Executive Summary

Morrow BioScience Ltd. (MBL) has now completed the fifth year of a five-year contract term as mosquito control contractors for the Meadow Creek and Pine Ridge program within the Regional District of Central Kootenay (RDCK). The mosquito control program reduces floodwater and snowmelt mosquito abundance within the program purview. Most control activity takes place along the Duncan River foreshore (below the Lardeau), along the Kootenay Lake foreshore, and at associated seepage sites.

In April, immediately preceding the mosquito monitoring season, the snowpack in the West Kootenay and Upper Columbia basins was higher than normal. The snowpack was augmented in April and May, with cooler-than-average temperatures lending to a freshet delay of 2-4 weeks. In late-May, a strong ridge of high-pressure within contributing basins largely initiated the greatest input of the 2022 freshet. Significant and consistent precipitation in May and June resulted in further amplified Duncan River and Kootenay Lake levels. Both variables contributed to the Duncan River peak on 6 June (3.265 m) and the Kootenay Lake peak on 15 June at 533.885 m. The 2022 Duncan River and Kootenay Lake peaks were the highest since 2018. The Duncan River peak was attenuated by the Duncan Dam. Despite this attenuation, high and sustained Duncan River and Kootenay Lake levels resulted in a compounded number of floodwater mosquito eggs that were triggered to hatch at peak levels. Thus, environmental conditions were optimal for floodwater mosquito development in 2022.

The total mosquito habitat treated by ground was approximately 95 ha. The total floodwater mosquito habitat treated by air was 673 ha (10, 29 June). More aerial treatments took place in 2022 due to extensive and ground-access challenged mosquito development sites at the head of the Kootenay Lake. At all known sites, efficacy was assessed as high. However, high river and lake levels can create micro-sites within debris and seepage areas which are difficult to identify and may have gone untreated. Additional reconnaissance around the confluence of the Duncan River and Kootenay Lake should be conducted in high-water years. Increased program inclusion consent from residents may allow for additional floodwater mosquito development area to be treated. A real-time monitoring and treatment data dashboard was provided to the RDCK program manager. When operational, the dashboard enabled the program manager to view up-to-date treatment information and ensure quality control.

The total concern call and email volume from residents was eight (six calls, two emails), which is a relatively high number for the program area. The timeline for annoyance reports coincides with the adult mosquito dispersal timeline following peak River and Lake levels. In the future, a stronger ground-based treatment program may help alleviate smaller pockets of larval mosquito development in high-water years. Additionally, direct communication with residents may help reduce container mosquito habitats around homes. These direct communications may include a door-knocking campaign to distribute information packets, a mail-out campaign facilitated by the RDCK, a field tour led by MBL biologists for residents to better understand potential mosquito habitat sites, and/or early-season attendance at the Lardeau Valley Sunday Market.

MBL staff were able to participate in a RDCK-facilitated open house pertaining to the mosquito program on 4 May. MBL staff discussed program objectives, a summary of the 2021 season and a projection of the 2022 season. The BCCDC has not reported human cases of West Nile virus or Zika virus yet. West Nile virus data are expected from the province in mid-December and will be provided to the RDCK Program Manager.

Season Highlights

- The 2022 peak Duncan River level at the gauge below the Lardeau occurred on 6 June at 3.265 m.
- The 2022 Duncan River peak was approximately 0.35 m higher than the 2021 peak and 0.37 m higher than the 2020 peak.
- The 2022 peak Kootenay Lake level at the Queens Bay gauge occurred on 15 June at 533.885 m.
- The 2022 Kootenay Lake peak was approximately 1.28 m higher than the 2021 peak and 0.46 m higher than the 2020 peak.
- On 1 April, the snowpack in the West Kootenay Basin and the Upper Columbia Basin were 101 and 115 percent of normal, respectively.
- La Nina weather patterns augmented the snowpack in contributing basins through May.
- The freshet was delayed by 2-4 weeks.
- Local precipitation accumulation for May and June combined was >40 mm above average.
- Peak River and Lake levels exceeded those since 2018.
- A compounded number of mosquito eggs left to hatch, the late freshet, and sustained high water levels led to high larval abundance in 2022.
- Two aerial campaigns were required within the Meadow Creek and Pine Ridge mosquito program purview.
- Floodwater mosquito habitat associated with the Duncan River and Kootenay Lake was aerially treated on 10 and 29 June.
- Total area treated by air was 673 ha (2,694 kg granular Aquabac®)
- Ground treatments at floodwater mosquito development sites in Meadow Creek were applied to 90 ha (361 kg granular Aquabac®)
- Ground treatments at snowmelt and permanent-water mosquito development sites in Pine Ridge were applied to 4.4 ha (17.5 kg).
- A total of 6 concern calls were received to the Mosquito Hotline in 2022.
- A total of 2 concern emails were received by MBL.
- Calls were received from 29 June – 14 July.
- The timeline for annoyance reports coincides with the adult mosquito dispersal timeline following peak River and Lake levels.
- MBL staff presented at the 2022 Town Hall event hosted by the RDCK on 4 May.
- The BCCDC has yet to provide an update on West Nile virus cases in the province, but a report is expected in mid-December. Relatively low levels of WNv activity were reported in Washington State and Idaho State following a cooler-than-normal spring and early summer.

Table of Contents

Executive Summary i
Season Highlights iii
Introduction 6
Carbon Offsets 6
Methodology 6
Environmental Conditions 8
- Snowpack 8
- Local Precipitation 10
- Ambient Temperature 11
  - West Kootenay and Upper Columbia Basin Temperatures 12
  - Local temperatures 12

River and Lake Levels 15
Larval Control 18
- Ground Application Summary 18
- Aerial Application Summary 21

Public Relations 22
- Phone Calls and Emails 23
- Direct Communications 23
- Public Engagement 24
- Education Outreach 25

West Nile virus Summary 26
Zika virus Summary 26
2023 Program Recommendations 27
References 28
Project Contacts at Morrow BioScience Ltd. 28

Cover Image: Multiple floodwater Meadow Creek mosquito development sites (June 2022)

List of Figures

Figure 1. Snow Water Equivalent (SWE; mm) data from the East Creek snow survey (station ID: 2D08P) within the West Kootenay Basin (2021-2022 data represented by green line). 9
Figure 2. Precipitation values (rainfall and snow accumulation; mm) recorded at the Nelson Rixen Creek weather gauge (ID: 114EMDM) for 01 April – 31 August 2022 (blue) and average station precipitation values (2008-2018; green). 11
Figure 3. Maximum daily ambient temperatures (C) as recorded at the Nelson Rixen Weather Station (ID: 114EMDM) 01 April – 31 August 2022. 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. 13
Figure 4. 2022 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. Duncan Dam (DDM – Duncan) average daily discharge (m^3/s) as reported by BCHydro. All data reported from 1 April – 31 August 2022. 16
Figure 5. 2022 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). 17
Figure 6. 2022 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). 17
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 2022 for Meadow Creek. Note ground treatments (ha) are recorded on the alternate y-axis. 19
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 2022 for Pine Ridge. Note ground treatments (ha) are recorded on the alternate y-axis. ..20
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 2022. Note treatment values (ha) are on the alternate y-axis. 22

List of Tables

Table 1. 2022 treated area (ha) by method (i.e., ground vs. aerial) and month from April – August for Meadow Creek. 21
Table 2. 2022 treated area (ha) by method (i.e., ground vs. aerial) and month from April – August for Pine Ridge. 21

List of Appendices (see Attached)

Appendix I. 2022 treatment data (kg, ha) by site and date for all ground (A) and aerial (B) treatments

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 – 2022 – is the final year of the contract.

The considerable mosquito habitat, program reach, 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 2022 was approximately 11,200 km (ground transportation only).

