Columbia River Project Water Use Plan

Kinbasket Reservoir Fish & Wildlife Information Plan

Mica Tailrace Fish Indexing Study

Implementation Year 13

Reference: CLBMON-60

Program Summary Report

Study Period: 2013-2021

Ktunaxa Nation Council
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WLR Monitoring Study No. CLBMON-60
Mica Tailrace Fish Indexing Study (Summary Report)

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Cover Photo:
View of the Mica Dam looking upstream (April 18, 2015). Photos in this document © Katrina Caley and Jon Bisset, KNC.

EXECUTIVE SUMMARY

During the development of BC Hydro's Water Use Plan (WUP) for the Columbia River Mica Dam Hydroelectric Project (BC Hydro 2007) and the Environmental Impact Assessment (EIA) process for the installation of two new turbines (Mica 5 and 6), two key concerns were identified:

1. Changes in the distribution of ichthyofauna downstream of the tailrace; and
2. The effects of the addition of Mica 5 and 6 turbines on water temperatures downstream of the Mica Dam Tailrace (BC Hydro 2011).

It was anticipated that the addition of the two turbines would elevate surface water levels and increase water velocities in the tailrace. As well, it was a concern that operation of the two additional turbines could alter water temperatures in the tailrace. To address these key concerns two field surveys were initiated: 1) an ichthyofaunal survey of the section of Columbia River between the Mica Dam tailrace and the Blue Bridge ~2.5 km downstream, and 2) a temperature study, which involved deployment of temperature loggers at eight locations along the two banks between the tailrace and the Blue Bridge.

Prior to the installation and operation of Mica 5/6, fish indexing surveys were conducted in October 2012 and 2013. The additional turbines, Mica 5 and 6, became operational on January 28th, 2015 and December 22nd, 2015, respectively. Subsequently, four years of post-Mica 5/6 fish indexing surveys were completed. This report presents the fish indexing results from all six study years, including one year of historical data from 2008, as well as thermal monitoring in the Mica Dam headpond and tailrace. Results from the 2020 study year are highlighted in this report as they have not yet been reported elsewhere.

This study employed three types of survey methods to evaluate the fish community in the Mica tailrace: boat electrofishing observations and netting, and backpack electrofishing. Boat electrofishing was used to enumerate and characterize the ichthyofauna within the study area, while backpack electrofishing targeted small-bodied and juvenile fishes along the shoreline. Discharges of 400-800 m^3/s from Mica Dam were originally targeted for the fish surveys for consistency, efficiency and safety.

A total of 753 fishes were observed during the 2020 boat electrofishing study. Mountain Whitefish accounted for 58% (N=436) of observed fishes. Other species observed were Kokanee (N=185), Bull Trout (N=60), Suckers (N=18), and unidentified salmonids (N=53). No Rainbow Trout were observed in 2020. No significant difference in fish composition due to the operation of Mica 5/6 was identified. A total of 117 fishes were netted during the capture study, including: 50 Mountain Whitefish, 41 Kokanee, 18 Bull Trout, and 8 Suckers. Overall, average fish body condition has not significantly changed relative to pre-Mica 5/6 surveys.

Backpack electrofishing was completed at three of four original indexing sites (EF01, EF02 and EF03) and one alternate site (EF04). A total of one Kokanee fry and nine Sculpins were captured in 2020.

Continuous temperature monitoring using HOBO TidbiT® v2 loggers occurred from October 2012 until October 2019 in both the headpond and the tailrace. The headpond array broke during the 2018-2019 deployment period and could not be recovered, so BC Hydro provided headpond temperature data for the analyses. Overall temperature patterns in the tailrace continued to follow a typical seasonal pattern. Generally, temperature differences between the right and left banks, as well as 1-3 km downstream from the dam, were all within the error of the temperature loggers (±0.2°C).

One of the objectives of this study was to monitor water temperature to assess whether or not the operation of two additional turbines increased the water temperature in the Mica tailrace. An hourly temperature model was developed to better understand how the operation of each turbine affected the tailrace water temperatures at different times of year. The model suggests that increasing discharge through turbines 3, 4, 5, and 6 does not increase the downstream water temperature by more than 0.5°C; however, operation of turbines 1 and 2 can increase the downstream water temperature by more than 1.5°C during periods of thermal stratification. This increase is not sufficient to raise the temperature above the general upper temperature preference of 18°C.

Overall, this study has provided a good foundation for understanding the inter-annual variation of ichthyofaunal community composition, distribution and body condition in the Mica tailrace pre- and post-Mica 5/6. However, due to the high levels of inter-annual variation the estimates of the effect of Mica 5/6 are highly uncertain.

Final status of CLBMON-60

Objective	Management Question	Summary of Monitoring Results
	MQ-1: Does the operation of Mica 5/6 generate changes in the ichthyofauna in the Mica Dam tailrace?	Overall, the diversity of ichthyofauna in the Mica Dam tailrace is low; however, community composition is similar to other areas of the Revelstoke Reservoir. The Mica tailrace fish fauna is predominantly composed of Mountain Whitefish, Kokanee and Bull Trout, with Mountain Whitefish being the most abundant species. No clear directional changes in the composition or distribution of ichthyofauna were identified as a result of Mica 5/6. However, as this study only has three years of pre-Mica 5/6 and four years of post-Mica 5/6 data, it is difficult to separate any effects of Mica 5/6 from natural variation.
	MQ-2: Does the operation of Mica 5/6 generate changes in the aquatic thermal regime of the Mica Dam tailrace?	Temperature patterns in the tailrace continued to follow a typical seasonal pattern. Generally, temperature differences between the right and left banks, as well as between upstream and downstream sites, were not considered significantly different. An hourly temperature model was developed to understand how the operation of the six turbine units operating under different discharge regimes affected the temperature in the tailrace during the study period. The model suggested that the operation of units 5 and 6 during periods of thermal stratification did not contribute to increases in water temperature above the thermal preferences of fish species found in the tailrace.

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Last but not least, thank you to Jason Watson, Trish Joyce and Mark Sherrington at BC Hydro for management of this project.

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BT	Bull Trout
CI	Confidence Interval
CL	Credible Limits
CRIs	Credibility Intervals
EACA	Environmental Assessment Certificate Applications
EF	Electrofishing
EIA	Environmental Impact Assessment
GPS	Global Positioning System
KO	Kokanee
masl	metres above sea level
MCMC	Markov Chain Monte Carlo
MQ	Management Question
MW	Megawatts
MW	Mountain Whitefish
QA/QC	Quality Assurance / Quality Control
RB	Rainbow Trout
Rkm	River km
SU	Sucker
TMB	Template Model Builder
TOR	Terms of Reference
UTM	Universal Transverse Mercator
WSC	Water Surveys Canada
WUP	Water Use Plan

GLOSSARY

Tailrace: Stream channel below a dam.

Ichthyofauna: Fish species inhabiting a specific region or habitat.

Electrofishing: A survey method using non-lethal electrical currents to sample fish populations and determine abundance, density, and species composition.

Thermal regime: variations in water temperature observed in a stream in response to climatic conditions and/or dam operation.

Thermal stratification: Phenomenon in which lakes develop two discrete layers of water of different temperatures (warm on top (epilimnion) and cold below (hypolimnion)) caused by the change in water's density with temperature.

Fish indexing: Fisheries study assessing species abundance and composition in a given community.

1.0 INTRODUCTION

In 2007, BC Hydro completed a Water Use Plan (WUP) for the Columbia River (RL & L 2001; BC Hydro 2004, 2007), along with the Kinbasket Reservoir Fish and Wildlife Information Plan (BC Hydro 2011b), which outlined the Terms of Reference (TOR) for monitoring programs required for all of its operations. The WUP seeks to balance power generation with other water uses that provide social, environmental and economic benefits to British Columbians. Subsequently, Monitoring Program TOR (BC Hydro 2011a) were developed to implement and assess recommendations from the WUP.

In 2009, an Environmental Impact Assessment was triggered by the proposed addition of two turbines to the Mica Dam (Mica 5/6). In accordance with the BC Environmental Assessment Act, BC Hydro submitted two Environmental Assessment Certificate Applications (EACAs), one for each of the proposed Mica Unit 5 and Mica Unit 6 projects. The four-turbine generating station has the capacity to generate 1,805 megawatts (MW) of power (BC Hydro 2007; KCB 2009). The expansion was proposed to increase generating capacity to 2,805 MW. The application identified that the potential effects of the operation of the proposed project on the downstream fish community in the Columbia River were unknown. This study, CLBMON-60, was then designed to assess the impacts to fish and fish habitat and monitor the thermal regime in the Mica Dam Tailrace as a result of the proposed expansion (KCP 2009; BC Hydro 2011c).

Specifically, the purpose of the current study was to assess the potential impacts of operation of turbines 5 and 6 on the thermal regime and fish distribution within the ~2.5 km section between the tailrace and the Blue Bridge (Figure 1). Pre-operation monitoring was completed in 2012 (Irvine et al 2013) and 2013 (Bisset et al 2015) to characterize the ichthyofauna in the tailrace. Temperature monitoring was also conducted during that time and continued throughout the construction phase of the project. The additional turbines, Mica 5 and 6, became operational on January 28th, 2015 and December 22nd, 2015, respectively. The first of five years of post-operation studies was initiated in 2016. Other studies have been or are currently being completed with respect to flows, temperature, fish habitat and fish distribution in the Kinbasket Reservoir and Columbia River downstream of the dam, including CLBMON-1 (Total Gas Pressure Monitoring), CLBMON-2 (Kokanee population monitoring), and others.

The primary objectives of the monitoring program were to monitor the ichthyofauna and thermal regime in the Mica Dam tailrace during the summer before and after the service date for full operations of Mica 5 and 6 (BC Hydro 2011a, 2011b).

The management questions and study objectives were addressed through two field studies: 1) a fish indexing study below the Mica Dam, and 2) temperature monitoring above and below the Mica Dam. The fish indexing study was composed of three components: 1) boat electrofishing observations, 2) boat electrofishing capture, and 3) backpack electrofishing capture. The boat electrofishing studies targeted larger-bodied fishes and were intended to enumerate and characterize the ichthyofauna within the study area. The backpack electrofishing study was carried out in shallow water habitats along the shoreline and targeted juvenile and small-bodied fishes. The purpose of the temperature monitoring study was to understand how the thermal regime downstream of the Mica Dam responded to the operation of two additional turbines.

2.0 STUDY AREA

The Columbia River Mica Dam hydroelectric project is part of BC Hydro's integrated generation system and is located approximately 137 km north of Revelstoke on Highway 23 (Figure 1 inset). The Mica Dam impounds the Columbia River and forms Kinbasket Reservoir. The study area includes Kinbasket Reservoir immediately above the Mica Dam (the headpond) and the Columbia River from 1 km downstream of the dam to the Blue Bridge (approximately 2.5 km downstream of the dam).

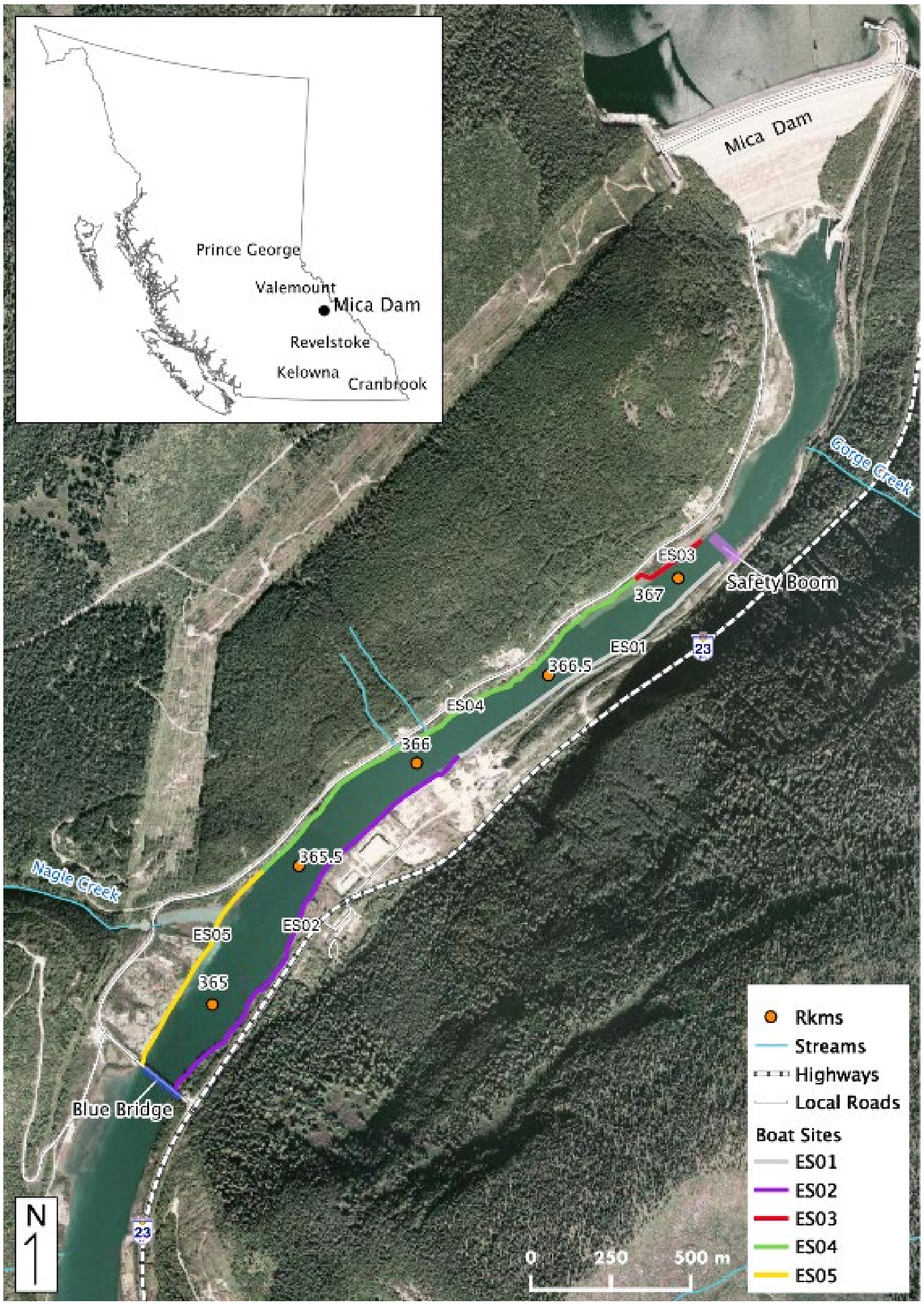

Figure 1. Boat electrofishing locations and study area (inset) for the Mica Tailrace Fish Indexing study.

Hydrology Patterns

The hydrograph peak in the study area is dominated by snowmelt runoff in the spring, while secondary rainfall events in the summer and fall also increase seasonal flow variation (KCB 2009). There are currently two operating Water Survey of Canada (WSC) gauging stations (WSC 08NE049, 08NB005) and several historic stations that provide baseline hydrology information. There is also a continuous gauge above the Mica Dam at Donald operated by BC Hydro, which characterises flow patterns and precipitation within the Columbia River. The WSC data reflect the fact that the Columbia River is a snowmelt dominated system, with peak runoff/freshet conditions typically observed in late May through to early July and winter low flows from October to April. Low flow periods are typically observed in the late winter, when most precipitation occurs as snowfall. The annual peak monthly inflow for the period from 1940 to 1999 at Mica averaged 574.25 m^3/s, with winter low flows ranging from mean monthly inflows of 103 to 132 m^3/s (BC Hydro 2007).

These background data were used to develop hydrographs for the Columbia River and inform hydrological studies. The hydrologic studies were then used to identify constraints and determine operational requirements for the facility, identify periods of low (i.e., critical) flows relative to fish habitat use and develop minimum flow requirements.

Fish Community

Previous fish studies have observed that the Columbia River below Mica Dam supports populations of Rainbow Trout (*Oncorhynchus mykiss*), Kokanee (*O. nerka*), Bull Trout (*Salvelinus confluentus*) and Mountain Whitefish (*Prosopium williamsoni*), as well as Slimy (*Cottus cognatus)*, Torrent (*C. rhotheus*) and Prickly Sculpins (*C. asper*) as outlined in Table 1.

Table 1. Fish species documented in the Columbia River downstream of the Mica Dam (RL & L 2001; Golder 2008; BC Hydro 2007, 2011b).

Common Name	Scientific Name
Rainbow Trout	*Oncorhynchus mykiss*
Bull Trout	*Salvelinus confluentus*
Kokanee	*O. nerka*
Mountain Whitefish	*Prosopium williamsoni*
Slimy Sculpin	*Cottus cognatus*
Torrent Sculpin	*C. rhotheus*
Prickly Sculpin	*C. asper*
Burbot	*Lota lota*
Lake Whitefish	*Coregonus clupeaformis*
Yellow Perch	*Perca flavescens*
White Sturgeon	*Acipenser transmontanus*
Pygmy Whitefish	*P. coulteri*
Cutthroat Trout	*O. clarkii*
Lake Chub	*Couesius plumbeus*
Bridgelip Sucker	*Catostomus columbianus*

3.0 METHODS

3.1 Overview

This study employed three types of survey methods to evaluate the fish community in the Mica tailrace: boat electrofishing observations and captures, and backpack electrofishing captures. Boat electrofishing was used to enumerate and characterize the ichthyofauna within the study area, while backpack electrofishing targeted small-bodied and juvenile fishes along the shoreline. These methods were implemented to collect information on the abundance, distribution, and condition of fish. Fish surveys were conducted when discharges ranged from 400 to 800 m^3/s to ensure consistent observer efficiency and safety within achievable range of operations during October of each study year (2012-2013 for pre-operation and 2017-2020 for post-operation phases of Mica 5 and 6 turbines; see Section 3.2 and 8.2).

