Columbia River Water Use Plan

LOWER COLUMBIA RIVER FISH MANAGEMENT PLAN

Reference: CLBMON-45

Lower Columbia River Fish Population Indexing Surveys

Study Period: 2007 – 2019

Final Summary Report

Golder Associates Ltd.

Poisson Consulting Ltd.

Okanagan Nation Alliance

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Lower Columbia River
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Final Summary Report – 2019

Author:
Golder Associates Ltd.
Poisson Consulting Ltd.
Okanagan Nation Alliance

Prepared for:
BC Hydro

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Okanagan Nation Alliance
#101-3535 Old Okanagan Hwy,
Westbank, BC V4T 1V4
Phone: (250) 707-0095 Fax: (250) 707-0166

GOLDER

Poisson
CONSULTING

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Executive Summary

Discharge reductions at hydroelectric dams can result in the dewatering and mortality of fish eggs that are incubating in the river downstream. Operation of Hugh L. Keenleyside Dam (HLK) on the lower Columbia River (LCR) includes the Mountain Whitefish and Rainbow Trout flow regimes, which are strategies intended to reduce egg dewatering during the spawning and incubation periods for these species. The LCR Fish Population Indexing Program (CLBMON-45) was designed to monitor changes in populations of index fish species over time and assess the effects of the Mountain Whitefish and Rainbow Trout flow regimes on fish populations. The index fish species were Mountain Whitefish, Rainbow Trout, and Walleye.

The study area was the 56.5 km section of the Columbia River between HLK and the Canada-US border and the 2.8 km section of the Kootenay River from Brilliant Dam (BRD) downstream to the confluence with the Columbia River. Fish were sampled by boat electroshocking at night along the shoreline at 28 index sites. Captured fish were measured for length, weighed, and implanted with a small, uniquely-coded tag. From 2001 to 2019, each site was sampled four to six times per year in consecutive weeks. Statistical models were used to assess trends in fish populations between sites and years. The effect of egg dewatering on recruitment of juvenile (age-1) fish was assessed through the analysis of age-1:2 ratio as a recruitment index for Mountain Whitefish and through stock-recruitment models that included egg loss as a covariate for Mountain Whitefish and Rainbow Trout.

The results suggested a three-fold increase in abundance of adult Rainbow Trout from 2005 (15,000) to 2018 (46,000), and a small decrease in 2019 (38,000). High abundance in recent years coincided with lower body condition and growth, suggesting density-dependence and that the adult population may be at carrying capacity. Data for Walleye suggested relatively low but stable abundance from 2012 to 2019 compared to earlier years, and no persistent changes in growth, body condition, or survival during the study period. The abundance of Mountain Whitefish varied widely over the study period, with estimates of subadults that were relatively stable from 2013 to 2017, but more than 50% lower in 2018 and 2019. Estimated abundance of adult Mountain Whitefish was relatively stable since 2010, except in 2018 when abundance was approximately 65% higher. Length-at-age and body condition of Mountain Whitefish suggested relatively little change during the study period.

Modelling of the effect of egg dewatering mortality on the recruitment of age-1 juveniles did not suggest a strong effect of egg mortality for Mountain Whitefish or Rainbow Trout. For Mountain Whitefish, there was a negative but uncertain and not statistically significant relationship between the age-1:2 recruitment index and estimated egg losses across all years of the study (1999 to 2017 spawning years). However, the large estimated egg loss (59%) in the 2016 spawning year corresponded to a large decrease in the recruitment index and a >50% decrease in the estimated abundance of age-1 Mountain Whitefish. The stock-recruitment model for Mountain Whitefish did not suggest an effect of egg loss on recruitment. Based on these results, there was not strong support for an effect of egg dewatering mortality on subsequent recruitment of Mountain Whitefish but a large negative effect cannot be ruled out.

For Rainbow Trout, there was no evidence of a negative effect of egg losses on recruitment at the observed levels of egg loss, which were less than 2% in all years. The age-1:2 index was not calculated for Rainbow Trout because age-2 individuals could not be distinguished from age-3 and older fish. The conclusions regarding egg loss for both Mountain Whitefish and Rainbow Trout should be considered uncertain because of the poor fit in modelled relationships, and the possibility that sampling biases or environmental variability masked real effects of egg dewatering.

Flow variability in the LCR is expected to have less of an effect on Walleye than Rainbow Trout and Mountain Whitefish because the abundance of Walleye is thought to depend on spawning and early life history survival outside of the study area.

Table E1. Summary of final status of the management questions of CLBMON-45.

Management Question	Summary of Key Results
What is the abundance, growth rate, survival rate, body condition, age distribution, and spatial distribution of subadult and adult Whitefish, Rainbow Trout and Walleye in the Lower Columbia River?	**Abundance:** The abundance of Mountain Whitefish varied widely over the study period, with estimates of subadults that were relatively stable from 2013 to 2017, but more than 50% lower in 2018 and 2019. Estimated abundance of adult Mountain Whitefish was relatively stable since 2010, except for 2018 when abundance was approximately 65% higher. The results suggested a three-fold increase in abundance of adult Rainbow Trout from 2005 (15,000) to 2018 (46,000), and a small decrease in 2019 (38,000). The estimated abundance of subadult Rainbow Trout was greatest in 2001 to 2002 (29,000), fluctuated between 10,000 and 24,000 between 2003 and 2017, and was lowest in 2018 and 2019 (8,000–9,000). Data for Walleye suggested relatively low but stable abundance from 2012 to 2019 compared to earlier years. All of the Walleye captured were considered adults and juveniles are rarely captured in the study area. **Growth rate:** The growth of Rainbow Trout decreased since 2006, coinciding with increasing abundance. Mountain Whitefish growth generally increased from ~100 mm/yr in 2005 to 245 mm/yr in 2016, and decreased to approximately 140 mm/yr in 2017 to 2019. There was no substantial change in growth of Walleye in the LCR during the study period. **Survival rate:** Survival of adult Mountain Whitefish generally increased between 2002 and 2008 and was relatively stable between 2011 and 2019 (67%–85%). Survival estimates of Rainbow Trout increased gradually from 34% in 2003 to 50% in 2011, but declined to 35%–42% in 2012 to 2019. Survival of Walleye did not change substantially during the study period with estimates between 44% and 59% in most years. **Body condition:** The body condition of Mountain Whitefish and Walleye did not show any large or sustained trends. Subadult and adult Rainbow Trout body condition declined during recent years when their abundance increased. **Age distribution:** Previous years of the study showed that older fish (age-3 or older for Mountain Whitefish, age-2 and older for Rainbow Trout) in the LCR cannot be reliably aged based on scale samples. Age distribution was not explicitly described or compared between years. The age distribution was partly addressed through estimates of abundance of subadults vs. adults, and through age-ratio analyses used to address management question #2. **Spatial distribution:** The results provide a good description of spatial distribution of the index species in the LCR. There was a trend towards a less even distribution (more clustered) of Mountain Whitefish and Walleye and more even distribution of Rainbow Trout over time.

What is the effect of inter-annual variability in the Whitefish and Rainbow Trout flow regimes on the abundance, growth rate, survival rate, body condition, and spatial distribution of subadult and adult Whitefish, Rainbow Trout, and Walleye in the Lower Columbia River?	The primary way that variability in the flow regimes is expected to influence fish is through egg mortality due to dewatering during discharge reductions. Dewatering could affect recruitment of juvenile Mountain Whitefish and Rainbow Trout and the subsequent **abundance** of these index species. The effect of egg dewatering on recruitment of juveniles was assessed through the analysis of age-1:2 ratio as a recruitment index and through stock-recruitment models that included egg loss as a covariate. For Mountain Whitefish, the data were consistent with a small negative effect of egg dewatering mortality on recruitment but the possibility of a large negative effect, or no effect, could not be excluded. There was a negative but not statistically significant relationship between the age-1:2 recruitment index and estimated egg losses. Large estimated egg loss (59%) in the 2016 spawning year corresponded to a large decrease in the recruitment index and a >50% decrease in abundance of age-1 Mountain Whitefish. The stock-recruitment model for Mountain Whitefish did not suggest an effect of egg loss on recruitment. For Rainbow Trout, there was no evidence of negative effects of egg losses on recruitment at the observed levels of egg loss, which were less than 2% in all years. These conclusions for both Mountain Whitefish and Rainbow Trout should be considered uncertain because of the poor fit in modelled relationships, and the possibility that sampling biases or environmental variability masked real effects of egg dewatering. Flow variability in the LCR is expected to have little effect on Walleye abundance because spawning and early life history occur outside of the study area. Effect of flow variability on the **growth**, **survival**, **body condition**, and **spatial distribution** of the three index species are possible but likely involve indirect mechanisms such as changes in primary and secondary productivity (food availability) or habitat quality. Possible effects of flow variability on these fish population metrics are discussed in this report.

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Darin Nishi	Natural Resource Specialist		
Okanagan Nation Alliance			
Michael Zimmer	Advisor		
Amy Duncan	Biologist, Project Manager		
Dave DeRosa	Biologist, Project Manager		
Eleanor Duifhuis	Technician		
Bronwen Lewis	Biologist		
Ryan Poitras	Technician		
Charlotte Whitney	Biologist		
Evan Smith	Technician		
Paul Snow	Technician		
Autumn Solomon	Technician		
Andrew Clarke	Technician		
Davina Dube	Technician		
Golder Associates Ltd.			
Natasha Audy	Technician	Bronwen Lewis	Biologist
Demitria Burgoon	Biologist	Kevin Little	Biologist
Carissa Canning	Biologist	Carrie McAllister	Administrative Assistant
Bob Chapman	Technician, Senior Reviewer	Sarah McKinnon	Biostatistician
Blaine Cook	Technician	Teal Moffat	Biologist
Megan Crozier	Technician	Kim Poupard	Biologist
Dustin Ford	Project Manager, Advisor	Shawn Redden	Project Director
Ron Giles	Warehouse Technician	David Roscoe	Biologist, Project Manager
Jamie Goodier	GIS Analyst	Geoffrey Sawatzky	Technician
Paul Grutter	Biologist	Dana Schmidt	Project Director
Robert Harrison	Biologist	Sarah Stephenson	Biologist
Brad Hildebrand	Biologist	Sima Usvyatsov	Data Analyst
Larry Hildebrand	Project Advisor	Bob Wescott	Biologist
Mike Hildebrand	Biologist	Lynn Westcott	Biologist
Chris King	Technician	Steve Whitehead	Technician
Ed Lem	Technician		
Poisson Consulting Ltd.			
Joseph Thorley	Computational Biologist		
Robyn Irvine	Statistical Ecologist		
Seb Dalgarno	Computational Biologist		
Chris Muir	Statistician		
Patrick Hogan	Statistician		

Acronyms and Abbreviations

Acronym	Definition
BRD	Brilliant Dam
BRX	Brilliant Expansion Plant
CLBMON-45	Lower Columbia River Fish Population Indexing Surveys
CL	Credible Limit / Confidence Limit
CRI	Credible Interval / Condfidence Interval
FL	Fork Length
GPS	Global Positioning System
GPP	Generator Powered Pulsator
GRTS	Generalized Random Tessellation Stratified
HBM	Hierarchical Bayesian Model
HLK	Hugh L Keenleyside Dam
k	The growth coefficient from the von Bertalanffy growth model
L_∞	The asymptotic body length from the von Bertalanffy growth model
LCR	Lower Columbia River
LRFIP	Large River Fish Indexing Program
masl	Meters above sea level
MLE	Maximum Likelihood Estimate
PIT	Passive Integrated Transponder
RKm	River Kilometer
sd	Standard deviation
UTM	Universal Transverse Mercator
WUP	Water Use Plan
WUP CC	Water Use Plan Consultative Committee

Definitions

Term	Definition
Abundance	Number of individuals per species
Age-1:2 ratio	The ratio of the number of age-1 to age-2 fish, which was used an indicator of the relative number of fish produced by different spawning years
Body condition	A metric calculated from the weight and length of fish that is used as indicator of fish health
Capture efficiency	The probability of a fish being captured, which was calculated from fish tagging and recapture data, and used in the estimation of fish abundance
Egg dewatering	The process of eggs becoming dewatered and exposed to air when the river level decreases due to discharge reductions at the dam
Evenness	The evenness in the abundance of fish of a certain species between sites, which was used to monitor changes in spatial distribution over time
Index sites	Non-randomly selected sites that were sampled in all years of the program to monitor fish populations
Maximum growth rate	The predicted maximum growth rate during early life history that was calculated from the von Bertalanffy growth model and used as an indicator of annual growth
Mountain Whitefish and Rainbow Trout flow regimes	Operational strategies at HLK Dam and the resulting pattern in discharge in the Columbia River that are intended to improve the survival of Mountain Whitefish and Rainbow Trout eggs
Recruitment	The number of juvenile fish that are produced by a given spawning year and survive to a certain age (age-1 is considered the age of recruitment in the LCR).
Site fidelity	Site fidelity was the probability of a recaptured fish being caught at the same site at which it was previously encountered during the same year
Spawning protection flows	Operational strategies at HLK Dam and the resulting pattern in discharge in the Columbia River that are intended to improve the survival of Mountain Whitefish and Rainbow Trout eggs.
Stock-recruitment	The relationship between the number of spawning adults (“stock”) and the number of juveniles produced by those spawners (“recruitment”).
von Bertalanffy growth curve	A type of growth curve used to model mean length of each age

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1. Introduction

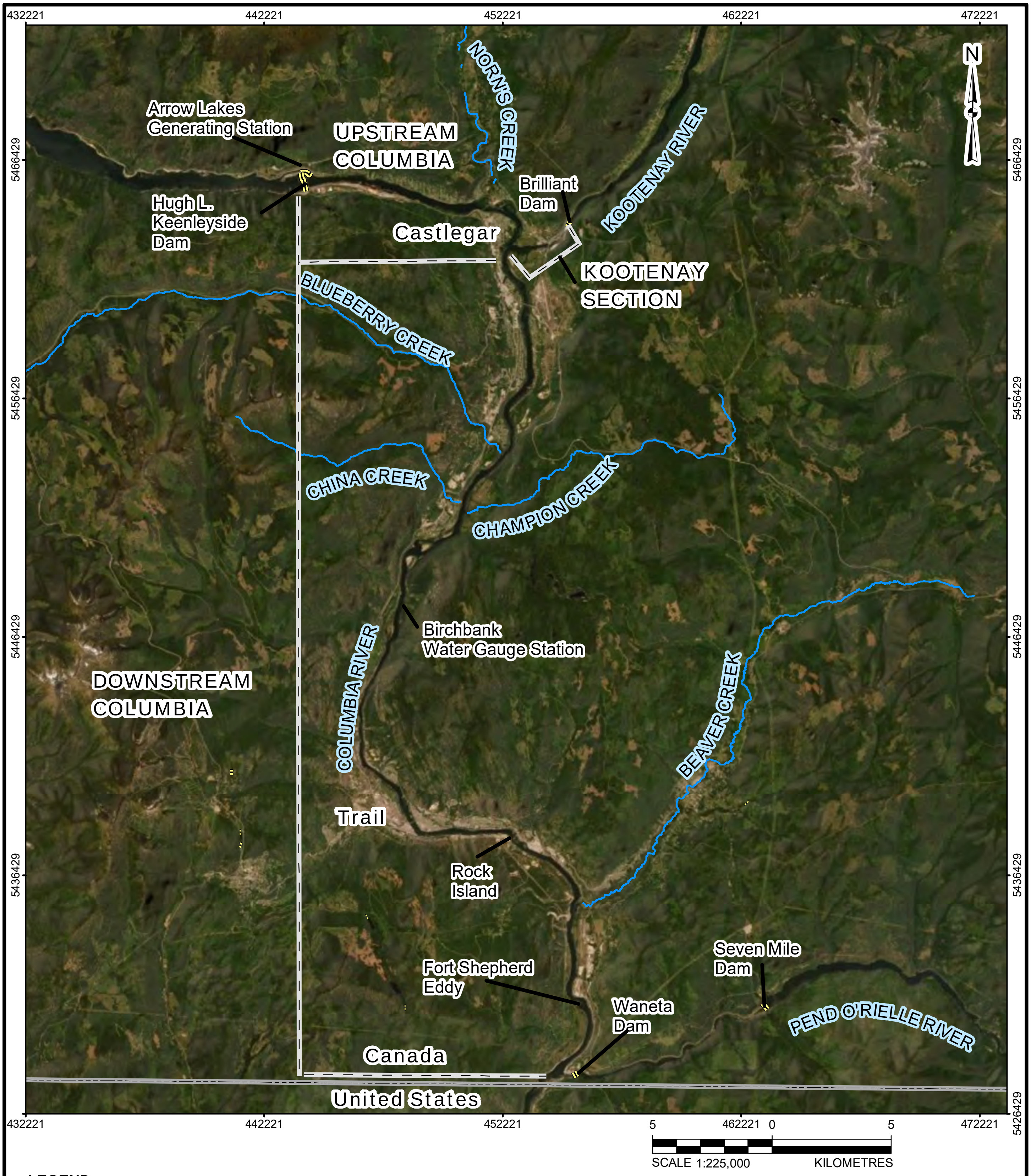
Discharge reductions at hydroelectric dams can result in the dewatering and mortality of fish eggs that are incubating in the river downstream. In the mid-1990s, BC Hydro initiated water management at Hugh L. Keenleyside Dam (HLK) on the Columbia River during the Mountain Whitefish (*Prosopium williamsoni*) and Rainbow Trout (*Oncorhynchus mykiss*) spawning seasons to reduce egg mortality downstream of the dam. During the Mountain Whitefish spawning season (December to February), BC Hydro decreases flow from HLK during the peak spawning period (24 December to 21 January; Golder 2010) to encourage spawning at lower water level elevations to reduce egg dewatering during the winter and early spring when annual minimum flows typically occur. Subsequently, flows are managed to provide stable or increasing water levels during the middle of the Rainbow Trout spawning season (early April to late June) to reduce the likelihood that Rainbow Trout eggs are dewatered during spring flow management. These operational strategies are referred to as the Mountain Whitefish and Rainbow Trout flow regimes.

BC Hydro implemented a Water Use Plan (WUP; BC Hydro 2005) for the Columbia River in 2007. As part of the WUP, the Columbia River Water Use Plan Consultative Committee recommended the establishment of the Lower Columba River (LCR) Fish Indexing Surveys (CLBMON-45) to monitor the effects of water management at HLK on downstream fish populations. CLBMON-45 represents a continuation of the Large River Fish Indexing Program (LRFIP), a program initiated by BC Hydro in 2001 to monitor the fish community downstream of HLK. For both programs, the index fish species targeted were Mountain Whitefish, Rainbow Trout, and Walleye (*Sanders vitreus*).

Together the LRFIP (2001–2006) and CLBMON-45 (2007–2019) provide a 19-year data set regarding fish populations in the LCR. These data were used to address the program's objectives of monitoring changes in populations of index fish species over time and assessing the effects of the Mountain Whitefish and Rainbow Trout flow regimes. This report provides a summary of the monitoring program over this 19-year period, including a brief overview of the methods (Section 3.0) and a summary of the key results as they relate to the program's management questions (Section 4.0). Detailed background, methods, results, and interpretation are provided in the appendices. Following the format for final reports for WUP monitoring programs, a separate appendix is provided with the technical details pertaining to each of the program's management questions. In addition to this WUP summary report, the results from 2001 to 2019 are detailed in a conventional scientific technical report (Golder et al. 2020).

2. Study Area

The study area was the 56.5 km section of the Columbia River from HLK to the Canada-U.S. border (Figure 1). The study area also included a 2 km section of the Kootenay River from its confluence with the Columbia River to 1 km downstream of Brilliant Dam. The Kootenay River joins the Columbia River 10 km downstream of HLK. Discharge in the Columbia River downstream of the confluence with the Kootenay is regulated by HLK and the adjacent Arrow Lakes Generating Station, and by Brilliant Dam and Expansion Powerplant on the Kootenay River. There are several minor tributaries that join the LCR within the study area but they contribute less than 5% of the total discharge of the LCR (Plewes et al. 2017). Sites within the study area that were sampled for fish during the monitoring program are described in Section 3.1.



LEGEND

═ DAM

— WATERCOURSE

REFERENCE

1. WATERCOURSE AND DAM CONTAINS INFORMATION LICENCED UNDER THE OPEN GOVERNMENT LICENCE – BRITISH COLUMBIA
2. SERVICE LAYER CREDITS: SOURCE: ESRI, MAXAR, GEOEYE, EARTHSTAR GEOGRAPHICS, CNES/AIRBUS DS, USDA, USGS, AEROGRID, IGN, AND THE GIS USER COMMUNITY

PROJECTION: UTM ZONE 11 DATUM: NAD 83

PROJECT

LOWER COLUMBIA RIVER FISH POPULATION INDEXING SURVEY

TITLE

STUDY AREA OVERVIEW

GOLDER

PROJECT		1537874/2018	FILE No.	
DESIGN	DR	14 JUN. 2016	SCALE AS SHOWN	REV. 0
GIS	JG/CD	12 JUN. 2020	**FIGURE: 1**	
CHECK	DR	12 JUN. 2020		
REVIEW	SR	12 JUN. 2020		

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3. Methods

3.1 *Overview*

Boat electroshocking was used to capture fish in the LCR each year from 2001 to 2019. Nearshore habitats along the left and right banks were sampled at night. During each year, sites were sampled four to six times during consecutive weekly sessions as part of a mark-recapture study design. Sampling was conducted in the fall between late September and early November.

There were 28 "index" sites along the left and right banks sampled each year from 2001 to 2019 (Figure **1**). Index sites were between 0.44 and 3.79 km in length. Index site boundaries were selected during previous fish monitoring studies based on changes in habitat type, as well as on the length of shoreline that could be sampled before the onboard livewell was typically full of fish. Index sites included approximately 30% of the total shoreline in the study area. From the shoreline not included in index sites, 62 additional sites were delineated. Each year from 2011 to 2019, 20 of the 62 sites were randomly selected and sampled after the sample sessions at index sites were completed. These randomly selected sites were intended to improve understanding of fish populations in areas outside the index sites, and to assess potential biases that could arise from re-sampling the same index sites each year.

During boat electroshocking, the boat operator maneuvered the boat downstream along the shoreline while two netters standing on the bow placed captured fish into an onboard livewell. Netters also counted observed fish that were not captured. Only the three index species, Mountain Whitefish, Rainbow Trout, and Walleye were captured whereas other species were recorded as observed. Captured fish larger than 120 mm in fork length were implanted with a Passive Integrated Transponder (PIT) tag that allowed individual identification if recaptured and their length and weight was measured before being released back into the river.

In addition to the mark-recapture surveys, georeferenced visual surveys were conducted from 2011 to 2019. These surveys consisted of a boat electroshocking pass of each index sample site where observers standing on the bow would identify, count, and estimate the length of all fish but not net and capture them. The location of all observed fish was recorded using a handheld GPS. The rationale for these surveys was that during mark-recapture surveys, netters are unable to catch or count all the fish while placing fish in the livewell, particularly when fish densities are high, and that visual surveys may provide more accurate estimates of abundance. The visual surveys also provided finer-scale distribution data.

A timeline of the monitoring program including sampling effort and dates is provided in Appendix 1. Detailed descriptions of the methods of the monitoring program are provided in Section 3.0 of Appendix 2.

3.2 *Data*

All the data collected during CLBMON-45 are stored in the LCR Fish Population Indexing Database in Microsoft Access format. The key data used to address the management questions were the fish capture data, including the species, unique identification number, length, and weight of each fish. This data set includes four to six sample sessions at index sites each year from 2001 to 2019 and one sample session at 20 randomly sampled non-index sites each year from 2011 to 2019.

Years were the primary level of replication for the monitoring program. Annual estimates from the 19-year data set were used to assess changes in the abundance, distribution, growth, length-at-age, body condition, and survival of index fish species in the LCR.

Data collected in the study area between 1990 and 1996 (R.L.&L. 1995, 1997) also were used in analyses of length-at-age and body condition to extend the time-series. Studies conducted during that period involved boat electrofishing and mark-recapture programs, with protocols similar to the 2001 to 2019 monitoring studies, including many of the same sample sites. Only years between 1990 and 1996 with sufficient sample sizes were used.

In addition to monitoring trends in fish population metrics over time, one of the objectives was to assess the effect of interannual variability in the Mountain Whitefish and Rainbow Trout flow regimes on fish populations. These flow regimes (also referred to as spawning protection flows) are intended to reduce the number of incubating eggs that are dewatered. Therefore, the estimated percentage of eggs dewatered was used a variable to assess the effect of the spawning protection flows on fish populations. For Mountain Whitefish, the estimated percentage of eggs dewatered was obtained using the Egg Stranding Model, which estimates egg mortality due to dewatering each year using discharge and temperature data, and egg densities estimated from egg stranding surveys (Golder 2013). For Rainbow Trout, estimates of egg mortality due to dewatering were based on counts of dewatered redds and estimates of total numbers of redds (Irvine et al. 2018).

The database also includes information about sample sites (locations and descriptions) and data about each site-specific sampling event, including sampling effort, electroshocker settings, and habitat data. These meta-data were not used to address management questions but are summarized in Appendix B of Appendix 2 and included in the project database.

3.3 *Data Analysis*

Using the data described above, the abundance, distribution, growth, length-at-age, body condition, and survival of index fish species in the LCR were analyzed using statistical models. Models were used to show the variation in the response variables (e.g., abundance or body condition) between sites and years. Analyses were also conducted to assess the effect of the percentage of egg dewatering on subsequent abundance of juvenile fish. A brief overview of the models that were used to address the management questions is provided below. Detailed statistical methods are described in Section 3.2 of Appendices 2 and 3.

Estimates of the response variables (e.g., abundance or body condition) were presented as point estimates, which represent the most likely value, and the 95% credible interval (CI). If the model assumptions are correct, there is a 95% probability that the actual value of the response variable is within the range shown by the CI.

3.3.1 Abundance

A mark-recapture model was used to estimate total abundance of each index fish species. This model used data from tagged fish from the mark-recapture surveys and counted fish from the georeferenced visual survey. Abundance was estimated separately for subadult (age-1) and adult (age-2 and older) fish, where ages were based on fork length and the cutoffs from the length-at-age model (Section 3.3.4).

3.3.2 Spatial Distribution

The spatial distribution of index fish species was assessed using the abundance model (Section 3.3.1). Plots of the estimated density (fish/km) by sample site and river kilometre were used to show the distribution of index species in the LCR.

To assess changes in spatial distribution over time, the evenness in distribution of each species and life stage among index sites was calculated using Shannon's index of evenness. The index was calculated using the formula: $\frac{-\sum p_i \times \log(p_i)}{\log(S)}$, where S is the number of sites and p_i is the proportion of the total density belonging to the i^{th} site. An evenness value of 100% would indicate the same density at all sites while an evenness of 0% would indicate that all the fish are clustered a single site.

3.3.3 Growth

Growth was analyzed using the change in body length of fish that were recaptured in multiple years. These growth data were analyzed using the Fabens (1965) method of estimating von Bertalanffy (1938) growth parameters (Ogle 2016). The two parameters of interest from the von Bertalanffy curve are the asymptotic length (L_∞), and the growth coefficient (k). L_∞ represents the average maximum length (mm) at which fish stop growing. The growth coefficient k represents the rate at which fish approach the asymptotic size, and has units of year^{-1}. Multiplying k by L_∞ results in an estimate of the maximum growth rate (mm/yr) during early life, which can be used to compare growth between populations or years (Gallucci and Quinn 1979; Shuter et al. 1998). To assess trends in growth over time and between sites, the growth coefficient k and the maximum growth rate were plotted versus year and site.

3.3.4 Length-At-Age

The length-at-age analysis was conducted to 1) determine body length cutoffs by life stage (age-0, age-1 subadult, or age-2 and older adult); and 2) compare length-at-age among years. The expected length-at-age of Mountain Whitefish and Rainbow Trout was estimated from annual length-frequency distributions using a finite mixture distribution model (Macdonald and Pitcher 1979). There were assumed to be four distinguishable normally-distributed age-classes for Mountain Whitefish (age-0, age-1, age-2 and age-3+) and three for Rainbow Trout (age-0, age-1, age-2+). Length-at-age is used as an indicator of previous growth of age-0 fish. Length-at-age of age-1 and age-2 and older groupings was not presented as an indicator of growth, because their size depends on growth during more than one year, which complicates interpretation.

Walleye could not be separated by life stage due to a lack of discrete modes in the length-frequency distributions for this species. Consequently, all captured Walleye were considered adults.

3.3.5 Body Condition

Weight-at-length is often used as an indicator of fish health, under the assumption that heavier fish for a given length are in better condition (Froese 2006). Weight-length regression was used to assess body condition in the LCR using the relationship $\mathrm{W} = \alpha \mathrm{L}^{\beta}$, where W is the weight (mass), α is the coefficient, β is the exponent, and L is the length. The relationship was transformed using the natural logarithm to linearize the relationship, resulting in the equation: $\log(W) = \log(a) + b \times \log(L)$. This model was used to predict annual weight-at-length for fish of selected lengths to represent the typical size of subadult and adult fish of each index species. The effect size for body condition (predicted weight of a typical length fish) was presented in terms of the percent difference relative to a typical year (based on the 19-year LCR data set), rather than the actual weight in grams. Representative sizes were 200 and 350 mm for subadult and adult Mountain Whitefish, 250 and 500 mm for subadult and adult Rainbow Trout, and 400 mm for adult Walleye.

3.3.6 Survival

Survival was estimated by fitting a Cormack-Jolly-Seber (CJS) model to inter-annual recapture data. Survival was only estimated for adults because the low number of recaptures of subadults resulted in uninformative estimates.

3.3.7 Effect of Egg Dewatering on Juvenile Abundance

If eggs die due to dewatering, then it could affect the number of juvenile fish produced by that spawning year. The number of fish produced by a spawning year is often referred to as the "recruitment" to the population. The amount of recruitment is reflected by the abundance of the youngest age of fish that is captured by the sampling method. During boat electrofishing in the LCR, very small numbers of age-0 Mountain Whitefish and Rainbow Trout are captured, and the first age class that is captured in appreciable numbers is age-1. Therefore, age-1 is considered the recruitment age class for Mountain Whitefish and Rainbow Trout in the LCR. Two analyses were conducted to assess the effect of egg dewatering on the recruitment of age-1 fish in the LCR, as described in the following sections.

The effect of egg mortality due to dewatering was assessed using both the statistical significance and the effect size. The effect size was the size of the difference in recruitment across values of egg mortality and was presented in terms of the point estimate, which represents the most likely effect size, and the 95% credible interval (CI), which represents the range of possible values of the effect size. To assess statistical significance of the effect of egg loss due to dewatering, *P*-values were calculated to represent the probability that the range of possible effects included no effect[1]. *P*-values less than 0.05 were considered statistically significant.

Age Ratios

The ratio of age-1:age-2 fish (age-1:2 ratio) was calculated and used as an index of annual recruitment. The age ratio analysis used ages assigned using the length-at-age model (Section 3.3.4). Age ratio analyses were conducted for Mountain Whitefish, which was the only species for which there were data regarding the proportion of age-1 and age-2 fish from 2001 to 2019. The age ratio could not be assessed for Rainbow Trout because age-2 individuals could not be reliably distinguished from age-3 and older based on their fork lengths.

The age-1:2 ratio was used as an indicator of recruitment instead of simply using the abundance of age-1, because it does not depend on estimates of capture efficiency and is not affected by violations of the assumptions of the mark-recapture models. Years with strong recruitment are expected to result in greater age-1:2 ratios than years with weaker recruitment.

The age-1:2 ratio for a given spawning year (r_t) was calculated based on the abundance of age-1 (N^1) and age-2 (N^2) fish two years after the spawning year ($t + 2$):

$$r_t = \frac{N^1_{t+2}}{N^1_{t+2} + N^2_{t+2}}$$

Mountain Whitefish in the LCR spawn in November and December, hatch primarily in March and April of the following year (referred to as the hatch year), and are therefore age-1 two years after the spawning year ($t + 2$). The effect of egg dewatering on recruitment was tested with a statistical model that included the relative amount of annual egg mortality for Mountain Whitefish as a predictor variable, and the annual age-1:2 ratio as the response variable.

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[1] The models for CLBMON-45 were estimated using Bayesian methods and the interpretation of *P*-values differs from *P*-values from frequentist methods. Bayesian *P*-values were the probability that the range of possible values, described by the 95% credible interval of the posterior probability distribution, included no effect of the egg dewatering on recruitment. *P*-values are easy to misinterpret (Greenland et al. 2016), which is why they are not presented in this summary report.

Stock-Recruitment

Stock-recruitment models are a standard fisheries analysis used to describe the relationship between the reproductive potential of a population (“stock”), typically measured as the number of spawners or the number of eggs deposited, and the resulting number of fish recruited to the catchable population of fish (“recruits”). At low spawner abundance, recruitment is expected to be driven by density-independent factors and the number of recruits will increase with the number of spawners. At high spawner abundance, density-dependent factors such as competition for limited resources can result in a decrease in per capita recruitment with increasing numbers of spawners.

For the LCR, stock-recruitment analyses were used to assess the effect of egg dewatering on recruitment, while accounting for the abundance of spawning adults each year. This was done because the effect of egg dewatering on subsequent recruitment may depend on the density of juveniles rearing in the river. For instance, at high spawner abundance, mortality due to dewatering may have less of an effect on recruitment because many of the dewatered progeny would have died naturally due to lower survival at high densities of fish. At low spawner abundance, a greater negative effect of dewatering on recruitment is predicted because natural survival is expected to be greater at low density when there is less competition.

A Beverton-Holt stock-recruitment model was used to describe the relationship between the estimated number of eggs deposited (“stock”) and the resultant number of subadults the following year (“recruitment”). The Beverton-Holt model is a common model that assumes recruitment reaches an asymptote at high abundance of spawners due to density-dependent factors like competition for food or space (Walters and Martell 2004). The Beverton-Holt model can be expressed as:

$$R = \frac{\alpha E}{1 + \beta E}$$

where E is the estimated number of eggs deposited, R is the estimated number of age-1 subadults (recruits), α is the egg to recruit survival at low density and β determines the density-dependence. The ratio of α to β defines the carrying capacity, which is the predicted maximum value of the mean number of recruits at large values of egg deposition. To test for effects of egg dewatering, the estimated relative amount of egg mortality was included as a predictor variable affecting the number of recruits in the stock-recruitment model. The egg survival was calculated from the stock recruitment equation to show the percentage of eggs that survived to age-1 for each year.

Stock-recruitment results are presented in terms of the spawning year. For Rainbow Trout, which spawn from March to July and hatch in June to August in the LCR (Irvine et al. 2015), the spawning year is the same as the hatch year. For Mountain Whitefish, spawning occurs mostly in November to December in the LCR and hatch occurs mostly between March and April; therefore, the hatch year is one year greater than the corresponding spawning year. For both species, the age-0 life stage is defined as the first year beginning on the hatch date.

The number of eggs deposited each year was calculated from estimates of adult abundance, an assumed sex ratio of 50% females, and species-specific relationships that predict fecundity (i.e., the number of eggs) based on the expected body weight of an average-length fish (Section 3.2.4 of Appendix 3).

4. Results and Discussion

A summary of the results and conclusions are presented below in a section for each of the monitoring program's management questions. Technical details, such as *P*-values and parameter estimates, and detailed discussion of the results are not included in this summary report but are provided in Appendices 2 and 3 for management questions #1 and #2, respectively, and in the technical report (Golder et al. 2020).

4.1 *Management Question #1*

"What is the abundance, growth rate, survival rate, body condition, age distribution, and spatial distribution of subadult and adult Whitefish, Rainbow Trout, and Walleye in the LCR?"

Results of the statistical models show the trends in abundance, growth, survival, body condition, and spatial distribution between sites and years. Trends for each of these variables are discussed in the following sub-sections.

Trends in age distribution are not discussed because previous annual reports showed that older fish (age-3 or older for Mountain Whitefish, age-2 and older for Rainbow Trout) cannot be reliably aged in the LCR (Golder et al. 2018). Although the age distribution was not explicitly compared between sites or years, other analyses partially address the age component of the management question. Age-ratios were used as an index of recruitment and show trends in the proportion of young fish (age-1) each year (Section 4.2.1). In addition, the abundance of subadult (age-1) and adult (age-2 older) Mountain Whitefish and Rainbow Trout were estimated for each year separately and provided an assessment of the numbers of subadult versus adult fish in the LCR (Section 4.1.1).

4.1.1 Abundance

The estimated abundance of subadult Mountain Whitefish was much greater in 2001 and 2002 (57,000-64,000) than all other years (Figure 2). In 2018 and 2019, the estimated abundance of subadult Mountain Whitefish (10,000–12,000) was one third of the values from the previous five years (29,000-32,000). Estimates of adult Mountain Whitefish abundance were relatively stable between 2010 and 2019 (44,000–58,000), with the exception of 2018 when the estimate was higher (91,000).

Low abundance of subadult Mountain Whitefish in 2018 indicates low recruitment from the 2016 spawning year, which was a year with the largest estimated egg loss due to dewatering observed in all years of the program (Section 4.2.1). Subadult abundance remained low in 2019, despite relatively low estimates of egg loss in 2017, the corresponding spawning year. This is likely because factors other than egg loss due to dewatering also affect recruitment of age-1 Mountain Whitefish in the LCR. The very high estimated abundance of subadults in 2001 and 2002 may be partly explained by sampling bias, because different electrofisher settings (i.e., 60 Hz instead of 30 Hz pulse frequency) that are more effective at catching smaller-bodied fish were used those years (Section 5.2.1 of Appendix 2).

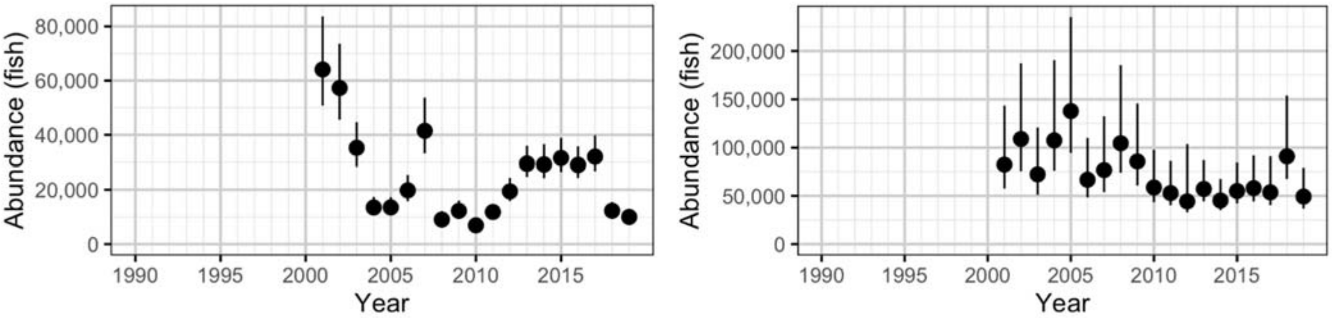

Figure 2. Abundance (means with 95% CIs) of subadult (age-1; left panel) and adult (age-2 and older; right panel) Mountain Whitefish at index sites in the lower Columbia River, 2001–2019.

The estimated abundance of subadult Rainbow Trout was greatest in 2001 to 2002 (29,000), fluctuated between 10,000 and 24,000 between 2003 and 2017, and was lowest in 2018 and 2019 (8,000–9,000; Figure 3). Low abundance of age-1 Rainbow Trout in 2018 and 2019 coincided with a similar decrease in age-1 Mountain Whitefish during those years. Low abundance of age-1 Mountain Whitefish in 2018 coincided with a large estimated egg loss due to dewatering for the 2016 spawning year. However, the discharge reduction that caused the Mountain Whitefish egg loss for the 2016 spawning year occurred in the winter of 2017, which was before the age-1 Rainbow Trout from 2018 were spawned. Therefore, the decrease in age-1 Rainbow Trout could not have been caused by the discharge reductions that dewatered a high proportion of Mountain Whitefish eggs from the 2016 spawning year. This raises the possibility that some common factor other than egg dewatering contributed to the decrease in age-1 recruits of both Mountain Whitefish and Rainbow Trout in 2018.

For adult Rainbow Trout, the estimated abundance was stable from 2001 to 2006 but increased three-fold from 2005 (15,000) to 2018 (46,000), with a small decrease in 2019 (38,000; Figure 3). A large increase in the abundance of adult Rainbow Trout was also reported by the LCR Rainbow Trout Spawning Assessment (CLBMON-46), which estimated the number of spawners based on aerial counts of spawners and redds and an area-under-the-curve model (Poisson et al. 2020). The CLBMON-46 monitoring program reported an increase from ~3,000 spawners in 2001 to 10,000–14,000 in 2015 to 2019. Both the adult mark-recapture estimates from CLBMON-45 and the spawner estimates from CLBMON-46 suggested a small decrease in abundance in 2019, suggesting that the system may have reached the carrying capacity for adult Rainbow Trout.

It is not clear why estimates of subadult Rainbow Trout decreased or stayed the same over the period during which adult abundance increased substantially. One explanation is that the juvenile population is at carrying capacity. An alternative explanation is that because the boat electrofishing sampling program for CLBMON-45 was designed to target adult Rainbow Trout, the abundance estimates of subadult (age-1) Rainbow Trout are not representative of true abundance in the study area (Section 5.2.2. of Appendix 2). As discussed for Mountain Whitefish, the high abundance of subadult Rainbow Trout in 2001 and 2002 may be overestimates due to different boat electrofisher settings used those years.

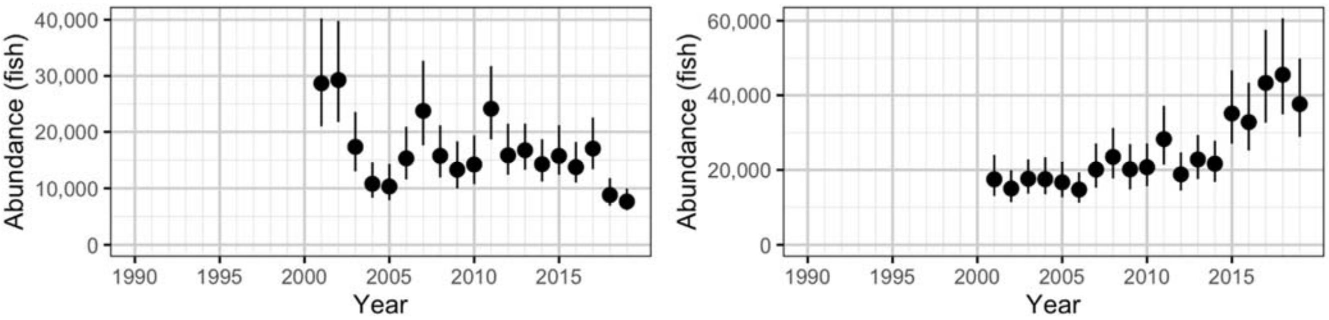

Figure 3. Abundance (means with 95% CIs) of subadult (age-1; left panel) and adult (age-2 and older; right panel) Rainbow Trout at index sites in the lower Columbia River, 2001–2019.

Since 2001, Walleye abundance has fluctuated with peaks in 2003 to 2005 and in 2011 (**Figure 4**). Walleye abundance estimates have remained relatively stable between 2012 and 2019 (8,000–13,000). Overall, the results suggest stable abundance of Walleye over time, with pulses of stronger recruitment in some years. Walleye migrate into the LCR to feed, but spawn and complete early life history downstream in the Columbia River watershed in Lake Roosevelt and its tributaries. Abundance in the LCR is thought to depend largely on spawning success and early life stage survival outside of the study area. Years with high abundance (e.g., 2003–2005, 2011) generally were associated with lower than normal body condition and survival, suggesting density-dependence and resource competition in years of high abundance in the LCR.

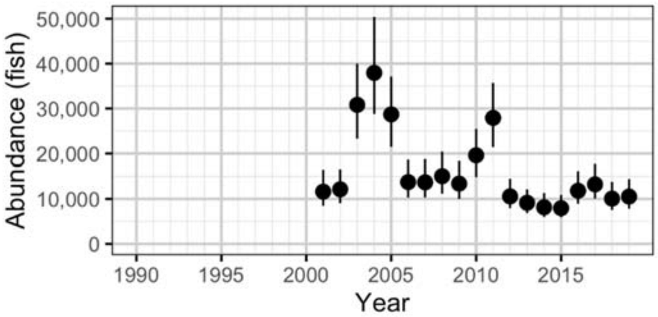

Figure 4. Abundance (means with 95% CIs) of adult Walleye at index sites in the lower Columbia River, 2001–2019.

4.1.2 Distribution

The density of subadult Mountain Whitefish was greatest in the 10-km section between HLK and the Kootenay River confluence (**Figure 5**). This section of the LCR has more low velocity habitats, such as bays and backwaters, which are preferred by juvenile Mountain Whitefish, than downstream of the Kootenay River confluence. Areas with high water velocities, such as the sites in the Kootenay River, typically had low densities of subadult Mountain Whitefish.

The density of adult Mountain Whitefish was greatest near Norn’s Creek Fan (River km [Rkm] 8 to 9), in the downstream portions of the Kootenay River, and near Genelle, BC (Rkm 27; Figure 5). All of these locations are at or near known spawning locations of Mountain Whitefish (Golder 2012), and their high abundance in these areas during sampling in October may indicate Mountain Whitefish congregating and holding in these habitats prior to spawning, which occurs primarily in November and December. Other than these locations of high density, the densities were similar at all other sites in the LCR.

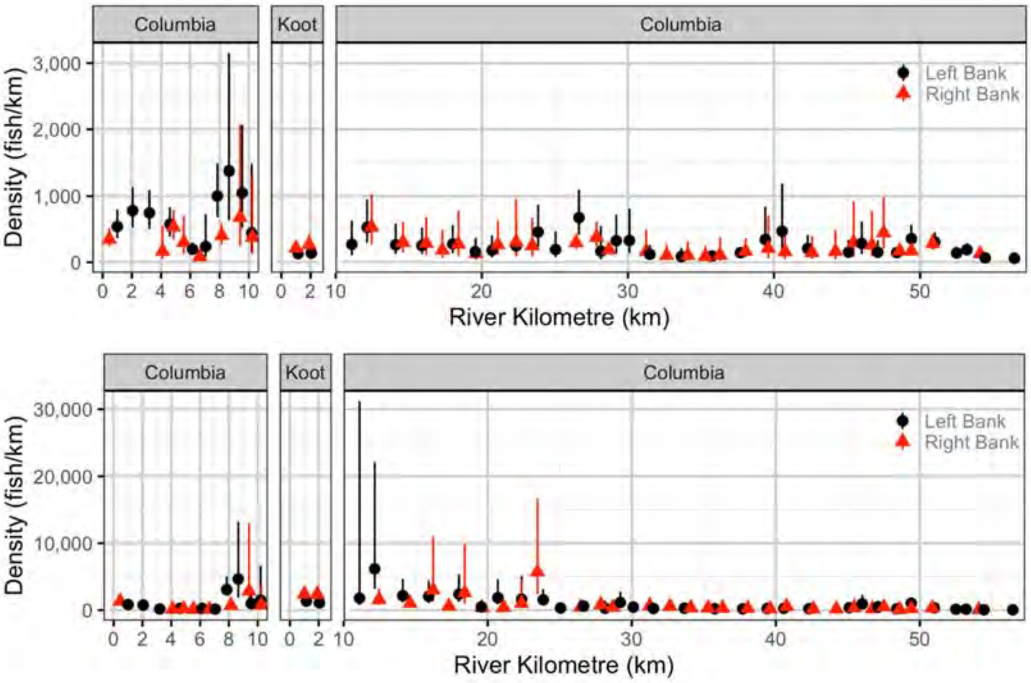

Figure 5. Density (means with 95% CIs) of subadult (age-1; top panel) and adult (age 2 and older; bottom panel) Mountain Whitefish by river kilometre in the lower Columbia River, 2001–2019.

The estimated evenness of subadult Mountain Whitefish was lower in some years (e.g., 2001, 2004 and 2011) but did not indicate any changes over time. The estimated evenness of adult Mountain Whitefish decreased between 2001 and 2006 but was stable between 2006 and 2019.

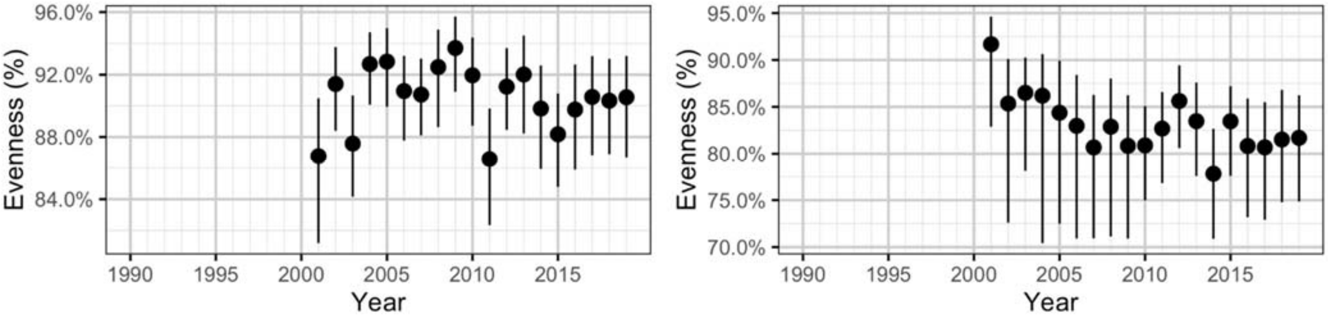

Figure 6. Estimated evenness in the density between index sites for subadult (left panel) and adult (right panel) Mountain Whitefish by year (with 95% CIs) in the lower Columbia River, 2001–2019.

Densities of subadult Rainbow Trout were greater at most sites between Genelle (near RKm 25) and Beaver Creek (RKm 47.8), than in other sections of the study area (Figure 7). Many of the sites with high density in this section were randomly sampled sites that were only sampled in some years between 2011 and 2019, not index sites that sampled several times each year from 2001 to 2019. Low sampling effort in the areas with the highest densities of age-1 Rainbow Trout could make it more difficult to detect trends in recruitment and may explain why estimates of subadult abundance did not increase while adult abundance increased drastically during recent years.

Adult Rainbow Trout densities were high at most sites between the Kootenay River confluence and Genelle (Rkm 11 to 25), from the Birchbank side channel to Rivervale, BC (Rkm 30.5 to 35), and near the Bear Creek confluence (Rkm 46.4 to 45.6; Figure 7). The high densities of Rainbow Trout in previously unsampled portions of the study area (non-index sites) indicate that a large portion of the overall Rainbow Trout population is missed during the mark-recapture sampling at index sites. Higher densities in these areas than in index sites could result in underestimates of overall population density in the LCR. These findings illustrate the importance of continuing to sample random non-index sites, in addition to index sites, during future monitoring programs in the LCR.

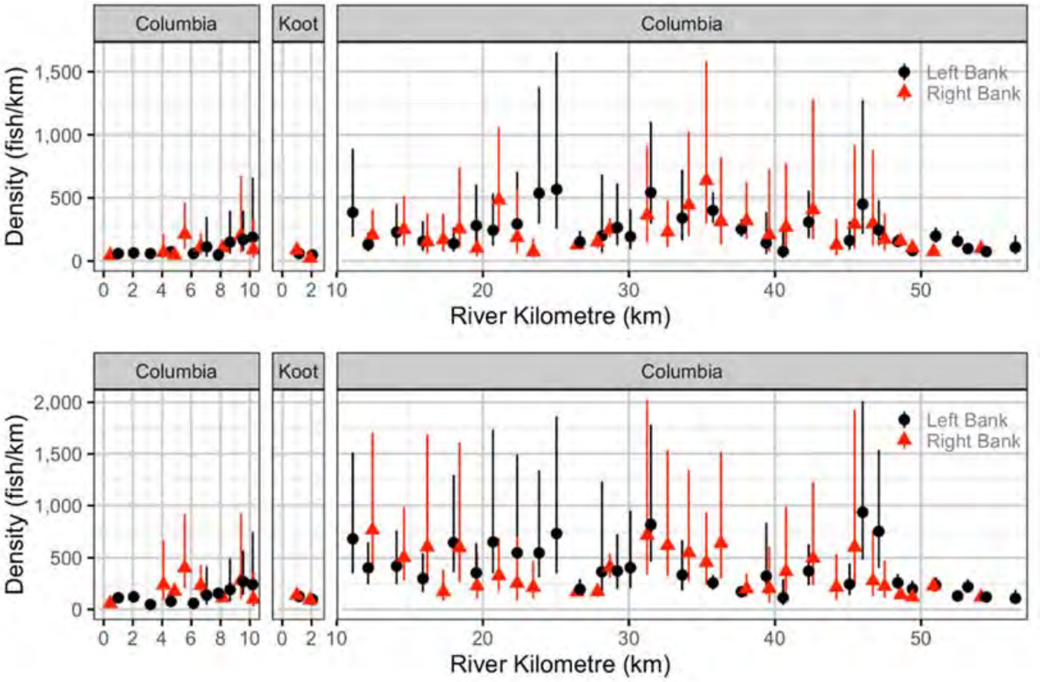

Figure 7. Density (means with 95% CIs) of subadult (age-1; top panel) and adult (age 2 and older; bottom panel) Rainbow Trout by river kilometre in the lower Columbia River, 2001–2019.

Estimates of the evenness of the density of Rainbow Trout between sites were similar for subadults and adults (Figure 8). For both life stages, the estimates indicated generally increasing evenness between the mid-2000s and 2015, and stable evenness from 2015 to 2019. The period of increasing evenness of adults corresponded to the period of increasing abundance of adult Rainbow Trout in the LCR. This could be because at low abundance, Rainbow Trout were more concentrated in sites with the highest quality habitat, whereas at higher overall abundance, density increased disproportionately more at lower quality sites, because higher quality sites had reached their carrying capacity. However, evenness also increased for subadults, which did not increase in abundance during this time period. The increase in evenness was larger for subadult Rainbow Trout, with values between 85% and 95%, than for adults, which had values of 93% to 97% in all years except 2003.

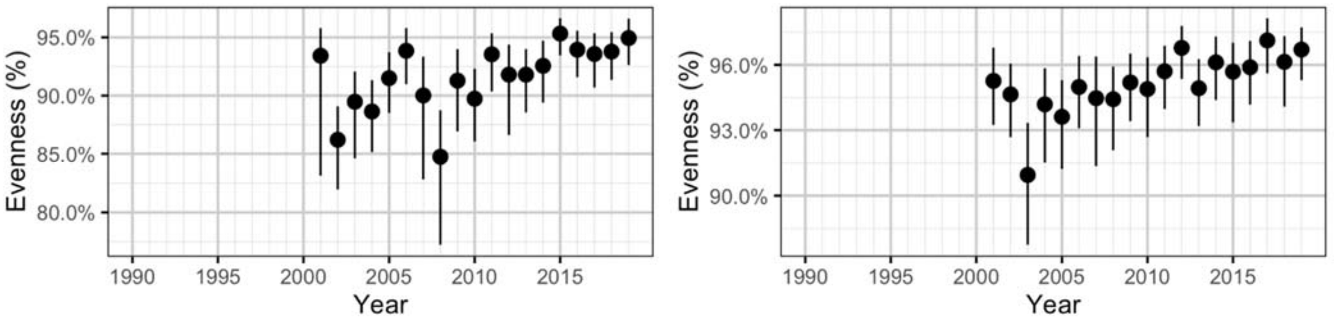

Figure 8. Estimated evenness in the density between index sites for subadult (left panel) and adult (right panel) Rainbow Trout by year (with 95% CIs) in the lower Columbia River, 2001–2019.

Walleye densities were highest immediately downstream of HLK, in the Kootenay River downstream of Brilliant Dam, and near the confluence of the Pend d’Oreille River, which is immediately downstream of Waneta Dam. Walleye densities may be highest downstream of HLK, Brilliant Dam, and Waneta Dam because Walleye are feeding on fish entrained through the dams. Walleye densities were similar between other sections of the LCR and similar between index and randomly sampled sites.

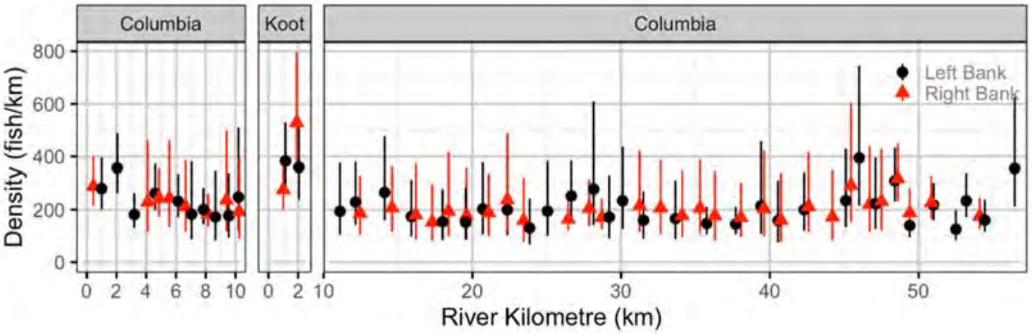

Figure 9. Density (means with 95% CIs) of adult Walleye by river kilometre in the lower Columbia River, 2001–2019.

Estimates of the evenness of the density of Walleye between sites generally decreased between 2001 and 2013, but were relatively stable from 2014 to 2019 (Figure 10). The change in evenness of Walleye distribution was smaller than changes in evenness of the other two index species, with values decreasing from 98% to 96%.

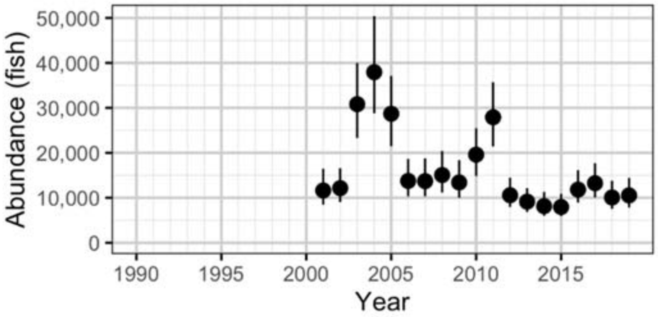

Figure 10. Estimated evenness in the density between index sites for adult Walleye by year (with 95% CIs) in the lower Columbia River, 2001–2019.

4.1.3 Growth

The change in body length of fish recaptured in more than one year was used to assess growth using a von Bertalanffy model. Using this model, the predicted maximum growth rate, which represents the theoretical maximum growth during early life, was calculated for each year. Although the maximum growth rate is the theoretical maximum growth rate when fish are 0 mm in length, the recapture data used in the model were generally from older fish (some age-1, but mostly age-2 and older). Therefore, trends in the maximum growth rate are attributed to both juvenile and adult growth. In addition to the growth model, the mean body length of age-0 fish was estimated as an indicator of growth of young-of-the-year fish.

For Mountain Whitefish, the predicted maximum growth generally increased from ~100 mm/yr in 2003-2005 to 245 mm/yr in 2016 (with the exception of lower growth in 2012), and decreased to approximately 140 mm/yr in 2017 to 2019. The mean fork length of age-0 Mountain Whitefish was relatively stable from 2002 to 2015, when values ranged from 120 to 140 mm. The mean fork length of age-0 Mountain Whitefish was greater than average in three of the last four years (2016, 2018, and 2019), when values were between approximately 140 and 160 mm. Increased length of young-of-the-year Mountain Whitefish in recent years corresponded to low abundance of subadults in 2018 and 2019, which could indicate increased growth due to decreased competition for resources. Compared to Mountain Whitefish in other large rivers, length-at-age of juveniles and growth estimates of Mountain Whitefish in the LCR were greater than in the Peace River in northern BC, but similar to large rivers in the north-western USA (Section 5.1.1 of Appendix 2).

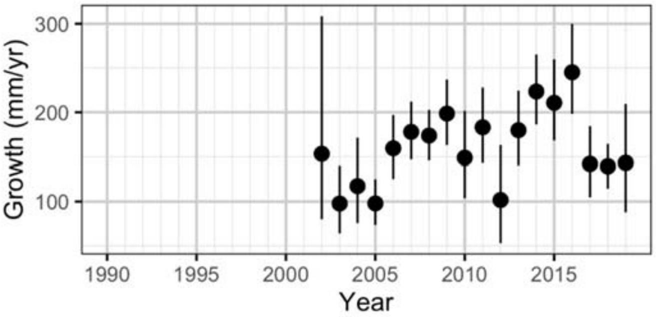

Figure 11. Predicted maximum growth rate (mean with 95% CIs) from the von Bertalanffy model for Mountain Whitefish based on recaptured individuals in the lower Columbia River, 2001–2019.

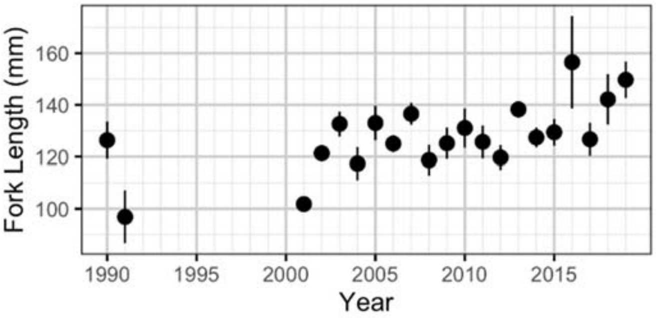

Figure 12. Mean fork length of age-0 Mountain Whitefish in the lower Columbia River, 1990 to 1991 and 2001 to 2019.

The maximum growth rate of Rainbow Trout decreased substantially during the monitoring period. The predicted maximum growth rate generally decreased between 2006 and 2018, with some exceptions, such as short-term decreases in 2008 and 2010 (Figure 13). The predicted maximum growth rate decreased from 643 mm/yr in 2006 to 247 mm/yr in 2018 and 301 mm/yr in 2019. These maximum growth rates represent the theoretical maximum growth rate when fish are 0 mm in length, and therefore should not be interpreted as the rate for the entire first year of life. Regardless, the large decrease in maximum growth rate during the study period (643 to 247 mm/yr) suggests a substantial change in growth.

The mean fork length of age-0 Rainbow Trout did not show the same trend as the maximum growth rate. Mean fork length of age-0 Rainbow Trout increased from 106 mm in 2011 to 145 mm in 2015, and varied from 102 to 127 mm between 2016 and 2019 with large and overlapping credible intervals (Figure 14). The greater uncertainty in the estimates from 2015 to 2019 than previous years was due to lower catch of age-0 Rainbow Trout during these recent years.

Overall, the growth estimated from recaptured Rainbow Trout indicated a sustained decrease in growth between 2006 and 2019, which corresponded with increasing abundance of the species. The mean size of age-0 Rainbow Trout did not follow the same trend, and fluctuated during the monitoring period with no sustained directional trend. Compared to populations in other rivers, Rainbow Trout in the LCR had high values of maximum growth and length-at-age, suggesting relatively rapid growth during early life stages. Rapid growth during early life of Rainbow Trout in the LCR may be related to relatively warm and stable water temperatures, and abundant food availability, compared to smaller or higher elevation streams (Section 5.1.2 of Appendix 2).

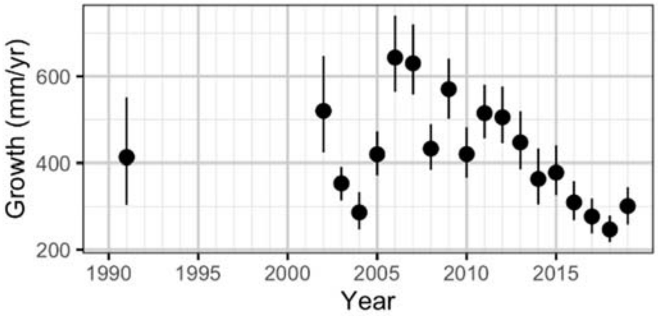

Figure 13. Predicted maximum growth rate (mean with 95% CIs) from the von Bertalanffy model for Rainbow Trout based on recaptured individuals in the lower Columbia River, 2001–2019.

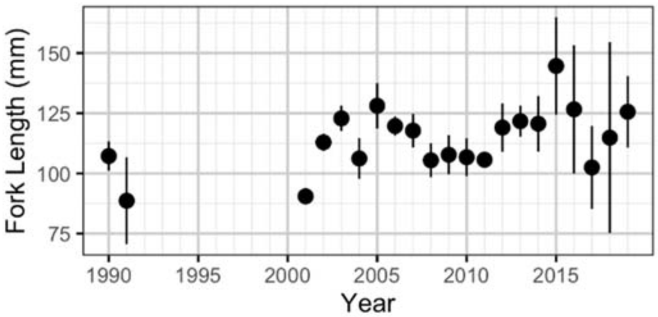

Figure 14. Mean fork length of age-0 Rainbow Trout in the lower Columbia River, 1990 to 1991 and 2001 to 2019.

For Walleye, the results do not suggest any substantial change in growth in the LCR during the study period. The predicted maximum growth rate during early life ranged from 48 to 82 mm, except in 2013 when the maximum growth rate was 113 mm/yr. The analysis of growth of Walleye was hindered by relatively few recaptures, lack of juvenile (age-0 and age-1) fish in the data, and highly variable annual growth (0 to 60 mm per year) for large adult Walleye. These limitations resulted in larger uncertainty in the growth estimates for Walleye than for the other index species.

Mean length of age-0 Walleye was not calculated because this age class was not captured in the LCR. Walleye are thought to spawn and complete early life stages downstream of the study area in Lake Roosevelt Reservoir, and migrate into the LCR as subadults or adults. A portion of the adult population in the LCR are seasonal residents that spend the summer and fall in the LCR and return to Lake Roosevelt in the late fall and early winter months (R.L.&L. 1995). Because part of the life history of Walleye occurs in Lake Roosevelt, factors outside of the study area also likely affect growth estimates of Walleye in the LCR.

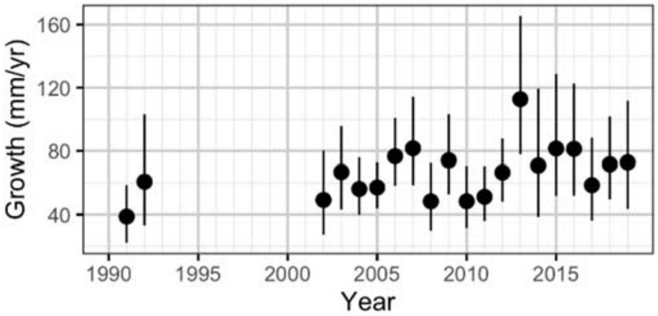

Figure 15. Predicted maximum growth rate (mean with 95% CIs) from the von Bertalanffy model for Walleye based on recaptured individuals in the lower Columbia River, 2001–2019.

4.1.4 Body Condition

The body condition (weight-at-length) of subadult Mountain Whitefish did not suggest any sustained directional changes over time. Subadult body condition was lower in 1990–1991 and 2002–2003, but relatively stable from 2006 to 2019, when effect sizes ranged from -2% to 3%.

Estimates of the body condition of adult Mountain Whitefish indicated a range of variability of approximately 10% during the current monitoring period (2001 to 2019), and average to greater-than-average body condition in recent years. Effect sizes for adult body condition increased from -1% in 2001 to 9% in 2006, were relatively stable from 2007 to 2018 (-1% to 5%), and were greater than average in 2019 (7%). In the 1990s, the body condition of adult Mountain Whitefish was much lower (-6% to -15% effect sizes), which was likely related to poor water quality and industrial pollution (Nener et al. 1995). Reductions in industrial pollution have resulted in improved water quality and fish health in the LCR since the mid-1990s (CRIEMP 2005), which likely explains the greater body condition in 2001 to 2019 than during the early 1990s.

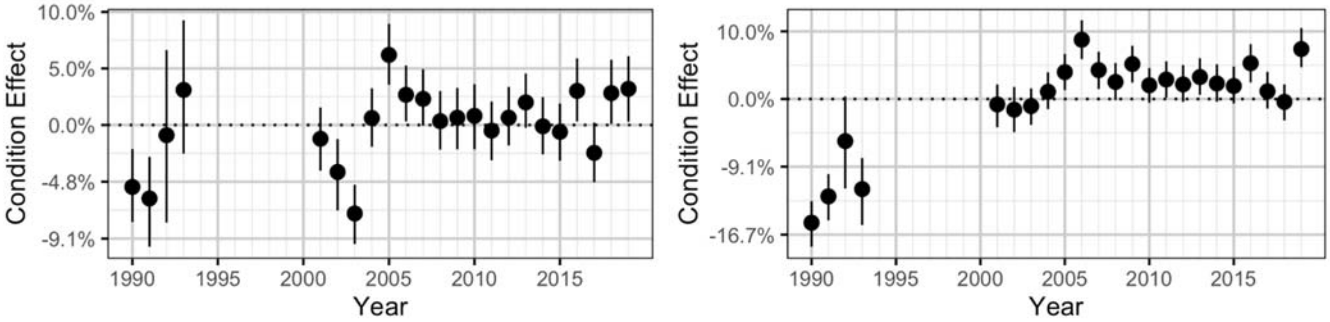

Figure 16. Body condition effect size estimates (mean with 95% CIs) for subadult (200 mm; left panel) and adult (350 mm; right panel) Mountain Whitefish in the lower Columbia River, 1990 to 1993 and 2001 to 2019.

The estimated effect size for the body condition of subadult Rainbow Trout fluctuated between -4% and 4% between 1990 and 2019 (Figure 17). Subadult body condition was lower than average in 2017 and 2019.

The body condition of adult Rainbow Trout decreased from 3% in 2011 in to -7% in 2018 (Figure 17). This 10% decrease in body condition of adults coincided with high and increasing abundance of Rainbow Trout. This may indicate an increase in intra-specific competition for food that caused the decrease in body condition (Figure 17) and growth (Figure 13). The recent high abundance, low body condition, and low growth also coincided with lower adult survival estimates (Section 4.1.5), which suggests that low body condition and growth may lead to lower survival of Rainbow Trout in the LCR. In 2019, there was a small increase in body condition and a small decrease in abundance. These trends suggest that the population is at carrying capacity at the current level of adult abundance, as reduced growth in the post-recruit (i.e., adult) life stage is expected when populations are near carrying capacity (Lorenzen 2008).

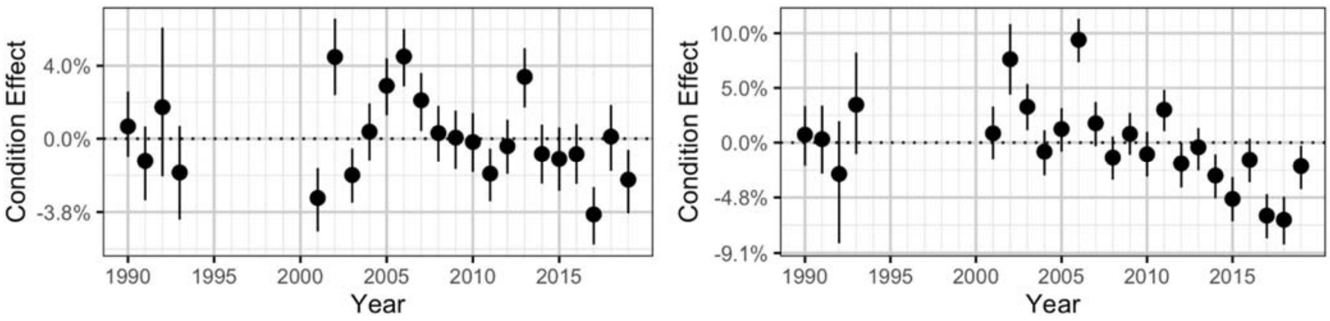

Figure 17. Body condition effect size estimates (mean with 95% CIs) for subadult (250 mm; left panel) and adult (500 mm; right panel) Rainbow Trout in the lower Columbia River, 1990 to 1993 and 2001 to 2019.

Walleye body condition fluctuated with no consistent trend between 1990 and 2011 (Figure 18). Body condition estimates were relatively high in 2012 (5% effect size) and decreased to an effect size of -1% in 2018 and 2019. Overall, the results suggest good body condition from 2012 to 2015, but a declining trend to more typical values in the last few years.