As an estimation, the driving requirements for this program result in the production of approximately 2.54 tonnes of CO_2 emissions. To offset this addition of CO_2 to the environment, MBL has committed to purchasing carbon offsets. In fulfillment of this commitment, carbon offsets are purchased through the Neighbours United – formerly West 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

As large areas of the mosquito control program are within the Duncan River's and Kootenay Lake's floodplains, the primary targets of the Meadow Creek and Pine Ridge mosquito control program are floodwater mosquito larvae. Female floodwater mosquitoes (e.g., *Aedes vexans*, *Ae. sticticus*) deposit their eggs on damp substrate that experiences interannual flooding. Within the program purview, floodwater mosquito development sites

[1] https://neighboursunited.org

primarily exist along the flooding corridor of the Lower Duncan River and Kootenay Lake, including associated seepage sites. When water floods these sites, due to the freshet and/or significant localized precipitation, the result is large-scale floodwater mosquito egg hatching. If more than one season has passed between high-water years, then high river and lake levels may trigger a compounded number of mosquito eggs to hatch, resulting in a compounded number of mosquito larvae. While study results vary, Breeland and Pickard (1967) estimate that *Aedes vexans* eggs can remain viable for up to four (4) years while they await environmental hatching cues.

MBL field technicians began monitoring floodwater mosquito development sites within the program purview prior to consistently increasing regional Duncan River and Kootenay Lake levels. Consequently, the 2022 mosquito-monitoring season started in mid-April as regional temperatures began to slowly increase and the local snow started to show signs of melting. 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 potential accelerated mosquito development rates with rising temperatures (Read and Moon 1996). Hence, as regional river levels, lake levels, and ambient temperatures begin to rise consistently, monitoring efforts increase accordingly.

Image 1. Standard dip (350 ml) with 3rd and 4th instar floodwater mosquito larvae.

Larval mosquitoes in sufficient number (i.e., >4/dip; Image 1) are treated by applications of a microbial larvicide product, Aquabac®. This product has the active ingredient *Bacillus thuringiensis* var. *israelensis* (Bti). In 2022, only the granular formulations of Aquabac® was used, which is carried on a corncob mixture. The mode of action is relatively simple and with a high degree of target species specificity. Receptors within the mid-gut region of the mosquito larvae are compatible with the toxin proteins that are produced alongside each bacterial spore. After the mosquito larvae ingest the toxin protein, disruption of the larval mid-gut cells occurs. This event causes damage to the wall of the gut and quickly leads to larval death (Boisvert and Boisvert 2000).

As the season progresses and more mosquito eggs are triggered to hatch, it becomes increasingly difficult to treat sites in a timely manner by ground due to access challenges and concurrent site activation. At this point, a helicopter is used to

conduct aerial treatments. Aerial treatment campaigns use the same pesticide as ground applications, although typically with a higher application rate to permeate canopy cover.

Treatments are timed to target the 3rd and 4th larval instars. If treatments are applied too early, the larvae will not have reached their highest feeding rate yet and may not ingest the Bti spore. 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 in the ecosystem.

Sites are treated when a standard dip (350ml) collects >4 late instar (3rd or 4th instar) larvae per dip. When flooding commences and ambient temperatures rise, many dips easily exceed this threshold. Larval densities within the range of 200-500 per dip are commonly detected (Image 1). All sites are checked within one or two days of the initial treatment to ensure treatment efficacy. If necessary, touch-up treatments are conducted.

Environmental Conditions

The three primary environmental conditions that affect Duncan River and Kootenay 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 Duncan River and Kootenay 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 immediately prior to the springtime snowmelt, 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.

On April 1, immediately preceding the 2022 Meadow Creek and Pine Ridge mosquito monitoring season, the snowpack within the West Kootenay Basin and Upper Columbia Basin was 101 and 115 percent of normal, respectively[2]. The greater-than-normal snowpack was likely a result of the impacts of the La Nina weather pattern that was in place during the spring of 2022. As is consistent with La Nina weather patterns in British Columbia, unstable weather within influential basins throughout April and most of May resulted in considerable snowpack augmentation through the spring. Throughout most of the province, unstable conditions coincided with cooler-than-average ambient temperatures across the province in April and the majority of May, which led to a delayed freshet. A

[2] https://www2.gov.bc.ca/assets/gov/environment/air-land-water/water/river-forecast/2022.pdf

short-lived ridge of high pressure in early May resulted in the initial pulse of the freshet in most provincial rivers. Subsequent weather patterns slowed the freshet and further augmented snowpack until late-May.

Snow survey stations throughout the West Kootenay Basin and Upper Columbia Basin provide a more refined perspective of regional snowmelt trends. The East Creek snow survey station (ID: 2D08P) reflects weather trends in the West Kootenay Basin and serves as a representative site for the regional snowmelt trajectory of high-elevation snowpack (2,030 m; Figure 1). Notably, snowpack increased through April. Low and some middle elevation snowpack melted in early-May. This point of regional low-elevation snowpack reduction is reflected in the spike in Duncan River levels. Snowpack augmentation at the East Creek snow survey station continued through late-May (Figure 1). The trend in visible snowpack reduction started in late-May, approximately 3 weeks later than normal (Figure 1). Warmer weather in the first half of June resulted in the consistent depletion of most middle and high elevation snowpack in the East Creek snow survey station[3]. This trend is consistent with other high elevation snow survey station data throughout the influential basins.

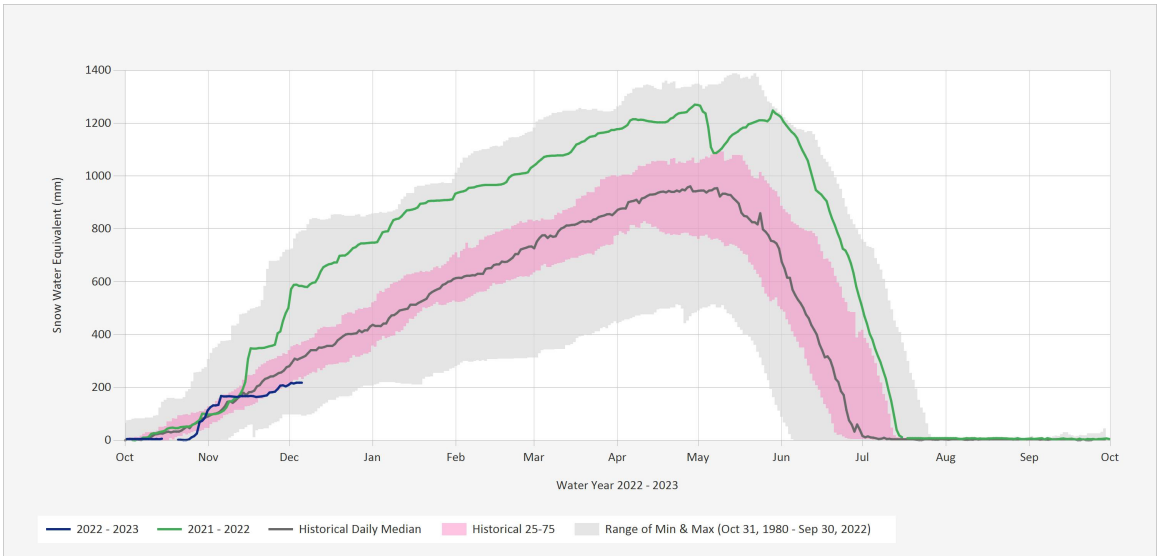

Figure 1. Snow Water Equivalent (SWE; mm) data from the East Creek snow survey (station ID: 2D08P) within the West Kootenay Basin (2021-2022 data represented by green line).

In normal years, by 15 June most of the snowpack has melted within Duncan River and Kootenay Lake-associated basins. However, despite warming ambient temperatures in those basins during early June, snowpack was still relatively high through mid-June. The 15 June snow basin indices for the West Kootenay and Upper Columbia basins were 215 and 212 percent of normal, respectively[4]. These relatively high values reflect the abnormality of snow remaining in those basins in mid-June. Warming ambient temperatures within influential snow basins continued through June and July, lending to the depletion of snowpack by mid-July.

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

Generally, the snowpack remained within the West Kootenay and Upper Columbia basins for approximately 2-3 weeks longer than normal. The late-season input of water to the Duncan River and Kootenay Lake impacted the length and intensity of the mosquito control season within Meadow Creek and Pine Ridge. The 2022 Duncan River freshet was set apart in two ways: 1) the greater than average snowpack within associated basins and 2) the prolonged snowmelt. Both features led to higher-than-normal and sustained Duncan River levels through late-July, when increased mosquito egg hatching cues were more abundant within the program purview. Of note, this sustained high water level occurred despite Duncan Dam attenuation, although the natural peak of the Duncan River would've been considerably higher in mid-June without the attenuation.

