nature Trust	20.00	5.00
2021-06-08	RDCK-MC-031	Wes	10.00	2.50
2021-06-08		Cooper creek rd ditch	4.00	1.00
2021-06-08	RDCK-MC-063	Jacobs slough	50.00	12.50
2021-06-08	7	Marblehead 2	20.00	5.00
2021-06-08	RDCK-MC-016	Halleran	50.00	12.50
2021-06-10	RDCK-MC-031	Wes	20.00	5.00
2021-06-11	6	Marblehead 1	5.00	1.25
2021-06-17	RDCK-MC-051	McKinney	10.00	2.50
2021-06-17	RDCK-MC-030	Fiona's	0.50	0.13
2021-06-18	RDCK-MC-063	Jacobs slough	0.05	0.01
2021-06-23	RDCK-MC-051	McKinney	3.00	0.75
2021-06-27		Sonja’s channel	3.00	0.75
2021-06-27	RDCK-MC-028	Meadow Creek Cedar	3.00	0.75

Treatment Date	Site Code	Site Name	Amount Treated (Kg)	Area Treated (Ha)
2021-06-30	RDCK-MC-030	Fiona's	2.00	0.50
2021-07-03	RDCK-MC-020	River road	4.00	1.00
2021-07-06	RDCK-MC-011	Floods into Trees	3.00	0.75
2021-07-06	RDCK-MC-030	Fiona's	2.00	0.50
2021-07-06	RDCK-MC-030	Fiona's	2.00	0.50
2021-07-06	RDCK-MC-030	Fiona's	2.00	0.50
2021-07-06	RDCK-MC-030	Fiona's	3.00	0.75
2021-07-06	RDCK-MC-008	Hamill Creek Park	5.00	1.25
2021-07-06		Sonja's channel	3.00	0.75
2021-07-06	6	Marblehead 1	5.00	1.25
2021-07-06	RDCK-MC-007	Hamil Creek Park	5.00	1.25
2021-07-07	RDCK-MC-040	End of the lake	4.00	1.00
2021-07-08	5	Mainland	300.00	75.00
2021-07-08	RDCK-MC-028	Meadow Creek Cedar	2.00	0.50
2021-07-08	7	Marblehead 2	1.00	0.25
2021-07-08	RDCK-MC-038	Upper Duncan dam	0.20	0.05

Pine Ridge

Treatment Date	Site Code	Site Name	Amount Treated (Kg)	Area Treated (Ha)
2021-05-26	RDCK-PR-001	Pine Ridge Swamp #2	0.03	0.01
2021-05-26	RDCK-PR-001	Pine Ridge Swamp #2	0.05	0.01
2021-05-29	RDCK-PR-007	Pine Ridge Swamp #1	5.00	1.25
2021-05-29	RDCK-PR-001	Pine Ridge Swamp #2	0.50	0.13
2021-05-29	RDCK-PR-001	Pine Ridge Swamp #2	5.00	1.25
2021-06-02	RDCK-PR-007	Pine Ridge Swamp #1	0.20	0.05

Appendix III B. 2021 aerial treatment data (kg, ha) by day for Meadow Creek.

Treatment Date	Sites Name	Amount Treated (Kg)	Area Treated (Ha)
2021-06-09	Duncan Road, Edwards Road, Head of Kootenay Lake, Lake and River channels, Hydro sites, large wetlands	1783.60	445.90