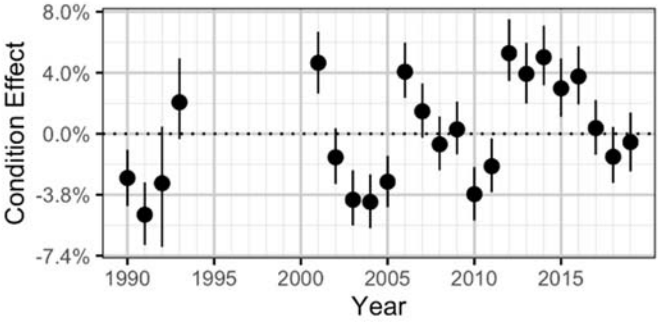

Figure 18. Body condition effect size estimates (mean with 95% CIs) for adult (350 mm) Walleye in the lower Columbia River, 1990 to 1993 and 2001 to 2019.

4.1.5 Survival

For adult Mountain Whitefish, annual survival estimates varied from 21% to 92%. Adult survival generally increased between 2002 and 2008 and was relatively stable between 2011 and 2019 (67%–85%; Figure 19). The high survival rate of adults in the last nine years (>65%) was not unexpected, as Mountain Whitefish are known to be a relatively long-lived species with most populations containing individuals greater than 10 years of age (McPhail 2007). In comparison, estimated survival rates ranged between 63% and 91% (mean 82%) for Mountain Whitefish in Idaho (Meyer et al. 2009).

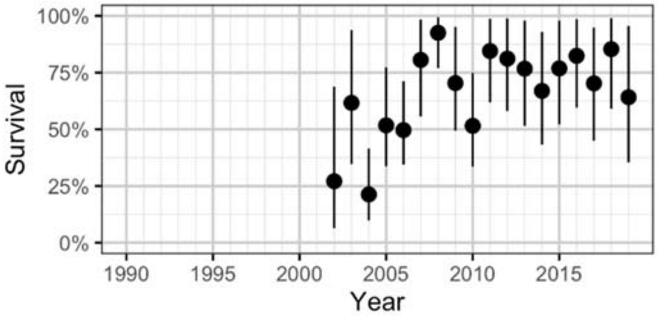

Figure 19. Survival estimates (mean with 95% CIs) from the mark-recapture model for adult (age-2 and older) Mountain Whitefish in the lower Columbia River, 2001–2019.

The results indicate relatively stable survival of adult Rainbow Trout in the last nine years, and a range of survival between 34% and 50% during the entire monitoring period. Survival of adult Rainbow Trout can vary significantly between waterbodies and between years within the same waterbody, but these estimates of 34% to 50% are similar to survival estimates from other waterbodies. For instance, estimated survival of Rainbow Trout was 0.41 for spawners and 0.77 for non-spawners in Kootenay Lake, BC (Thorley and Andrusak 2017) and 0.55 for age-1 and older Rainbow Trout in streams in southern Idaho (Meyer et al. 2012).

Survival estimates of Rainbow Trout increased gradually from 34% in 2003 to 50% in 2011, but declined to 35%–42% in 2012 to 2019 (Figure 20). Some of the recent years with lower survival coincided with high abundance of Rainbow Trout (Section 4.1.1), which could indicate reduced survival due to within-species competition. However, the decrease in survival in 2012, occurred before the largest increase in Rainbow Trout abundance, which occurred in 2015. This suggests that adults increased in abundance despite the lower adult survival, or that estimates of survival or abundance may be biased. The increase in abundance appears to be real as it was supported by a similar trend in abundance from the CLBMON-46 spawner assessment. Reasons for increased abundance of adults after an apparent decrease adult survival include: 1) increased survival of juveniles recruiting to the adult population; 2) underestimated survival due to the violation of model assumptions, such as greater movements or migrations out of the study area. These discrepancies result in high uncertainty in the estimates and trends in survival.

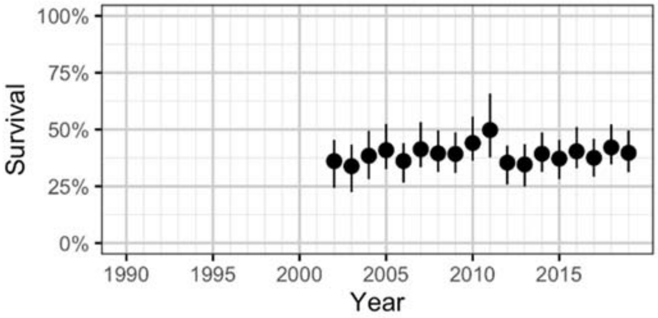

Figure 20. Survival estimates (mean with 95% CIs) from the mark-recapture model for adult (age-2 and older) Rainbow Trout in the lower Columbia River, 2001–2019.

The estimated survival of Walleye ranged between 44% and 59% during the study period, with the exception of lower survival (35%) in 2004. In recent years, the results indicated a decrease in survival from 57% in 2016 to 41% in 2019. As a portion of the Walleye population is thought to be migratory and spend only part of the year in the LCR before moving downstream into Lake Roosevelt (R.L.&L. 1995), annual survival could be confounded by fish movements and affected by factors outside of the study area.

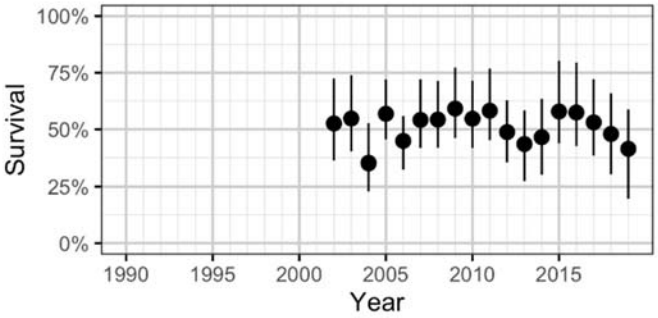

Figure 21. Survival estimates (mean with 95% CIs) from the mark-recapture model for adult Walleye (all age-classes) in the lower Columbia River, 2001–2019.

4.2 *Management Question #2*

"What is the effect of inter-annual variability in the Whitefish and Rainbow Trout flow regimes on the abundance, growth rate, survival rate, body condition, and spatial distribution of subadult and adult Whitefish, Rainbow Trout and Walleye in the LCR?"

The Mountain Whitefish and Rainbow Trout flow regimes, also referred to as "spawning protection flows", are intended to reduce mortality of eggs due to dewatering. Effects of the flow regimes on the growth, body condition, adult survival, and spatial distribution are possible, but are not the main intent of the spawning protection flows. Therefore, the focus of the monitoring program was to assess the effects of variation in the flow regime on the subsequent recruitment and abundance of Mountain Whitefish and Rainbow Trout. As spawning, rearing, and recruitment of Walleye is thought to occur primarily or entirely outside of the study area, effects of flow variability and related egg dewatering were not assessed for this species.

Inter-annual variability in the flow regime was quantified as the percent of the total egg deposition that was dewatered during discharge reductions. For Mountain Whitefish, the percentage of egg mortality due to dewatering was estimated using a model that accounted for the river level, the size of the discharge reduction, and egg densities from surveys (Golder 2013). For Rainbow Trout, the percentage of egg mortality due to dewatering was calculated from surveys of the number of redds dewatered during discharge reductions (Irvine et al. 2018). Egg dewatering was used a predictor variable in models that assessed the corresponding changes in the recruitment of subadult (age-1) Mountain Whitefish and Rainbow Trout (Section 4.2.1).

For fish population metrics that are less directly linked to the spawning protection flows, including growth, body condition, adult survival, and distribution, potential effects of flow variability and discharge reductions are discussed in Section 4.2.2. Statistical analyses were not conducted for these variables.

4.2.1 Effect of Egg Dewatering on Juvenile Abundance

Stock-Recruitment

Stock-recruitment models were used to assess the effect of egg dewatering on age-1 recruits, while accounting for the amount of egg deposition (“stock”) each spawning year. For Mountain Whitefish, there was no relationship between the estimated number of eggs deposited by spawners and the resulting number of age-1 recruits (Figure 22). This is consistent with density-dependent survival, where the number of recruits per egg (i.e., egg survival) decreases with increasing number of spawners (Figure 23). There was no statistically significant effect of egg loss on the resulting number of age-1 recruits, based on the stock-recruitment model (Figure 24). However, the stock-recruitment curve did not have any data on the lower part of the curve where decreased egg deposition would be expected to result in a large decrease in recruitment. Estimates of the effect of egg dewatering mortality showed high uncertainty, with the possible effect size ranging from a 135% increase to a 67% decrease in age-1 recruitment when egg dewatering mortality was 40%. The most likely effect (i.e., predicted mean value) was a 15% decrease in recruitment when egg dewatering mortality was 40%. Therefore, the data were the most consistent with a small negative effect of egg dewatering mortality on recruitment, but a large negative or positive effect cannot be ruled out (Figure 24).

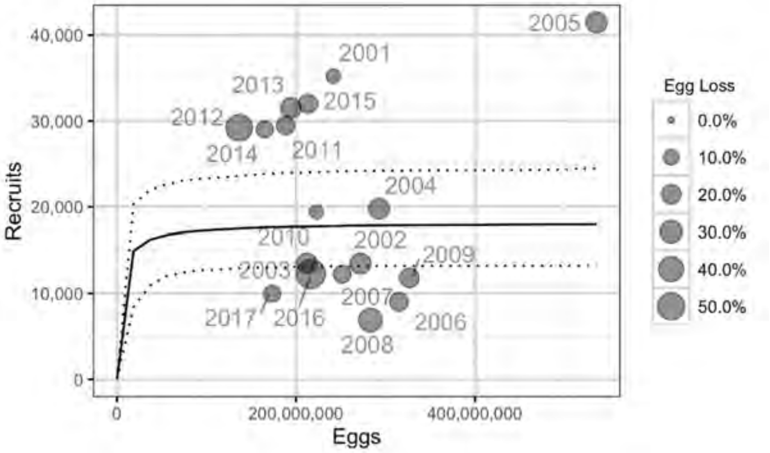

Figure 22. Predicted stock-recruitment relationship between number of eggs deposited by spawners ("stock") and subsequent age-1 Mountain Whitefish ("recruits") by spawning year (with 95% CIs shown by dotted line). Estimated proportion of egg loss due to dewatering for each spawning year is shown by size of shaded circles.

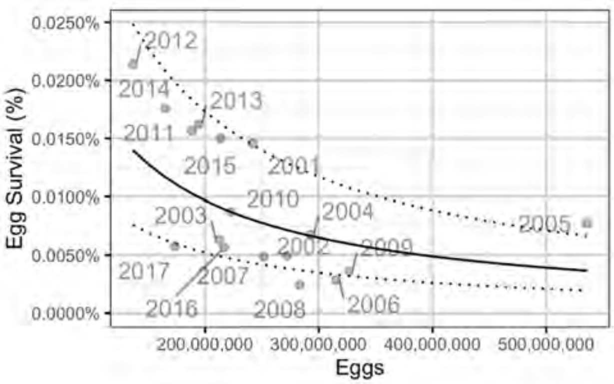

Figure 23. Predicted egg to age-1 survival by total egg deposition (with 95% CIs shown by dotted line) for Mountain Whitefish.

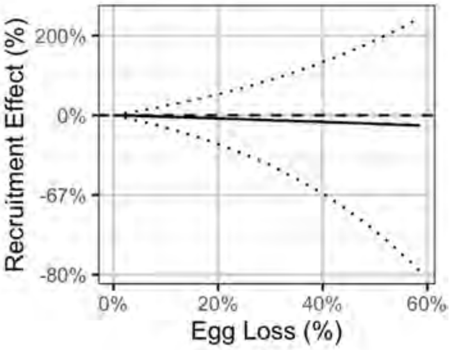

Figure 24. Predicted effect of egg loss on the number of age-1 Mountain Whitefish recruits (dashed line) by percentage egg loss (with 95% CIs shown by dotted line).

The stock-recruitment model for Rainbow Trout did not suggest any effect of increasing number of eggs deposited ("stock") on the resulting number of age-1 recruits (Figure 25). There were no data points on the lower part of the stock-recruitment curve (<10,000,000 eggs) where a decrease in recruitment but an increase in egg survival is predicted by the curve. As with Mountain Whitefish, no data are available to inform the number of spawners required to reach the carrying capacity for recruits, or the egg survival at low spawner abundance.

The estimated egg survival decreased from 0.1% at the lowest estimated egg deposition to 0.05% at the greatest estimated egg deposition (Figure 26). This reflects the density-dependent relationship shown in the stock-recruitment curve, where increased egg deposition did not result in increased recruitment of age-1 fish (Figure 25), due to reduced egg survival at higher densities.

Estimated egg losses for Rainbow Trout were relatively small between 2001 and 2018, with estimates less than 1.0% in 16 of 18 years, and the greatest observed egg loss of 1.6% in 2006. The stock-recruitment model predicted a positive effect of egg loss on recruitment of age-1 Rainbow Trout (Figure 27) but the effect was not statistically significant (*P*=0.06). At an egg loss of 1.0%, there was a predicted 46% increase in recruitment. However, the predicted relationship between egg loss and recruitment had very large estimates of uncertainty. For instance, at an egg loss of 1.0%, the credible intervals for the predictions indicated that the effect size could be anywhere between a 1% decrease and a 127% increase in recruitment, given the data.

Egg mortality due to dewatering cannot realistically have a positive causal effect on recruitment of juveniles. The unexpected positive effect of egg loss on recruitment was likely due to other, unmeasured factors that are correlated with both egg dewatering and recruitment success. For instance, lower water levels during the spawning season could be associated with lower amounts of subsequent egg dewatering, but have some other negative effect on spawning and recruitment success, such as less available spawning habitat and greater competition than during higher water levels.

Based on the available data, there is no evidence of negative effects of egg losses less than 2% on recruitment of Rainbow Trout in the LCR. Although the data do not support an effect of egg loss on recruitment at the range of adult abundances observed, the effects of egg loss at lower abundance, or higher levels of egg loss (>1.6%) are unknown based on this analysis.

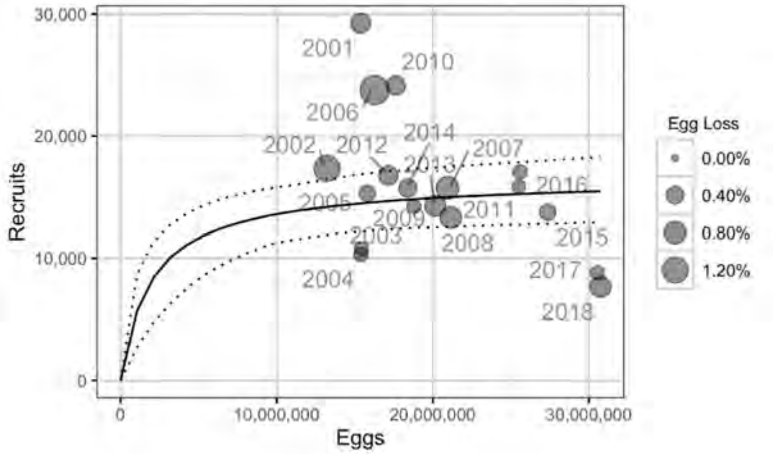

Figure 25. Predicted stock-recruitment relationship between number of eggs deposited by spawners ("stock") and subsequent age-1 Rainbow Trout ("recruits") by spawning year (with 95% CIs shown by dotted line). Estimated proportion of egg loss due to dewatering for each spawning year is shown by size of shaded circles.

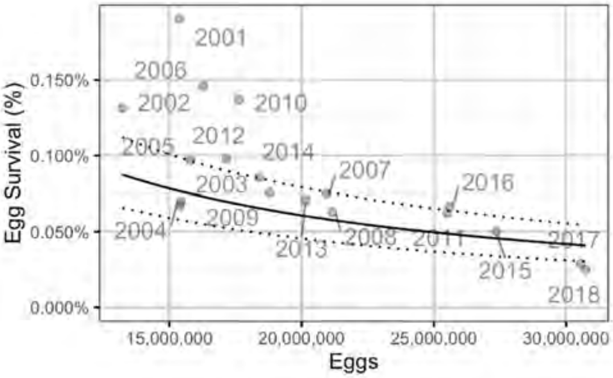

Figure 26. Predicted egg to age-1 survival by total egg deposition (with 95% CIs shown by dotted line) for Rainbow Trout.

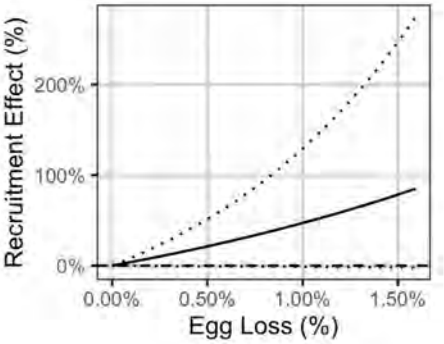

Figure 27. Predicted effect of egg loss on the number of age-1 Rainbow Trout recruits by percentage egg loss (with 95% CIs shown by dotted line).

Age Ratios

The ratio of age-1:2 Mountain Whitefish was used as an indicator of recruitment to assess the effects of egg dewatering. The age-1:2 ratio ranged from 25% to 79% during the 1999 to 2017 spawning years, suggesting large variability in recruitment during the study period (left panel; Figure 28). The age-1:2 ratio was relatively stable from 2010 to 2015 (63% to 74%) but decreased to 33% in 2016. The decrease in age-1:2 ratio for the 2016 spawning year coincided with a large estimated egg loss that year, when an estimated 59% of eggs were dewatered (middle panel; Figure 28). In the 2017 spawning year, egg loss was only 14% but the age-1:2 ratio remained relatively low (44%). The analysis using all spawning years indicated a negative but non-statistically significant effect of egg loss on the age-1:2 ratio (right panel; Figure 28). From this modeled relationship, the predicted effect size was a 24% decrease in recruitment at 50% egg loss compared to the recruitment at 10% egg loss (Figure 29). At 50% egg loss, although the mean prediction was a 24% decrease (relative to 10% egg loss), the 95% credible interval for the effect on recruitment ranged from 67% decrease to a 65% increase, which indicates considerable uncertainty in the relationship.

Together, the weak relationship between egg loss and age-1:2 ratio, and the large decrease in age-1:2 ratio in 2016 when there was substantial egg loss, suggest a possible effect of egg loss on the recruitment of Mountain Whitefish. However, there was considerable uncertainty in the relationship, and a large amount of variability in recruitment was not explained by egg loss. This may be because other factors, such as environmental conditions or ecological interactions, had a larger effect on recruitment than mortality due to egg loss in most study years.

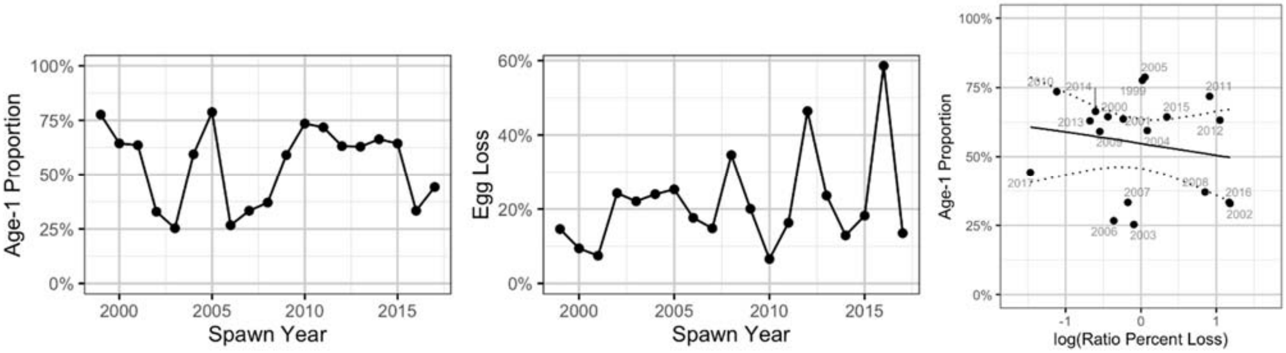

Figure 28. Proportion of age-1 Mountain Whitefish (left panel) and estimated percent egg loss (middle panel) by spawning year. The modeled relationship between these two variables is shown in the right panel, where the variable representing egg loss in the model is shown on the horizontal axis.

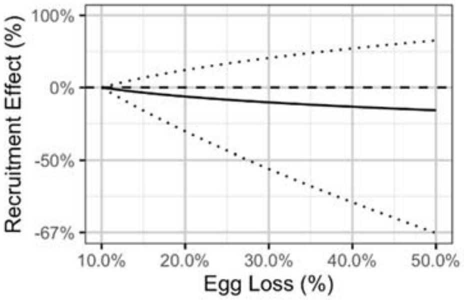

Figure 29. Predicted percent change in the number of age-1 recruits (vertical axis) by percentage egg loss relative to 10% egg loss (horizontal axis). Solid line is the mean prediction, dotted line is the 95% CRI, and dashed line is 0% effect size for reference.

4.2.2 Effect of Flow Regime Variability on Growth, Condition, Survival, and Distribution

Variability in the flow regime affects the amount of fluctuation in the river level and the resulting amount of substrate dewatering each year. One way that more stable flows and less substrate dewatering could affect fish populations indirectly is through changes in primary and secondary productivity. Less dewatering and more stable flows may result in greater primary (algae) and secondary (insects) productivity, which could lead to greater food availability and increased growth or body condition of fish. If changes in growth or body condition are large enough, then survival could be affected as well.

The LCR Physical Habitat and Ecological Productivity program suggested that water velocity and discharge variability can affect invertebrate productivity, especially during the Mountain Whitefish protection flow period (Olson-Russello et al. 2015), which supports a potential pathway between flow variability, food availability, and the growth and body condition of fish. Information about the relative abundance of invertebrates in the LCR has been collected (Olson-Russello et al. 2015) but is only available for five years (2008–2010, 2012, and 2014), which means that relationships between annual flow variability, invertebrates, and fish cannot be compared across the entire timespan of the fish indexing program (2001–2019) without a predictive model. Changes in primary productivity that influence aquatic life further up the food chain like fish are often referred to as “bottom-up” effects. Bottom-up effects of variability in flow regime on growth and body condition of fish are more likely for insectivorous species like Mountain Whitefish and Rainbow Trout, and less likely for Walleye, which are piscivorous.

Flow regime variability could also influence fish by changes in the amount and quality of habitat, displacement during discharge fluctuations, or stranding during discharge reductions. Early life stages of fish that have poorer swimming ability and generally require slower velocity or off-channel habitat would likely be the most sensitive to these types of effects. Changes in the amount, quality, and variability in fish habitat could potentially affect several aspects of fish populations, including growth, body condition, survival, or spatial distribution.

Changes to productivity or habitat quality that affect fish populations, if occurring, could result in persistent changes in body size, body condition, or recruitment that would be detectable outside of (i.e., after) the time period of the spawning protection flows. In contrast, the spatial distribution of fish during boat electrofishing for this program (October) is likely not affected by variability in spawning protection flows that occur much earlier in the year (winter and spring).

5. Conclusion

The sampling program conducted since 2001 provides a high-quality, long-term data set to address the first management question, which is about changes in fish population metrics over time in the LCR.

The results suggested a large increase in abundance of adult Rainbow Trout in recent years that coincided with lower body condition and growth, suggesting density-dependence and that the adult population may be at or near the carrying capacity.

Data for Walleye suggested relatively low but stable abundance from 2012 to 2019 compared to earlier years, and no persistent changes in growth, body condition, or survival during the study period. The abundance of Mountain Whitefish varied widely over the study period, with estimates of subadults that were relatively stable from 2013 to 2017, but more than 50% lower in 2018 and 2019.

Estimated abundance of adult Mountain Whitefish was relatively stable since 2010, except in 2018 when abundance was approximately 65% higher. Length-at-age and body condition of Mountain Whitefish suggest relatively little change during the monitoring period.

The second management question of this monitoring program pertains to the effect of inter-annual flow variability on fish population metrics of the index species. One of the ways that flow variability can affect fish populations is through egg dewatering following discharge reductions. The effect of egg dewatering on fish abundance was assessed through the analysis of age ratio as a recruitment index and through stock-recruitment models that included egg loss as a covariate.

For Mountain Whitefish, the data were most consistent with a small negative effect of egg dewatering mortality on recruitment, but a large negative or positive effect cannot be ruled out. There was a negative but uncertain and not statistically significant relationship between the age-1:2 recruitment index and estimated egg losses across all years of the study (1999 to 2017 spawning years). However, the large estimated egg loss (59%) in the 2016 spawning year corresponded to a large decrease in the recruitment index and a more than 50% decrease in the estimated abundance of age-1 Mountain Whitefish. In the stock-recruitment model, the effect of egg dewatering on recruitment was uncertain and not statistically significant, but a small negative effect was most likely, given the data.

For Rainbow Trout, the data suggested a positive effect of egg loss on recruitment of age-1 juveniles. This unexpected relationship was likely due to other unmeasured factors that are correlated with egg dewatering. At the relatively low levels of egg loss between 2001 and 2018 (≤1.6%), other unknown factors appear to have a much larger effect on recruitment than egg loss. Based on the available data, there is no evidence of negative effects of egg losses less than 2% on recruitment of Rainbow Trout in the LCR.

These conclusions for both Mountain Whitefish and Rainbow Trout should be considered uncertain because of the poor fit in modelled relationships, and the possibility that sampling biases or environmental variability masked real effects of egg dewatering.

Flow variability in the LCR is expected to have less of an effect on Walleye than on Rainbow Trout and Mountain Whitefish because the abundance of Walleye is thought to depend on spawning and early life history survival outside of the study area.

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Appendix 1 – Timeline of CLBMON-45

The Lower Columbia River Fish Population Indexing Program (CLBMON-45) was conducted annually from 2007 to 2019 under the Water Use Plan. CLBMON-45 represents a continuation of the Large River Fish Indexing Program (LRFIP), which was used to monitor the fish community downstream of HLK from 2001 to 2006. The combined data set from 2001 to 2019 was used to answer the management questions for CLBMON-45. A summary of the timing of data collection and sampling effort by year is provided in Table 1. New components added during the program included the addition of randomly sampled sites, referred to as GRTS sites, in 2011, and a geo-referenced visual survey in 2013. For details of the two components, refer to Sections 3.1.5 and 3.1.8 of Appendix 2.

Table 1: Summary of annual study periods and number of sites sampled for boat electrofishing surveys conducted in the lower Columbia River, 2001 to 2019.

Monitoring Program[a]	Year	Start Date	End Date	Number of Sites			Number of Weekly Sample Sessions	Duration (in days)
				Index Sites[b]	GRTS Sites[c]	Visual Survey[d]		
LRFIP	2001	13 August	23 September	21	-	-	5	42
LRFIP	2002	16 September	27 October	24	-	-	6	42
LRFIP	2003	15 September	26 October	23	-	-	6	42
LRFIP	2004	13 September	30 October	23	-	-	7	48
LRFIP	2005	19 September	1 November	23	-	-	6	44
LRFIP	2006	18 September	2 November	23	-	-	6	46
CLBMON-45	2007	27 September	6 November	23	-	-	5	41
CLBMON-45	2008	22 September	3 November	23	-	-	5	43
CLBMON-45	2009	28 September	30 October	22	-	-	5	33
CLBMON-45	2010	27 September	30 October	28	-	-	5	34
CLBMON-45	2011	26 September	5 November	28	20	-	6	41
CLBMON-45	2012	24 September	25 October	28	20	-	5	32
CLBMON-45	2013	2 October	6 November	28	20	47	5	36
CLBMON-45	2014	6 October	7 November	28	20	28	5	33
CLBMON-45	2015	13 October	10 November	28	20	28	5	29
CLBMON-45	2016	3 October	4 November	28	20	28	5	33
CLBMON-45	2017	2 October	7 November	28	20	28	5	37
CLBMON-45	2018	1 October	4 November	28	20	28	5	35
CLBMON-45	2019	30 September	3 November	28	20	28	5	36

a. LRFIP = Large River Fish Indexing Program; CLBMON-45 = Lower Columbia River Fish Population Indexing Program

b. Index sites that were longer than one habitat type were split up in in 2002 and 2010. The same bank length was sampled in all years of the program and the difference in the number of sites samples reflects changes in site naming. The exception was a few sites that were not sampled in some years because they could not be safely accessed.

c. GRTS sites were added to the program in 2011. See Section 2.1.5 for details.

d. Geo-referenced visual surveys started in 2013. See Section 2.1.8 for details. GRTS sites were also included in the visual survey in 2013 whereas only index sites were included in the visual survey in 2014 to 2019.

Appendix 2 – Management Question #1

1.0 INTRODUCTION

In the mid-1990s, BC Hydro initiated water management from Hugh L. Keenleyside Dam (HLK) during the Mountain Whitefish (*Prosopium williamsoni*) and Rainbow Trout (*Oncorhynchus mykiss*) spawning seasons to reduce egg losses downstream of the dam. Throughout the Mountain Whitefish spawning season (December to February), BC Hydro decreases flow from HLK during the peak spawning period (24 December to 21 January; Golder 2010a) to encourage spawning at lower water level elevations and to reduce egg dewatering over the winter and early spring when annual minimum flows typically occur. Subsequently, flows are managed (within the constraints of the Columbia River Treaty and flood protection considerations) to provide stable or increasing water levels during the middle of the Rainbow Trout spawning season (early April to late June) to protect Rainbow Trout spawners by reducing the likelihood that Rainbow Trout eggs (and other larval fishes) are dewatered.

BC Hydro implemented a Water Use Plan (WUP; BC Hydro 2005) for the Columbia River in 2007. As part of the WUP, the Columbia River Water Use Plan Consultative Committee recommended the establishment of the Lower Columba River (LCR) Fish Indexing Program (CLBMON-45) to address data gaps regarding the effects of water management at HLK (particularly during the Mountain Whitefish and Rainbow Trout spawning seasons) on downstream fish populations. The LCR Fish Indexing Program represents a continuation of the Large River Fish Indexing Program (LRFIP), a program initiated by BC Hydro in 2001 to develop a reliable and cost-effective method of indexing the fish community downstream of HLK.

In 2001, the LRFIP gathered baseline information on fish distribution, life history characteristics, and population abundance of fish species present in the LCR (Golder 2002). Between 2002 and 2006 (Golder 2003, 2004, 2005, 2006, 2007), the program was refined, based on the results of previous study years, to provide a systematic and repetitive index of fish population parameters for three index species: Mountain Whitefish, Rainbow Trout, and Walleye (*Sanders vitreus*). A detailed summary of the life history requirements for these three species was prepared by Golder (2009a, 2010b).

The current study year (2019) is the final year of planned monitoring under the WUP. The final reports for monitoring programs under the WUP are summary reports in a less technical format than a conventional scientific technical report. Technical details are provided in appendices with a separate appendix for each management question. Appendix 2 provides the details of the background, methods, results, and interpretation relevant to the program’s first of two management questions, which was:

- What is the abundance, growth rate, survival rate, body condition, age distribution, and spatial distribution of subadult and adult Whitefish, Rainbow Trout, and Walleye in the LCR?

The management hypotheses related to this management question are:

- Ho_1: There is no change in the population levels of Whitefish in the LCR over the course of the monitoring period.
    - Ho_{1a}: There is no change in the abundance of adult and subadult Whitefish.
    - Ho_{1b}: There is no change in the mean size-at-age of subadult and adult Whitefish.
    - Ho_{1c}: There is no change in the mean survival of adult and subadult Whitefish.
    - Ho_{1d}: There is no change in the morphological (condition factor) index of body condition of adult and subadult Whitefish.
    - Ho_{1e}: There is no change in the distribution of adult and subadult Whitefish.
- Ho_2: There is no change in the population levels of Rainbow Trout in the LCR over the course of the monitoring period.

  - Ho_{2a}: There is no change in the abundance of adult and subadult Rainbow Trout.
  - Ho_{2b}: There is no change in the mean size-at-age of subadult and adult Rainbow Trout.
  - Ho_{2c}: There is no change in the mean survival of adult and subadult Rainbow Trout.
  - Ho_{2d}: There is no change in the morphological (condition factor) index of body condition of adult and subadult Rainbow Trout.
  - Ho_{2e}: There is no change in the distribution of adult and subadult Rainbow Trout.
- Ho_3: There is no change in the population levels of Walleye in the LCR over the course of the monitoring period.
  - Ho_{3a}: There is no change in the abundance of adult and subadult Walleye.
  - Ho_{3b}: There is no change in the mean size-at-age of subadult and adult Walleye.
  - Ho_{3c}: There is no change in the mean survival of adult and subadult Walleye.
  - Ho_{3d}: There is no change in the morphological (condition factor) index of body condition of adult and subadult Walleye.
  - Ho_{3e}: There is no change in the distribution of adult and subadult Walleye.

This management question and the related hypotheses are addressed in this appendix (Appendix 2) using data collected from 2001 to 2019 during the LRFIP (2001–2006) and CLBMON-45 (2007–2019).

Supporting information including maps, parameter estimates, and additional results are provided in sub-appendices A to H of Appendix 2.

Details of the program’s second management question are provided in Appendix 3.

2.0 Study Area and Study Period

The study area for the LCR Fish Indexing Program encompasses the 56.5 km section of riverine habitat from HLK to the Canada-U.S. border (Figure 1). This study area also includes the Kootenay River below Brilliant Dam (BRD) and the Columbia-Pend d’Oreille rivers confluence below Waneta Dam. For the purposes of this study, the study area was divided into three sections. The upstream section of the Columbia River extended 10.7 km from HLK (river kilometre [RKm] 0.0) downstream to the Kootenay River confluence (RKm 10.7). The downstream section of the Columbia River extended 48.5 km from the Kootenay River confluence downstream to the Canada-U.S. border (RKm 56.5). The Kootenay River section was established as a separate sample section that extended 2.8 km from the Kootenay-Columbia rivers confluence upstream to BRD.

Sample sites were distributed throughout the study area in similar locations to all study years from 2001 to 2019. In total, nine index sites were sampled in the upstream section of the Columbia River (Appendix A, Figure A1), 15 index sites were sampled in the downstream section of the Columbia River (Appendix A, Figures A2 and A3), and four index sites were sampled in the Kootenay River (Appendix A, Figure A1). Site descriptions and UTM locations for all sites are listed in Appendix A, Table A1. Each of the 28 index sites was sampled at least four times (i.e., 4 sessions) each year (Table 1).

Beginning in 2011, 20 additional sites were randomly selected for sampling in Session 5 using a Generalized Random Tessellation Stratified (GRTS) survey (see Section 3.1.5). Session 5 was completed in the last week of sampling in each year.

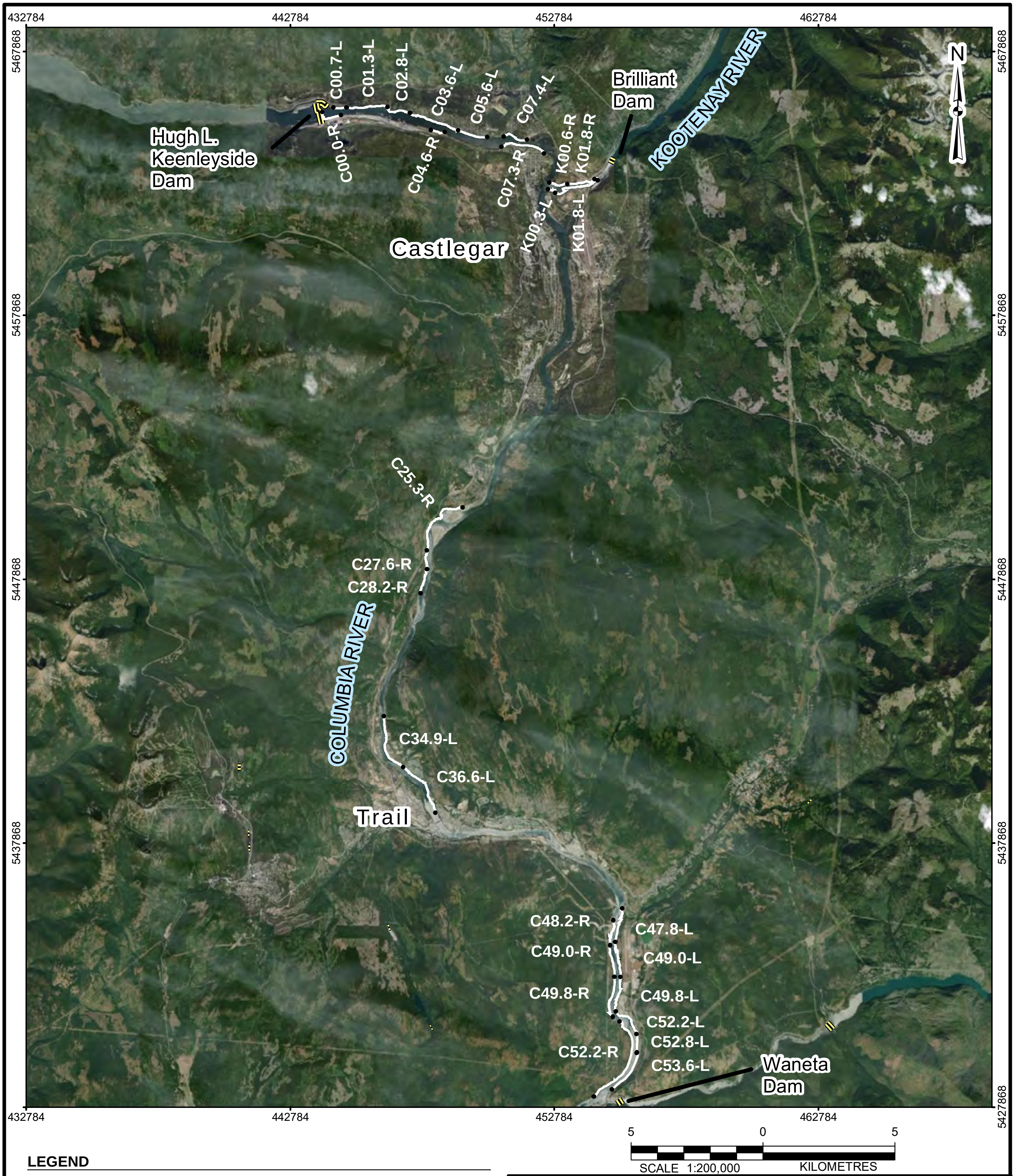
Table 1: Summary of annual study periods and number of sites sampled for boat electrofishing surveys conducted in the lower Columbia River, 2001 to 2019.

Year	Start Date	End Date	Number of Sites			Number of Sessions	Duration (in days)
			Index Sites[a]	GRTS Sites[b]	Geo-referenced Visual Survey[c]		
2001	13 August	23 September	21	-	-	5	42
2002	16 September	27 October	24	-	-	6	42
2003	15 September	26 October	23	-	-	6	42
2004	13 September	30 October	23	-	-	7	48
2005	19 September	1 November	23	-	-	6	44
2006	18 September	2 November	23	-	-	6	46
2007	27 September	6 November	23	-	-	5	41
2008	22 September	3 November	23	-	-	5	43
2009	28 September	30 October	22	-	-	5	33
2010	27 September	30 October	28	-	-	5	34
2011	26 September	5 November	28	20	-	6	41
2012	24 September	25 October	28	20	-	5	32
2013	2 October	6 November	28	20	47	5	36
2014	6 October	7 November	28	20	28	5	33
2015	13 October	10 November	28	20	28	5	29
2016	3 October	4 November	28	20	28	5	33
2017	2 October	7 November	28	20	28	5	37
2018	1 October	4 November	28	20	28	5	35
2019	30 September	3 November	28	20	28	5	36

a. Index sites that were longer than one habitat type were split up in in 2002 and 2010. The same bank length was sampled in all years of the program and the difference in the number of sites samples reflects changes in site naming. The exception was a few sites that were not sampled in some years because they could not be safely accessed.

b. GRTS sites were added to the program in 2011. See Section 3.1.5 for details.

c. Geo-referenced visual surveys started in 2013. See Section 3.1.8 for details. GRTS sites were also included in the visual survey in 2013 whereas only index sites were included in the visual survey in 2014 to 2019.



LEGEND

•—•	Index Sites
═	DAM

REFERENCE

1. WATERCOURSE AND DAM CONTAINS INFORMATION LICENCED UNDER THE OPEN GOVERNMENT LICENCE – BRITISH COLUMBIA
2. SERVICE LAYER CREDITS: SOURCE: ESRI, DIGITALGLOBE, GEOEYE, EARTHSTAR GEOGRAPHICS, CNES/AIRBUS DS, USDA, USGS, AEROGRID, IGN, AND THE GIS USER COMMUNITY

PROJECTION: UTM ZONE 11 DATUM: NAD 83

PROJECT

LOWER COLUMBIA RIVER FISH POPULATION INDEXING SURVEY

TITLE

STUDY AREA OVERVIEW

GOLDER

PROJECT		1537874/2018	FILE No.
DESIGN	DR	12 JUN. 2020	SCALE AS SHOWN REV. 0
GIS	JG/GS	12 JUN. 2020	FIGURE: 1
CHECK	DR	12 JUN. 2020	
REVIEW	SR	12 JUN. 2020	

Document Path: Y:\burnaby\CAD-GIS\Client\ONALCR\99_PROJECTS\1537874\02_PRODUCTION\INDEXING\MXD\Report\2019\1537874_FIG_99_OVERVIEW_2019.mxd

3.0 METHODS

The data set used to address the management questions was the fish capture data that was collected as described in Sections 3.1.4 to 3.1.9 below. Habitat data were recorded (Section 3.1.3) and environmental conditions (Sections 3.1.1 to 3.1.2) are presented as context when interpreting the fish population data.

3.1 Data Collection

3.1.1 Discharge

Discharge data were obtained from BC Hydro's Columbia Basin Hydrological Database. Data used in this report included discharge for the Columbia River below HLK (combined discharge from HLK and Arrow Lakes Generating Station), the Columbia River at Birchbank (Water Survey of Canada gauging station No. 08NE049), and the Kootenay River (combined discharge through the BRD and Brilliant Expansion [BRX] plants). Discharge values throughout this report are presented as cubic metres per second (m^3/s).

3.1.2 Water Temperature

Water temperatures for the mainstem Columbia River from 2001 to 2019 (except 2012 and 2017) were obtained at hourly intervals from the Water Survey of Canada gauging station at Birchbank. In 2012 and 2017, water temperature data from the Birchbank station were not available for a large portion of the year because of a data logger malfunction. Columbia River water temperatures presented for 2012 were measured near Fort Shepherd (used with permission from Columbia Power Corporation; Golder 2013). Columbia River water temperature presented for 2017 were measured in Kinnaird Eddy, approximately 3 km downstream of the Kootenay-Columbia confluence (J. Crossman, BC Hydro, pers. comm.) during March to November and measured at Birchbank for the remainder of the year. Water temperatures for the mainstem Kootenay River were obtained at hourly intervals using an Onset Tidbit™ temperature data logger (accuracy ± 0.5°C) installed 1.8 km upstream of the Columbia-Kootenay rivers confluence. All available temperature data were summarized to provide daily average temperatures. Spot measurements of water temperature were obtained at all sample sites at the time of sampling using a hull-mounted digital thermometer (accuracy ± 0.2°C).

3.1.3 Habitat Conditions

Several habitat variables were qualitatively assessed at all sample sites (Table 2). Variables selected were limited to those for which information had been obtained during previous study years and were intended to detect gross changes in habitat availability or suitability in the sample sites between study years. The data collected were not intended to quantify habitat availability or imply habitat preferences.

The type and amount of instream cover for fish were qualitatively estimated at all sites (Table 2). Surface water velocities were visually estimated and categorized at each site as low (less than 0.5 m/s), medium (0.5 to 1.0 m/s), or high (greater than 1.0 m/s). Water clarity was visually estimated and categorized at each site as low (less than 1.0 m depth), medium (1.0 to 3.0 m depth), or high (greater than 3.0 m depth). To determine visibility categories, the boat operator called out depths displayed on the boats depth sounder while angling the boat from the thalweg into shore. The netters looked over the bow of the boat to become familiar with how deep they could see based on the depths relayed by the boat operator. Mean and maximum depths were estimated by the boat operator based on the boat's sonar depth display.

Habitat at each site was categorized using the Bank Habitat Types Classification System (Appendix B, Table B1; R.L.&L. 1995). The length of each bank habitat type within each site was calculated using ArcView® GIS software (Appendix B, Table B2). While electrofishing, netters estimated the number of observed fish that were not captured by species within each bank habitat type. Bank habitat types less than approximately 100 m in length were combined with adjacent bank habitat types to facilitate the netters' ability to remember observed fish counts.

Table 2: List and description of habitat variables recorded at each sample site in the lower Columbia River.

Variable	Description
Date	The date the site was sampled
Time	The time the site was sampled
Air Temp	Air temperature at the time of sampling (to the nearest 1°C)
Water Temp	Water temperature at the time of sampling (to the nearest 1°C)
Conductivity	Water conductivity at the time of sampling (to the nearest 10 µS)
Cloud Cover	A categorical ranking of cloud cover (clear=0–10% cloud cover; partly cloudy=10–50% cloud cover; mostly cloudy=50–90% cloud cover; overcast=90–100% cloud cover)
Weather	A general description of the weather at the time of sampling (e.g., comments regarding wind, rain, or fog)
Water Surface Visibility	A categorical ranking of water surface visibility (low - waves; medium - small ripples; high - flat surface)
Boat Model	The model of boat used during sampling
Range	The range of voltage used during sampling (high or low)
Percent	The setting on the "Percent of Range" dial, which affects voltage and duty cycle
Amperes	The average amperes used during sampling
Mode	The mode (AC or DC) and frequency (in Hz) of current used during sampling
Length Sampled	The length of shoreline sampled (to the nearest 1 m)
Time Sampled	The time of electrofisher operation (to the nearest 1 second)
Mean Depth	The estimated mean depth sampled (to the nearest 0.1 m)
Maximum Depth	The estimated maximum depth sampled (to the nearest 0.1 m)
Water Clarity	A categorical ranking of water clarity (high - greater than 3.0 m visibility; medium - 1.0 to 3.0 m visibility; low - less than 1 m visibility)
Instream Velocity	A categorical ranking of water velocity (high - greater than 1.0 m/s; medium - 0.5 to 1.0 m/s; low - less than 0.5 m/s)
Instream Cover	The type (i.e., interstices; woody debris; cutbank; turbulence; flooded terrestrial vegetation; aquatic vegetation; shallow water; deep water) and amount (as a percent) of available instream cover
Crew	The field crew that conducted the sampling
Sample Comments	Any additional comments regarding the sample

3.1.4 Fish Capture

Fish were captured and sampled using methods similar to previous years of the project (Golder et al. 2019). Physiological stress on fish associated with capture and processing is greater at warmer water temperatures (Golder 2002; Gale et al. 2013). Therefore, sampling in the present study (as in during most other study years) did not commence until after water temperatures decreased below 15°C.

Boat electrofishing was conducted at all sites along the channel margin, typically within a range of 0.5 to 4.0 m water depth. Boat electrofishing employed a Smith-Root Inc. high-output Generator Powered Pulsator (GPP 7.5) electrofisher operated out of an outboard jet-drive riverboat with a three-person crew. The electrofishing procedure consisted of manoeuvring the boat downstream along the shoreline of each sample site. Two crew members positioned on a netting platform at the bow of the boat netted stunned fish, while a third individual operated the boat and electrofishing unit. The two netters attempted to capture all three index species. Captured fish were immediately sorted by the bank habitat type they were captured in and placed into an onboard compartmentalized live well. Index species that avoided capture and all other species that were positively identified but avoided capture were enumerated by bank habitat type and recorded as "observed". Both time sampled (seconds of electrofisher operation) and length of shoreline sampled (in kilometres) were recorded for each sample site. Electrofishing sites ranged from 0.44 to 3.79 km in length. If a site could not be completed because of logistical reasons, the distance that was actually sampled was estimated and recorded on the site form, then used as the sampled length in the subsequent analyses.

To further reduce fish mortalities and stress on the fish associated with capturing and handling, compressed oxygen was pumped into the live well through an air stone.

Voltage was adjusted to the lowest voltage that had the desired effect on fishes i.e., forced swimming towards the anode (known as electrotaxis or galvanotaxis), or narcosis, which is when fish become immobilized by the electric field. This typically correspond to an amperage output of ~1.75 A on the electroshocking boat used from 2001 to 2016. The boat used in 2017 to 2019 had a different amperage gauge that measured a different part of the electrical wave form than the previous boat. Amperages in 2019 ranged from 3.5 to 4.0 A. A pulsed direct current with a frequency of 30 Hz was used. These settings result in less electrofishing-induced injuries on Rainbow Trout than when using greater frequencies (60 or 120 Hz) and amperages (1.5 to 3.3. A as measured on older amperage gauges; Golder 2004, 2005).

To reduce the possibility of capturing the same fish at multiple sites in one session, fish were released near the middle of the site where they were captured so they were less likely to move upstream or downstream into an adjacent site after release. In previous years when releasing fish in the middle of site, fish were occasionally recaptured in a different site during the same session, but this was fairly rare (typically less than 5 times per year).

3.1.5 Generalized Random Tessellation Stratified Survey

In 2001, sites selected for inclusion in the LRFIP (Golder 2002) were based on sites established and data collected during surveys conducted in the early 1980's (Ash et al. 1981) and early 1990's (R.L.&L. 1991). During those two programs, virtually all areas of the LCR were surveyed with individual site lengths determined by the length of shoreline traversed by the boat in the amount of time it took netters to fill the live well with fish (L. Hildebrand, Golder Associates Ltd., pers. comm.). A subsample of sites established during those original programs was selected for inclusion in the LRFIP in 2001 to provide a representative sample of general bank habitat types available throughout the LCR; however, emphasis was placed on sites known to contain higher densities of the three index species, which may result in overestimates of abundance in the entire LCR study area. This same subsample of sites has been used for annual sampling since 2001, including the continuation of the survey program as part of CLBMON-45, which was initiated in 2007. Approximately 30% of the total shoreline habitat available in the LCR was repetitively sampled each year as part of the LRFIP and CLBMON-45.

The stratified sampling design detailed above represents a repeated measures concept, where a mark-recapture program is conducted annually at each site over an approximately five-week study period. The same sites are surveyed each year, resulting in annual estimates of abundance with relatively constant temporal and spatial sample design parameters. Stratified sampling programs like this may result in biased estimates because not all portions of a study area are surveyed or potentially available to be surveyed in any particular year. This bias can arise if inter-annual fish distribution changes with abundance rather than only with fish density. Additionally, repetitively sampling the same sites each session (i.e., within a year) may introduce biases due to fish moving between sampled and non-sampled sections of the study areas within or between sessions.

Starting in 2011, additional sites were randomly selected using the GRTS survey design (Stevens and Olsen 2004) and sampled after field crews completed the conventional mark-recapture program. The GRTS survey was conducted to identify potential biases and to provide a better understanding of the population dynamics of the three index species.

Portions of shoreline habitat that were not sampled as part of CLBMON-45 prior to 2011 were divided up into potential sites. Upstream and downstream boundaries of each site were established using several different criteria, including historic site delineations (i.e., sites surveyed during the 1990s; R.L.&L. 1991), sampling effectiveness (e.g., overall length, ease of access, etc.), natural breaks in bank habitat type, and the location of obvious geographical boundaries (e.g., islands, tributary mouths, bridges, etc.). Established CLBMON-45 indexing sites ranged in length from 0.4 to 3.8 km; these lengths were used as general guidelines when establishing the GRTS survey sites. Overall, 62 new GRTS survey sites ranging from 0.6 to 3.9 km in length, were established in areas of the LCR that were not sampled between 2001 and 2010 (Table A2). The same habitat variables recorded for indexing sites were also recorded for GRTS survey sites (Appendix B, Table B3). In general, there was a similar range of habitat types at indexing and GRTS survey sites.

The GRTS sampling design combines the features of stratified sampling with the benefits of a totally random design, ensuring full spatial coverage and randomization so that all potential habitats are surveyed. A feature of the GRTS strategy is that new sites may be selected during each study year; therefore, all fish habitats are included within the potential sampling “frame”. A detailed description of the GRTS design strategy is available at http://www.epa.gov/nheerl/arm/designing/design_intro.htm.

Software used to create the GRTS design included the *spsurvey* package (Kincaid and Olsen 2016) in the statistical program R (R Core Team 2020), and ArcGIS. Each year since 2011, the GRTS methodology was used to select a subsample of 20 sites from the 62 GRTS survey sites. In addition, 15 “oversample” sites also were selected to replace selected GRTS sites that were unable to be sampled for logistical reasons. For the current project, excluded sites included those located immediately downstream of HLK, BRD, and Waneta Dam and inside the log booms at Zellstoff Celgar (all due to safety concerns), the perimeter of Waldie Island (a nature preserve), and the west shore of Zuckerberg Island (too shallow to safely navigate). Oversample sites also were used if the same site was selected more than once by the software. The use of oversample sites ensured that both randomness and spatial balance were maintained as part of the study design. GRTS sites selected in 2019 are presented in Appendix A, Table A2.

A single-pass boat electrofishing survey was conducted at each GRTS survey site between 24 October and 3 November 2019 using the same procedures described above. The GRTS surveys were always conducted after sampling at index sites was completed. Fish captured during GRTS surveys were processed in the same manner as fish captured during the conventional mark-recapture program (Section 3.1.6).

3.1.6 Fish Processing

Site habitat conditions (Table 2) and the number of fish observed were recorded after sampling each site. Data collection for each captured fish included the variables in Table 3. The length (to the nearest 1 mm) and weight (to the nearest 1 g) of each fish was measured. All sampled fish were automatically assigned a unique identifying number by the database that provided a method of cataloguing associated ageing structures.

All index fish > 120 mm were marked with a Passive Integrated Transponder (PIT) tag (Datamars, FDX-B, food safe polymer, 11.4 x 2.18 mm, Hallprint Pty Ltd., Australia). For fish between 120 and 160 mm FL, tags were implanted into the abdominal cavity of the fish just off the mid-line and anterior to the pelvic girdle using a single shot applicator (model MK7, Biomark Inc., Boise, Idaho, USA). For fish >160 mm FL, tags were inserted with a single shot 12 mm polymer PIT tag applicator gun (Hallprint Pty Ltd., Australia) into the dorsal musculature on the left side below the dorsal fin near the pterygiophores. Only fish that were in good condition received PIT tags whereas fish in poor physical condition (e.g., large open wounds, unable to maintain upright orientation) were not tagged. All tags and tag injectors were immersed in an antiseptic (Super Germiphene™) and rinsed with distilled water prior to insertion. Tags were checked to ensure they were inserted securely and the tag number was recorded in the LCR Fish Indexing Database.

During the 2001 to 2005 studies, fish were marked exclusively with T-bar anchor tags (i.e., PIT tags were not used). Fish captured during the present study that had previously been marked with and retained a T-bar anchor tag did not receive a second tag (i.e., a PIT tag) unless the T-bar anchor tag was not inserted properly, the tag number was illegible, or a large wound was present at the tag's insertion point (on these occasions, the T-bar anchor tag was carefully removed and a PIT tag was applied).

Table 3: List and description of variables recorded for each fish recorded in the lower Columbia River.

Variable	Description
Species	The species recorded
Size Class	A general size class for observed fish (YOY = age-0; Immature = <250 mm FL; Adult = >250 mm FL)
Length	The fork length to the nearest 1 mm
Weight	The wet weight to the nearest 1 g
Sex and Maturity	The sex and maturity (determined where possible through external examination)
Scale	Whether or not a scale sample was collected for ageing purposes
Tag Colour/Type	The type (i.e., T-bar anchor, PIT, or PIP tag) and colour (for T bar anchor tags only) of tag applied
Tag Number	The number of the applied tag
Condition	The general condition of the fish (e.g., alive, dead, unhealthy, etc.)
Preserve	Details regarding sample collection (e.g., stomach contents, DNA, whole fish, etc.)
Habitat Type	The bank habitat type where the fish was recorded
Comments	Any additional comments

Scale samples were collected from Mountain Whitefish and Rainbow Trout in accordance with the methods outlined in Mackay et al. (1990). All scales were stored in appropriately labelled coin envelopes and air-dried before processing. Scale samples were not collected from Walleye because scales are not a reliable ageing structure for Walleye (Mackay et al. 1990). Walleye are primarily seasonal residents in the LCR, which is used for feeding by adult and subadult cohorts. As a result, sensitive early life stages of Walleye are unlikely to be affected by river regulation in the study area.

3.1.7 Scale Ageing

In 2019, fish were not aged using scale samples. Various techniques have been used in past years of the program to assign ages using scale samples. For all ageing methods used in past years, only age-0, age-1, and sometimes age-2 fish could be reliably aged and there was considerable uncertainty and error in ages assigned to all age-3 and older age-classes (Golder et al. 2018). Therefore, Mountain Whitefish and Rainbow Trout captured between 2001 and 2019 were assigned age-classes based on their fork length and the length-at-age model (Section 3.2.3). Scale-based ages assigned during previous years of the program were not used in this report.

3.1.8 Geo-referenced Visual Enumeration Survey

A visual enumeration survey was conducted at each index site during the week before the mark-recapture indexing surveys began. The survey consisted of a boat electrofishing pass using the same methods as the mark-recapture survey (Section 3.1.4), except that fish were only counted and not captured. Two observers were positioned in the same location as they would have been for netting, where they identified, enumerated, and estimated the length of all fishes observed. Two other individuals recorded all the observation data dictated by the observers, and recorded the geographical location of each observation using a hand-held Global Positioning System (GPS) unit. The rationale behind these geo-referenced visual enumeration surveys was that by not having to net fish and then turn to put captured fish in the live well (and thereby not counting or capturing additional fish), continuous direct counts of observed fish would be more accurate than the intermittent observations made by netters during the mark-recapture surveys. In addition, the visual surveys provide fine-scale distribution data, which could be used to understand mesohabitat use by fishes in the LCR and better address management questions regarding spatial distribution. Fish species counted and recorded in the survey were the three index species. The only other species recorded was Northern Pike because they are an invasive species of concern in the study area.

3.1.9 Historical Data

In addition to the data collected between 2001 and 2019, data collected in the study area between 1990 and 1996 (R.L.&L. 1995, 1997) also were used in some analyses. Studies conducted during this period involved boat electrofishing and mark-recapture programs, with protocols very similar to the 2001 to 2019 monitoring studies, including many of the same sample sites. There were some differences in sampling methodology between the 1990s and the current sampling program including different electrofisher settings and tag types. Despite these relatively minor differences, the 1990s data were considered comparable to data collected between 2001 and 2019 and were combined for many of the analyses in this report. Data from the 1990s were used in the analyses of length-at-age, growth and body condition, but only years with large enough sample sizes were included. There were not enough data to estimate abundance or survival from the 1990s. Incorporating data from the 1990s in the analyses provides a longer time series and historical context to better address management questions about fish population trends in the LCR.

3.2 Data Analyses

3.2.1 Data Compilation and Validation

Data were entered directly into the LCR Fish Indexing Database (Attachment A) using Microsoft® Access software. The database has several integrated features to ensure that data are entered correctly, consistently, and completely.

Various input validation rules programmed into the database checked each entry to verify that the data met specific criteria for that particular field. For example, all species codes were automatically checked upon entry against a list of accepted species codes that were saved as a reference table in the database; this feature forced the user to enter the correct species code for each species (e.g., Rainbow Trout had to be entered as “RB”; the database would not accept “RT” or “rb”). Combo boxes were used to restrict data entry to a limited list of choices, which kept data consistent and decreased data entry time. For example, a combo box limited the choices for Cloud Cover to: Clear; Partly Cloudy; Mostly Cloudy; or Overcast. The user had to select one of those choices, which decreased data entry time (e.g., by eliminating the need to type out “Partly Cloudy”) and ensured consistency in the data (e.g., by forcing the user to select “Partly Cloudy” instead of typing “Part Cloud” or “P.C.”). The database contained input masks that required the user to enter data in a pre-determined manner. For example, an input mask required the user to enter the Sample Time in 24-hour short-time format (i.e., HH:mm:ss). Event procedures ensured that data conformed to the underlying data in the database. For example, after the user entered the life history information for a particular fish, the database automatically calculated the body condition of that fish. If the body condition was outside a previously determined range for that species (based on the measurements of other fish in the database), a message box would appear on the screen informing the user of a possible data entry error. This allowed the user to double-check the species, length, and weight of the fish before it was released. The database also allowed a direct connection between the PIT tag reader and the data entry form, which eliminated transcription errors associated with manually recording a 15-digit PIT tag number.

All raw data collected as part of the program between 2001 and 2019 are included in the LCR Fish Indexing Database (Attachment A).

For all figures in this appendix, sites are ordered by increasing distance from HLK (RKm 0.0) based on the upstream boundary of each site. Unless stated otherwise, black points represent sites located on the left bank (as viewed facing downstream) and red points represent sites located on the right bank (as viewed facing downstream).

3.2.2 Hierarchical Bayesian Analyses

The temporal and spatial variation in abundance, growth, body condition, and survival were analyzed using Hierarchical Bayesian Models (HBMs). The book 'Bayesian Population Analysis using WinBUGS: A hierarchical perspective' by Kéry and Schaub (2011) provides an excellent reference for hierarchical Bayesian methods. In short, a hierarchical Bayesian approach:

- Allows complex models to be logically defined using the BUGS language (Kéry and Schaub 2011: 41).
- Permits the incorporation of prior information (Kéry and Schaub 2011: 41).
- Readily handles missing values.
- Provides readily interpretable parameter estimates whose reliability does not depend on the sample size.
- Allows derived quantities, such as the percent change in the expected weight of a 200 mm FL Mountain Whitefish at a particular site in a typical year, to be calculated (Kéry and Schaub 2011: 41).
- Enables the efficient modelling of spatial and temporal variations and correlations (Kéry and Schaub 2011: 78-82).
- Permits the separation of ecological and observational processes (Kéry and Schaub 2011: 44).

The analyses were implemented using R version 4.0.0 (R Core Team 2020) and the mbr family of packages. Models were fit using JAGS (Plummer 2015) and STAN (Carpenter et al. 2017). The one exception is the length-at-age estimates which were produced using the mixdist package (Macdonald 2012) in R, which implements Maximum Likelihood with Expectation Maximization. The technical aspects of the analyses, including the general approach, model definitions, and the resultant parameter estimates are provided in Appendix C. In addition, the statistical methodology, sample code, parameter estimates, and figures of results are available online (Thorley 2020).

The parameters are summarized in terms of the point estimate, standard deviation (sd), the z-score, lower and upper 95% confidence/credible limits (CLs) and the p-value (Kéry and Schaub 2011, 37, 42). The z-scores were used to calculate p-values for each of the parameter estimates. Lower and upper 95% confidence limits are used to describe uncertainty in maximum likelihood estimates. Credible limits are the Bayesian equivalent of confidence limits. The range from the lower CL to the upper CL is referred to as a credible/confidence interval (CI). For maximum likelihood models, the point estimate is the maximum likelihood estimate (MLE), the standard deviation is the standard error, the z-score is MLE/sd, and the 95% CLs are the MLE±1.96×sd. For Bayesian models, the estimate is the median (50th percentile) of the MCMC samples, the z-score is mean/sd and the 95% CLs are the 2.5th and 97.5th percentiles. A p-value of 0.05 indicates that the lower or upper 95% CL is 0. Where relevant, model adequacy was confirmed by examination of residual plots for the full model(s).

The results were displayed graphically by plotting the modeled relationships between a particular variable (e.g., year) and the response variable with the remaining variables held constant. Continuous and discrete fixed variables were held constant at their mean and first level values, respectively, while random variables were 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 was expressed in terms of the effect size (i.e., percent change in the response variable) with 95% CIs (Bradford et al. 2005).

If the model assumptions are correct, there is 95% probability that the actual underlying values lie within the credible intervals (CIs). An estimate is statistically significant if its 95% CIs do not include zero. If two values have non-overlapping CIs, then the difference between them is by definition statistically significant. However, estimates can have overlapping CIs but the difference between them can still be statistically significantly different. For example, the estimates of abundance depend on the differences between years, as well as the abundance in a typical year. As uncertainty in the abundance in a typical year affects all the estimates, it can cause the CIs to overlap even if the differences between years are significantly different. If it is important to establish the statistical significance of a difference or trend where the CIs overlap, this can be determined from the posterior probability distributions.

Statistical significance does not indicate biological importance. For example, a difference may be statistically significant but so small as to be of no consequence for the population. Conversely, the uncertainty in a difference may include zero thus rendering the difference statistically insignificant while also admitting the possibility of a large and potentially impactful effect. For further information on the limitations of statistical significance, see Greenland et al. (2016).

3.2.3 Length-At-Age

The length-at-age analysis was conducted to 1) determine length-at-age cutoffs by life stage (age-0 fry, age-1 subadult, or age-2 and older adult); and 2) compare length-at-age among years. The expected length-at-age of Mountain Whitefish and Rainbow Trout was estimated from annual length-frequency distributions using a finite mixture distribution model (Macdonald and Pitcher 1979).

There were assumed to be four distinguishable normally-distributed age-classes for Mountain Whitefish (age-0, age-1, age-2 and age-3+) and three for Rainbow Trout (age-0, age-1, age-2+). Initially the model was fitted to the data from all years combined. The model was then fitted to the data for each year separately with the initial values set to the estimates from the combined values. The only constraints were that the standard deviations of the Mountain Whitefish age-classes were identical in the combined analysis and fixed at the initial values in the individual years. For each Mountain Whitefish and Rainbow Trout, the probability of belonging to each age-class was predicted by the model, and the age-class with the highest probability was assigned to each fish.

Rainbow Trout and Mountain Whitefish were categorized as fry (age-0), subadult (age-1) or adult (age-2 or older) based on their length-based ages. Walleye could not be separated by life stage due to a lack of discrete modes in the length-frequency distributions for this species. Consequently, all captured Walleye were considered adults.

Because of low numbers of recaptured fish in the 1990s historical data, only years between 1990 and 1996 with sufficient recapture data were used for length-at-age analyses. The results include plots of the age-class density for each year by length as predicted by the length-at-age model. Density is a measure of relative frequency for continuous values. To compare among years, mean length-at-age was plotted for age-0 fish. Length-at-age of age-1 and older age-classes are not presented because the size depends on growth during more than one year, which complicates interpretation.

3.2.4 *Observer Length Correction*

The annual bias (inaccuracy) and error (imprecision) in observer's estimates of fish length during the geo-referenced visual survey were quantified and used to correct lengths before assigning life stages based on length-at-age cutoffs. Bias and error were quantified using a function that minimized the divergence of the length distribution of the observed fish (visual survey) and the length distribution of the measured fish (mark-recapture survey). The percent length correction that minimized the Jensen-Shannon divergence (Lin 1991) between the two distributions provided a measure of the inaccuracy while the minimum divergence (the Jensen-Shannon divergence was calculated with log to base 2 which means it lies between 0 and 1) provided a measure of the imprecision.

Key assumptions of the length correction model include the following:

- The length-frequency distribution varied among years.
- The expected length bias and error for a given observer varied among but not within years.

3.2.5 *Growth*

Annual growth was estimated from inter-annual recaptured fish using the Fabens (1965) method for estimating the von Bertalanffy (1938) growth curve.

Key assumptions of the growth model include the following:

- The mean value of maximum length (L_∞) was constant.
- The growth coefficient (k) varied randomly with year.
- The residual variation in growth was normally distributed.

In the von Bertalanffy growth model, the growth coefficient, k, represents the rate at which fish approach the asymptotic size (L_∞). Plots of growth show the effect size (percent change) relative to a typical year in the annual estimates of the mean growth coefficient. In addition to plots of the growth coefficient, the maximum growth in mm per year was calculated by multiplying the growth coefficient by the asymptotic length and plotted for each year. The maximum growth rate can be interpreted as the maximum growth during early life (i.e., theoretical growth rate when fish are 0 mm in length) and can be used to compare between populations or years (Galluci and Quinn 1979; Shuter et al. 1998).

The estimated growth curve for Walleye predicted unrealistic length-at-age, which was attributed to highly variable growth even for large fish (e.g., 0–60 mm per year for 500 mm Walleye). To try to address this concern, the growth model was re-run using only Walleye less than 450 mm in fork length and these results are included in the report to represent the growth coefficient of smaller adult Walleye (mostly 300–450 mm) in the study area. As predictions of length-at-age were not realistic for younger fish, even after removing fish larger than 450 mm, Walleye were not included in the plot showing length-at-age predicted by the von Bertalanffy curve. Despite this limitation, estimates of the growth coefficient and maximum growth rate, which are of interest for assessing the management questions, are considered reliable indicators of growth for typical adult Walleye (300-450 mm) in the study area.

3.2.6 *Site Fidelity*

The extent to which fish remained at the same site between sample sessions was evaluated using a logistic analysis-of-covariance (ANCOVA; Kery 2010). The model estimated the probability of a recaptured fish being caught at the same site where it was previously encountered.

Key assumptions of the site fidelity model include the following:

- Observed site fidelity was described by a Bernoulli distribution.
- Expected site fidelity varied with body length.

Length as a second-order polynomial was not found to be a significant predictor for site fidelity so was not included in the model.

Site fidelity was defined as the probability of fish remaining at the same site between sessions in a particular year. The estimated probability of being caught at the same site versus a different site from the logistic ANCOVA was converted into the site fidelity by assuming that those fish which were recaptured at a different sampling site represented 32% of fish that left the site. The correction factor corresponds to the proportion of shoreline of the LCR that is included in index sites. This correction accounts for the fact that fish that leave the site where they were initially captured may move to different index sites within the study area, or to parts of LCR that are not index sites.

Site fidelity estimates also were used to adjust the capture efficiencies in the analysis of mark-recapture data (see Section 3.2.7).

3.2.7 Capture Efficiency

The probability of capture was estimated using a recapture-based binomial model (Kéry and Schaub 2011: 134-136, 384-388).

Key assumptions of the capture efficiency model include the following:

- The capture probability varied randomly by session within year.
- The probability of a marked fish remaining at a site was the estimated site fidelity.
- The number of recaptures was described by a binomial distribution.

3.2.8 Abundance

The abundance of each index fish species was estimated using the catch data from the mark-recapture survey and the observer count data from geo-referenced visual surveys using an over-dispersed Poisson model (Kéry and Schaub 2011: 55-56). The model used the estimates of capture efficiency from the mark-recapture data (Section 3.2.7) to generate the estimated density of captured and uncaptured fish at each site. Observer count efficiency was estimated for the geo-referenced visual surveys, and was calculated by adjusting the capture efficiency based on the ratio of counted (visual surveys) to captured fish (four mark-recapture sessions). Count efficiency was then used in the model to estimate the total density of counted and uncounted fish present at each site. Abundance estimates represent the total number of fish in the study area.

Key assumptions of the abundance model include the following:

- The capture efficiency at a typical fish density was the point estimate for a typical sample session from the capture efficiency model.
- The count efficiency from the visual survey varied from the capture efficiency from the mark-survey.
- The capture efficiency (but not the count efficiency) varied with fish density.
- The fish density varied randomly with site, year and site within year.

- The overdispersion varied by visit type.
- The catches and counts were described by a Poisson-gamma distribution.

Plots of annual abundance represent the estimated total number of fish at all sites combined. Plots showing the variation in abundance by site show the lineal density (fish/km) at each site. Abundance was estimated separately for subadults (age-1) and adults (age-2 and older), where ages were based on fork length and the cutoffs from the length-at-age model (Section 3.2.3).

3.2.9 Spatial Distribution

Changes in the spatial distribution of index species over time were assessed by calculating the Shannon index of evenness (Shannon and Weaver 1949; Pielou 1966) in each year for each species and life stage. The index was calculated using the following formula where S is the number of sites and p is the proportion of the total density belonging to the ith site.

$$E = \frac{-\sum_{i=1}^{S}(p_i \log(p_i))}{\log(S)}$$

An evenness value of 100% would indicate the same density at all sites while an evenness of 0% would indicate that all the fish are clustered a single site.

3.2.10 Survival

The annual survival rate was estimated by fitting a Cormack-Jolly-Seber (CJS) model (Kéry and Schaub 2011: 172-175, 220) to inter-annual recapture data. Survival was only estimated for adults because sparse recapture data for subadults resulted in uninformative estimates.

Key assumptions of the survival model include the following:

- Survival varied randomly with year.
- The encounter probability varied with the total bank length sampled.

In addition to the recapture-based CJS estimate of survival, survival was estimated based on the estimated abundances of subadult (age-1) and adult (age-2 and older) fish. The subadult (S_t) and adult (A_t) abundance estimates were used to calculate the subadult and adult survival ($\emptyset_t$) in year t based on the relationship:

$$\emptyset_t = \frac{A_t}{S_{t-1} + A_{t-1}}$$

Abundance-based survival was estimated for Mountain Whitefish and Rainbow Trout. This analysis assumes the same survival rate for subadult and adult fish.