Local Precipitation

Substantial temporally and spatially concentrated precipitation accumulation may elevate Duncan River levels and increase seepage site levels. Tracking local precipitation accumulation can aid MBL field staff in determining how long mosquito development 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 created, be higher or sustained for longer. All scenarios may lead to additional floodwater mosquito egg hatches.

Precipitation received to the Nelson Rixen Creek weather station in April was lower-than-average (Figure 2). It is unlikely that local precipitation impacted target mosquito development in April due to a relatively low input and the lack of additional hatching cues. Local precipitation in May and in June was higher-than-average in 2022. The high precipitation values noted in May and June are consistent with the low-pressure systems typical of La Nina weather patterns in the southern part of the province. Together, the precipitation received in May and June was approximately 40 mm higher than the average sum of the two months. Given that a considerable amount of precipitation was received during the Duncan River freshet, it is likely that precipitation augmented river levels above those that would have been observed due to the freshet alone.

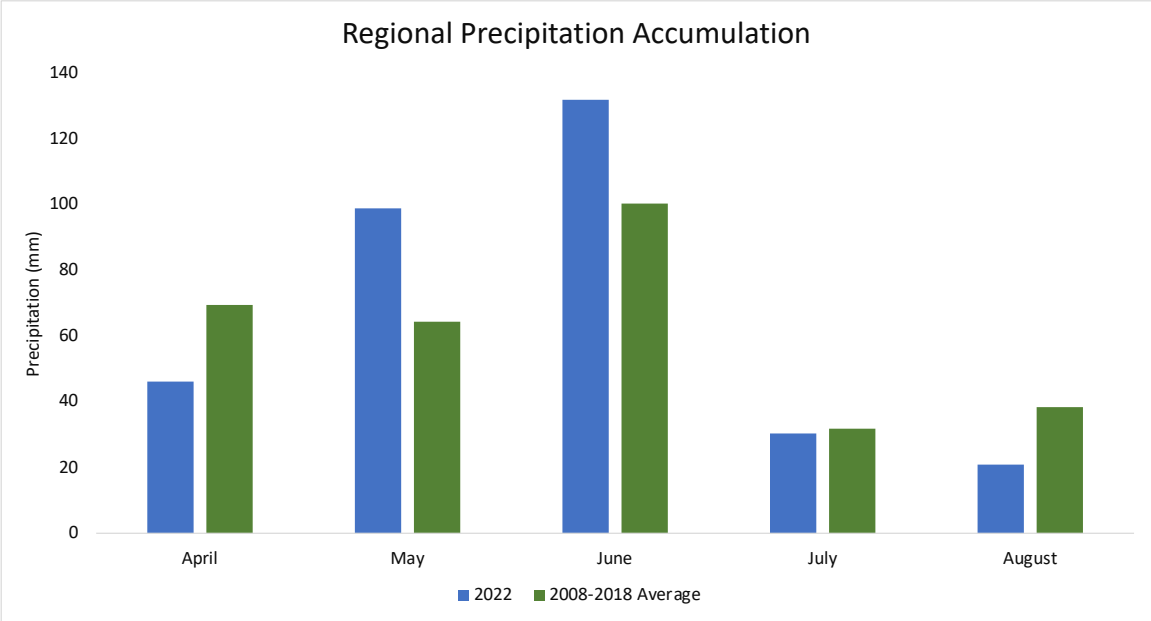

Figure 2. Precipitation values (rainfall and snow accumulation; mm) recorded at the Nelson Rixen Creek weather gauge (ID: 114EMDM) for 01 April – 31 August 2022 (blue) and average station precipitation values (2008-2018; green).

Relatively little precipitation accumulated in July at the Nelson Rixen Creek weather station (Figure 2). The recorded amount of precipitation in July 2022 was only slightly lower than the station's July average. However, a measurable rain event occurred over 3 and 4 July which likely sustained seepage sites associated with the Duncan River and Kootenay Lake beyond normal.

August precipitation was also lower than average (Figure 2). Thus, it is unlikely that precipitation received to the region in the latter half of July through August augmented mosquito development sites. Of note, precipitation received in August was of little consequence to the Duncan River and Kootenay Lake levels and associated mosquito development sites. At that point in the season the univoltine floodwater mosquito species had already hatched. However, it's possible that precipitation received in July and August created habitat for container mosquito species to reproduce. Thus, adult mosquito presence toward the end of the season was likely due to mosquito development from these sites, not floodwater mosquito species in certain areas.

Ambient Temperature

Local ambient temperature and ambient temperature within the Duncan River-associated basins are important variables to track. Local ambient temperature fluctuations from April through August can affect mosquito egg hatching, larval development rates, adult dispersal, and adult survival within Meadow Creek and Pine Ridge mosquito development habitat. Within contributing snow basins, ambient temperature dictates the commencement and often the intensity of the freshet, which directly impacts floodwater mosquito development habitat.

West Kootenay and Upper Columbia Basin Temperatures

The 2022 mosquito monitoring season began in April with below-average ambient temperatures within most basins contributing to the Duncan River. The weather in April was unstable across much of the province [4], with ambient temperatures ranging from 4.5°C - 1.5°C below average. Similarly, ambient temperatures across the province in May were 3°C – 0.5°C below average[5].

Although two short-lived, high-pressure systems occurred in early May and toward the end of May, temperatures remained relatively low and didn't result in the normal extent of snowmelt. The first significant spike in ambient temperature occurred in late-May[6]. The spike caused low and some middle-elevation snowmelt within the Duncan River watershed and the consistent rise of the Duncan River and Kootenay Lake levels. Following the brief spike in ambient temperature, the weather within contributing basins returned to an unstable state for most of June. However, the fluctuating ambient temperatures were sufficient to lead to the slow release of remaining middle-elevation snowmelt, which resulted in the 2022 peak for both the Duncan River and Kootenay Lake on 6 and 15 June, respectively.

A strong high-pressure ridge was in place over most of the province during the last week of June. This warming stint led to the depletion of high-elevation snowpack within the basins affecting the Duncan River. Ambient temperatures continued to rise through July and August. However, after the depletion of the Duncan River-associated snowpack, ambient temperatures within those basins does not typically impact floodwater mosquito habitat within the program purview. Ambient temperature data are consistent with 2022 automated snow station data depicting snowmelt points correlating with regional ambient temperature spikes[7].

Local temperatures

Local ambient temperature is a predictive tool when gauging floodwater egg hatch commencement. If the ground proximate to the Duncan River and 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). Local ambient temperature data are acquired from the Nelson Rixen Creek weather station (ID: 114EMDM).

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

[4] https://www2.gov.bc.ca/assets/gov/environment/air-land-water/water/river-forecast/2022_may1.pdf
[5] https://www2.gov.bc.ca/assets/gov/environment/air-land-water/water/river-forecast/2022_june1.pdf
[6] https://www2.gov.bc.ca/assets/gov/environment/air-land-water/water/river-forecast/2022_june15.pdf
[7] 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

temperature, of the five temperatures tested, for hatching and larval development (Figure 3). While *Ae. sticticus* is not the sole floodwater species present in the Meadow Creek and Pine Ridge areas, it serves as a representative species for our purposes and provides general developmental benchmarks.

Local ambient temperature also impacts snowmelt mosquitoes. 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.