Another objective of this study was to monitor water temperature to assess whether or not the operation of two additional turbines increased the water temperature in the Mica tailrace. Temperature monitoring occurred in the headpond and tailrace from October 2012 to October 2019 using HOBO TidbiT® v2 temperature loggers (see Section 3.2 and 8.2).

3.2 Datasets

Error! Reference source not found. provides a summary of all datasets collected between 2012 and 2020.

Table 2: Summary of datasets collected for the CLBMON-60 of Kinbasket Reservoir.

	Activity					
Dataset	**Study Period**	**Boat Electrofishing**	**Backpack Electrofishing**	**Temperature Logging**	**Reference**	**Management Question Addressed**
Year 1 Ichthyofauna survey - pre-operation of Mica 5 and 6 turbines	Oct 2012	X	X		https://www.bchydro.com/content/dam/BCHydro/customer-portal/documents/corporate/environment-sustainability/water-use-planning/southern-interior/clbmon-60-yr1-2013-11-01.pdf	MQ1
Year 1 and 2 Aquatic temperature study - pre-operation of Mica 5 and 6 turbines	Sept 2012 to May 2014			X	https://www.bchydro.com/content/dam/BCHydro/customer-portal/documents/corporate/environment-sustainability/water-use-planning/southern-interior/clbmon-60-yr2-2015-01-01.pdf	MQ2
Year 2 Ichthyofauna survey - pre-operation of Mica 5 and 6 turbines	Oct 2013	X	X		https://www.bchydro.com/content/dam/BCHydro/customer-portal/documents/corporate/environment-sustainability/water-use-planning/southern-interior/clbmon-60-yr2-2015-01-01.pdf	MQ1

Year 3 Aquatic temperature study - pre-operation of Mica 5 and 6 turbines	May 2014 to Oct 2014			X	https://www.bchydro.com/content/dam/BCHydro/customer-portal/documents/corporate/environment-sustainability/water-use-planning/southern-interior/CLBMON-60%20Yr6%202019-09-20.pdf	MQ2
Year 1 Aquatic temperature study - construction phase of Mica 5 and 6 turbines	Oct 2014 to Oct 2015			X	https://www.bchydro.com/content/dam/BCHydro/customer-portal/documents/corporate/environment-sustainability/water-use-planning/southern-interior/CLBMON-60%20Yr6%202019-09-20.pdf	MQ2
Year 2 Aquatic temperature study - construction phase of Mica 5 and 6 turbines	Oct 2015 to Dec 2015			X	https://www.bchydro.com/content/dam/BCHydro/customer-portal/documents/corporate/environment-sustainability/water-use-planning/southern-interior/CLBMON-60%20Yr6%202019-09-20.pdf	MQ2
Year 1 Aquatic temperature study – post-construction of Mica 5 and 6 turbines	Jan 2016 to Oct 2016			X	https://www.bchydro.com/content/dam/BCHydro/customer-portal/documents/corporate/environment-sustainability/water-use-planning/southern-interior/CLBMON-60%20Yr6%202019-09-20.pdf	MQ2
Year 1 Ichthyofauna survey (backpack electrofishing only) - post-operation of Mica 5 and 6 turbines	Oct 2017		X		https://www.bchydro.com/content/dam/BCHydro/customer-portal/documents/corporate/environment-sustainability/water-use-planning/southern-interior/CLBMON-60%20Yr6%202019-09-20.pdf	MQ1
Year 2 Aquatic temperature study - post-operation of Mica 5 and 6 turbines	Oct 2016 to Oct 2017			X	https://www.bchydro.com/content/dam/BCHydro/customer-portal/documents/corporate/environment-sustainability/water-use-planning/southern-interior/CLBMON-60%20Yr6%202019-09-20.pdf	MQ2
Year 1 Ichthyofauna	Oct 2018	X			https://www.bchydro.com/content/dam/BCHydro/cu	

survey (boat electrofishing only) - post-operation of Mica 5 and 6 turbines					stomer-portal/documents/corporate/environment-sustainability/water-use-planning/southern-interior/CLBMON-60%20Yr6%202019-09-20.pdf	
Year 2 Ichthyofauna survey (backpack electrofishing only) - post-operation of Mica 5 and 6 turbines	Oct 2018		X		https://www.bchydro.com/content/dam/BCHydro/customer-portal/documents/corporate/environment-sustainability/water-use-planning/southern-interior/CLBMON-60%20Yr6%202019-09-20.pdf	MQ1
Year 3 Aquatic temperature study - post-operation of Mica 5 and 6 turbines	Oct 2017 to Oct 2018			X	https://www.bchydro.com/content/dam/BCHydro/customer-portal/documents/corporate/environment-sustainability/water-use-planning/southern-interior/CLBMON-60%20Yr6%202019-09-20.pdf	MQ2
Year 2 Ichthyofauna survey (boat electrofishing only) - post-operation of Mica 5 and 6 turbines	Oct 2019	X[a]			Current report	MQ1
Year 3 Ichthyofauna survey (backpack electrofishing only) - post-operation of Mica 5 and 6 turbines	Oct 2019		X		Current report	MQ1
Year 4 Aquatic temperature study - post-operation of Mica 5 and 6 turbines	Oct 2018 to Oct 2019			X	Current report	MQ2
Year 3 Ichthyofauna survey (boat electrofishing only) - post-operation of Mica 5 and 6 turbines	Oct 2020	X			Current report	MQ1
Year 4 Ichthyofauna survey (backpack electrofishing only) - post-operation of Mica 5 and 6 turbines	Oct 2020		X		Current report	MQ1

[a] Only the boat observation pass was completed. The capture pass was not completed.

4.0 MANAGEMENT QUESTIONS

The studies for CLBMON-60 were designed to improve our understanding of the impacts of Mica 5/6 on the ichthyofauna and thermal regime in the Mica Dam tailrace. No management hypotheses were developed for this study; therefore, only the management questions were addressed below.

4.1 MQ1: Does the operation of Mica 5/6 generate changes in the ichthyofauna in the Mica Dam tailrace?

Fish Abundance and Distribution

As only two years of pre-operation and three years of post-operation data are available for this project it is difficult to determine if a meaningful change in species composition, distribution and condition occurred as a result of the operation of Mica 5/6. For this reason and to focus on effect size the study did not include the testing of specific management hypotheses. Based on both observation and capture sessions, species diversity was low across all five sites; however, community composition in the Mica tailrace is similar to what other studies have reported in the Revelstoke Reservoir (RL & L 2001; Golder 2008). The Mica tailrace is predominantly composed of Mountain Whitefish, Kokanee and Bull Trout, with Mountain Whitefish being the most abundant species. Rainbow Trout and Suckers were also observed, but their numbers were consistently low across all sites and sampling years.

Several ripe female Kokanee were observed in the Mica tailrace during the fall electrofishing studies. Suitable spawning habitat was not observed at any of the shallow water sites used for backpack electrofishing. It is possible that suitable spawning sites exist in deeper water areas; however, additional monitoring would be required to confirm their presence or absence.

Generally, there were no obvious patterns or changes in fish distribution in the Mica tailrace (A2 Figure 10 to A2 Figure 14; see 'Relative Distributions' section of the online analytic appendix at *https://www.poissonconsulting.ca/f/955630057*).

Overall, there was a lack of appropriate locations for backpack electrofishing throughout the 2.5 km of study area originally established for this project. Accessing the limited shallow water sites has been difficult in some years. Only one of the original index sites (EF01) could be accessed in all study years. Golder (2008) also observed that backpack electrofishing sites were limited due to high water levels and steep banks. The limited amount of information on fishes occupying shallow water habitats makes it challenging to evaluate changes to juveniles and small-bodied fishes. It is possible that shallow water sites will become less stable and result in less habitat for juveniles and small-bodied fishes under an operating regime of higher flows and increased frequency of high flows (Freeman 2001). Suitable shallow water habitats may be created downstream in areas less affected by flow regulation where sediment can be deposited; however, the spatial scope of this study did not extend downstream of the blue bridge.

Fish Condition

There was large inter-annual variation in fish condition. As a result the fish body condition data are consistent with a 20% or greater increase or a 20% or greater decrease in weight for all of the species. Additional years of data with and without the operation of Mica 5/6 would be required to reduce the uncertainty.

Conclusion
The evaluation of changes in the ichthyofauna in the Mica Dam tailrace were based on three years of pre-Mica 5/6 and four years of post-Mica 5/6 observations and data. Based on this limited dataset, there was substantial uncertainty in the effect of Mica 5/6 on the abundance or distribution of index fish species in the tailrace. The Mica tailrace is a Mountain Whitefish dominated system, which is also utilized by Bull Trout, Kokanee, Suckers, and Rainbow Trout. A previous indexing study by Golder (2008) observed Burbot in the tailrace; however, this species was not observed during any year of this study. Fish body condition was also evaluated over the course of this study: the fish body condition data were consistent with a 20% or greater increase or a 20% or greater decrease in weight for all of the species.

4.2 MQ2: Does the operation of Mica 5/6 generate changes in the aquatic thermal regime in the Mica Dam tailrace?

This study was designed to assess the impact of the operation of Mica 5/6 on the thermal regime in the tailrace. The study demonstrated that any systematic differences between the left and right bank and up and downstream are negligible during moderate to high flows. The study also demonstrated that at increasing discharge levels turbines 1 and 2 effectively draw water from higher in the water column, which during periods of thermal stratification, results in an increase of almost 1°C relative to the other turbines. Due to the complexity of the data it was not possible to estimate the uncertainty in the magnitude of this effect. There is no evidence that water temperatures in the tailrace exceed or even approach the nominal thermal threshold of 18°C.

Large decreases in tailrace water temperatures (4.5-5.2°C) were reported to have occurred immediately following rapid increases in discharges from Mica Dam to over 400 m^3/s following a period of discharges less than 100 m^3/s (Golder, 2008). This is likely because warmer water due to solar heating or tributary inputs was displaced by the increased flow. These events all occurred during the summer and early fall when the water column in the headpond was stratified, but the turbines were drawing from the deeper, cooler hypolimnion (Petts 1986; Clarkson and Childs 2000).

Conclusion
Temperature patterns in the tailrace follow a typical seasonal pattern. Generally, temperature differences between the right and left banks, as well as between upstream and downstream sites, are not considered significantly different. An hourly temperature model was developed to understand how the operation of the six turbine units operating under different discharge regimes affected the temperature in the tailrace during the study period. The model suggests that the operation of units 5 and 6 during periods of thermal stratification did not contribute to increases in water temperature above the thermal preferences of fish species found in the tailrace.

5.0 RECOMMENDATIONS

The purpose of this study was to evaluate the impact of Mica 5/6 on the ichthyofauna and thermal regime in the Mica tailrace. The study aimed to address the management questions provided in the Terms of Reference for the study, which also align with the commitments outlined in the Environmental Assessment Certificate #E09-09. The conclusions from the study were constrained by the limitations of this study, namely the uncertainty in the effect of Mica 5/6 on the abundance and distribution of index fish species in the tail race due to the lack of pre-Mica 5/6 and post-Mica 5/6 data. We present recommendations for future studies and monitoring below:

1) **Temperature monitoring study.** Additional insight into the thermal regime is required through an assessment of the influence of solar inputs, discharge from Nagle Creek and groundwater on the thermal regime, as well as the development of a model to characterize the thermal stratification in the headpond.

2) **Seasonal fish indexing and habitat use study.** The present study provided an annual snapshot of fish community composition in the Mica tailrace with seven years of sampling data collected over an twelve-year period. An expanded fish indexing study is recommended to gain a better understanding of the seasonal changes in community composition. Alternative methods for sampling juveniles and small-bodied fishes should be considered for future indexing studies in the Mica Dam tailrace as current methods were often insufficient due to limited shallow water habitat. An indexing study in the Peace River (Mainstream Aquatics Ltd 2012) used small raft electrofishing methods to sample juveniles and small-bodied fishes which would be useful in areas that are too deep to backpack electrofish and where boat electrofishing methods would result in low capture rates of small-sized fishes. Additional effort should also be spent on assessing fish habitat availability and use by juveniles and small-bodied fishes.

3)

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7.0 Appendix 1. Timeline of CLBMON-60

Milestone	Study Period	Reference
Year 1 Ichthyofauna survey - pre-operation of Mica 5 and 6 turbines	Sept 2012 to Feb 2013	Year 1 Report (2013)
Year 1 and 2 Aquatic temperature study - pre-operation of Mica 5 and 6 turbines	Mar 2013 to May 2014	Year 2 Report (2015)
Year 2 Ichthyofauna survey - pre-operation of Mica 5 and 6 turbines	Mar 2013 to May 2014	Year 2 Report (2015)
Year 1 and 2 Aquatic temperature study – construction of Mica 5 and 6 turbines	Oct 2014 to Dec 2015	Year 6 Report (2019)
Year 1 Ichthyofauna survey (boat electrofishing only) - post-operation of Mica 5 and 6 turbines	Oct 2018	Year 6 Report (2019)
Year 1 and 2 Ichthyofauna survey (backpack electrofishing only) - post-operation of Mica 5 and 6 turbines	Oct 2017 and Oct 2018	Year 6 Report (2019)
Years 1 to 3 Aquatic temperature study - post-operation of Mica 5 and 6 turbines	Oct 2014 to Oct 2018	Year 6 Report (2019)
Year 2 and 3 Ichthyofauna survey (boat electrofishing only) - post-operation of Mica 5 and 6 turbines	Oct 2019 and Oct 2020	Final Report (2021)
Year 3 and 4 Ichthyofauna survey (backpack electrofishing only) - post-operation of Mica 5 and 6 turbines	Oct 2019 and Oct 2020	Final Report (2021)
Year 4 Aquatic temperature study - post-operation of Mica 5 and 6 turbines	Oct 2018 to Oct 2019	Final Report (2021)

8.0 Appendix 2. Ichthyofauna Survey

8.1 Introduction

See Sections 1.2 and 2.0.

8.2 Methods

Discharge

The target range of discharge values for the fish sampling study of 400 to 800 m^3/s was chosen to ensure relatively constant observer efficiency while also being operationally achievable and safe to boat electrofish. In order to assess the range of discharge values over which sampling was conducted, hourly discharge values were averaged for the 3 hours prior to sampling and during sampling to obtain the approximate mean discharge at which fish were counted or captured.

Fish Observation and Capture

Boat Electrofishing

This study utilized boat electrofishing to enumerate and characterize the ichthyofauna within the study area. In the final study year, boat electrofishing was conducted October 2-4, 2020 at all five sites previously established by Golder (2008) and used for pre-Mica 5/6 fish indexing (Figure 1). As in previous years, the start location for the farthest upstream boat electrofishing locations (ES01 and ES03) had to be modified as a safety boom had been installed approximately 100 m downstream of the original start locations. It is not expected that this minor alteration in the study design will impact the results as counts are georeferenced and fish densities are calculated based on lineal distance traveled during the sampling run.