3.2.11 Body Condition

Condition was estimated via an analysis of the weight-length relationship (He et al. 2008). Key assumptions of the condition model include the following:

- Weight varied with length and date.
- Weight varied randomly with year.
- The relationship between length and weight varied with date.
- The relationship between length and weight varied randomly with year.
- The residual variation in weight was log-normally distributed.

Only previously untagged fish were included in models to avoid potential effects of tagging on body condition.

4.0 RESULTS

4.1 Physical Habitat

4.1.1 Discharge

Discharge in the LCR followed a bimodal pattern with a peak during spring freshet and a smaller second peak during early winter associated with hydropower generation. Daily mean discharge below BRD, below HLK, and downstream of the confluence of the Kootenay and Columbia rivers at the Birchbank gauging station are shown for each year from 2001 to 2019 in Appendix D.

4.1.2 Temperature

Between 2001 and 2019, water temperature in the Columbia River at Birchbank reached a maximum daily mean temperature of approximately 16°C to 19°C, with peak temperatures occurring during mid-August (Appendix D, Figure D3). Temperature of the Columbia River measured at the time of sampling was typically between 8°C and 15°C (Appendix B, Table B3). In the Kootenay River, annual maximum mean water temperatures of approximately 19°C occur in August and annual minimum average temperatures of 4°C occur in January and February (Appendix D, Figure D5).

4.1.5 Aquatic Vegetation

In the upstream section of the Columbia River (upstream of the Kootenay confluence), habitat data collected since 2001 indicates that aquatic vegetation comprised a small percentage of the available cover in 2001 to 2003 but a substantial portion of available cover in sites with lower velocity in all years from 2004 to 2019 (Attachment A; Appendix B, Table B3). Shallower sandy locations are dominantly Eurasian watermilfoil (EWM; *Myriophyllum spicatum*), and small areas of invasive curly pond weed (*Potamogeton crispus*; Golder and ONA 2018). Sites that drop off more steeply and with more velocity contain native Potamogeton sp., Chara sp., and a native watermilfoil, (*Myriophyllum verticilatum*; Golder and ONA 2018).

Aquatic vegetation in the downstream section of the Columbia River and the Kootenay River are more sporadic and typically located in embayments off the mainstem. Although aquatic vegetation cover data were not recorded during programs conducted in the early 1990s (R.L.&L. 1995), vegetation was not a common cover type in any sections of the LCR (L. Hildebrand, Golder Associates Ltd., pers. comm.). An effectiveness monitoring study was conducted in 2017 in the upper section of the LCR, including in some of the indexing electrofishing sites, to assess methods to reduce the amount of invasive EWM, and in turn, potential habitat for invasive Northern Pike (Golder and ONA 2018). The study involved laying long sections of mat material in areas of high concentrations of EWM, which was found to be effective at preventing growth of EWM, but has not been implemented on a large scale.

4.2 Catch

In total, 15,527 fish were recorded in the LCR in 2019 (Table 4). This total included both captured fish and observed fish that were identified to species at both the index and GRTS sites combined.

Table 4: Number of fish caught and observed during boat electrofishing surveys and their frequency of occurrence in sampled sections of the LCR, 30 September to 3 November 2019. This table includes data from index and GRTS sites.

Species	**Columbia River Upstream**		**Kootenay River**		**Columbia River Downstream**		**All Sections**	
	***n*[a]**	**%[b]**	***n*[a]**	**%[b]**	***n*[a]**	**%[b]**	***n*[a]**	**%[b]**
Sportfish								
Brook Trout (*Salvelinus fontinalis*)					2	<1	2	<1
Brown Trout (*Salmo trutta*)	1	<1			2	<1	3	<1
Bull Trout (*Salvelinus confluentus*)	1	<1					1	<1
Burbot (*Lota lota*)	1	<1			15	<1	16	<1
Kokanee (*Oncorhynchus nerka*)	45	2			14	<1	59	1
Lake Whitefish (*Coregonus clupeaformis*)	4	<1	1	1	81	1	86	1
Mountain Whitefish (*Prosopium williamsoni*)	1021	37	97	55	1499	22	2617	27
Northern Pike (*Esox lucius*)	23	1	1	1	1	<1	25	<1
Rainbow Trout (*Oncorhynchus mykiss*)	1060	39	45	26	4207	61	5312	54
Pumpkinseed (*Lepomis gibbosus*)					1	<1	1	<1
Walleye (*Sanders vitreus*)	498	18	29	16	1007	15	1534	16
White Sturgeon (*Acipenser transmontanus*)	73	3	3	2	30	<1	106	1
Yellow Perch (*Perca flavescens*)	1	<1			3	<1	4	<1
Sportfish Subtotal	2728	100	176	101	6862	99	9766	100
Non-sportfish								
Carp spp. (*Cyprinus carpio*)	1	<1					1	<1
Northern Pikeminnow (*Ptychocheilus oregonensis*)	76	3	6	4	31	1	113	2
Peamouth (*Mylocheilus caurinus*)	5	<1	1	1			6	<1
Redside Shiner (*Richardsonius balteatus*)	343	12	17	13	170	6	530	9
Sculpin spp. (*Cottidae*)	1162	41	46	34	2247	81	3455	60
Sucker spp. (*Catostomidae*)	1267	44	64	48	325	12	1656	29
Non-Sportfish Subtotal	2854	100	134	100	2773	100	5761	100
Total	5582	100	310	100	9635	100	15527	100

[a] Includes fish observed and identified to species; does not include intra-year recaptured fish.

[b] Percent composition of sportfish or non-sportfish catch.

[c] Not identified to species or species combined for analysis.

Summaries of catch and effort and life history metrics were used to provide supporting information and to help set initial parameter values in some of the statistical models. Although these summaries are important, they are not presented nor specifically discussed in detail. However, these metrics are provided in the appendices for reference purposes and are referred to when necessary to support or discount results of the models. Metrics presented in the appendices include:

- captured and observed fish count data by site and bank habitat type (Appendix B, Table B4), 2019;
- catch and percent composition by species, 2001 to 2019 (Appendix E, Table E1);
- catch-rates for all sportfish (Appendix E, Table E2) and non-sportfish (Appendix E, Table E3), 2019;
- length-frequency histograms by section for Mountain Whitefish (Appendix F, Figure F1), Rainbow Trout (Appendix F, Figure F2), and Walleye (Appendix F, Figure F3), 2019;
- length-frequency histograms by year for Mountain Whitefish (Appendix F, Figure F4), Rainbow Trout (Appendix F, Figure F5), and Walleye (Appendix F, Figure F6), all years combined; and
- length-weight relationships by year for Mountain Whitefish (Appendix F, Figure F7), Rainbow Trout (Appendix F, Figure F8), and Walleye (Appendix F, Figure F9), all years combined.

4.3 Length-At-Age and Growth Rate

Outputs from the length-at-age model are presented in Table 5 and represent the best estimates of the length cut-offs between age-classes of Mountain Whitefish and Rainbow Trout during each sample year. Based on the length-at-age model, four age-classes were distinguishable for Mountain Whitefish and three were distinguishable for Rainbow Trout (Table 5). Length-density plots show the relative frequency of lengths by age-class (Appendix G; Figures G1 and G2). Separate age-classes were not distinguishable based on length-frequency data for Walleye so all individuals were classified as adults. The von Bertalanffy growth curves show the average rate of growth and asymptotic size for Mountain Whitefish and Rainbow Trout (Figure 2). The von Bertalanffy growth curve for Walleye is not shown because predictions of length-at-age were not realistic for younger fish, as discussed in Section 5.1.3.

Table 5: Estimated minimum and maximum fork lengths (in mm) by age-class and year for Mountain Whitefish and Rainbow Trout in the lower Columbia River, 1990 to 1991 and 2001 to 2019. Estimates were derived from the length-at-age model (Section 3.2.3).

Year	Mountain Whitefish				Rainbow Trout		
	Age-0	Age-1	Age-2	Age-3+	Age-0	Age-1	Age-2+
1990	≤167	168–274	≥275	≥275	≤155	156–354	≥355
1991	≤144	145–226	227–296	≥297	≤127	128–343	≥344
2001	≤141	142–258	259–344	≥345	≤134	135–325	≥326
2002	≤163	164–260	261–344	≥345	≤155	156–350	≥351
2003	≤159	160–263	264–354	≥355	≤162	163–343	≥344
2004	≤158	159–249	250–342	≥343	≤143	144–333	≥334
2005	≤168	169–263	264–363	≥364	≤164	165–347	≥348
2006	≤175	176–284	285–357	≥358	≤171	172–365	≥366
2007	≤171	172–280	281–337	≥338	≤166	167–375	≥376
2008	≤170	171–247	248–340	≥341	≤146	147–340	≥341
2009	≤169	170–265	266–355	≥356	≤148	149–339	≥340
2010	≤177	178–272	273–352	≥353	≤147	148–337	≥338
2011	≤163	164–269	270–348	≥349	≤156	157–344	≥345
2012	≤162	163–268	269–347	≥348	≤152	153–345	≥346

Year	Mountain Whitefish				Rainbow Trout		
	Age-0	Age-1	Age-2	Age-3+	Age-0	Age-1	Age-2+
2013	≤185	186–282	283–349	≥350	≤170	171–355	≥356
2014	≤178	179–284	285–362	≥363	≤155	156–338	≥339
2015	≤167	168–278	279–366	≥367	≤167	168–335	≥336
2016	≤164	165–283	284–352	≥353	≤155	156–338	≥339
2017	≤158	159–270	271–354	≥355	≤133	134–318	≥319
2018	≤177	178–262	263–346	≥347	≤144	145–314	≥315
2019	≤188	189–282	283–363	≥364	≤161	162–315	≥316

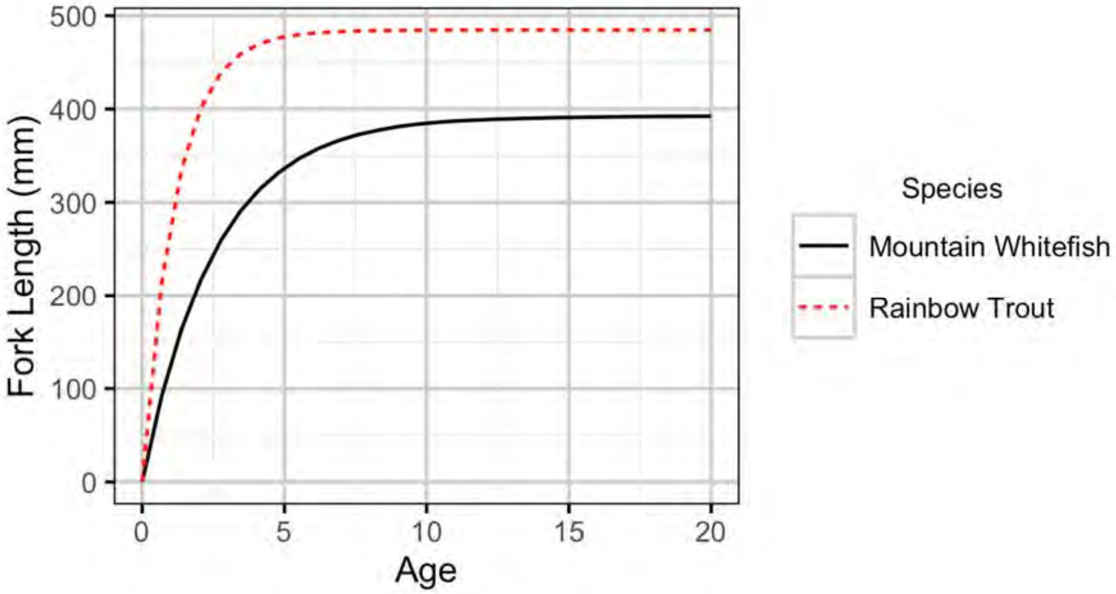


Figure 2: **Growth curve showing length-at-age by species as predicted by the von Bertalanffy model for the lower Columbia River, 2001–2019.**

4.3.1 Mountain Whitefish

The mean fork length of Mountain Whitefish fry (age-0) typically ranged from 120 to 140 mm in most years of the program. The mean fork length of age-0 Mountain Whitefish was greater than average in three of the last four years (2016, 2018, and 2019) when mean fork lengths were between 140 and 160 mm. Two years, 1991 and 2001, had smaller length-at-age (approximately 100 mm) for age-0 Mountain Whitefish than all other years.

The length-at-age plots for age-1, age-2, and age-3 and older age-classes are not presented because they depend on growth in more than one previous year, which complicates interpretation.

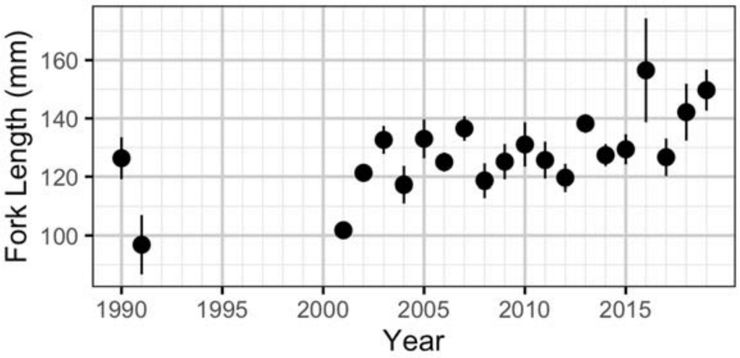


Figure 3: **Mean fork length of age-0 Mountain Whitefish in the lower Columbia River, 1990 to 1991 and 2001 to 2019.**

Analysis of growth of recaptured Mountain Whitefish indicated generally increasing annual growth between 2005 and 2016 with the exception of 2012 (Figure 4). Growth was lower in 2017 to 2019, with effect sizes of -8% to -11%, compared to an effect size of 58% in 2016. These effect sizes are based on the growth coefficient, k, in a particular year compared to a typical year. The predicted maximum growth rate during early life increased from 98 mm/yr in 2005 to 245 mm/yr in 2016 and decreased to approximately 140 mm/yr in 2017 to 2019 (Figure 5).

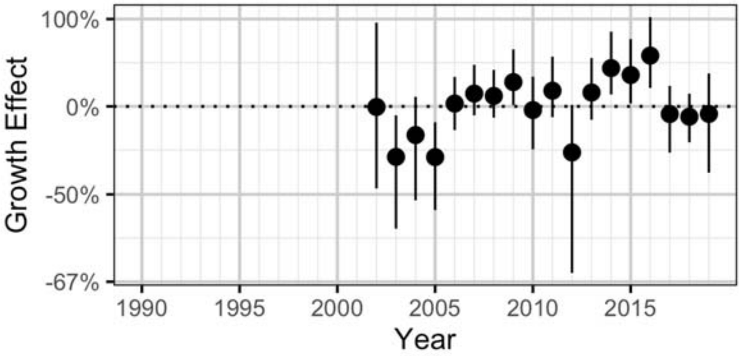


Figure 4: **Estimated percent change in the von Bertalanffy growth coefficient (mean with 95% CIs) relative to a typical year for Mountain Whitefish based on recaptured individuals in the lower Columbia River, 2001 to 2019.**

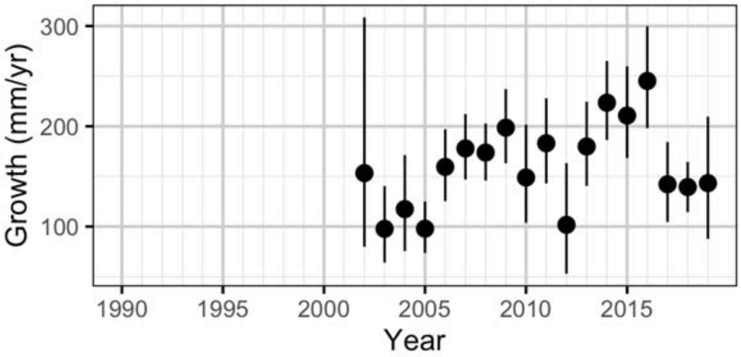


Figure 5: **Predicted maximum growth rate (mean with 95% CIs) from the von Bertalanffy model for Mountain Whitefish based on recaptured individuals in the lower Columbia River, 2001 to 2019.**

4.3.2 Rainbow Trout

The length-at-age model indicated an increase in the mean length of Rainbow Trout fry (age-0) from 106 mm in 2011 to 145 mm in 2015 (Figure 6). Mean length of age-0 Rainbow Trout varied from 102 to 127 mm between 2016 and 2019 with large and overlapping credible intervals. The greater uncertainty in the estimates from 2015 to 2019 than previous years was due to lower catch of age-0 Rainbow Trout in recent years. Catch of age-0 Rainbow Trout ranged from 2 to 15 fish per year between 2015 and 2019 and between 22 and 319 fish per year between 2001 and 2014. Mean length-at-age of fry was much lower in 1991 (89 mm) and 2001 (90 mm) than other years. Length-at-age is not presented for subadult or adult Rainbow Trout (i.e., age-1 and older) because more than one previous year affects the length-at-age, which complicates interpretation.

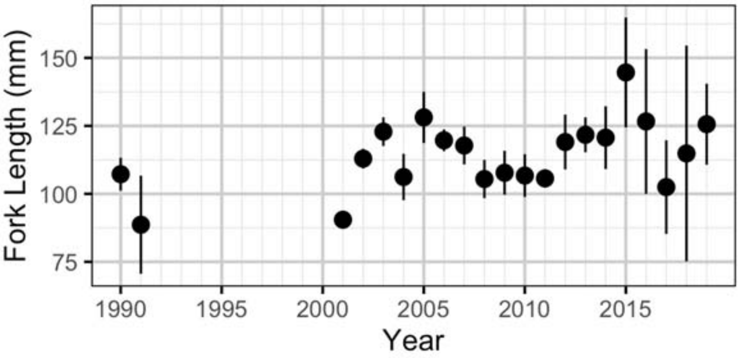


Figure 6: **Mean fork length of age-0 Rainbow Trout in the lower Columbia River, 1990 to 1991 and 2001 to 2019.**

Analysis of annual growth of recaptured Rainbow Trout indicated a low growth coefficient in 2003 and 2004 (-13% to -30% effect size; Figure 7). Estimates of the growth coefficient generally declined from a 58% effect size in 2006 to -39% in 2018. In 2019, there was a small increase to an effect size of -27%. The predicted maximum growth during early life suggested a similar trend with a decrease from 643 mm/yr in 2006 to 247 mm/yr in 2018 and 301 mm/yr in 2019 (Figure 8). These maximum growth rates represent the theoretical maximum growth rate when fish are 0 mm in length, and therefore should not be interpreted as the rate for the entire first year of life. Regardless, the large decrease in maximum growth rate during the study period (643 to 247 mm/yr) suggests a substantial change in growth.

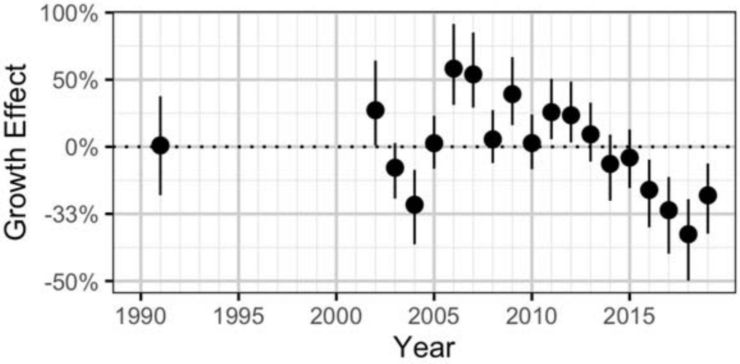


Figure 7: **Estimated percent change in the von Bertalanffy growth coefficient (mean with 95% CIs) relative to a typical year for Rainbow Trout based on recaptured individuals in the lower Columbia River, 2001 to 2019.**

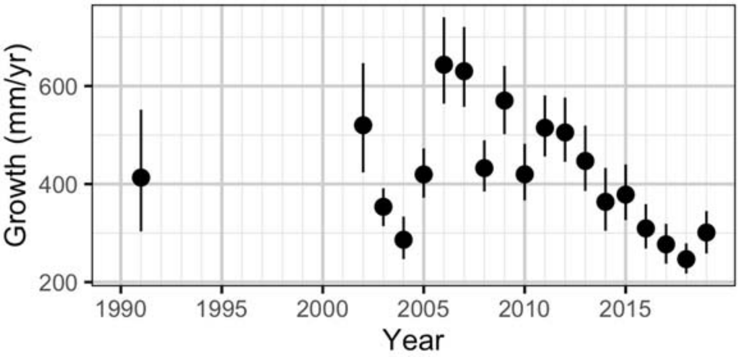


Figure 8: **Predicted maximum growth rate (mean with 95% CIs) from the von Bertalanffy model for Rainbow Trout based on recaptured individuals in the lower Columbia River, 2001 to 2019.**

4.3.3 Walleye

Analysis of annual growth of recaptured Walleye indicated a near-average growth coefficient in 2019 with an effect size of 14%, which was within the range of effect sizes observed in most years (typical range of -24% to 27%; Figure 9). The estimated growth coefficient generally increased from 2010 (-24% effect size) until 2016 (27%), but there was a very high growth coefficient (76%) in 2013. Credible intervals for the growth coefficient were large because of large variability in the annual growth among recaptured Walleye of all sizes. For instance, annual growth of Walleye initially captured at ~300 mm in fork length varied from ~15 to 70 mm/year, and growth of Walleye initially captured at ~500 m ranged from ~5 to 60 mm (data not shown). Because of the large variability in annual growth, especially for the largest Walleye, the von Bertalanffy curve (Figure 2) and effect size based on the model's growth coefficient (Figure 9) were calculated using only Walleye <450 mm in fork length. Predicted values of maximum growth rate during early life ranged from 48 to 82 mm, except in 2013 when the maximum growth rate was 113 mm/yr (Figure 10).

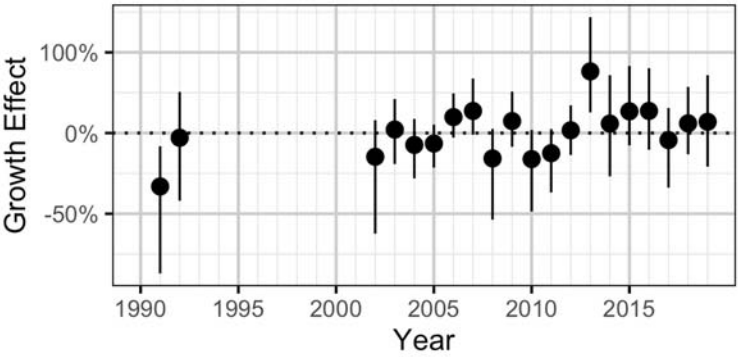


Figure 9: Estimated percent change in the von Bertalanffy growth coefficient (mean with 95% CIs) relative to a typical year for Walleye based on recaptured individuals <450 mm in fork length in the lower Columbia River, 2001 to 2019.

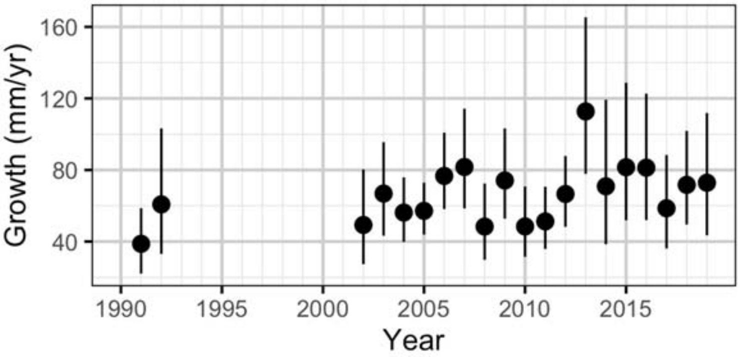


Figure 10: Predicted maximum growth rate (mean with 95% CIs) from the von Bertalanffy model for Walleye based on recaptured individuals in the lower Columbia River, 2001 to 2019.

4.3.4 Observer Length Correction

The length bias model used the length-frequency distribution of captured fish to estimate the bias in the estimated lengths of observed fish. The results suggested that most observers underestimated fork lengths for all three index species (Figure 11). The inaccuracy for Mountain Whitefish varied by observer with bias of -40 to 40 mm relative to captured fish of known length (Figure 12). Inaccuracy of Rainbow Trout lengths varied between -60 and 10 mm. Inaccuracy in estimated Walleye fork lengths ranged between -80 and 40 mm. Estimates of observer bias were used to correct estimated fork lengths (Appendix G, Figure G12) before classifying fish into age-classes for abundance analyses.

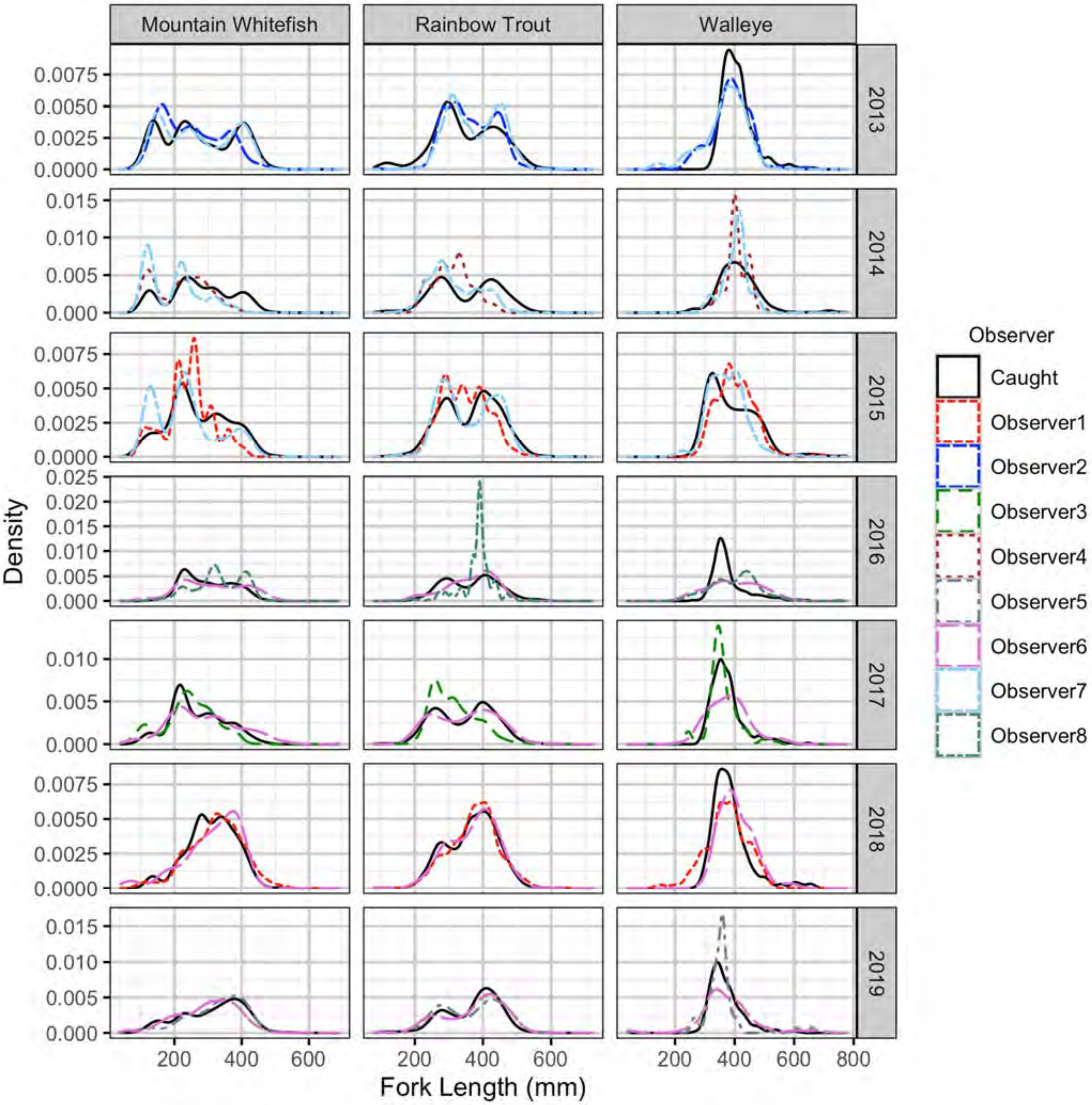


Figure 11: **Fork length-density plots for measured and estimated fork lengths of fish caught or observed in the lower Columbia River, 2013–2019. The black line shows fish that were caught. Observed data from the georeferenced visual survey are shown by coloured dashed lines.**

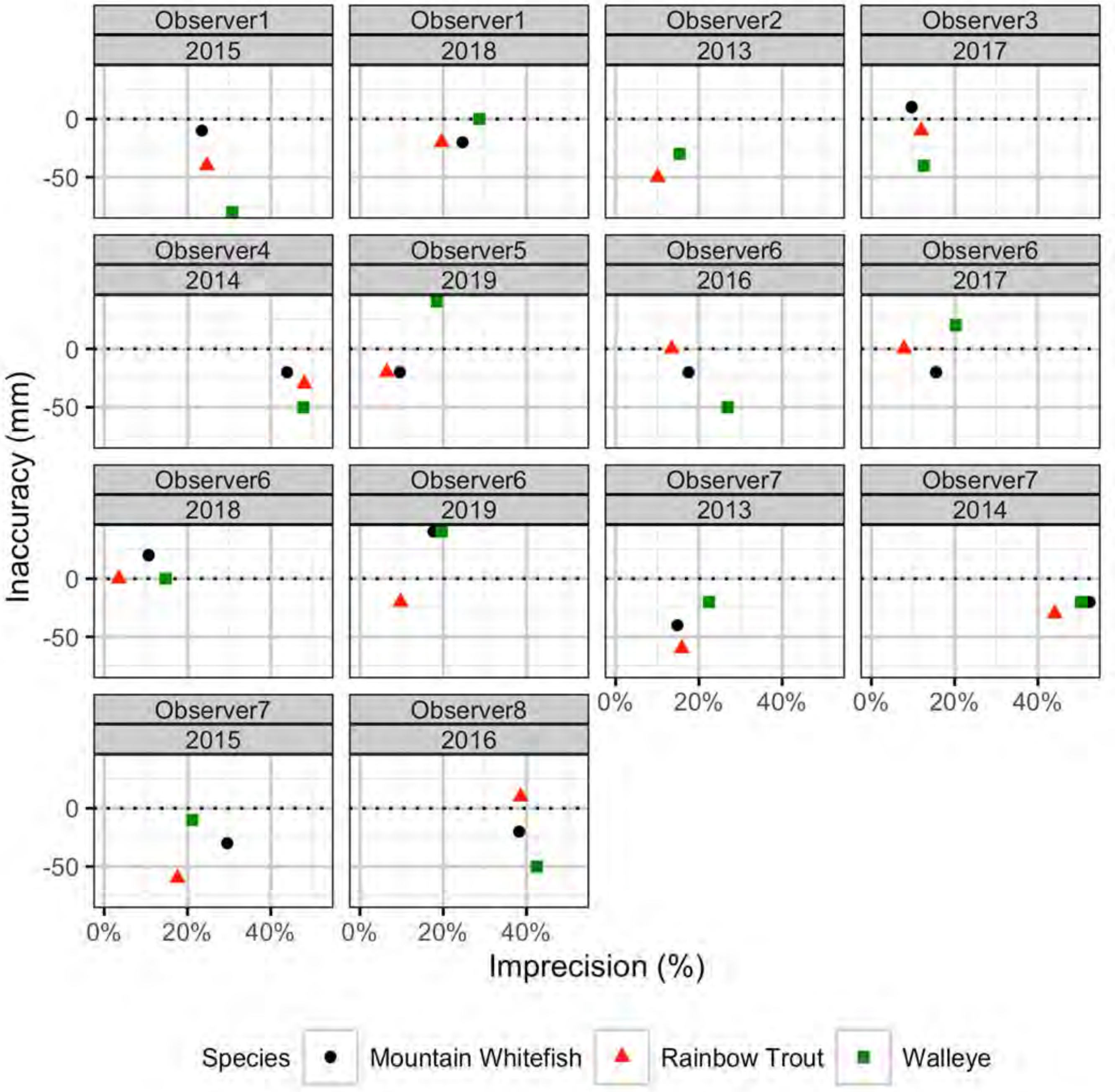


Figure 12: **Fish length inaccuracy (bias) and imprecision by observer, year of observation and species. Observations use the length bias model of captured (mark-recapture surveys) compared to estimated (geo-referenced visual surveys) length-frequency distributions from the lower Columbia River, 2013–2019.**

4.4 Spatial Distribution and Abundance

4.4.1 Site Fidelity

Site fidelity was greater for Rainbow Trout and Walleye (~25–63%) than for Mountain Whitefish (<25%; Figure 13). Site fidelity decreased with increasing fork length for all three species but the slope of this relationship was only significant for Rainbow Trout (*P* < 0.001) and not for Mountain Whitefish or Walleye (*P* > 0.5).

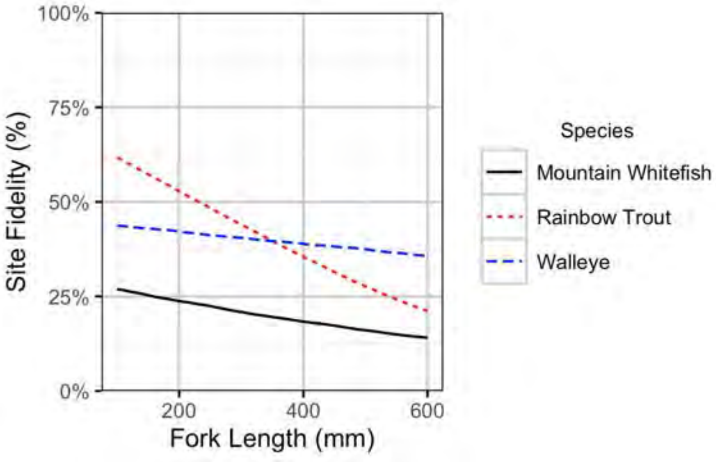


Figure 13: Site fidelity, defined as the expected probability that a fish is recaptured at the same site where it was marked, by species and fork length in the lower Columbia River, 2001 to 2019.

4.4.2 Efficiency

Estimated capture efficiency was greatest for Rainbow Trout (3% to 4.5%) and lowest for Mountain Whitefish (~1%; Figure 14). Capture efficiency was lower for adult (3%) than subadult (4.5%) Rainbow Trout but similar between subadult and adult Mountain Whitefish. For most species and age-classes, capture efficiency was similar among sampling sessions and years without any apparent seasonal or temporal trends (Appendix G, Figures G3–G7). One exception was that in some years the capture efficiency of subadult Rainbow Trout and Walleye decreased in subsequent sample sessions (Appendix G, Figures G5 and G7). Estimates of capture efficiency were used to estimate total abundance in the sample sites (Section 4.4.3–4.4.5).

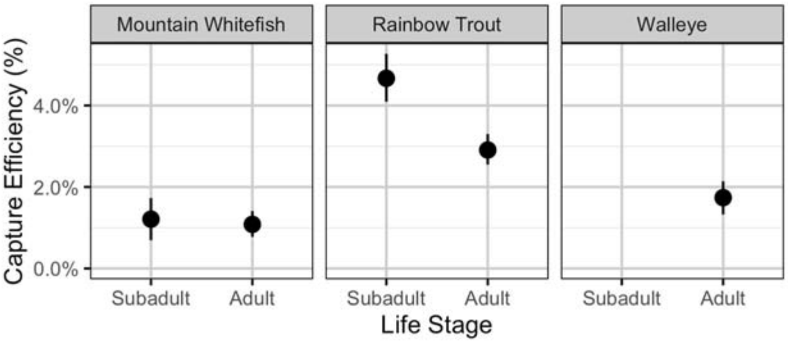


Figure 14: Capture efficiency (mean with 95% CIs) by species from mark-recapture data from the lower Columbia River, 2001–2019.

4.4.3 *Mountain Whitefish*

The estimated abundance of subadult Mountain Whitefish in index sites in the LCR was much greater in 2001 and 2002 (57,000-64,000) than all other years (Figure 15). In 2018 and 2019, the estimated abundance of subadult Mountain Whitefish (10,000-12,000) was one third of the values from the previous five years (29,000–32,000). Estimates of adult Mountain Whitefish abundance have been relatively stable between 2010 and 2019 (44,000–58,000) with the exception of 2018 when the estimate was higher (91,000).

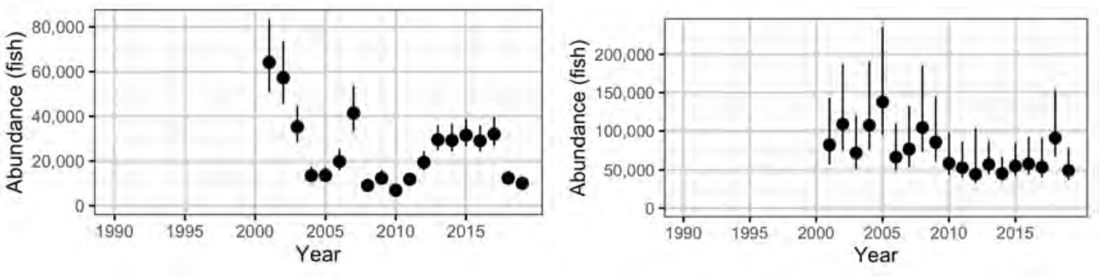


Figure 15: Abundance (means with 95% CIs) of subadult (age-1; left panel) and adult (age-2 and older; right panel) Mountain Whitefish at index sites in the lower Columbia River, 2001–2019.

The density of both subadult and adult Mountain Whitefish was highest near the confluence of the Columbia and Kootenay rivers and lowest near the Canada-US border (Figure 16). Subadult Mountain Whitefish densities were highest in low water velocity areas, such as Balfour Bay (RKm 2.8), just downstream of the log booms near Zellstoff-Celgar (both banks; RKm 4.5), upstream and downstream of Norn's Creek Fan (RKm 7.4), and along the left bank between Waldie Island and Tin Cup Rapids (RKm 9.2; Figure 16). Subadult Mountain Whitefish densities were low in the Kootenay River and in the Columbia River downstream of the Kootenay River confluence, river sections that typically have higher water velocities.

Adult Mountain Whitefish site-level density estimates (Figure 16) had larger credible intervals than estimates of subadult Mountain Whitefish. Density estimates of adult Mountain Whitefish were generally higher in sites known to contain suitable spawning habitat for this species. These areas include Norn's Creek Fan (RKm 7.4) downstream to CPR Island, the Kootenay River, between the Kootenay River confluence (RKm 10.6) and Kinnaird Bridge (RKm 13.4), and the Genelle area (RKm 27.0).

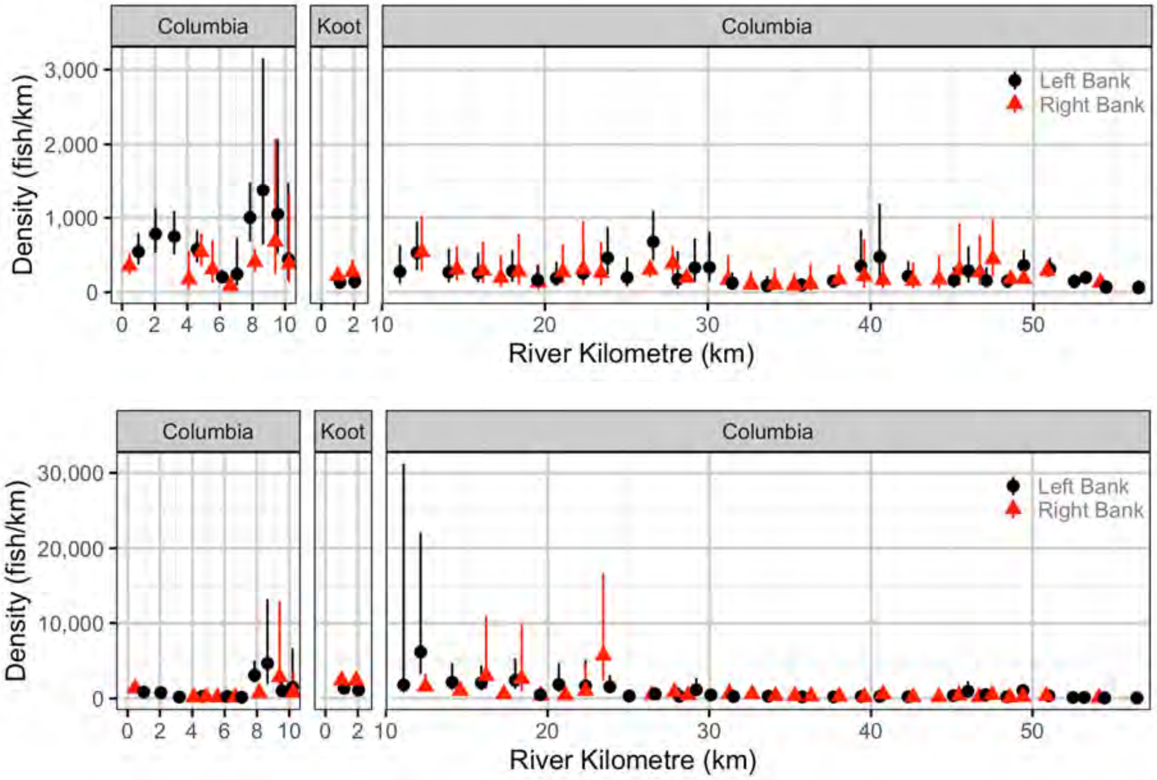


Figure 16: **Density (means with 95% CIs) of subadult (age-1; top panel) and adult (age-2 and older; bottom panel) Mountain Whitefish by river kilometre in the lower Columbia River, 2001–2019.**

The evenness in the distribution of subadult Mountain Whitefish among index sites did not show a consistent trend between 2001 and 2019 (Figure 17; left panel). Evenness of adult Mountain Whitefish distribution declined by 6% between 2003 and 2006 but was 81% from 2016 to 2019 (Figure 17; right panel). The density of subadult Mountain Whitefish at randomly selected non-index sites sampled during the GRTS survey was similar to the density at index sites (Appendix G, Figure G13). The density of adult Mountain Whitefish was greater at random sampled GRTS sites than at index sites, with the difference ranging from 50% to 150% in most years (Appendix G, Figure G13).

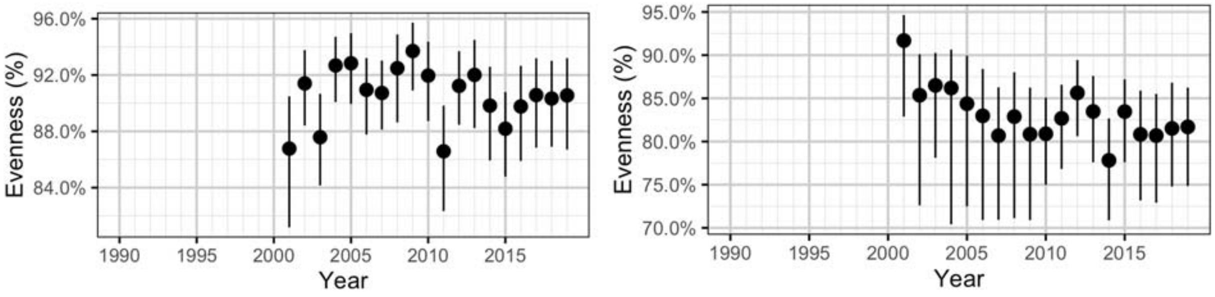


Figure 17: **Estimated evenness in abundance between index sites for subadult (left) and adult (right) Mountain Whitefish by year.**

4.4.4 Rainbow Trout

The abundance of subadult Rainbow Trout declined from 2001 to 2005 and fluctuated with no long-term increase or decrease from 2006 to 2017 (Figure 18). The estimated abundance of subadult Rainbow Trout was lower in both 2018 and 2019 (~8,000) than the previous six years when abundance was relatively stable (13,000–17,000). Adult Rainbow Trout abundance estimates increased from ~15,000 in 2002 to 46,000 in 2018, with a small decrease to 38,000 in 2019.

Rainbow Trout site-level density estimates had large credible intervals (Figure 19), particularly at sites that were only sampled between 2012 and 2019 (GRTS sites). The analysis suggests higher densities of subadult Rainbow Trout in most sites between Genelle (RKm 21.0) and Beaver Creek (RKm 47.8) than in other sections of the study area (Figure 19). The distribution of adult Rainbow Trout was similar to that of subadults with greater densities in the Columbia River between the Kootenay River confluence and the Beaver Creek confluence and lower densities in the Columbia River upstream of the Kootenay River confluence (Figure 19). Adult Rainbow Trout densities were substantially higher below the Bear Creek confluence (Sites C46.4-L and C45.6-L), from the Birchbank side channel to Murphy Creek (both banks; C30.5-R and C30.6-L), between the Champion Creek and Jordan Creek confluences (Site C24.3-L), and on the opposing bank downstream of the Kootenay River confluence (Site C11.5-R) when compared to neighbouring sites.

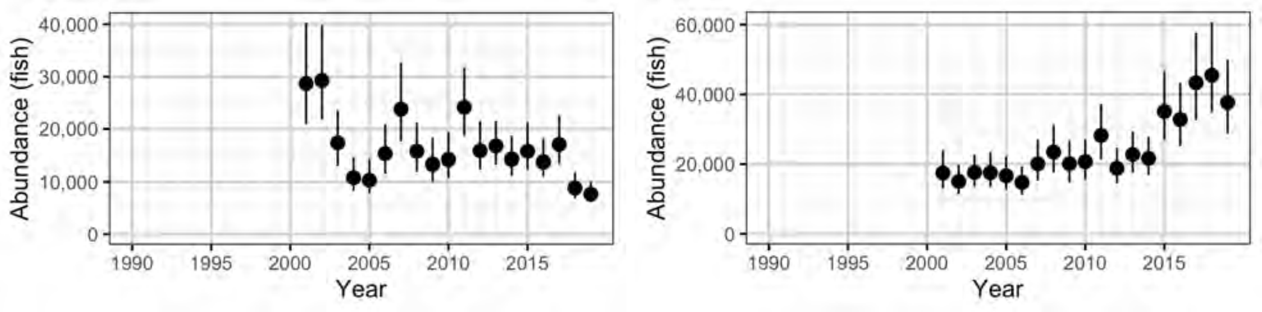


Figure 18: Abundance (means with 95% CIs) of subadult (age-1; left panel) and adult (age-2 and older; right panel) Rainbow Trout at index sites in the lower Columbia River, 2001–2019.

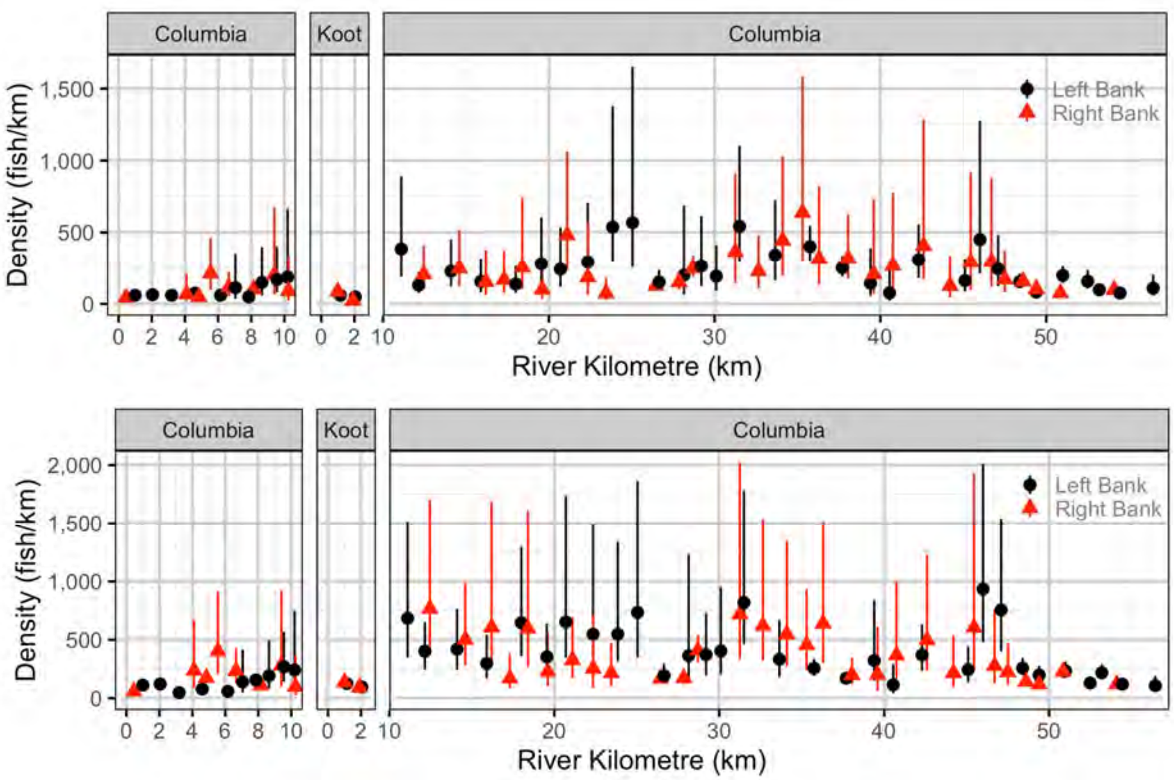


Figure 19: **Density (means with 95% CIs) of subadult (age-1; top panel) and adult (age-2 and older; bottom panel) Rainbow Trout by river kilometre in the lower Columbia River, 2001–2019.**

Evenness in the abundance of subadult Rainbow Trout between index sites generally increased from 2002 (86%) to 2019 (95%), with the exception of lower evenness in 2008 (Figure 20; left panel). The evenness of adult Rainbow Trout distribution in index sites increased between the early 2000s (91% to 95%) and 2019 (97%; Figure 20; right panel). The density of Rainbow Trout was approximately 100% to 250% greater at randomly selected non-index sites sampled during the GRTS survey than at index sites for both subadults and adults (Appendix G, Figure G14).

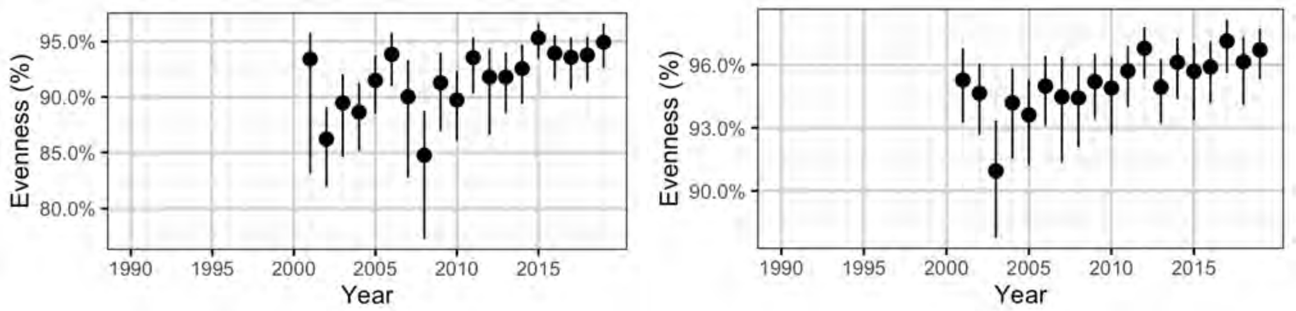


Figure 20: **Estimated evenness in abundance between index sites for subadult (left) and adult (right) Rainbow Trout by year.**

4.4.5 Walleye

Since 2001, Walleye abundance fluctuated with peaks in 2003 to 2005 and in 2011 (Figure 21). Walleye abundance estimates remained relatively stable between 2012 and 2019 (8,000–13,000). Density estimates for Walleye were greatest in the Kootenay River (Sites K0.6-R, K0.3-L and K1.38L), downstream of HLK (Site C1.3-L), in a small bay downstream of Bear Creek (Site C45.6-L), and at the site adjacent to the Canada-US border (C56.0-L; Figure 22). Density estimates for all other areas were similar and did not suggest differences in Walleye densities among sites.

The evenness in abundance of Walleye between index sites decreased from ~98% in the early 2000s to values 96% to 97% in 2010 to 2019 (Figure 23). The density at sites randomly selected non-index sites sampled during the GRTS survey was comparable to but slightly lower than the density at index sites (Appendix G, Figure G15).

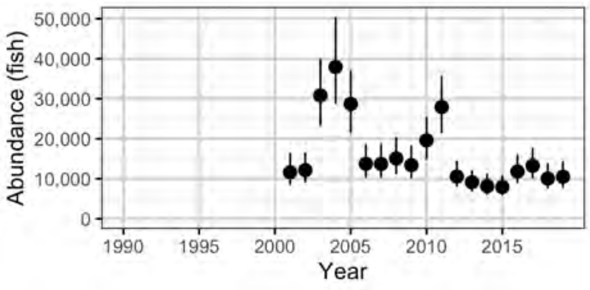


Figure 21: **Abundance (means with 95% CIs) of adult Walleye (all age-classes) at index sample sites in the lower Columbia River, 2001–2019.**

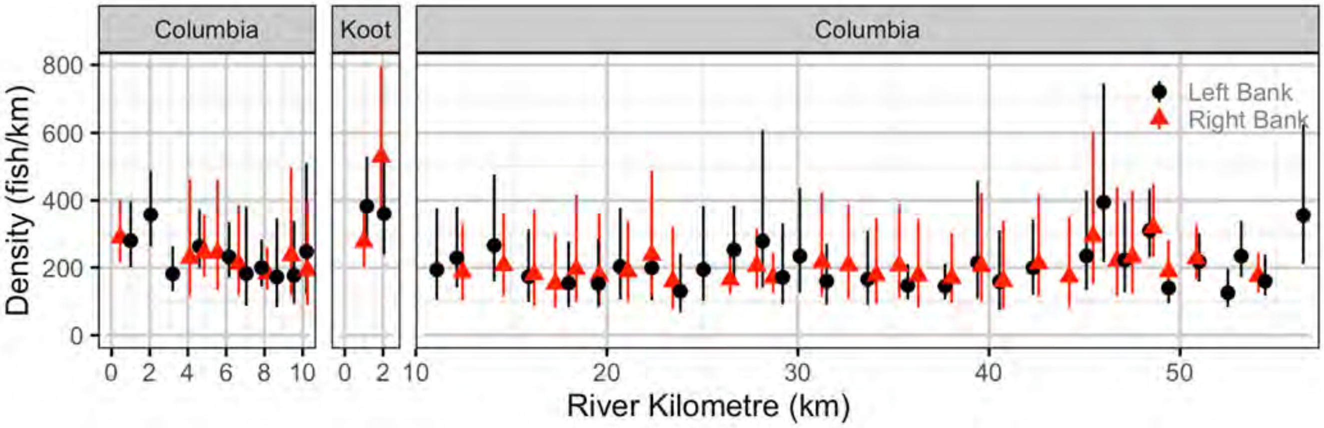


Figure 22: **Density (means with 95% CIs) of adult Walleye (all age-classes) by river kilometre in the lower Columbia River, 2001–2019.**

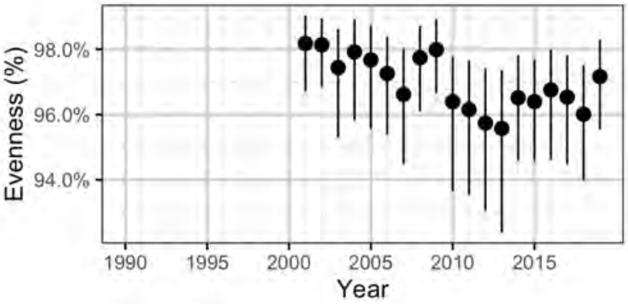


Figure 23: Estimated evenness in abundance between index sites for Walleye at index sites by year.

4.4.6 Geo-referenced Visual Enumeration Surveys

The visual surveys provided data regarding the within-site distribution of fish in the LCR. Maps showing the observed densities of the three index species by age-class distributed throughout sample sites are provided as an example of the spatial dataset (Appendix H). This type of map can be used to identify important fish habitats, and to compare to future years to assess the effects of flow regime variations on fish distribution and habitat usage.

4.5 Survival

4.5.1 Mountain Whitefish

For adult Mountain Whitefish, annual survival estimates varied from 21% to 92%. Adult survival generally increased between 2002 and 2008 and was relatively stable between 2011 and 2019 (67%–85%; Figure 24). The inter-annual capture efficiency, on which the survival estimate was based, was approximately 1%–4% (Appendix G, Figure G8).

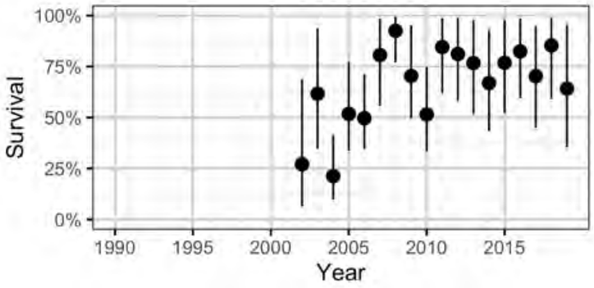


Figure 24: Survival estimates (mean with 95% CIs) for adult (age-2 and older) Mountain Whitefish in the lower Columbia River, 2001–2019.

The abundance-based survival estimates for subadult and adult Mountain Whitefish show a decreasing trend between 2007 to 2019 with the exception of 2018 when survival was estimated over 100% (Figure 25). Annual survival estimates ranged between 60% and 100% except for lower values in 2003, 2006 and 2019 (43% to 47%).

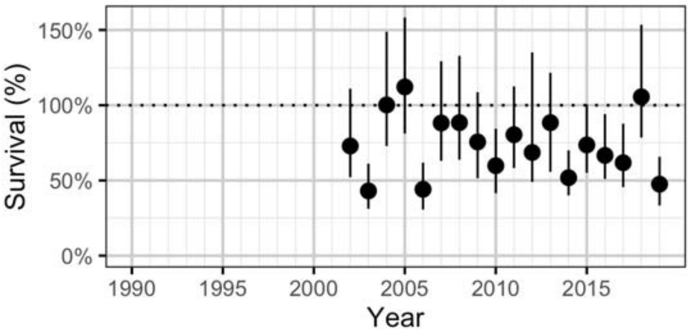


Figure 25: **Abundance-based survival estimates (mean with 95% CIs) for subadult and adult Mountain Whitefish by year.**

4.5.2 Rainbow Trout

Survival estimates of Rainbow Trout increased gradually from 34% in 2003 to 50% in 2011, but declined to 35%–42% in 2012 to 2019 (Figure 26). The inter-annual capture efficiency was 7%–8% (Appendix G, Figure G9).

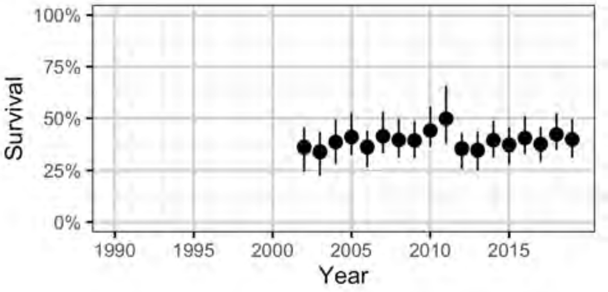


Figure 26: **Survival estimates (mean with 95% CIs) for adult (age-2 and older) Rainbow Trout in the lower Columbia River, 2001–2019.**

Abundance-based survival of Rainbow Trout showed an increasing trend between 2002 and 2011 and no consistent trend thereafter (Figure 27). Estimates were lowest in 2002 (32%) and 2012 (36%) and highest in 2015 (97%).

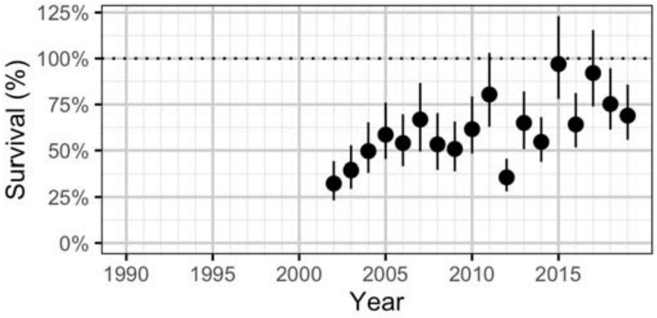


Figure 27: **Abundance-based survival estimates (mean with 95% CIs) for subadult and adult Rainbow Trout.**

4.5.3 Walleye

The estimated survival of Walleye ranged between 44% and 59% throughout the study period, with the exception of a drop in survival to 35% in 2004 (Figure 28). In recent years, the results indicated a decrease in survival from 57% in 2016 to 41% in 2019. However, credible intervals overlapped for all years. The inter-annual capture efficiency was 3%–4% (Appendix G, Figure G10).

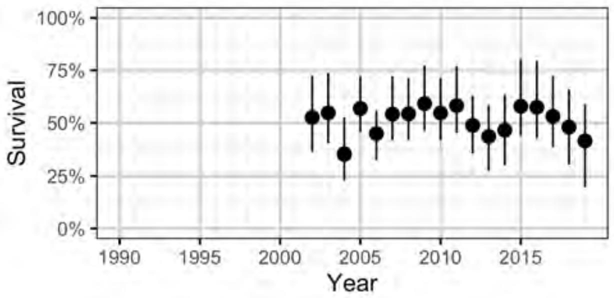


Figure 28: Survival estimates (mean with 95% CIs) for adult Walleye (all age-classes) in the lower Columbia River, 2001–2019.

4.6 Body Condition

4.6.1 Mountain Whitefish

The body condition of subadult Mountain Whitefish varied little from 2008 to 2015 (-1% to 2%), but was lower in 2017 (-2%) and greater in 2016, 2018 and 2019 (3%; Figure 29; left panel). Adult Mountain Whitefish body condition was also stable between 2010 and 2015, with effect sizes of 2% to 3%, but was greater in 2016 (5%) and 2019 (7%; Figure 29; right panel). Adult body condition was much lower in the 1990s than between 2001 and 2019, with effect sizes 6% to 15% lower than a typical year.

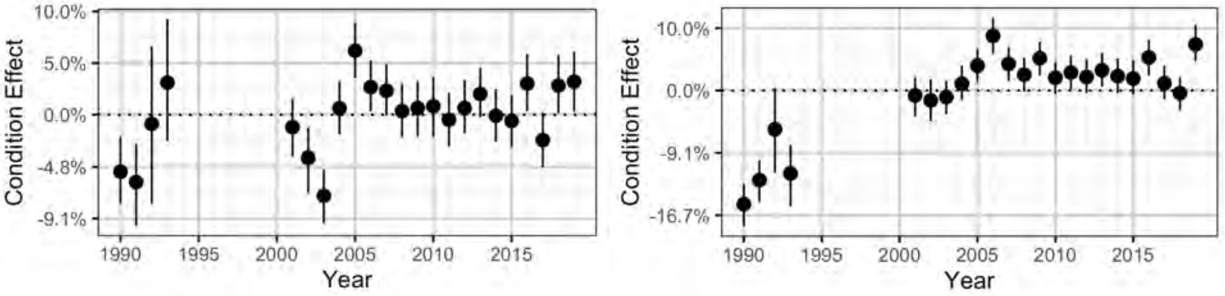


Figure 29: Body condition effect size estimates (mean with 95% CIs) for subadult (200 mm; left panel) and adult (350 mm; right panel) Mountain Whitefish in the lower Columbia River, 1990 to 1993 and 2001 to 2019.

4.6.2 Rainbow Trout

The estimated body condition of subadult and adult Rainbow Trout was higher in 2002 and 2006 than in other study years (Figure 30). Since 2008, subadult body condition was relatively stable with effect sizes near 0% except for higher body condition in 2013 (3%) and low body condition in 2017 (-4%). Adult body condition declined from 3% in 2011 to -7% in 2018, which coincided with increasing abundance estimates (Section 4.4.4).

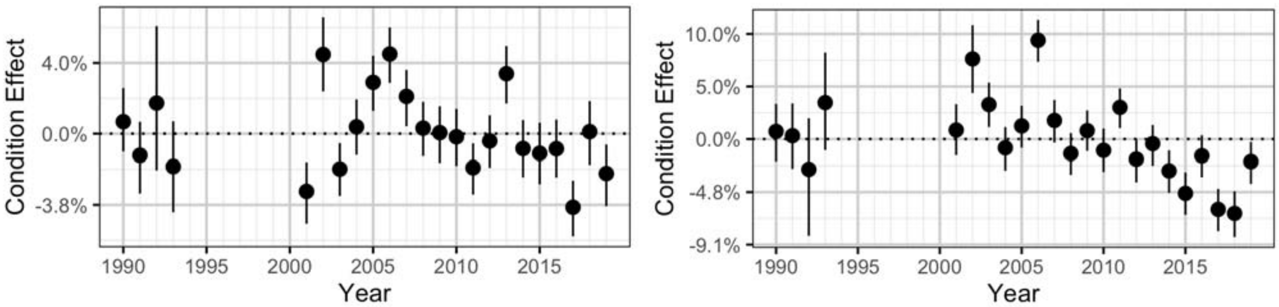


Figure 30: Body condition effect size estimates (mean with 95% CIs) for subadult (250 mm; left panel) and adult (500 mm; right panel) Rainbow Trout in the lower Columbia River, 1990 to 1993 and 2001 to 2019.

4.6.3 Walleye

Walleye body condition fluctuated with no consistent trend between 1990 and 2011 (Figure 29). Body condition estimates were relatively high in 2012 (6% effect size) but decreased gradually until 2018 and 2019, when the effect size was -1%. Overall, the results suggest good body condition from 2012 to 2015, but a declining trend to more typical values in the last few years.

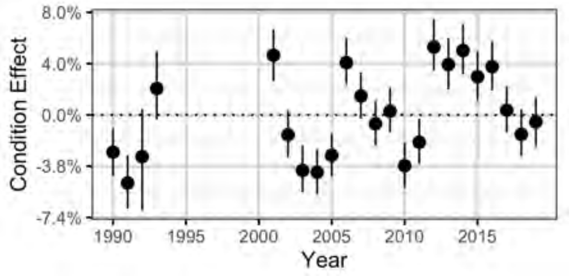


Figure 31: Body condition effect size estimates (median with 95% CIs) by year for adult (600 mm) Walleye in the lower Columbia River, 1990 to 1993 and 2001 to 2019.

5.0 DISCUSSION

The first management question of this monitoring program assesses annual fish population metrics in the LCR. Annual estimates and observed trends or differences are summarized in the following sections.

5.1 Length-at-Age and Growth

For Mountain Whitefish and Rainbow Trout, the mean length of age-0 individuals was used as an indicator of growth during the first year of life. For all three index species, a von Bertalanffy growth model was estimated using data from inter-year recaptured fish. The growth coefficient from the model represents the rate of approach to the asymptotic length. A lower value of the growth coefficient indicates a flatter curve and a slower rate of approach to the asymptotic length. The maximum growth rate during early life represents the growth rate at a theoretical fork length of zero and has units (mm/yr) that are easier to understand than the growth coefficient (units of yr^{-1}). Together, the growth coefficient and maximum growth rate were used to assess inter-annual variation in growth of sub-adult and adult fish of the index species.

5.1.1 *Mountain Whitefish*

There was little variation in the mean length of age-0 Mountain Whitefish from 2001 to 2015, when mean fork lengths were between approximately 120 and 140 mm (Figure 3). In the three of the last four years (2016, 2018, and 2019), the mean length of age-0 Mountain Whitefish was between approximately 140 and 160 mm, suggesting greater growth of young-of-the year in recent years. Increased length of young-of-the-year Mountain Whitefish in recent years corresponded to low abundance of subadults in 2018 and 2019, which could indicate increased growth due to decreased competition for resources.

The length-at-age model was used to assign age-class groupings based on length-frequency data. For Mountain Whitefish, the model classified age-0, age-1, and age-2 fish, whereas age-3 and older fish (age-3+) were grouped together because individual age-classes for older fish could not be distinguished by fork length. Separating age-2 fish from the age-3 and older age-class allowed these length-based ages to be used for the age-1:2 ratio, which was used as an indicator of annual recruitment strength (Appendix 3).

The von Bertalanffy growth model based on inter-year recapture suggested generally increasing growth from 2006 to 2016 and slower growth from 2017 to 2019. The effect size for the growth coefficient was -8% to -11% in 2017–2019 compared to 58% in 2016. The predicted maximum growth rate declined from 245 mm/yr in 2016 to approximately 140 mm/yr in 2017–2019. Water temperature in the Columbia River from February to May of 2016 was higher than the last 15 years (1°C greater than average) and could have supported increased growth rates and larger age-0 Mountain Whitefish that year. Water temperature in the Columbia was near average for most of the year in 2017 to 2019. The changes in von Bertalanffy growth coefficient and predicted maximum growth during early life history in 2017 to 2019 are relatively large, compared to the range observed from 2001 to 2016, but the population-level impacts of these changes in growth are not known.

To provide context of growth in the LCR compared to other rivers, estimates of von Bertalanffy growth parameters and length-at-age of juvenile age-classes were compared to values from the literature (Table 7). Estimates of the growth coefficient, k, were greater in the LCR than other populations, but the asymptotic size (L_∞) and length-at-age were comparable, based on the selected literature reviewed. Rapid growth during early life stages in the LCR, as suggested by the relatively large values of k and maximum growth rate, may be related to the warm water temperatures, large volume, and low elevation of the LCR, attributes that correspond to faster growth of Mountain Whitefish, compared to smaller, cooler streams (Pettit and Wallace 1975; Meyer et al. 2009).

Table 6: Comparison of growth parameters and length-at-age between the LCR and other populations of Mountain Whitefish.

von Bertalanffy Parameters[a]			Mean Length-At-Age (mm) in Fall		Source[c]	Study Location
k	L_∞	Max. Growth[b]	Age-0	Age-1		
0.4	393	155	128	223	This report	Lower Columbia River, BC
0.20	446	88	88	169	Golder and Gazey 2019	Peace River, BC
0.26 – 0.31	382 – 409	113	134	226	Meyer et al. 2009	5th to 7th order streams, Idaho, USA
0.31 – 0.33	453 – 472	148	140	230	Boyer 2016	Madison River, Montana, USA

a. Values are mean, or typical values. If a range is presented, it corresponds to the range of values for different groupings such as sexes or samples sites.

b. Predicted maximum growth during early life history was calculated by multiplying estimates of k and L_∞ (Galluci and Quinn 1989; Shuter et al. 1998).

c. A non-exhaustive literature search was conducted and selected studies are included for comparison.

5.1.2 Rainbow Trout

The mean length of age-0 Rainbow Trout ranged between 100 and 130 mm in all years except 2015 (145 mm) and 1991/2001 (~90 mm; Figure 6). The trend in length-at-age of age-0 Rainbow Trout did not agree with the trend in growth for older individuals suggested by the von Bertalanffy growth coefficient, which decreased from a 58% effect size in 2006 to -39% in 2018 (Figure 7). A decrease in growth coefficient indicates a flatter growth curve and slower approach to the asymptotic size than in recent years. The corresponding decrease for the maximum growth rate was from 643 mm/yr in 2006 to 247 mm/yr in 2018 and 301 mm/yr in 2019. These maximum growth rates correspond to growth at a theoretical fork length of zero and therefore do not suggest that Rainbow Trout grow at that rate (e.g., 643 mm/yr) for the entire first year of life. However, the large difference in values between 2006 (643 mm/yr) and 2018 (247 mm/yr) suggest a substantial and biologically important change in the growth of Rainbow Trout during this period.

Compared to populations in other rivers, Rainbow Trout in the LCR had high values of the growth coefficient (k), maximum growth, and length-at-age (Table 8), suggesting relatively rapid growth during early life stages. As with Mountain Whitefish, rapid growth during early life of Rainbow Trout in the LCR may be related to relatively warm and stable water temperatures and abundant food availability, compared to smaller or higher elevation streams. Metrics of primary and secondary productivity in the LCR were on the moderate to high end of values reported in the literature from other large rivers (Plewes et al. 2017), which supports the hypothesis of good food availability supporting rapid growth rates of Rainbow Trout in the LCR.