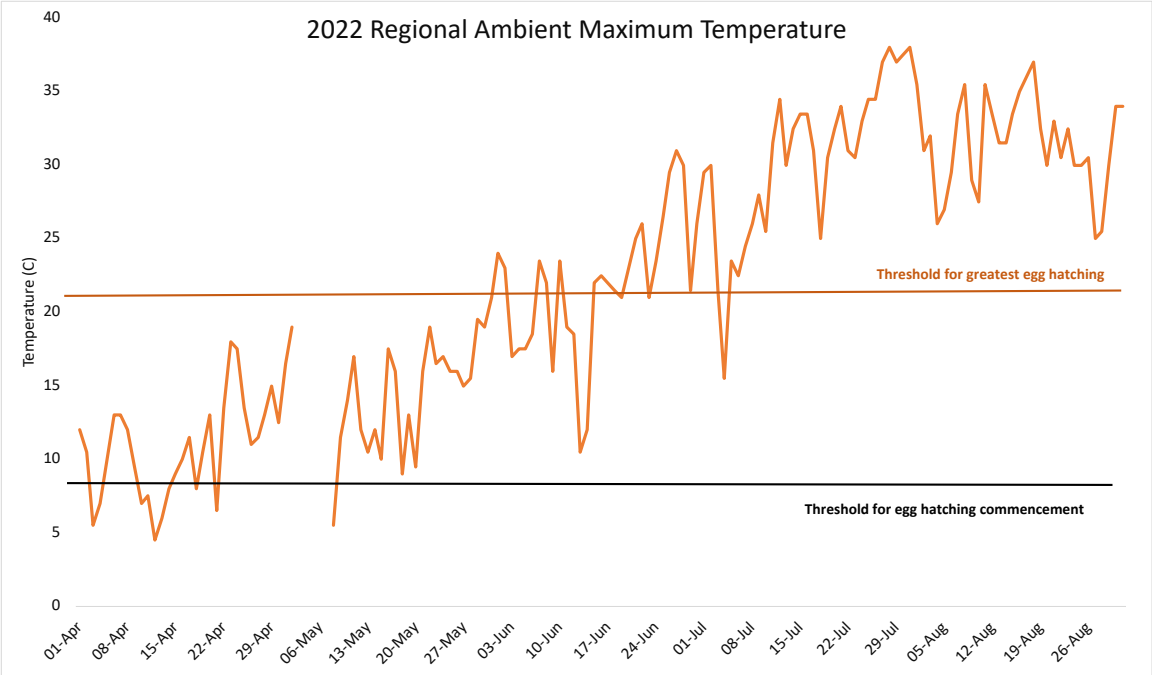

Figure 3. Maximum daily ambient temperatures (C) as recorded at the Nelson Rixen Weather Station (ID: 114EMDM) 01 April – 31 August 2022. Lower black line illustrates threshold at which *Ae. sticticus* eggs can commence hatching; upper orange line illustrates threshold at which most *Ae. sticticus* eggs hatch.

Within the program purview the 2022 season began with lower-than-average ambient temperatures for April. The monthly average for April (10.7 °C) was 3.1°C lower than the historical station average for April (i.e., 13.8°C). Given that April temperatures frequently dropped below the lower temperature bound for successful floodwater mosquito egg hatching, floodwater mosquito eggs within the program purview were not likely triggered to hatch within April if exposed to flooding conditions (Figure 3). If mosquito eggs were exposed to water during this month, the larval development at cooler temperatures would have been slow and survivorship likely low (Trpis and Horsfall 1969).

Local ambient temperatures in May were relatively warmer and within the temperature range for favorable larval development conditions for target mosquito species (Figure 3). The average maximum daily temperature for May was 14.8°C, approximately 6°C lower than the historical station average. Mosquito egg hatching and larval development rates increased within May, although larval development was still notably slower than normal for that point in the season. Appropriately, larval mosquito treatments increased in mid-May as local ambient temperatures approached the upper bounds of temperatures associated with higher floodwater mosquito hatching success rates (Figure 3).

Ambient temperatures in June were higher than May temperatures and provided sufficient hatching cues for all floodwater mosquito eggs exposed to water. Ambient temperatures in early-June were closer to normal, followed by a cooler weather system in mid-June. Although local ambient temperatures cooled in mid-June, other environmental conditions combined with fair temperature cues allowed for large-scale mosquito hatching events. A stint of warm weather occurred in late June and into early July, which contributed additional strong mosquito hatching cues. This stint of warm weather also corresponded with high Duncan River and Kootenay Lake levels. When river and lake levels are high during periods of higher heat, the result is large-scale mosquito egg hatching events and increased larval development rates. Therefore, because considerable floodwater development sites were still high in late-June and early July, the need to treat mosquito larvae during those times was directly associated with ambient temperature.

As predicted by the Temperature and Precipitation Probabilistic Forecasts for Canada, July and August ambient temperatures were higher than average. Local daily maximum ambient temperatures were 2°C and 3°C above normal for July and August, respectively. Because the freshet was delayed by 2-4 weeks, there was still considerable floodwater mosquito habitat and activity through July. Warming weather coupled with sufficient habitat farther into the summer meant that floodwater mosquito treatments were required for longer than normal in 2022. High ambient temperatures, such as those noted in later July and August, increase the lifecycle of adult mosquitoes (Ciota et al. 2014). Thus, any mosquitoes that successfully emerged would have had a reduced lifespan with the heightened ambient temperatures into late August (Figure 3).

While not a target of the Meadow Creek and Pine Ridge mosquito control program, container mosquito abundance typically increases in July and August. Container mosquito habitats near residential homes can be created throughout warmer summer months whenever is allowed to collect somewhere and is accompanied by high ambient temperatures. MBL technicians regularly inform residents that container-bred mosquitoes can be reduced around homes by ensuring that conducive environments (i.e., bird baths, kiddy pools, flowerpot holders, etc.) 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 early-May due to the first small pulse of the freshet from the West Kootenay Basin and, to a lesser extent, from the Upper Columbia Basin. Snowpack augmentation occurred until late-May, resulting in low input to the regional River and Lake systems. However, a spike in ambient temperature in late-May coupled with significant regional precipitation occurred in May and June resulted in high Duncan River and Kootenay Lake levels beginning in late-May. The continued provincial warming trend into early-June led to the Duncan River peak on 6 June (3.265 m) and the Kootenay Lake peak on 15 June at 533.885 m (Figure 4). Of note, it is likely that the Duncan Dam attenuated Duncan River water such that the noted River peak was artificially low. The Duncan Dam did not release any water from 11 June – 13 July (Figure 4).

The West Kootenay Basin and Upper Columbia Basin snowpack was depleted over a month later than the noted peaks of both the Duncan River and Kootenay Lake. Thus, the continual input from the regional snowmelt was contributing to relatively high-water levels after the peaks, sustaining those water levels for longer than normal. High regional precipitation through 4 July also prolonged floodwater mosquito development site occurrence and may have expanded seepage sites. The Duncan Dam released a considerable amount of water beginning on 13 July, with fluctuating releases occurring through August. These pulses of water to the Duncan River also led to extended high-water of the Duncan River through August.

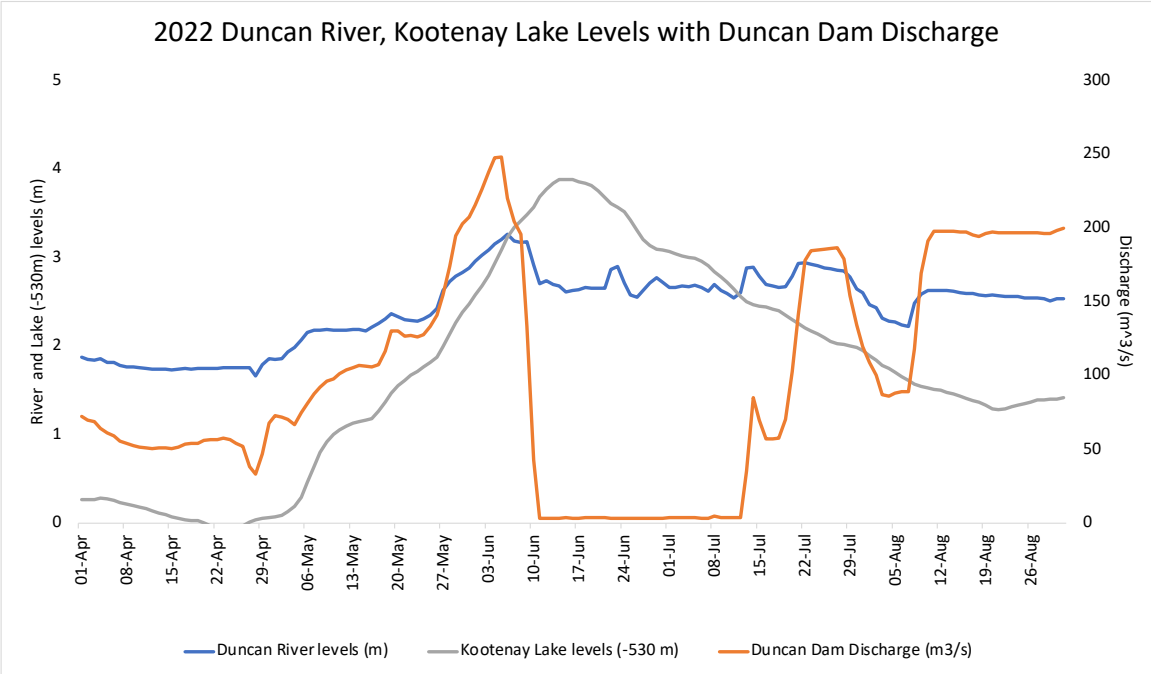

Figure 4. 2022 water levels (m) as recorded for the Duncan River (Below Lardeau gauge, 08NH118; Blue) and Kootenay Lake (Queens Bay gauge, 08NH064; grey). Note that 530 is subtracted from Kootenay Lake levels for ease of trend comparison. Duncan Dam (DDM – Duncan) average daily discharge (m^3/s) as reported by BCHydro. All data reported from 1 April – 31 August 2022.