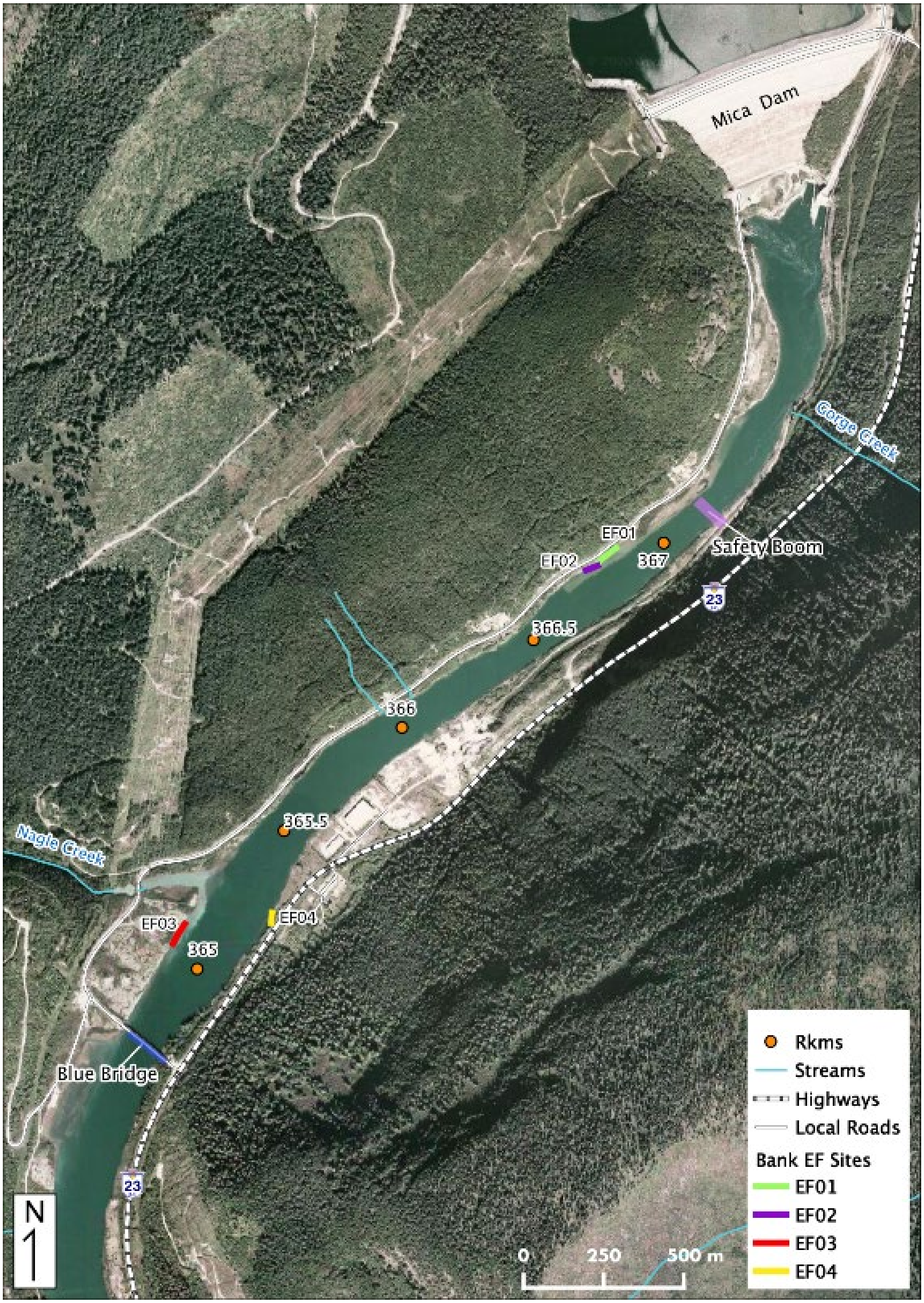
The boat electrofishing study was completed in two phases. The purpose of the two phases was to collect information on both the community structure and distribution as well as the average body condition of each species. The first phase consisted of an initial pass with the boat electrofisher at all five sites (moving upstream to downstream) to observe fish, record the species and estimate the size (to the nearest 10 cm) of all individuals. The observers were stationed in standard netting positions and each observer was paired with a recorder who had a watch synchronized to the time displayed by the GPS unit. Each recorder noted the fish data as well as the exact time of the observation so the observation could be georeferenced. Two GPS units (Garmin 62S/64S) ran track logs during the sampling session to reduce the chances of data loss in the case of equipment failure. The primary device was on the console of the electrofishing vessel with an external antenna (the distance from the console GPS to the midpoint of the anode and boom when extended was 6.2 m). The backup device was in a backpack carried by one of the observers.

Standard boat electrofishing capture was then completed at each of the five sites. Observation and capture passes were conducted on separate nights to minimize the likelihood of frightening the fish and to improve capture efficiency. Fish of all targeted indexing species were captured, transferred to the live well, and at the end of each site were measured, weighted and sexed (if possible). Crew members were also aware of the study’s stated objective to collect opportunistic information about rare or invasive species. The boat electrofisher settings were consistent between all observation and capture sessions (400 volts, 30 Hertz, and a pulse width of 38%).

Backpack Electrofishing

Small-bodied fishes were targeted along the shoreline using a Smith-Root LR 24 backpack electrofisher (185 volts, 30 Hertz and a pulse width of 12%) with a three-person crew during daylight hours. Four sites have been established for the backpack electrofishing study which are based on previous work by Golder (2008; A2 Figure 2). Upstream sites (EF01 and EF02) are situated in close proximity as there were few areas in the tailrace with appropriate habitat or that could be safely electrofished.

In 2020, backpack electrofishing was conducted at three of the four original sites on October 3rd. The water depth at site EF04 was too high to access or safely electrofish. In 2019, an alternate site was identified for EF04, approximately 30 m downstream of the original location. This site was accessible again in 2020 and was backpack electrofished. Photos and descriptions of all backpack electrofishing sites are provided in Appendix A.



A2 Figure 2: Backpack electrofishing locations for the Mica Tailrace Fish Indexing study. Site EF04 shown here is the alternate site, which is approximately 30 m downstream of the original EF04 location.

Spatial data from the Garmin 62S and 64S GPS units were downloaded after each night's survey into Garmin BaseCamp software and were saved as .gpx files. A shape file provided by Karen Bray of BC Hydro provided a center line down the thalweg of the river and river kilometer references that will be common to all Water License Requirement projects on the Columbia River (K. Bray, Pers. Comm.). The observations of individual fish were spatially located by taking the exact time of the recorded observation from the data sheet and matching that to the spatial point on the time referenced .gpx file to give a UTM coordinate in the river for that fish. The specific locations were then assigned a river kilometer by drawing a perpendicular line from the fish's location to the provided thalweg line and assessing where on the line it was located.

8.3 Dataset

A2 Table 1: Summary of boat electrofishing locations for ichthyofauna survey of CLBMON-60.

Site	Bank	Length of pass (km)	Longitude – Upstream point	Latitutde – Upstream point	Longitude – Downstream point	Latitude – Downstream point
ES01	River Left	1.01	-118.568	52.06464	-118.5799885	52.05903
ES02	River Left	1.35	-118.58	52.05903	-118.5923579	52.04959
ES03	River Right	0.25	-118.569	52.06513	-118.5722003	52.06406
ES04	River Right	1.47	-118.572	52.06406	-118.5887089	52.05567
ES05	River Right	0.69	-118.589	52.05567	-118.5939445	52.05032

A2 Table 2: Summary of boat electrofishing sampling replicates for ichthyofauna survey of CLBMON-60.

Sampling Year	Pass Type	Site				
		ES01	ES02	ES03	ES04	ES05
2008	Capture	2	2	2	2	2
2012	Observation	1	1	1	1	1
2012	Capture	1	2	1	1	1
2013	Observation	1	1	1	1	1
2013	Capture	1	1	1	1	1
2018	Observation	2	1	1	1	1
2018	Capture	1	1	1	1	1
2019	Observation	1	1	1	1	1
2020	Observation	1	1	1	1	1
2020	Capture	1	1	1	1	1

A2 Table 3: Summary of backpack electrofishing locations for ichthyofauna survey of CLBMON-60.

Site	Bank	Length of pass (km)	Longitude – Upstream point	Latitutde – Upstream point	Longitude – Downstream point	Latitude – Downstream point
EF01	River Right	0.1	-118.572	52.06406	-118.573	52.06352
EF02	River Right	0.1	-118.573	52.06352	-118.574	52.06323
EF03	River Right	0.1	-118.591	52.05337	-118.592	52.05263
EF04	River Left	0.1	-118.587	52.05413	-118.587	52.05359
EF04b	River Left	0.18	-118.588	52.05351	-118.587	52.05329

A2 Table 4: Summary of backpack electrofishing sampling replicates for ichthyofauna survey of CLBMON-60.

Sampling Year	Site				
	EF01	EF02	EF03	EF04	EF04b
2008	1	1	1	1	0
2012	2	1	0	0	0
2013	1	1	1	1	0
2017	1	0	1	0	0
2018	1	0	1	0	0
2019	1	0	1	0	1
2020	1	1	1	0	1

A2 Table 5: Summary of river kilometer references for Water License Requirements projects used to record locations of fish observed during ichthyofauna surveys of CLBMON-60.

rkm Location	Bank	Longitude	Latitude
367.5R	River Right	-118.566	52.06805
367.5L	River Left	-118.565	52.06715
367R	River Right	-118.571	52.06443
367L	River Left	-118.57	52.06369
366.3R	River Right	-118.579	52.06112
366.3L	River Left	-118.578	52.05979
365.6R	River Right	-118.587	52.05671
365.6L	River Left	-118.586	52.05589
364.8R	River Right	-118.593	52.05117
364.8L	River Left	-118.591	52.0504

8.4 Analyses

As per the Terms of Reference (BC Hydro 2011c), the following variables were assessed from the fish observation and capture data: relative abundance, condition, and spatial distribution throughout the study area.

Model parameters were estimated using Bayesian methods. The estimates were produced using JAGS (Plummer 2003). For additional information on Bayesian estimation the reader is referred to McElreath (2016).

Unless stated otherwise, the Bayesian analyses used weakly informative normal and half-normal prior distributions (Gelman, Simpson, and Betancourt 2017). The posterior distributions were estimated from 1500 Markov Chain Monte Carlo (MCMC) samples thinned from the second halves of 3 chains (Kéry and Schaub 2011, 38–40). Model convergence was confirmed by ensuring that the potential scale reduction factor $\hat{R} \leq 1.05$ (Kéry and Schaub 2011, 40) and the effective sample size (Brooks et al. 2011) "ESS"≥150 for each of the monitored parameters (Kéry and Schaub 2011).

The parameters are summarised in terms of the point estimate, lower and upper 95% credible limits (CLs) and the surprisal s-value (Greenland 2019). The estimate is the median (50th percentile) of the MCMC samples while the 95% CLs are the 2.5th and 97.5th percentiles. The s-value can be considered a test of directionality. More specifically it indicates how surprising (in bits) it would be to discover that the true value of the parameter is in the opposite direction to the estimate. An s-value of 4.3 bits, which is equivalent to a p-value of 0.05 (Kéry and Schaub 2011; Greenland and Poole 2013), indicates that the surprise would be equivalent to throwing 4.3 heads in a row. The requirement that non-essential explanatory variables have s-values ≥ 4.3 bits provides a useful model selection heuristic (Kéry and Schaub 2011).

The results are displayed graphically by plotting the modeled relationships between particular variables and the response(s) with the remaining variables held constant. In general, continuous and discrete fixed variables are held constant at their mean and first level values, respectively, while random variables are held constant at their typical values (expected values of the underlying hyperdistributions) (Kéry and Schaub 2011, 77–82). When informative the influence of particular variables is expressed in terms of the effect size (i.e., percent or n-fold change in the response variable) with 95% credible intervals (CIs, Bradford, Korman, and Higgins 2005).

The analyses were implemented using R version 4.0.3 (R Core Team 2020) and the mbr family of packages. For additional information on the analysis including parameter tables see the online analytic appendix at https://www.poissonconsulting.ca/f/955630057.

Body Condition

The annual variation in condition (body weight when accounting for body length) was estimated from the boat and backpack electrofishing captures using a mass-length model (He et al. 2008).

Key assumptions of the condition model include:

- Weight varies with body length as an allometric relationship, i.e., $W = \alpha L^{\beta}$.
- α varies by period (pre versus post Mica 5 and 6).
- α varies randomly with year.
- The residual variation in weight is log-normally distributed.

Preliminary analyses indicated that site and day of the year were not informative predictors of condition.

Relative Abundance

The annual variation in relative abundance was estimated from the boat count and catch data using an over-dispersed Poisson model (Kéry and Schaub 2011). Lineal densities are by kilometre of river (as opposed to kilometre of bank).

Key assumptions of the relative abundance model include:

- Lineal density varies by period.
- Lineal density varies randomly with year.
- Lineal catch efficiency is a fixed multiplier of lineal count efficiency.
- Expected counts (and catches) are the product of the count (catch) density and the length of river (half the length of bank) sampled.
- Observed counts (and catches) are described by a Poisson-gamma distribution.

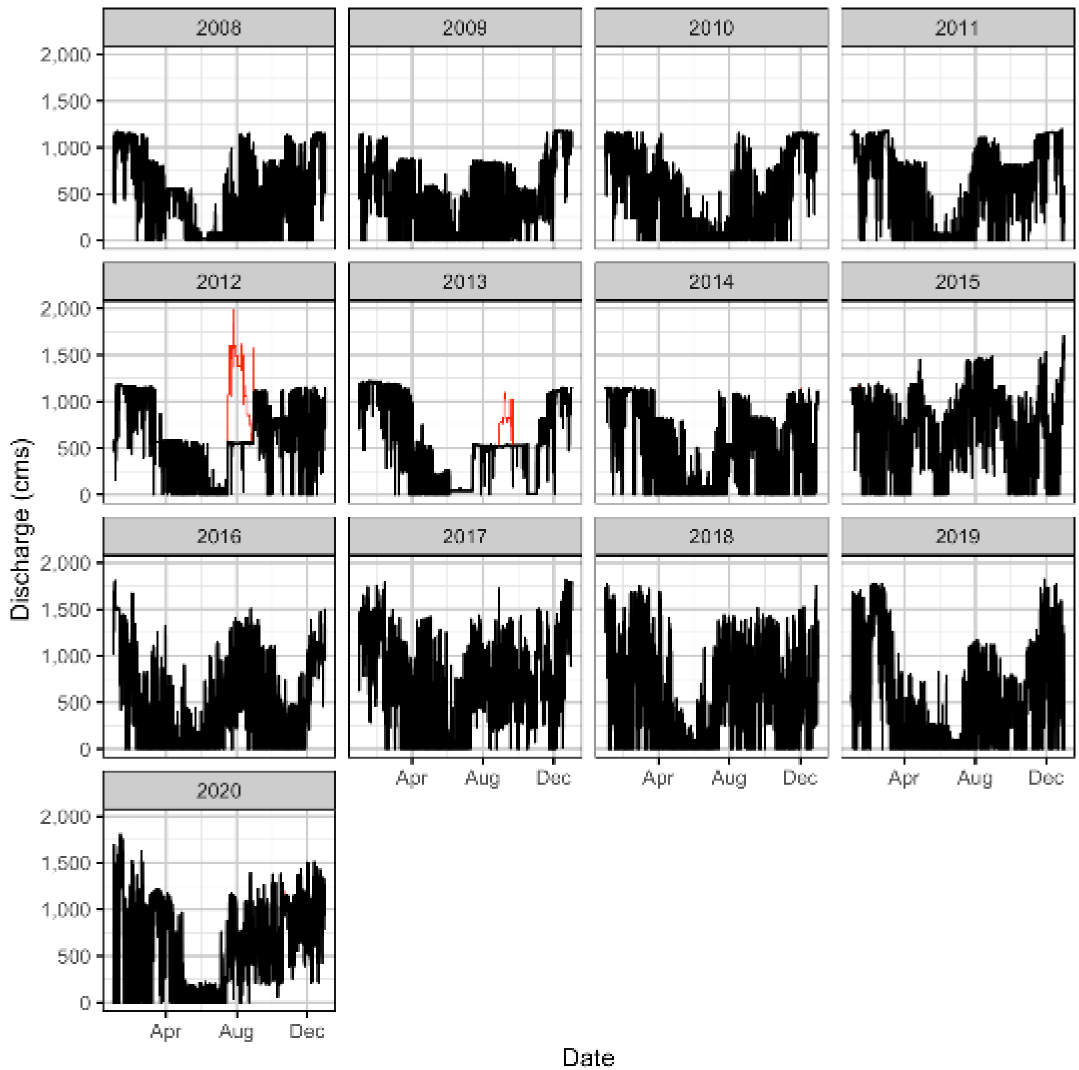
Preliminary analyses indicated that site and discharge were not informative predictors of the lineal count (or catch) density.

The model does not distinguish between the abundance and observer efficiency; i.e., it estimates the count, which is the product of the two. As such, it is necessary to assume that changes in observer efficiency by year are negligible in order to interpret the estimates as relative abundance.

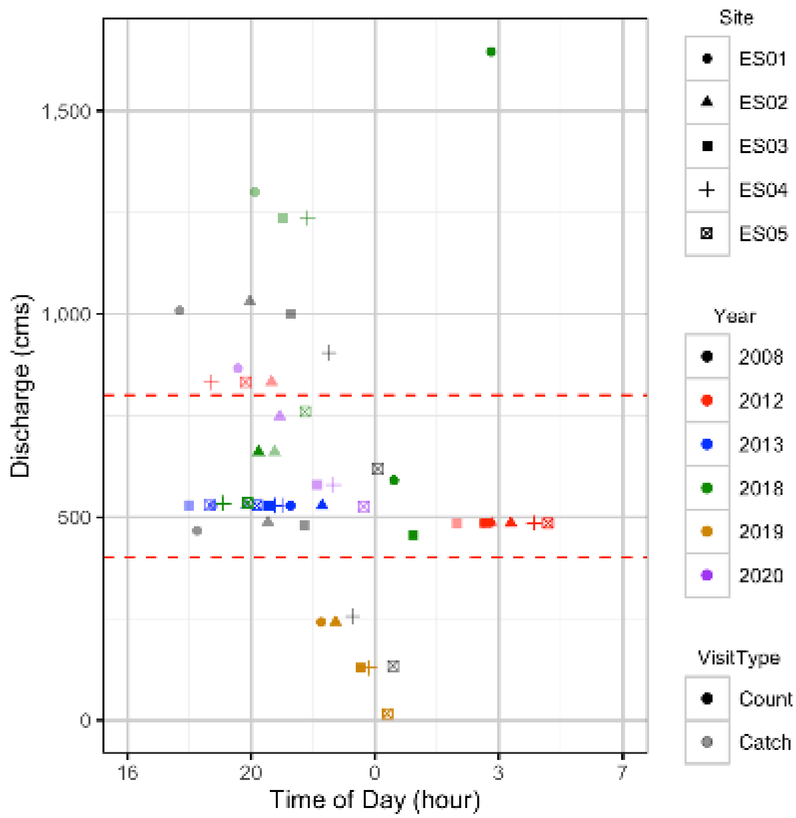
8.5 Results

Discharge

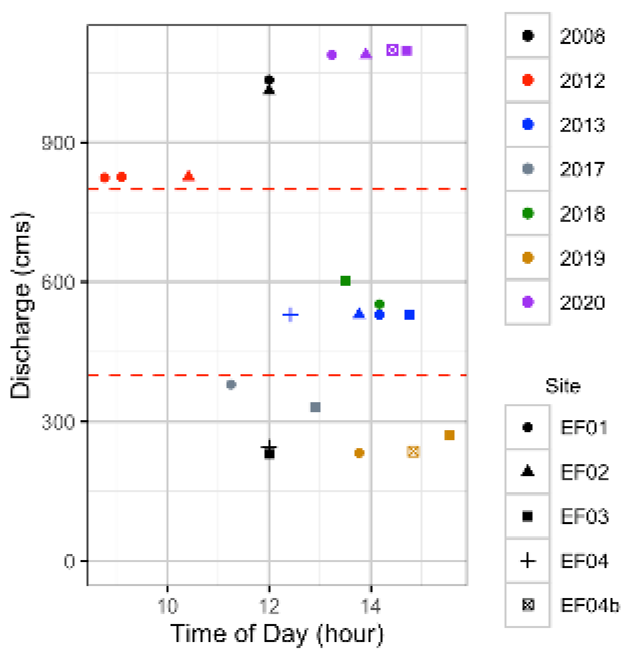
Annual discharge from Mica Dam for 2008 to 2020 is summarized in A2 Figure 3. Additional turbines, Mica 5 and 6, became operational on January 28th, 2015 and December 22nd, 2015, respectively. Boat and backpack electrofishing have occurred over a range of flows throughout the CLBMON-60 study (A2 Figure 4 and A2 Figure 5). Generally, sampling was conducted within the desired range (400-800 m^3/s); however, some sampling events occurred outside of the range when required flows could not be provided.