The different trends suggested by length-at-age (fluctuating up and down between 2006 and 2019) and the growth model (continuous decline from 2006 to 2018) could reflect differences in growth between life stages. This is because mean length of age-0 fish reflects growth during the first year of life, whereas the growth rate and the coefficient from the von Bertalanffy model were primarily driven by larger sub-adult and adult fish that were more commonly recaptured during the survey. Therefore, the interpretation is that growth of age-0 Rainbow Trout has fluctuated up and down over the past 15 years, but growth of sub-adult and adult Rainbow Trout has consistently declined since 2006.

The decreasing growth of sub-adult and adult Rainbow Trout coincided with increasing adult abundance and may reflect density-dependence and reduced growth due to intra-specific competition. Mean length-at-age of age-0 Rainbow Trout may not have consistently declined over the same time because they were not in direct competition with adults for food or other resources.

Table 7: Comparison of growth parameters and length-at-age between the LCR and other populations of Rainbow Trout.

von Bertalanffy Parameters[a]			Mean Length-At-Age (mm) in Fall		Source[c]	Study Location
k	L_∞	Max. Growth[b]	Age-0	Age-1		
0.85	485	410	114	268	This report	Lower Columbia River, BC
0.21	566	116	n/a	163	Golder and Gazey 2019	Peace River, BC
0.17	924	157	n/a	n/a	Andrusak and Andrusak 2015	Kootenay Lake, BC
0.34 – 1.0	330 – 740	288	n/a	n/a	FishBase.org	Canada, Australia, Mexico

von Bertalanffy Parameters[a]			Mean Length-At-Age (mm) in Fall		Source[c]	Study Location
k	L_∞	Max. Growth[b]	Age-0	Age-1		
0.51	409	209	n/a	n/a	Seals et al. 2014	Deschutes River, Oregon, USA
0.37	425	157	n/a	n/a	Fetherman et al. 2014	Colorado River, Colorado, USA
0.47	522	245	n/a	n/a	Baker et al. 1991	Kenai River, Alaska, USA
0.19 – 0.36	416 – 887	n/a	n/a	~190 –240	Cox 2000	Lakes in southern interior BC
n/a	n/a	n/a	~100	n/a	Korman 2009	Colorado River, Arizona, USA

a. Values are mean, or typical values. If a range is presented, it corresponds to the range of values for different groupings such as sexes or samples sites.

b. Predicted maximum growth during early life history was calculated by multiplying estimates of k and L_∞ (Galluci and Quinn 1989; Shuter et al. 1998).

c. A non-exhaustive literature search was conducted and selected studies are included for comparison.

5.1.3 Walleye

Estimates of the von Bertalanffy growth coefficient for Walleye were variable and uncertain. For instance, effect sizes relative to a typical year ranged from -40% to 76% across years (high variability), and the 95% CI of the 2019 estimate ranged from -29% to 72% (high uncertainty). The predicted maximum growth rate in 2019 was 73 mm/yr with a 95% CI of 44 to 112 mm/yr.

One of the main issues leading to variable and uncertain growth is the variability in annual growth across the whole range of sizes. If some 450 mm fish grow 5 mm per year but some grow 60 mm per year, then the model has a difficult time predicting the size at which growth slows as fish approach the asymptotic length. Another limitation of the von Bertalanffy model for Walleye was the lack of small, young fish in the data set. Lack of information about the size-at-age or inter-year growth of age-0 and age-1 hinders estimation of the growth coefficient. For these reasons, predictions of length-at-age for Walleye were not realistic and the von Bertalanffy curve was not presented in Figure 2. However, the growth coefficient and maximum growth rate can be used as relative indicators of growth, to compare inter-annual variation of growth of Walleye of the sizes used in the model (~300 to 450 mm).

Highly variable growth of Walleye could be related to sexual maturity and investment of energy in reproduction versus somatic growth. The amount of energy used for somatic growth (i.e., increase in body size) versus reproduction is expected to change throughout the lifespan of fishes, which may require different growth models for before and after sexual maturity, and can differ between males and females (Lester et al. 2004). Alternative growth models that account for different phases of growth are possible (Quince et al. 2008; Ohnishi et al. 2012) and could be considered for modelling growth in the LCR but may require additional data (e.g., reproductive information and energy budgets) that are not available for the LCR.

The large differences in the growth coefficient (-40% to 76% effect sizes; Figure 9) and maximum growth rate (39 to 112 mm/yr; Figure 10) suggested substantial variability in Walleye growth between years. However, a lack of age data, limited number of inter-year recaptures, and high variability in growth are all factors that hinder growth analyses. Substantially more recaptures would be required to detect significant changes in Walleye growth using current methods. Walleye feed in the LCR during the summer and fall but a large number of individuals migrate out of the LCR into Lake Roosevelt in the late fall and early winter months (R.L.&L. 1995). The seasonal residency of a proportion of the Walleye population means that factors outside of the LCR likely also influence the growth of Walleye in the study area.

5.2 Abundance and Site Fidelity

5.2.1 Mountain Whitefish

In 2018 and 2019, the estimated abundance of subadult Mountain Whitefish (approximately 11,000) was one third less than the values from the previous five years (approximately 30,000); this may be attributed to poor recruitment from the 2016 and 2017 spawning years (Figure 3 in Appendix 3). Poor recruitment from the 2016 cohort may have been related to the large estimated egg dewatering mortality that year (59%), which is discussed in Appendix 3.

The estimated abundance of adult Mountain Whitefish ranged between 44,000 and 57,000 from 2010 to 2019 with the exception of 2018 when the estimate was 91,000 (Figure 15). The increase in adult abundance in 2018 may be related to high proportions of age-1 Mountain Whitefish in 2016 and 2017 (2014 and 2015 spawning years) recruiting into to the adult population (Appendix F, Figure F4). Relatively strong recruitment from the 2014 and 2015 spawning years was supported by the age-1:2 ratio (Figure 3 in Appendix 3) and coincided with relatively low levels of estimated egg loss (13% to 18%; Figure 2 in Appendix 3).

Differences in electrofisher settings during the first two years of the monitoring program in 2001 and 2002 may have contributed to high abundance estimates of subadult Mountain Whitefish in 2001 and 2002. Pulse frequencies used were 120 or 60 Hz in 2001 and 2002, 60 or 30 Hz in 2003, and 30 Hz from 2004 to 2019. Higher pulse frequencies are more effective for catching smaller-bodied fish than lower frequencies (Dolan and Miranda 2003) and therefore the high catch of age-1 Mountain Whitefish in 2001 and 2002 could have been because of the high pulse frequency used. If this was the case, greater capture efficiency estimates 2001 and 2002 would also be expected, but this was not observed in the LCR data (Appendix G, Figure G3). It may be that higher pulse frequency led to greater catch of age-1 in 2001 and 2002, but a change in capture efficiency was not detected because of the small number of age-1 recaptures. If age-1 abundance estimates in 2001 and 2002 are biased high, then it would also affect the stock-recruitment analysis.

Little is known about the factors influencing the abundance of Mountain Whitefish in the LCR but there is some information to suggest that predation on Mountain Whitefish by piscivorous fish species could play a role. Walleye feed on Mountain Whitefish (Wydoski and Bennett 1981), and densities of subadult Mountain Whitefish decreased from 2001 to 2005, while Walleye densities generally increased during that time period. Walleye stomach content data collected in the fall of 2009 (Golder 2010b) and 2010 (Ford and Thorley 2011) did not indicate that young Mountain Whitefish are a major food source for Walleye. However, age-0 Mountain Whitefish may be more susceptible to Walleye predation during the early to mid-summer (i.e., when they are smaller) than during the fall (i.e., when they are larger). Mountain Whitefish were the most common prey item found in the stomachs of Northern Pike caught by gill-netting in the upstream section of the LCR, comprising 42% of the fish prey fish identified (Baxter and Doutaz 2017) and 100% of the prey identified in the fall (Baxter and Neufeld 2015). Therefore, there is potential for Northern Pike to influence the abundance and distribution of Mountain Whitefish in the upper LCR.

Since 2002, more than 148,000 hatchery-reared juvenile White Sturgeon have been released into the Transboundary Reach section of the LCR (BC Hydro 2018). Although most of these fish would have been too small to prey on Mountain Whitefish during the early 2000s, predation by White Sturgeon may have influenced Mountain Whitefish abundance in more recent years. White Sturgeon are capable of feeding on both subadult and adult Mountain Whitefish, and as many as 12 adult Mountain Whitefish have been recorded in the stomach contents of a single adult White Sturgeon (R.L.&L. 2000). White Sturgeon become piscivorous at approximately 500 mm FL (Scott and Crossman 1973). In the LCR, this equates to an approximately age-3 individual (Golder 2009b); therefore, predation by White Sturgeon on Mountain Whitefish is expected to have increased since approximately 2005.

The second management question of this program is related to the effects of variation in flow regime on Mountain Whitefish abundance, which is discussed in Appendix 3. This program estimated subadult and adult abundance but the multiple cohorts and large number of factors that can affect survival and abundance of adults likely make it difficult to detect a relationship with annual flow variation. The effects of flow variability and specifically, egg dewatering, would be most likely to be detected by measuring fry (age-0) abundance. However, reliable estimates of fry density were not possible using the current sampling method because boat electrofishing is not efficient for sampling very shallow (< 30 cm) habitats that are likely preferred by fry. The analysis of age ratios as a recruitment index (Appendix 3) provides an alternative way to assess the effects of flow variation on recruitment.

5.2.2 Rainbow Trout

The abundance of subadult Rainbow Trout decreased between 2001 and 2005 and remained stable between 13,000 and 24,000 in all other years except 2018 and 2019 when estimates dropped to 8,000 (Figure 18). The estimated abundance of adults tripled from 15,000 in 2002 to 46,000 in 2018 and remained high in 2019 (38,000). In comparison, estimates of spawner abundance based on visual observations and an area-under-the-curve model increased from ~3,000 spawners in 2001 to 10,000–14,000 in 2015 to 2019 (Poisson et al. 2020). It is not clear why spawner estimates increased more dramatically than adult population estimates and subadult abundance did not increase at all over the same time period. Possible reasons for this discrepancy include:

1) capture efficiency for adults was low (<3%), which provided little information about annual or inter-session variation in recapture rates, and could have masked real changes in Rainbow Trout abundance;

2) some of the adults counted during the spawner surveys migrate into the study area to spawn but leave before the fall and are therefore not sampled by the indexing program; and

3) with increasing total abundance, Rainbow Trout could be more widely distributed in the river during the non-spawning season, with little change in density in the index sites, which would result in underestimates of total abundance based on only indexing sites.

Another discrepancy between the spawner survey and mark-recapture estimates was that the abundance of spawners remained at similarly high levels from 2015 to 2018, suggesting the system may have reached carrying capacity for adult Rainbow Trout, whereas the mark-recapture abundance estimates continued to increase during this period. This difference could be because not all the age-2 and older Rainbow Trout included in the abundance estimate are mature spawners, or because of sampling biases and differences between the survey methods like those listed above.

The abundance of age-1 Rainbow Trout was lower in 2018 and 2019 (~8,000) than in the previous six years when abundance was relatively stable (13,000–17,000). This coincided with a similar decrease in age-1 Mountain Whitefish in 2018 and 2019. Intuitively, the decrease in age-1 Mountain Whitefish could be related to the large estimated egg loss due to dewatering for the 2016 spawning year (Appendix 3); however, the discharge reduction that caused the Mountain Whitefish egg loss for the 2016 spawning year occurred in the winter of 2017, which was before the age-1 Rainbow Trout from 2018 were spawned. Therefore, the decrease in age-1 Rainbow Trout could not have been caused by the discharge reductions that dewatered a high proportion of Mountain Whitefish eggs from the 2016 spawning year. This raises the possibility that some common factor other than egg dewatering caused the decrease in age-1 recruits of both Mountain Whitefish and Rainbow Trout in 2018.

The probability of a fish being recaptured in the same site was highest for small Rainbow Trout among all index species and fish lengths. This indicates that subadult Rainbow Trout exhibited higher site fidelity than all other index species and life stages. High site fidelity in juvenile Rainbow Trout may reflect territorial behaviour as has been reported for this species in small streams (Imre et al. 2002). Estimated capture efficiencies were highest for subadult Rainbow Trout, which indicates that this cohort was also the easiest to catch. Site fidelity decreased with increasing fork length, indicating that older Rainbow Trout were more likely to migrate out of sample sites.

5.2.3 Walleye

Walleye abundance was greater in 2003 to 2005 and 2011 than in other study years. These results likely reflect strong year-classes of Walleye present in the study area during those years. Walleye migrate into the LCR to feed in summer and fall but spawn and complete early life history in further downstream in the Columbia River watershed (e.g., Lake Roosevelt and its tributaries). Abundance in the LCR depends on suitable feeding conditions but also largely on factors that influence spawning success and early life stage survival and growth outside of the study area. Based on length-frequency data and Lake Roosevelt length-at-age data (unpublished data, Washington Department of Fish and Wildlife, Spokane Tribe of Indians, and Colville Confederated Tribes), age-2 and age-3 fish are the most dominant age-classes present in the study area during most study years; therefore, the abundance of this species in the study area during any particular year is strongly influenced by the spawning success of this species during the previous two to three years.

Years with high abundance (e.g., 2003–2005, 2011) were generally associated with lower than normal body condition and survival, suggesting density-dependence and resource competition in years of high abundance in the LCR. Variability in the flow regime in the LCR is less likely to be related to the abundance of Walleye than the abundance of other index species, because the abundance of Walleye in the LCR is thought to depend on spawning and early life history in Lake Roosevelt.

5.3 Spatial Distribution

5.3.1 Mountain Whitefish

Subadult Mountain Whitefish densities were greatest in the 10-km section between HLK and the Kootenay River confluence. This distribution is likely related more to channel morphology than the presence or operation of the dam. Large bays and backwater areas, which are preferred habitats for subadult Mountain Whitefish, are more common near HLK than downstream of the Kootenay River confluence. Specific examples include Balfour Bay (RKm 2.6), downstream of the log booms near Zellstoff-Celgar (RKm 5.1), and upstream of Norn's Creek Fan (i.e., Lions Head RKm 7.4). These areas have exhibited increases in aquatic vegetation abundance (dominantly Eurasian watermilfoil) between 2001 and 2019 (Attachment A). Since 2010, Northern Pike have been captured in these same areas. Mountain Whitefish were found to be one of the main components of Northern Pike diets in this reach, based on stomach content analysis (Baxter and Doutaz 2017). Effects of predation by Northern Pike on the distribution or survival of subadult Mountain Whitefish are not known. Fine scale distributional data are only available since 2013 and not prior to colonization by Northern Pike.

The spatial distribution of adult Mountain Whitefish during the fall sample period may be related to the location of key spawning areas for this species. Densities of adults were highest near Norn's Creek Fan, in the downstream portions of the Kootenay River, upstream of Sullivan Creek, and near the City of Trail Airport. Norn's Creek Fan, the Kootenay River, and the City of Trail Airport area are known Mountain Whitefish spawning locations (Golder 2012), whereas the site located upstream of Sullivan Creek is close to a known spawning area (i.e., Lower Cobble Island), which may indicate that Mountain Whitefish use these areas for holding purposes prior to spawning.

The evenness in the distribution of adult Mountain Whitefish between index sites decreased between 2001 and 2006 but was stable between 2006 and 2019 (Figure 17). These results do not suggest any large changes in the spatial distribution of Mountain Whitefish.

5.3.2 Rainbow Trout

Subadult Rainbow Trout densities were noticeably higher in the Columbia River between the Kootenay River confluence and Genelle, and from Birchbank downstream to the Beaver Creek confluence, compared to other portions of the study area. A large portion of these areas are not included in the index sites and are only occasionally sampled during the GRTS survey. Low sampling effort in the areas with the highest densities of age-1 Rainbow Trout could make it more difficult to detect trends in recruitment and may help explain why estimates of subadult abundance did not increase while adult abundance increased drastically during recent years. No large changes in the evenness of the spatial distribution of subadults across index sites were observed during the study period.

The densities of adult Rainbow Trout at randomly sampled non-index sites (i.e., sites that were not systematically sampled prior to 2011) were 100% to 250% greater than densities at index sites. The high densities of Rainbow Trout in previously unsampled portions of the study area indicate that a large portion of the overall Rainbow Trout population is potentially missed during the typical mark-recapture sampling at index sites. These results suggest the importance of continuing to sample in randomly sampled sites, as well as the indexing sites, to detect changes in fish abundance and distribution that may not be detected by sampling only the indexing sites.

The results indicated increasing evenness in distribution of Rainbow Trout between index sites between the early 2000s and 2019. The period of increasing evenness corresponded to increasing abundance of Rainbow Trout in the LCR. This could be because at low abundance, Rainbow Trout were more concentrated in sites with the highest quality habitat, whereas at higher overall abundance, density increased disproportionately more at lower quality sites, because higher quality sites had reached their carrying capacity.

5.3.3 Walleye

Walleye densities were high immediately downstream of HLK and BRD (Figure 22). Sculpin species and Redside Shiner are a common prey fish for Walleye based on stomach sample analyses and in 2010, results indicated higher densities of sculpin species and Redside Shiner in this portion of the study area (Ford and Thorley 2011). In addition, Walleye densities are probably higher immediately downstream of HLK and BRD because they are feeding on fish entrained through the dams.

Walleye densities were similar throughout the remaining sections of the LCR. Their wide distribution throughout the study area indicates an ability to utilize a wide variety of habitats and tolerate a wide range of habitat conditions. This reflects the primary use of the LCR as a summer and fall feeding area, and as a result, this species is generally found wherever prey fish are present.

The data did not suggest any temporal change in the evenness in the spatial distribution across index sites during the study period.

5.4 Survival

5.4.1 Mountain Whitefish

Estimated survival of adult Mountain Whitefish varied throughout all study years (21% to 93%) and has been above 50% in all years except for 2002 and 2004 (Figure 24). The high survival rate of adults was not unexpected, as Mountain Whitefish are known to be a relatively long-lived species with most populations containing individuals greater than 10 years of age (McPhail 2007; Meyer et al. 2009). In comparison, estimated survival rates ranged between 63% and 91% (mean 82%) for Mountain Whitefish in Idaho (Meyer et al. 2009).

Currently, each of the management hypotheses is tested using separate models, which simplifies the testing of the hypotheses. This approach also allows the model outputs to be checked for inconsistencies. When this check was conducted on subadult and adult Mountain Whitefish abundance, the estimates were not compatible with survival estimates for some years. For instance, if a subadult survival rate of 50% is assumed, then half of the 32,000 subadults in 2017 would be recruited into the 2018 adult population (16,000 recruits), in addition to the 46,000 surviving adults (54,000 adults in 2017 and 85% survival), which yields a predicted adult population of 62,000. This prediction is much lower than the 2018 adult population estimate of 91,000. These types of discrepancies are also illustrated by the abundance-based survival estimates (Figure 25), which were more than 100% some years. However, in other years such as 2017, the population estimate (53,600) agreed well with the predicted population (54,500) based on 2016 abundance, estimated adult survival (69%), and an assumed subadult survival of 50%. Years when survival and abundance estimates are not compatible indicate that either the abundance or survival model (or possibly both) make at least one unreliable assumption concerning Mountain Whitefish biology or behaviour that biases the estimates.

One possible explanation for the inconsistency between survival and abundance estimates is that the large-scale spawning migrations by adult Mountain Whitefish during the study period results in the loss of tagged fish from sample sites at a substantially greater rate than that estimated by the site fidelity model. If a fish moved from the shallow water margins, where sampling occurred, into the main channel, , that fish would not be available for recapture and the site fidelity model would underestimate the losses of tagged fish. This bias would result in an underestimation of capture efficiency and a concomitant overestimation of abundance.

Mountain Whitefish recapture probabilities were less than half of those for Rainbow Trout and Walleye, which further suggests that fish movements could be influencing recapture estimates. In addition, during BC Hydro’s MCR Fish Population Indexing Program (CLBMON-16), recapture rates for adult Mountain Whitefish were greater in the spring than in fall from 2011 to 2016, possibly because Mountain Whitefish were moving into and out of the study area in the fall study period for spawning migrations (Golder et al. 2017). Based on telemetry data collected under CLBMON-48 (Golder 2009c), a substantial proportion of the adult Mountain Whitefish population in the LCR undertakes spawning related movements, often to other areas of the river during the fall study period. This would explain why abundance estimates are inconsistent with estimates of survival in the LCR and would account for lower recapture estimates for Mountain Whitefish when compared to other species in the LCR.

5.4.2 *Rainbow Trout*

Adult survival ranged from 33% to 50% across all study years (Figure 24). For adult Rainbow Trout, both survival and abundance increased gradually between 2003 and 2011. However, survival decreased to 34% to 42% during 2012 to 2019. Lower survival during recent years coincided with high abundances, as indicated by mark-recapture estimates (Section 4.4.4) and spawner surveys (Poisson et al. 2020), which may reflect density-dependent survival and intra-specific competition for resources. Survival of adults is unlikely to be affected directly by variability in the flow regime, although changes in productivity related to flow variability could affect growth or condition, which could ultimately affect survival. Flow variability is more likely to affect the survival of juvenile fish, through effects on habitat, displacement, or stranding. This is true for Rainbow Trout as well as Mountain Whitefish. Survival cannot be assessed using the mark-recapture data for juvenile fish because they are not effectively sampled by boat electrofishing. The effect of flow variability on survival and recruitment of juveniles can be assessed using the stock-recruitment models and age ratio analyses.

5.4.3 *Walleye*

The estimated survival of Walleye was 41% in 2019, which is the second lowest survival rate in all the years of sampling. Some years that had lower survival, such as 2004 (35% survival), were associated with high abundance of Walleye but there was not a consistent relationship between abundance and survival, which suggest that factors other than density are also influencing adult survival. As a large portion of the Walleye population is thought to be migratory and spend only part of the year in the LCR before moving downstream into Lake Roosevelt (R.L.&L. 1995), annual survival could be confounded by fish movements, and affected by factors outside of the study area.

5.5 *Body Condition*

5.5.1 *Mountain Whitefish*

The body condition of subadult and adult Mountain Whitefish was fairly stable (≤5% change; Figure 29) between 2010 and 2018. However, adult Mountain Whitefish body condition was higher in 2019 (7%). Across all years when data were available, the effect sizes for the body condition of subadult Mountain Whitefish ranged between -7% to 6% and between -15% to 9% for adult Mountain Whitefish (Figure 29). Fluctuations in body condition are known to affect reproductive potential and population productivity in other fish species (Ratz and Lloret 2003). However, it is not known what percent change in body condition is biologically significant and could affect populations of Mountain Whitefish. The Canadian Environmental Effects Monitoring (EEM) program for mining and pulp and paper effluents considers a 10% change in fish body condition to be the critical threshold for higher risk to the environment (Munkittrick et al. 2009; Environment Canada 2012). This criterion suggests that the range of 24% variation (-15% to 9%) in adult Mountain Whitefish body condition could be biologically significant. Studies of the effects of body condition on reproduction and other life history processes are required to understand the implications of body condition variation in Mountain Whitefish and other index fish species in the LCR.

Lower body condition (-6% to -15% effect size) in the early 1990s compared to between 2001 and 2019 could be related to lower water quality and industrial pollution. A number of industries including a pulp and paper mill, a fertilizer plant, and a metal smelter contributed to much poorer water quality in the 1980s and early 1990s than since the mid-1990s (MacDonald Environmental Services Ltd. 1997). Fish health monitoring studies in the early 1990s found that Mountain Whitefish had higher rates of stress-related abnormalities compared to fish from reference sites, which was thought to be related to degraded water quality (Nener et al. 1995). Reductions in industrial pollution have resulted in improved water quality and fish health in the LCR since the mid-1990s (CRIEMP 2005), which likely explains the greater body condition in 2001 to 2019 than during the early 1990s.

Little is known about what factors influence changes in body condition or growth of Mountain Whitefish in the LCR. In the Skeena River, a large, unregulated river in British Columbia, food abundance was the main factor limiting growth and abundance for Mountain Whitefish (Godfrey 1955 as cited by Ford et al. 1995). Mountain Whitefish body condition also is likely related to the abundance of invertebrate prey in the LCR. With regard to the program's second management question, variability in the flow regime could affect invertebrate abundance, which in turn could affect the body condition of insectivorous fish including Mountain Whitefish. The LCR Physical Habitat and Ecological Productivity program suggested that water velocity and discharge variability can affect invertebrate productivity, especially during the Mountain Whitefish protection flow period (Olson-Russello et al. 2015), which supports a potential pathway between flow variability, food availability, and Mountain Whitefish body condition. Information about the relative abundance of invertebrates in the LCR has been collected (Olson-Russello et al. 2015) but is only available for five years (2008–2010, 2012, and 2014), which means that relationships between annual flow variability, invertebrates, and fish cannot be compared across the entire timespan of the fish indexing program (2001–2019).

The small spatial differences in body condition suggest that either there is little variation attributable to habitat differences among sites, or that fish do not stay within particular sites long enough to result in large inter-site differences in body condition. Therefore, sample site was not included in the body condition models for Mountain Whitefish or other species. The low site fidelity estimates support the idea that fish movements may prevent large inter-site differences in body condition, especially for Mountain Whitefish, which had the lowest site fidelity estimates.

5.5.2 Rainbow Trout

The body condition of Rainbow Trout was greater in 2002 and 2006 than in other study years for both subadult and adult life stages. Both water temperature and discharge in the Columbia River were near historical averages in 2002 and 2006 which suggests that variations in flow regime do not explain the inter-annual differences in Rainbow Trout body condition. However, the relationship between flow variability and invertebrate productivity suggested by Olson-Russello et al. (2015) and discussed in Section 5.5.1 also has implications for Rainbow Trout. Changes in invertebrate abundance due to flow variability would be expected to affect food availability and possibly body condition of Rainbow Trout.

The 10% decrease in body condition of adult Rainbow Trout between 2011 and 2018 coincided with high and increasing abundance. This may indicate an increase in intra-specific competition for food that caused the decrease in body condition and growth (Section 5.1.2) during this period. Conversely, adult Rainbow Trout body condition and growth estimates increased in 2019 which coincided with a decrease in abundance. These trends suggest that the population may be near carrying capacity above 40,000 adults, as reduced growth in the post-recruit (i.e., adult) life stage is expected when populations are near carrying capacity (Lorenzen 2008). Body condition values of Rainbow Trout in the LCR were generally higher than those recorded downstream of Revelstoke Dam during the same time of the year (CLBMON-16; Golder et al. 2020).

5.5.3 Walleye

Body condition of Walleye was greater in 2012 to 2014 than in most previous years but decreased between 2015 to 2019. The years with high body condition (2012 to 2014) had low abundance estimates of Walleye, suggesting density-dependent growth that could be due to intra-specific competition for food and cover, similar to that reported for this species by other researchers (Forney 1977; Hartman and Margraf 1992; Porath and Peters 1997). However, there was not a consistent relationship between abundance and body condition across all years of the monitoring program. Variability in the flow regime is less likely to have direct effects on food availability and body condition of Walleye compared to insectivorous fish species, because Walleye are piscivorous.

5.6 Summary

The sampling program conducted since 2001 provides a high-quality, long-term dataset to address **the first management question**, which is about changes in fish population metrics over time in the LCR. Hierarchical Bayesian models suggested that the abundance of adult **Rainbow Trout** increased substantially between 2001 and 2019, and high abundances in recent years coincided with a decline in body condition, growth, and survival, suggesting density-dependence and that the adult population may be near the carrying capacity. Data for **Walleye** suggested relatively low but stable abundance from 2012 to 2019 compared to earlier years, and declining body condition since 2015. The estimated abundance of **Mountain Whitefish** declined since 2001 but was relatively stable from 2012 to 2017. In 2019, the estimated abundance of age-1 Mountain Whitefish decreased by one third while the estimated abundance of adults remained stable between 2010 and 2019 except for an increase in 2018. Length-at-age of fry and body condition of Mountain Whitefish suggested relatively little change during the monitoring period.

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Appendix A - Maps

Table A1 Locations and distances from Hugh L. Keenleyside Dam of boat electrofishing index sites in the lower Columbia River, 2019.

Site Designation[a]	Location (km)[b]	Bank[c]	UTM Coordinates		
			Zone	Easting	Northing
Columbia River Upstream					
C00.0-R U/S	0.0	RDB	11U	443996	5465466
C00.0-R D/S	0.9	RDB	11U	444649	5465448
C00.7-L U/S	0.7	LDB	11U	444387	5465734
C00.7-L D/S	1.3	LDB	11U	445015	5465719
C01.3-L U/S	1.3	LDB	11U	445015	5465719
C01.3-L D/S	2.8	LDB	11U	446504	5465652
C02.8-L U/S	2.8	LDB	11U	446504	5465652
C02.8-L D/S	3.6	LDB	11U	447294	5465482
C03.6-L U/S	3.6	LDB	11U	447294	5465482
C03.6-L D/S	5.6	LDB	11U	449206	5464833
C04.6-R U/S	4.6	RDB	11U	448162	5464921
C04.6-R D/S	5.1	RDB	11U	448614	5464820
C05.6-L U/S	5.6	LDB	11U	449206	5464833
C05.6-L D/S	6.7	LDB	11U	450212	5464594
C07.3-R U/S	7.3	RDB	11U	450808	5464265
C07.3-R D/S	9.0	RDB	11U	452366	5464096
C07.4-L U/S	7.4	LDB	11U	450892	5464632
C07.4-L D/S	8.3	LDB	11U	451742	5464481
Kootenay River					
K00.3-L U/S	0.3	LDB	11U	453656	5462748
K00.3-L D/S	0.0	LDB	11U	452578	5462650
K00.6-R U/S	0.6	RDB	11U	453151	5462849
K00.6-R D/S	0.0	RDB	11U	452627	5462822
K01.8-L U/S	1.8	LDB	11U	454451	5462972
K01.8-L D/S	0.3	LDB	11U	453656	5462748
K01.8-R U/S	1.8	RDB	11U	454398	5463053
K01.8-R D/S	0.6	RDB	11U	453151	5462849
Columbia River Downstream					
C25.3-R U/S	25.3	RDB	11U	449606	5450670
C25.3-R D/S	27.6	RDB	11U	448277	5450106
C27.6-R U/S	27.6	RDB	11U	448277	5450106
C27.6-R D/S	28.1	RDB	11U	447985	5448428
C28.2-R U/S	28.2	RDB	11U	447985	5448428
C28.2-R D/S	29.2	RDB	11U	447749	5447453
C34.9-L U/S	34.9	LDB	11U	446321	5442589
C34.9-L D/S	36.6	LDB	11U	447116	5440687
C36.6-L U/S	36.6	LDB	11U	447116	5440687
C36.6-L D/S	38.8	LDB	11U	448286	5438982
C47.8-L U/S	47.8	LDB	11U	455317	5435244
C47.8-L D/S	49.0	LDB	11U	455121	5434301
C48.2-R U/S	48.2	RDB	11U	455021	5434885
C48.2-R D/S	49.0	RDB	11U	455177	5434013
C49.0-L U/S	49.0	LDB	11U	455121	5434301
C49.0-L D/S	49.8	LDB	11U	455204	5433379
C49.0-R U/S	49.0	RDB	11U	455177	5434013
C49.0-R D/S	49.8	RDB	11U	454993	5433410
C49.8-L U/S	49.8	LDB	11U	455204	5433379
C49.8-L D/S	52.2	LDB	11U	455385	5431291
C49.8-R U/S	49.8	RDB	11U	454993	5433410
C49.8-R D/S	51.9	RDB	11U	454976	5431377
C52.2-L U/S	52.2	LDB	11U	455385	5431291
C52.2-L D/S	52.8	LDB	11U	455888	5430887
C52.2-R U/S	52.2	RDB	11U	455350	5431088
C52.2-R D/S	56.0	RDB	11U	454287	5428238
C52.8-L U/S	52.8	LDB	11U	455888	5430887
C52.8-L D/S	53.6	LDB	11U	455898	5429799

[a] U/S = Upstream limit of site; D/S = Downstream limit of site.

[b] River kilometres downstream from Hugh L. Keenleyside Dam.

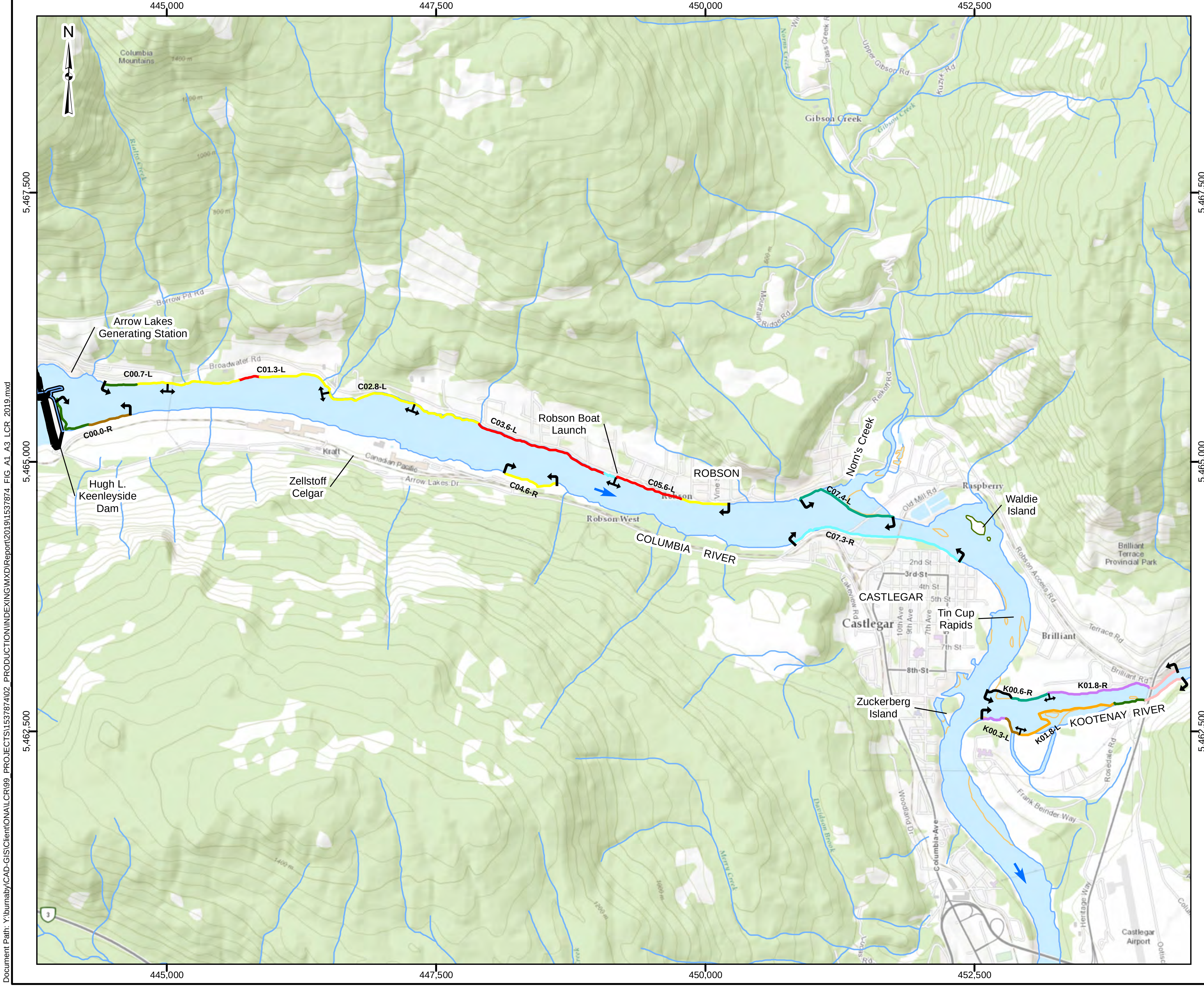
[c] LDB=Left bank as viewed facing downstream; RDB=Right bank as viewed facing downstream.

Table A2 Locations of selected sites and available sites included in the Generalized Random Tessellation Stratified (GRTS) survey, 2019.

Site Designation	Location (km)[a]	Bank[b]	Upstream UTM Coordinates			Downstream UTM Coordinates			Sites Selected in 2019
			Zone	Easting	Northing	Zone	Easting	Northing	
Columbia River Upstream									
C01.0-R	1.0	RDB	11U	444717	5465448	11U	447236	5465125	
C03.6-R	3.6	RDB	11U	447236	5465125	11U	448125	5464914	
C05.1-R	5.1	RDB	11U	448612	5464808	11U	449518	5464513	X
C06.0-R	6.0	RDB	11U	449518	5464513	11U	450804	5464243	X
C06.7-L	6.7	LDB	11U	450223	5464603	11U	450876	5464645	
C08.4-L	8.4	LDB	11U	451833	5464445	11U	452304	5464244	
C08.6-L	8.6	LDB	11U	452132	5464468	11U	452720	5464206	
C08.9-R	8.9	RDB	11U	452375	5464074	11U	452797	5463486	
C09.0-L	9.0	LDB	11U	452286	5462718	11U	452286	5462718	
C09.2-L	9.2	LDB	11U	452720	5464206	11U	452987	5463481	
C09.8-L	9.8	LDB	11U	452926	5463604	11U	452620	5462860	
C09.8-R	9.8	RDB	11U	452761	5463608	11U	452416	5462880	
Columbia River Downstream									
C10.7-R	10.7	LDB	11U	452416	5462880	11U	452217	5462050	X
C10.8-R	10.8	RDB	11U	452154	5462718	11U	452154	5462718	
C10.9-L	10.9	LDB	11U	452584	5462607	11U	453290	5460373	X
C11.5-R	11.5	RDB	11U	452217	5462050	11U	453103	5460426	X
C13.4-L	13.4	LDB	11U	453290	5460373	11U	453321	5459007	
C13.4-R	13.4	RDB	11U	453103	5460426	11U	453221	5458057	
C14.8-L	14.8	LDB	11U	453321	5459007	11U	453210	5456890	
C15.8-R	15.8	RDB	11U	453221	5458057	11U	453234	5457317	
C16.6-R	16.6	RDB	11U	453234	5457317	11U	452358	5456216	
C17.0-L	17.0	LDB	11U	453210	5456890	11U	452622	5455322	
C18.0-R	18.0	RDB	11U	452358	5456216	11U	452351	5455401	
C18.8-R	18.8	RDB	11U	452351	5455401	11U	452122	5454012	
C19.0-L	19.0	LDB	11U	452622	5455322	11U	452444	5454183	X
C20.1-L	20.1	LDB	11U	452444	5454182	11U	451645	5453285	
C20.4-R	20.4	RDB	11U	452122	5454012	11U	451093	5453191	X
C21.3-L	21.3	LDB	11U	451645	5453285	11U	450603	5451637	X
C21.8-R	21.8	RDB	11U	451093	5453191	11U	450495	5452148	
C22.9-R	22.9	RDB	11U	450495	5452148	11U	450188	5451058	X
C23.4-L	23.4	LDB	11U	450603	5451637	11U	450368	5450764	X
C24.0-R	24.0	RDB	11U	450188	5451058	11U	449356	5450418	
C24.3-L	24.3	LDB	11U	450368	5450764	11U	449178	5449989	
C25.3-L	25.3	MID	11U	448978	5450229	11U	448978	5450229	
C26.2-L	26.2	MID	11U	448938	5449626	11U	448938	5449626	
C27.5-L	27.5	LDB	11U	448193	5449036	11U	448064	5447758	
C28.8-L	28.8	LDB	11U	448064	5447758	11U	447820	5446998	
C29.2-R	29.2	RDB	11U	447715	5447420	11U	447397	5446252	
C29.6-L	29.6	LDB	11U	447820	5446998	11U	447491	5446079	X
C30.5-R	30.5	RDB	11U	447397	5446252	11U	446817	5444824	X
C30.6-L	30.6	LDB	11U	447491	5446079	11U	446746	5444432	X
C32.0-R	32.0	RDB	11U	446817	5444824	11U	446256	5443655	X
C32.4-L	32.4	LDB	11U	446746	5444432	11U	446353	5442572	
C33.3-R	33.3	RDB	11U	446256	5443655	11U	446260	5442116	X
C34.9-R	34.9	RDB	11U	446260	5442116	11U	446294	5441253	
C35.7-R	35.7	RDB	11U	446294	5441253	11U	447152	5440472	X
C36.9-R	36.9	RDB	11U	447152	5440472	11U	448305	5438607	X
C38.8-L	38.8	LDB	11U	448340	5439017	11U	449001	5438233	
C39.2-R	39.2	RDB	11U	448305	5438607	11U	448995	5438083	
C40.0-L	40.0	LDB	11U	449001	5438233	11U	450090	5438405	X
C40.0-R	40.0	RDB	11U	448995	5438083	11U	450459	5438222	X
C41.1-L	41.1	LDB	11U	450090	5438405	11U	452466	5438365	
C41.5-R	41.5	RDB	11U	450459	5438222	11U	452579	5438015	
C43.5-L	43.5	LDB	11U	452466	5438365	11U	453245	5437597	
C43.7-R	43.7	RDB	11U	452579	5438015	11U	453275	5437384	
C44.6-L	44.6	LDB	11U	453245	5437597	11U	454179	5437228	
C44.7-R	44.7	RDB	11U	453275	5437384	11U	454560	5436673	
C45.6-L	45.6	LDB	11U	454179	5437228	11U	454855	5436623	
C46.2-R	46.2	RDB	11U	454560	5436673	11U	455141	5435856	
C46.4-L	46.4	LDB	11U	454855	5436623	11U	455319	5435321	
C47.2-R	47.2	RDB	11U	455141	5435856	11U	455017	5434942	X
C56.0-L	56.0	LDB	11U	454774	5428024	11U	453949	5427733	X

[a] River kilometres downstream from Hugh L. Keenleyside Dam.

[b] LDB=Left bank as viewed facing downstream; RDB=Right bank as viewed facing downstream.



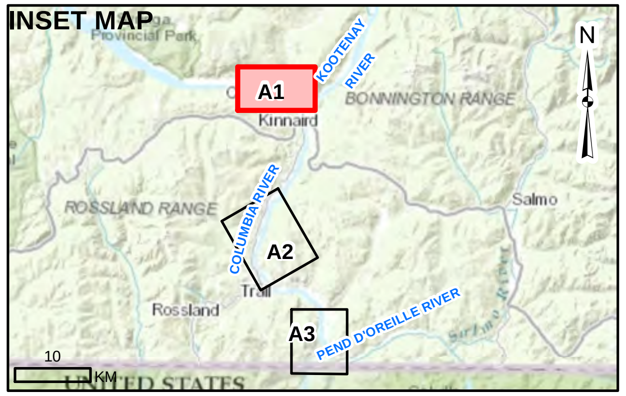
LEGEND

- RIVER KILOMETRE DOWNSTREAM OF HUGH L. KEENLEYSIDE DAM
- C00.0-R BOAT ELECTROSHOCKING SITE
- FLOW DIRECTION
- WATERCOURSE
- BREAKWATER
- DAM SECTION
- ISLAND
- SAND OR GRAVEL BAR

BANK HABITAT TYPE

- A1 - ARMOURED COBBLE/GRAVEL
- A1+A2 - ARMOURED COBBLE/GRAVEL/SMALL BOULDER
- A2 - ARMOURED COBBLE/SMALL BOULDER
- A2+A3 - ARMOURED COBBLE/SMALL/LARGE/BOULDER
- A3 - ARMOURED SMALL/LARGE BOULDER
- A4 - ARMOURED LARGE BOULDER
- A5 - BEDROCK BANKS
- A6 - MAN-MADE RIP-RAP
- BW - BACKWATER
- D1 - DEPOSITIONAL SAND/SILT
- D1+D2 - DEPOSITIONAL SAND/SILT/GRAVEL/COBBLE
- D2 - DEPOSITIONAL GRAVEL/COBBLE
- D3 - DEPOSITIONAL LARGE COBBLE
- EDDY - EDDY

INSET MAP



REFERENCE

SERVICE LAYER CREDITS: SOURCES: ESRI, HERE, GARMIN, INTERMAP, INCREMENT P CORP., GEBCO, USGS, FAO, NPS, NRCAN, GEOBASE, IGN, KADASTER NL, ORDNANCE SURVEY, ESRI JAPAN, METI, ESRI CHINA (HONG KONG), (C) OPENSTREETMAP CONTRIBUTORS, AND THE GIS USER COMMUNITY.

PROJECTION: UTM ZONE 11 DATUM: NAD 83

600 0 600

SCALE 1:35,000 METRES

PROJECT

LOWER COLUMBIA RIVER FISH POPULATION INDEXING SURVEY

TITLE

UPPER SECTION OF STUDY AREA SAMPLE SITE LOCATIONS

GOLDER

PROJECT No. 1537874			SCALE AS SHOWN	REV. 0
DESIGN	DR	14 JUN. 2016	FIGURE: A1	
GIS	JG/CD	8 JUN. 2020		
CHECK	DR	8 JUN. 2020		
REVIEW	SR	8 JUN. 2020		

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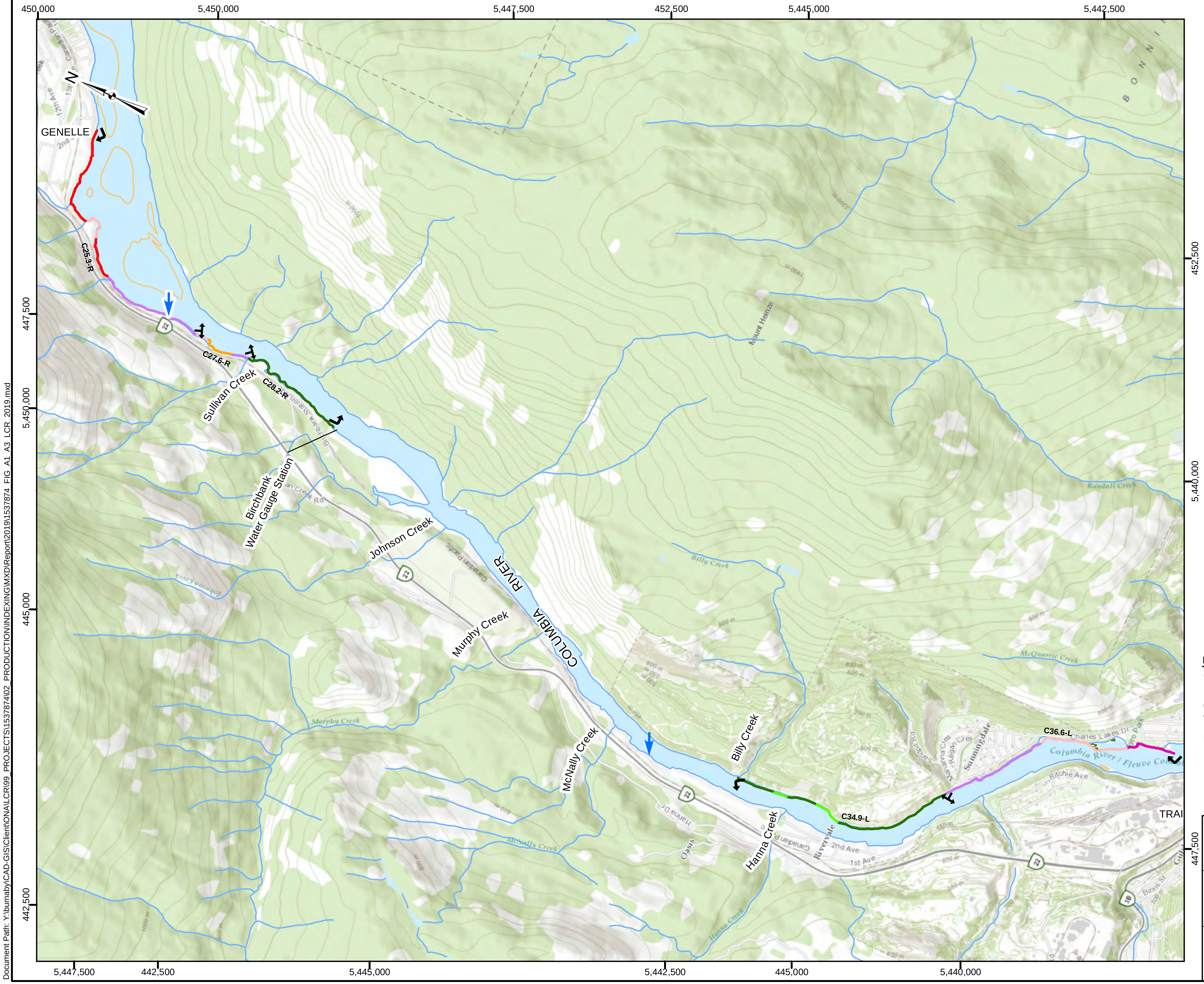


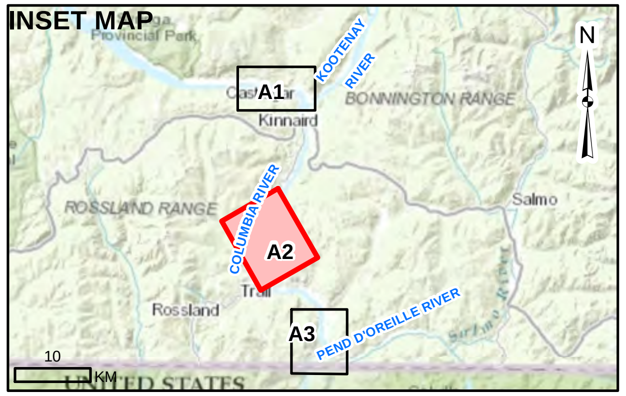
LEGEND

- ● RIVER KILOMETRE DOWNSTREAM OF HUGH L. KEENLEYSIDE DAM
- ↱C00.0-R↰ BOAT ELECTROSHOCKING SITE
- ➔ FLOW DIRECTION
- WATERCOURSE
- BREAKWATER
- DAM SECTION
- ISLAND
- SAND OR GRAVEL BAR

BANK HABITAT TYPE

- A1 - ARMOURED COBBLE/GRAVEL
- A1+A2 - ARMOURED COBBLE/GRAVEL/SMALL BOULDER
- A2 - ARMOURED COBBLE/SMALL BOULDER
- A2+A3 - ARMOURED COBBLE/SMALL/LARGE/BOULDER
- A3 - ARMOURED SMALL/LARGE BOULDER
- A4 - ARMOURED LARGE BOULDER
- A5 - BEDROCK BANKS
- A6 - MAN-MADE RIP-RAP
- BW - BACKWATER
- D1 - DEPOSITIONAL SAND/SILT
- D1+D2 - DEPOSITIONAL SAND/SILT/GRAVEL/COBBLE
- D2 - DEPOSITIONAL GRAVEL/COBBLE
- D3 - DEPOSITIONAL LARGE COBBLE
- EDDY - EDDY

INSET MAP



REFERENCE

SERVICE LAYER CREDITS: SOURCES: ESRI, HERE, GARMIN, INTERMAP, INCREMENT P CORP., GEBCO, USGS, FAO, NPS, NRCAN, GEOBASE, IGN, KADASTER NL, ORDNANCE SURVEY, ESRI JAPAN, METI, ESRI CHINA (HONG KONG), (C) OPENSTREETMAP CONTRIBUTORS, AND THE GIS USER COMMUNITY.

PROJECTION: UTM ZONE 11 DATUM: NAD 83

600 0 600

SCALE 1:35,000 METRES

PROJECT

LOWER COLUMBIA RIVER FISH POPULATION
INDEXING SURVEY

TITLE

MIDDLE SECTION OF STUDY AREA
SAMPLE SITE LOCATIONS

GOLDER

PROJECT No. 1537874			SCALE AS SHOWN	REV. 0
DESIGN	DR	14 JUN. 2016	FIGURE: A2	
GIS	JG/CD	8 JUN. 2020		
CHECK	DR	8 JUN. 2020		
REVIEW	SR	8 JUN. 2020		

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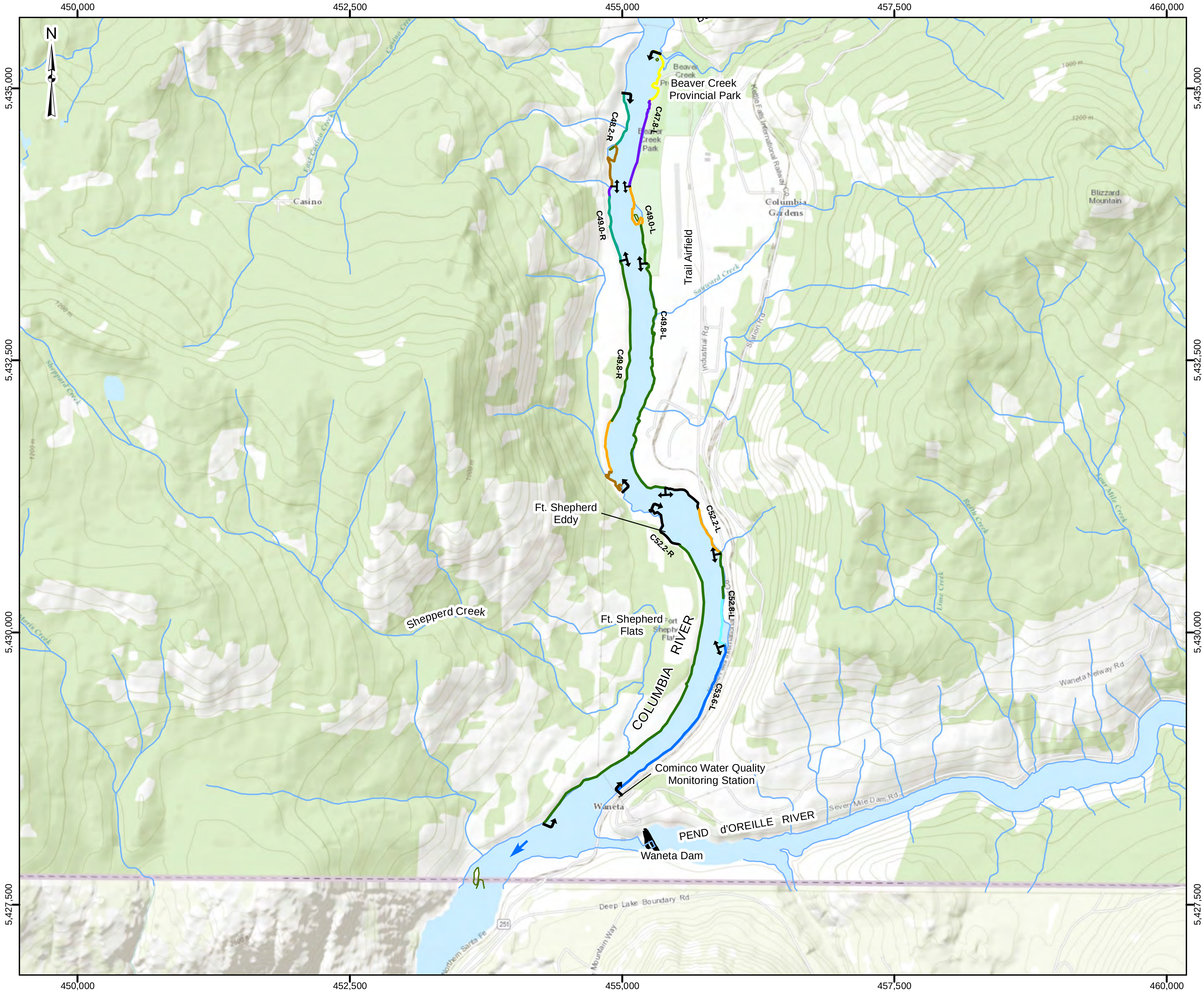


LEGEND

● RIVER KILOMETRE DOWNSTREAM OF HUGH L. KEENLEYSIDE DAM

C00.0-R BOAT ELECTROSHOCKING SITE

➔ FLOW DIRECTION

WATERCOURSE

BREAKWATER

DAM SECTION

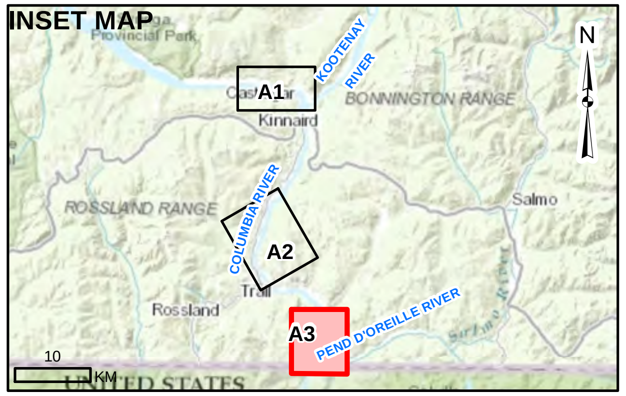
ISLAND

SAND OR GRAVEL BAR

BANK HABITAT TYPE

- A1 - ARMOURED COBBLE/GRAVEL
- A1+A2 - ARMOURED COBBLE/GRAVEL/SMALL BOULDER
- A2 - ARMOURED COBBLE/SMALL BOULDER
- A2+A3 - ARMOURED COBBLE/SMALL/LARGE/BOULDER
- A3 - ARMOURED SMALL/LARGE BOULDER
- A4 - ARMOURED LARGE BOULDER
- A5 - BEDROCK BANKS
- A6 - MAN-MADE RIP-RAP
- BW - BACKWATER
- D1 - DEPOSITIONAL SAND/SILT
- D1+D2 - DEPOSITIONAL SAND/SILT/GRAVEL/COBBLE
- D2 - DEPOSITIONAL GRAVEL/COBBLE
- D3 - DEPOSITIONAL LARGE COBBLE
- EDDY - EDDY

INSET MAP



REFERENCE

SERVICE LAYER CREDITS: SOURCES: ESRI, HERE, GARMIN, INTERMAP, INCREMENT P CORP., GEBCO, USGS, FAO, NPS, NRCAN, GEOBASE, IGN, KADASTER NL, ORDNANCE SURVEY, ESRI JAPAN, METI, ESRI CHINA (HONG KONG), (C) OPENSTREETMAP CONTRIBUTORS, AND THE GIS USER COMMUNITY.

PROJECTION: UTM ZONE 11 DATUM: NAD 83

600 0 600

SCALE 1:35,000 METRES

PROJECT

LOWER COLUMBIA RIVER FISH POPULATION INDEXING SURVEY

TITLE

LOWER SECTION OF STUDY AREA SAMPLE SITE LOCATIONS

GOLDER

PROJECT No. 1537874			SCALE AS SHOWN	REV. 0
DESIGN	DR	14 JUN. 2016	FIGURE: A3	
GIS	JG/CD	8 JUN. 2020		
CHECK	DR	8 JUN. 2020		
REVIEW	SR	8 JUN. 2020		

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Appendix B – Habitat Summary Information

Table B1 Descriptions of categories used in the Lower Columbia River Bank Habitat Types Classification System.

Category	Code	Description
Armoured/Stable	A1	Banks generally stable and at repose with cobble/small boulder/gravel substrates predominating; uniform shoreline configuration with few/minor bank irregularities; velocities adjacent to bank generally low-moderate, instream cover limited to substrate roughness (i.e., cobble/small boulder interstices).
	A2	Banks generally stable and at repose with cobble/small boulder and large boulder substrates predominating; irregular shoreline configuration generally consisting of a series of armoured cobble/boulder outcrops that produce Backwater habitats; velocities adjacent to bank generally moderate with low velocities provided in BW habitats: instream cover provided by BW areas and substrate roughness; overhead cover provided by depth and woody debris; occasionally associated with C2, E4, and E5 banks.
	A3	Similar to A2 in terms of bank configuration and composition although generally with higher composition of large boulders/bedrock fractures; very irregular shoreline produced by large boulders and bed rock outcrops; velocities adjacent to bank generally moderate to high; instream cover provided by numerous small BW areas, eddy pools behind submerged boulders, and substrate interstices; overhead cover provided by depth; exhibits greater depths offshore than found in A1 or A2 banks; often associated with C1 banks.
	A4	Gently sloping banks with predominantly small and large boulders (boulder garden) often embedded in finer materials; shallow depths offshore, generally exhibits moderate to high velocities; instream cover provided by “pocket eddies” behind boulders; overhead cover provided by surface turbulence.
	A5	Bedrock banks, generally steep in profile resulting in deep water immediately offshore; often with large bedrock fractures in channel that provide instream cover; usually associated with moderate to high current velocities; overhead cover provided by depth.
	A6	Man-made banks usually armoured with large boulder or concrete rip-rap; depths offshore generally deep and usually found in areas with moderate to high velocities; instream cover provided by rip-rap interstices; overhead cover provided by depth and turbulence.
Depositional	D1	Low relief, gently sloping bank type with shallow water depths offshore; substrate consists predominantly of fines (i.e., sand/silt); low current velocities offshore; instream cover generally absent or, if present, consisting of shallow depressions produced by dune formation (i.e., in sand substrates) or embedded cobble/boulders and vegetative debris; this bank type was generally associated with bar formations or large backwater areas.
	D2	Low relief, gently sloping bank type with shallow water depths offshore; substrate consists of coarse materials (i.e., gravels/cobbles); low-moderate current velocities offshore; areas with higher velocities usually producing riffle areas; overhead cover provided by surface turbulence in riffle areas; instream cover provided by substrate roughness; often associated with bar formations and shoal habitat.
	D3	Similar to D2 but with coarser substrates (i.e., large cobble/small boulder) more dominant; boulders often embedded in cobble/gravel matrix; generally found in areas with higher average flow velocities than D1 or D2 banks; instream cover abundantly available in form of substrate roughness; overhead cover provided by surface turbulence; often associated with fast riffle transitional bank type that exhibits characteristics of both Armoured and Depositional bank types.
SPECIAL HABITAT FEATURES		
BACKWATER POOLS	-	These areas represent discrete areas along the channel margin where backwater irregularities produce localized areas of counter-current flows or areas with reduced flow velocities relative to the mainstem; can be quite variable in size and are often an integral component of Armoured and erosional bank types. The availability and suitability of Backwater pools are determined by flow level. To warrant separate identification as a discrete unit, must be a minimum of 10 m in length; widths highly variable depending on bank irregularity that produces the pool. Three classes are identified:
	BW-P1	Highest quality pool habitat type for adult and subadult cohorts for feeding/holding functions. Maximum depth exceeding 2.5 m, average depth 2.0 m or greater; high availability of instream cover types (e.g., submerged boulders, bedrock fractures, depth, woody debris); usually with Moderate to High countercurrent flows that provide overhead cover in the form of surface turbulence.
	BW-P2	Moderate quality pool type for adult and subadult cohorts for feeding/holding; also provides moderate quality habitat for smaller juveniles for rearing. Maximum depths between 2.0 to 2.5 m, average depths generally in order of 1.5 m. Moderate availability of instream cover types; usually with Low to Moderate countercurrent flow velocities that provide limited overhead cover.

Continued.

Table B1 Concluded.

	BW-P3	Low quality pool type for adult/subadult classes; moderate-high quality habitat for y-o-y and small juveniles for rearing. Maximum depth <1.0 m. Low availability of instream cover types; usually with Low-Nil current velocities.
EDDY POOL	EDDY	Represent large (<30 m in diameter) areas of counter current flows with depths generally >5 m; produced by major bank irregularities and are available at all flow stages although current velocities within eddy are dependent on flow levels. High quality areas for adult and subadult life stages. High availability of instream cover.
SNYE	SN	A side channel area that is separated from the mainstem at the upstream end but retains a connection at the lower end. SN habitats generally present only at lower flow stages since area is a flowing side channel at higher flows: characterized by low-nil velocity, variable depths (generally <3 m) and predominantly depositional substrates (i.e., sand/silt/gravel); often supports growths of aquatic vegetation; very important areas for rearing and feeding.

Velocity Classifications:

Low: <0.5 m/s
Moderate: 0.5 to 1.0 m/s
High: >1.0 m/s

Table B2 Length of bank habitat types at boat electrosfishing index sites within the lower Columbia River.

Section	**Site**[a]	**Length (m) of Bank Habitat Type**[b]														**Total Length (m)**
		A1	**A2**	**A3**	**A4**	**A5**	**A6**	**A1+A2**	**A2+A3**	**D1**	**D2**	**D3**	**D1+D2**	**BW**	**Eddy**	
Upstream Columbia	C00.0-R		543											394		**937**
	C00.7-L		290							303						**593**
	C01.3-L	200								1401						**1601**
	C02.8-L									882						**882**
	C03.6-L	1276			121					691						**2087**
	C04.6-R									517						**517**
	C05.6-L	654								447						**1101**
	C07.3-R				1705											**1705**
	C07.4-L												998			**998**
Upstream Columbia Total		2130	833		1826					4241			998	394		**10 422**
Kootenay River	K00.3-L								230					207		**436**
	K00.6-R												364		232	**596**
	K01.8-L		304			387					1179					**1871**
	K01.8-R					326			971							**1296**
Kootenay River Total			304			713			1200		1179		364	207	232	**4199**
Downstream Columbia	C25.3-R	1380				317			1029							**2727**
	C27.6-R					122			185		306					**613**
	C28.2-R		1131													**1131**
	C34.9-L		1740	396												**2136**
	C36.6-L					880			1031			483				**2395**
	C47.8-L								826	613						**1439**
	C48.2-R												495	514		**1009**
	C49.0-L		379								550					**930**
	C49.0-R							101					618			**720**
	C49.8-L		2447													**2447**
	C49.8-R		1511								489			391		**2391**
	C52.2-L										458				431	**889**
	C52.2-R		3272												518	**3790**
	C52.8-L		428		464											**893**
	C53.6-L						1518									**1518**
Downstream Columbia Total		1380	10909	396	464	1320	1518	101	3072	613	1802	483	1113	905	949	**25 026**
Grand Total		**3510**	**12047**	**396**	**2290**	**2033**	**1518**	**101**	**4272**	**4854**	**2982**	**483**	**2475**	**1506**	**1181**	**39 648**

[a] See Appendix A, Figures A1 to A3 for sample site locations.

[b] See Appendix B, Table B1 for bank habitat type descriptions.

Table B3 Summary of habitat variables recorded at boat electroshocking index sites in the Lower Columbia River, 30 September to 26 October 2019.

Section	**Site**[a]	**Session**	**Air Temperature (°C)**	**Water Temperature (°C)**	**Conductivity (µS)**	**Cloud Cover**[b]	**Water Surface Visibility**	**Instream Velocity**[c]	**Water Clarity**[d]	**Cover Types (%)**						
										Substrate Interstices	**Woody Debris**	**Turbulence**	**Aquatic Vegetation**	**Terrestrial Vegetation**	**Shallow Water**	**Deep Water**
Kootenay	K00.6-R	1	2.0	14.1	160	Clear	High	High	High	15	0	0	15	0	70	0
Kootenay	K00.6-R	2	8.0	13.6	150	Partly cloudy	High	High	High	30	0	0	10	0	60	0
Kootenay	K00.6-R	3	6.0	11.7	150	Mostly cloudy	High	High	High	20	0	0	30	0	50	0
Kootenay	K00.6-R	4	4.0	10.9	150	Clear	Medium	Low	High	0	0	0	80	0	20	0
Kootenay	K00.3-L	1	2.0	14.0	160	Clear	High	High	High	25	0	0	0	0	35	40
Kootenay	K00.3-L	2	8.0	13.6	150	Partly cloudy	High	High	High	25	0	0	0	0	40	35
Kootenay	K00.3-L	3	7.0	11.7	150	Mostly cloudy	High	Medium	High	30	0	0	0	0	30	40
Kootenay	K00.3-L	4	4.0	11.1	150	Clear	Medium	High	High	40	0	0	0	0	20	40
Lower	C53.6-L	1	6.0	12.7	140	Partly cloudy	High	High	High	30	0	0	0	0	60	10
Lower	C53.6-L	2	1.0	12.0	140	Clear	High	High	High	40	0	0	0	0	40	20
Lower	C53.6-L	3	5.0	11.5	140	Partly cloudy	High	High	High	30	0	0	0	0	40	30
Lower	C53.6-L	4	6.0	10.1	150	Clear	High	High	High	40	0		0	0	30	30
Lower	C52.8-L	1	6.0	12.7	140	Partly cloudy	High	High	High	30	0	0	0	0	20	50
Lower	C52.8-L	2	2.0	12.0	140	Clear	High	High	High	25	0	0	0	0	25	50
Lower	C52.8-L	3	5.0	11.6	140	Partly cloudy	High	High	High	30	0	0	0	0	30	40
Lower	C52.8-L	4	6.0	9.9	140	Clear	High	High	High	30	0	0	0	0	40	30
Lower	C52.2-R	1	4.0	13.1	140	Partly cloudy	High	High	High	15	0	0	0	0	75	10
Lower	C52.2-R	2	-2.0	12.2	140	Clear	High	High	High	10	0	0	0	0	85	5
Lower	C52.2-R	3	9.0	11.6	140	Mostly cloudy	High	High	High	15	0	0	0	0	70	15
Lower	C52.2-R	4	6.0	10.5	140	Partly cloudy	High	High	High	10	0	0	0	0	75	15
Lower	C52.2-L	1	6.0	12.7	140	Mostly cloudy	High	High	High	15	0	0	1	0	9	75
Lower	C52.2-L	2	2.0	12.2	140	Clear	High	High	High	20	0	0	0	0	30	50
Lower	C52.2-L	3	5.0	11.7	140	Partly cloudy	High	High	High	10	0	0	0	0	40	50
Lower	C52.2-L	4	6.0	9.9	140	Clear	High	Low	High	10	0	0	0	0	40	50
Lower	C49.8-R	1	6.0	13.3	140	Mostly cloudy	High	High	High	10	0	0	0	0	80	10
Lower	C49.8-R	2	1.0	11.9	140	Clear	High	High	High	10	0	0	1	0	89	0
Lower	C49.8-R	3	9.0	11.6	140	Mostly cloudy	High	High	High	10	0	0	0	0	80	10
Lower	C49.8-R	4	7.0	10.5	140	Mostly cloudy	High	High	High	20	0	0	0	0	70	10
Lower	C49.8-L	1	6.0	12.7	140	Mostly cloudy	High	High	High	10	0	0	0	0	70	20
Lower	C49.8-L	2	3.0	12.2	140	Clear	High	High	High	10	0	0	0	0	70	20
Lower	C49.8-L	3	5.0	11.6	140	Clear	High	High	High	20	0	0	0	0	70	10
Lower	C49.8-L	4	1.0	10.0	150	Clear	Medium	High	High	0	0	0	0	0	90	10
Lower	C49.0-R	1	7.0	13.2	140	Mostly cloudy	High	High	High	0	0	0	0	0	75	25
Lower	C49.0-R	2	1.0	12.2	140	Clear	High	High	High	0	0	0	0	0	80	20
Lower	C49.0-R	3	9.0	11.7	140	Mostly cloudy	High	High	High	20	0	0	0	0	70	10
Lower	C49.0-R	4	7.0	10.5	140	Mostly cloudy	High	High	High	0	0	0	0	0	60	40
Lower	C49.0-L	1	7.0	12.7	140	Mostly cloudy	High	High	High	0	0	0	0	0	90	10
Lower	C49.0-L	2	6.0	12.2	140	Clear	High	High	High	0	0	0	0	0	90	10
Lower	C49.0-L	3	6.0	11.7	140	Partly cloudy	High	High	High	0	0	0	0	0	95	5
Lower	C49.0-L	4	1.0	9.9	150	Clear	High	High	High	0	0	0	0	0	90	10

Continued...

[a] See Appendix A, Figures A1 to A3 for sample site locations.

[b] Clear = <10%; Partly Cloudy = 10-50%; Mostly Cloudy = 50-90%; Overcast = >90%.

[c] High = >1.0 m/s; Medium = 0.5-1.0 m/s; Low = <0.5 m/s.

[d] High = >3.0 m; Medium = 1.0-3.0 m; Low = <1.0 m.

Table B3 Continued.