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 the preceding season, 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 2020. Figure 6 shows Kootenay Lake levels since 2020. The 2022 season was considered a high-water year. The 2022 peak of the local Duncan River was 0.35 m higher than the 2021 peak and 0.37 m higher than the 2020 peak (Figure 5). Similarly, the 2022 peak of the local Kootenay Lake was approximately 1.28 m higher than the 2021 peak and 0.46 m higher than the 2020 peak (Figure 6). Duncan River and Kootenay Lake peaks had not been as high since 2018. Given the relative peak water levels between 2020, 2021, and 2022 it is likely that the 2022 peak Duncan River and Kootenay Lake levels triggered dormant eggs to hatch. As such, a higher-than-average larval abundance was noted in 2022.

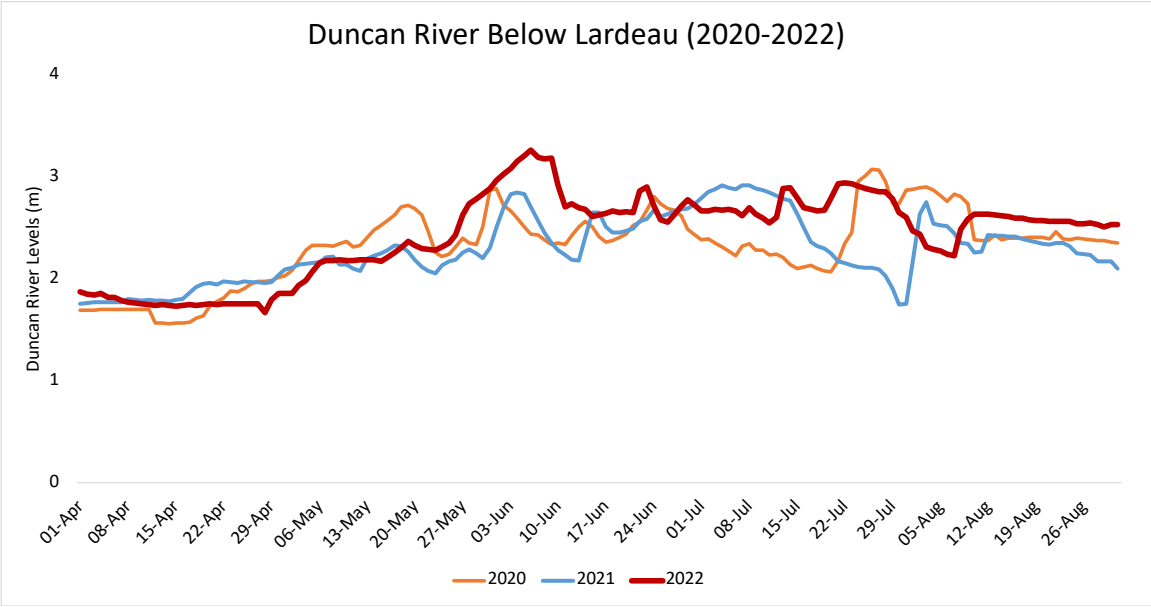

Figure 5. 2022 river levels (m) as recorded at the Duncan River (Below Lardeau gauge, 08NH118; red) with recent River levels, as reported by the River Forecast Centre (01 April – 31 August).

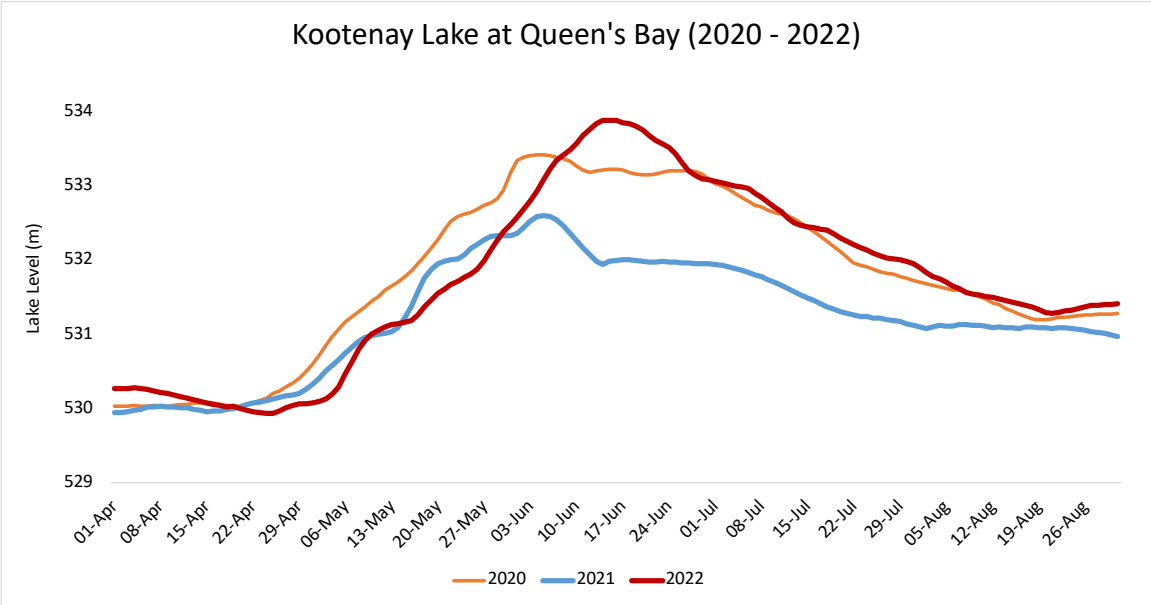

Figure 6. 2022 Kootenay Lake levels (m) as recorded at Queens Bay gauge (08NH064; red) with recent Lake levels, as reported by the River Forecast Centre (01 April – 31 August).

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.

By mid-July 2022, the West Kootenay Basin and Upper Columbia Basin were largely depleted of snow[8]. This depletion corresponds with a slow decline in the Kootenay Lake water levels into mid-August (Figures 4, 6). Duncan River levels decreased slowly into August following the continuous discharge from the Duncan Dam (Figures 4, 5).

Larval Control

Monitoring within the Meadow Creek and Pine Ridge program began in mid-April, primarily at snowmelt sites in Pine Ridge. Floodwater sites were monitored beginning approximately a week later than snowmelt sites. Although most of the floodwater mosquito development sites are not active until the Duncan River (below Lardeau) levels and Kootenay Lake levels exceed winter levels, sites were monitored beginning in April to evaluate site conditions and catch the leading edge of any potential hatching events that resulted from the considerable precipitation received in April. The relatively warmer ambient temperatures coincided with increased monitoring and larval mosquito treatments in mid-May.

Unfortunately, the real-time data collection platform used by MBL was not working correctly for this program until July. This challenge and other technological issues led to relatively few electronic data records being collected. Hand-written records were kept and are included in Appendix I. The areas with highest recorded larval abundance and associated treatment needs sites are located along the Duncan River, Meadow Creek, and Marblehead areas.