A2 Figure 3. Hourly discharge from Mica Dam by turbines (black) and turbines plus spill (red), 2008-2020. Fish surveys were completed in October of 2012, 2013, 2017 (backpack electrofishing only), and 2018-2020. Mica 5 and 6 became operational on January 28th, 2015 and December 22nd, 2015, respectively.



A2 Figure 4. Mean discharge for the period three hours before and during each boat visit. Red dashed lines show the target discharge range of 400-800 m^3/s.



A2 Figure 5. Mean discharge for the period three hours before and during each backpack visit. Red dashed lines show the target discharge range of 400-800 m^3/s.

Fish Observations and Capture

Fish Abundance and Distribution

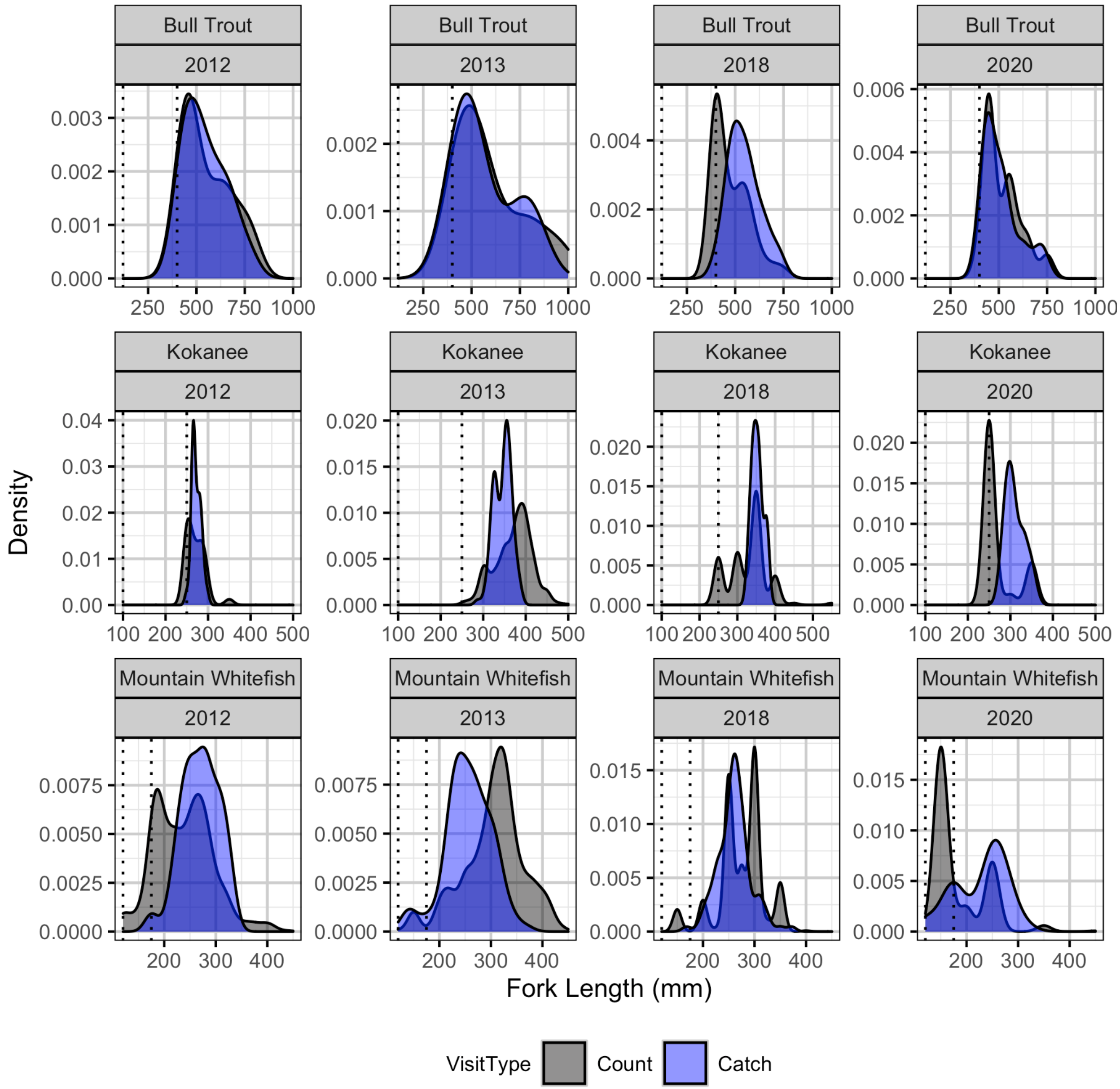
The observation passes for all five boat electrofishing sites took place on October 2nd and 3rd, 2020 between 22:28h and 00:21h. A total of 753 fishes were observed across all five sites. The most common species observed was Mountain Whitefish (MW) with 436 individuals counted (58% of all observations). Kokanee (KO) were also numerous with 185 individuals counted (25%). Other species observed were Bull Trout (BT; N=60), Suckers (*Catostomus* sp.; SU; N=18), and unidentified salmonids (N=53). No Rainbow Trout were observed during the observation passes in 2020. Species evenness (calculated using the Shannon Evenness Index), which is very low (<0.2), was not calculated for each year as it is almost exclusively driven by changes in the density of MW.

Boat electrofishing capture was completed on October 3rd and 4th (21:34h to 01:54h). A total of 117 fishes were captured for assessing biometric data and verifying the observers' estimated sizes. Weights are only available for some individuals as there were issues with the scale during the capture pass. 18 adult Bull Trout were captured ranging from 275 to 720 mm in length, and only one weight measurement was recorded (3,640 g). 41 Kokanee (5 fry, 3 juveniles, 33 adults) were captured ranging from 50 to 359 mm and 3.5 to 924 g in weight. 50 Mountain Whitefish (2 fry, 10 juveniles, 38 adults) were captured ranging from 70 to 318 mm in length and 16 to 237 g in weight. Eight Suckers were captured ranging from 415 to 496 mm in length. No weights were recorded for Suckers.

The length frequency data for the four salmonid species counted by observers and caught by netters in all years of the study (2012-2020) are plotted with adult and juvenile length cut-off values (A2 Figure 6). The observers were generally good at size estimation as shown by the similarity between the distributions of the observed vs. measured lengths; however, there was a slight underestimation of the size of KO in 2020. Size estimation of MW was generally accurate; however, many more small MW were observed than were captured in 2020. No RB were captured to compare to the estimated lengths of the observed individuals. Individuals were classified as fry (age-0), juvenile (age-1 and older sub-adults) or adult (sexually mature) based on the length cut-offs by species outlined in A2 Table 1.

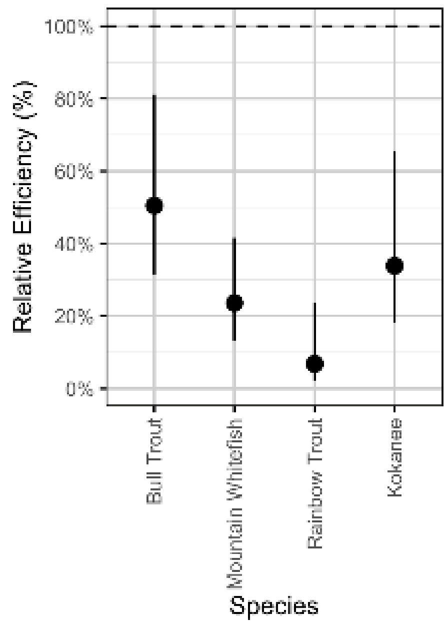
A2 Table 1. Size cut-offs for life stages of four salmonid species observed and captured.

Species	Fry	Juvenile	Adult
Bull Trout	<120	120-399	>400
Mountain Whitefish	<120	120-174	>175
Rainbow Trout	<120	120-249	>250
Kokanee	<100	120-249	>250



A2 Figure 6. Length density by species and for boat count (observed) versus boat catch (2012-2020). Fry and juvenile cut-offs are indicated by dotted vertical lines.

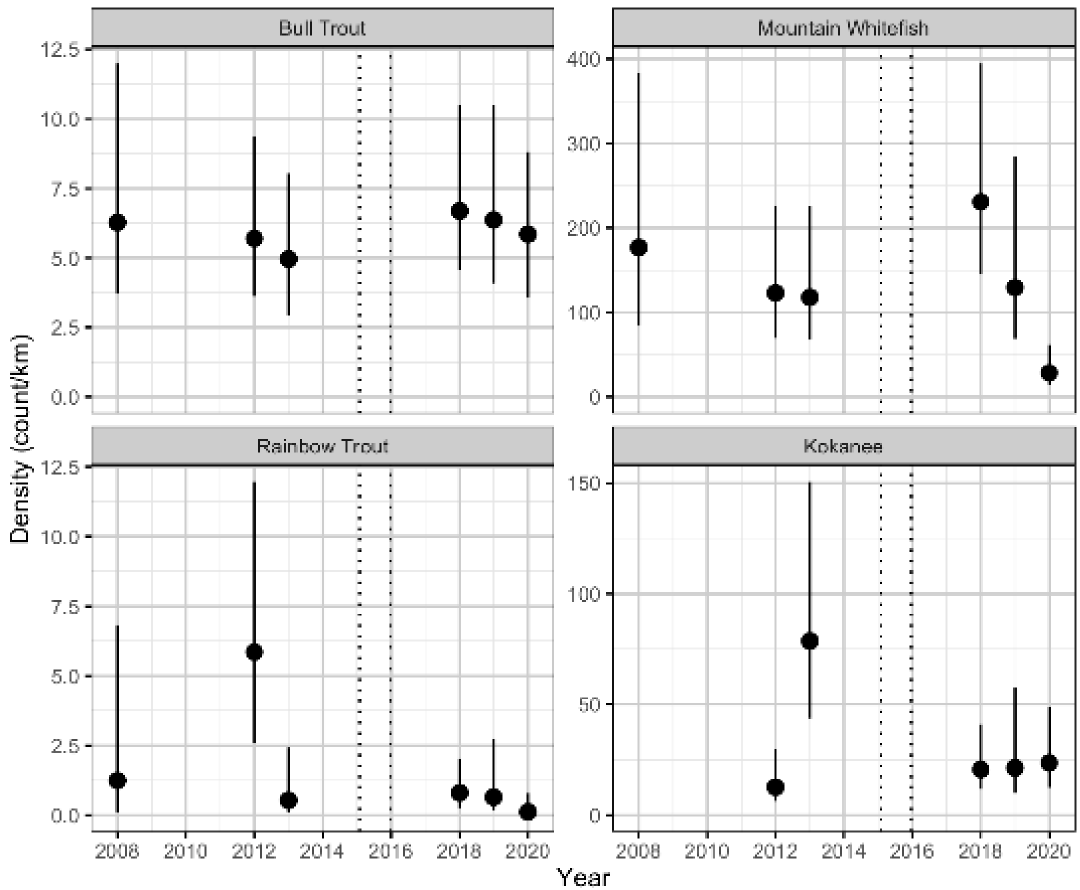
The relative abundance model (A2 Figure 7) estimated how efficient counting was relative to netting for all years of the study. The best estimate is that, on average, the netters catch 49% of the observed BT, 21% of the observed MW, and 33% of the observed KO. Less than 10% of the Rainbow Trout observed are netted.



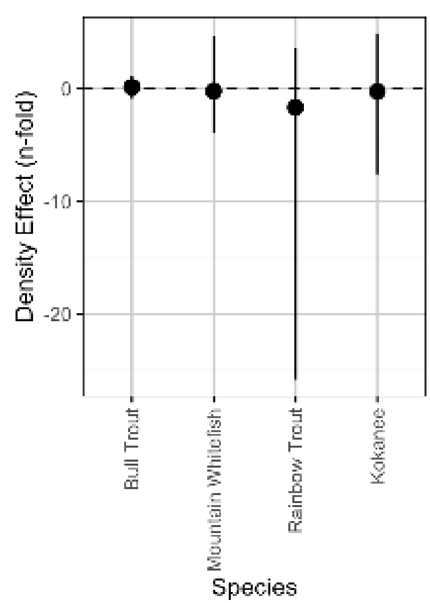
A2 Figure 7. Predicted boat catch to count relative efficiency (with 95% CRI).

The lineal count density for all four salmonid species (adult and juvenile) is provided in A2 Figure 8 and the estimated effect of Mica 5/6 on lineal count density in A2 Figure 9. In 2020, the lineal count density of MW was lower than in all previous study years but as 2018 was the highest year the model did not attribute the change to Mica 5/6. Densities of BT have been relatively consistent across all years. Lineal count densities of KO have also been fairly consistent, with higher densities observed in 2013. Overall, densities of RB have generally been low during both pre-and post-operation years although they were on average higher pre Mica 5/6 there is too much inter-annual variation to attribute the decline to Mica 5/6.

The estimated n-fold change in the expected lineal count density by species due to Mica 5/6 operation is plotted in A2 Figure 9. With respect to lineal count density, the estimated effect of Mica 5/6 includes the possibility of a positive change for all four species.



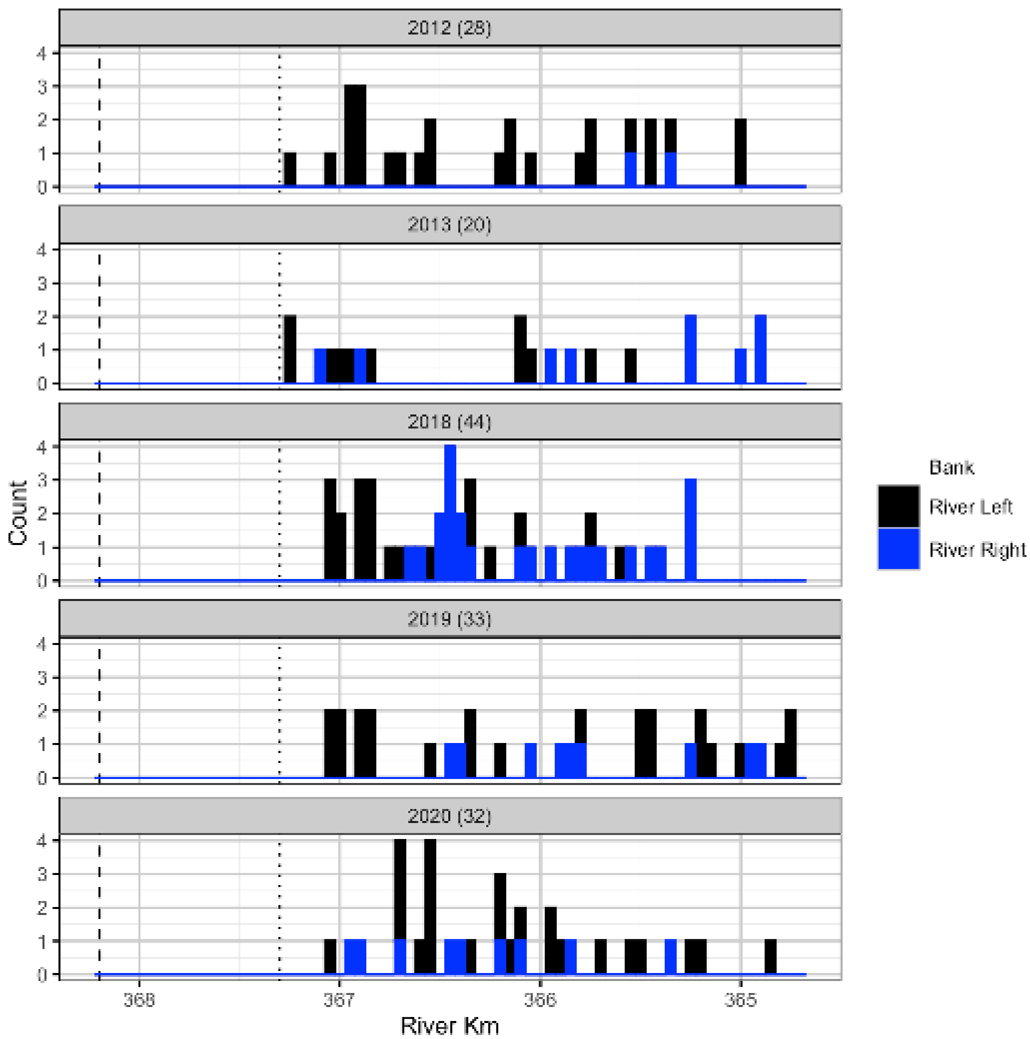
A2 Figure 8. Estimated lineal count density (with 95% CRIs). Dotted lines represent the dates when Mica 5 and 6 became operational (January 28th, 2015 and December 22nd, 2015, respectively).