Section	Site[a]	Session	Air Temperature (°C)	Water Temperature (°C)	Conductivity (µS)	Cloud Cover[b]	Water Surface Visibility	Instream Velocity[c]	Water Clarity[d]	Cover Types (%)						
										Substrate Interstices	Woody Debris	Turbulence	Aquatic Vegetation	Terrestrial Vegetation	Shallow Water	Deep Water
Kootenay	K00.6-R	1	2.0	14.1	160	Clear	High	High	High	15	0	0	15	0	70	0
Kootenay	K00.6-R	2	8.0	13.6	150	Partly cloudy	High	High	High	30	0	0	10	0	60	0
Kootenay	K00.6-R	3	6.0	11.7	150	Mostly cloudy	High	High	High	20	0	0	30	0	50	0
Kootenay	K00.6-R	4	4.0	10.9	150	Clear	Medium	Low	High	0	0	0	80	0	20	0
Kootenay	K00.3-L	1	2.0	14.0	160	Clear	High	High	High	25	0	0	0	0	35	40
Kootenay	K00.3-L	2	8.0	13.6	150	Partly cloudy	High	High	High	25	0	0	0	0	40	35
Kootenay	K00.3-L	3	7.0	11.7	150	Mostly cloudy	High	Medium	High	30	0	0	0	0	30	40
Kootenay	K00.3-L	4	4.0	11.1	150	Clear	Medium	High	High	40	0	0	0	0	20	40
Lower	C53.6-L	1	6.0	12.7	140	Partly cloudy	High	High	High	30	0	0	0	0	60	10
Lower	C53.6-L	2	1.0	12.0	140	Clear	High	High	High	40	0	0	0	0	40	20
Lower	C53.6-L	3	5.0	11.5	140	Partly cloudy	High	High	High	30	0	0	0	0	40	30
Lower	C53.6-L	4	6.0	10.1	150	Clear	High	High	High	40	0		0	0	30	30
Lower	C52.8-L	1	6.0	12.7	140	Partly cloudy	High	High	High	30	0	0	0	0	20	50
Lower	C52.8-L	2	2.0	12.0	140	Clear	High	High	High	25	0	0	0	0	25	50
Lower	C52.8-L	3	5.0	11.6	140	Partly cloudy	High	High	High	30	0	0	0	0	30	40
Lower	C52.8-L	4	6.0	9.9	140	Clear	High	High	High	30	0	0	0	0	40	30
Lower	C52.2-R	1	4.0	13.1	140	Partly cloudy	High	High	High	15	0	0	0	0	75	10
Lower	C52.2-R	2	-2.0	12.2	140	Clear	High	High	High	10	0	0	0	0	85	5
Lower	C52.2-R	3	9.0	11.6	140	Mostly cloudy	High	High	High	15	0	0	0	0	70	15
Lower	C52.2-R	4	6.0	10.5	140	Partly cloudy	High	High	High	10	0	0	0	0	75	15
Lower	C52.2-L	1	6.0	12.7	140	Mostly cloudy	High	High	High	15	0	0	1	0	9	75
Lower	C52.2-L	2	2.0	12.2	140	Clear	High	High	High	20	0	0	0	0	30	50
Lower	C52.2-L	3	5.0	11.7	140	Partly cloudy	High	High	High	10	0	0	0	0	40	50
Lower	C52.2-L	4	6.0	9.9	140	Clear	High	Low	High	10	0	0	0	0	40	50
Lower	C49.8-R	1	6.0	13.3	140	Mostly cloudy	High	High	High	10	0	0	0	0	80	10
Lower	C49.8-R	2	1.0	11.9	140	Clear	High	High	High	10	0	0	1	0	89	0
Lower	C49.8-R	3	9.0	11.6	140	Mostly cloudy	High	High	High	10	0	0	0	0	80	10
Lower	C49.8-R	4	7.0	10.5	140	Mostly cloudy	High	High	High	20	0	0	0	0	70	10
Lower	C49.8-L	1	6.0	12.7	140	Mostly cloudy	High	High	High	10	0	0	0	0	70	20
Lower	C49.8-L	2	3.0	12.2	140	Clear	High	High	High	10	0	0	0	0	70	20
Lower	C49.8-L	3	5.0	11.6	140	Clear	High	High	High	20	0	0	0	0	70	10
Lower	C49.8-L	4	1.0	10.0	150	Clear	Medium	High	High	0	0	0	0	0	90	10
Lower	C49.0-R	1	7.0	13.2	140	Mostly cloudy	High	High	High	0	0	0	0	0	75	25
Lower	C49.0-R	2	1.0	12.2	140	Clear	High	High	High	0	0	0	0	0	80	20
Lower	C49.0-R	3	9.0	11.7	140	Mostly cloudy	High	High	High	20	0	0	0	0	70	10
Lower	C49.0-R	4	7.0	10.5	140	Mostly cloudy	High	High	High	0	0	0	0	0	60	40
Lower	C49.0-L	1	7.0	12.7	140	Mostly cloudy	High	High	High	0	0	0	0	0	90	10
Lower	C49.0-L	2	6.0	12.2	140	Clear	High	High	High	0	0	0	0	0	90	10
Lower	C49.0-L	3	6.0	11.7	140	Partly cloudy	High	High	High	0	0	0	0	0	95	5
Lower	C49.0-L	4	1.0	9.9	150	Clear	High	High	High	0	0	0	0	0	90	10

Continued...

[a] See Appendix A, Figures A1 to A3 for sample site locations.

[b] Clear = <10%; Partly Cloudy = 10-50%; Mostly Cloudy = 50-90%; Overcast = >90%.

[c] High = >1.0 m/s; Medium = 0.5-1.0 m/s; Low = <0.5 m/s.

[d] High = >3.0 m; Medium = 1.0-3.0 m; Low = <1.0 m.

Table B3 Continued.

Section	Site[a]	Session	Air Temperature (°C)	Water Temperature (°C)	Conductivity (μS)	Cloud Cover[b]	Water Surface Visibility	Instream Velocity[c]	Water Clarity[d]	Cover Types (%)						
										Substrate Interstices	Woody Debris	Turbulence	Aquatic Vegetation	Terrestrial Vegetation	Shallow Water	Deep Water
Upper	C04.6-R	1	1.0	14.5	120	Mostly cloudy	High	Low	High	0	0	0	100	0	0	0
Upper	C04.6-R	2	6.0	13.3	120	Mostly cloudy	High	Low	High	0	0	0	100	0	0	0
Upper	C04.6-R	3	6.0	11.8	120	Mostly cloudy	High	Low	High	0	0	0	100	0	0	0
Upper	C04.6-R	4	5.0	10.9	130	Mostly cloudy	High	Low	High	0	0	0	100	0	0	0
Upper	C03.6-L	1	1.0	14.4	120	Mostly cloudy	High	Low	High	0	0	0	40	0	60	0
Upper	C03.6-L	2	4.0	12.3	130	Partly cloudy	High	Low	High	0	0	0	75	0	20	5
Upper	C03.6-L	3	6.0	11.7	120	Mostly cloudy	High	Low	High	0	0	0	80	0	20	0
Upper	C03.6-L	4	5.0	10.8	130	Mostly cloudy	High	Low	High	0	0	0	30	0	60	10
Upper	C02.8-L	1	4.0	14.6	120	Mostly cloudy	High	Low	High	0	0	0	50	0	50	0
Upper	C02.8-L	2	5.0	12.5	130	Mostly cloudy	High	Low	High	0	0	0	75	0	25	0
Upper	C02.8-L	3	7.0	11.7	120	Mostly cloudy	High	Low	High	0	0	0	15	0	80	5
Upper	C02.8-L	4	6.0	10.7	130	Mostly cloudy	Medium	Low	High	0	0	0	90	0	10	0
Upper	C01.3-L	1	4.0	14.6	120	Mostly cloudy	High	Low	High	0	0	0	45	0	55	0
Upper	C01.3-L	2	6.0	12.6	130	Mostly cloudy	High	Low	High	0	0	0	20	0	60	20
Upper	C01.3-L	3	9.0	11.8	120	Mostly cloudy	High	Low	High	0	0	0	20	0	70	10
Upper	C01.3-L	4	6.0	10.8	130	Mostly cloudy	High	Low	High	0	0	0	40	0	50	10
Upper	C00.7-L	1	5.0	14.7	120	Mostly cloudy	High	Low	High	15	0	0	20	0	55	10
Upper	C00.7-L	2	6.0	12.6	130	Mostly cloudy	Medium	Low	High	10	0	0	0	0	80	10
Upper	C00.7-L	3	10.0	11.8	120	Mostly cloudy	High	Low	High	5	0	0	5	0	80	10
Upper	C00.7-L	4	8.0	10.6	130	Mostly cloudy	High	Low	High	20	0	0	0	0	70	10
Upper	C00.0-R	1	5.0	14.6	120	Mostly cloudy	High	Low	High	0	2	0	20	0	60	18
Upper	C00.0-R	2	6.0	12.4	130	Mostly cloudy	Medium	Low	High	25	0	0	0	0	50	25
Upper	C00.0-R	3	10.5	11.8	120	Mostly cloudy	High	Low	High	30		0	0	0	50	20
Upper	C00.0-R	4	8.0	10.7	130	Mostly cloudy	High	Low	High	10	0	0	0	0	65	25

[a] See Appendix A, Figures A1 to A3 for sample site locations.

[b] Clear = <10%; Partly Cloudy = 10-50%; Mostly Cloudy = 50-90%; Overcast = >90%.

[c] High = >1.0 m/s; Medium = 0.5-1.0 m/s; Low = <0.5 m/s.

[d] High = >3.0 m; Medium = 1.0-3.0 m; Low = <1.0 m.

Table B4 Summary of species counts adjacent to bank habitat types in index sites in the Lower Columbia River, 30 September to 26 October 2019.

Section	**Site**[a]	**Species**	**Bank Habitat Type**[a]														**Total**
			A1	**A1+A2**	**A2**	**A2+A3**	**A3**	**A4**	**A5**	**A6**	**BW**	**D1**	**D1+D2**	**D2**	**D3**	**Eddy**	
Upstream Columbia River	C00.0-R	Kokanee			1												**1**
	C00.0-R	Mountain Whitefish			39						15						**54**
	C00.0-R	Rainbow Trout			38						18						**56**
	C00.0-R	Redside Shiner			44						13						**57**
	C00.0-R	Sculpin spp.			78						65						**143**
	C00.0-R	Sucker spp.			10						2						**12**
	C00.0-R	Walleye			15						8						**23**
	C00.0-R	White Sturgeon			3						1						**4**
	Site C00.0-R Total		**0**	**0**	**228**	**0**	**0**	**0**	**0**	**0**	**122**	**0**	**0**	**0**	**0**	**0**	**350**
	C00.7-L	Mountain Whitefish			4							69					**73**
	C00.7-L	Northern Pikeminnow										1					**1**
	C00.7-L	Peamouth			2												**2**
	C00.7-L	Rainbow Trout			11							37					**48**
	C00.7-L	Redside Shiner			7							10					**17**
	C00.7-L	Sculpin spp.			47							15					**62**
	C00.7-L	Sucker spp.										6					**6**
	C00.7-L	Walleye			9												**9**
	C00.7-L	White Sturgeon										2					**2**
	Site C00.7-L Total		**0**	**0**	**80**	**0**	**0**	**0**	**0**	**0**	**0**	**140**	**0**	**0**	**0**	**0**	**220**
	C01.3-L	Mountain Whitefish	16									144					**160**
	C01.3-L	Northern Pike										2					**2**
	C01.3-L	Northern Pikeminnow										3					**3**
	C01.3-L	Peamouth										3					**3**
	C01.3-L	Rainbow Trout	22									149					**171**
	C01.3-L	Redside Shiner	3									66					**69**
	C01.3-L	Sculpin spp.	15									182					**197**
	C01.3-L	Sucker spp.	86									219					**305**
	C01.3-L	Walleye	9									87					**96**
	C01.3-L	White Sturgeon	1									4					**5**
	Site C01.3-L Total		**152**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**859**	**0**	**0**	**0**	**0**	**1011**
	C02.8-L	Carp spp.										1					**1**
	C02.8-L	Mountain Whitefish										45					**45**
	C02.8-L	Northern Pike										3					**3**
	C02.8-L	Rainbow Trout										104					**104**
	C02.8-L	Redside Shiner										52					**52**
	C02.8-L	Sculpin spp.										111					**111**
	C02.8-L	Sucker spp.										85					**85**
	C02.8-L	Walleye										27					**27**
	Site C02.8-L Total		**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**428**	**0**	**0**	**0**	**0**	**428**
	C03.6-L	Mountain Whitefish	59					9				40					**108**
	C03.6-L	Northern Pike	6									2					**8**
	C03.6-L	Northern Pikeminnow	13					26									**39**
	C03.6-L	Rainbow Trout	89					7				113					**209**
	C03.6-L	Redside Shiner	10					20				26					**56**
	C03.6-L	Sculpin spp.	50					66				65					**181**
	C03.6-L	Sucker spp.	195					19				158					**372**
	C03.6-L	Walleye	57					7				50					**114**
	C03.6-L	White Sturgeon	6									8					**14**
	Site C03.6-L Total		**485**	**0**	**0**	**0**	**0**	**154**	**0**	**0**	**0**	**462**	**0**	**0**	**0**	**0**	**1101**
	C04.6-R	Mountain Whitefish										10					**10**
	C04.6-R	Northern Pike										2					**2**
	C04.6-R	Rainbow Trout										62					**62**
	C04.6-R	Redside Shiner										25					**25**
	C04.6-R	Sculpin spp.										58					**58**
	C04.6-R	Sucker spp.										72					**72**
	C04.6-R	Walleye										13					**13**
	C04.6-R	White Sturgeon										1					**1**
	C04.6-R	Yellow Perch										1					**1**
	Site C04.6-R Total		**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**244**	**0**	**0**	**0**	**0**	**244**
	C05.6-L	Kokanee	25									5					**30**
	C05.6-L	Mountain Whitefish	8									3					**11**
	C05.6-L	Northern Pike	3									4					**7**
	C05.6-L	Northern Pikeminnow	31									2					**33**
	C05.6-L	Rainbow Trout	39									35					**74**
	C05.6-L	Redside Shiner	33									9					**42**
	C05.6-L	Sculpin spp.	168									50					**218**
	C05.6-L	Sucker spp.	103									82					**185**
	C05.6-L	Walleye	33									4					**37**
	C05.6-L	White Sturgeon	3									1					**4**
	Site C05.6-L Total		**446**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**195**	**0**	**0**	**0**	**0**	**641**
	C07.3-R	Brown Trout						1									**1**
	C07.3-R	Bull Trout						1									**1**
	C07.3-R	Burbot						1									**1**
	C07.3-R	Kokanee						1									**1**
	C07.3-R	Lake Whitefish						4									**4**
	C07.3-R	Mountain Whitefish						150									**150**
	C07.3-R	Rainbow Trout						143									**143**
	C07.3-R	Redside Shiner						25									**25**
	C07.3-R	Sculpin spp.						121									**121**
	C07.3-R	Sucker spp.						20									**20**
	C07.3-R	Walleye						108									**108**
	C07.3-R	White Sturgeon						6									**6**
	Site C07.3-R Total		**0**	**0**	**0**	**0**	**0**	**581**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**581**
	C07.4-L	Kokanee											13				**13**
	C07.4-L	Mountain Whitefish											411				**411**
	C07.4-L	Rainbow Trout											137				**137**
	C07.4-L	Sculpin spp.											22				**22**
	C07.4-L	Sucker spp.											145				**145**
	C07.4-L	Walleye											45				**45**
	C07.4-L	White Sturgeon											37				**37**
	Site C07.4-L Total		**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**810**	**0**	**0**	**0**	**810**
Upstream Columbia River Total			**1083**	**0**	**308**	**0**	**0**	**735**	**0**	**0**	**122**	**2328**	**810**	**0**	**0**	**0**	**5386**
Kootenay	K00.3-L	Lake Whitefish				1											**1**
	K00.3-L	Mountain Whitefish				12					4						**16**
	K00.3-L	Rainbow Trout				10					11						**21**
	K00.3-L	Sculpin spp.									2						**2**
	K00.3-L	Sucker spp.				2					1						**3**
	K00.3-L	Walleye				3					7						**10**
	Site K00.3-L Total		**0**	**0**	**0**	**28**	**0**	**0**	**0**	**0**	**25**	**0**	**0**	**0**	**0**	**0**	**53**

[a] See Appendix A, Figures A1 to A3 for sample site locations.

[b] See Appendix B, Table B1 for bank habitat type descriptions.

Continued...

Table B4 Continued.

Section	Site[a]	Species	Bank Habitat Type[a]														Total
			A1	A1+A2	A2	A2+A3	A3	A4	A5	A6	BW	D1	D1+D2	D2	D3	Eddy	
	K00.6-R	Mountain Whitefish											75			6	**81**
	K00.6-R	Northern Pike														1	**1**
	K00.6-R	Northern Pikeminnow											1			5	**6**
	K00.6-R	Peamouth														1	**1**
	K00.6-R	Rainbow Trout											8			17	**25**
	K00.6-R	Redside Shiner														17	**17**
	K00.6-R	Sculpin spp.											9			35	**44**
	K00.6-R	Sucker spp.											18			43	**61**
	K00.6-R	Walleye											4			15	**19**
	K00.6-R	White Sturgeon											2			1	**3**
	Site K00.6-R Total		**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**117**	**0**	**0**	**141**	**258**
Kootenay Total			**0**	**0**	**0**	**28**	**0**	**0**	**0**	**0**	**25**	**0**	**117**	**0**	**0**	**141**	**311**
Downstream Columbia River	C25.3-R	Burbot							1								**1**
	C25.3-R	Kokanee	11						2								**13**
	C25.3-R	Lake Whitefish	9			15											**24**
	C25.3-R	Mountain Whitefish	45			135			1								**181**
	C25.3-R	Northern Pikeminnow	2			1			1								**4**
	C25.3-R	Rainbow Trout	89			68			6								**163**
	C25.3-R	Redside Shiner	69														**69**
	C25.3-R	Sculpin spp.	147			17			7								**171**
	C25.3-R	Sucker spp.	6			8											**14**
	C25.3-R	Walleye	43			12			15								**70**
	C25.3-R	White Sturgeon	1			1											**2**
	Site C25.3-R Total		**422**	**0**	**0**	**257**	**0**	**0**	**33**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**712**
	C27.6-R	Mountain Whitefish				6			1					60			**67**
	C27.6-R	Northern Pikeminnow												1			**1**
	C27.6-R	Rainbow Trout				45			6					37			**88**
	C27.6-R	Redside Shiner							3								**3**
	C27.6-R	Sculpin spp.							11					31			**42**
	C27.6-R	Sucker spp.												5			**5**
	C27.6-R	Walleye				6			2					23			**31**
	C27.6-R	White Sturgeon							1								**1**
	Site C27.6-R Total		**0**	**0**	**0**	**57**	**0**	**0**	**24**	**0**	**0**	**0**	**0**	**157**	**0**	**0**	**238**
	C28.2-R	Burbot			1												**1**
	C28.2-R	Mountain Whitefish			13												**13**
	C28.2-R	Northern Pikeminnow			4												**4**
	C28.2-R	Rainbow Trout			162												**162**
	C28.2-R	Redside Shiner			5												**5**
	C28.2-R	Sculpin spp.			136												**136**
	C28.2-R	Sucker spp.			4												**4**
	C28.2-R	Walleye			38												**38**
	C28.2-R	White Sturgeon			2												**2**
	Site C28.2-R Total		**0**	**0**	**365**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**365**
	C34.9-L	Lake Whitefish			1												**1**
	C34.9-L	Mountain Whitefish			13												**13**
	C34.9-L	Northern Pikeminnow			4		4										**8**
	C34.9-L	Rainbow Trout			241		56										**297**
	C34.9-L	Sculpin spp.			145		20										**165**
	C34.9-L	Sucker spp.			11		1										**12**
	C34.9-L	Walleye			38		19										**57**
	C34.9-L	White Sturgeon					1										**1**
	Site C34.9-L Total		**0**	**0**	**453**	**0**	**101**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**554**
	C36.6-L	Lake Whitefish													3		**3**
	C36.6-L	Mountain Whitefish				22			5						33		**60**
	C36.6-L	Northern Pikeminnow							7						1		**8**
	C36.6-L	Rainbow Trout				192			111						17		**320**
	C36.6-L	Sculpin spp.				34			8								**42**
	C36.6-L	Sucker spp.				1			1								**2**
	C36.6-L	Walleye				38			19						13		**70**
	C36.6-L	White Sturgeon				2			2								**4**
	Site C36.6-L Total		**0**	**0**	**0**	**289**	**0**	**0**	**153**	**0**	**0**	**0**	**0**	**0**	**67**	**0**	**509**
	C47.8-L	Brook Trout										1					**1**
	C47.8-L	Lake Whitefish										3					**3**
	C47.8-L	Mountain Whitefish		8								7					**15**
	C47.8-L	Rainbow Trout		111								129					**240**
	C47.8-L	Redside Shiner										45					**45**
	C47.8-L	Sculpin spp.		146								11					**157**
	C47.8-L	Sucker spp.		4								61					**65**
	C47.8-L	Walleye		34								33					**67**
	C47.8-L	White Sturgeon										2					**2**
	C47.8-L	Yellow Perch										1					**1**
	Site C47.8-L Total		**0**	**303**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**293**	**0**	**0**	**0**	**0**	**596**
	C48.2-R	Lake Whitefish											1				**1**
	C48.2-R	Mountain Whitefish									3		27				**30**
	C48.2-R	Rainbow Trout									51		83				**134**
	C48.2-R	Sculpin spp.									11		45				**56**
	C48.2-R	Sucker spp.									10		8				**18**
	C48.2-R	Walleye									27		39				**66**
	C48.2-R	White Sturgeon											2				**2**
	Site C48.2-R Total		**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**102**	**0**	**205**	**0**	**0**	**0**	**307**
	C49.0-L	Lake Whitefish			5									3			**8**
	C49.0-L	Mountain Whitefish			76												**76**
	C49.0-L	Rainbow Trout			67									60			**127**
	C49.0-L	Sculpin spp.												25			**25**
	C49.0-L	Sucker spp.			17									7			**24**
	C49.0-L	Walleye			8									10			**18**
	C49.0-L	White Sturgeon			1												**1**
	Site C49.0-L Total		**0**	**0**	**174**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**105**	**0**	**0**	**279**
	C49.0-R	Lake Whitefish											2				**2**
	C49.0-R	Mountain Whitefish											9				**9**
	C49.0-R	Northern Pike											1				**1**
	C49.0-R	Rainbow Trout		24									12				**36**
	C49.0-R	Sculpin spp.		12									6				**18**
	C49.0-R	Sucker spp.		6									1				**7**
	C49.0-R	Walleye		19									4				**23**
	Site C49.0-R Total		**0**	**61**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**35**	**0**	**0**	**0**	**96**

Continued...

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[a] See Appendix A, Figures A1 to A3 for sample site locations.

[b] See Appendix B, Table B1 for bank habitat type descriptions.

Table B4 Concluded.

Section	Site[a]	Species	Bank Habitat Type[a]														Total
			A1	A1+A2	A2	A2+A3	A3	A4	A5	A6	BW	D1	D1+D2	D2	D3	Eddy	
	C49.8-L	Burbot			4												**4**
	C49.8-L	Lake Whitefish			7												**7**
	C49.8-L	Mountain Whitefish			116												**116**
	C49.8-L	Rainbow Trout			328												**328**
	C49.8-L	Redside Shiner			10												**10**
	C49.8-L	Sculpin spp.			577												**577**
	C49.8-L	Sucker spp.			33												**33**
	C49.8-L	Walleye			101												**101**
	C49.8-L	White Sturgeon			4												**4**
	Site C49.8-L Total		**0**	**0**	**1180**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1180**
	C49.8-R	Burbot												3			**3**
	C49.8-R	Lake Whitefish												1			**1**
	C49.8-R	Mountain Whitefish			74						4			4			**82**
	C49.8-R	Northern Pikeminnow			1												**1**
	C49.8-R	Pumpkinseed									1						**1**
	C49.8-R	Rainbow Trout			90						51			73			**214**
	C49.8-R	Sculpin spp.			116						3			76			**195**
	C49.8-R	Sucker spp.			12						14			11			**37**
	C49.8-R	Walleye			32						13			20			**65**
	C49.8-R	Yellow Perch									2						**2**
	Site C49.8-R Total		**0**	**0**	**325**	**0**	**0**	**0**	**0**	**0**	**88**	**0**	**0**	**188**	**0**	**0**	**601**
	C52.2-L	Lake Whitefish														3	**3**
	C52.2-L	Mountain Whitefish												2		3	**5**
	C52.2-L	Rainbow Trout												5		102	**107**
	C52.2-L	Sculpin spp.														22	**22**
	C52.2-L	Sucker spp.												1		3	**4**
	C52.2-L	Walleye														25	**25**
	C52.2-L	White Sturgeon														1	**1**
	Site C52.2-L Total		**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**8**	**0**	**159**	**167**
	C52.2-R	Brown Trout			1												**1**
	C52.2-R	Kokanee			1												**1**
	C52.2-R	Lake Whitefish			5											1	**6**
	C52.2-R	Mountain Whitefish			90												**90**
	C52.2-R	Rainbow Trout			144											112	**256**
	C52.2-R	Sculpin spp.			30											17	**47**
	C52.2-R	Sucker spp.			9											18	**27**
	C52.2-R	Walleye			60											14	**74**
	C52.2-R	White Sturgeon			2												**2**
	Site C52.2-R Total		**0**	**0**	**342**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**162**	**504**
	C52.8-L	Burbot						1									**1**
	C52.8-L	Lake Whitefish						3									**3**
	C52.8-L	Mountain Whitefish						6									**6**
	C52.8-L	Rainbow Trout			25			100									**125**
	C52.8-L	Walleye			24			44									**68**
	Site C52.8-L Total		**0**	**0**	**49**	**0**	**0**	**154**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**203**
	C53.6-L	Lake Whitefish								2							**2**
	C53.6-L	Mountain Whitefish								7							**7**
	C53.6-L	Rainbow Trout								83							**83**
	C53.6-L	Sculpin spp.								16							**16**
	C53.6-L	Sucker spp.								1							**1**
	C53.6-L	Walleye								49							**49**
	Site C53.6-L Total		**0**	**0**	**0**	**0**	**0**	**0**	**0**	**158**	**0**	**0**	**0**	**0**	**0**	**0**	**158**
Downstream Columbia River Total			**422**	**364**	**2888**	**603**	**101**	**154**	**210**	**158**	**190**	**293**	**240**	**458**	**67**	**321**	**6469**
Grand Total			**1505**	**364**	**3196**	**631**	**101**	**889**	**210**	**158**	**337**	**2621**	**1167**	**458**	**67**	**462**	**12166**

[a] See Appendix A, Figures A1 to A3 for sample site locations.

[b] See Appendix B, Table B1 for bank habitat type descriptions.

Appendix C – Modelling Methods and Parameter Estimates

Lower Columbia River Fish Population Indexing 2019

Methods

Data Preparation

The fish indexing data were provided by Okanagan Nation Alliance and Golder Associates in the form of an Access database. The discharge and temperature data were obtained from the Columbia Basin Hydrological Database maintained by Poisson Consulting. The Rainbow Trout egg dewatering estimates were provided by CLBMON-46 (Irvine, Baxter, and Thorley 2015) and the Mountain Whitefish egg stranding estimates by Golder Associates (2013).

Discharge

Missing hourly discharge values for Hugh-Keenleyside Dam (HLK), Brilliant Dam (BRD) and Birchbank (BIR) were estimated by first leading the BIR values by 2 hours to account for the lag. Values missing at just one of the dams were then estimated assuming $HLK + BRD = BIR$. Negative values were set to be zero. Next, missing values spanning ≤ 28 days were estimated at HLK and BRD based on linear interpolation. Finally any remaining missing values at BIR were set to be $HLK + BRD$. The complete discharge data sets including missing values filled as described above were used for the calculation of egg dewatering mortality using the Mountain Whitefish Egg Stranding Model.

The data were prepared for analysis using R version 4.0.1 (R Core Team 2018).

Data Analysis

Model parameters were estimated using hierarchical Bayesian methods. The parameters were produced using JAGS (Plummer 2015) and STAN (Carpenter et al. 2017). For additional information on Bayesian estimation the reader is referred to McElreath (2016).

The one exception is the length-at-age estimates which were produced using the mixdist R package (Macdonald 2012) which implements Maximum Likelihood with Expectation Maximization.

Unless indicated otherwise, the Bayesian analyses used normal and uniform prior distributions that were vague in the sense that they did not constrain the posteriors (Kery and Schaub 2011, 36). The posterior distributions were estimated from 1500 Markov Chain Monte Carlo (MCMC) samples thinned from the second halves of 3 chains (Kery and Schaub 2011, 38–40). Model convergence was confirmed by ensuring that $\hat{R} \leq 1.05$ (Kery and Schaub 2011, 40) and ESS ≥ 150 for each of the monitored parameters (Kery and Schaub 2011, 61). Where $\hat{R}$ is the potential scale reduction factor and ESS is the effective sample size (Brooks et al. 2011).

The parameters are summarised in terms of the point *estimate*, standard deviation (*sd*), the *z-score*, *lower* and *upper* 95% confidence/credible limits (CLs) and the *p-value* (Kery and

Schaub 2011, 37, 42). For ML models, the point estimate is the MLE, the standard deviation is the standard error, the z-score is MLE/sd and the 95% CLs are the MLE ± 1.96 · sd. For Bayesian models, the estimate is the median (50th percentile) of the MCMC samples, the z-score is mean/sd and the 95% CLs are the 2.5th and 97.5th percentiles. A p-value of 0.05 indicates that the lower or upper 95% CL is 0.

Where relevant, model adequacy was confirmed by examination of residual plots for the full model(s).

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) (Kery and Schaub 2011, 77–82). When informative the influence of particular variables is expressed in terms of the *effect size* (i.e., percent change in the response variable) with 95% confidence/credible intervals (CIs, Bradford, Korman, and Higgins 2005).

The analyses were implemented using R version 4.0.1 (R Core Team 2018) and the mbr family of packages.

Model Templates

Condition

```
 data {
  int nYear;
  int nObs;

  vector[nObs] Length;
  vector[nObs] Weight;
  vector[nObs] Dayte;
  int Year[nObs];

parameters {
  real bWeight;
  real bWeightLength;
  real bWeightDayte;
  real bWeightLengthDayte;
  real sWeightYear;
  real sWeightLengthYear;

  vector[nYear] bWeightYear;
  vector[nYear] bWeightLengthYear;
  real sWeight;

model {

  vector[nObs] eWeight;

  bWeight ~ normal(5, 5);
  bWeightLength ~ normal(3, 2);
```

```
  bWeightDayte ~ normal(0, 2);
  bWeightLengthDayte ~ normal(0, 2);

  sWeightYear ~ normal(0, 2);
  sWeightLengthYear ~ normal(0, 2);

  for (i in 1:nYear) {
    bWeightYear[i] ~ normal(0, exp(sWeightYear));
    bWeightLengthYear[i] ~ normal(0, exp(sWeightLengthYear));
  }

  sWeight ~ normal(0, 5);
  for(i in 1:nObs) {
    eWeight[i] = bWeight + bWeightDayte * Dayte[i] + bWeightYear[Year[i]] + (bWeightL
ength + bWeightLengthDayte * Dayte[i] + bWeightLengthYear[Year[i]]) * Length[i];
    Weight[i] ~ lognormal(eWeight[i], exp(sWeight));
  }
```

Block 1.

Growth

```
.model {
  bK ~ dnorm (0, 5^-2)
  sKYear ~ dnorm(0, 5^-2)

  for (i in 1:nYear) {
    bKYear[i] ~ dnorm(0, exp(sKYear)^-2)
    log(eK[i]) <- bK + bKYear[i]
  }

  bLinf ~ dnorm(500, 250^-2) T(100, 1000)
  sGrowth ~ dnorm(0, 5^-2)
  for (i in 1:length(Year)) {
    eGrowth[i] <- (bLinf - LengthAtRelease[i]) * (1 - exp(-sum(eK[Year[i]:(Year[i] +
dYears[i] - 1)])))
    Growth[i] ~ dnorm(max(eGrowth[i], 0), exp(sGrowth)^-2)
  }
```

Block 2.

Movement

```
.model {

  bFidelity ~ dnorm(0, 2^-2)
  bLength ~ dnorm(0, 2^-2)

  for (i in 1:length(Fidelity)) {
    logit(eFidelity[i]) <- bFidelity + bLength * Length[i]
    Fidelity[i] ~ dbern(eFidelity[i])
  }
```

Block 3.

Survival

```
.model{
  bEfficiency ~ dnorm(0, 5^-2)
```

```
  bEfficiencySampledLength ~ dnorm(0, 5^-2)

  bSurvival ~ dnorm(0, 5^-2)

  sSurvivalYear ~ dnorm(0, 5^-2)
  for(i in 1:nYear) {
    bSurvivalYear[i] ~ dnorm(0, exp(sSurvivalYear)^-2)
  }

  for(i in 1:(nYear-1)) {
    logit(eEfficiency[i]) <- bEfficiency + bEfficiencySampledLength * SampledLength[i
]
    logit(eSurvival[i]) <- bSurvival + bSurvivalYear[i]

    eProbability[i,i] <- eSurvival[i] * eEfficiency[i]
    for(j in (i+1):(nYear-1)) {
      eProbability[i,j] <- prod(eSurvival[i:j]) * prod(1-eEfficiency[i:(j-1)]) * eEff
iciency[j]
    }
    for(j in 1:(i-1)) {
      eProbability[i,j] <- 0
    }
  }
  for(i in 1:(nYear-1)) {
    eProbability[i,nYear] <- 1 - sum(eProbability[i,1:(nYear-1)])
  }

  for(i in 1:(nYear - 1)) {
    Marray[i, 1:nYear] ~ dmulti(eProbability[i,], Released[i])
  }
```

Block 4.

Capture Efficiency

```
.model {

  bEfficiency ~ dnorm(-4, 3^-2)

  sEfficiencySessionAnnual ~ dnorm(0, 2^-2) T(0,)
  for (i in 1:nSession) {
    for (j in 1:nAnnual) {
      bEfficiencySessionAnnual[i, j] ~ dnorm(0, sEfficiencySessionAnnual^-2)
    }
  }

  for (i in 1:length(Recaptures)) {

    logit(eEfficiency[i]) <- bEfficiency + bEfficiencySessionAnnual[Session[i], Annua
l[i]]

    eFidelity[i] ~ dnorm(Fidelity[i], FidelitySD[i]^-2) T(FidelityLower[i], FidelityU
pper[i])
    Recaptures[i] ~ dbin(eEfficiency[i] * eFidelity[i], Tagged[i])
  }
```

Block 5.

Abundance

```
.model {
  bDensity ~ dnorm(5, 5^-2)

  sDensityAnnual ~ dnorm(0, 2^-2)
  for (i in 1:nAnnual) {
    bDensityAnnual[i] ~ dnorm(0, exp(sDensityAnnual)^-2)
  }

  sDensitySite ~ dnorm(0, 2^-2)
  sDensitySiteAnnual ~ dnorm(0, 2^-2)
  for (i in 1:nSite) {
    bDensitySite[i] ~ dnorm(0, exp(sDensitySite)^-2)
    for (j in 1:nAnnual) {
      bDensitySiteAnnual[i, j] ~ dnorm(0, exp(sDensitySiteAnnual)^-2)
    }
  }

  bEfficiencyVisitType[1] <- 0
  bEfficiencyVisitTypeDensity[1] ~ dnorm(0, 2^-2)
  for (i in 2:nVisitType) {
    bEfficiencyVisitType[i] ~ dnorm(0, 2^-2)
    bEfficiencyVisitTypeDensity[i] <- 0
  }

  sDispersion ~ dnorm(0, 2^-2)
  sDispersionVisitType[1] <- 0
  for(i in 2:nVisitType) {
    sDispersionVisitType[i] ~ dnorm(0, 2^-2)
  }

  for (i in 1:length(Fish)) {
    log(eDensity[i]) <- bDensity + bDensitySite[Site[i]] + bDensityAnnual[Annual[i]]
+ bDensitySiteAnnual[Site[i],Annual[i]]

    eAbundance[i] <- eDensity[i] * SiteLength[i]

    logit(eEfficiency[i]) <- logit(Efficiency[i]) + bEfficiencyVisitType[VisitType[i]
] + bEfficiencyVisitTypeDensity[VisitType[i]] * (eDensity[i] - exp(bDensity + sDensit
yAnnual^2/2 + sDensitySite^2/2 + sDensitySiteAnnual^2/2))

    log(esDispersion[i]) <- sDispersion + sDispersionVisitType[VisitType[i]]

    eDispersion[i] ~ dgamma(esDispersion[i]^-2 + 0.1, esDispersion[i]^-2 + 0.1)
    eFish[i] <- eAbundance[i] * ProportionSampled[i] * eEfficiency[i]
    Fish[i] ~ dpois(eFish[i] * eDispersion[i])
  }
```

Block 6.

Fecundity

```
model {
  bFecundity ~ dnorm(3, 2^-2) T(0,)
```

```
  bFecundityWeight ~ dnorm(1, 1^-2) T(0,)

  sFecundity ~ dnorm(0, 1^-2) T(0,)
  for(i in 1:length(Weight)) {
    eFecundity[i] = log(bFecundity) + bFecundityWeight * log(Weight[i])
    Fecundity[i] ~ dlnorm(eFecundity[i], sFecundity^-2)
  }
```

Block 7.

Stock-Recruitment

```
.model {
  bAlpha ~ dnorm(0, 0.005^-2) T(0,)
  bBeta ~ dnorm(0, 0.01^-2) T(0, )
  bEggLoss ~ dnorm(0, 2^-2)

  sRecruits ~ dnorm(0, 1^-2) T(0,)
  for(i in 1:length(Recruits)){
    log(eRecruits[i]) <- log(bAlpha * Eggs[i] / (1 + bBeta * Eggs[i])) + bEggLoss * E
ggLoss[i]
    Recruits[i] ~ dlnorm(log(eRecruits[i]), sRecruits^-2)
  }
```

Block 8.

Age-Ratios

```
.model{
  bProbAge1 ~ dnorm(0, 2^-2)
  bProbAge1Loss ~ dnorm(0, 2^-2)

  sProbAge1 ~ dnorm(0, 2^-2) T(0,)
  for(i in 1:length(Age1Prop)){
    eAge1Prop[i] <- bProbAge1 + bProbAge1Loss * LossLogRatio[i]
    Age1Prop[i] ~ dnorm(eAge1Prop[i], sProbAge1^-2)
  }
```

Block 9.

Results

Tables

Condition

Table 1. Parameter descriptions.

Parameter	Description
`bWeight`	Intercept of `log(eWeight)`
`bWeightDayte`	Effect of `Dayte` on `bWeight`
`bWeightLength`	Intercept of effect of `Length` on `bWeight`
`bWeightLengthDayte`	Effect of `Dayte` on `bWeightLength`
`bWeightLengthYear[i]`	Effect of `i`th `Year` on `bWeightLength`
`bWeightYear[i]`	Effect of `i`th `Year` on `bWeight`

`Dayte[i]`	Standardised day of year `i`th fish was captured
`eWeight[i]`	Expected `Weight` of `i`th fish
`Length[i]`	Log-transformed and centered fork length of `i`th fish
`sWeight`	Log standard deviation of residual variation in `log(Weight)`
`sWeightLengthYear`	Log standard deviation of `bWeightLengthYear`
`sWeightYear`	Log standard deviation of `bWeightYear`
`Weight[i]`	Recorded weight of `i`th fish
`Year[i]`	Year `i`th fish was captured

Mountain Whitefish

Table 2. Model coefficients.

term	estimate	sd	zscore	lower	upper	pvalue
bWeight	5.4584816	0.0094215	579.366814	5.4387979	5.4771345	0.0006662
bWeightDayte	-0.0185924	0.0019068	-9.744552	-0.0222386	-0.0147221	0.0006662
bWeightLength	3.1611315	0.0235436	134.264923	3.1172191	3.2054775	0.0006662
bWeightLengthDayte	-0.0138623	0.0047531	-2.920980	-0.0231713	-0.0044996	0.0073284
sWeight	-1.9101787	0.0059346	-321.823757	-1.9209560	-1.8978873	0.0006662
sWeightLengthYear	-2.2801420	0.1839999	-12.350844	-2.6126335	-1.9027586	0.0006662
sWeightYear	-3.0853356	0.1651631	-18.669259	-3.3972819	-2.7517237	0.0006662

Table 3. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
14721	7	3	500	2	423	1.011	TRUE

Rainbow Trout

Table 4. Model coefficients.

term	estimate	sd	zscore	lower	upper	pvalue
bWeight	6.0085065	0.0058014	1035.72561	5.9974303	6.0207085	0.0006662
bWeightDayte	-0.0043596	0.0012076	-3.61860	-0.0066671	-0.0019982	0.0006662
bWeightLength	2.9227486	0.0119517	244.56392	2.8995689	2.9459682	0.0006662
bWeightLengthDayte	0.0372528	0.0036358	10.26442	0.0305628	0.0447161	0.0006662
sWeight	-2.2731632	0.0058706	-387.23188	-2.2852034	-2.2616154	0.0006662
sWeightLengthYear	-2.9419511	0.1935919	-15.13472	-3.2913492	-2.5260907	0.0006662
sWeightYear	-3.6380073	0.1656295	-21.93262	-3.9363094	-3.2807587	0.0006662

Table 5. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
15429	7	3	500	2	316	1.006	TRUE

Walleye

Table 6. Model coefficients.

term	estimate	sd	zscore	lower	upper	pvalue
bWeight	6.2882829	0.0076693	819.930784	6.2729275	6.3030276	0.0006662

bWeightDayte	0.0156879	0.0013761	11.435309	0.0129814	0.0182437	0.0006662
bWeightLength	3.2315414	0.0184538	175.112707	3.1957776	3.2662059	0.0006662
bWeightLengthDayte	-0.0095241	0.0083553	-1.136963	-0.0265168	0.0065334	0.2445037
sWeight	-2.3745891	0.0072884	-325.794383	-2.3892316	-2.3598153	0.0006662
sWeightLengthYear	-2.5580662	0.1935659	-13.172976	-2.9168206	-2.1664570	0.0006662
sWeightYear	-3.3536993	0.1609045	-20.810332	-3.6449256	-3.0057883	0.0006662

Table 7. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
9548	7	3	500	2	261	1.01	TRUE

Growth

Table 8. Parameter descriptions.

Parameter	Description
`bK`	Intercept of `log(eK)`
`bKYear[i]`	Effect of `i`th `Year` on `bK`
`bLinf`	Mean maximum length
`dYears[i]`	Years between release and recapture of `i`th recapture
`eGrowth`	Expected `Growth` between release and recapture
`eK[i]`	Expected von Bertalanffy growth coefficient from `i-1`th to `i`th year
`Growth[i]`	Observed growth between release and recapture of `i`th recapture
`LengthAtRelease[i]`	Length at previous release of `i`th recapture
`sGrowth`	Log standard deviation of residual variation in `Growth`
`sKYear`	Log standard deviation of `bKYear`
`Year[i]`	Release year of `i`th recapture

Mountain Whitefish

Table 9. Model coefficients.

term	estimate	sd	zscore	lower	upper	pvalue
bK	-0.9298442	0.0983887	-9.482098	-1.132372	-0.7407841	0.0006662
bLinf	393.1783613	3.1119832	126.348086	387.250321	399.2876248	0.0006662
sGrowth	2.4530782	0.0444962	55.135395	2.362481	2.5407411	0.0006662
sKYear	-1.1287979	0.2485045	-4.516800	-1.590515	-0.6117755	0.0006662

Table 10. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
268	4	3	500	20	674	1.005	TRUE

Rainbow Trout

Table 11. Model coefficients.

term	estimate	sd	zscore	lower	upper	pvalue
bK	-0.1666498	0.0776961	-2.194483	-0.3235851	-0.0153518	0.0326449
bLinf	484.7735665	2.6074266	185.891683	479.6234263	489.9486010	0.0006662

sGrowth	3.3847261	0.0204100	165.869086	3.3464664	3.4280472	0.0006662
sKYear	-1.2077437	0.1805386	-6.675126	-1.5481350	-0.8490818	0.0006662

Table 12. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
1249	4	3	500	20	417	1.007	TRUE

Walleye

Table 13. Model coefficients.

term	estimate	sd	zscore	lower	upper	pvalue
bK	-2.414957	0.2319111	-10.472146	-2.902455	-1.9960650	0.0006662
bLinf	718.376747	72.5254532	10.077145	617.178702	898.5808074	0.0006662
sGrowth	2.862012	0.0464237	61.677257	2.775366	2.9558908	0.0006662
sKYear	-1.182396	0.2528809	-4.659215	-1.663723	-0.6895219	0.0006662

Table 14. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
266	4	3	500	40	278	1.013	TRUE

Movement

Table 15. Parameter descriptions.

Parameter	Description
`bFidelity`	Intercept of `logit(eFidelity)`
`bLength`	Effect of length on `logit(eFidelity)`
`eFidelity[i]`	Expected site fidelity of `i`th recapture
`Fidelity[i]`	Whether the `i`th recapture was encountered at the same site as the previous encounter
`Length[i]`	Length at previous encounter of `i`th recapture

Mountain Whitefish

Table 16. Model coefficients.

term	estimate	sd	zscore	lower	upper	pvalue
bFidelity	-0.1505813	0.1898082	-0.8072006	-0.5203856	0.2235875	0.4163891
bLength	-0.1021129	0.1908350	-0.5856587	-0.4840599	0.2404870	0.5562958

Table 17. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
117	2	3	500	1	896	1.002	TRUE

Rainbow Trout

Table 18. Model coefficients.

term	estimate	sd	zscore	lower	upper	pvalue
bFidelity	0.7656021	0.0757955	10.101933	0.6218986	0.9162266	0.0006662

bLength	-0.3136296	0.0753277	-4.177067	-0.4676122	-0.1736919	0.0006662

Table 19. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
784	2	3	500	1	828	1.001	TRUE

Walleye

Table 20. Model coefficients.

term	estimate	sd	zscore	lower	upper	pvalue
bFidelity	0.7106462	0.1443674	4.9440862	0.4312474	0.9927679	0.0006662
bLength	-0.0318958	0.1396369	-0.1945803	-0.2925810	0.2436723	0.8161226

Table 21. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
224	2	3	500	1	879	1.002	TRUE

Length-At-Age

Mountain Whitefish

Table 22. The estimated upper length cutoffs (mm) by age and year.

Year	Age0	Age1	Age2
1990	167	274	NA
1991	144	226	296
2001	141	258	344
2002	163	260	344
2003	159	263	354
2004	158	249	342
2005	168	263	363
2006	175	284	357
2007	171	280	337
2008	170	247	340
2009	169	265	355
2010	177	272	352
2011	163	269	348
2012	162	268	347
2013	185	282	349
2014	178	284	362
2015	167	278	366
2016	164	283	352
2017	158	270	354
2018	177	262	346
2019	188	282	363

Rainbow Trout

Table 23. The estimated upper length cutoffs (mm) by age and year.

Year	Age0	Age1
1990	155	354
1991	127	343
2001	134	325
2002	155	350
2003	162	343
2004	143	333
2005	164	347
2006	171	365
2007	166	375
2008	146	340
2009	148	339
2010	147	337
2011	156	344
2012	152	345
2013	170	355
2014	155	338
2015	167	335
2016	155	338
2017	133	318
2018	144	314
2019	161	315

Survival

Table 24. Parameter descriptions.

Parameter	Description
`bEfficiency`	Intercept for `logit(eEfficiency)`
`bEfficiencySampledLength`	Effect of `SampledLength` on `bEfficiency`
`bSurvival`	Intercept for `logit(eSurvival)`
`bSurvivalYear[i]`	Effect of `Year` on `bSurvival`
`eEfficiency[i]`	Expected recapture probability in `i`th year
`eSurvival[i]`	Expected survival probability from `i-1`th to `i`th year
`SampledLength`	Total standardised length of river sampled
`sSurvivalYear`	Log SD of `bSurvivalYear`

Mountain Whitefish

Table 25. Model coefficients.

term	estimate	sd	zscore	lower	upper	pvalue
bEfficiency	-4.2237551	0.1032607	-40.9338843	-4.4320404	-4.0279198	0.0006662
bEfficiencySampledLength	0.4224959	0.1194200	3.5553034	0.1998537	0.6744037	0.0006662
bSurvival	0.8724257	0.4007615	2.2893582	0.2165853	1.8150606	0.0166556

sSurvivalYear	0.2372481	0.3294372	0.7118431	-0.3851908	0.8923736	0.4670220

Table 26. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
18	4	3	500	200	1203	1.005	TRUE

Rainbow Trout

Table 27. Model coefficients.

term	estimate	sd	zscore	lower	upper	pvalue
bEfficiency	-2.5151801	0.0862713	-29.1732858	-2.6862156	-2.3517941	0.0006662
bEfficiencySampledLength	0.0012740	0.0684467	0.0435731	-0.1268280	0.1428251	0.9800133
bSurvival	-0.4420696	0.1012484	-4.3544759	-0.6416376	-0.2450412	0.0019987
sSurvivalYear	-1.3687378	1.7519223	-1.0749647	-7.8119228	-0.6681411	0.0006662

Table 28. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
18	4	3	500	200	222	1.054	FALSE

Walleye

Table 29. Model coefficients.

term	estimate	sd	zscore	lower	upper	pvalue
bEfficiency	-3.4178812	0.1051365	-32.5107849	-3.6226693	-3.2070081	0.0006662
bEfficiencySampledLength	0.1113331	0.0867545	1.3034582	-0.0548939	0.2926155	0.1805463
bSurvival	0.0618898	0.1573432	0.4172927	-0.2246040	0.4206770	0.6682212
sSurvivalYear	-0.7961020	1.4733787	-0.7662400	-6.1666284	-0.1207164	0.0166556

Table 30. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
18	4	3	500	200	460	1.012	TRUE

Capture Efficiency

Table 31. Parameter descriptions.

Parameter	Description
`Annual[i]`	Year of `i`th visit
`bEfficiency`	Intercept for `logit(eEfficiency)`
`bEfficiencySessionAnnual`	Effect of `Session` within `Annual` on `logit(eEfficiency)`
`eEfficiency[i]`	Expected efficiency on `i`th visit
`eFidelity[i]`	Expected site fidelity on `i`th visit
`Fidelity[i]`	Mean site fidelity on `i`th visit
`FidelitySD[i]`	SD of site fidelity on `i`th visit
`Recaptures[i]`	Number of marked fish recaught during `i`th visit
`sEfficiencySessionAnnual`	SD of `bEfficiencySessionAnnual`
`Session[i]`	Session of `i`th visit

`Tagged[i]`	Number of marked fish tagged prior to `i`th visit

Mountain Whitefish

Subadult

Table 32. Model coefficients.

term	estimate	sd	zscore	lower	upper	pvalue
bEfficiency	-4.4022543	0.2413323	-18.344741	-4.9645823	-4.039661	0.0006662
sEfficiencySessionAnnual	0.5982391	0.3350114	1.809473	0.0460121	1.299151	0.0006662

Table 33. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
1413	2	3	500	100	410	1.007	TRUE

Adult

Table 34. Model coefficients.

term	estimate	sd	zscore	lower	upper	pvalue
bEfficiency	-4.5153162	0.1541342	-29.348675	-4.8524690	-4.2469832	0.0006662
sEfficiencySessionAnnual	0.2252906	0.1842918	1.424164	0.0188266	0.6606298	0.0006662

Table 35. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
1612	2	3	500	100	333	1.013	TRUE

Rainbow Trout

Subadult

Table 36. Model coefficients.

term	estimate	sd	zscore	lower	upper	pvalue
bEfficiency	-3.0168593	0.0668081	-45.161350	-3.1535824	-2.8892848	0.0006662
sEfficiencySessionAnnual	0.4070429	0.0663440	6.179898	0.2893543	0.5473549	0.0006662

Table 37. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
1625	2	3	500	100	1185	1.004	TRUE

Adult

Table 38. Model coefficients.

term	estimate	sd	zscore	lower	upper	pvalue
bEfficiency	-3.5082606	0.0701509	-50.038311	-3.6431650	-3.3776106	0.0006662
sEfficiencySessionAnnual	0.2080676	0.1074069	1.927936	0.0175895	0.4145411	0.0006662

Table 39. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
1702	2	3	500	100	489	1.003	TRUE

Walleye

Table 40. Model coefficients.

term	estimate	sd	zscore	lower	upper	pvalue
bEfficiency	-4.0344124	0.1248467	-32.383370	-4.3097577	-3.8228995	0.0006662
sEfficiencySessionAnnual	0.5891211	0.1236341	4.837124	0.3705731	0.8662024	0.0006662

Table 41. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
1743	2	3	500	100	1071	1.003	TRUE

Abundance

Table 42. Parameter descriptions.

Parameter	Description
`Annual`	Year
`bDensity`	Intercept for `log(eDensity)`
`bDensityAnnual`	Effect of `Annual` on `bDensity`
`bDensitySite`	Effect of `Site` on `bDensity`
`bDensitySiteAnnual`	Effect of `Site` within `Annual` on `bDensity`
`bEfficiencyVisitType`	Effect of `VisitType` on `Efficiency`
`eDensity`	Expected density
`Efficiency`	Capture efficiency
`esDispersion`	Overdispersion of `Fish`
`Fish`	Number of fish captured or counted
`ProportionSampled`	Proportion of site surveyed
`sDensityAnnual`	Log SD of effect of `Annual` on `bDensity`
`sDensitySite`	Log SD of effect of `Site` on `bDensity`
`sDensitySiteAnnual`	Log SD of effect of `Site` within `Annual` on `bDensity`
`sDispersion`	Intercept for `log(esDispersion)`
`sDispersionVisitType`	Effect of `VisitType` on `sDispersion`
`Site`	Site
`SiteLength`	Length of site
`VisitType`	Survey type (catch versus count)

Mountain Whitefish

Subadult

Table 43. Model coefficients.

term	estimate	sd	zscore	lower	upper	pvalue
bDensity	4.8250928	0.1937149	24.885167	4.4307029	5.2057983	0.0006662
bEfficiencyVisitType[2]	1.4612101	0.0785260	18.615478	1.3058105	1.6172014	0.0006662

bEfficiencyVisitTypeDensity[1]	0.0001765	0.0001485	1.315720	-0.0000296	0.0005308	0.1232512
sDensityAnnual	-0.4057605	0.1735332	-2.317653	-0.7227642	-0.0428791	0.0326449
sDensitySite	-0.2867744	0.1117254	-2.562494	-0.5115147	-0.0609439	0.0113258
sDensitySiteAnnual	-0.8900578	0.0757100	-11.752949	-1.0360406	-0.7430948	0.0006662
sDispersion	-0.7788726	0.0448675	-17.371421	-0.8692974	-0.6947752	0.0006662
sDispersionVisitType[2]	0.6491613	0.0891304	7.290551	0.4831272	0.8275177	0.0006662

Table 44. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
2704	8	3	500	200	252	1.017	TRUE

Adult

Table 45. Model coefficients.

term	estimate	sd	zscore	lower	upper	pvalue
bDensity	5.6007061	0.1564133	35.844583	5.3235471	5.9199423	0.0006662
bEfficiencyVisitType[2]	1.7001739	0.0995298	17.064698	1.5164148	1.8833874	0.0006662
bEfficiencyVisitTypeDensity[1]	-0.0001509	0.0001035	-1.225928	-0.0002532	0.0001469	0.2258494
sDensityAnnual	-1.0122364	0.1943617	-5.165514	-1.3622657	-0.6100152	0.0006662
sDensitySite	0.1770787	0.1106092	1.613592	-0.0306820	0.3985325	0.1019320
sDensitySiteAnnual	-0.8438217	0.0779400	-10.855958	-1.0063246	-0.6999064	0.0006662
sDispersion	-0.6552920	0.0348905	-18.819257	-0.7246031	-0.5882711	0.0006662
sDispersionVisitType[2]	0.5506052	0.0805087	6.820394	0.3979994	0.7066297	0.0006662

Table 46. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
2704	8	3	500	200	256	1.023	TRUE

Rainbow Trout

Subadult

Table 47. Model coefficients.

term	estimate	sd	zscore	lower	upper	pvalue
bDensity	4.3783250	0.1180030	37.133197	4.1610379	4.6188809	0.0006662
bEfficiencyVisitType[2]	1.5663479	0.1035810	15.170383	1.3873077	1.7959842	0.0006662
bEfficiencyVisitTypeDensity[1]	-0.0013277	0.0002183	-6.051549	-0.0017443	-0.0008577	0.0006662
sDensityAnnual	-0.9906399	0.1831421	-5.393067	-1.3255722	-0.6197375	0.0006662
sDensitySite	-0.2228498	0.1026771	-2.119471	-0.4092154	-0.0041303	0.0473018
sDensitySiteAnnual	-0.7582063	0.0563818	-13.463099	-0.8753757	-0.6504735	0.0006662
sDispersion	-0.9739051	0.0396207	-24.542522	-1.0487763	-0.8941963	0.0006662
sDispersionVisitType[2]	0.6570725	0.0913966	7.186126	0.4740584	0.8292727	0.0006662

Table 48. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
2704	8	3	500	200	384	1.007	TRUE

Adult

Table 49. Model coefficients.

term	estimate	sd	zscore	lower	upper	pvalue
bDensity	4.8539666	0.1172235	41.405608	4.6238847	5.0721034	0.0006662
bEfficiencyVisitType[2]	1.5366310	0.1314562	11.781443	1.3329478	1.8509682	0.0006662
bEfficiencyVisitTypeDensity[1]	-0.0008686	0.0002036	-4.271955	-0.0012648	-0.0004509	0.0006662
sDensityAnnual	-0.9887749	0.1874731	-5.253355	-1.3306738	-0.6069727	0.0006662
sDensitySite	-0.2516487	0.1094050	-2.282908	-0.4530507	-0.0308308	0.0273151
sDensitySiteAnnual	-1.1545947	0.0706026	-16.349141	-1.2911872	-1.0156479	0.0006662
sDispersion	-1.0107240	0.0418675	-24.136459	-1.0942149	-0.9313889	0.0006662
sDispersionVisitType[2]	0.5921317	0.0870660	6.771774	0.4134781	0.7617791	0.0006662

Table 50. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
2704	8	3	500	200	368	1.011	TRUE

Walleye

Table 51. Model coefficients.

term	estimate	sd	zscore	lower	upper	pvalue
bDensity	4.6427856	0.1357874	34.241262	4.4029326	4.9567215	0.0006662
bEfficiencyVisitType[2]	1.3698666	0.1596632	8.574899	1.0427096	1.6790653	0.0006662
bEfficiencyVisitTypeDensity[1]	-0.0008384	0.0003696	-2.114710	-0.0013895	0.0000287	0.0686209
sDensityAnnual	-0.7418542	0.1908977	-3.863853	-1.0904848	-0.3514978	0.0006662
sDensitySite	-0.9998078	0.1420442	-7.016725	-1.2743769	-0.7181159	0.0006662
sDensitySiteAnnual	-1.1852576	0.1018339	-11.690375	-1.3982607	-0.9998099	0.0006662
sDispersion	-0.8226840	0.0393352	-20.926137	-0.9070715	-0.7499663	0.0006662
sDispersionVisitType[2]	0.4977312	0.0937107	5.277692	0.3061947	0.6692273	0.0006662

Table 52. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
2704	8	3	500	200	375	1.007	TRUE

Fecundity

Table 53. Parameter descriptions.

Parameter	Description
`bFecundity`	Intercept of `eFecundity`
`bFecundityWeight`	Effect of `log(Weight)` on `log(bFecundity)`
`eFecundity[i]`	Expected `Fecundity` of `i`th fish
`Fecundity[i]`	Fecundity of `i`th fish (eggs)
`sFecundity`	SD of residual variation in `log(Fecundity)`
`Weight[i]`	Weight of `i`th fish (g)

Mountain Whitefish

Table 54. Model coefficients.

term	estimate	sd	zscore	lower	upper	pvalue
bFecundity	6.558029	1.4966173	4.407335	3.7847514	9.616090	0.0006662
bFecundityWeight	1.156593	0.0369055	31.419608	1.0975742	1.237526	0.0006662
sFecundity	0.146218	0.0218205	6.801552	0.1136218	0.198902	0.0006662

Table 55. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
28	3	3	500	100	588	1.006	TRUE

Stock-Recruitment

Table 56. Parameter descriptions.

Parameter	Description
`bAlpha`	`eRecruits` per `Stock` at low `Stock` density
`bBeta`	Expected density-dependence
`bEggLoss`	Effect of `EggLoss` on `log(eRecruits)`
`EggLoss`	Proportional egg loss
`Eggs`	Total egg deposition
`eRecruits`	Expected `Recruits`
`Recruits`	Number of Age-1 recruits
`sRecruits`	SD of residual variation in `log(Recruits)`

Mountain Whitefish

Table 57. Model coefficients.

term	estimate	sd	zscore	lower	upper	pvalue
bAlpha	0.0059749	0.0032116	2.0001089	0.0013778	0.0136410	0.0006662
bBeta	0.0000003	0.0000002	1.6901171	0.0000001	0.0000008	0.0006662
bEggLoss	-0.3242001	0.9965688	-0.3571425	-2.3249369	1.6119259	0.7308461
sRecruits	0.5818882	0.1159473	5.1830190	0.4240657	0.8582623	0.0006662

Table 58. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
17	4	3	500	50	1023	1.002	TRUE

Rainbow Trout

Table 59. Model coefficients.

term	estimate	sd	zscore	lower	upper	pvalue
bAlpha	0.0070972	0.0030335	2.4562684	0.0026559	0.0141167	0.0006662
bBeta	0.0000004	0.0000002	2.1425926	0.0000001	0.0000009	0.0006662
bEggLoss	0.2467779	1.9536395	0.1292155	-3.6289225	3.9698910	0.9120586
sRecruits	0.3713011	0.0714415	5.3346980	0.2700265	0.5449033	0.0006662

Table 60. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
18	4	3	500	50	886	1.002	TRUE

Age-Ratios

Table 61. Parameter descriptions.

Parameter	Description
`Age1[i]`	The number of Age-1 fish in the `i`th year
`Age1and2[i]`	The number of Age-1 and Age-2 fish in the `i`th year
`bProbAge1`	Intercept for `logit(eProbAge1)`
`bProbAge1Loss`	Effect of `LossLogRatio` on `bProbAge1`
`eProbAge1[i]`	The expected proportion of Age-1 fish in the `i`th year
`LossLogRatio[i]`	The `log` of the ratio of the percent egg losses
`sDispersion`	SD of extra-binomial variation

Table 62. Model coefficients.

term	estimate	sd	zscore	lower	upper	pvalue
bProbAge1	0.1885840	0.1870391	1.0215322	-0.1741812	0.5620935	0.2938041
bProbAge1Loss	-0.1704875	0.2590813	-0.6565344	-0.6844687	0.3123391	0.5096602
sProbAge1	0.8113812	0.1529181	5.4497438	0.6037947	1.1959987	0.0006662

Table 63. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
19	3	3	500	1	663	1.003	TRUE

Appendix D – Discharge and Temperature Data

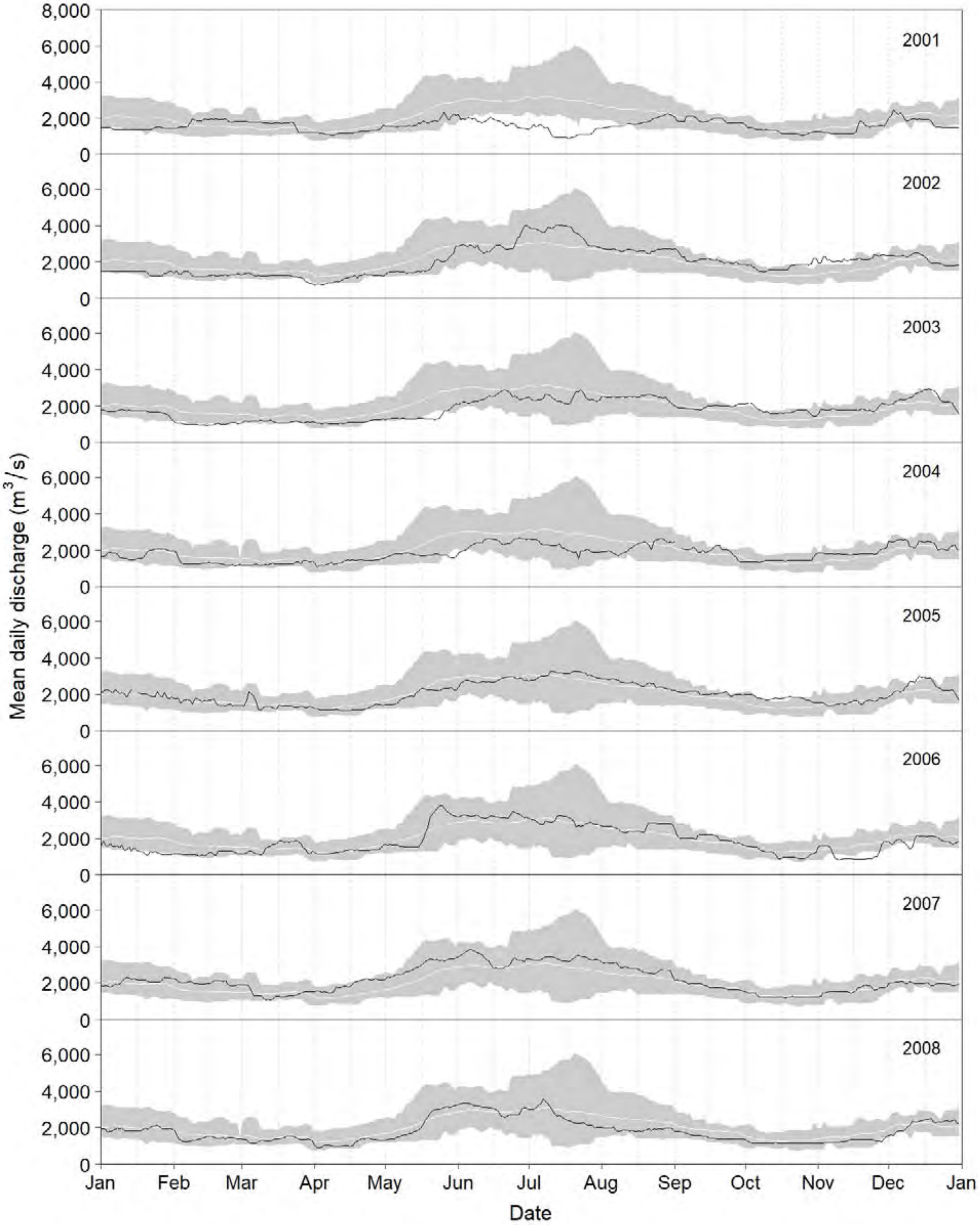

Figure D1. Mean daily discharge (m^3/s) for the Columbia River at the Birchbank water gauging station (black line), 2001 to 2019. The shaded area represents minimum and maximum mean daily discharge recorded at Birchbank during other study years between 2001 and 2019. The white line represents average mean daily discharge over the same time period.

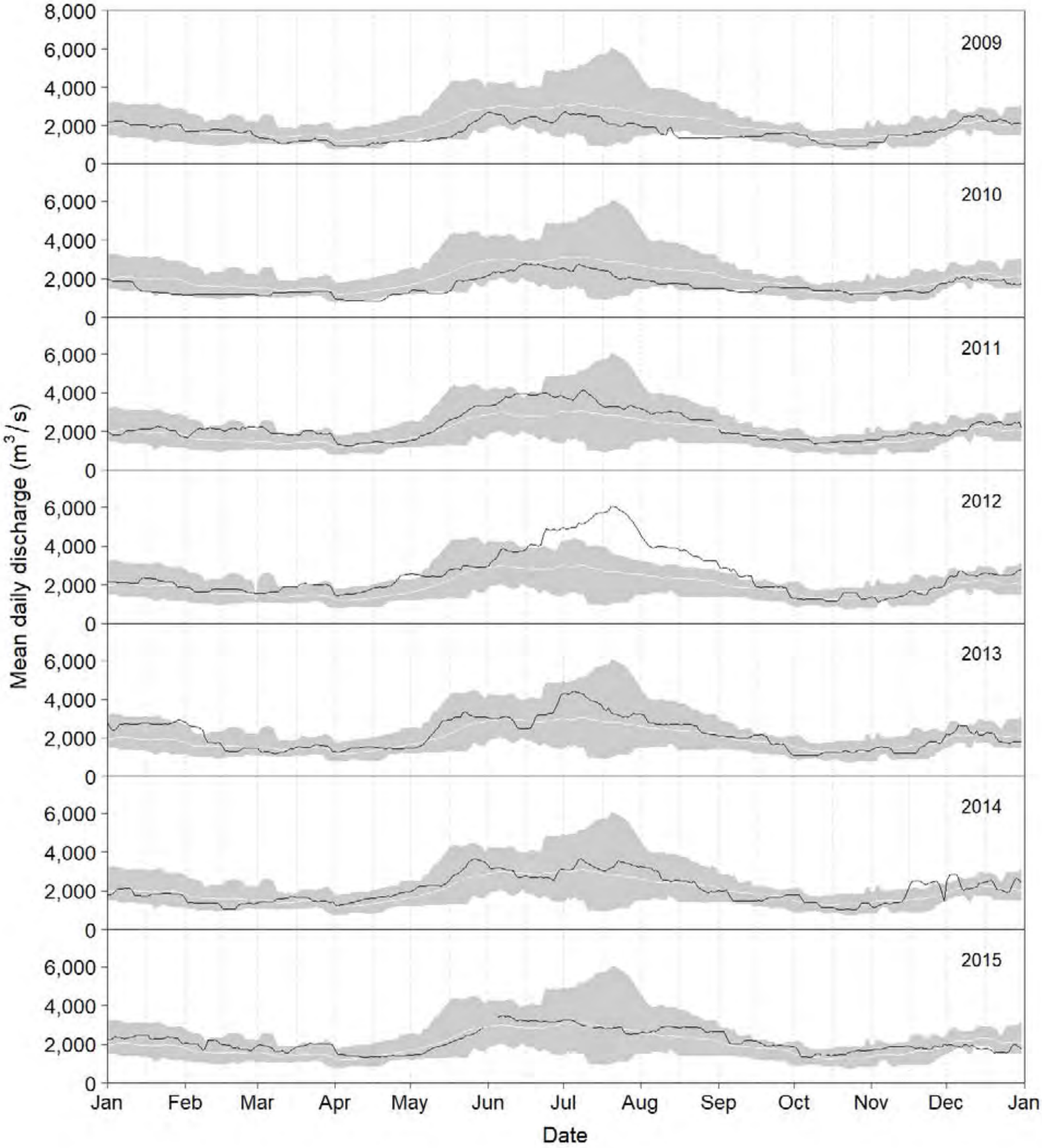

Figure D1. Continued.

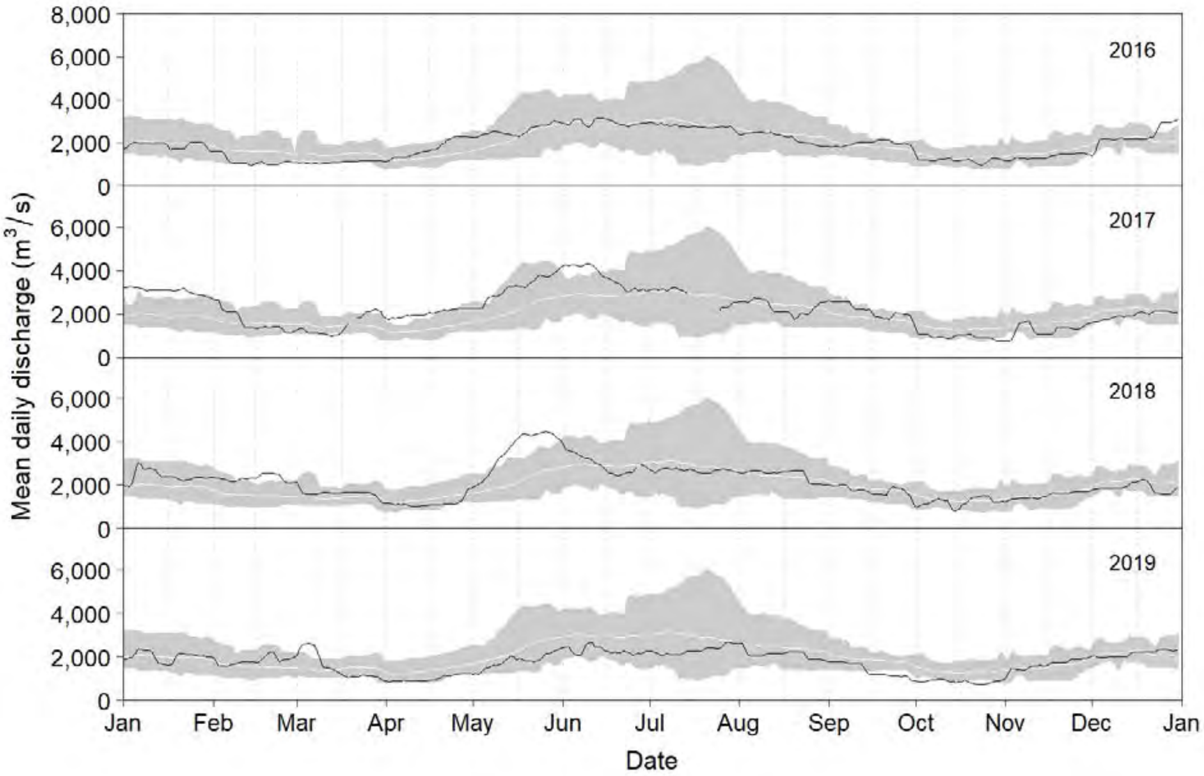

Figure D1. Concluded.