Higher and sustained Duncan River and Kootenay Lake levels resulted in the need for more treatments in 2022. A total of approximately 768 ha (3,072 kg) were treated within the Meadow Creek and Pine Ridge mosquito control program in 2022. For comparison, MBL has treated approximately 100 fewer hectares in 2022 than in 2021. No known sites were missed in ground-based or aerial treatment efforts although it is possible that there is unidentified floodwater mosquito habitat in high-water years at the head of the lake. Additional reconnaissance at the head of Kootenay Lake and ground-based treatments should occur in future high-water years.

Ground Application Summary

Floodwater mosquito development sites within Meadow Creek and Pine Ridge are visited on a weekly basis unless conditions required more frequent monitoring (i.e., peak Duncan River and Kootenay Lake levels, ambient temperatures > 20°C, large precipitation event). Sites are treated when a standard dip (350ml) collects 5 or more late instar (3rd or 4th instar) larvae per dip. All sites are checked within two days of the initial treatment to ensure high treatment efficacy. If necessary, touch-up treatments are conducted.

The first snowmelt mosquito development site was treated in Meadow Creek by ground on 5 May (Figure 7). Snowmelt development site treatments were clustered between 5 – 13.

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

Floodwater mosquito habitat required treatment beginning on 24 May. Floodwater sites were treated in response to consistently increasing Kootenay Lake and Duncan River levels. Due to the prolonged high-water state in 2022, smaller scale treatments continued until 25 July (Figures 7). Ground treatments in Pine Ridge took place between 15 and 31 May (Figure 8). Ground treatments in Pine Ridge were more associated with the ambient temperatures creating snowmelt mosquito habitats in mid-May and at permanent water mosquito development sites in late-May. All known sites were wet this season.

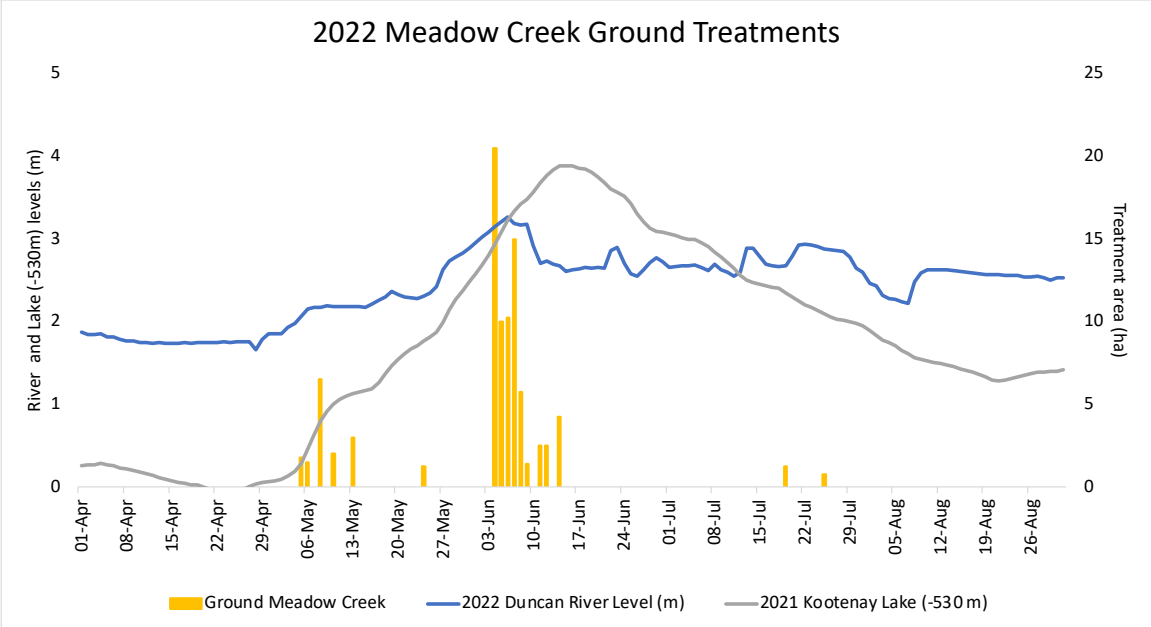

Figure 7. Duncan River levels (m; Below Lardeau gauge) and Kootenay Lake (m; Queens Bay gauge) with total mosquito development area treated by ground (ha) from 1 April – 31 August 2022 for Meadow Creek. Note ground treatments (ha) are recorded on the alternate y-axis.

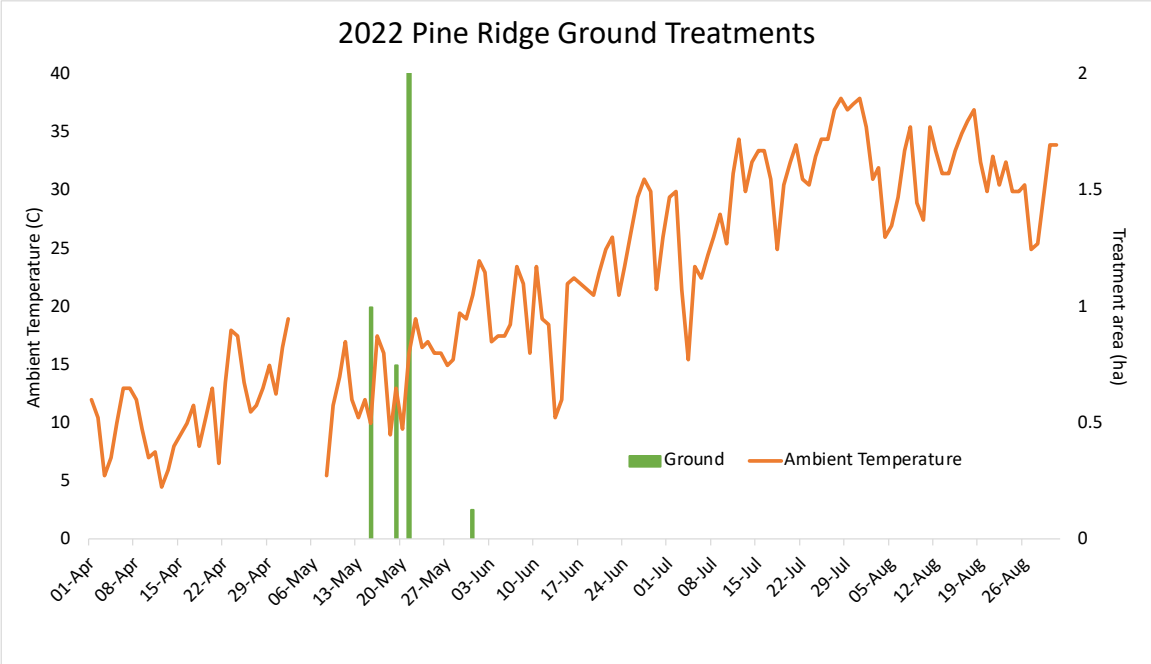

Figure 8. Daily high ambient temperature (C°; Nelson Rixen weather station) with total mosquito development area treated by ground (ha) from 1 April – 31 August 2022 for Pine Ridge. Note ground treatments (ha) are recorded on the alternate y-axis.

Aquabac® (a.i., *Bacillus thuringiensis* var. *israelensis* (BTI)) is the product used for all larval mosquito treatments conducted by MBL. Bti has high target specificity and achieves 95% - 100% efficacy in typical field conditions (Aquabac® Mosquito Biolarvicide - Technical Bulletin). Within the Meadow Creek and Pine Ridge's highly organic water conditions at floodwater sites, MBL staff note an average field efficacy rate of approximately 85%-90%. The granular formulation was used in 2022. Certain sites in the Meadow Creek and Pine Ridge require a ground application rate of 6 kg/ha, although the majority require 4 kg/ha.

The total area treated by ground in Meadow Creek was approximately 90.1 ha (360.5 kg) and the total area treated in Pine Ridge was approximately 4.3 ha (17.5 kg) (Tables 1, 2). For a high-water year, this total is relatively low. Numerous properties have opted out of the mosquito control program. This means that fewer areas are available to treat and the untreated areas may result in increased adult floodwater mosquito production. A lower ground-based treatment total in Meadow Creek is also due to the high and sustained Duncan River and Kootenay Lake levels making ground-based site access more challenging. If sites are inaccessible by ground, they are included in aerial treatment campaigns. Real-time data associated with each treatment are available through MBL's client-registered, real-time program portal.