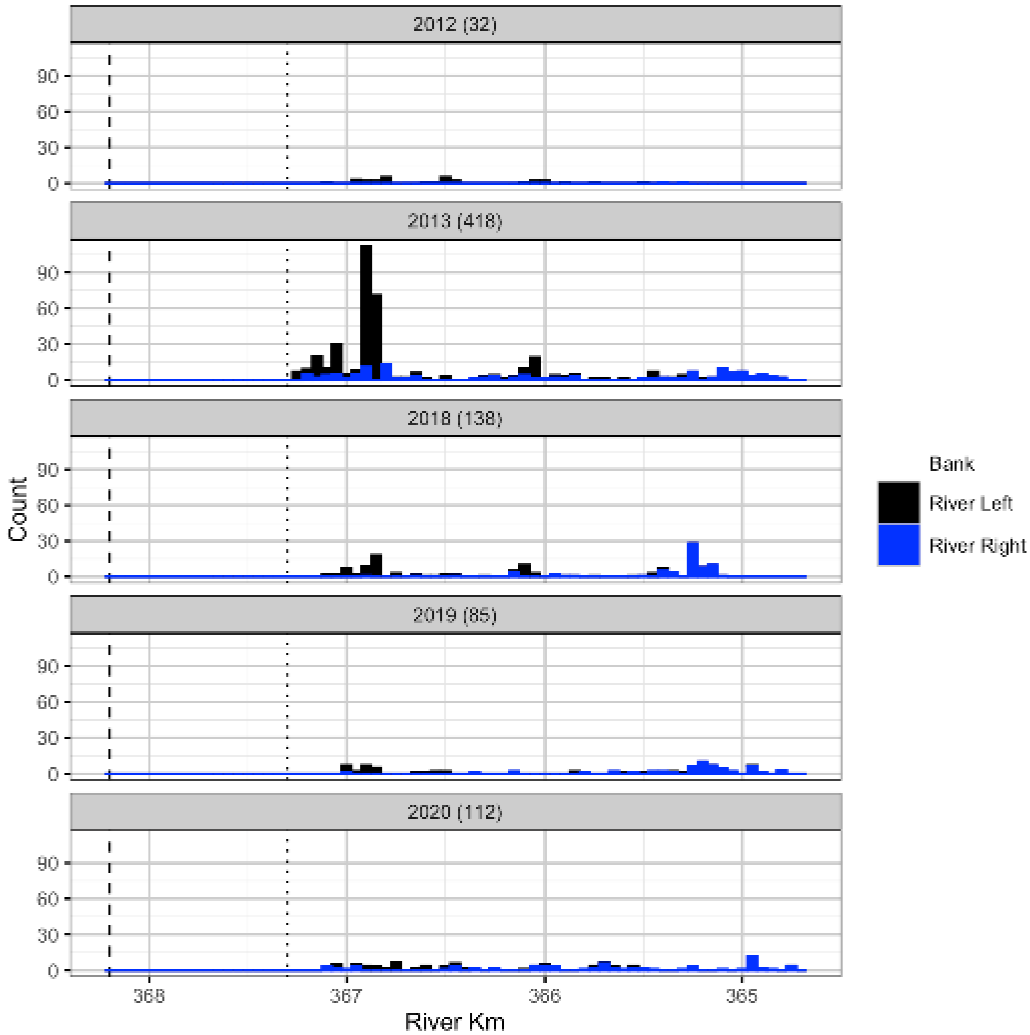
A2 Figure 9. Estimated effect of Mica 5/6 on the lineal count density (with 95% CRIs). The dotted line represents average pre-Mica 5/6 densities.

Fish counts were plotted by bank, river km and year in A2 Figure 10 to A2 Figure 14. Generally, fish were evenly distributed along both banks during the 2020 fish indexing study. BT were observed to have slightly higher densities along the left bank than to the right (A2 Figure 10). Adult KO counts in 2020 were similar to what was observed in 2019 with more fish observed on the right bank than on the left (A2 Figure 11). Adult MW observations in 2020 were the lowest of any years of the study (A2 Figure 12), whereas counts of juvenile MW (**Error! Reference source not found.**) were the highest in 2020. Juvenile MW were observed in greatest numbers just downstream of 367 Rkm, similar to what was observed in 2019. No RB were observed during the 2020 counts. Overall, few RB have been observed during this study, except for the 2012 study year. RB were found to be evenly distributed between both banks and along the length of the study area in 2012.

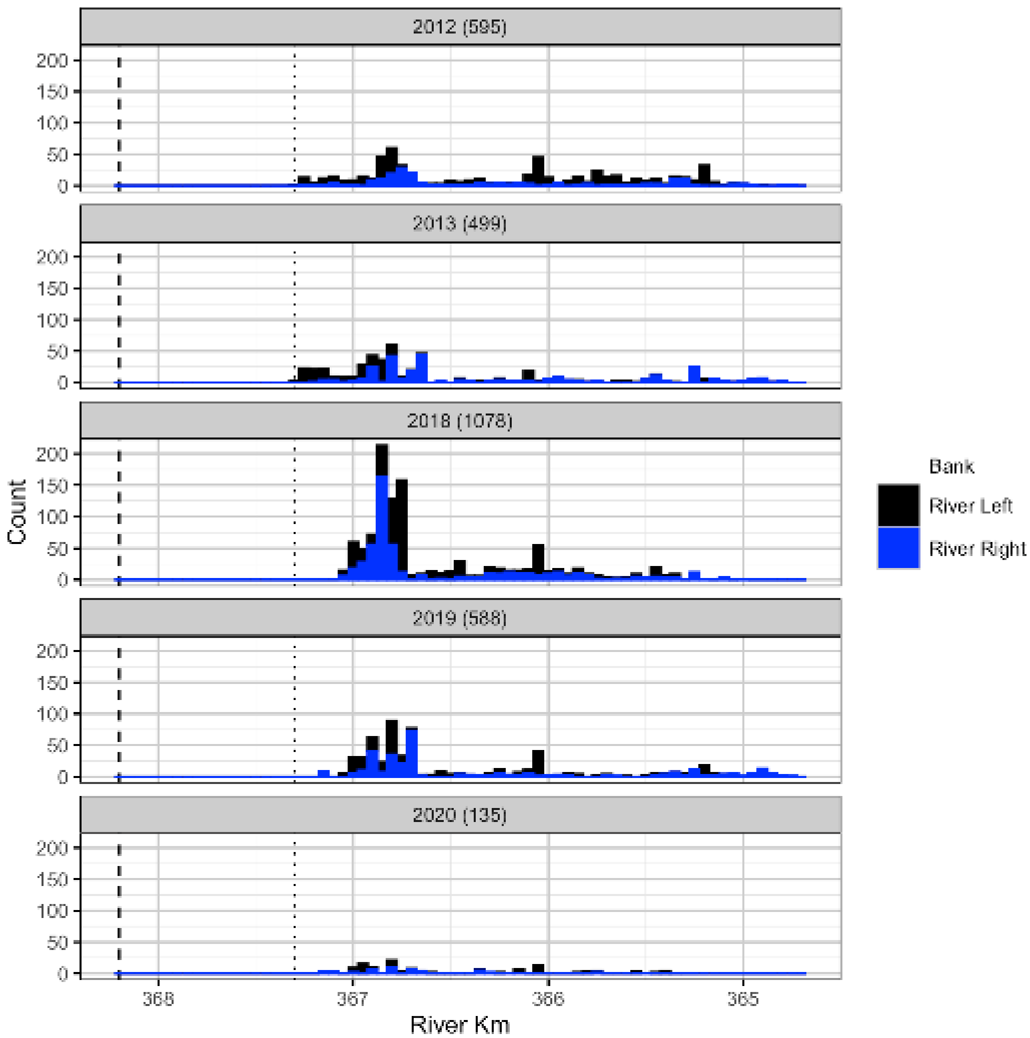
These data are also shown on maps with each fish's georeferenced location shown (Appendix B).



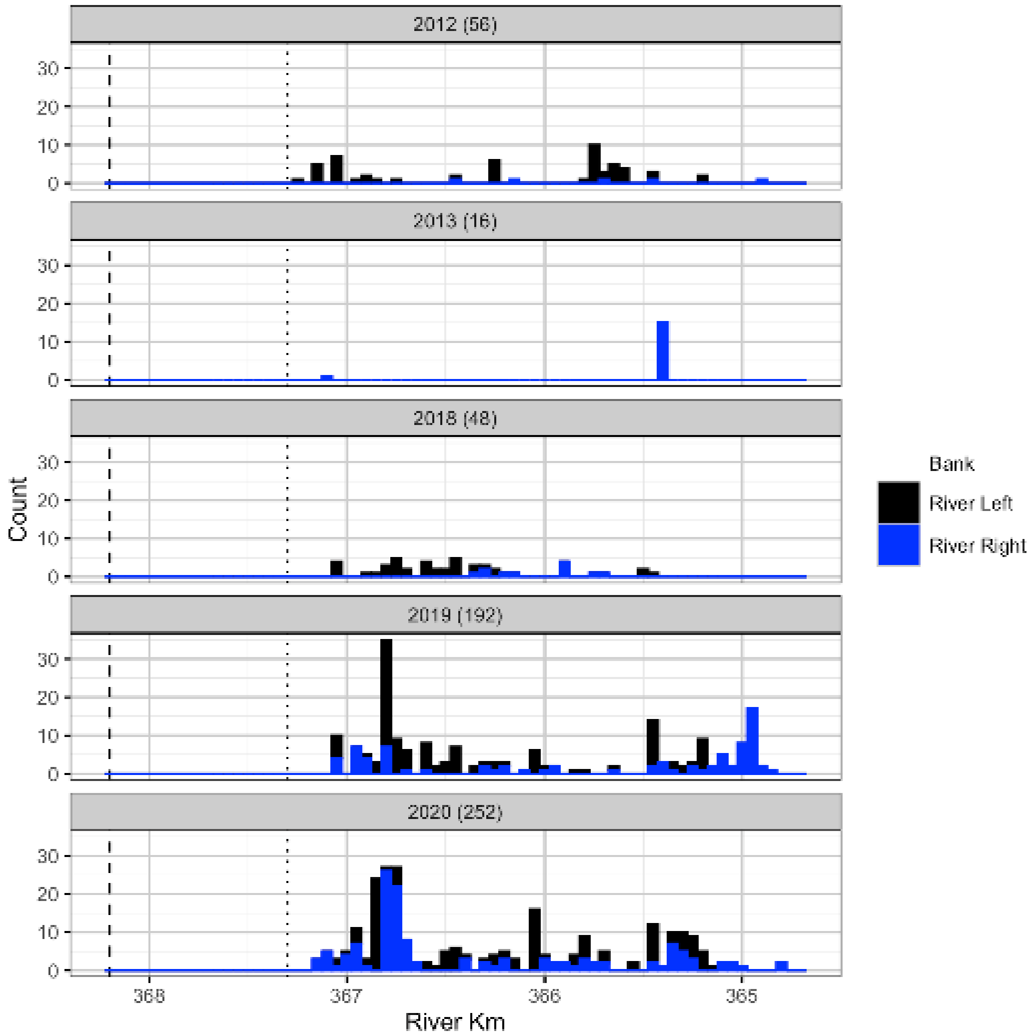
A2 Figure 10. Boat counts by river km and bank for adult Bull Trout. Mica Dam is indicated by the vertical dashed line and the log boom by the vertical dotted line.



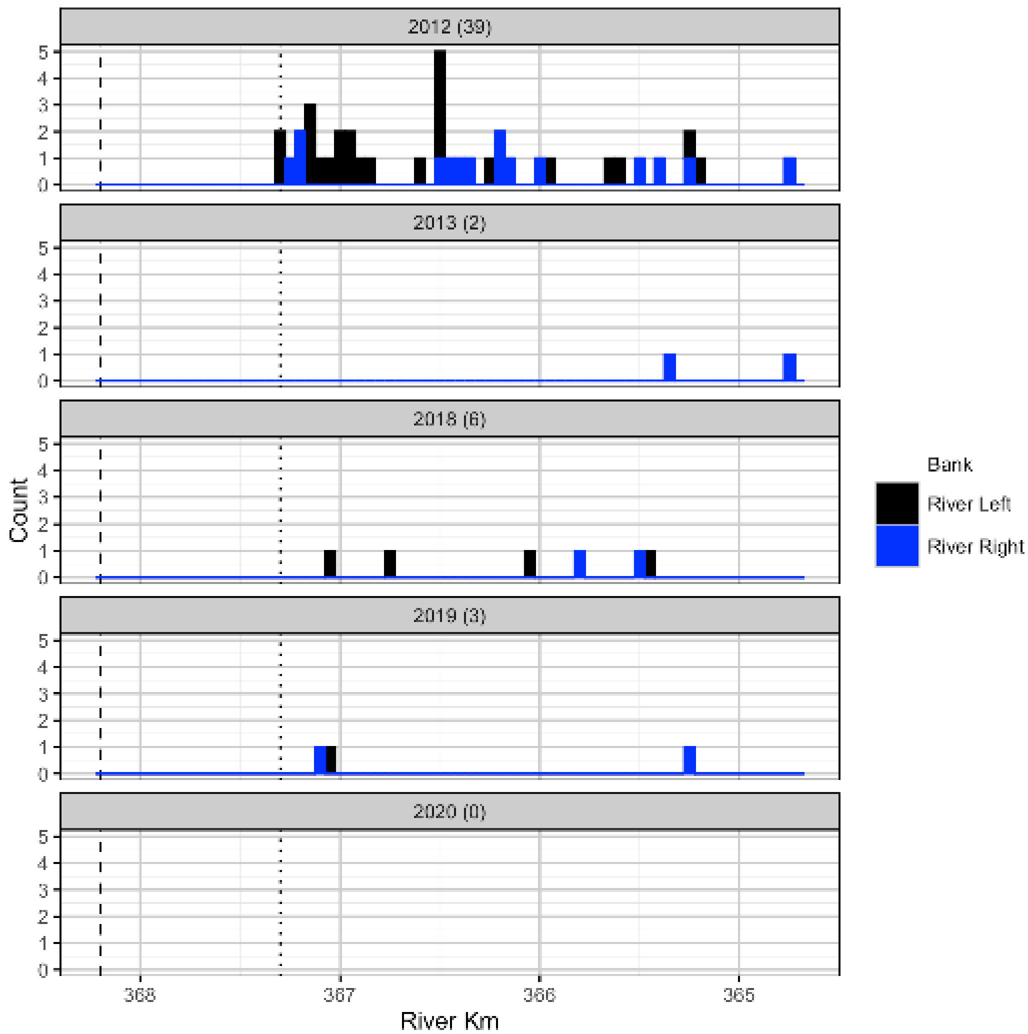
A2 Figure 11. Boat counts by river km and bank for adult Kokanee. Mica Dam is indicated by the vertical dashed line and the log boom by the vertical dotted line.



A2 Figure 12. Boat counts by river km and bank for adult Mountain Whitefish. Mica Dam is indicated by the vertical dashed line and the log boom by the vertical dotted line.



A2 Figure 13. Boat counts by river km and bank for juvenile Mountain Whitefish. Mica Dam is indicated by the vertical dashed line and the log boom by the vertical dotted line.

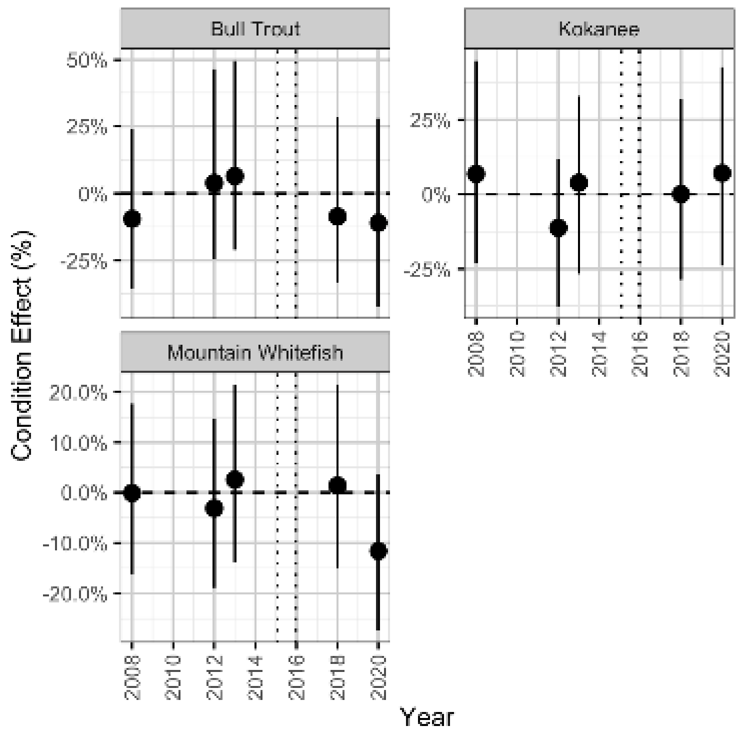


A2 Figure 14. Boat counts by river km and bank for adult Rainbow Trout. Mica Dam is indicated by the vertical dashed line and the log boom by the vertical dotted line.