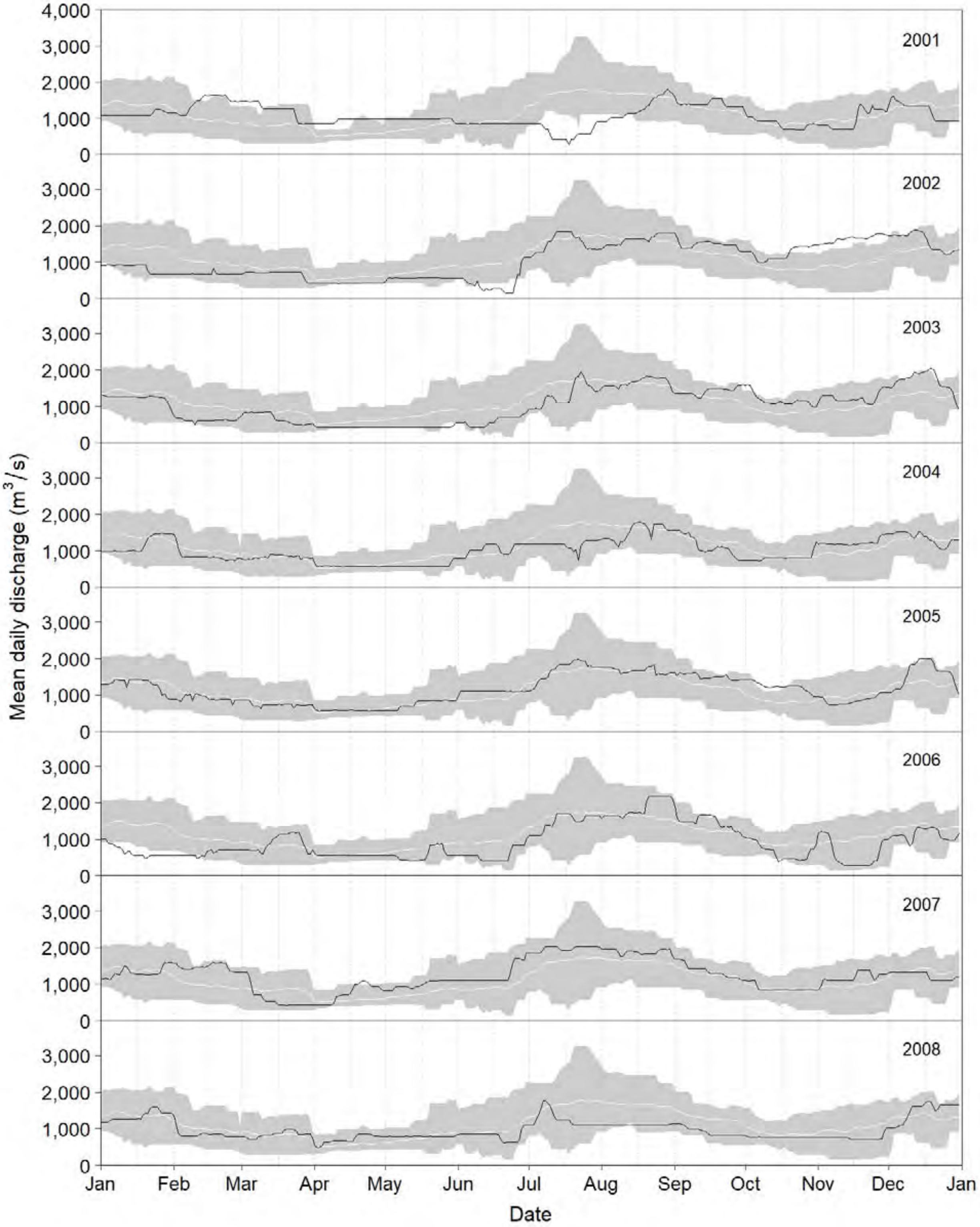

Figure D2. Mean daily discharge (m³/s) for the Columbia River at Hugh L. Keenleyside Dam (HLK), 2001 to 2019 (black line). The shaded area represents minimum and maximum mean daily discharge recorded at HLK during other study years between 2001 and 2019. The white line represents average mean daily discharge over the same time period.

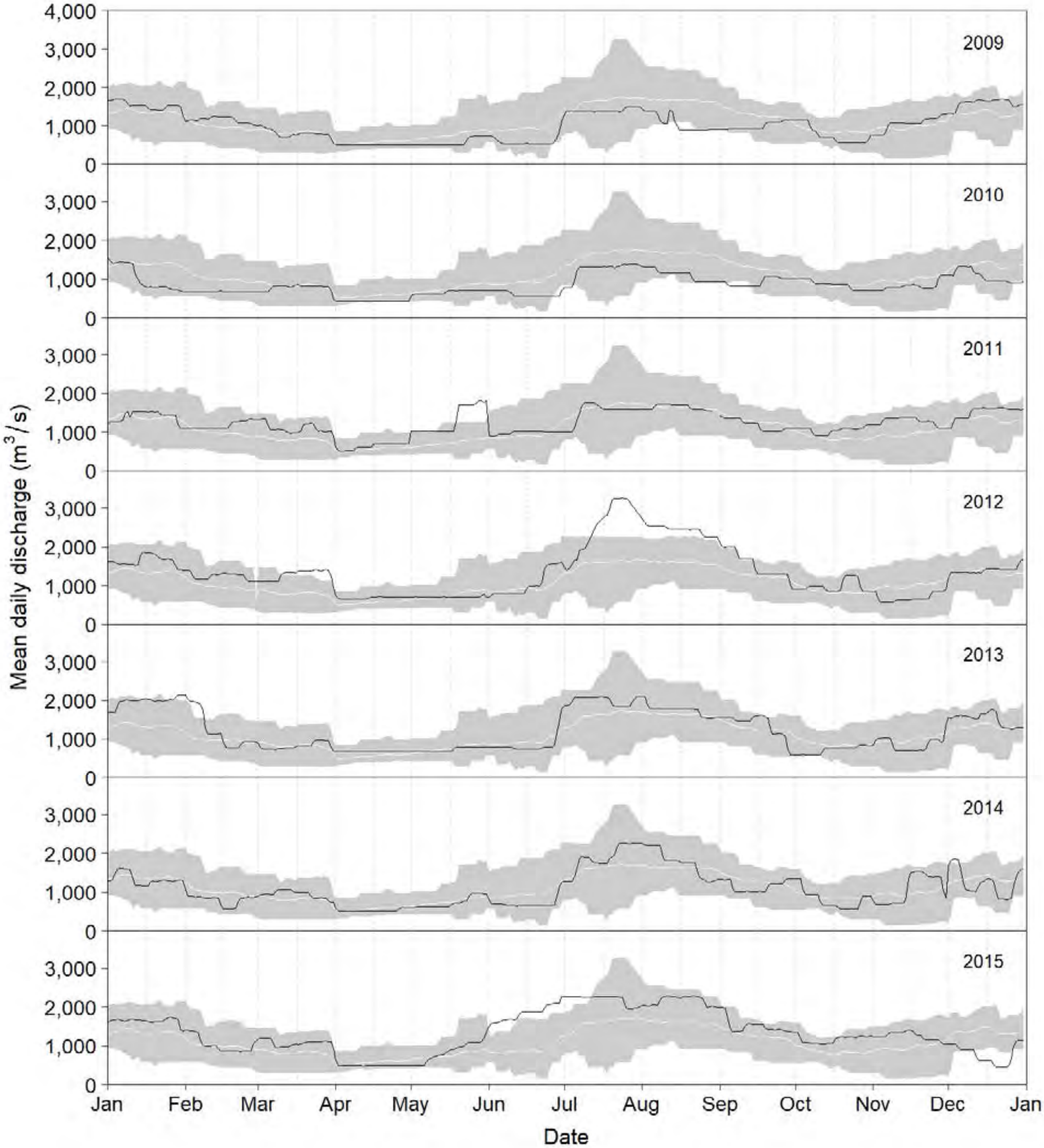

Figure D2. Continued.

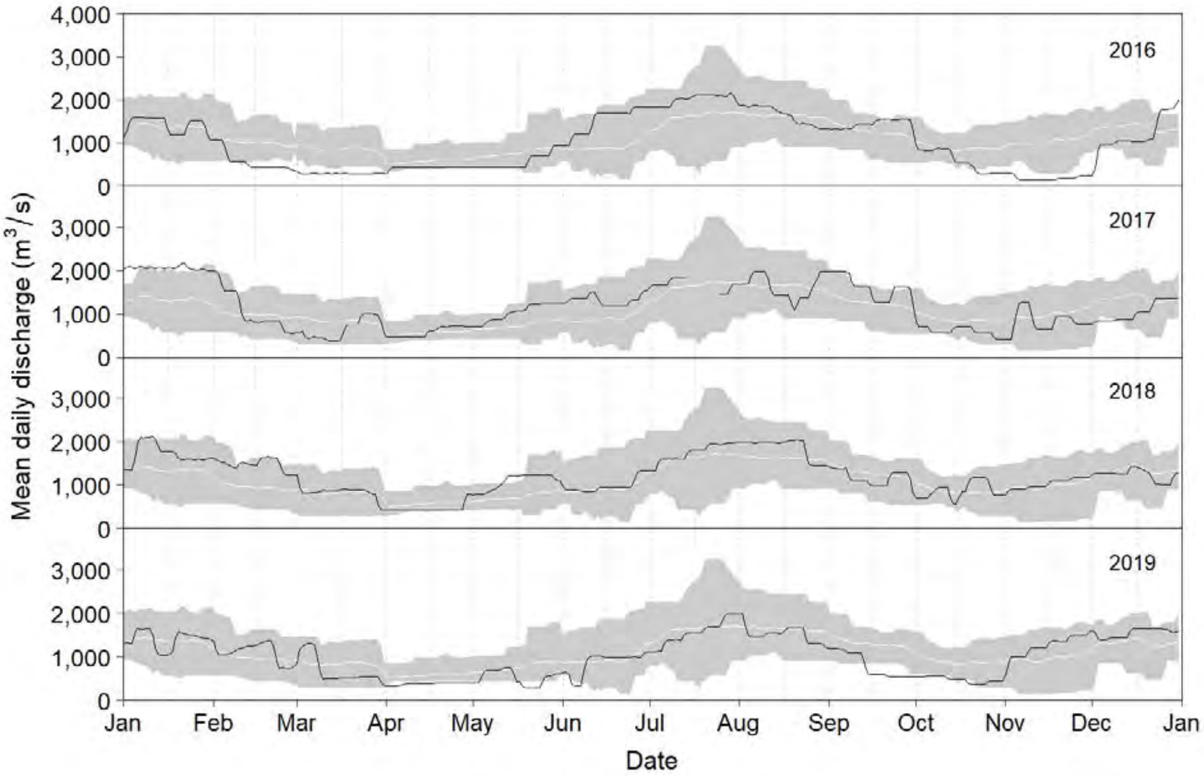

Figure D2. Concluded.

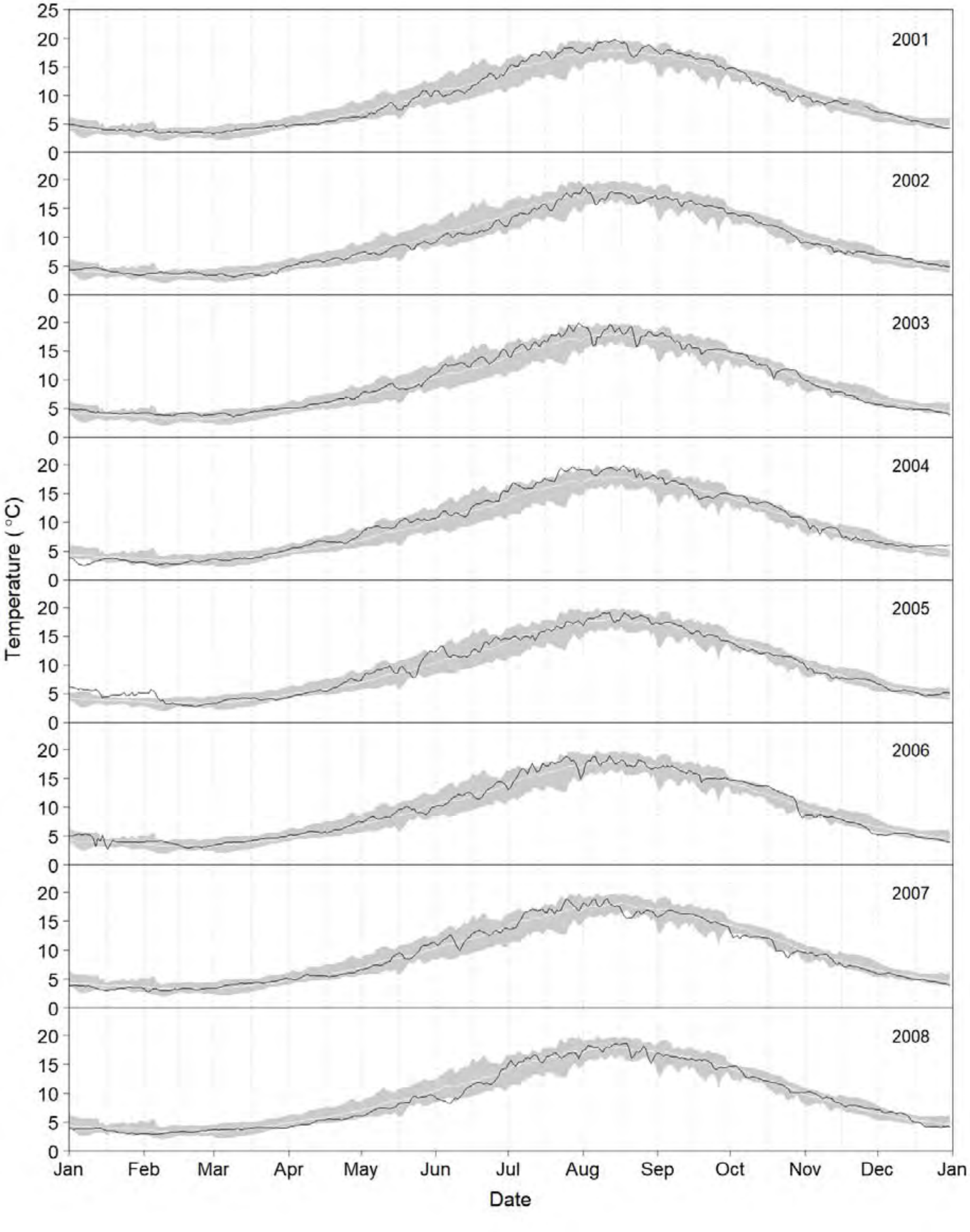

Figure D3. Mean daily water temperatures (°C) for the Columbia River (black line), 2001 to 2019. Data from all years except 2012 and March-April 2017 were recorded at the Birchbank water gauging station. Data from 2012 were recorded near Fort Shepherd. Data from March to November 2017 were recorded at Kinnaird Eddy. The shaded area represents minimum and maximum mean daily water temperatures during other study years between 2001 and 2019. The white line represents average mean daily water temperature over the same time period.

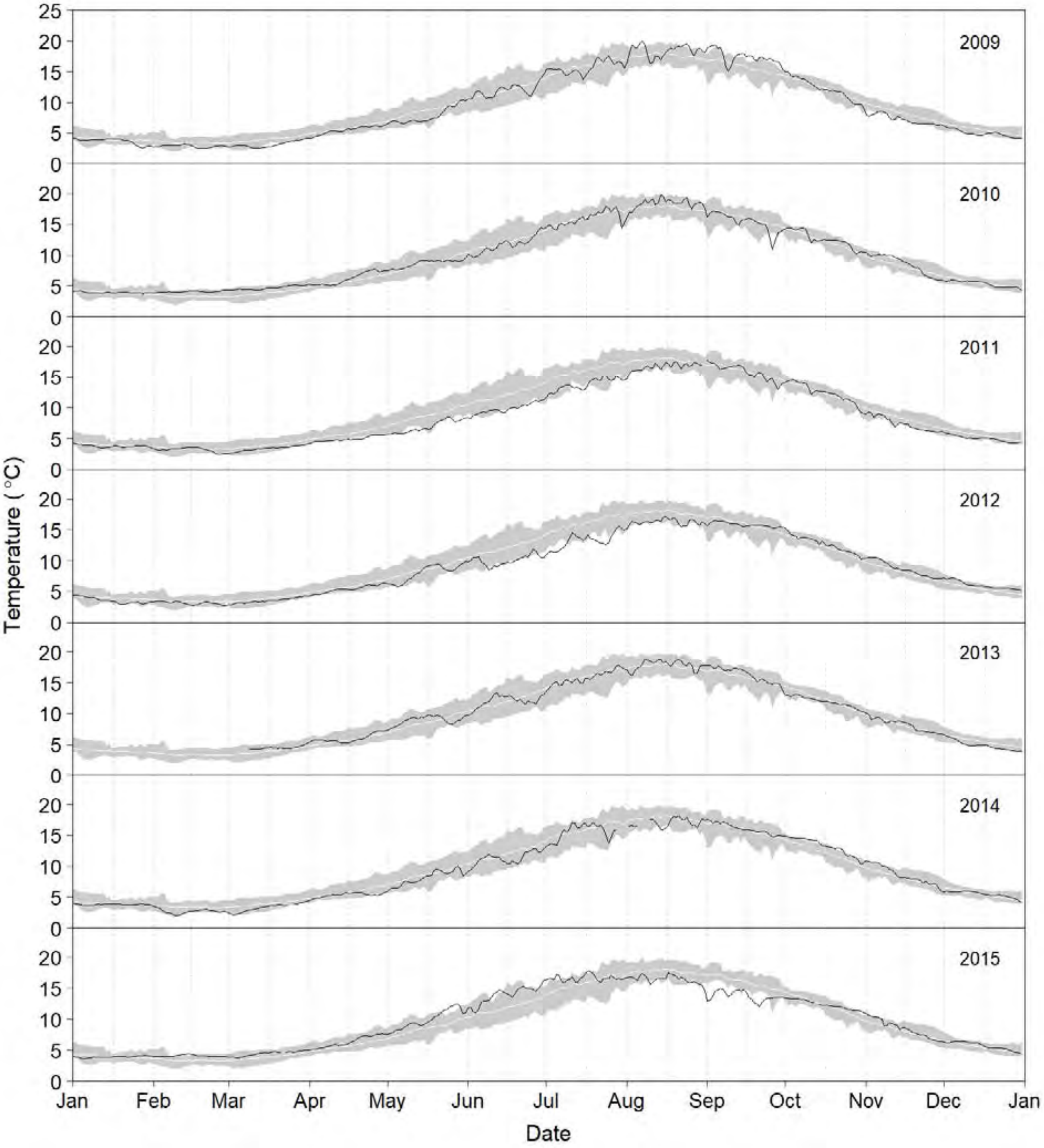

Figure D3. Continued.

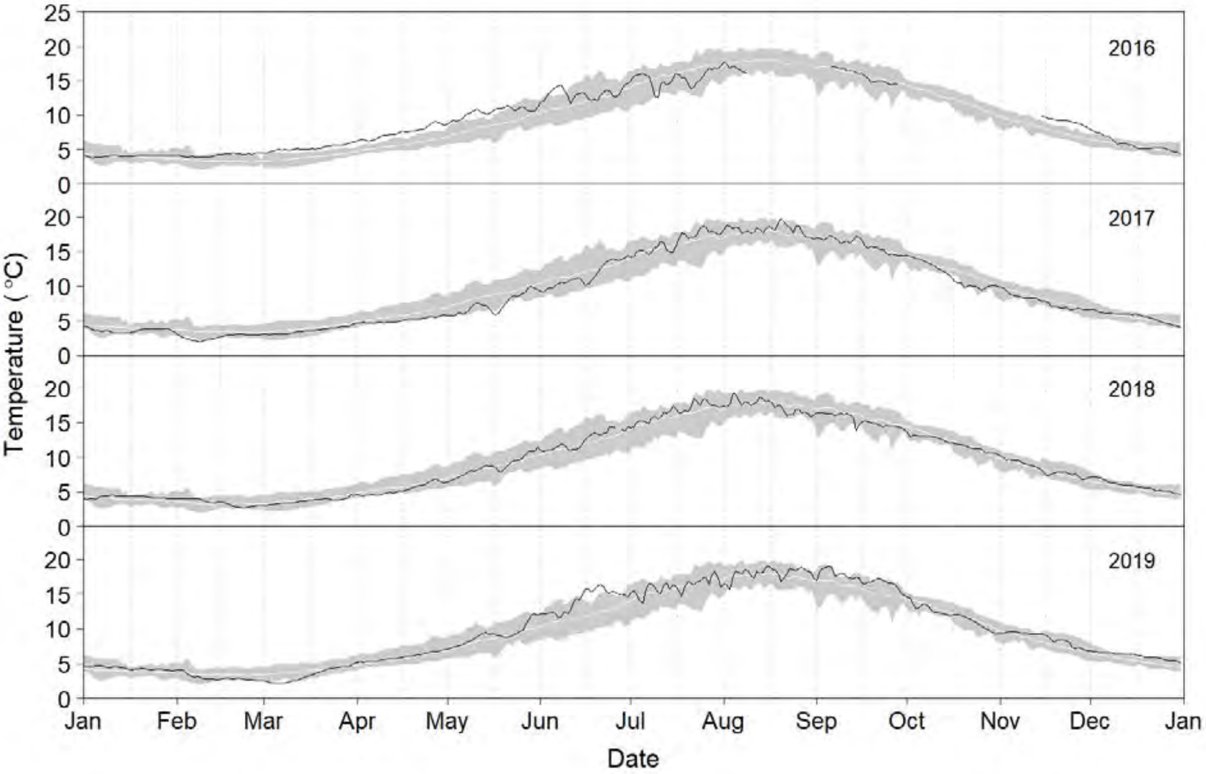

Figure D3. Concluded.

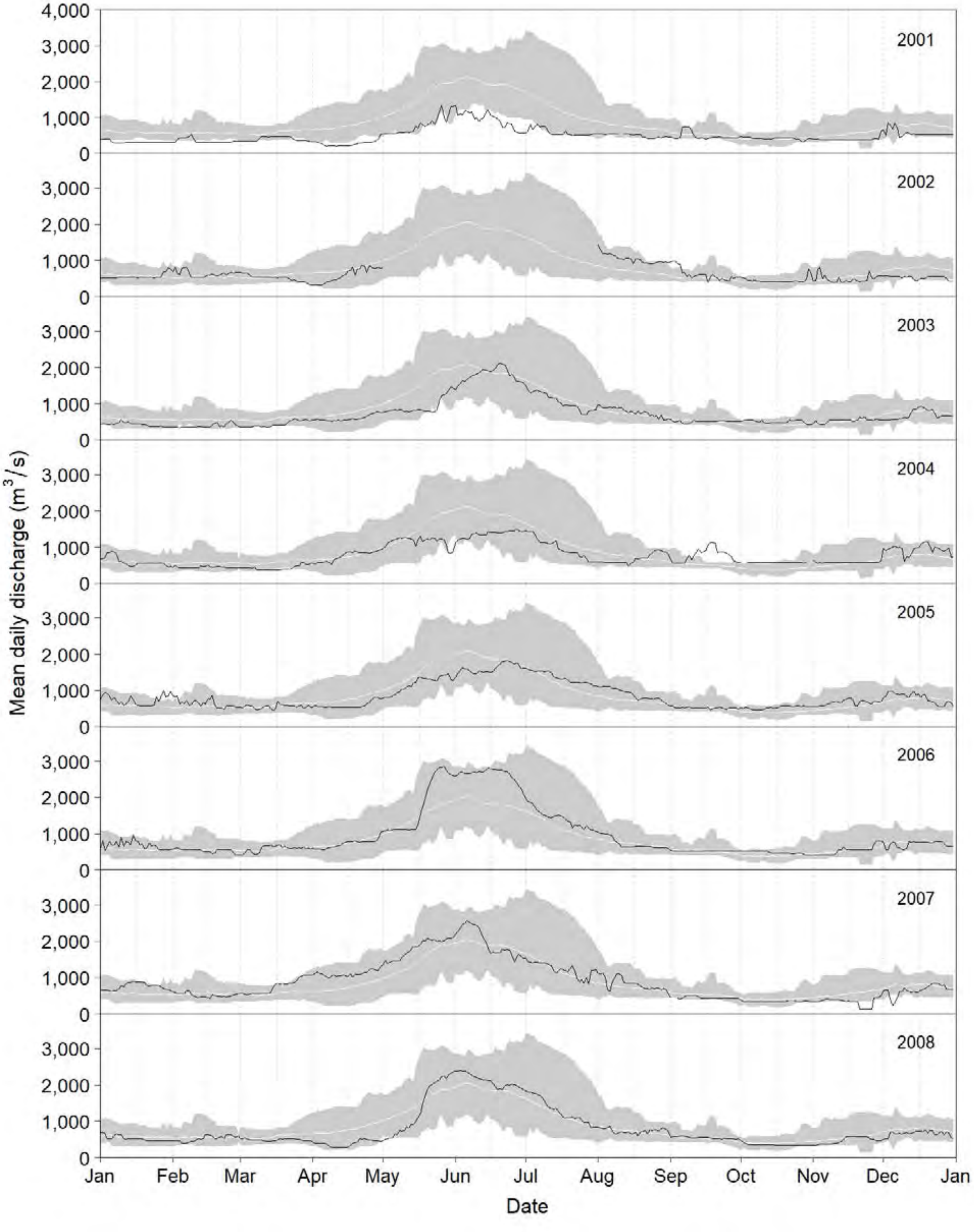

Figure D4. Mean daily discharge (m³/s) for the Kootenay River at Brilliant Dam (BRD), 2001 to 2019 (black line). The shaded area represents minimum and maximum mean daily discharge recorded at BRD during other study years between 2001 and 2019. The white line represents average mean daily discharge over the same time period.

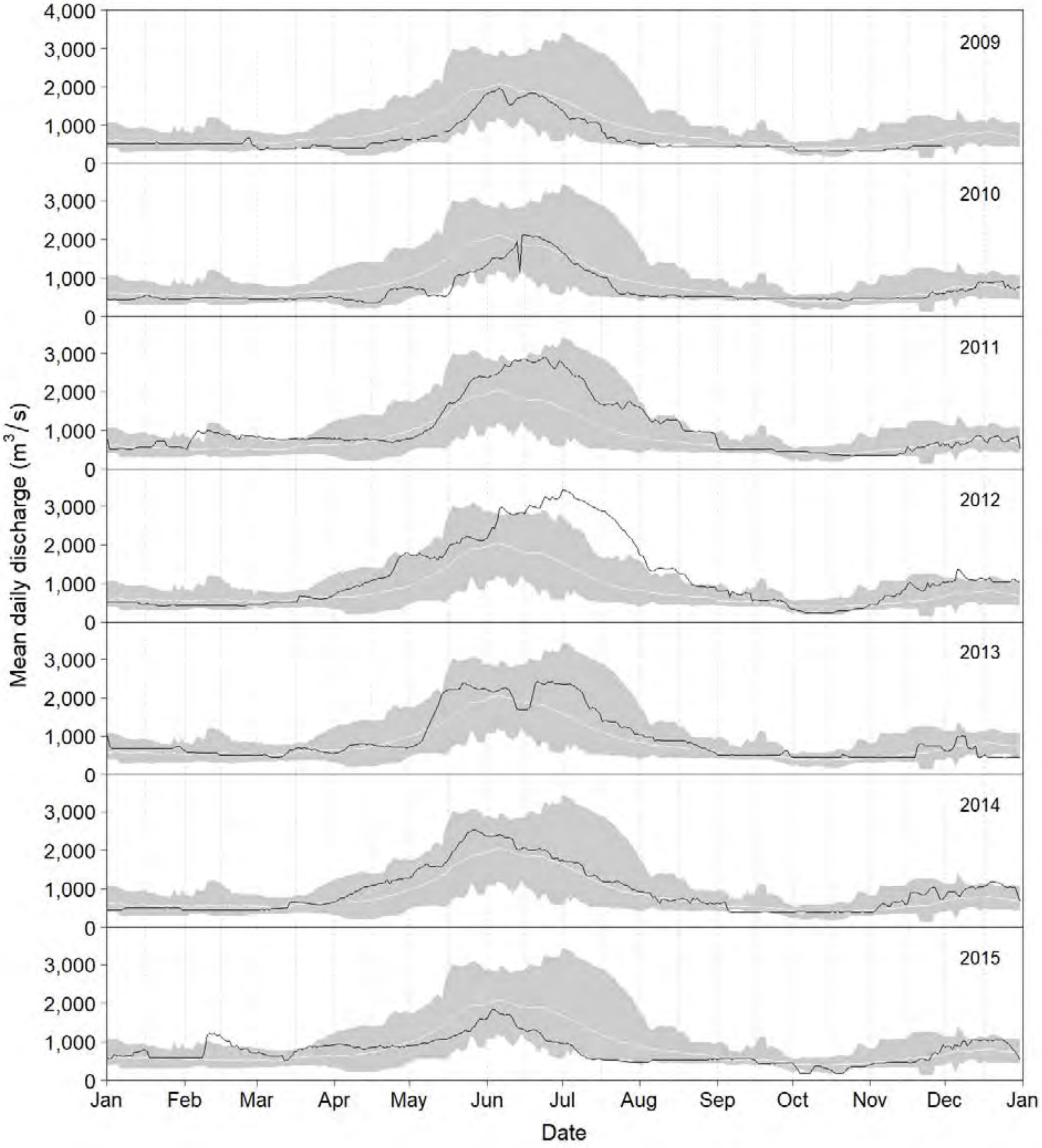

Figure D4. Continued.

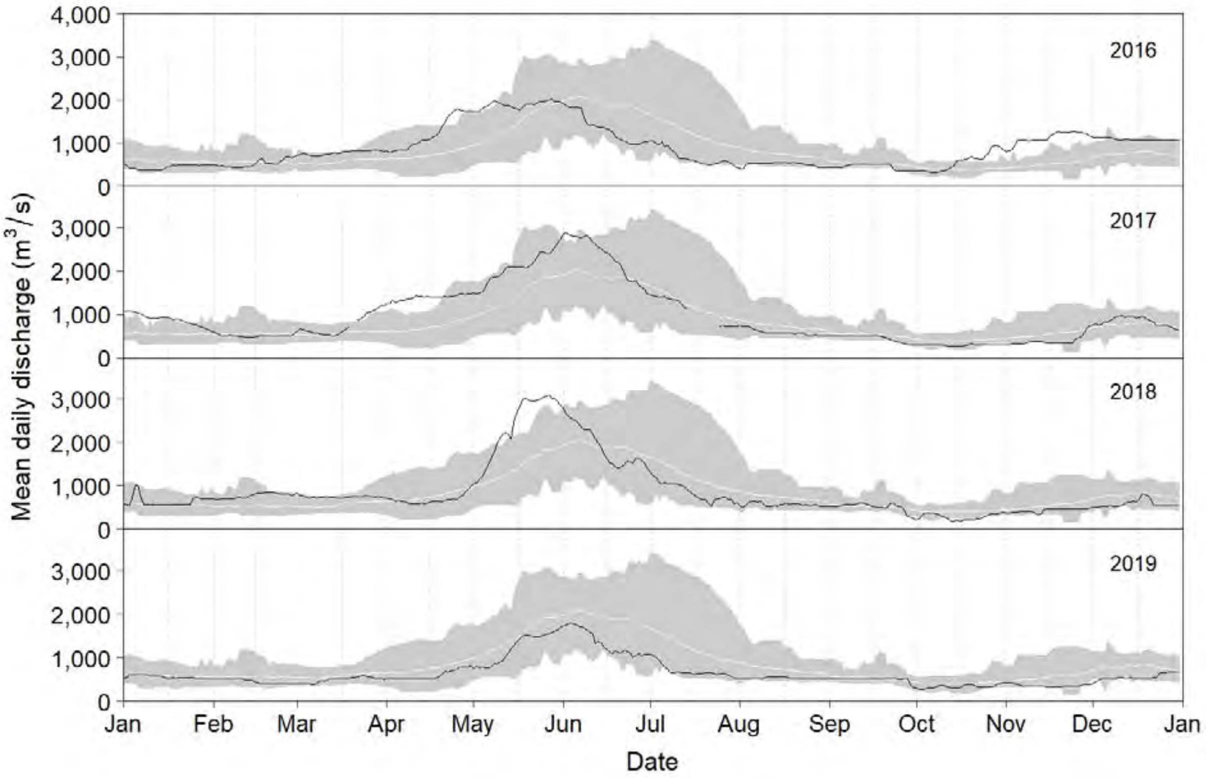

Figure D4. Concluded.

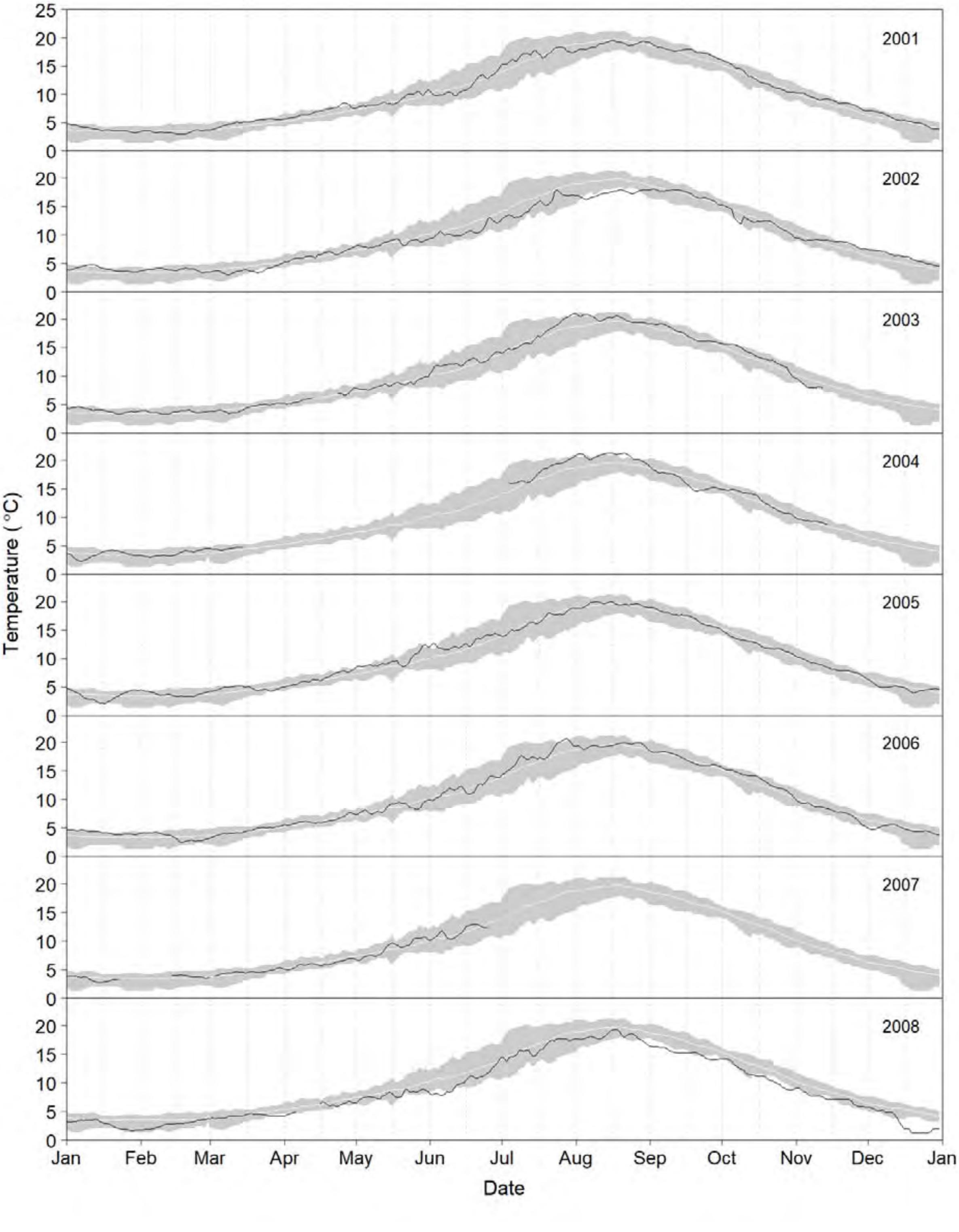

Figure D5. Mean daily water temperatures (°C) for the Kootenay River at Brilliant Dam (BRD), 2001 to 2019 (black line). The shaded area represents minimum and maximum mean daily water temperatures recorded at BRD during other study years between 2001 and 2019. The white line represents average mean daily water temperature over the same time period.

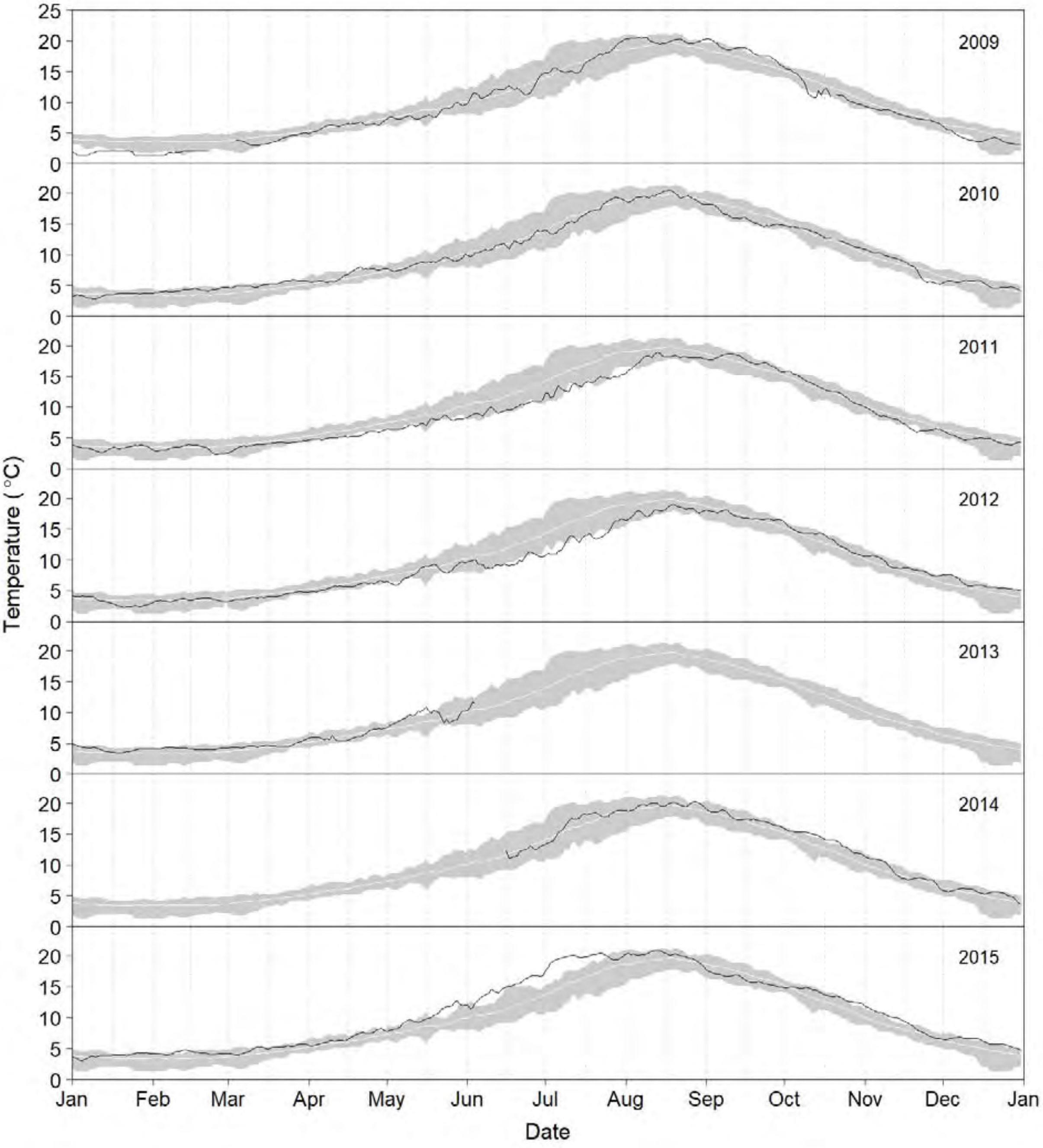

Figure D5. Continued.

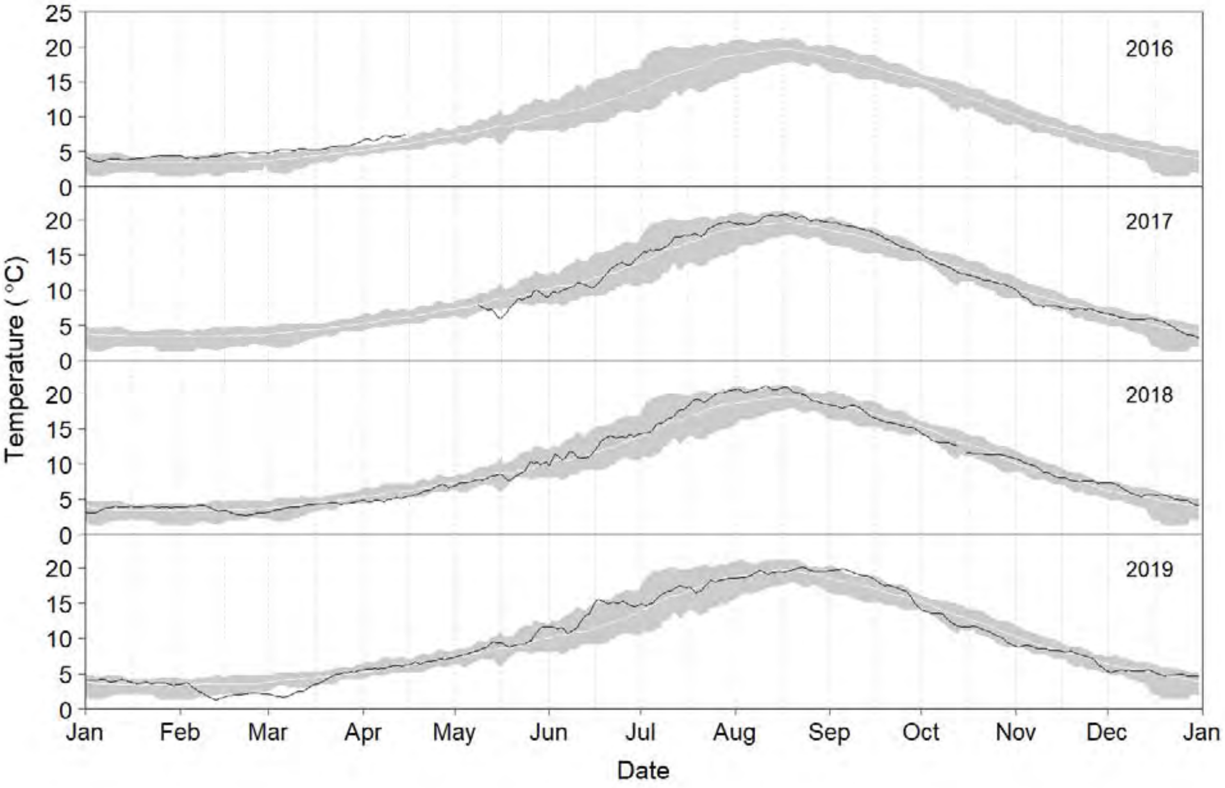

Figure D5. Concluded.

Appendix E – Catch and Effort

Table E1 Number of fish caught and observed during boat electroshocking surveys and their frequency of occurrence in sampled sections of the Lower Columbia River, 2001 to 2019. Data include index sites only; all data from GRTS sites were removed.

	2001		2002		2003		2004		2005		2006		2007		2008		2009		2010		2011		2012		2013		2014		2015		2016		2017		2018		2019		All Years[a]		
Species	n[a]	%[b]	n[a]	%[b]	n[a]	%[b]	n[a]	%[b]	n[a]	%[b]	n[a]	%[b]	n[a]	%[b]	n[a]	%[b]	n[a]	%[b]	n[a]	%[b]	n[a]	%[b]	n[a]	%[b]	n[a]	%[b]	n[a]	%[b]	n[a]	%[b]	n[a]	%[b]	n[a]	%[b]	n[a]	%[b]	n[a]	%[b]	n[a]	%[b]	%[c]
Sportfish																																									
Brook Trout	5	<1	8	<1	7	<1	3	<1	3	<1	4	<1	15	<1	8	<1	3	<1	4	<1	14	<1	15	<1	31	<1	17	<1	9	<1	1	<1	8	<1	1	<1	1	<1	157	<1	<1
Brown Trout	1	<1	2	<1			1	<1	1	<1	2	<1	7	<1	2	<1	3	<1	8	<1	4	<1	2	<1	3	<1	5	<1	1	<1	2	<1	2	<1	4	<1	2	<1	52	<1	<1
Bull Trout	16	<1	3	<1	18	<1	8	<1	8	<1	11	<1	30	<1	6	<1	9	<1	8	<1	12	<1	13	<1	6	<1	4	<1	8	<1	3	<1	2	<1	2	<1	1	<1	168	<1	<1
Burbot	3	<1	10	<1	59	<1	208	1	174	2	195	1	191	2	69	1	33	<1	70	1	247	2	39	<1	14	<1	20	<1	6	<1	11	<1	25	<1	13	<1	11	<1	1408	1	<1
Cutthroat Trout	1	<1	4	<1	2	<1			1	<1	5	<1	8	<1	5	<1	3	<1	6	<1	4	<1	4	<1	2	<1													45	<1	<1
Kokanee	2562	9	171	1	5180	19	120	1	32	<1	898	7	506	4	148	1	1128	11	57	1	77	1	156	1	18	<1	7	<1	22	<1	24	<1	19	<1	7	<1	59	1	11 248	4	1
Lake Trout			1	<1											1	<1											1	<1											3	<1	<1
Lake Whitefish	61	<1	140	1	230	1	160	1	262	2	290	2	163	1	159	1	192	2	239	3	220	2	61	1	71	1	70	1	71	1	205	2	86	1	90	1	69	1	2864	1	<1
Largemouth Bass																											1	<1											1	<1	<1
Mountain Whitefish	14 916	52	12 108	50	9685	35	6020	38	5024	43	5472	40	5595	45	5221	44	3800	36	2748	30	2933	27	4648	41	4880	49	4020	53	2997	45	4353	45	3925	36	3830	41	1885	26	104 836	42	12
Northern Pike																			7	<1	9	<1	11	<1	125	1	25	<1	9	<1	4	<1	8	<1	3	<1	24	<1	226	<1	<1
Pumpkinseed																																					1	<1	1	<1	<1
Rainbow Trout	9425	33	10 221	42	8466	30	5763	37	3844	33	5338	39	4953	39	5124	43	4219	40	4420	48	5501	51	5401	48	4110	41	2937	39	3081	46	4046	42	5755	52	4202	45	3683	51	101 288	40	11
Smallmouth Bass					4	<1	3	<1	4	<1	53	<1	16	<1	1	<1			1	<1	8	<1					9	<1	1	<1	2	<1	4	<1	3	<1			109	<1	<1
Walleye	1467	5	1478	6	4165	15	3413	22	2230	19	1421	10	1076	9	1208	10	1127	11	1588	17	1814	17	881	8	752	8	484	6	480	7	1047	11	1175	11	1051	11	1319	18	28 397	11	3
White Sturgeon	14	<1	6	<1	18	<1	5	<1	11	<1	14	<1	11	<1	9	<1	4	<1	11	<1	23	<1	9	<1	7	<1	13	<1	14	<1	35	<1	33	<1	49	1	98	1	386	<1	<1
Yellow Perch					1	<1	4	<1	1	<1	24	<1	1	<1					12	<1	2	<1			1	<1			2	<1	6	<1	1	<1	1	<1	4	<1	60	<1	<1
Sportfish subtotal	28 471	100	24 152	100	27 835	100	15 708	100	11 595	100	13 727	100	12 572	100	11 961	100	10 521	100	9179	100	10 868	100	11 240	100	10 020	100	7613	100	6701	100	9739	100	11 043	100	9256	100	7157	98	251 249	100	28
Non-sportfish																																									
Carp spp.	2	<1					1	<1	1	<1	3	<1	1	<1	2	<1			3	<1									1	<1					1	<1	1	<1	16	<1	<1
Dace spp.	2	<1					3	<1	15	<1	17	<1	1	<1	1	<1			13	<1	3	<1	1	<1															56	<1	<1
Northern Pikeminnow	570	3	2371	10	969	3	1337	3	522	2	1450	2	845	1	1452	2	241	1	393	1	764	2	681	3	453	<1	64	<1	138	2	42	<1	88	<1	184	5	108	2	12 714	2	1
Peamouth	80	<1	205	1	45	<1	51	<1	33	<1	52	<1	93	<1	3	<1	4	<1	25	<1	192	<1	488	2	12	<1	25	<1	156	2	3	<1	107	1	9	<1	6	<1	1595	<1	<1
Redside Shiner	8520	46	9026	40	5710	20	4605	12	1742	5	13 121	17	3119	5	8156	12	1592	5	2269	7	4626	11	5280	21	40 151	41	3437	26	1636	22	1094	10	6053	34	375	10	492	10	121 358	19	14
Sculpin spp.[e]	2724	15	7479	33	16 674	59	26 991	67	25 734	79	51 925	68	45 508	76	49 939	71	23 209	73	21 446	67	29 392	72	16 030	62	44 367	45	7856	59	4169	57	6850	66	10 736	60	2018	52	2828	57	397 013	62	45
Sucker spp.[e]	6509	35	3553	16	4779	17	7033	18	4378	14	9235	12	10 012	17	11 028	16	6896	22	7625	24	5949	15	3194	12	12 736	13	2029	15	1188	16	2441	23	1052	6	1303	33	1519	31	102 814	16	12
Tench											1	<1	5	<1	1	<1			2	<1					2	<1	1	<1			1	<1	1	<1	3	<1			17	<1	<1
Non-sportfish subtotal	18 407	100	22 634	100	28 177	100	40 021	100	32 425	100	75 804	100	59 584	100	70 582	100	31 942	100	31 776	100	40 926	100	25 674	100	97 721	100	13 412	100	7288	100	10 431	100	18 037	100	3893	100	4954	100	635 583	100	72
All species	46 878		46 786		56 012		55 729		44 020		89 531		72 156		82 543		42 463		40 955		51 794		36 914		107 741		21 025		13 989		20 170		29 080		13 149		12 111		886 832		

[a] Includes fish observed and identified to species; does not include recaptured fish.
[b] Percent composition of sportfish or non-sportfish catch.
[c] Percent composition of the total fish catch.
[d] Species combined for table or not identified to species.

Table E2 Summary of boat electroshocking sportfish catch (includes fish captured and observed and identified to species) and catch-per-unit-effort (CPUE = no. fish/km/hour) in the Lower Columbia River, 30 September to 03 November 2019.

Section	Session	Site	Date	Time Sampled (s)	Length Sampled (km)	Number Caught (CPUE = no. fish/km/hr)																											
						Brook Trout		Brown Trout		Bull Trout		Burbot		Kokanee		Lake Whitefish		Mountain Whitefish		Northern Pike		Pumpkinseed		Rainbow Trout		Walleye		White Sturgeon		Yellow Perch		All Species	
						No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE
Columbia River U/S	1	C00.0-R	30-Sep-19	983	0.94													10	39.08					16	62.53	4	15.63	3	11.72			33	128.96
		C00.7-L	30-Sep-19	598	0.59													3	30.44					20	202.94	6	60.88	1	10.15			30	304.41
		C01.3-L	30-Sep-19	1555	1.59													35	51.08					65	94.87	30	43.78	2	2.92			132	192.65
		C02.8-L	30-Sep-19	800	0.88													6	30.61					28	142.84	13	66.32					47	239.76
		C03.6-L	30-Sep-19	2012	2.09													41	35.15					101	86.58	25	21.43	2	1.71			169	144.87
		C04.6-R	01-Oct-19	488	0.50													4	58.73					15	220.22							19	278.95
		C05.6-L	01-Oct-19	1031	1.09													1	3.2	2	6.4			22	70.42	11	35.21	2	6.4			38	121.64
		C07.3-R	01-Oct-19	1051	1.70													45	90.41					49	98.45	41	82.37	4	8.04			139	279.27
		C07.4-L	01-Oct-19	884	1.00									9	36.72			89	363.11					35	142.79	16	65.28	13	53.04			162	660.93
	Session Summary			**1044.7**	**10.00**	**0**	***0***	**0**	***0***	**0**	***0***	**0**	***0***	**9**	***3.1***	**0**	***0***	**234**	***80.64***	**2**	***0.69***	**0**	***0***	**351**	***120.95***	**146**	***50.31***	**27**	***9.3***	**0**	***0***	**769**	***264.99***
	2	C00.0-R	08-Oct-19	932	0.94													14	57.7					17	70.07							31	127.77
		C00.7-L	08-Oct-19	639	0.59													22	208.91					17	161.43							39	370.34
		C01.3-L	08-Oct-19	1852	1.60													48	58.27					46	55.84	20	24.28	1	1.21			115	139.61
		C02.8-L	08-Oct-19	902	0.88													13	58.82	1	4.52			35	158.35	8	36.2					57	257.89
		C03.6-L	09-Oct-19	2033	2.09													21	17.82	3	2.55			66	55.99	32	27.15	4	3.39			126	106.89
		C04.6-R	07-Oct-19	568	0.52													5	61.24	1	12.25			12	146.98	3	36.74					21	257.21
		C05.6-L	07-Oct-19	1086	1.10													7	21.08					15	45.17	11	33.12	2	6.02			35	105.39
		C07.3-R	07-Oct-19	1015	1.70									1	2.08			39	81.14					24	49.93	9	18.72					73	151.87
		C07.4-L	07-Oct-19	899	1.00													87	349.02					16	64.19	12	48.14	8	32.09			123	493.45
	Session Summary			**1102.9**	**10.00**	**0**	***0***	**0**	***0***	**0**	***0***	**0**	***0***	**1**	***0.33***	**0**	***0***	**256**	***83.56***	**5**	***1.63***	**0**	***0***	**248**	***80.95***	**95**	***31.01***	**15**	***4.9***	**0**	***0***	**620**	***202.38***
	3	C00.0-R	15-Oct-19	950	0.94													24	97.05					10	40.44	6	24.26					40	161.74
		C00.7-L	15-Oct-19	506	0.59													35	419.71					5	59.96			1	11.99			41	491.67
		C01.3-L	15-Oct-19	1752	1.60													58	74.43	1	1.28			33	42.35	29	37.21	1	1.28			122	156.56
		C02.8-L	15-Oct-19	880	0.88													13	60.29					22	102.03	4	18.55					39	180.86
		C03.6-L	15-Oct-19	2244	2.09													20	15.37	3	2.31			24	18.45	36	27.67	4	3.07			87	66.87
		C04.6-R	15-Oct-19	606	0.52													1	11.48					13	149.24	9	103.32					23	264.04
		C05.6-L	16-Oct-19	1329	1.10									30	73.82			2	4.92	3	7.38			15	36.91	10	24.61					60	147.64
		C07.3-R	16-Oct-19	1071	1.70			1	1.97			1	1.97			4	7.89	46	90.69					32	63.09	30	59.15	1	1.97			115	226.74
		C07.4-L	16-Oct-19	935	1.00									4	15.43			103	397.3					37	142.72	7	27	7	27			158	609.45
	Session Summary			**1141.4**	**10.00**	**0**	***0***	**1**	***0.32***	**0**	***0***	**1**	***0.32***	**34**	***10.72***	**4**	***1.26***	**302**	***95.25***	**7**	***2.21***	**0**	***0***	**191**	***60.24***	**131**	***41.32***	**14**	***4.42***	**0**	***0***	**685**	***216.05***
	4	C00.0-R	21-Oct-19	958	0.94									1	4.01			6	24.06					13	52.13	13	52.13	1	4.01			34	136.33
		C00.7-L	21-Oct-19	666	0.59													13	118.44					6	54.67	3	27.33					22	200.44
		C01.3-L	21-Oct-19	1670	1.60													19	25.58	1	1.35			27	36.35	17	22.89	1	1.35			65	87.51
		C02.8-L	21-Oct-19	900	0.88													13	58.95	2	9.07			19	86.16	2	9.07					36	163.24
		C03.6-L	21-Oct-19	2255	2.09													26	19.89	2	1.53			18	13.77	21	16.06	4	3.06			71	54.3
		C04.6-R	22-Oct-19	548	0.52															1	12.7			22	279.29	1	12.7	1	12.7	1	12.7	26	330.07
		C05.6-L	22-Oct-19	1239	1.10													1	2.64	2	5.28			22	58.07	5	13.2					30	79.18
		C07.3-R	22-Oct-19	1150	1.70					1	1.84							20	36.72					38	69.77	28	51.41	1	1.84			88	161.58
		C07.4-L	22-Oct-19	951	1.00													132	500.6					49	185.83	10	37.92	9	34.13			200	758.48
	Session Summary			**1148.6**	**10.00**	**0**	***0***	**0**	***0***	**1**	***0.31***	**0**	***0***	**1**	***0.31***	**0**	***0***	**230**	***72.09***	**8**	***2.51***	**0**	***0***	**214**	***67.07***	**100**	***31.34***	**17**	***5.33***	**1**	***0.31***	**572**	***179.28***
	5	C05.1-R	01-Nov-19	1132	0.99													1	3.2	1	3.2			36	115.29	9	28.82					47	150.52
		C06.0-R	01-Nov-19	1420	1.49																			32	54.57	17	28.99					49	83.56
	Session Summary			**1276**	**2.00**	**0**	***0***	**0**	***0***	**0**	***0***	**0**	***0***	**0**	***0***	**0**	***0***	**1**	***1.41***	**1**	***1.41***	**0**	***0***	**68**	***95.92***	**26**	***36.68***	**0**	***0***	**0**	***0***	**96**	***135.42***
Section Total All Samples				**42490**	**44.13**	**0**		**1**		**1**		**1**		**45**		**4**		**1023**		**23**		**0**		**1072**		**498**		**73**		**1**		**2742**	
Section Average All Samples				**1118**	**1.16**	**0**	***0***	**0**	***0.07***	**0**	***0.07***	**0**	***0.07***	**1**	***3.28***	**0**	***0.29***	**27**	***74.65***	**1**	***1.68***	**0**	***0***	**28**	***78.22***	**13**	***36.34***	**2**	***5.33***	**0**	***0.07***	**72**	***200.08***
Section Standard Error of Mean						**0**	***0***	**0.03**	***0.05***	**0.03**	***0.05***	**0.03**	***0.05***	**0.82**	***2.17***	**0.11**	***0.21***	**5.06**	***21.22***	**0.16**	***0.56***	**0**	***0***	**3.07**	***9.84***	**1.81**	***3.72***	**0.48**	***1.88***	**0.03**	***0.33***	**8.1**	***27.22***

Table E2 Continued.

Section	Session	Site	Date	Time Sampled (s)	Length Sampled (km)	Number Caught (CPUE = no. fish/km/hr)																											
						Brook Trout		Brown Trout		Bull Trout		Burbot		Kokanee		Lake Whitefish		Mountain Whitefish		Northern Pike		Pumpkinseed		Rainbow Trout		Walleye		White Sturgeon		Yellow Perch		All Species	
						No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE
Kootenay River	1	K00.3-L	01-Oct-19	285	0.44													4	***115.81***					2	***57.9***	4	***115.81***					10	***289.52***
		K00.6-R	01-Oct-19	589	0.52													23	***270***							5	***58.7***	2	***23.48***			30	***352.17***
	Session Summary			**437**	**1.00**	**0**	***0***	**0**	***0***	**0**	***0***	**0**	***0***	**0**	***0***	**0**	***0***	**27**	***222.43***	**0**	***0***	**0**	***0***	**2**	***16.48***	**9**	***74.14***	**2**	***16.48***	**0**	***0***	**40**	***329.52***
	2	K00.3-L	07-Oct-19	245	0.44																			12	***404.14***	4	***134.71***					16	***538.86***
		K00.6-R	07-Oct-19	490	0.60													21	***259.02***					6	***74***	6	***74***	1	***12.33***			34	***419.36***
	Session Summary			**367.5**	**1.00**	**0**	***0***	**0**	***0***	**0**	***0***	**0**	***0***	**0**	***0***	**0**	***0***	**21**	***205.71***	**0**	***0***	**0**	***0***	**18**	***176.33***	**10**	***97.96***	**1**	***9.8***	**0**	***0***	**50**	***489.8***
	3	K00.3-L	16-Oct-19	258	0.44											1	***31.98***	2	***63.96***					3	***95.94***	1	***31.98***					7	***223.87***
		K00.6-R	16-Oct-19	532	0.60													34	***386.25***					12	***136.32***	7	***79.52***					53	***602.1***
	Session Summary			**395**	**1.00**	**0**	***0***	**0**	***0***	**0**	***0***	**0**	***0***	**0**	***0***	**1**	***9.11***	**36**	***328.1***	**0**	***0***	**0**	***0***	**15**	***136.71***	**8**	***72.91***	**0**	***0***	**0**	***0***	**60**	***546.84***
	4	K00.3-L	22-Oct-19	256	0.44													10	***322.31***					4	***128.93***	1	***32.23***					15	***483.47***
		K00.6-R	22-Oct-19	333	0.23													3	***140***	1	***46.67***			7	***326.67***	1	***46.67***					12	***560.01***
	Session Summary			**294.5**	**1.00**	**0**	***0***	**0**	***0***	**0**	***0***	**0**	***0***	**0**	***0***	**0**	***0***	**13**	***158.91***	**1**	***12.22***	**0**	***0***	**11**	***134.47***	**2**	***24.45***	**0**	***0***	**0**	***0***	**27**	***330.05***
Section Total All Samples				**2988**	**3.69**	**0**		**0**		**0**		**0**		**0**		**1**		**97**		**1**		**0**		**46**		**29**		**3**		**0**		**177**	
Section Average All Samples				**374**	**0.46**	**0**	***0***	**0**	***0***	**0**	***0***	**0**	***0***	**0**	***0***	**0**	***2.61***	**12**	***253.11***	**0**	***2.61***	**0**	***0***	**6**	***120.03***	**4**	***75.67***	**0**	***7.83***	**0**	***0***	**22**	***461.87***
Section Standard Error of Mean						**0**	***0***	**0**	***0***	**0**	***0***	**0**	***0***	**0**	***0***	**0.12**	***4***	**4.39**	***47.62***	**0.12**	***5.83***	**0**	***0***	**1.57**	***49.29***	**0.84**	***13.31***	**0.26**	***3.11***	**0**	***0***	**5.55**	***48.09***

Table E2 Continued.

Section	Session	Site	Date	Time Sampled (s)	Length Sampled (km)	Number Caught (CPUE = no. fish/km/hr)																											
						Brook Trout		Brown Trout		Bull Trout		Burbot		Kokanee		Lake Whitefish		Mountain Whitefish		Northern Pike		Pumpkinseed		Rainbow Trout		Walleye		White Sturgeon		Yellow Perch		All Species	
						No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE
Columbia River U/S	1	C00.0-R	30-Sep-19	983	0.94													10	***39.08***					16	***62.53***	4	***15.63***	3	***11.72***			33	***128.96***
		C00.7-L	30-Sep-19	598	0.59													3	***30.44***					20	***202.94***	6	***60.88***	1	***10.15***			30	***304.41***
		C01.3-L	30-Sep-19	1555	1.59													35	***51.08***					65	***94.87***	30	***43.78***	2	***2.92***			132	***192.65***
		C02.8-L	30-Sep-19	800	0.88													6	***30.61***					28	***142.84***	13	***66.32***					47	***239.76***
		C03.6-L	30-Sep-19	2012	2.09													41	***35.15***					101	***86.58***	25	***21.43***	2	***1.71***			169	***144.87***
		C04.6-R	01-Oct-19	488	0.50													4	***58.73***					15	***220.22***							19	***278.95***
		C05.6-L	01-Oct-19	1031	1.09													1	***3.2***	2	***6.4***			22	***70.42***	11	***35.21***	2	***6.4***			38	***121.64***
		C07.3-R	01-Oct-19	1051	1.70													45	***90.41***					49	***98.45***	41	***82.37***	4	***8.04***			139	***279.27***
		C07.4-L	01-Oct-19	884	1.00									9	***36.72***			89	***363.11***					35	***142.79***	16	***65.28***	13	***53.04***			162	***660.93***
	Session Summary			**1044.7**	**10.00**	**0**	***0***	**0**	***0***	**0**	***0***	**0**	***0***	**9**	***3.1***	**0**	***0***	**234**	***80.64***	**2**	***0.69***	**0**	***0***	**351**	***120.95***	**146**	***50.31***	**27**	***9.3***	**0**	***0***	**769**	***264.99***
	2	C00.0-R	08-Oct-19	932	0.94													14	***57.7***					17	***70.07***							31	***127.77***
		C00.7-L	08-Oct-19	639	0.59													22	***208.91***					17	***161.43***							39	***370.34***
		C01.3-L	08-Oct-19	1852	1.60													48	***58.27***					46	***55.84***	20	***24.28***	1	***1.21***			115	***139.61***
		C02.8-L	08-Oct-19	902	0.88													13	***58.82***	1	***4.52***			35	***158.35***	8	***36.2***					57	***257.89***
		C03.6-L	09-Oct-19	2033	2.09													21	***17.82***	3	***2.55***			66	***55.99***	32	***27.15***	4	***3.39***			126	***106.89***
		C04.6-R	07-Oct-19	568	0.52													5	***61.24***	1	***12.25***			12	***146.98***	3	***36.74***					21	***257.21***
		C05.6-L	07-Oct-19	1086	1.10													7	***21.08***					15	***45.17***	11	***33.12***	2	***6.02***			35	***105.39***
		C07.3-R	07-Oct-19	1015	1.70									1	***2.08***			39	***81.14***					24	***49.93***	9	***18.72***					73	***151.87***
		C07.4-L	07-Oct-19	899	1.00													87	***349.02***					16	***64.19***	12	***48.14***	8	***32.09***			123	***493.45***
	Session Summary			**1102.9**	**10.00**	**0**	***0***	**0**	***0***	**0**	***0***	**0**	***0***	**1**	***0.33***	**0**	***0***	**256**	***83.56***	**5**	***1.63***	**0**	***0***	**248**	***80.95***	**95**	***31.01***	**15**	***4.9***	**0**	***0***	**620**	***202.38***
	3	C00.0-R	15-Oct-19	950	0.94													24	***97.05***					10	***40.44***	6	***24.26***					40	***161.74***
		C00.7-L	15-Oct-19	506	0.59													35	***419.71***					5	***59.96***			1	***11.99***			41	***491.67***
		C01.3-L	15-Oct-19	1752	1.60													58	***74.43***	1	***1.28***			33	***42.35***	29	***37.21***	1	***1.28***			122	***156.56***
		C02.8-L	15-Oct-19	880	0.88													13	***60.29***					22	***102.03***	4	***18.55***					39	***180.86***
		C03.6-L	15-Oct-19	2244	2.09													20	***15.37***	3	***2.31***			24	***18.45***	36	***27.67***	4	***3.07***			87	***66.87***
		C04.6-R	15-Oct-19	606	0.52													1	***11.48***					13	***149.24***	9	***103.32***					23	***264.04***
		C05.6-L	16-Oct-19	1329	1.10									30	***73.82***			2	***4.92***	3	***7.38***			15	***36.91***	10	***24.61***					60	***147.64***
		C07.3-R	16-Oct-19	1071	1.70			1				1				4		46						32		30		1				115	
		C07.4-L	16-Oct-19	935	1.00									4	***15.43***			103	***397.3***					37	***142.72***	7	***27***	7	***27***			158	***609.45***
	Session Summary			**1141.4**	**10.00**	**0**	***0***	**1**	***0.32***	**0**	***0***	**1**	***0.32***	**34**	***10.72***	**4**	***1.26***	**302**	***95.25***	**7**	***2.21***	**0**	***0***	**191**	***60.24***	**131**	***41.32***	**14**	***4.42***	**0**	***0***	**685**	***216.05***

Table E2 Concluded.