Table 1. 2022 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	16.0	72.1	2.0	0
Aerial (ha)	0	0	673.4	0	0
TOTAL	0	16.0	745.5	2.0	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 an average treatment requirement; Pine Ridge treatments in most years amount to approximately 4 ha (Table 2). No known sites were missed and no new sites were identified in Pine Ridge.

Table 2. 2022 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	4.4	0	0	0
Aerial (ha)	0	0	0	0	0
TOTAL	0	4.4	0	0	0

Aerial Application Summary

Floodwater mosquito development sites are treated by air when multiple large-scale sites become active at once and/or when site-access by ground is unsafe. Two aerial campaigns were required within the Meadow Creek area in 2022. Treatments took place on 10 and 29 June (Figure 9). For comparison, one aerial campaign was conducted in 2021. The difference in required aerial treatment events signifies the relatively higher abundance of floodwater mosquito larvae within the region in 2022. The high mosquito larval abundance was due to a compounded mosquito eggs abundance triggered to hatch with high, sustained Duncan River and Kootenay Lake levels.

Aerial treatments were conducted using granular Aquabac®. Aerial treatments were applied at an average rate of approximately 4 kg/ha. A total of 673 ha was treated by air, equating to a total of approximately 2,694 kg of Aquabac® used. The total area treated in 2022 was approximately 230 ha more than that treated in 2021. Figure 9 shows the aerial treatment events (green) along with Duncan River and Kootenay Lake levels, as aerial treatment events primarily target floodwater habitat.

Aerial treatment events ideally take place immediately after the Duncan River and Kootenay Lake have peaked because the Bti is able to reach mosquito larvae before they disperse with rising water. As it is difficult to determine exactly when the peak will occur, aerial treatments often bookend a peak. Additionally, when the Duncan River and Kootenay Lake are sustained at high water levels, more floodwater mosquito eggs may have time and abundant environmental cues to hatch. Aerial treatments took place immediately following the Duncan River peak and prior to the Kootenay Lake peak (10 June) and following the Kootenay Lake peak (29 June; Figure 9). MBL staff were able to accompany the helicopter pilot again in 2022, which aids in identification and treatment of inconspicuous mosquito development areas. However, high river levels can create micro-sites within debris and seepage areas which are difficult to identify and may have gone untreated. Treatments successfully controlled targeted floodwater mosquito larvae at all known locations. Appendix I shows more specific information about site, treatment timing, and extent of treatment.

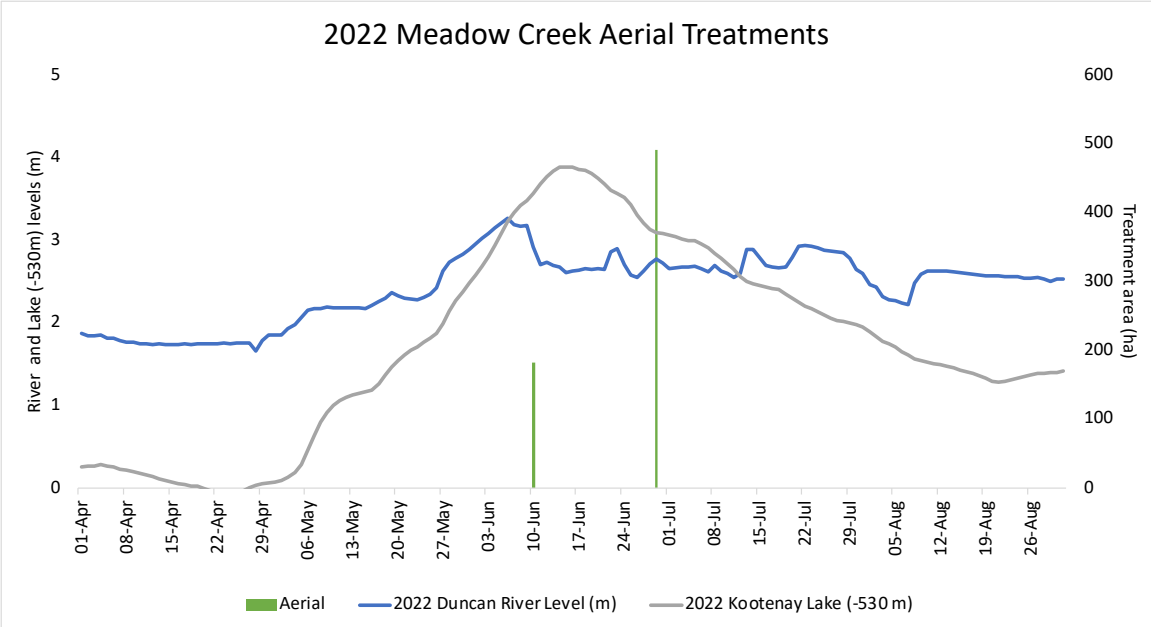

Figure 9. Aerial application events (green lines; ha) with Duncan River levels (blue line; m) and Kootenay Lake levels (grey line; m) from 1 April through 31 August 2022. Note treatment values (ha) are on the alternate y-axis.

Public Relations

Maintaining positive public relations continues to be a high priority for MBL. Public relations occur on several levels: in-person communication with members of the public, the mosquito hotline, presentations to stake holders, email correspondence, and social media presence. MBL continues to look for new areas to expand this aspect of our program.

Phone Calls and Emails

Meadow Creek and Pine Ridge residents have multiple venues to communicate with MBL. MBL's Mosquito Hotline (877-986-3363) and email form are outlined prominently on the contact tab of the MBL website (www.morrowbioscience.com). Additionally, the RDCK has developed a web page devoted to mosquito control updates and providing RDCK-based contact information[9]. All calls and emails received from the RDCK are forwarded to MBL staff for follow-up. Residents may also voice concern with MBL staff through social media platforms.

A total of seven (7) calls and two (2) annoyance-based emails were received to the Mosquito Hotline/MBL email contact form from the Meadow Creek and Pine Ridge areas in 2022. Of those, one call received in April was classified as an inquiry-based call; the resident was requesting information about the 2022 plan for mosquito control. All other calls and emails were classified as concern-based and received from 29 June – 14 July. Residential concerns noted high presence of adult mosquitoes. The timeline for annoyance reports coincides with the adult mosquito dispersal timeline following peak River and Lake levels. Additional reconnaissance was conducted at certain properties to assess potential new mosquito development habitat based on residential input, but no new sites were found. All calls and emails were returned within 24 hours of receipt if contact information was provided.

The total number of calls and emails received in 2022 was high for the Meadow Creek and Pine Ridge program. The high number of concern calls and emails is due to the compounded number of mosquito eggs that hatched in 2022 from high and sustained Duncan River and Kootenay Lake levels in the warmer part of the season. In the early portion of the season, it typically takes 2-3 weeks for mosquitoes to emerge and disperse following hatching events associated with peak river levels. When rivers rise at slow rates in the warmer part of the season, as occurred beginning in late-May this year, mosquitoes may emerge and disperse prior to peak levels. Thus, the potential timeline for mosquito emergence and dispersal in 2022 likely ranged from early-June through late-July. Accordingly, hotline calls and emails were concentrated between late-June and mid-July.

MBL remains committed to continuing reconnaissance efforts to identify floodwater mosquito development sites, adaptive site management, and expanding in-house knowledge of sites. Expanding public engagement reach may also result in the identification of new sites and reduction of mosquito larvae in the region. Through these efforts, MBL aims to further reduce adult mosquito nuisance within the Meadow Creek and Pine Ridge mosquito control program purview.

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 residents. These encounters provide an excellent opportunity for public relations. An important outcome of these interactions can be the identification of new sites.