Body Condition

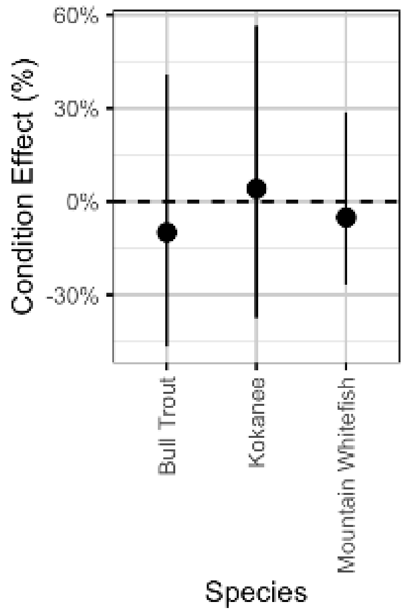
A2 Figure 15 presents body condition for MW, BT and KO for sampling events conducted between 2008 and 2020, except 2019 as a capture pass was not completed. Body condition was assessed with respect to the percent change in weight for a typical fish within a size class as compared to fish captured during an average pre-Mica 5/6 year. A typical fish for the small size class was 300 mm for BT, 80 mm for MW and 80 mm for KO. A typical fish for the large size class was 600 mm for BT, 250 mm for MW and 250 mm for KO.

Overall, body condition was relatively consistent across all sampling years and species. In 2020, MW had the lowest estimated body condition but the possibility of no change relative to a typical year could not be excluded.



A2 Figure 15. Estimated percent change in body condition (with 95% CRIs) by year relative to a typical year pre-Mica 5/6 (represented by dashed black line at 0%). The vertical dotted lines indicate the installation of Mica 5 and 6, respectively. Body condition information is not available for 2019 as a capture pass was not completed during the boat electrofishing study.

Additionally, percent change in fish body condition was evaluated with respect to pre- and post-Mica 5/6 operation (A2 Figure 16). This analysis shows how body condition has changed, on average, since Mica Dam began operating units 5 and 6. There is so much uncertainty in the change that the possibilities of a 20% or greater increase or a 20% or greater decrease in weight cannot be ruled out for any of the species.

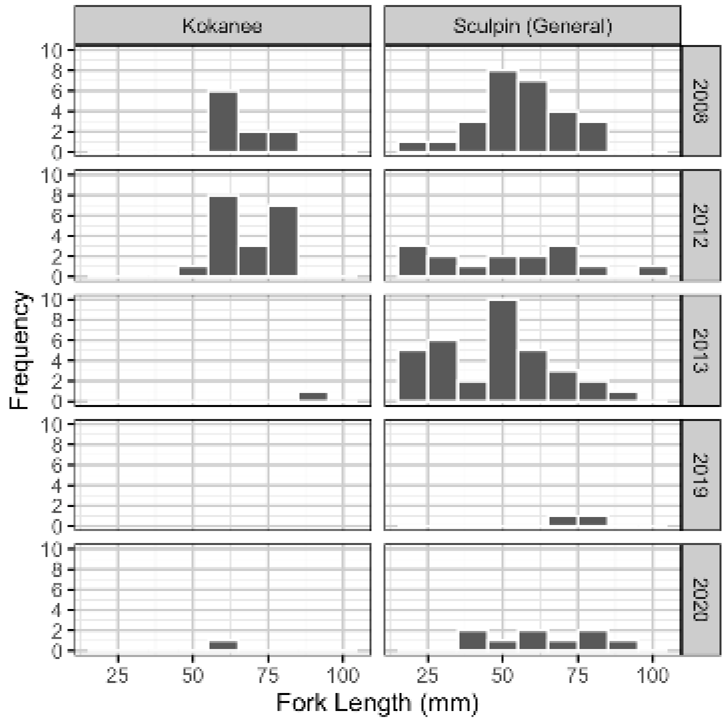


A2 Figure 16. Estimated percent change in body condition associated with Mica 5/6 by species (with 95% CIs).

Small-bodied Fishes & Juveniles

The backpack electrofishing study encountered some challenges with respect to accessing sites over the last four years (2017-2020). As stated in the previous annual report (Caley et al., 2019), attempts were made to find alternate sites; however, access was difficult due to high water levels and unstable substrates.

In 2020, it was possible to backpack electrofish sites EF01, EF02, EF03 as well as an alternate site for EF04. The sites were generally rocky with steep banks and consolidated substrates. Steep drop-offs limited the area suitable for backpack electrofishing and it was not possible to electrofish the full length of any of the sites. Total effort for EF01 sampling was 452 s; three sculpins were captured. Total effort for EF02 sampling was 340 s; four sculpins were observed and two of those were captured. Total effort for EF03 sampling was 393 s; one KO was captured and six sculpins were observed, three of which were captured. Total effort for EF04 (alternate site) sampling was 219 s; two sculpins were observed and one of those was captured. A2 Figure 17 provides length frequency distributions for Kokanee and Sculpin captured across all study years.



A2 Figure 17. Stacked length frequency histogram of fishes caught backpack electrofishing by species and year. The plot excludes two KO (256 mm, 302 mm) that were caught in 2012, as well as one KO (200 mm) and one MW (23 mm) that were observed in 2019.

8.6 Discussion

See Section 4.1.

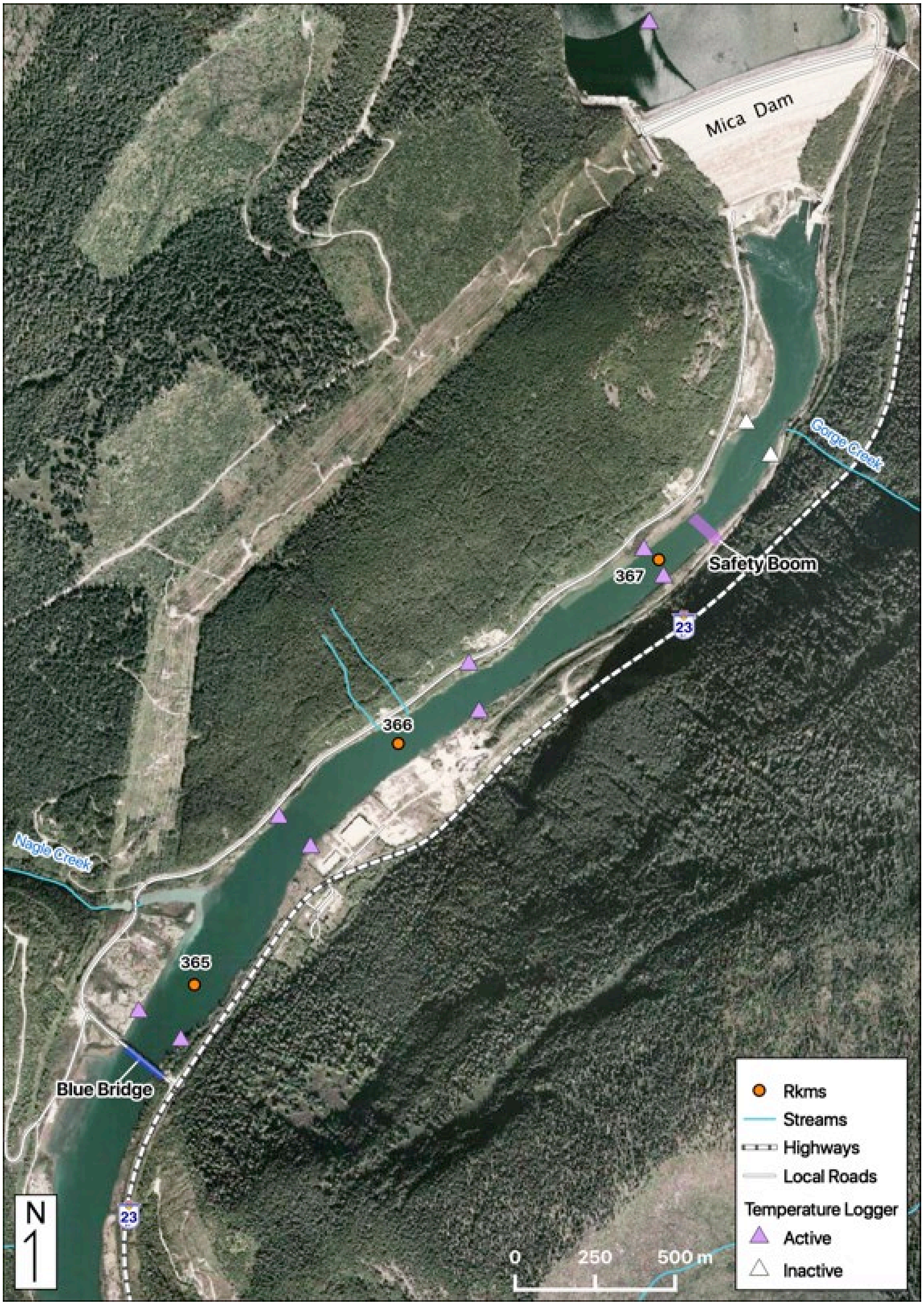
9.0 Appendix 3. Temperature Study

9.1 Introduction

See Sections 1.0 and 2.0.

9.2 Methods

Temperature loggers (HOBO TidbiT® v2) were installed in both the headpond and tailrace from October 2012 until October 2019. A3 Figure 1 shows the locations of the temperature loggers throughout the study area. Minor changes have been made to their locations and configurations, which are described in previous reports (Irvine et al 2013; Bisset et al 2015). Four arrays were located on each bank of the river downstream of the dam located approximately across from each other and dispersed along the length of the study reach. Each array had duplicate loggers (16 loggers in total). The headpond array was modified in May 2018 to address ongoing issues with the cable becoming tangled during drawdown and refilling of Kinbasket Reservoir. The configuration used by AMEC and Poisson (2012) in DDMMON-7 was used in this study as it does not result in the collapsing of the array during drawdown, thereby reducing the chance of tangling. See Caley et al (2019) for more details on the headpond array. All temperature loggers were programmed to record temperature measurements at 15 minute intervals. In the end, BC Hydro instrumentation of the headpond (9 thermistors) was used to provide water temperatures from 2013-2019 due to challenges with the installed array.



A3 Figure 1: Temperature logger locations in the Mica Dam headpond and tailrace. Inactive loggers show the locations of the loggers before being moved downstream of the public safety boom.

Temperature data were downloaded as .hobo files and exported to Excel spreadsheets for inclusion into the database. Fish faunal data were entered into Excel spreadsheets and underwent QA/QC procedures as outlined in the study plan for this project then imported into the database. The historical indexing information was obtained from the database for the 2008 study in the Mica Dam tailrace (Golder 2008).

The information about temperature loggers' deployment, individual logger's identification and locations as well as all downloaded temperature data from historical studies in the area and the current study were imported into the database. The discharge and elevation information for Kinbasket and Revelstoke Reservoirs were extracted from the Columbia Basin Hydrological Database, which is maintained by Poisson Consulting Ltd. for BC Hydro.

9.3 Dataset

A3 Table 1: Summary of proportion of year monitored for temperature study at each site for CLBMON-60.

Rkm Location	Proportion of Sampling Year Monitored for Temperature (%)						
	2013	2014	2015	2016	2017	2018	2019
367.5R	90	100	56	67	0	0	0
367.5L	89	93	54	80	0	0	0
367R	0	0	0	20	78	60	73
367L	0	0	0	20	100	36	0
366.3R	92	95	14	87	78	60	72
366.3L	74	95	58	100	100	60	72
365.6R	87	94	54	100	82	24	73
365.6L	89	94	58	100	100	36	0
364.8R	0	38	77	81	81	53	52
364.8L	0	59	54	99	100	60	72

9.4 Analyses

Tailrace

Climatic variation can cause large differences in annual temperatures. Consequently, we explored the data for an effect of the additional turbines on the difference in the water temperature between the right versus left bank and when moving downstream. All apparent systematic differences were within the accuracy of the temperature loggers (0.2°C).

Headpond and Tailrace

For the final summary report, BC Hydro thermistor data for the Mica Dam headpond were obtained. There is a total of nine thermistors located on Mica Dam that record hourly temperature at different heights in the water column.

These temperature data were analyzed using Maximum Likelihood (Millar 2001) and Template Model Builder (TMB) (Kristensen et al. 2016) to determine the extent to which discharge from the turbines and the air temperature influences the water temperature in the tailrace.

Key assumptions of the hourly temperature model include:

- The effective depth of each unit depends on the unit (as a random effect) and its discharge (as a fixed effect)
- The water temperature effect of each unit depends on its effective depth (elevation relative to the thermistor at 690 masl) and the stratification in the forebay.
- The water temperature is affected by release from the dam and the difference in air temperature and the water temperature.

- The temporal autocorrelation is a first order moving average process.
- The residual water temperature at the tailrace temperature logger is normally distributed.

Despite the incorporation of a first order moving average process the residual variation in the hourly tailrace water temperature was strongly autocorrelated. Consequently, CIs are not provided for the coefficients or estimates.

9.5 Results

All of the available reliable water temperature data collected throughout this study are presented in this report. Temperature data obtained from the headpond arrays have been presented here; however, they have not been included in the hourly temperature model as there were significant gaps in the dataset due to broken cables and lost loggers.

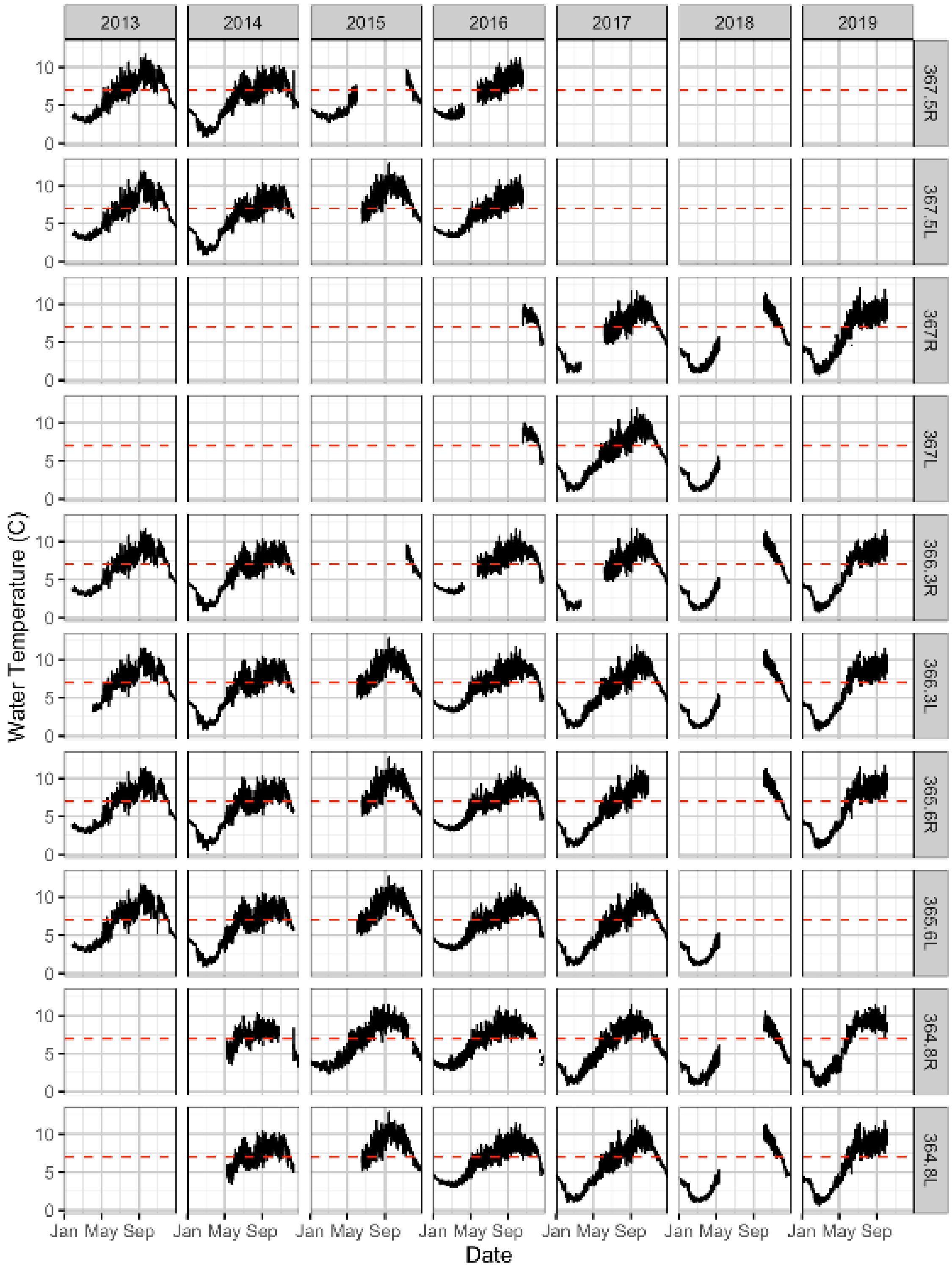
General Temperature Patterns

A3 Figure 2 shows the hourly water temperature for each site in the tailrace for every year of the study (2013-2019). Temperatures in the tailrace show a typical seasonal pattern. Hourly water temperature has not been analyzed with respect to pre- and post-Mica 5/6 as large inter-annual variation as well as climate change would obscure any changes in the thermal regime. Consequently, short-term spatial and temporal comparisons are used to identify the magnitude of any effect. In particular, hourly temperatures have been compared by bank and distance downstream.