Section	Session	Site	Date	Time Sampled (s)	Length Sampled (km)	Number Caught (CPUE = no. fish/km/hr)																									
						Brook Trout		Brown Trout		Bull Trout		Burbot		Kokanee		Lake Whitefish		Mountain Whitefish		Northern Pike		Pumpkinseed		Rainbow Trout		Walleye		White Sturgeon		Yellow Perch		All Species	
						No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE
Columbia River D/S	4	C25.3-R	23-Oct-19	1667	2.73							1	***0.79***			5	***3.96***	55	***43.56***					44	***34.85***	14	***11.09***					119	***94.25***
		C27.6-R	23-Oct-19	299	0.49													22	***539.72***					23	***564.25***	16	***392.52***					61	***1496.49***
		C28.2-R	23-Oct-19	802	1.13							1	***3.97***					2	***7.93***					46	***182.49***	10	***39.67***					59	***234.06***
		C34.9-L	23-Oct-19	2072	2.14													5	***4.07***					72	***58.57***	19	***15.46***					96	***78.09***
		C36.6-L	24-Oct-19	1717	2.39											2	***1.75***	12	***10.51***					77	***67.41***	22	***19.26***	2	***1.75***			115	***100.68***
		C47.8-L	25-Oct-19	1134	1.44													2	***4.41***					51	***112.49***	15	***33.08***	1	***2.21***			69	***152.19***
		C48.2-R	24-Oct-19	1018	1.01											1	***3.51***	19	***66.62***					44	***154.27***	21	***73.63***					85	***298.03***
		C49.0-L	25-Oct-19	547	0.93											1	***7.08***	11	***77.87***					43	***304.4***	6	***42.47***					61	***431.82***
		C49.0-R	24-Oct-19	354	0.72													4	***56.53***					9	***127.2***	7	***98.94***					20	***282.67***
		C49.8-L	26-Oct-19	2134	2.45											1	***0.69***	24	***16.55***					93	***64.13***	30	***20.69***					148	***102.05***
		C49.8-R	24-Oct-19	1408	2.39							1	***1.07***					25	***26.74***					80	***85.56***	30	***32.09***					136	***145.45***
		C52.2-L	26-Oct-19	602	0.43											2	***27.75***							22	***305.27***	6	***83.26***	1	***13.88***			31	***430.15***
		C52.2-R	24-Oct-19	2201	3.79			1	***0.43***									19	***8.2***					71	***30.64***	23	***9.93***	1	***0.43***			115	***49.63***
		C52.8-L	26-Oct-19	709	0.89							1	***5.69***			2	***11.37***	4	***22.75***					36	***204.75***	19	***108.06***					62	***352.62***
		C53.6-L	25-Oct-19	1260	1.52																			27	***50.82***	19	***35.77***					46	***86.59***
	Session Summary			**1194.9**	**24.00**	**0**	***0***	**1**	***0.13***	**0**	***0***	**4**	***0.5***	**0**	***0***	**14**	***1.76***	**204**	***25.61***	**0**	***0***	**0**	***0***	**738**	***92.64***	**257**	***32.26***	**5**	***0.63***	**0**	***0***	**1223**	***153.53***
	5	C10.7-R	01-Nov-19	340	0.91											1	***11.58***	5	***57.92***					40	***463.38***	5	***57.92***					51	***590.81***
		C10.9-L	02-Nov-19	1680	2.18											1	***0.98***	220	***216.25***					140	***137.61***	7	***6.88***	2	***1.97***			370	***363.7***
		C11.5-R	02-Nov-19	1361	1.90													101	***140.61***					119	***165.67***	14	***19.49***	2	***2.78***			236	***328.55***
		C19.0-L	27-Oct-19	1064	1.28													4	***10.57***					70	***185.03***	7	***18.5***					81	***214.11***
		C20.4-R	27-Oct-19	1428	1.47											2	***3.42***	15	***25.65***					103	***176.16***	27	***46.18***					147	***251.42***
		C21.3-L	03-Nov-19	1571	2.04							1	***1.12***					58	***65.18***					129	***144.98***	16	***17.98***	2	***2.25***			206	***231.51***
		C22.9-R	03-Nov-19	743	1.22													113	***448.41***					47	***186.51***	7	***27.78***	2	***7.94***			169	***670.63***
		C23.4-L	03-Nov-19	927	0.93											1	***4.18***	45	***187.91***					79	***329.89***							125	***521.98***
		C29.6-L	03-Nov-19	591	1.11											1	***5.51***	19	***104.69***					45	***247.96***	4	***22.04***					69	***380.21***
		C30.5-R	28-Oct-19	1430	1.53											1	***1.65***	10	***16.5***					113	***186.44***	19	***31.35***					143	***235.94***
		C30.6-L	03-Nov-19	1552	1.84			1	***1.26***							7	***8.82***	20	***25.21***					165	***208.01***	10	***12.61***					203	***255.91***
		C32.0-R	27-Oct-19	1228	1.37													32	***68.48***					87	***186.17***	13	***27.82***					132	***282.46***
		C33.3-R	03-Nov-19	1402	1.56							2	***3.29***					2	***3.29***					89	***146.21***	7	***11.5***					100	***164.28***
		C35.7-R	26-Oct-19	1255	1.25							1	***2.3***					2	***4.6***					107	***245.92***	12	***27.58***					122	***280.39***
		C36.9-R	26-Oct-19	1730	2.27	1	***0.92***											5	***4.58***					108	***99***	20	***18.33***					134	***122.84***
		C40.0-L	27-Oct-19	509	1.09											1	***6.51***	28	***182.4***					12	***78.17***	1	***6.51***					42	***273.6***
		C40.0-R	03-Nov-19	902	1.47							1	***2.72***			1	***2.72***	28	***76.23***					74	***201.46***	3	***8.17***					107	***291.3***
		C47.2-R	24-Oct-19	595	1.06											1	***5.71***	24	***136.99***					23	***131.28***	7	***39.96***					55	***313.94***
		C56.0-L	25-Oct-19	611	0.94																			17	***106.56***	10	***62.68***					27	***169.24***
	Session Summary			**1101**	**27.00**	**1**	***0.12***	**1**	***0.12***	**0**	***0***	**5**	***0.61***	**0**	***0***	**17**	***2.06***	**731**	***88.53***	**0**	***0***	**0**	***0***	**1567**	***189.77***	**189**	***22.89***	**8**	***0.97***	**0**	***0***	**2519**	***305.06***
Section Total All Samples				**87595**	**126.91**	**2**		**2**		**0**		**15**		**14**		**81**		**1501**		**1**		**1**		**4247**		**1011**		**30**		**3**		**6908**	
Section Average All Samples				**1109**	**1.61**	**0**	***0.05***	**0**	***0.05***	**0**	***0***	**0**	***0.38***	**0**	***0.36***	**1**	***2.07***	**19**	***38.39***	**0**	***0.03***	**0**	***0.03***	**54**	***108.63***	**13**	***25.86***	**0**	***0.77***	**0**	***0.08***	**87**	***176.7***
Section Standard Error of Mean						**0.02**	***0.03***	**0.02**	***0.02***	**0**	***0***	**0.06**	***0.11***	**0.16**	***0.15***	**0.21**	***0.71***	**3.47**	***11.33***	**0.01**	***0.23***	**0.01**	***0.01***	**3.9**	***12.53***	**0.89**	***5.99***	**0.08**	***0.37***	**0.03**	***0.04***	**6.47**	***24.89***
All Sections Total All Samples				**133073**	**174.73**	***2***	***0***	***3***	***0***	***1***	***0***	***16***	***0***	***59***	***0.01***	***86***	***0.01***	***2621***	***0.41***	***25***	***0***	***1***	***0***	***5365***	***0.83***	***1538***	***0.24***	***106***	***0.02***	***4***	***0***	***9827***	***1.52***
All Sections Average All Samples						***0***	***0.04***	***0***	***0.06***	***0***	***0.02***	***0***	***0.31***	***0***	***1.14***	***1***	***1.66***	***21***	***50.73***	***0***	***0.48***	***0***	***0.02***	***43***	***103.83***	***12***	***29.77***	***1***	***2.05***	***0***	***0.08***	***79***	***190.19***
All Sections Standard Error of Mean						***0.01***	***0.02***	***0.01***	***0.02***	***0.01***	***0.01***	***0.04***	***0.07***	***0.27***	***0.67***	***0.14***	***0.53***	***2.71***	***10.47***	***0.05***	***0.43***	***0.01***	***0.01***	***2.96***	***9.21***	***0.81***	***4.1***	***0.17***	***0.68***	***0.02***	***0.1***	***4.98***	***18.43***

Table E3 Summary of boat electroshocking non-sportfish catch (includes fish captured and observed and identified to species) and catch-per-unit-effort (CPUE = no. fish/km/hour) in the Lower Columbia River, 30 September to 03 November 2019.

Section	Session	Site	Date	Time Sampled (s)	Length Sampled (km)	Number Caught (CPUE = no. fish/km/hr)													
						Carp spp.		Northern Pikeminnow		Peamouth		Redside Shiner		Sculpin spp.		Sucker spp.		All Species	
						No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE
Columbia River U/S	1	C00.0-R	30-Sep-19	983	0.94							4	15.63	30	117.24	5	19.54	39	152.41
		C00.7-L	30-Sep-19	598	0.59			1	10.15	2	20.29	1	10.15	2	20.29	2	20.29	8	81.18
		C01.3-L	30-Sep-19	1555	1.59							15	21.89	18	26.27	84	122.6	117	170.76
		C02.8-L	30-Sep-19	800	0.88							2	10.2	21	107.13	15	76.52	38	193.85
		C03.6-L	30-Sep-19	2012	2.09			9	7.72			1	0.86	56	48	70	60.01	136	116.58
		C04.6-R	01-Oct-19	488	0.50									20	293.63	13	190.86	33	484.49
		C05.6-L	01-Oct-19	1031	1.09			5	16			10	32.01	60	192.06	60	192.06	135	432.12
		C07.3-R	01-Oct-19	1051	1.70									8	16.07	5	10.05	13	26.12
		C07.4-L	01-Oct-19	884	1.00											32	130.55	32	130.55
	Session Summary			**1044.7**	**10.00**	**0**	0	**15**	5.17	**2**	0.69	**33**	11.37	**215**	74.09	**286**	98.55	**551**	189.87
	2	C00.0-R	08-Oct-19	932	0.94							11	45.34	22	90.68			33	136.02
		C00.7-L	08-Oct-19	639	0.59							5	47.48	7	66.47			12	113.95
		C01.3-L	08-Oct-19	1852	1.60							18	21.85	35	42.49	39	47.34	92	111.68
		C02.8-L	08-Oct-19	902	0.88							5	22.62	15	67.87	13	58.82	33	149.31
		C03.6-L	09-Oct-19	2033	2.09			2	1.7			23	19.51	43	36.48	107	90.78	175	148.46
		C04.6-R	07-Oct-19	568	0.52							25	306.2	15	183.72	19	232.71	59	722.64
		C05.6-L	07-Oct-19	1086	1.10			1	3.01			32	96.36	32	96.36	29	87.33	94	283.05
		C07.3-R	07-Oct-19	1015	1.70									3	6.24	7	14.56	10	20.8
		C07.4-L	07-Oct-19	899	1.00									12	48.14	29	116.34	41	164.48
	Session Summary			**1102.9**	**10.00**	**0**	0	**3**	0.98	**0**	0	**119**	38.84	**184**	60.06	**243**	79.32	**549**	179.2
	3	C00.0-R	15-Oct-19	950	0.94							15	60.65	37	149.61	3	12.13	55	222.4
		C00.7-L	15-Oct-19	506	0.59							3	35.98	18	215.85	2	23.98	23	275.81
		C01.3-L	15-Oct-19	1752	1.60			2	2.57	3	3.85	33	42.35	112	143.72	101	129.61	251	322.09
		C02.8-L	15-Oct-19	880	0.88	1	4.64					30	139.13	25	115.94	38	176.23	94	435.93
		C03.6-L	15-Oct-19	2244	2.09			10	7.69			24	18.45	42	32.28	121	93	197	151.41
		C04.6-R	15-Oct-19	606	0.52									15	172.2	24	275.52	39	447.72
		C05.6-L	16-Oct-19	1329	1.10			13	31.99					75	184.55	56	137.8	144	354.33
		C07.3-R	16-Oct-19	1071	1.70									50	98.58	5	9.86	55	108.44
		C07.4-L	16-Oct-19	935	1.00									5	19.29	36	138.86	41	158.15
	Session Summary			**1141.4**	**10.00**	**1**	0.32	**25**	7.89	**3**	0.95	**105**	33.12	**379**	119.54	**386**	121.75	**899**	283.55
	4	C00.0-R	21-Oct-19	958	0.94							27	108.27	54	216.53	4	16.04	85	340.84
		C00.7-L	21-Oct-19	666	0.59							8	72.89	35	318.88	2	18.22	45	409.99
		C01.3-L	21-Oct-19	1670	1.60			1	1.35			3	4.04	32	43.08	81	109.05	117	157.51
		C02.8-L	21-Oct-19	900	0.88							15	68.02	50	226.72	19	86.16	84	380.9
		C03.6-L	21-Oct-19	2255	2.09			18	13.77			8	6.12	40	30.59	74	56.6	140	107.08
		C04.6-R	22-Oct-19	548	0.52									8	101.56	16	203.12	24	304.68
		C05.6-L	22-Oct-19	1239	1.10			14	36.95					51	134.61	40	105.57	105	277.13
		C07.3-R	22-Oct-19	1150	1.70							25	45.9	60	110.17	3	5.51	88	161.58
		C07.4-L	22-Oct-19	951	1.00									5	18.96	48	182.04	53	201
	Session Summary			**1148.6**	**10.00**	**0**	0	**33**	10.34	**0**	0	**86**	26.95	**335**	105	**287**	89.95	**741**	232.25
	5	C05.1-R	01-Nov-19	1132	0.99									14	44.84	13	41.63	27	86.47
		C06.0-R	01-Nov-19	1420	1.49									35	59.69	52	88.68	87	148.36
	Session Summary			**1276**	**2.00**	**0**	0	**0**	0	**0**	0	**0**	0	**49**	69.12	**65**	91.69	**114**	160.82
Section Total All Samples				**42490**	**44.13**	**1**		**76**		**5**		**343**		**1162**		**1267**		**2854**	
Section Average All Samples				**1118**	**1.16**	**0**	0.07	**2**	5.55	**0**	0.36	**9**	25.03	**31**	84.79	**33**	92.45	**75**	208.25
Section Standard Error of Mean						**0.03**	0.12	**0.73**	1.36	**0.09**	0.54	**1.78**	9.23	**3.82**	13.21	**5.39**	11.76	**9.16**	24.1

Table E3 Continued.

Section	Session	Site	Date	Time Sampled (s)	Length Sampled (km)	Number Caught (CPUE = no. fish/km/hr)													
						Carp spp.		Northern Pikeminnow		Peamouth		Redside Shiner		Sculpin spp.		Sucker spp.		All Species	
						No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE
Kootenay River	1	K00.3-L	01-Oct-19	285	0.44									2	***57.9***			2	***57.9***
		K00.6-R	01-Oct-19	589	0.52			1	***11.74***			11	***129.13***	12	***140.87***	15	***176.09***	39	***457.82***
	Session Summary			**437**	**1.00**	**0**	***0***	**1**	***8.24***	**0**	***0***	**11**	***90.62***	**14**	***115.33***	**15**	***123.57***	**41**	***337.76***
	2	K00.6-R	07-Oct-19	490	0.60							6	***74***	4	***49.34***	17	***209.68***	27	***333.02***
	Session Summary			**490**	**1.00**	**0**	***0***	**0**	***0***	**0**	***0***	**6**	***44.08***	**4**	***29.39***	**17**	***124.9***	**27**	***198.37***
	3	K00.3-L	16-Oct-19	258	0.44											1	***31.98***	1	***31.98***
		K00.6-R	16-Oct-19	532	0.60									13	***147.69***	20	***227.21***	33	***374.89***
	Session Summary			**395**	**1.00**	**0**	***0***	**0**	***0***	**0**	***0***	**0**	***0***	**13**	***118.48***	**21**	***191.39***	**34**	***309.87***
	4	K00.3-L	22-Oct-19	256	0.44											2	***64.46***	2	***64.46***
		K00.6-R	22-Oct-19	333	0.23			5	***233.34***	1	***46.67***			15	***700.01***	9	***420***	30	***1400.01***
	Session Summary			**294.5**	**1.00**	**0**	***0***	**5**	***61.12***	**1**	***12.22***	**0**	***0***	**15**	***183.36***	**11**	***134.47***	**32**	***391.17***
Section Total All Samples				**2743**	**3.25**	**0**		**6**		**1**		**17**		**46**		**64**		**134**	
Section Average All Samples				**392**	**0.46**	**0**	*0*	**1**	*16.94*	**0**	*2.82*	**2**	*48*	**7**	*129.88*	**9**	*180.71*	**19**	*378.36*
Section Standard Error of Mean						**0**	*0*	**0.7**	*33.1*	**0.14**	*6.67*	**1.66**	*19.67*	**2.47**	*93.34*	**3.14**	*54.76*	**6.33**	*180.78*

Table E3 Concluded.

Section	Session	Site	Date	Time Sampled (s)	Length Sampled (km)	Number Caught (CPUE = no. fish/km/hr)													
						Carp spp.		Northern Pikeminnow		Peamouth		Redside Shiner		Sculpin spp.		Sucker spp.		All Species	
						No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE
Columbia River D/S	1	C25.3-R	02-Oct-19	1408	2.73							23	***21.57***	45	***42.2***	10	***9.38***	78	***73.14***
		C27.6-R	02-Oct-19	296	0.59											5	***103.46***	5	***103.46***
		C28.2-R	02-Oct-19	694	1.13			2	***9.17***					35	***160.46***	3	***13.75***	40	***183.38***
		C34.9-L	02-Oct-19	1849	2.14			3	***2.73***					20	***18.23***	1	***0.91***	24	***21.88***
		C36.6-L	02-Oct-19	1501	2.39			8	***8.01***					3	***3***	1	***1***	12	***12.02***
		C47.8-L	04-Oct-19	944	1.44											5	***13.25***	5	***13.25***
		C48.2-R	03-Oct-19	792	1.01									2	***9.01***			2	***9.01***
		C49.0-L	04-Oct-19	438	0.93											4	***35.36***	4	***35.36***
		C49.8-L	04-Oct-19	1703	2.45									47	***40.61***	6	***5.18***	53	***45.79***
		C49.8-R	03-Oct-19	1096	2.39									13	***17.86***	4	***5.5***	17	***23.36***
		C52.2-L	04-Oct-19	778	0.89											2	***10.41***	2	***10.41***
		C52.2-R	03-Oct-19	1726	3.79											12	***6.6***	12	***6.6***
	Session Summary			**1102.1**	**22.00**	**0**	***0***	**13**	***1.93***	**0**	***0***	**23**	***3.41***	**165**	***24.5***	**53**	***7.87***	**254**	***37.71***
	2	C25.3-R	09-Oct-19	1414	2.73			2	***1.87***					27	***25.21***	1	***0.93***	30	***28.01***
		C27.6-R	09-Oct-19	354	0.61							3	***49.79***	8	***132.77***			11	***182.55***
		C28.2-R	09-Oct-19	584	1.13							5	***27.24***	50	***272.4***			55	***299.64***
		C34.9-L	09-Oct-19	1890	2.14			2	***1.78***					54	***48.16***	5	***4.46***	61	***54.4***
		C47.8-L	11-Oct-19	990	1.44							15	***37.9***	10	***25.26***	38	***96.01***	63	***159.17***
		C48.2-R	10-Oct-19	864	1.01									17	***70.23***	2	***8.26***	19	***78.49***
		C49.0-L	11-Oct-19	476	0.93									12	***97.62***	1	***8.13***	13	***105.75***
		C49.0-R	10-Oct-19	363	0.72									6	***82.7***	2	***27.57***	8	***110.27***
		C49.8-L	11-Oct-19	1750	2.45							10	***8.41***	120	***100.9***			130	***109.31***
		C49.8-R	10-Oct-19	1252	2.39									41	***49.31***	13	***15.64***	54	***64.95***
		C52.2-R	11-Oct-19	2003	3.79									11	***5.22***			11	***5.22***
		C53.6-L	12-Oct-19	1160	1.52									1	***2.04***			1	***2.04***
	Session Summary			**1091.7**	**21.00**	**0**	***0***	**4**	***0.63***	**0**	***0***	**33**	***5.18***	**357**	***56.06***	**62**	***9.74***	**456**	***71.61***
	3	C25.3-R	17-Oct-19	1387	2.73			1	***0.95***			16	***15.23***	49	***46.64***	2	***1.9***	68	***64.73***
		C27.6-R	17-Oct-19	377	0.61									19	***296.08***			19	***296.08***
		C28.2-R	17-Oct-19	740	1.13									16	***68.79***	1	***4.3***	17	***73.09***
		C34.9-L	17-Oct-19	1894	2.14			2	***1.78***					15	***13.35***	1	***0.89***	18	***16.02***
		C36.6-L	18-Oct-19	1575	2.39									16	***15.27***			16	***15.27***
		C47.8-L	19-Oct-19	1035	1.44							10	***24.17***	37	***89.41***	13	***31.42***	60	***145***
		C48.2-R	18-Oct-19	986	1.01									12	***43.44***	2	***7.24***	14	***50.68***
		C49.0-L	19-Oct-19	465	0.93									8	***66.62***	6	***49.96***	14	***116.58***
		C49.0-R	18-Oct-19	300	0.72									3	***50.03***	1	***16.68***	4	***66.71***
		C49.8-L	19-Oct-19	1940	2.45									320	***242.71***	16	***12.14***	336	***254.85***
		C49.8-R	18-Oct-19	1334	2.39			1	***1.13***					83	***93.69***	10	***11.29***	94	***106.11***
		C52.2-L	19-Oct-19	847	0.89									17	***81.28***	2	***9.56***	19	***90.84***
		C52.2-R	18-Oct-19	2468	3.79									10	***3.85***	8	***3.08***	18	***6.93***
	Session Summary			**1180.6**	**23.00**	**0**	***0***	**4**	***0.53***	**0**	***0***	**26**	***3.45***	**605**	***80.21***	**62**	***8.22***	**697**	***92.41***
	4	C25.3-R	23-Oct-19	1667	2.73			1	***0.79***			30	***23.76***	50	***39.6***	1	***0.79***	82	***64.94***
		C27.6-R	23-Oct-19	299	0.49			1	***24.53***					15	***367.99***			16	***392.52***
		C28.2-R	23-Oct-19	802	1.13			2	***7.93***					35	***138.85***			37	***146.79***
		C34.9-L	23-Oct-19	2072	2.14			1	***0.81***					76	***61.82***	5	***4.07***	82	***66.7***
		C36.6-L	24-Oct-19	1717	2.39									23	***20.14***	1	***0.88***	24	***21.01***
		C47.8-L	25-Oct-19	1134	1.44							20	***44.11***	110	***242.62***	9	***19.85***	139	***306.58***
		C48.2-R	24-Oct-19	1018	1.01									25	***87.65***	14	***49.09***	39	***136.74***
		C49.0-L	25-Oct-19	547	0.93									5	***35.39***	13	***92.03***	18	***127.42***
		C49.0-R	24-Oct-19	354	0.72									9	***127.2***	4	***56.53***	13	***183.74***
		C49.8-L	26-Oct-19	2134	2.45									90	***62.06***	11	***7.58***	101	***69.64***
		C49.8-R	24-Oct-19	1408	2.39									58	***62.03***	10	***10.7***	68	***72.73***
		C52.2-L	26-Oct-19	602	0.43									5	***69.38***			5	***69.38***
		C52.2-R	24-Oct-19	2201	3.79									26	***11.22***	7	***3.02***	33	***14.24***
		C53.6-L	25-Oct-19	1260	1.52									15	***28.24***	1	***1.88***	16	***30.12***
	Session Summary			**1229.6**	**24.00**	**0**	***0***	**5**	***0.61***	**0**	***0***	**50**	***6.1***	**542**	***66.12***	**76**	***9.27***	**673**	***82.1***
	5	C10.7-R	01-Nov-19	340	0.91									20	***231.69***	1	***11.58***	21	***243.27***
		C10.9-L	02-Nov-19	1680	2.18											15	***14.74***	15	***14.74***
		C11.5-R	02-Nov-19	1361	1.90			1	***1.39***					7	***9.75***	2	***2.78***	10	***13.92***
		C19.0-L	27-Oct-19	1064	1.28			1	***2.64***			20	***52.87***	87	***229.97***	4	***10.57***	112	***296.05***
		C20.4-R	27-Oct-19	1428	1.47			2	***3.42***			15	***25.65***	70	***119.72***	20	***34.21***	107	***183***
		C21.3-L	03-Nov-19	1571	2.04									81	***91.03***	15	***16.86***	96	***107.89***
		C22.9-R	03-Nov-19	743	1.22							3	***11.9***	15	***59.52***	11	***43.65***	29	***115.08***
		C23.4-L	03-Nov-19	927	0.93									30	***125.27***			30	***125.27***
		C30.5-R	28-Oct-19	1430	1.53									25	***41.25***	1	***1.65***	26	***42.9***
		C30.6-L	03-Nov-19	1552	1.84									25	***31.52***			25	***31.52***
		C32.0-R	27-Oct-19	1228	1.37			1	***2.14***					10	***21.4***	1	***2.14***	12	***25.68***
		C33.3-R	03-Nov-19	1402	1.56											1	***1.64***	1	***1.64***
		C35.7-R	26-Oct-19	1255	1.25									20	***45.97***			20	***45.97***
		C36.9-R	26-Oct-19	1730	2.27									80	***73.34***	1	***0.92***	81	***74.25***
		C40.0-L	27-Oct-19	509	1.09									30	***195.43***			30	***195.43***
		C47.2-R	24-Oct-19	595	1.06									78	***445.22***			78	***445.22***
	Session Summary			**1175.9**	**24.00**	**0**	***0***	**5**	***0.64***	**0**	***0***	**38**	***4.85***	**578**	***73.73***	**72**	***9.18***	**693**	***88.4***
Section Total All Samples				**77703**	**112.79**	**0**		**31**		**0**		**170**		**2247**		**325**		**2773**	
Section Average All Samples				**1160**	**1.68**	**0**	***0***	**0**	***0.85***	**0**	***0***	**3**	***4.68***	**34**	***61.83***	**5**	***8.94***	**41**	***76.3***
Section Standard Error of Mean						**0**	***0***	**0.14**	***0.42***	**0**	***0***	**0.79**	***1.53***	**5.62**	***11.31***	**0.8**	***2.76***	**6.12**	***12.01***
All Sections Total All Samples				**122936**	**160.17**	***1***	***0***	***113***	***0.02***	***6***	***0***	***530***	***0.1***	***3455***	***0.63***	***1656***	***0.3***	***5761***	***1.05***
All Sections Average All Samples						***0***	***0.02***	***1***	***2.31***	***0***	***0.12***	***5***	***10.85***	***31***	***70.75***	***15***	***33.91***	***51***	***117.97***
All Sections Standard Error of Mean						***0.01***	***0.04***	***0.27***	***2.14***	***0.03***	***0.45***	***0.82***	***3.66***	***3.64***	***9.9***	***2.27***	***6.87***	***5.08***	***17.05***

Appendix F – Life History

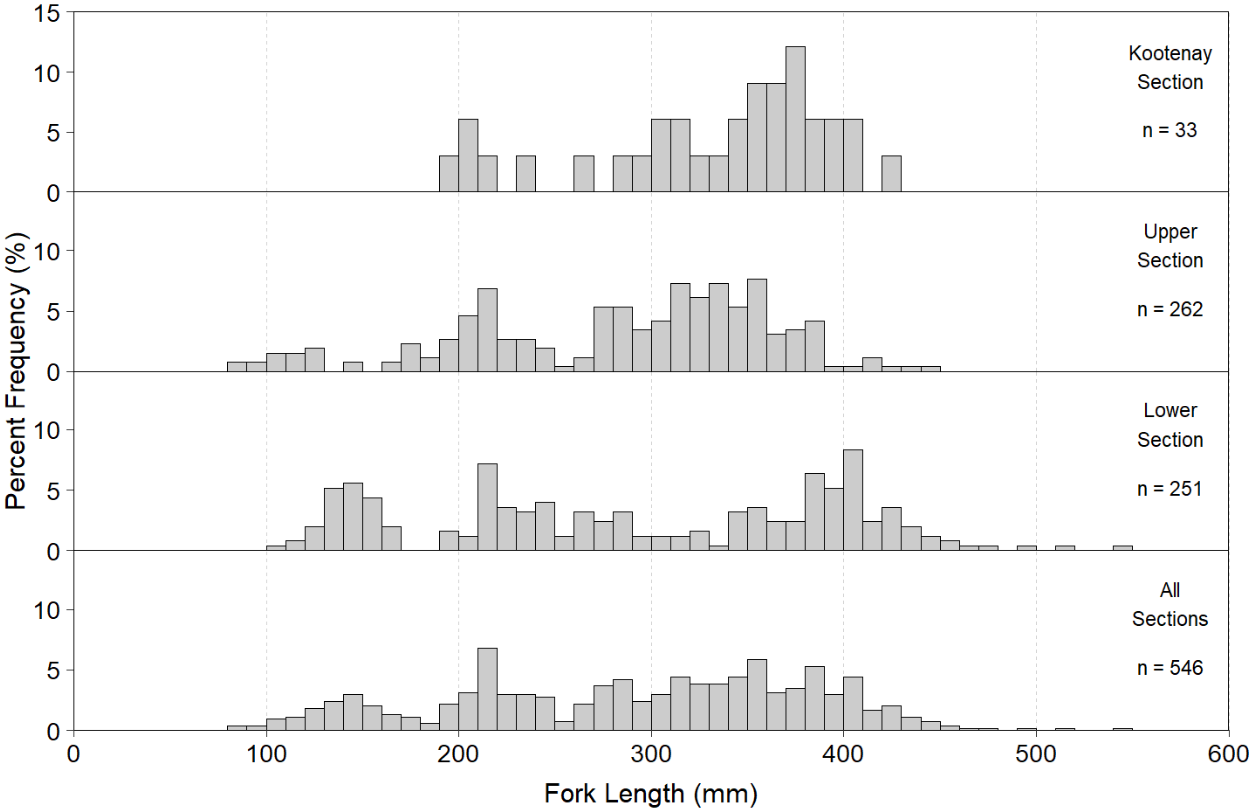

Figure F1. Length-frequency distributions by site for Mountain Whitefish captured by boat electroshocking in sampled sections of the lower Columbia River, 30 September to 3 November 2019.

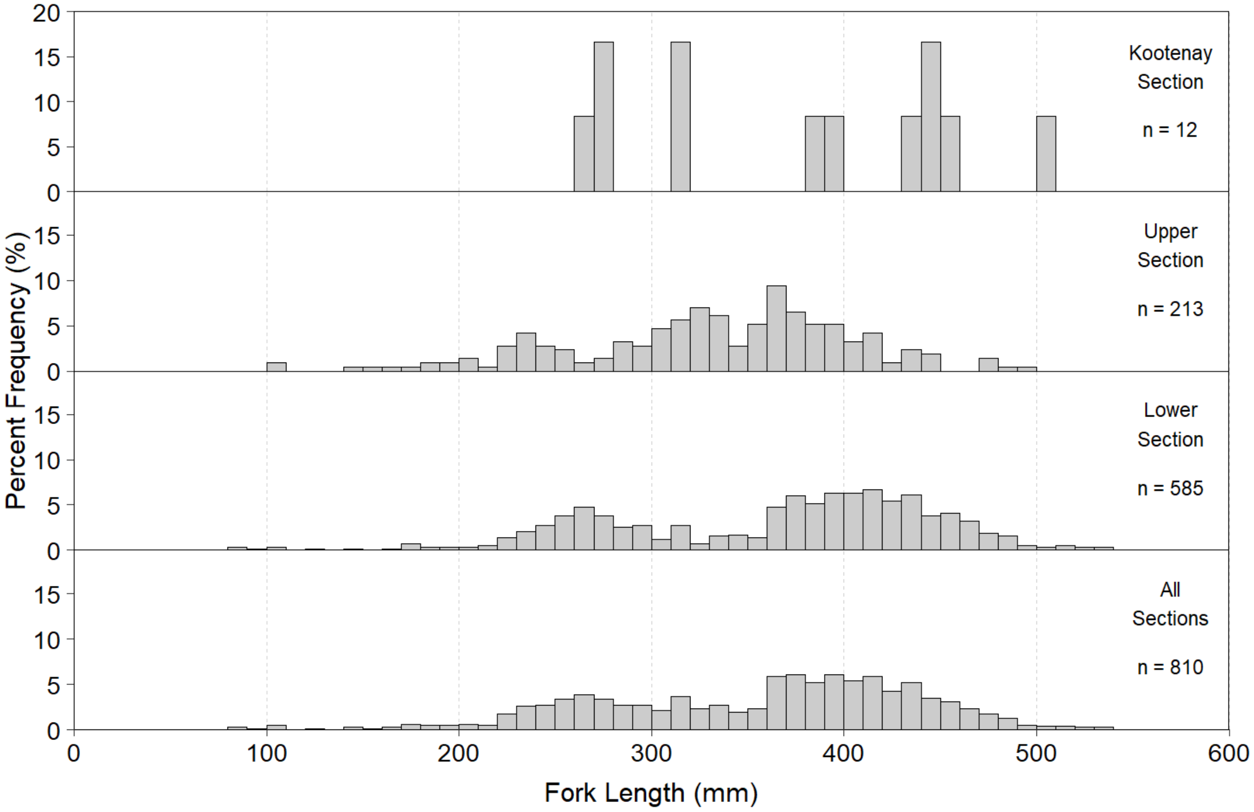

Figure F2. Length-frequency distributions by site for Rainbow Trout captured by boat electroshocking in sampled sections of the lower Columbia River, 30 September to 3 November 2019.

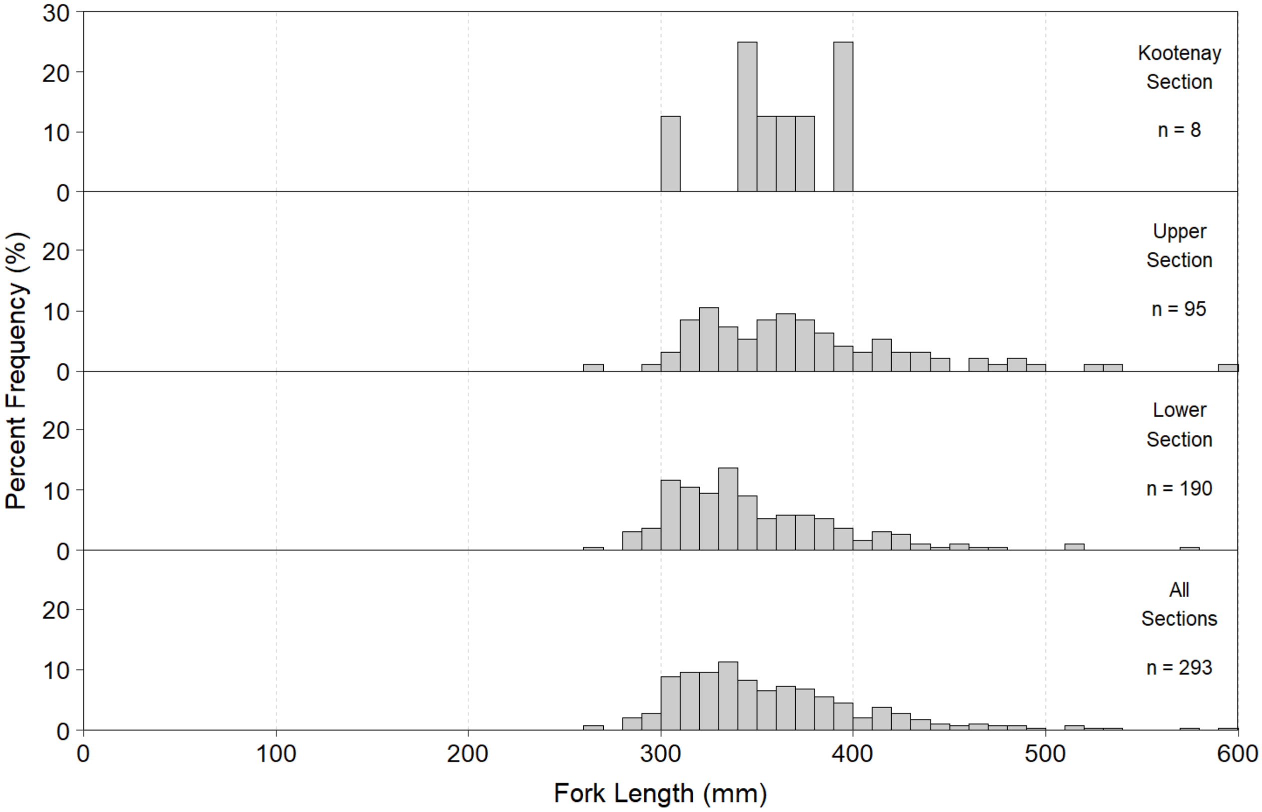

Figure F3. Length-frequency distributions by site for Walleye captured by boat electroshocking in sampled sections of the lower Columbia River, 30 September to 3 November 2019.

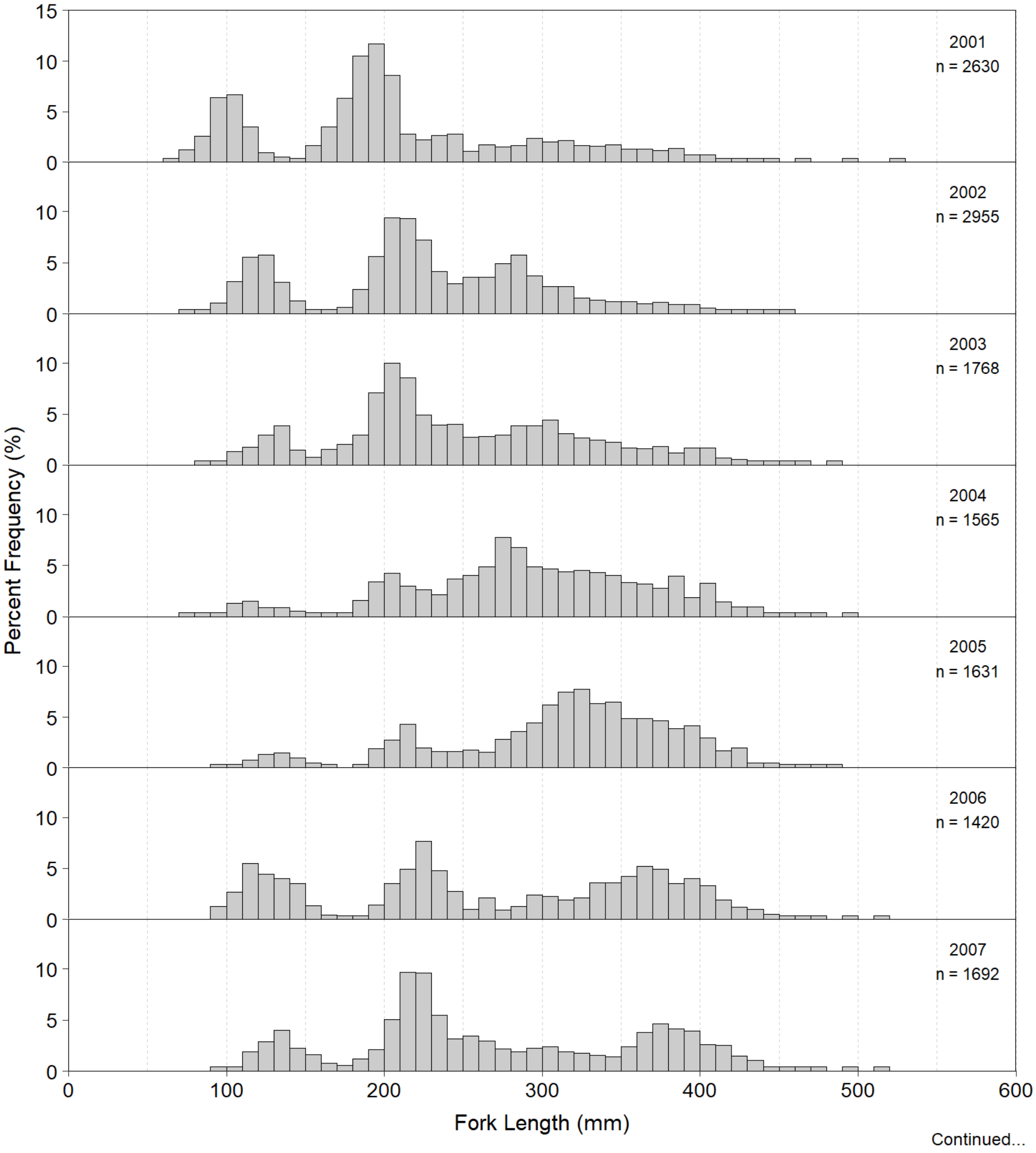

Figure F4. Length-frequency distributions by year for Mountain Whitefish captured by boat electroshocking in sampled sections of the lower Columbia River, 2001 to 2019.

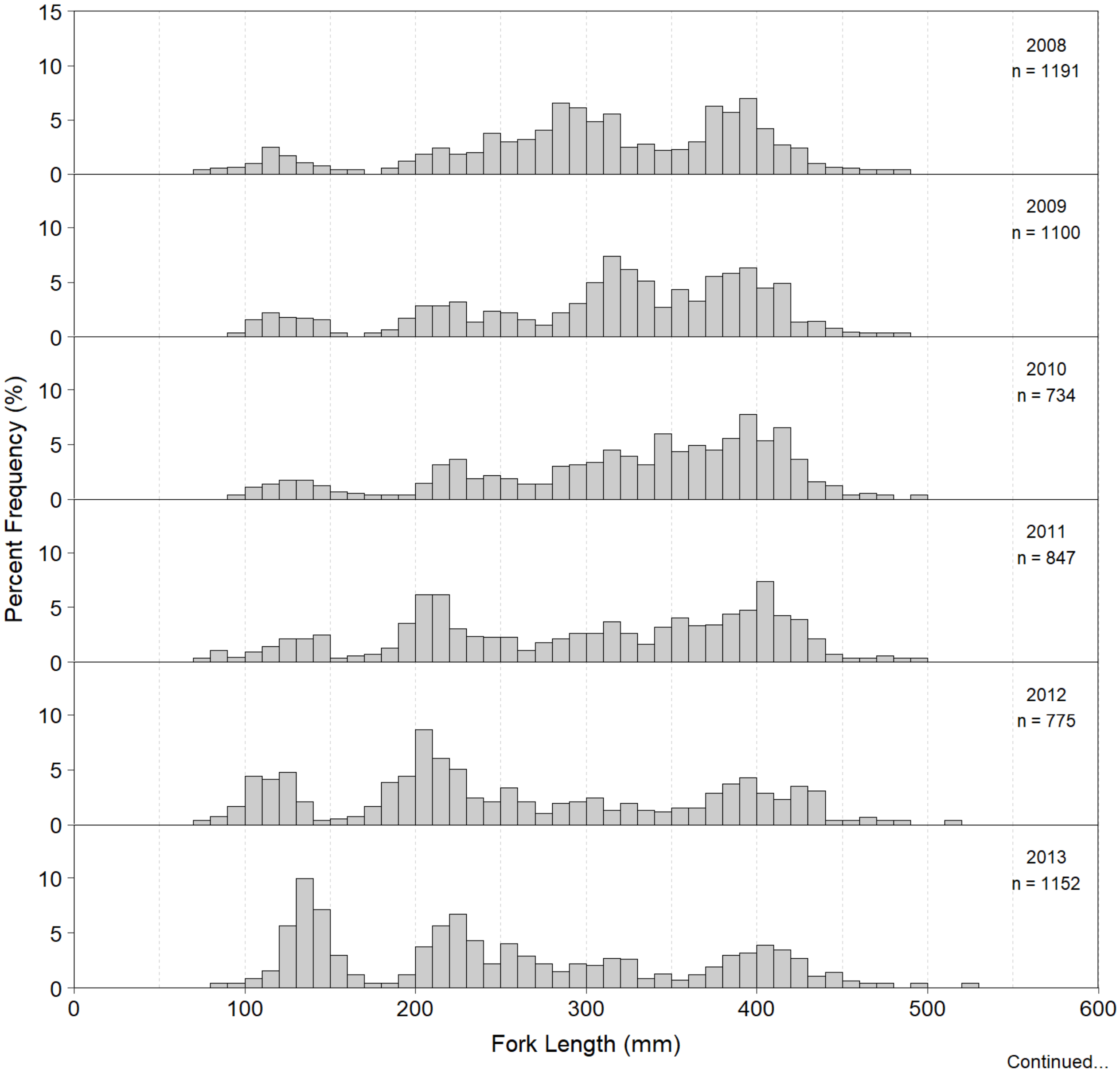

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Figure F4. Continued.

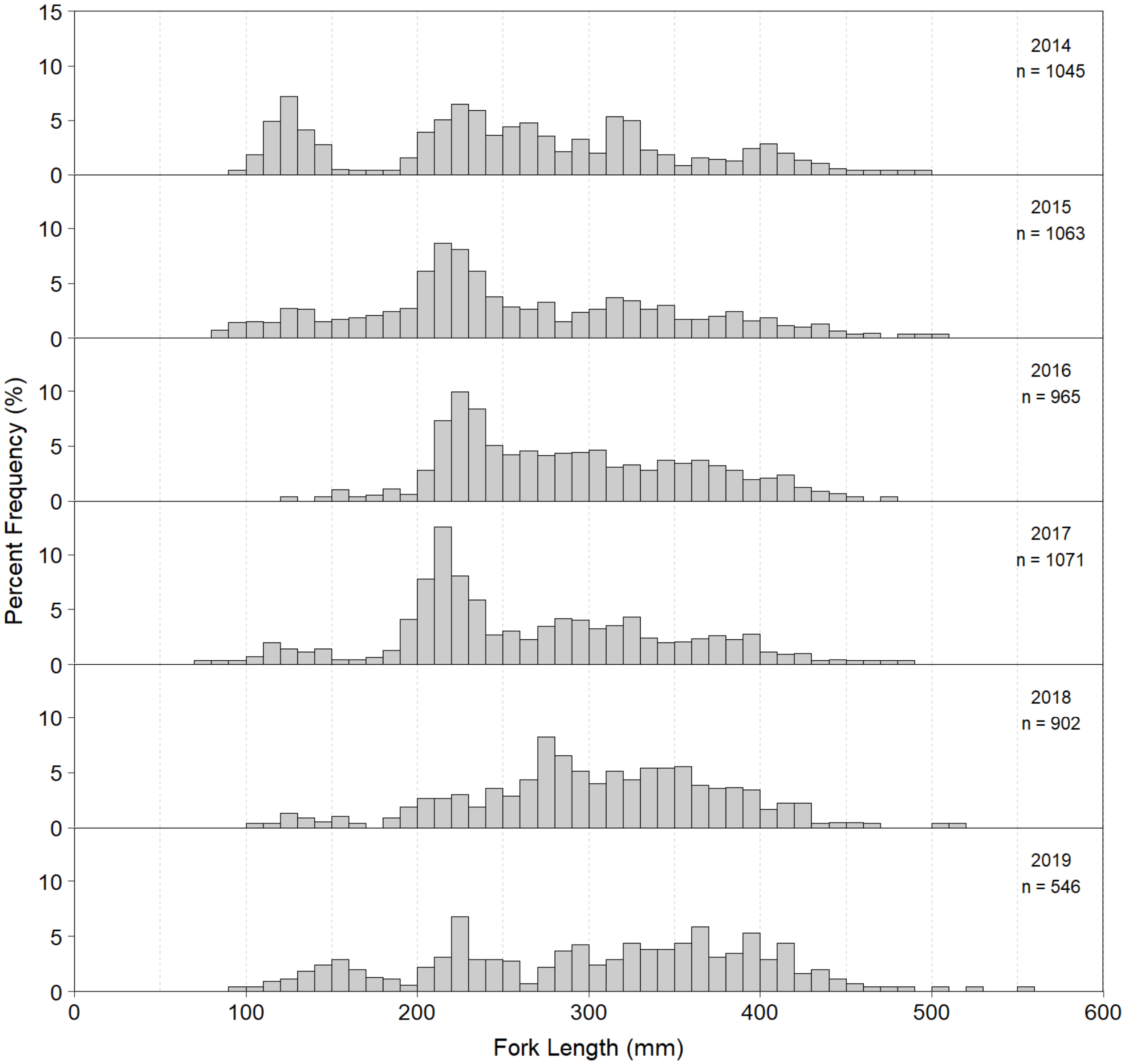

Figure F4. Concluded.

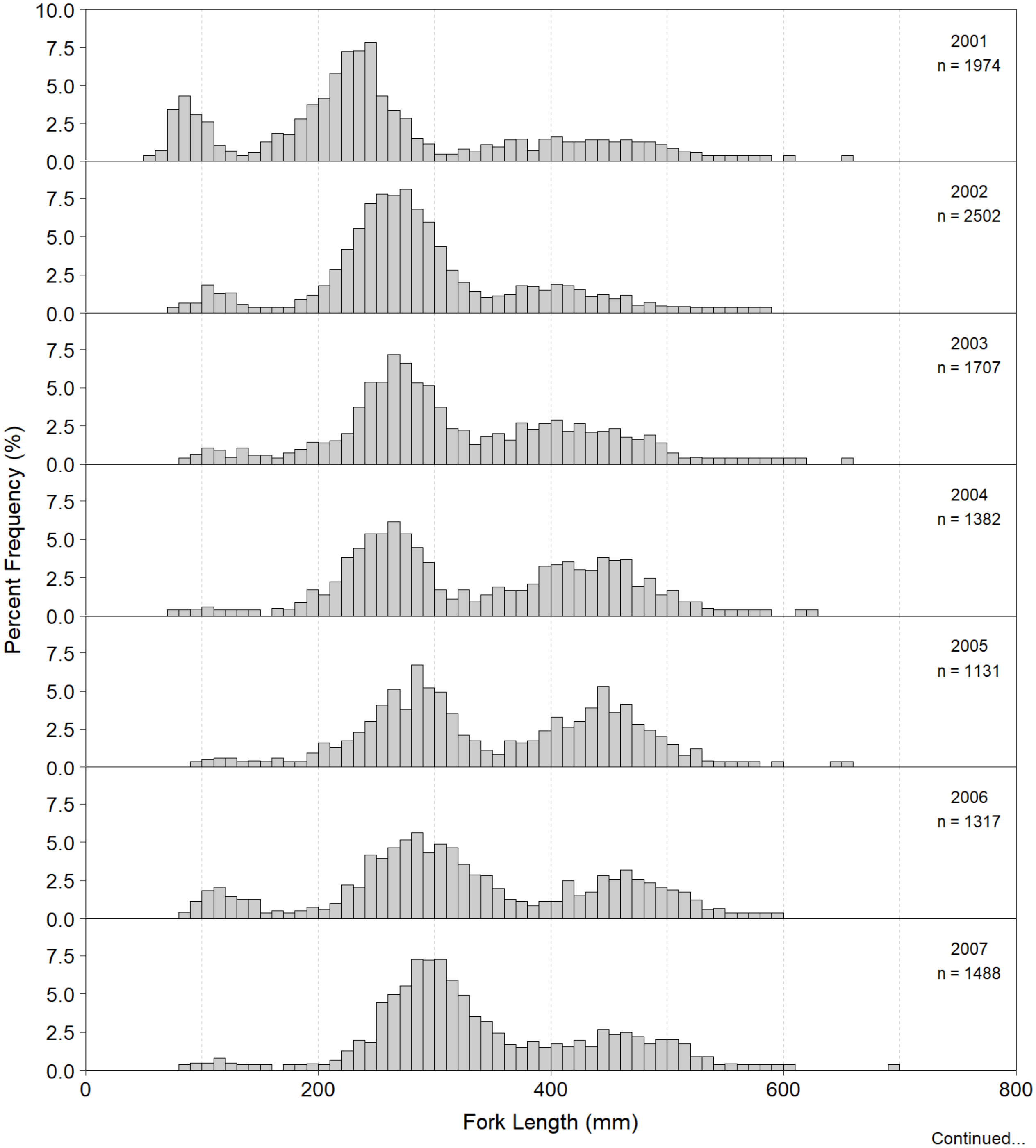

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Figure F5. Length-frequency distributions by year for Rainbow Trout captured by boat electroshocking in sampled sections of the lower Columbia River, 2001 to 2019.

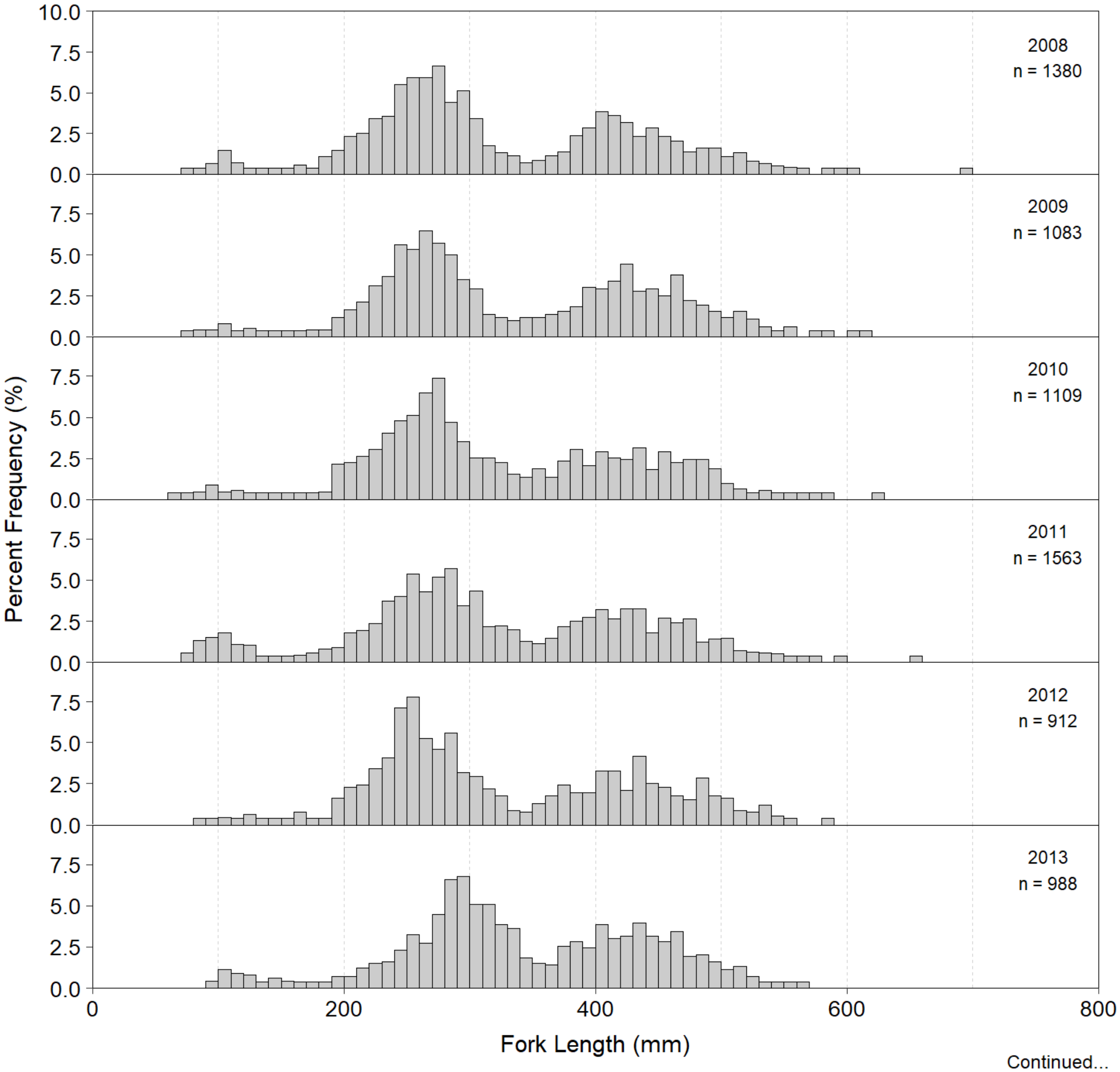

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Figure F5. Continued.

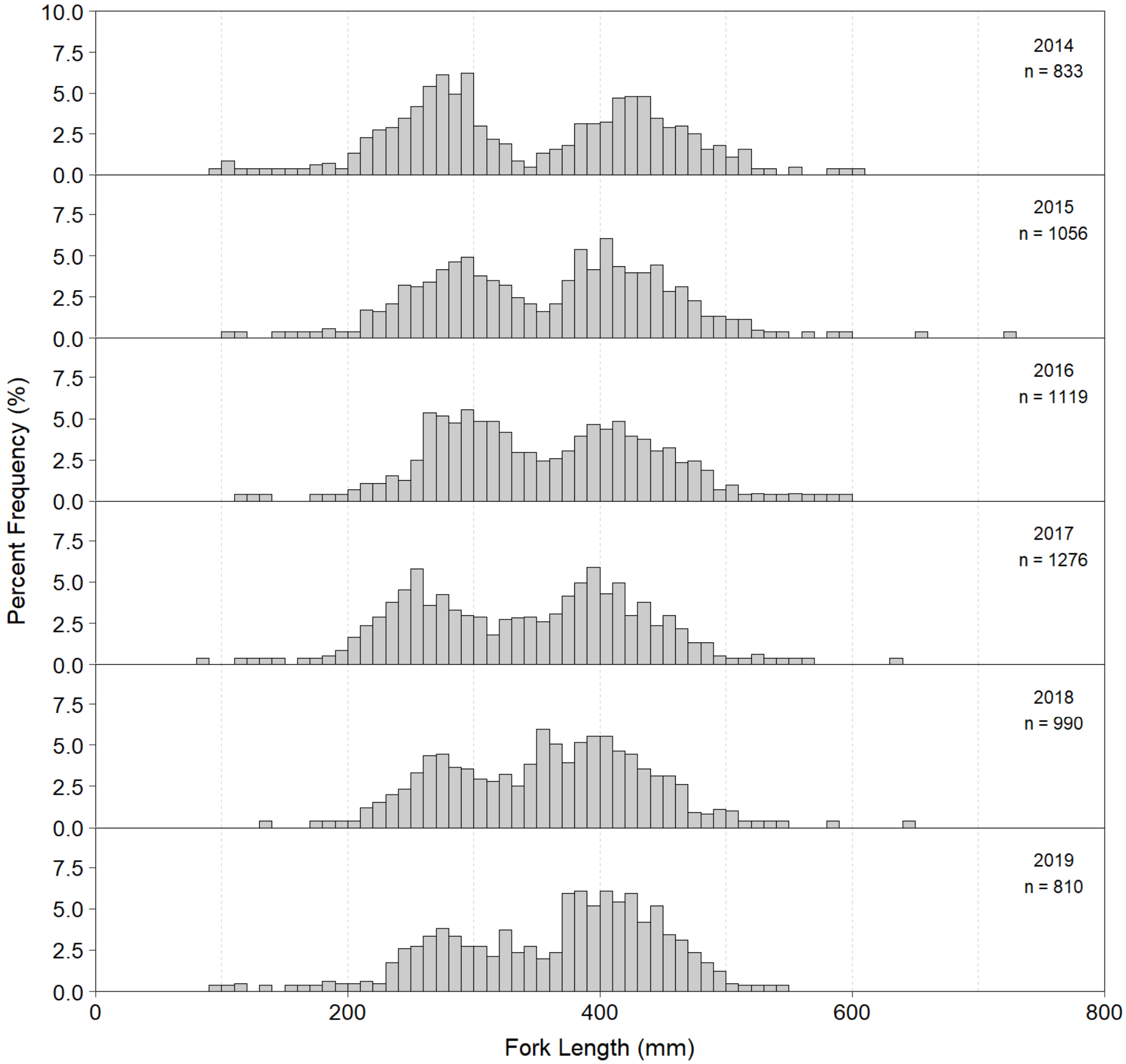

Figure F5. Concluded.

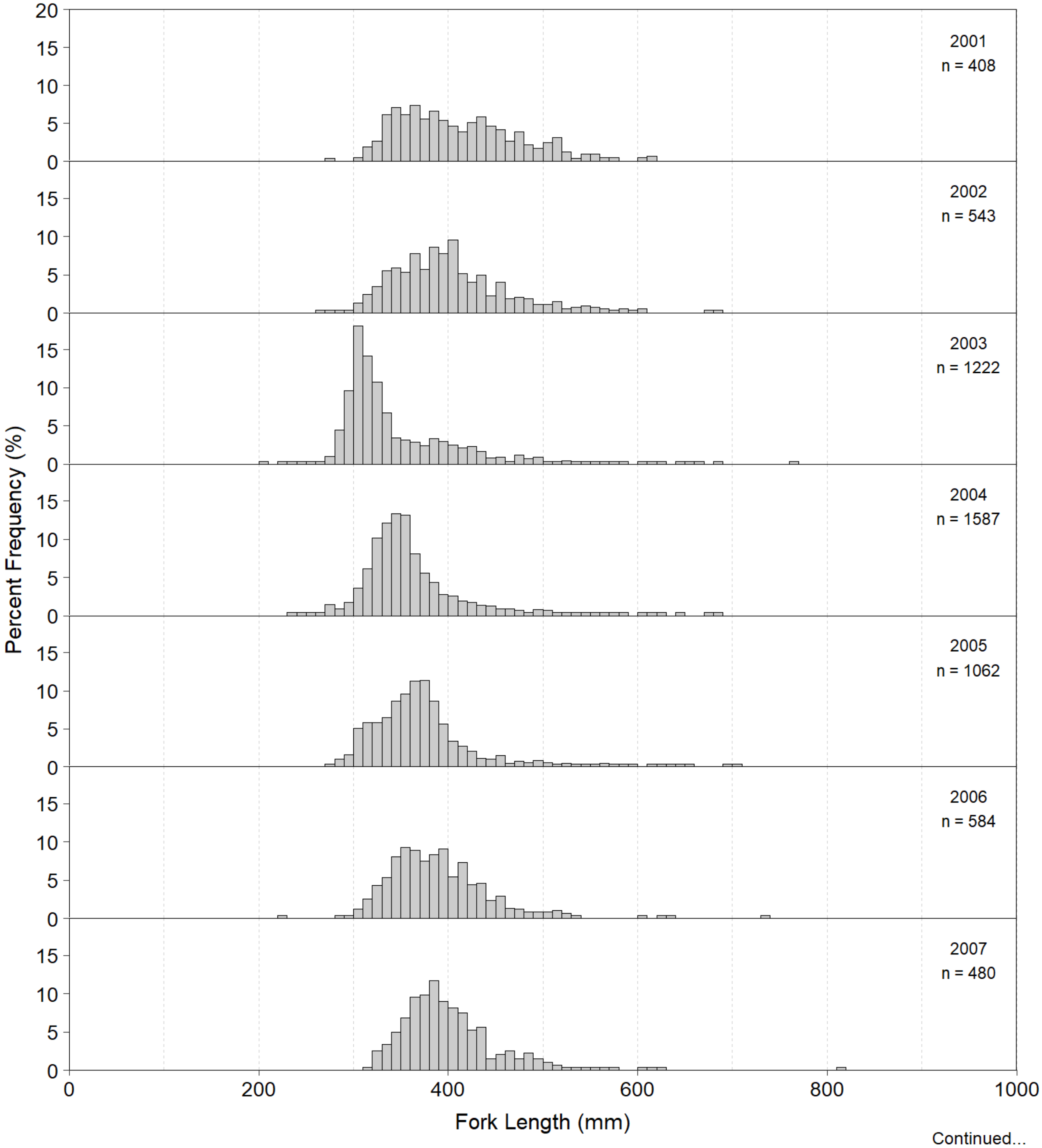

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Figure F6. Length-frequency distributions by year for Walleye captured by boat electroshocking in sampled sections of the lower Columbia River, 2001 to 2019.

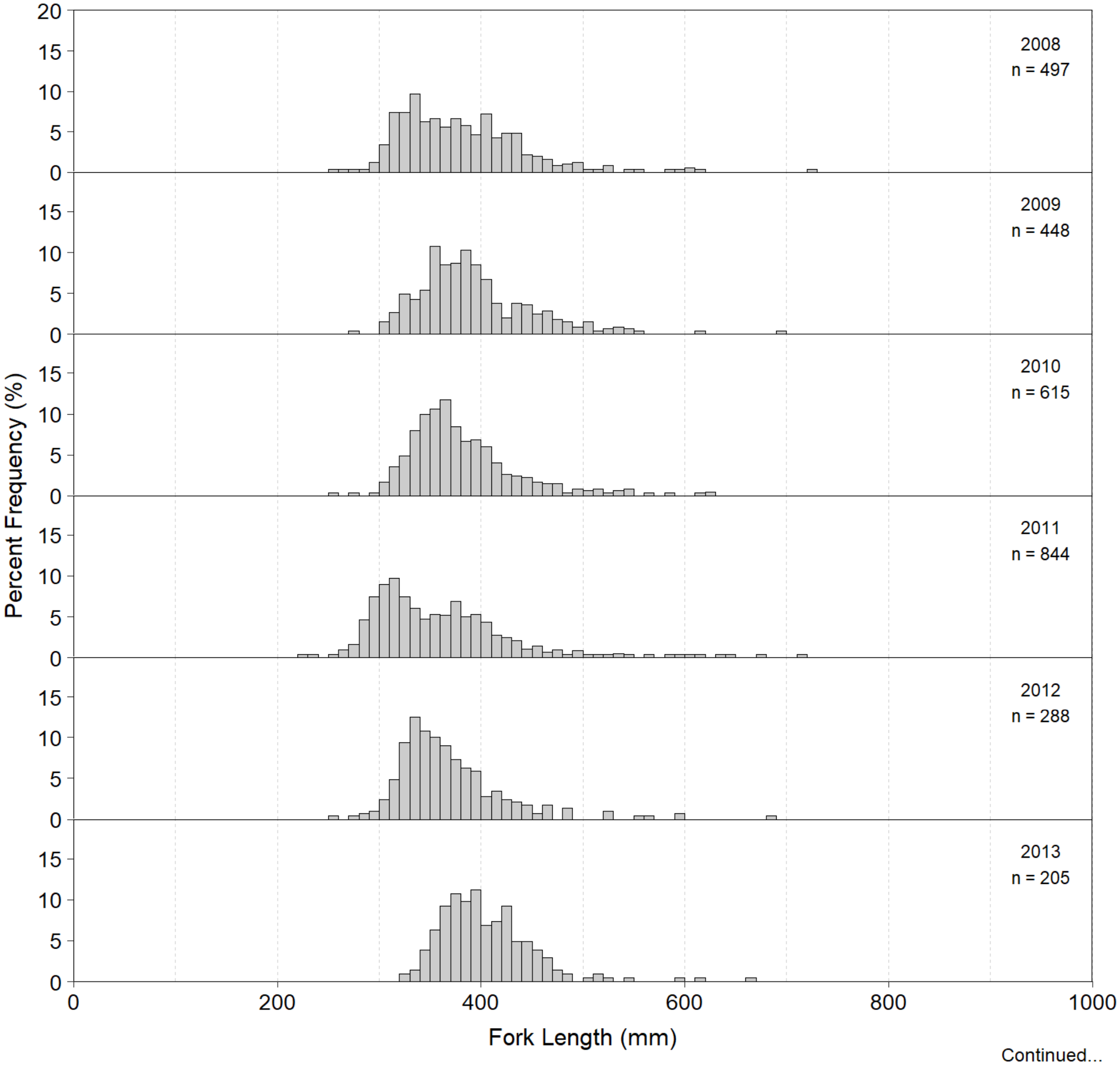

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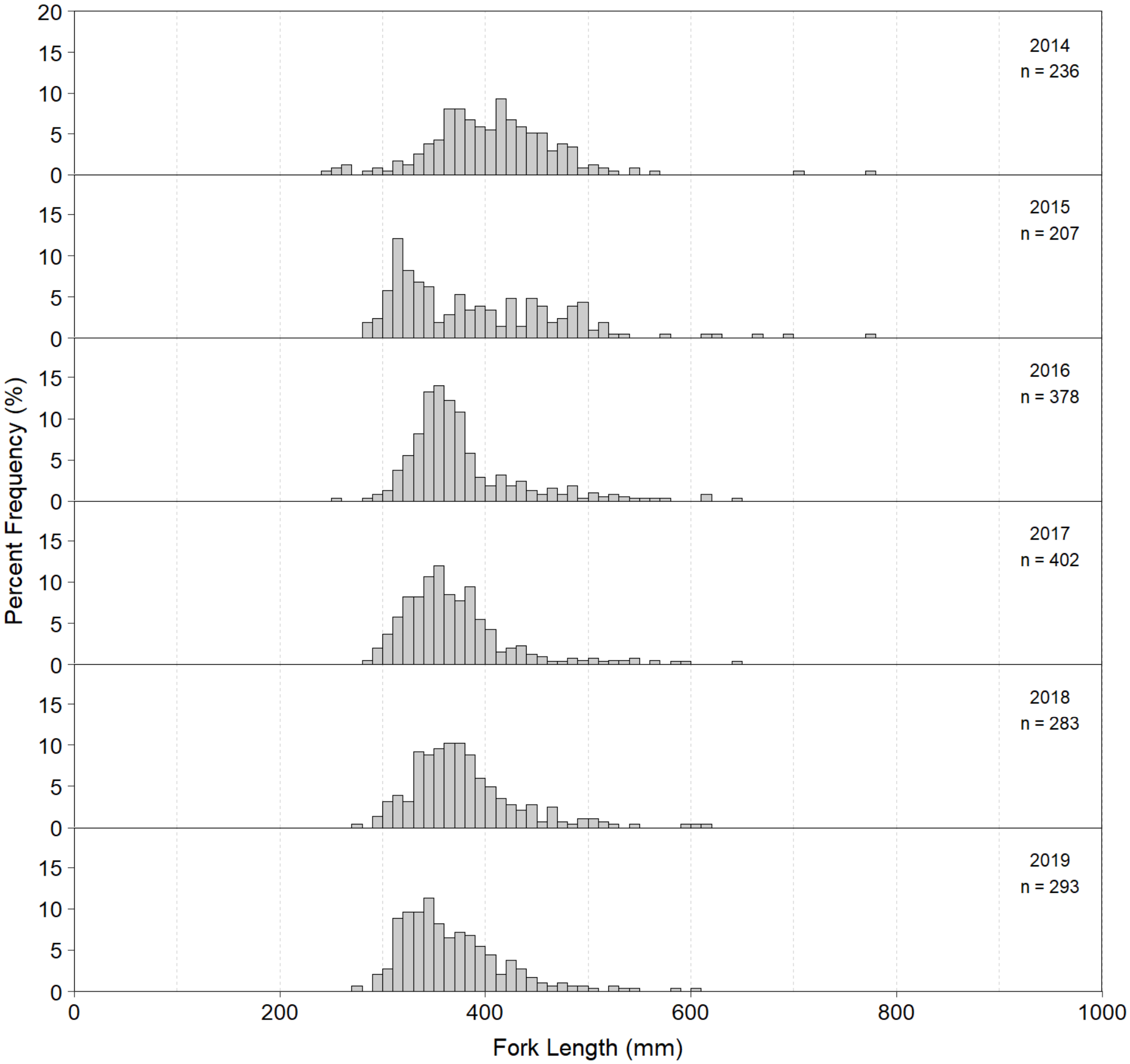
Figure F6. Continued.



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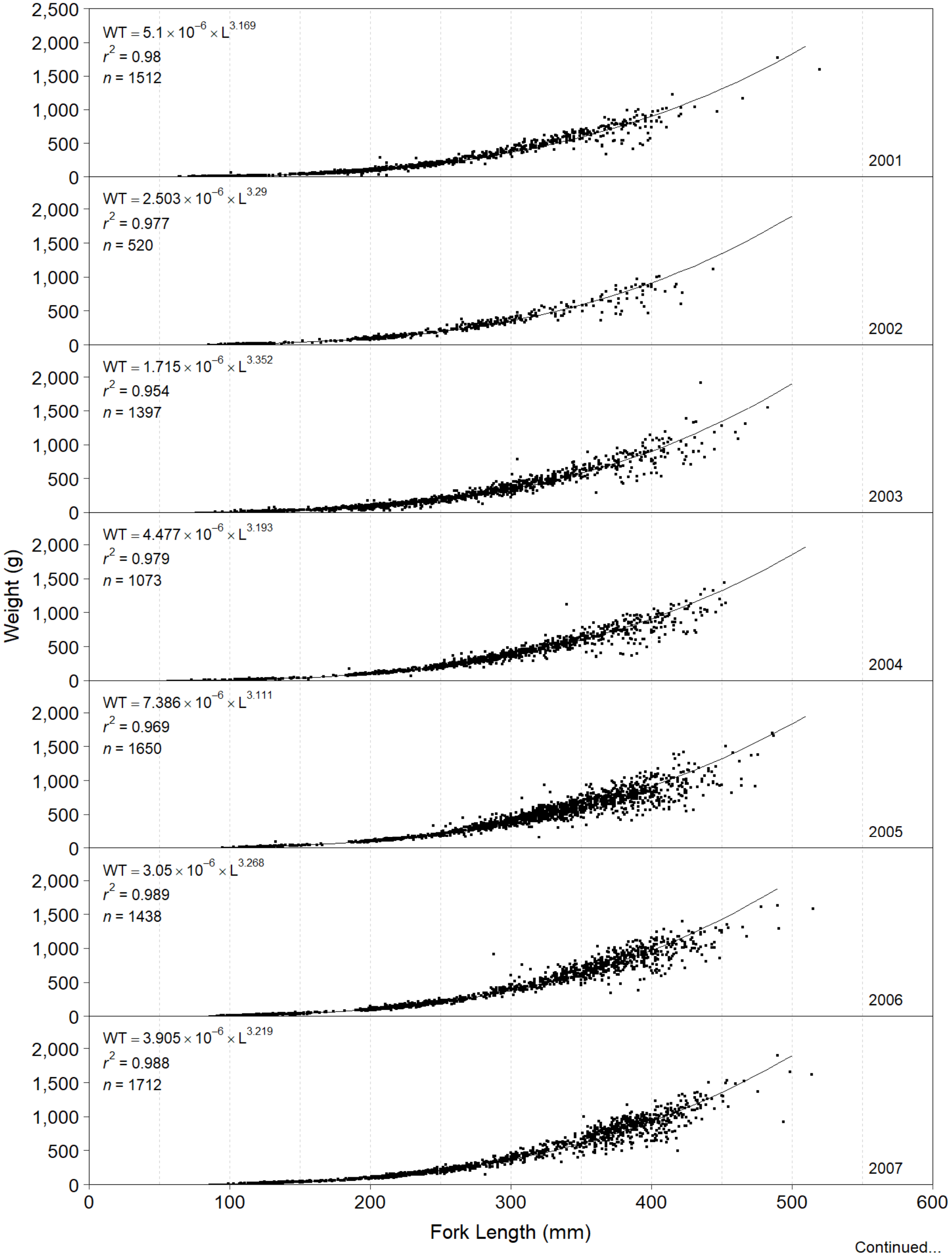

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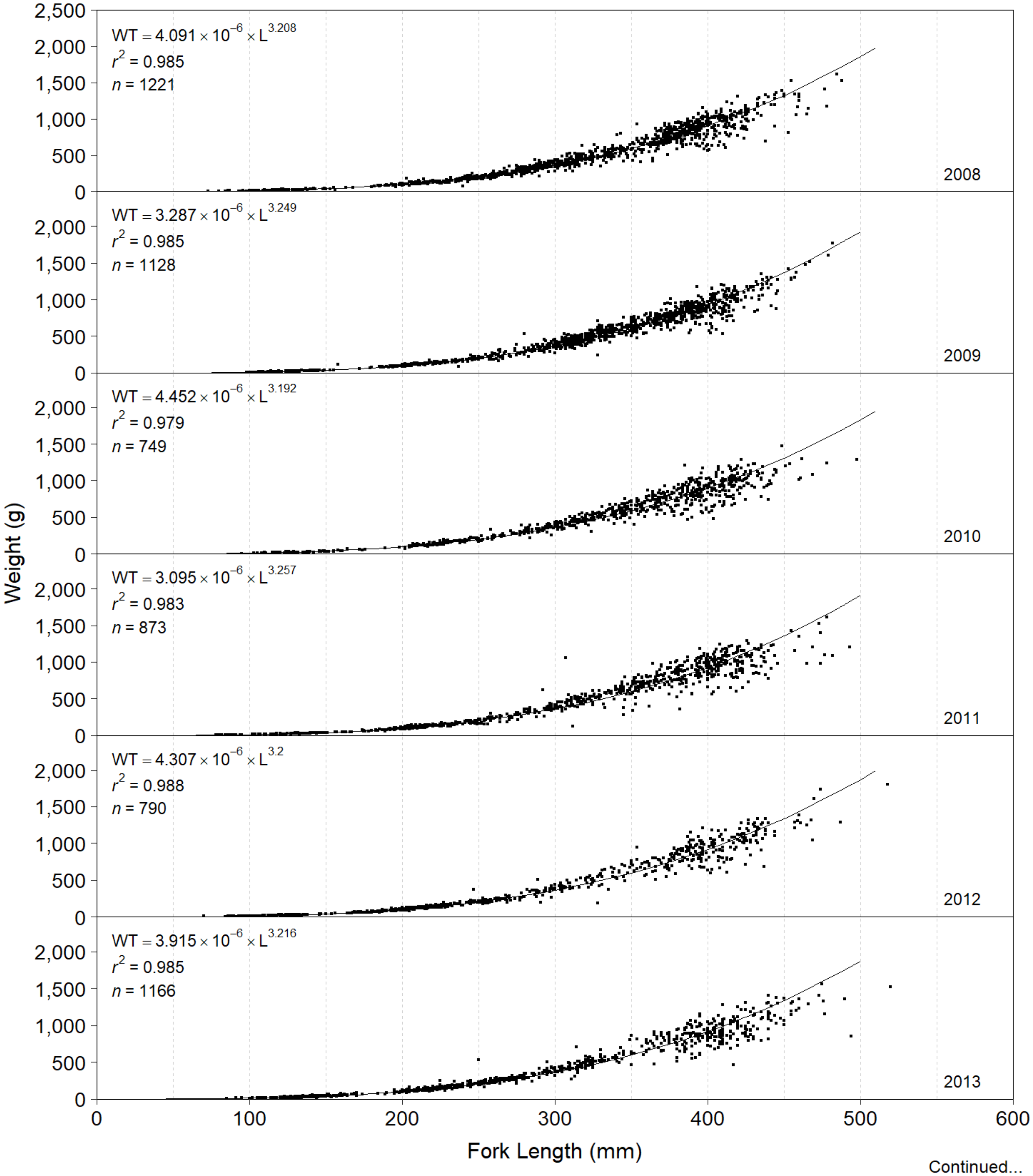
Figure F7. Length-weight regressions for Mountain Whitefish captured by boat electroshocking in the lower Columbia River, 2001 to 2019.