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

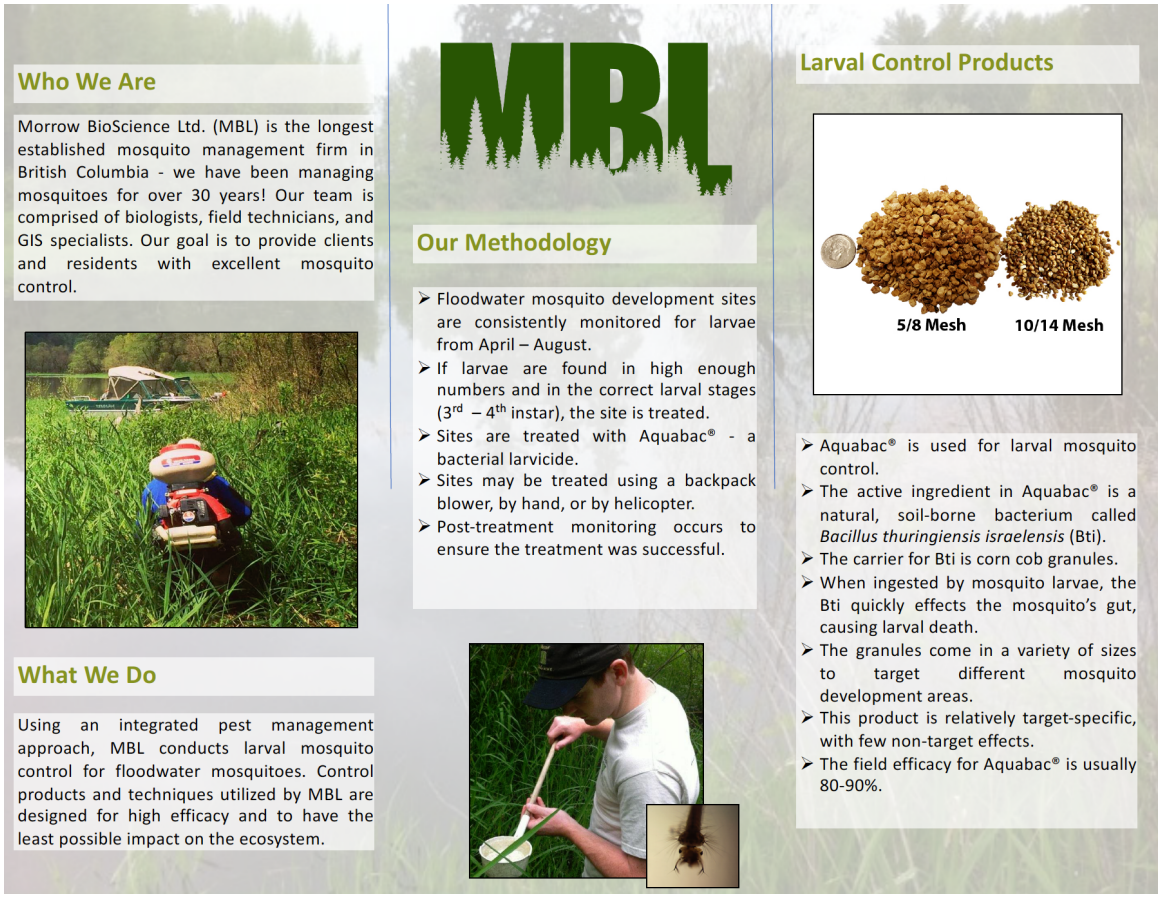

Image 2. MBL education outreach pamphlet.

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, Instagram). 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.

Public Engagement

MBL maintains a presence on social media with a Facebook account (facebook.com/morrowbioscience), Twitter account (@MoBioScience), and Instagram account (morrowbioscience), 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.

Facebook remains the primary avenue for MBL to disseminate mosquito-related information on social media. Regular updates on mosquito abundance began in early April. The total number of followers on the MBL Facebook page was 384 in November 2022. This number has increased by over 40 since November 2021.

In addition to social media, 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. homepage (www.morrowbioscience.com)

The website highlights two sets of FAQs focused on (1) mosquito biology and disease transmission, and (2) the active ingredient used in control efforts (*Bacillus thuringiensis* var. *israelensis*). MBL has added new blogs discussing relevant education outreach topics. Information dedicated specifically to mosquitoes and COVID-19 (published in May 2020) remains available on the website.

Education Outreach

A 2022 Town Hall presentation for residents in both Meadow Creek and Pine Ridge was facilitated by the RDCK on 4 May. MBL staff virtually attended and presented a summary of 2021 mosquito management efforts, challenges, and successes. The presentation also included a discussion about the early-season snowpack and larval mosquito abundance going into the 2022 season. Although attendance was not high, the presentation was well-received. No interviews were requested regarding the Meadow Creek and Pine Ridge mosquito program in 2022. However, the MBL Operations Manager and Lead Biologist provided interviews to the following news outlets:

- BC CTV (20 June)
- Global TV (12 July)
- City TV (13 July)
- CBC (14 July)
- CBC – Early Edition (18 August)

While these interviews were requested on behalf of mosquito control programs run by MBL on the coast, the interviews included tips for residents to reduce mosquito habitat around homes and how to increase personal protective measures. These recommendations are applicable to all program residents. If opportunities arise, MBL staff ensure that the RDCK mosquito program manager is consulted prior to agreeing to an interview. Every effort will be made to accommodate interviews which assist in raising awareness about mosquito control efforts and personal protective measures.

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 its 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 8 October, no human case of WNv were reported to Health Canada from British Columbia[10]. Similarly, no horse or bird cases were reported from British Columbia within 2022. Of note, previous reports were not published until mid-December, so it is likely that surveillance did occur in 2022 and will be published shortly. An update will be sent to the RDCK program manager once 2022 provincial WNv surveillance data are received. Also 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 30 October, no in-state cases of WNv were reported in Washington State[11]. Six mosquito pools tested positive for WNv. No horses/other mammals or birds tested positive in 2022. Of note, cooler ambient temperatures from May – early July contributed to a lower number of degree days during 2022, which likely contributed to lower incidence of WNv activity.

As of 30 October, 16 human WNv cases were identified in Idaho[12]. 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 since 2017 and Heath Canada will no longer be updating case counts[13]. HealthLinkBC reports that no Zika cases have originated in Canada due to presumed lack

[10] https://www.canada.ca/en/public-health/services/publications/diseases-conditions/west-nile-virus-surveillance/2021/week-37-38-september-13-26.html
[11] http://www.doh.wa.gov/DataandStatisticalReports/DiseasesandChronicConditions/WestNileVirus
[12] https://www.cdc.gov/westnile/statsmaps/preliminarymapsdata2022/index.html
[13] https://www.canada.ca/en/public-health/services/diseases/zika-virus/health-professionals.html#_Surveillance_in_Canada

of vector mosquito species[14]. There have been human Zika cases reported in Canada prior to 2022, although those were determined to have been acquired while traveling.

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.

2023 Program Recommendations

- Ground-based treatments should increase in future high-water years.
- Hire an additional staff member to assist with treatments and outreach efforts.
- Ensure the electronic data entry program is working throughout the season by conducting early and frequent QA/QC evaluations.
- Increase community engagement through door-knocking campaigns, mail-out campaigns, field tour, and/or attendance at the Lardeau Valley Sunday Market.
- Notify the Ministry of Environment of the RDCK intent to treat mosquitoes in 2023 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).

[14] https://www.healthlinkbc.ca/health-feature/zika-virus

References

Breeland SG and Pickard E (1967) Field observations on twenty-eight broods of floodwater mosquitoes resulting from controlled flooding of a natural habitat in the Tennessee Valley. *Mosq News* 27: 343-358.

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.

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.

Peach, D. (2018). An Updated List of the Mosquitoes of British Columbia with Distribution Notes. J. *Entomol. Soc. Brit. Columbia* 115: 126-129.

Peach, D.A.H., Almond, M., and Pol, J.C. (2019). Modeling Distributions of Aedes japonicus japonicus and Aedes togoi (Diptera: Culicidae) in the United States, Canada, and northern Latin America. *J Vect Ecol* (44(1): 119-129.

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.

Wood, D.M., Dang, P.T., and Ellis, R.A. (1979). *The Insects and Arachnids of Canada* (Part 6). Ottawa, Canada.

Project Contacts at Morrow BioScience Ltd.

Dirk Lewis
Owner/Biologist
dirk@morrowbioscience.com
604.317.1413

Barry McLane
GIS Manager
barry@morrowbioscience.com
250.231.6934

Morgan Sternberg
Research Manager
morgan@morrowbioscience.com
250.231.4455