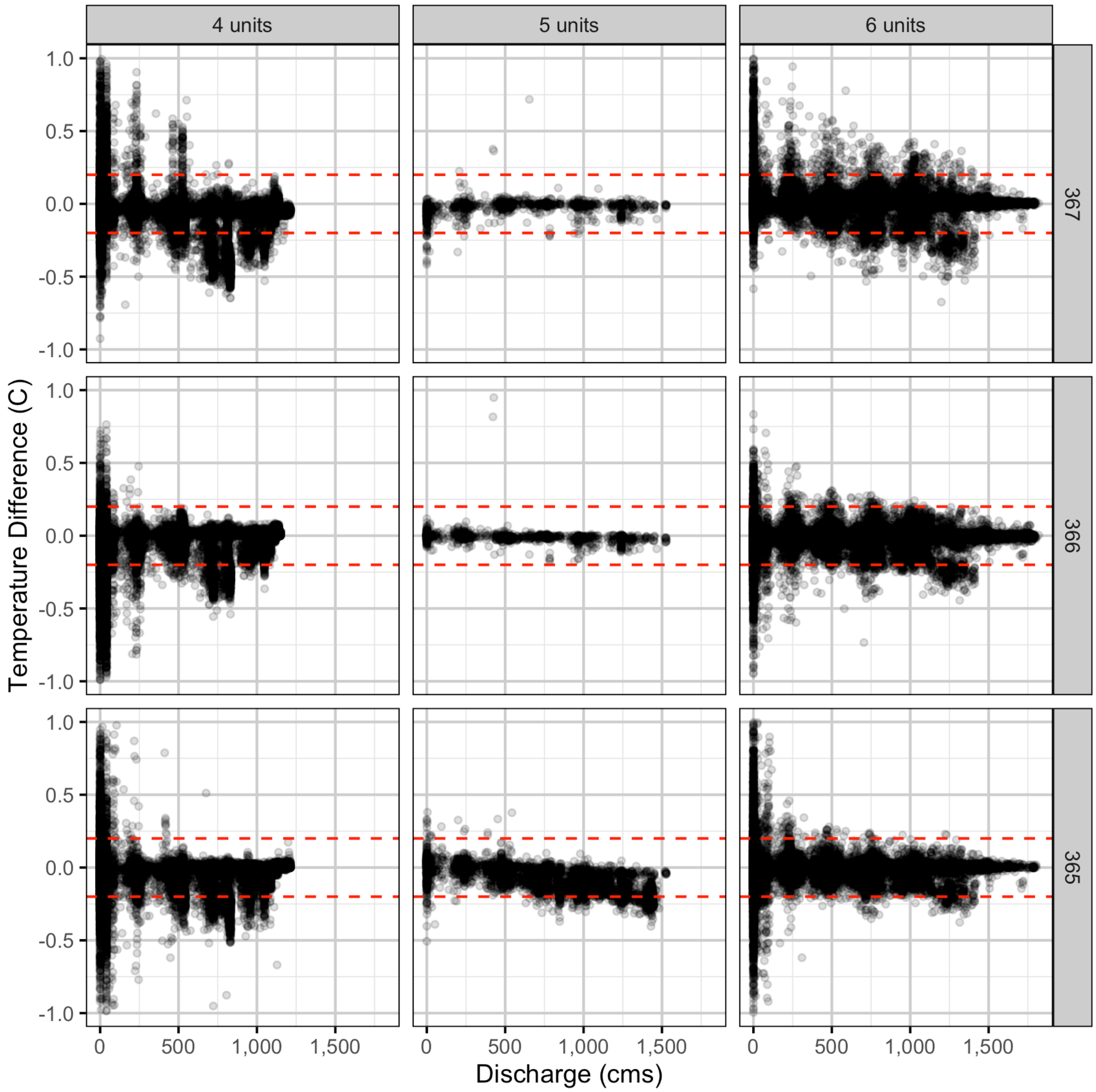
A3 Figure 2 also indicates the lower temperature limit (7°C) based on generalized temperature preferences for fish species found in the Mica tailrace (McCullough et al 2001; McPhail 2007). Water temperatures in the tailrace went below the lower preference seasonally. The generalized upper temperature preference of 18°C (McCullough et al 2001; McPhail 2007) is not shown on this figure as it was not exceeded at any logger in any year.

The differences in water temperature between the left and right bank by river km 365-367 and discharge are presented for 4, 5 and 6 turbines in A3 Figure 3. The accuracy of the temperature loggers is ±0.2°C and most of the observed systematic differences between the right and left bank were ± 0.2°C. The primary exception (not shown) was at very low flows when solar and tributary inputs can dramatically influence the temperature difference between the two banks. The data suggest that temperatures along the right bank tend to be slightly colder at higher discharge (difference of <0.2°C) compared to the left bank.

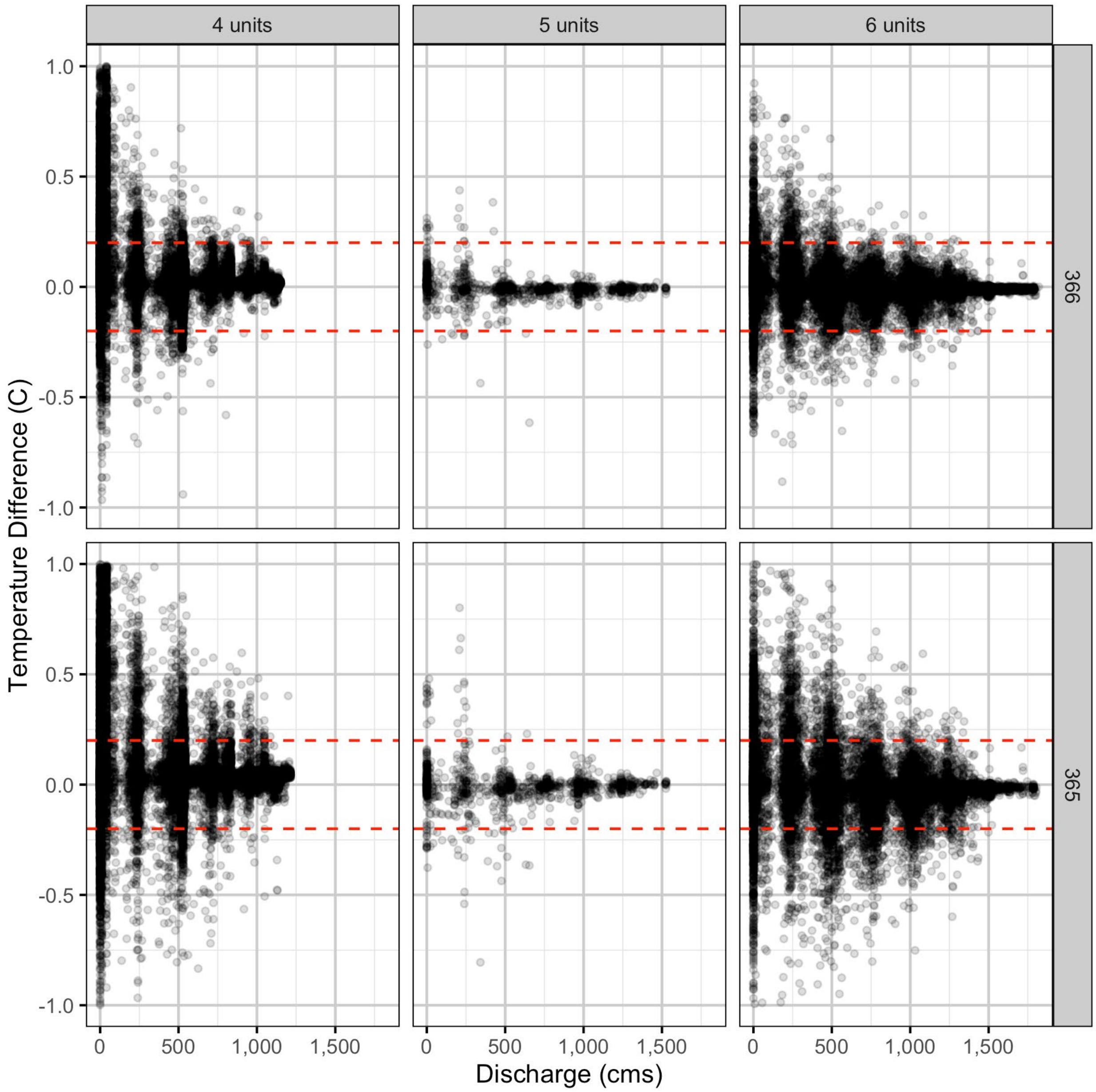
The differences in water temperature between sections of the tailrace (by river km) were also examined across discharge rates and the three operating scenarios (A3 Figure 4). Once again, most systematic differences were within ±0.2°C.



A3 Figure 2. Hourly water temperature in the Mica Dam tailrace by date, year, and site. The red dashed line shows the general lower temperature preference (7°C) of fish species found in the Mica tailrace. An upper temperature preference (18°C) is not shown as it was not exceeded at any location in any year.

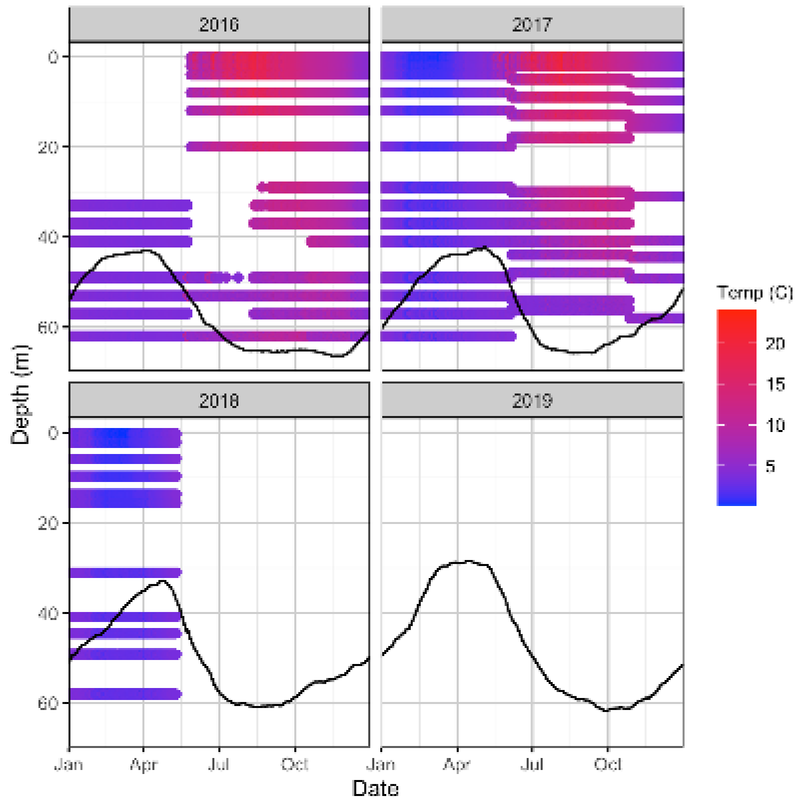


A3 Figure 3. The hourly water temperature difference between the left versus right bank for the 2013 to 2019 data by discharge, regime (4, 5 or 6 units), and river km for absolute differences less than or equal to 1.0°C. The red dashed lines indicate the accuracy of a temperature logger.



A3 Figure 4. The hourly water temperature difference compared to 367 river km for the 2013 to 2019 data by discharge, regime (4, 5 or 6 units), and river km for absolute differences less than or equal to 1.0°C. The red dashed lines indicate the accuracy of a temperature logger.

Water temperature profiles for the headpond from 2016 to 2019 are plotted in A3 Figure 5. Temperature data are not available for most of 2018 and all of 2019 due to broken cables and lost loggers.

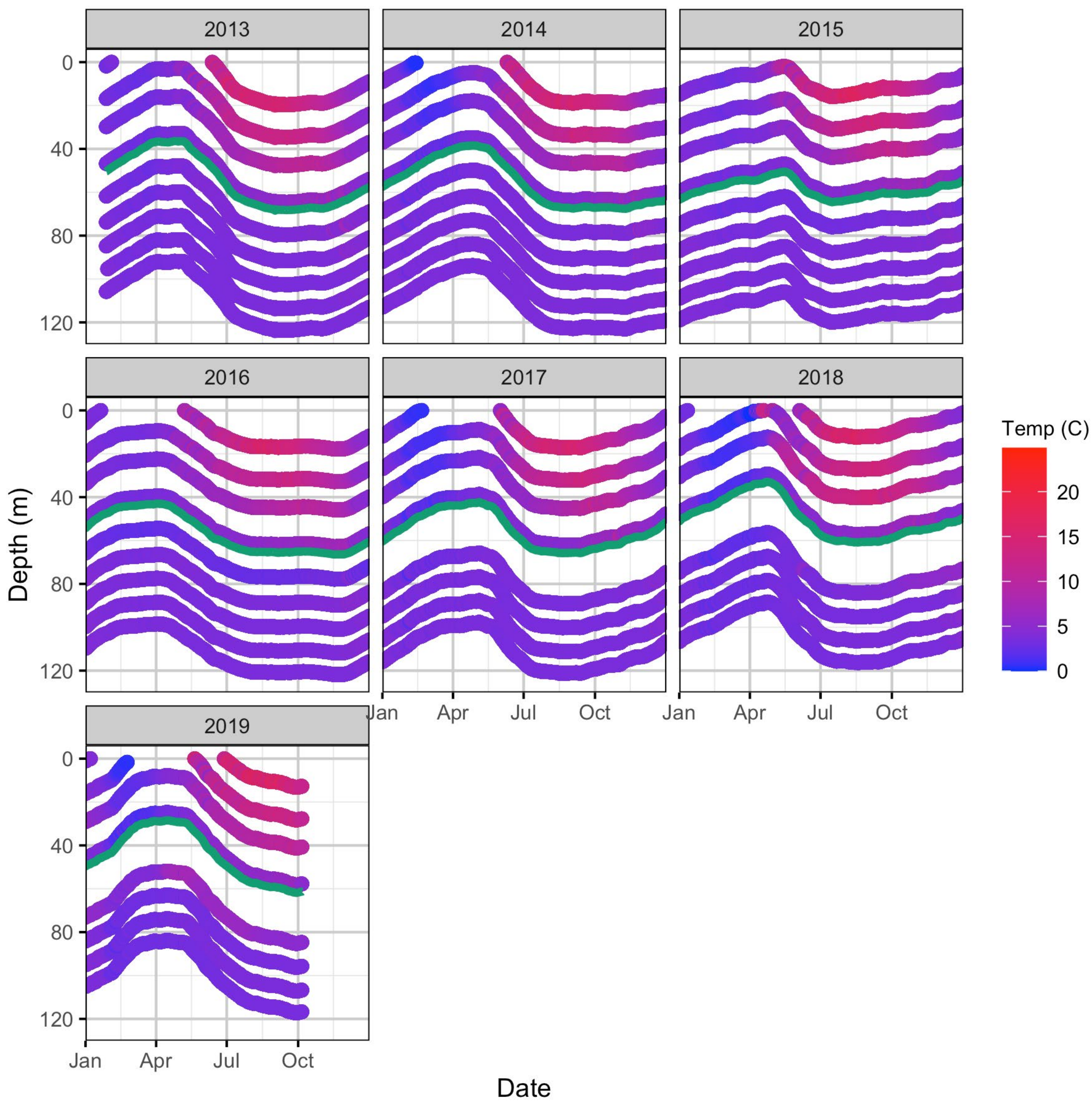


A3 Figure 5. Hourly water temperature in the Mica Dam headpond by date, depth, and year. The black line represents the location of the turbine intakes in the water column relative to the vertical arrays.

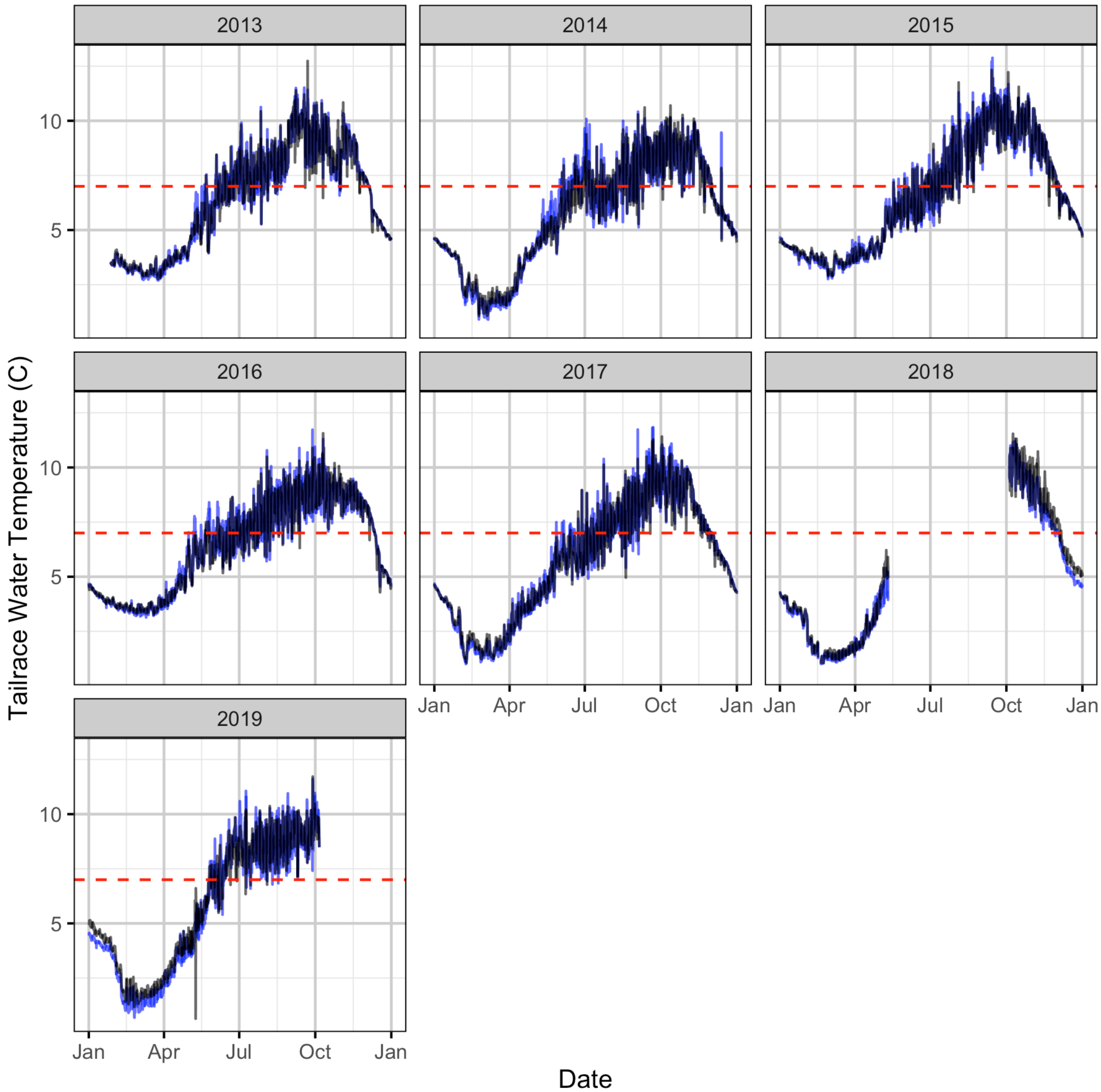
Hourly Temperature Model

The purpose of the model was to understand the factors influencing observed temperatures in the Mica tailrace. Thermistor temperatures from Mica Dam were used to understand the temperature regime in the Mica headpond and to determine when and to what extent thermal stratification occurred in the water column. BC Hydro also provided discharge data broken down by individual turbine and spill, which allowed the model to determine if one or more of the turbines influenced tailrace water temperatures to a larger extent than the others. Air temperature from the Government of Canada Weather station at Mica (Climate ID: 1175122) was also incorporated into the model.

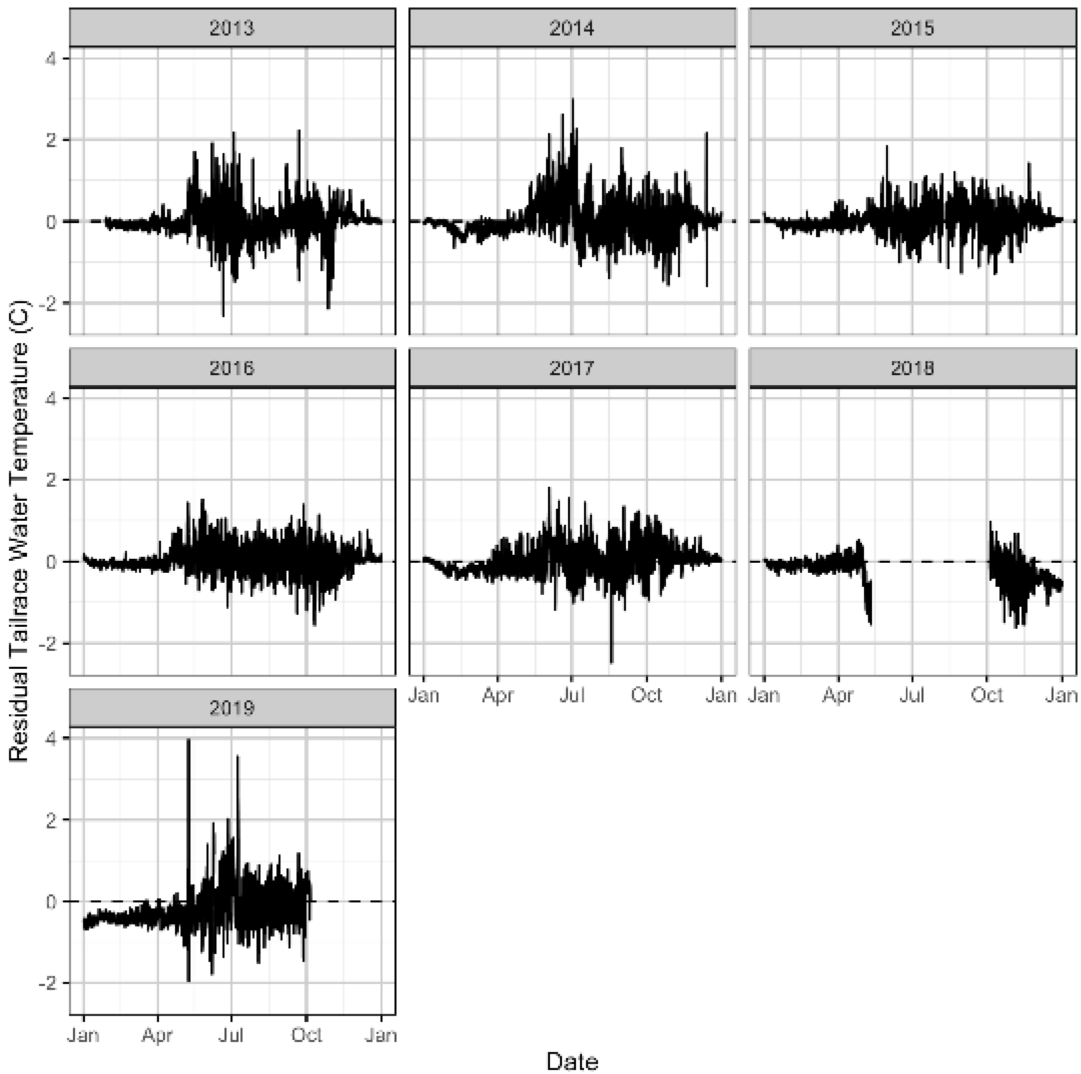
A3 Figure 6 presents the raw hourly temperature data for the study period (2013-2019) for each of the nine thermistors in the Mica headpond, as well as the location of the intake at the sill. The predictions of the hourly temperature model are presented in A3 Figure 7. Based on the data, the model predicted the hourly temperatures in the Mica tailrace over the study period. Predicted hourly water temperatures were compared to observed water temperatures at logger 366.3L (A3 Figure 2). Gaps in the dataset for logger 366.3L were filled where possible with temperature data recorded at logger 367.5R. The residual (unexplained) variation in the tailrace water temperature is plotted by date in A3 Figure 8.



A3 Figure 6. The Mica Dam thermistor water temperatures by date, depth and year. The green line indicates the turbine intake sill depth of 686.41 masl.

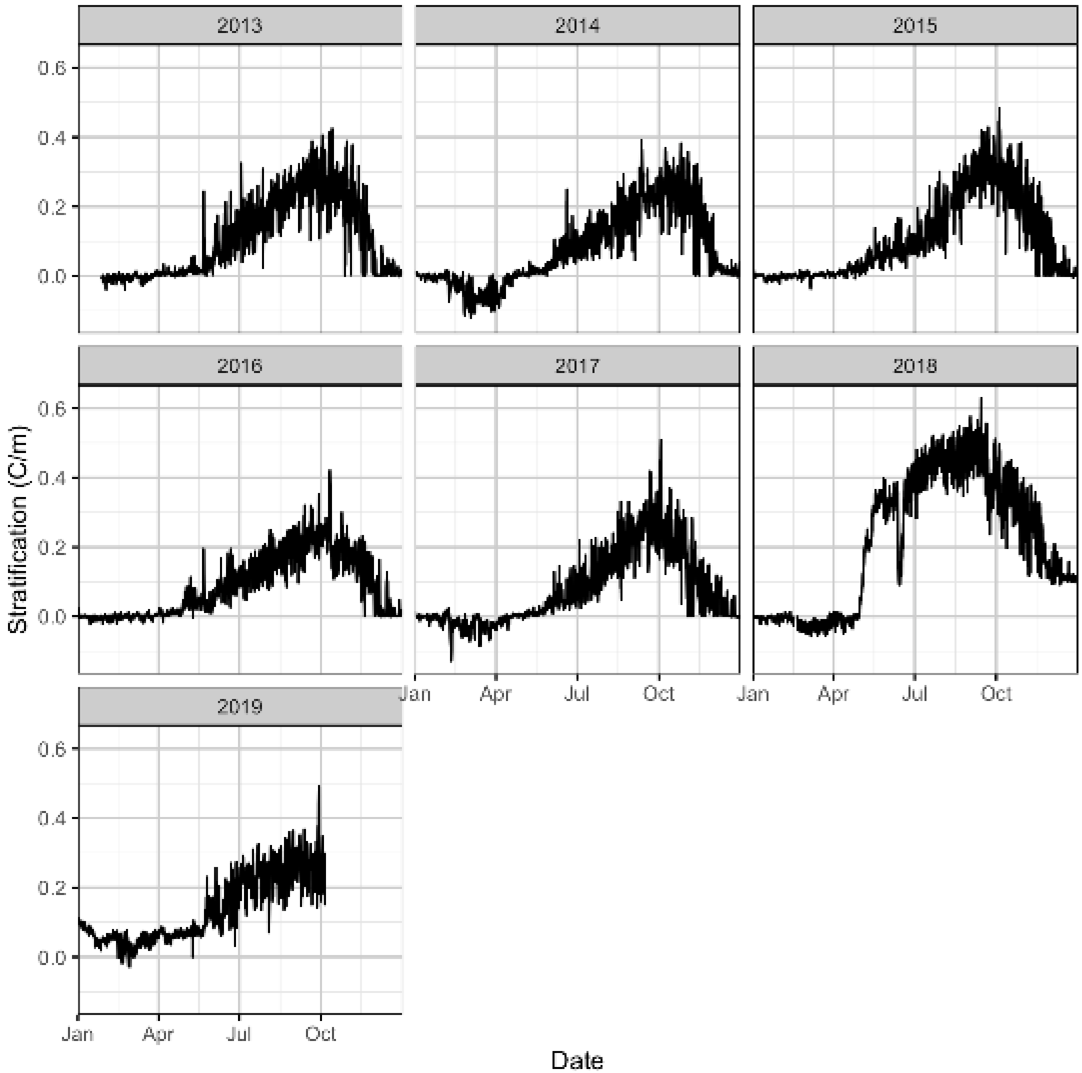


A3 Figure 7. The actual (blue) and estimated (black) hourly tailrace water temperature by date and year. The red dashed line shows the general lower temperature preference (7°C) of fish species found in the Mica tailrace. An upper temperature preference (18°C) is not shown as it was not exceeded at any location in any year.



A3 Figure 8. The raw residual hourly tailrace water temperature by date and year.

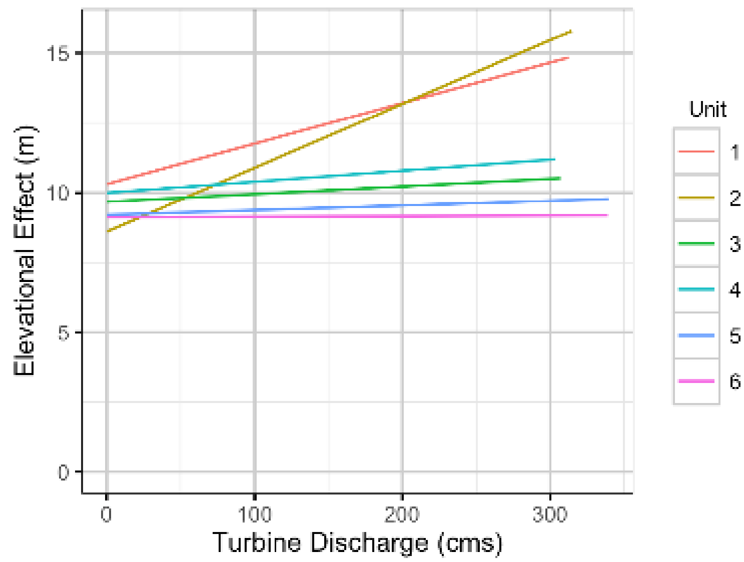
To understand the effect of the individual turbines on the water temperatures in the Mica tailrace, it was necessary to evaluate the timing and degree of thermal stratification in the Mica headpond. When thermal stratification occurs, it is possible for the turbines to draw from warmer water, thereby increasing the potential for warmer water to be discharged into the tailrace. To calculate the degree of thermal stratification occurring in the headpond, the two thermistors at 690 and 707 masl were used to calculate a gradient of temperature change (°C/m) in the water column. The timing and amount of thermal stratification observed over the study is plotted in A3 Figure 9. Generally, thermal stratification in the Mica headpond began in late May peaked in early October, and tapered off in late November. Overall, the pattern of thermal stratification and maximal differences in water temperature were consistent between years (~ 0.4-0.5°C/m). A slightly different pattern was observed in 2018 with thermal stratification beginning in May with initially a faster rate of change and a larger maximum degree of stratification (~ 0.63°C/m).



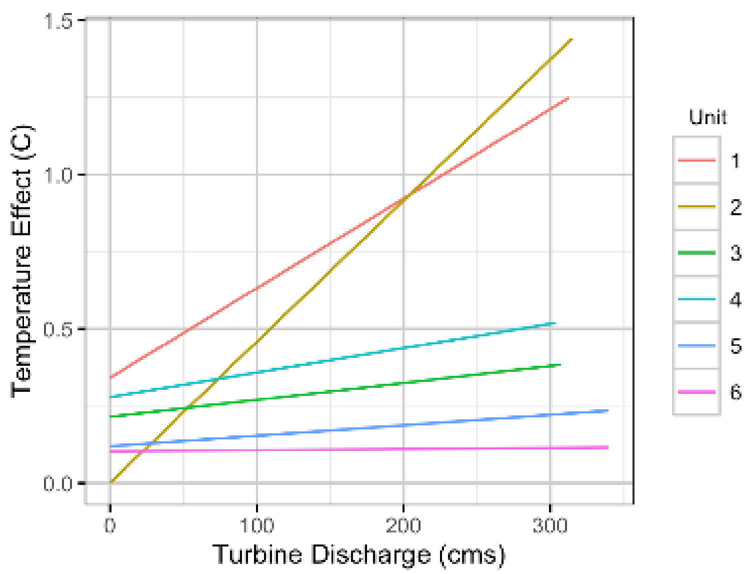
A3 Figure 9. The hourly water temperature stratification between the thermistors at 707 masl and 690 masl by date and year.

Using the changes in thermal stratification over time and discharge rates for individual turbines, an elevational effect was calculated (A3 Figure 10). This elevational effect describes the height in the water column above the thermistor at 690 masl that the turbine is effectively drawing from based on the water temperature in the downstream tailrace. The results indicate that at low discharge levels all turbines are effectively drawing water from a height of approximately 10 m above the thermistor at 690 masl but as the discharge increases turbines 1 and 2 are effectively draw from higher in the water column (up to 15 m) while turbines 3-6 draw from relatively similar heights (~ 10 m).

Based on the elevational effect it was then possible to calculate the temperature effect for each turbine at a typical stratification of 0.2°C/m (A3 Figure 11). The results indicate that at a typical thermal stratification levels turbines 1 and 2 draw from water almost 1°C warmer than the other turbines at high discharge.

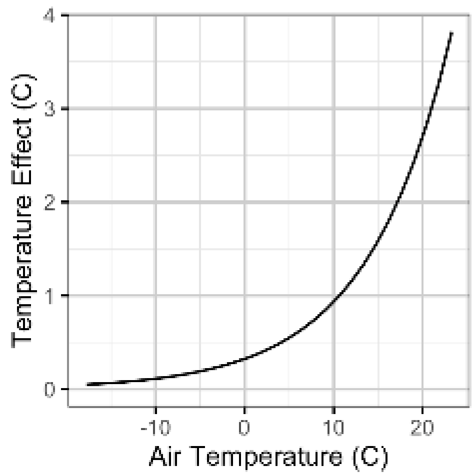


A3 Figure 10. The estimated elevational effect relative to the intake (690 masl) by the turbine discharge and unit number.



A3 Figure 11. The estimated temperature effect relative to no discharge at Unit 2 by the turbine discharge and unit number.

The temperature model also estimated that the temperature of the water discharge from the dam is influenced by the air temperature as shown in A3 Figure 12.



A3 Figure 12. Relationship between air temperature and the temperature effect in the hourly temperature model for Mica tailrace.

9.6 Discussion

See Section 4.2.