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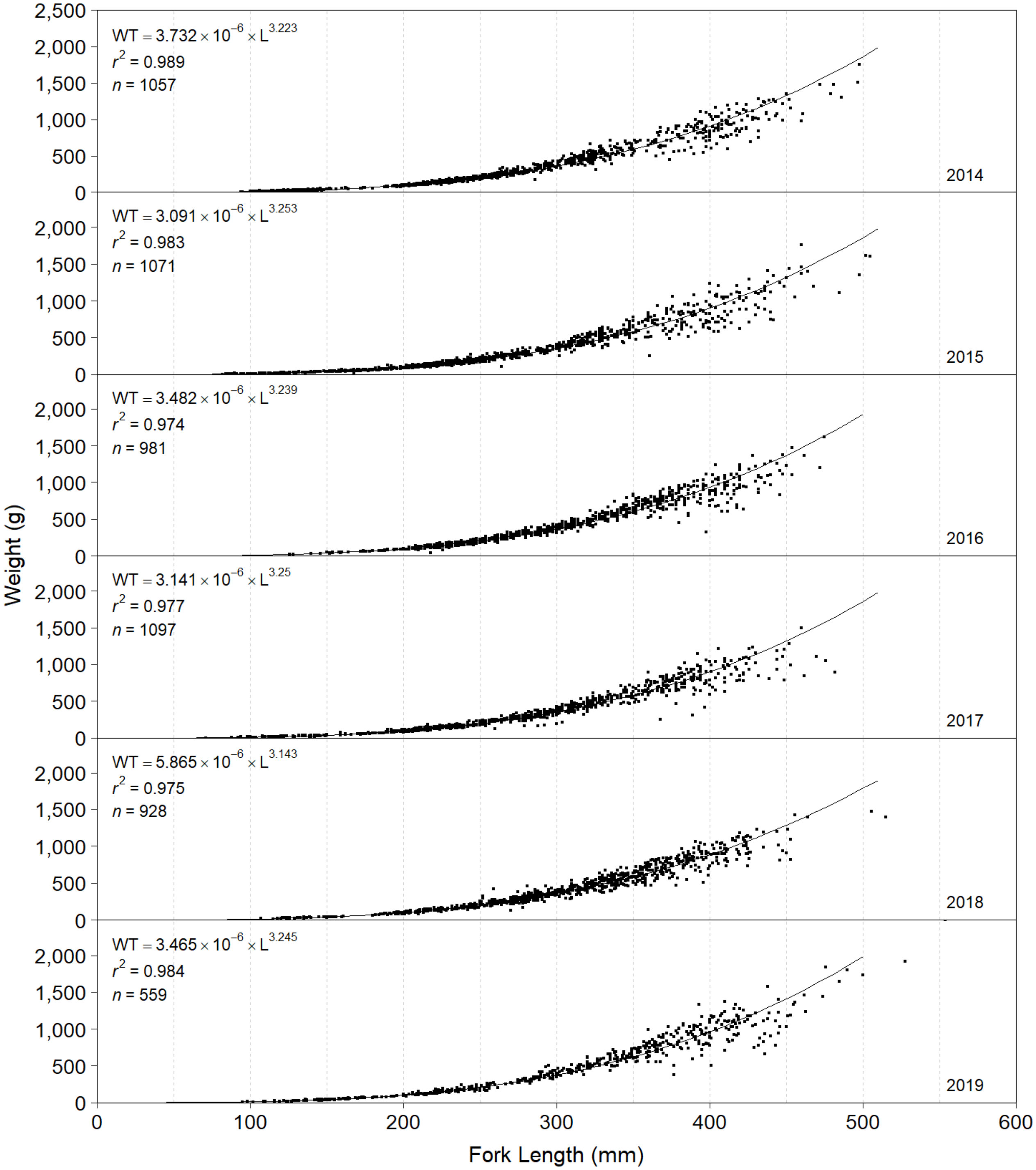

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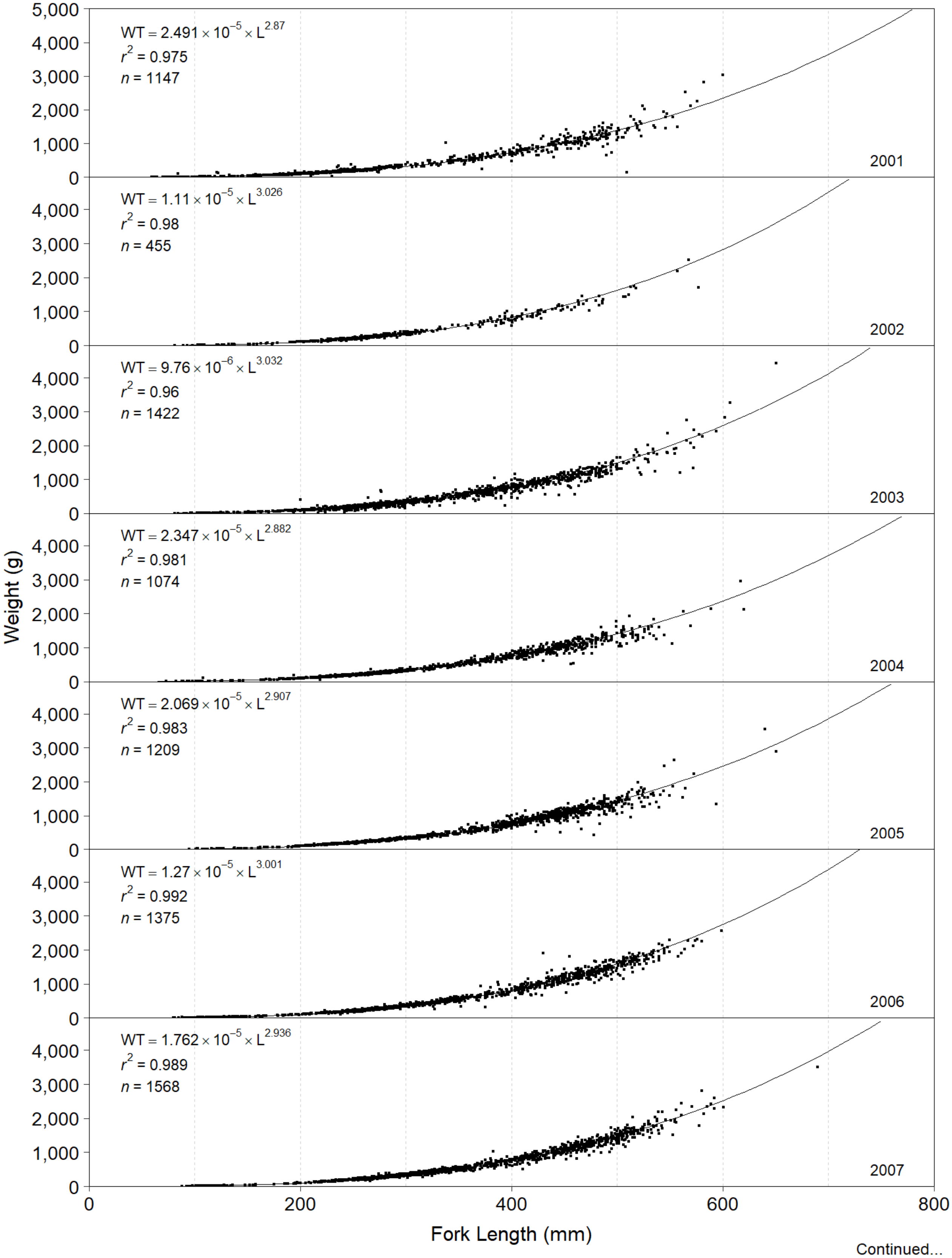

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Figure F8. Length-weight regressions for Rainbow Trout captured by boat electroshocking in the lower Columbia River, 2001 to 2019.

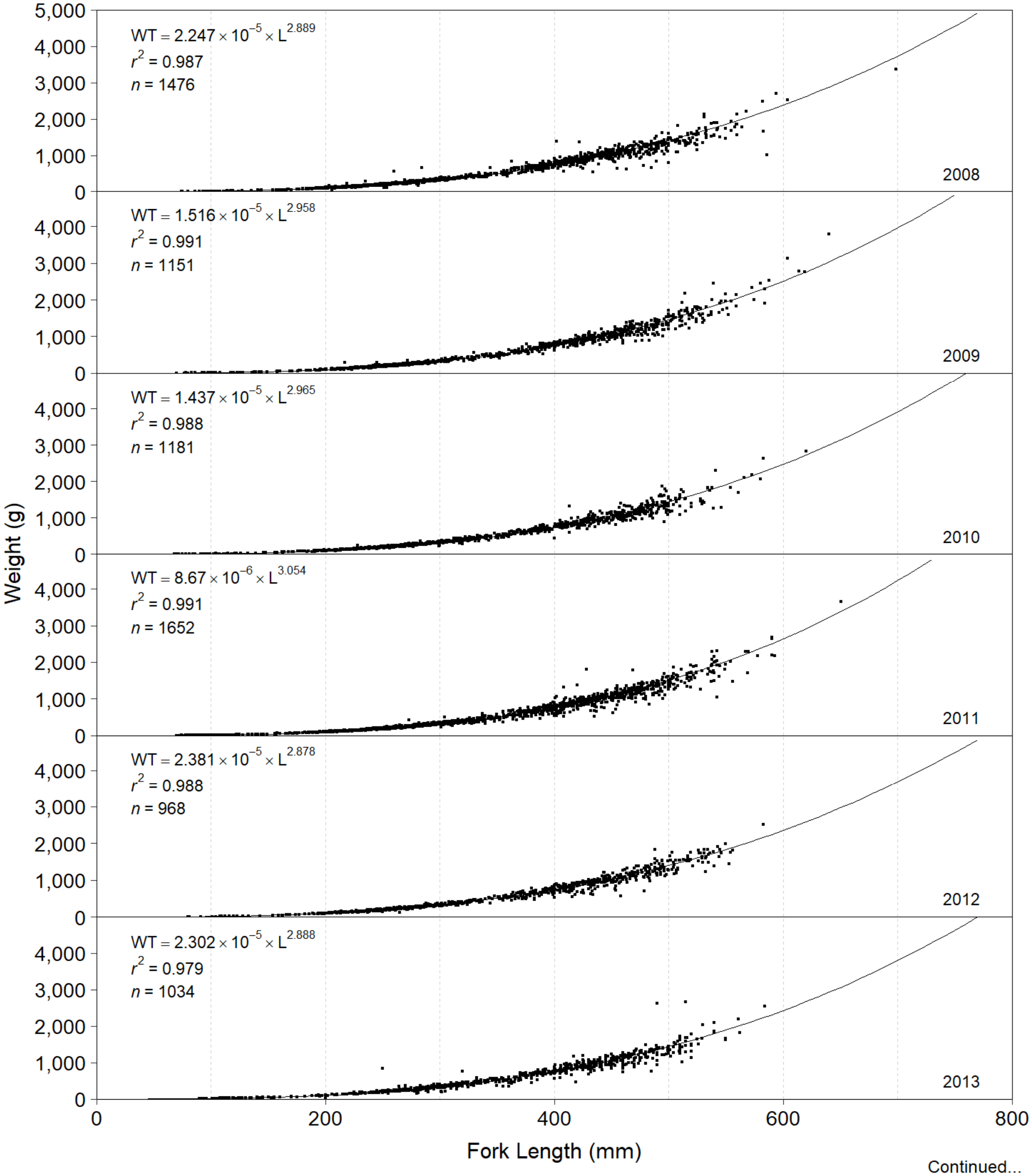

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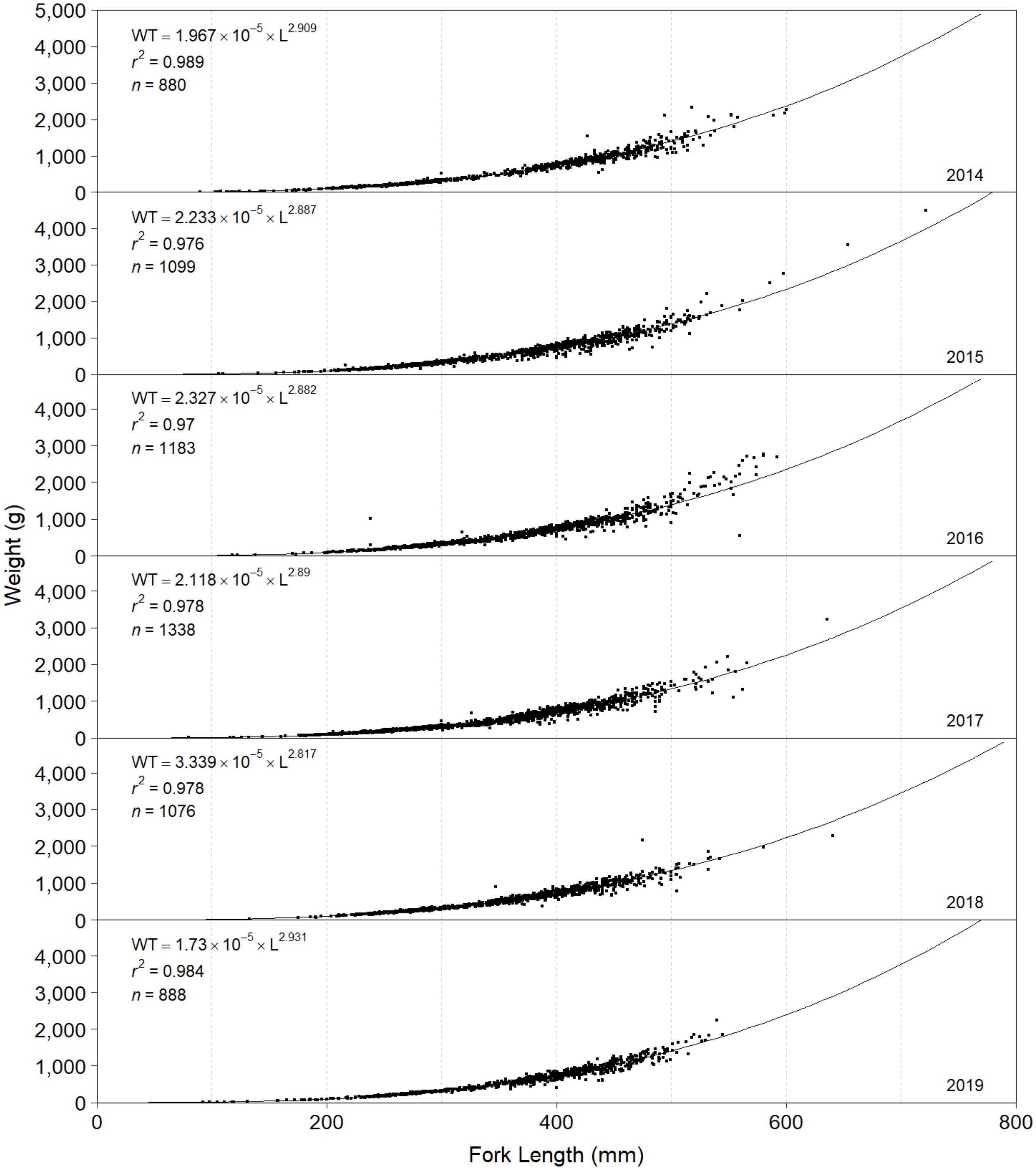
Figure F8. Continued.



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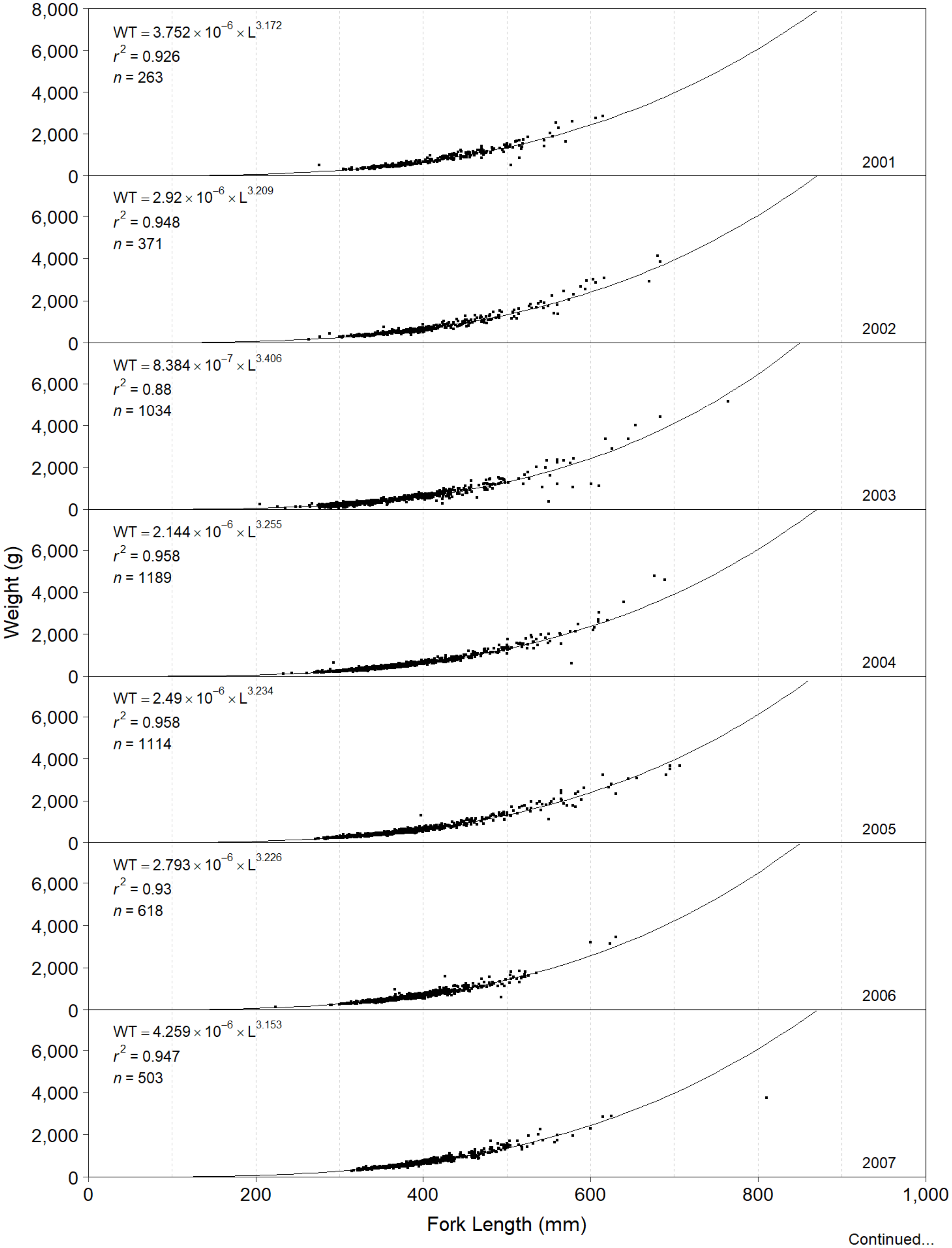

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Figure F9. Length-weight regressions for Walleye captured by boat electroshocking in the lower Columbia River, 2001 to 2019.

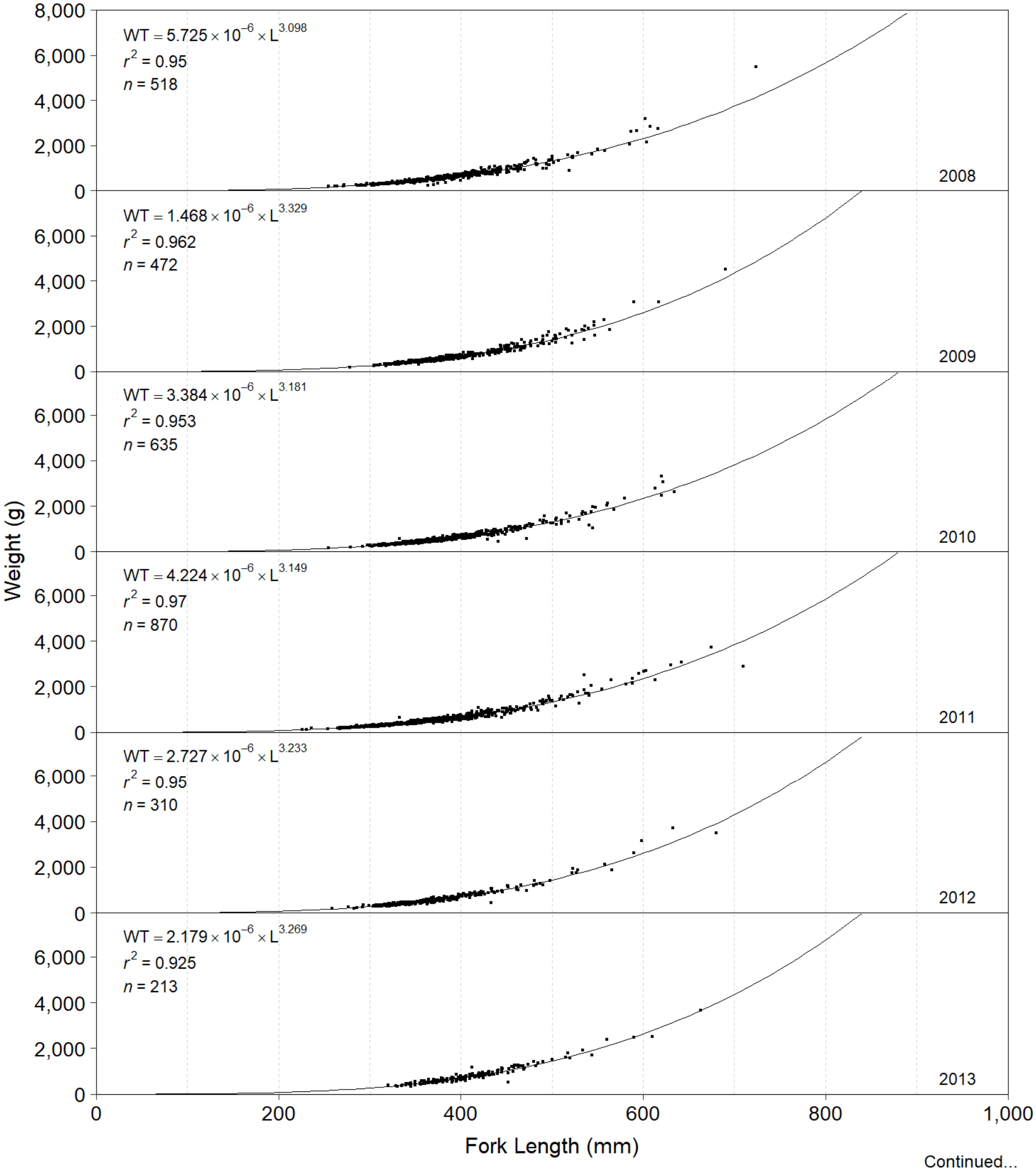

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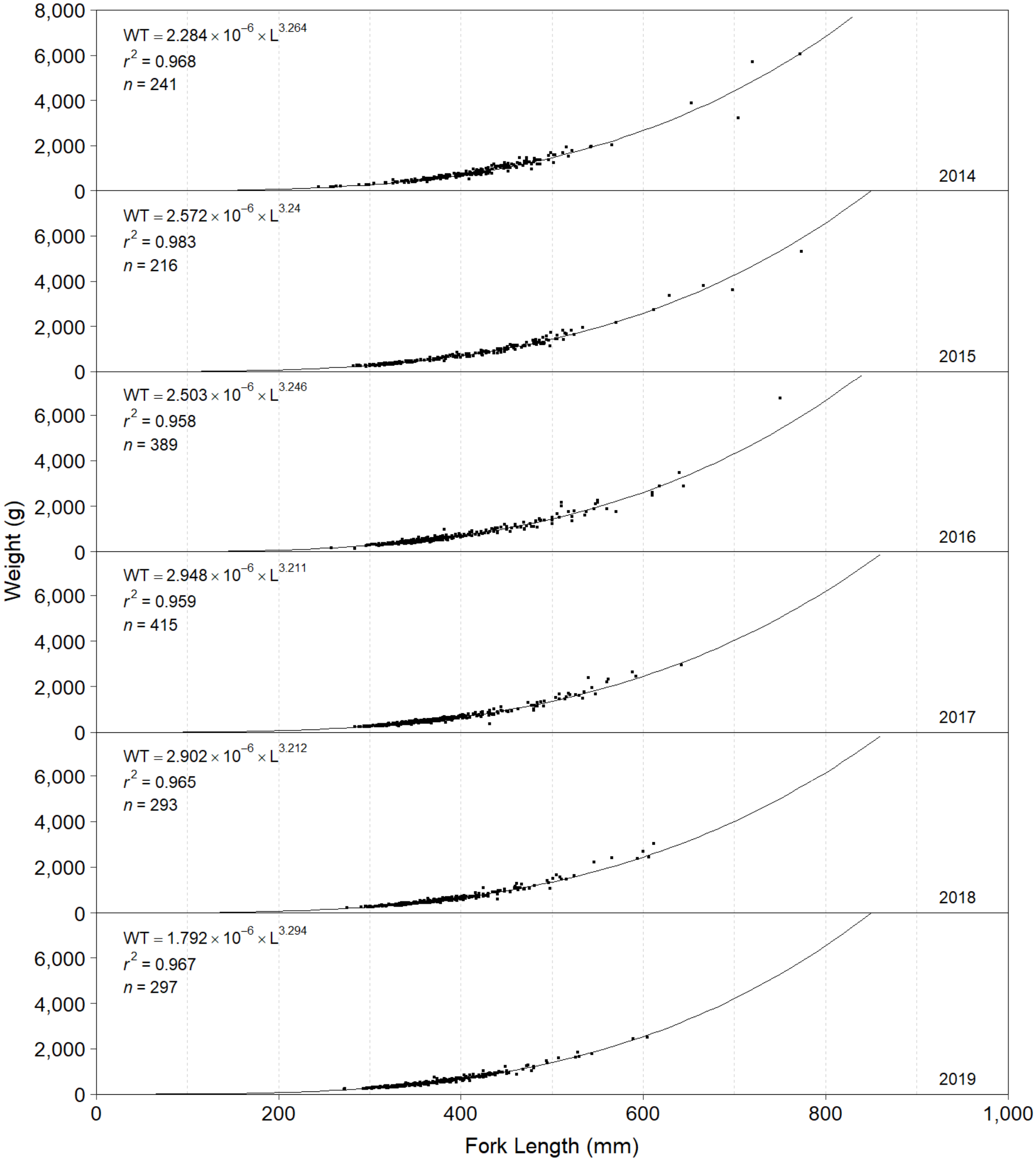
Figure F9. Continued.



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Appendix G – Additional Results

Appendix G: Additional Figures

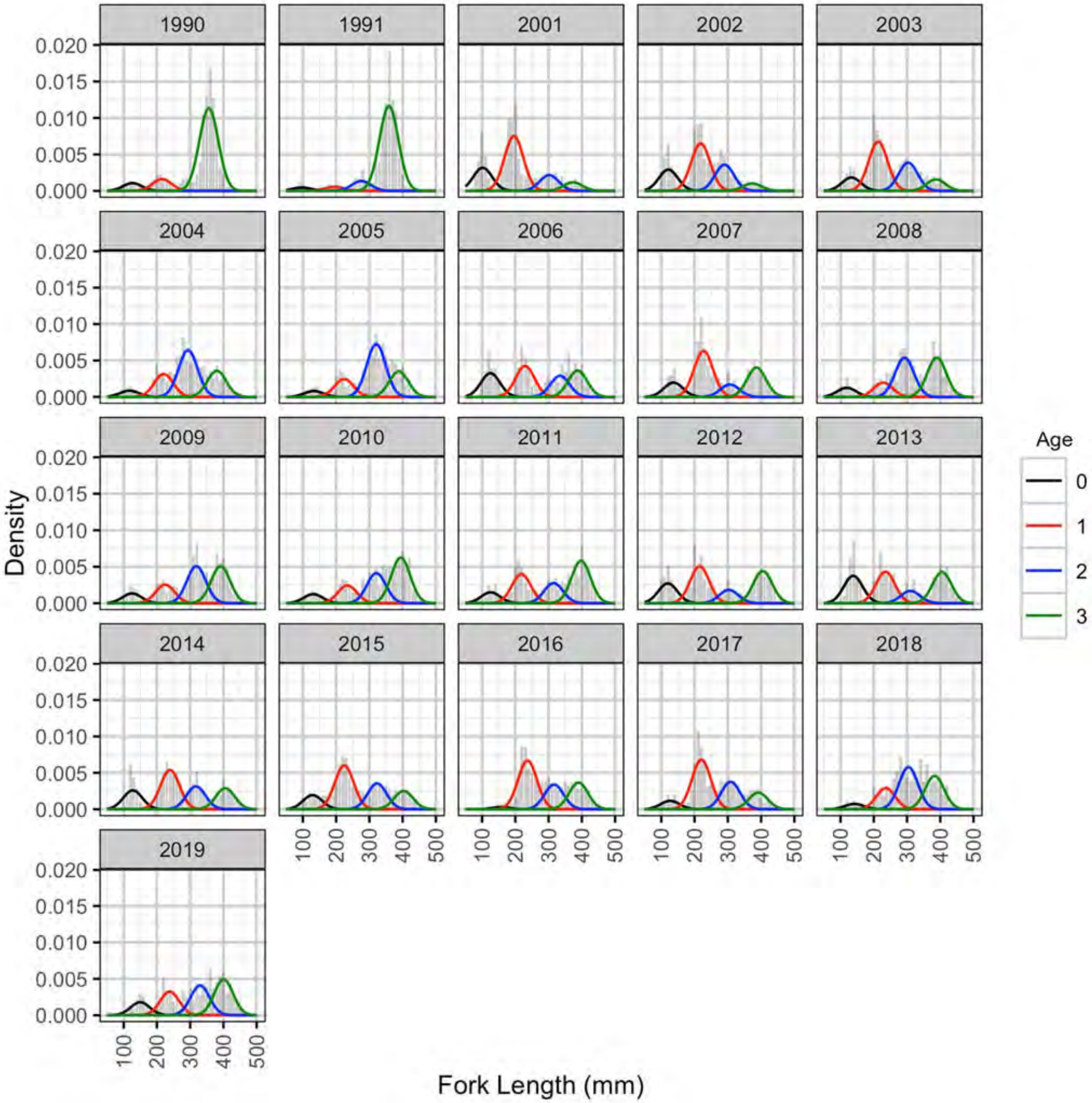


Figure G1: Predicted length-density plot for Mountain Whitefish by life stage and year.

Appendix G: Additional Figures

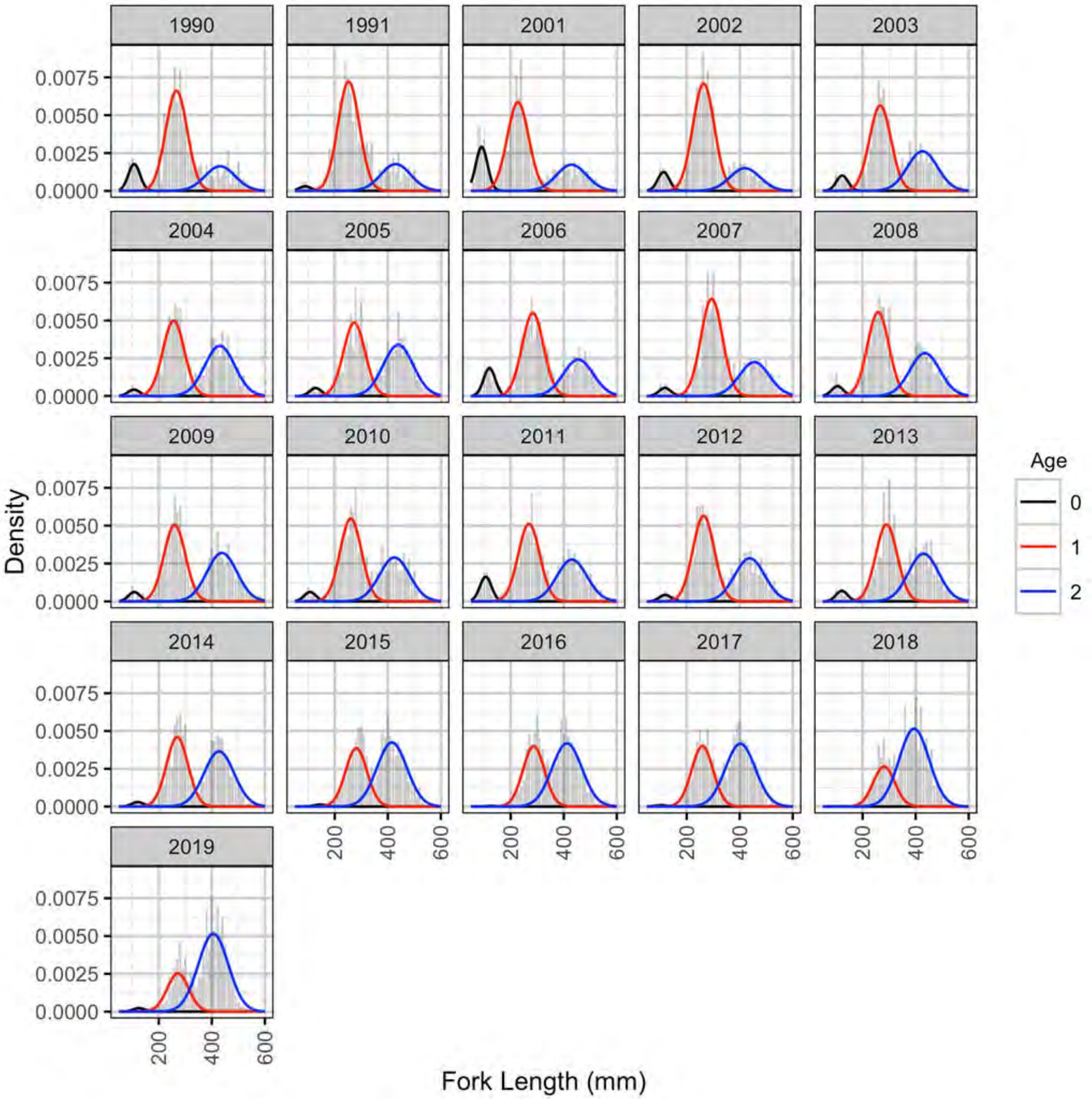


Figure G2: Predicted length-density plot for Rainbow Trout by life stage and year.

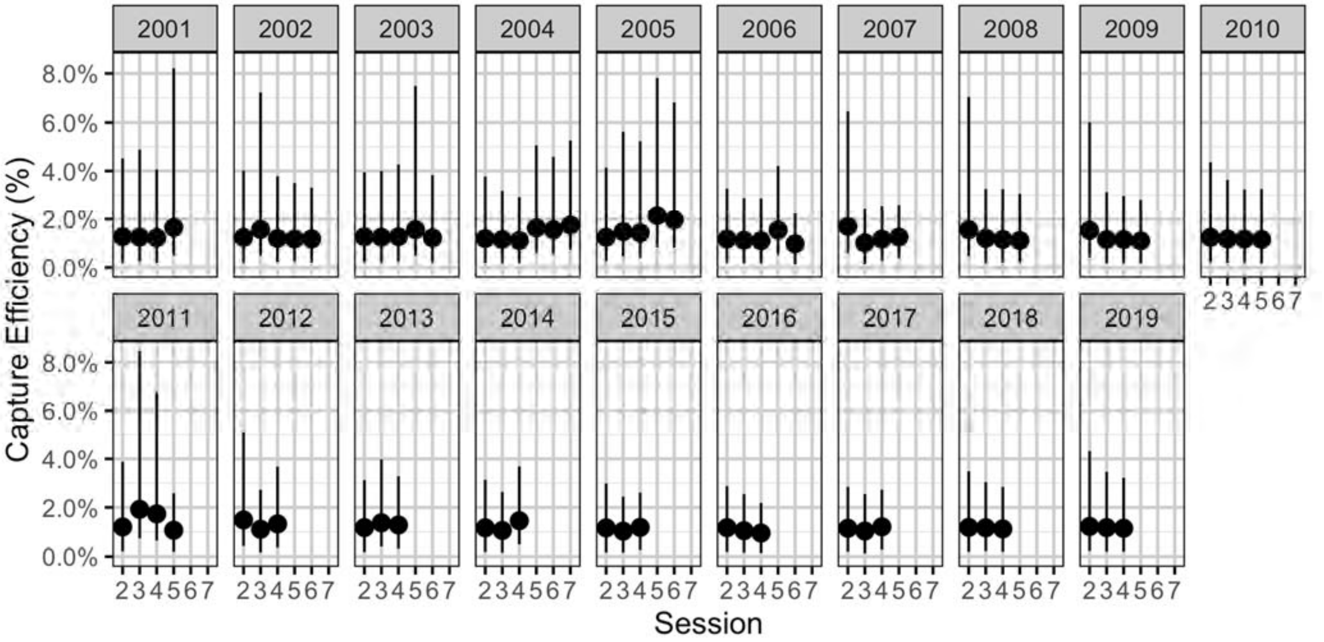


Figure G3: Capture efficiency (mean with 95% credible intervals) of subadult Mountain Whitefish by year and sample session in the lower Columbia River, 2001–2019.

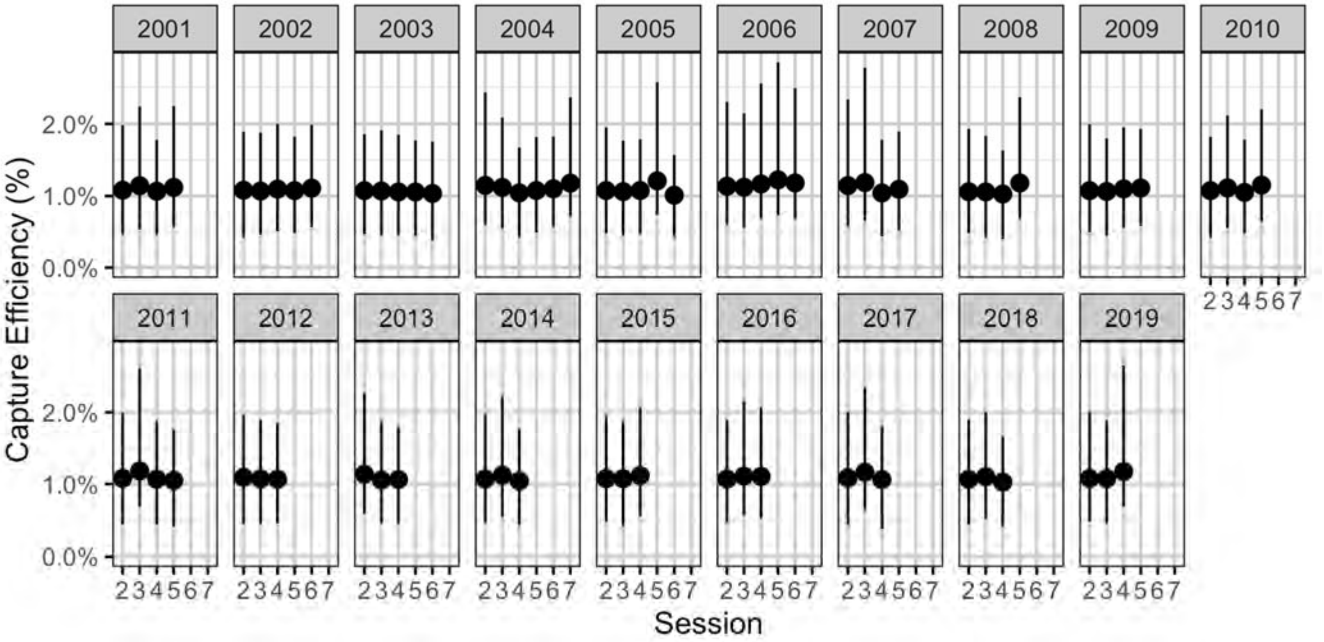


Figure G4: Capture efficiency (mean with 95% credible intervals) of adult Mountain Whitefish by year and sample session in the lower Columbia River, 2001–2019.

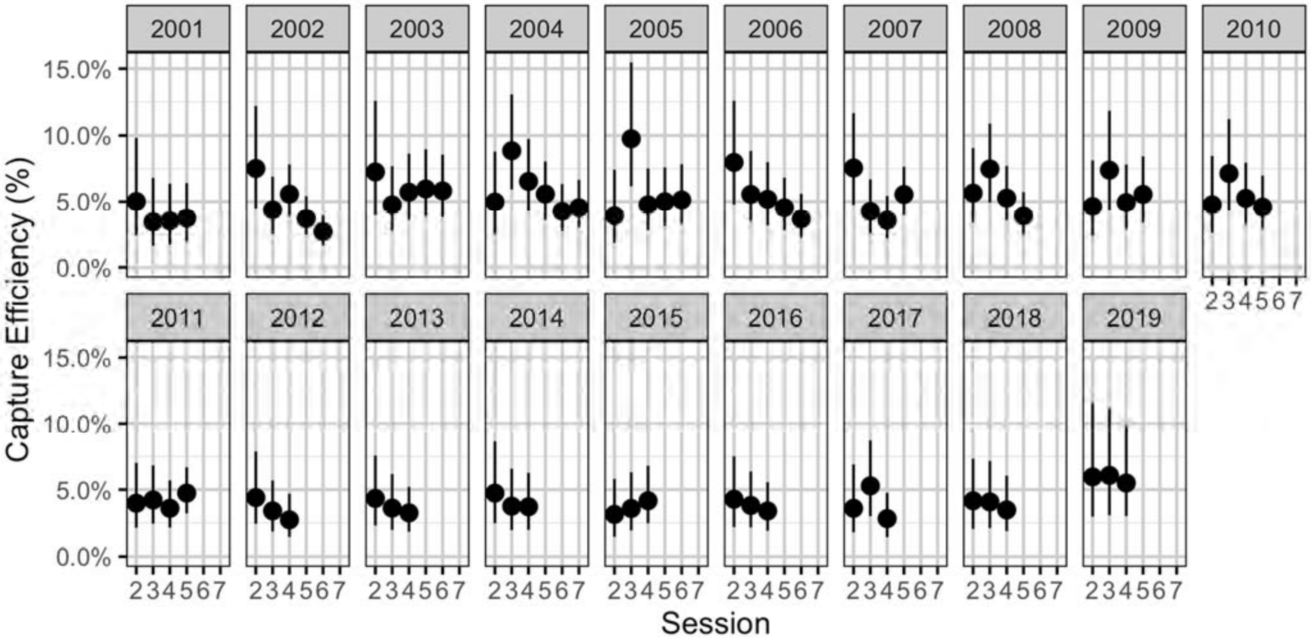


Figure G5: Capture efficiency (mean with 95% credible intervals) of subadult Rainbow Trout by year and sample session in the lower Columbia River, 2001–2019.

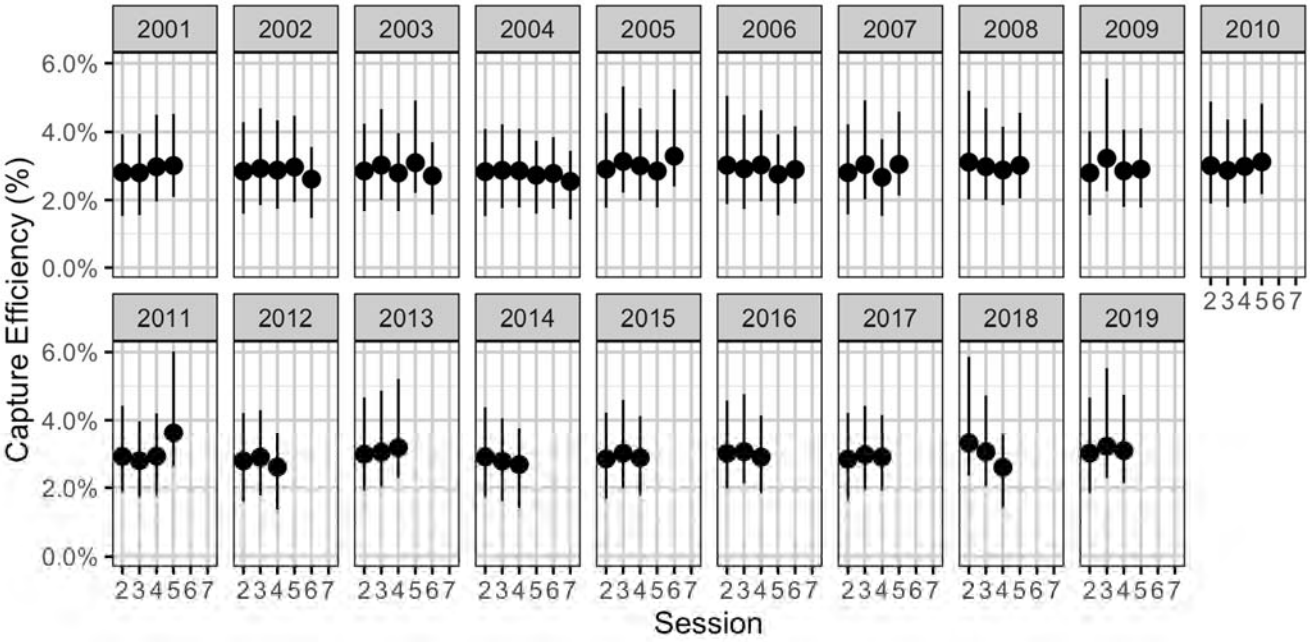


Figure G6: Capture efficiency (mean with 95% credible intervals) of adult Rainbow Trout by year and sample session in the lower Columbia River, 2001–2019.

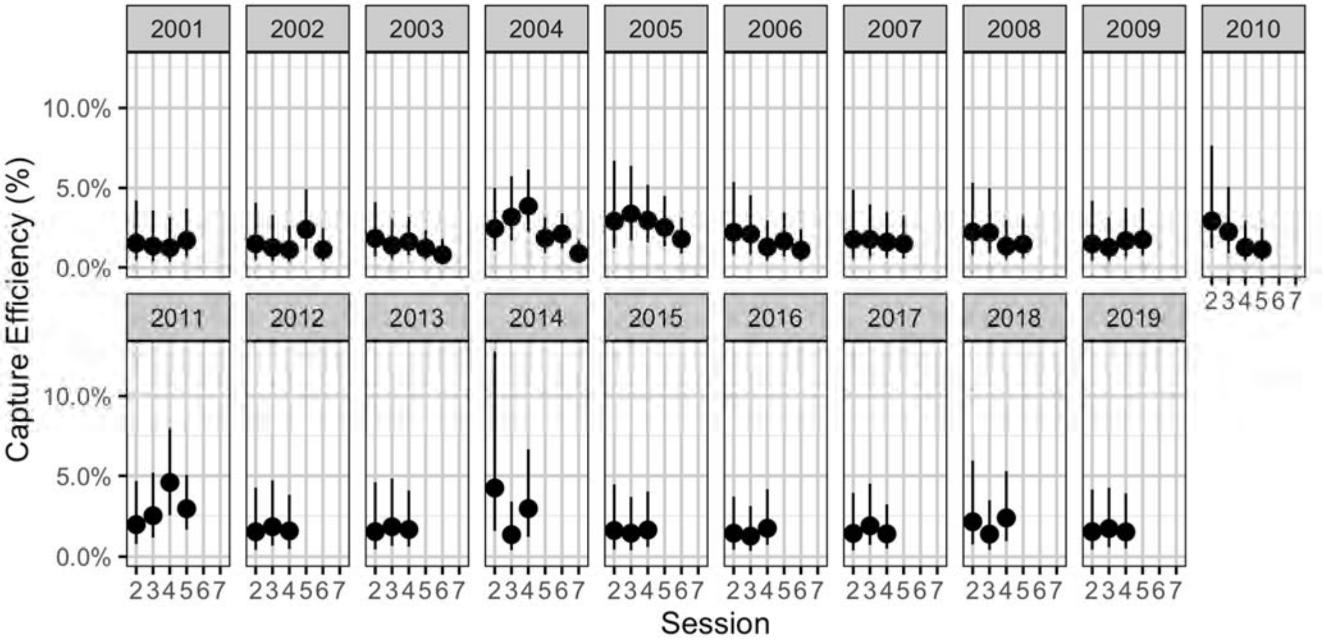


Figure G7: Capture efficiency (mean with 95% credible intervals) of adult Walleye by year and sample session in the lower Columbia River, 2001–2019.

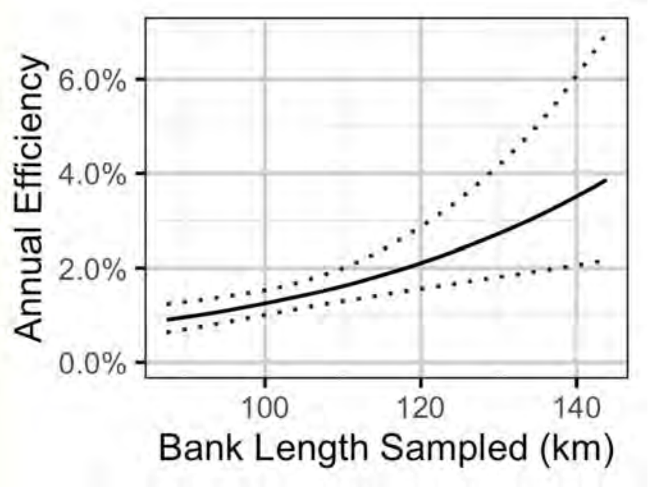


Figure G8: Predicted annual efficiency of capture for adult Mountain Whitefish by amount of bank length sampled (km).

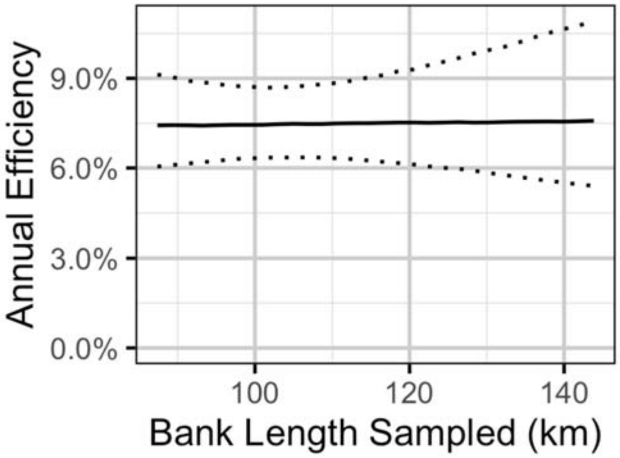


Figure G9: Predicted annual efficiency of capture for adult Rainbow Trout by amount of bank length sampled (km).

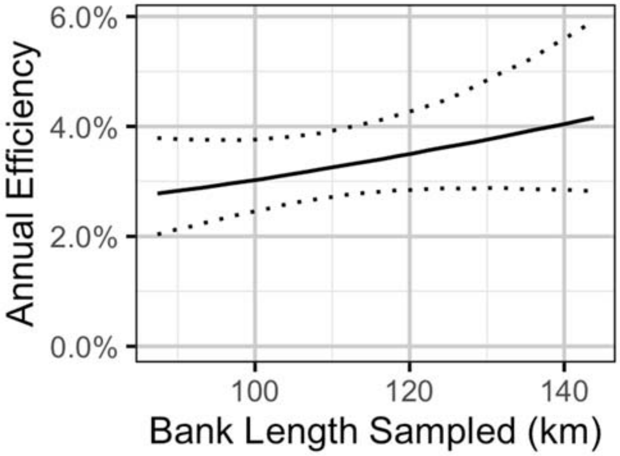


Figure G10: Predicted annual efficiency of capture for Walleye by amount of bank length sampled (km).

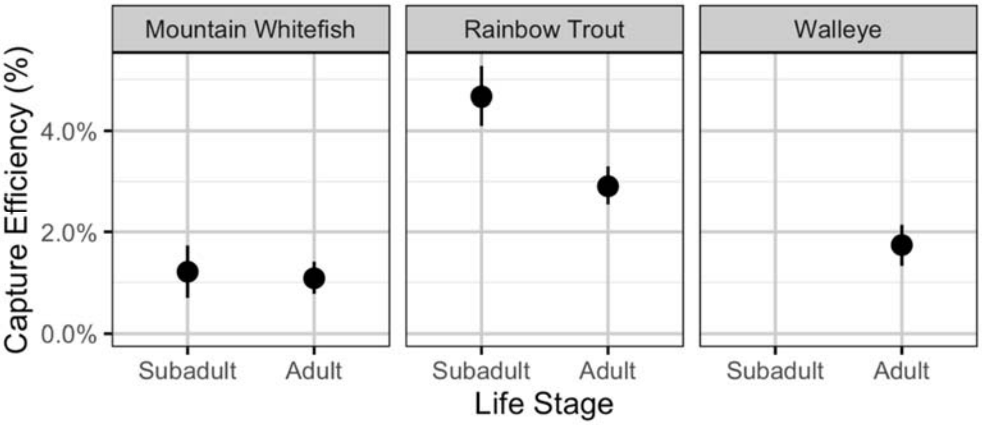


Figure G11: Predicted relative efficiency of capture vs counting for each species by life stage.

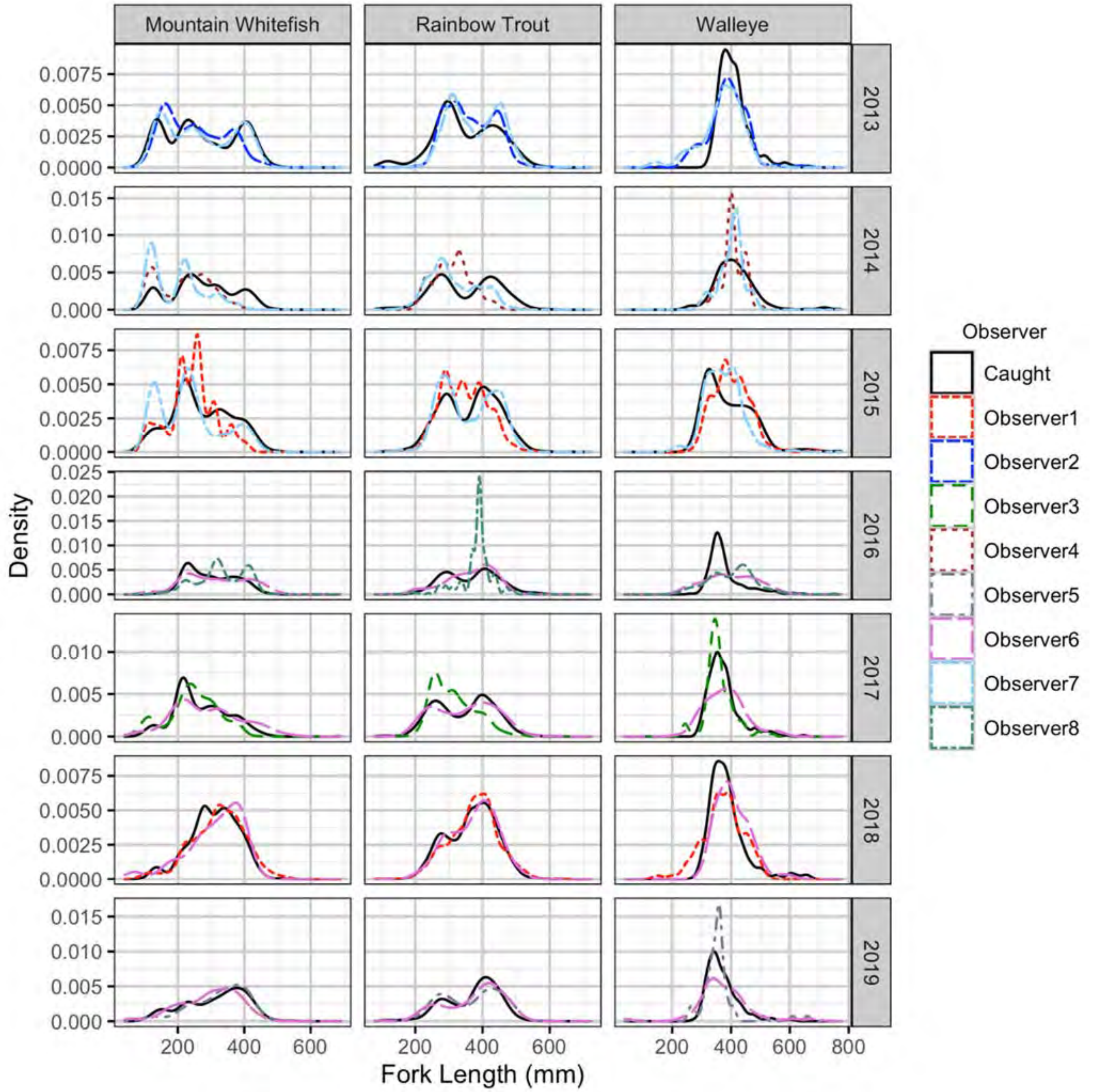


Figure G12: Corrected fork length-density plots for measured and estimated fork lengths of fish caught or observed in the lower Columbia River, 2013–2019. The black line shows fish that were caught. Observed data are shown by coloured dashed lines.

Appendix G: Additional Figures

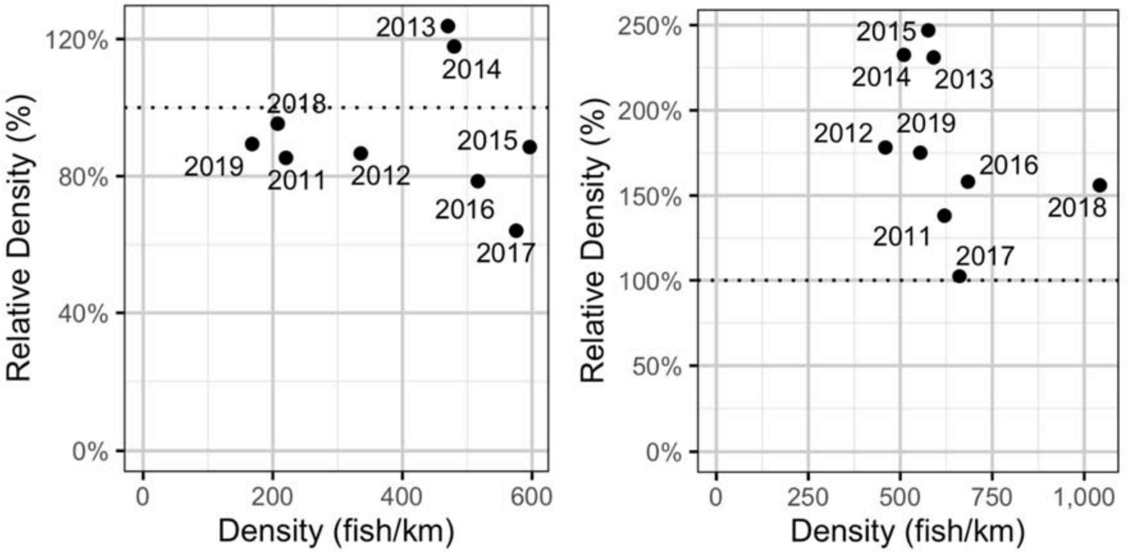


Figure G13: Estimated density of subadult (left) and adult (right) Mountain Whitefish at non-index relative to index sites by year.

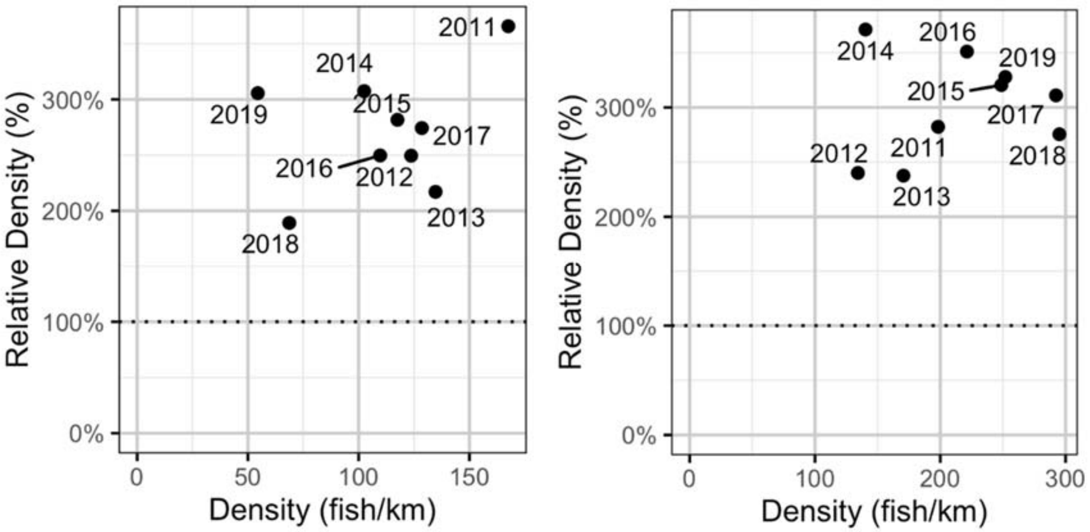


Figure G14: Estimated density of subadult (left) and adult (right) Rainbow Trout at non-index relative to index sites by year.

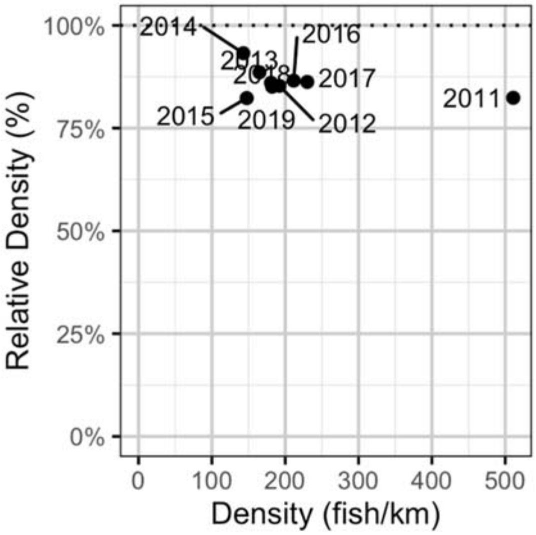
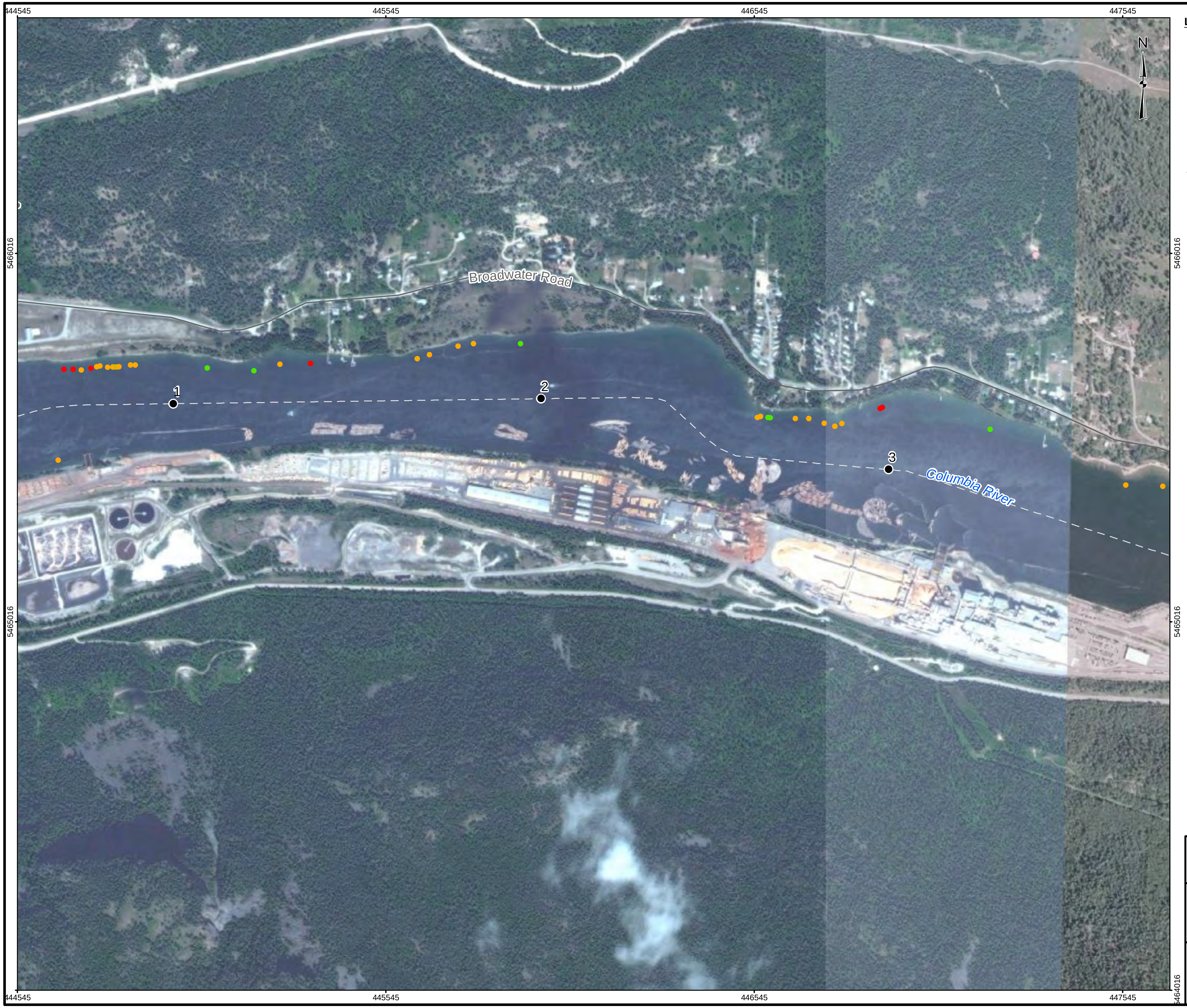


Figure G15: Estimated density of Walleye at non-index relative to index sites by year.

Appendix H – Spatial Distribution Maps



LEGEND

● PLACE NAME

● RIVER KILOMETRE POSTS

FISH_OBSERVATIONS_SURVEY_2019_UTM11

MOUNTAIN WHITEFISH OBSERVATIONS

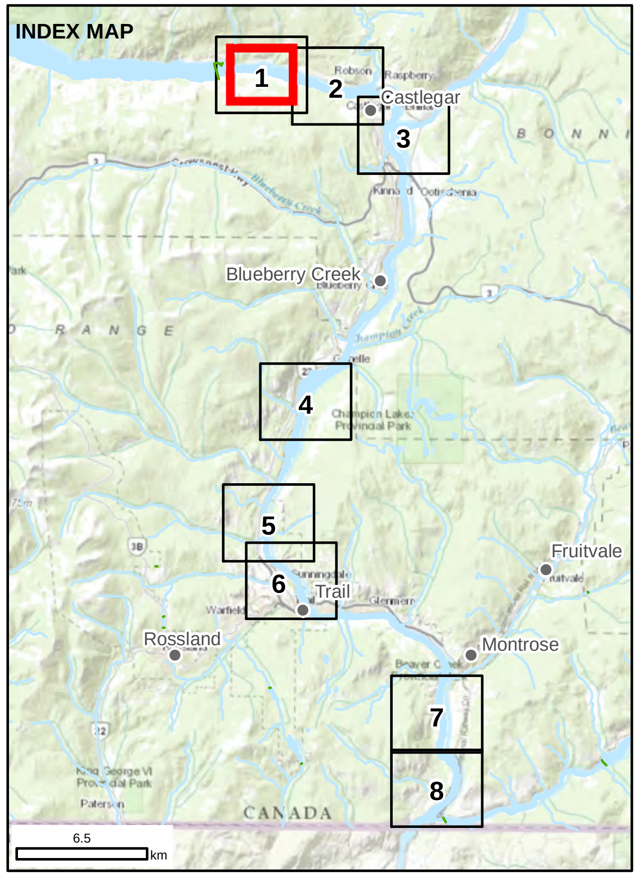
🔴 ADULT

🟠 JUVENILE

🟢 FRY

- - RIVER CENTRELINE

— ROAD



REFERENCE

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2. IMAGERY OBTAINED FROM BING MAPS FOR ARCGIS PUBLISHED BY MICROSOFT CORPORATION, REDMOND, WA, 2014
3. INSET: SOURCES: ESRI, HERE, GARMIN, INTERMAP, INCREMENT P CORP., GEBCO, USGS, FAO, NPS, NRCAN, GEOBASE, IGN, KADASTER NL, ORDNANCE SURVEY, ESRI JAPAN, METI, ESRI CHINA (HONG KONG), (C) OPENSTREETMAP CONTRIBUTORS, AND THE GIS USER COMMUNITY.

DATUM: NAD83 PROJECTION: UTM ZONE 11

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SCALE 1:10,305 METRES

PROJECT

LOWER COLUMBIA RIVER
GEO-REFERENCED VISUAL ENUMERATION SURVEY 2019

TITLE

MOUNTAIN WHITEFISH

GOLDER

PROJECT		1537874/2017	FILE No.	
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GIS	JG	24 JUN. 2019	**FIGURE H1** **1 OF 8**	
CHECK	DR	24 JUN. 2019		
REVIEW	SR	24 JUN. 2019		

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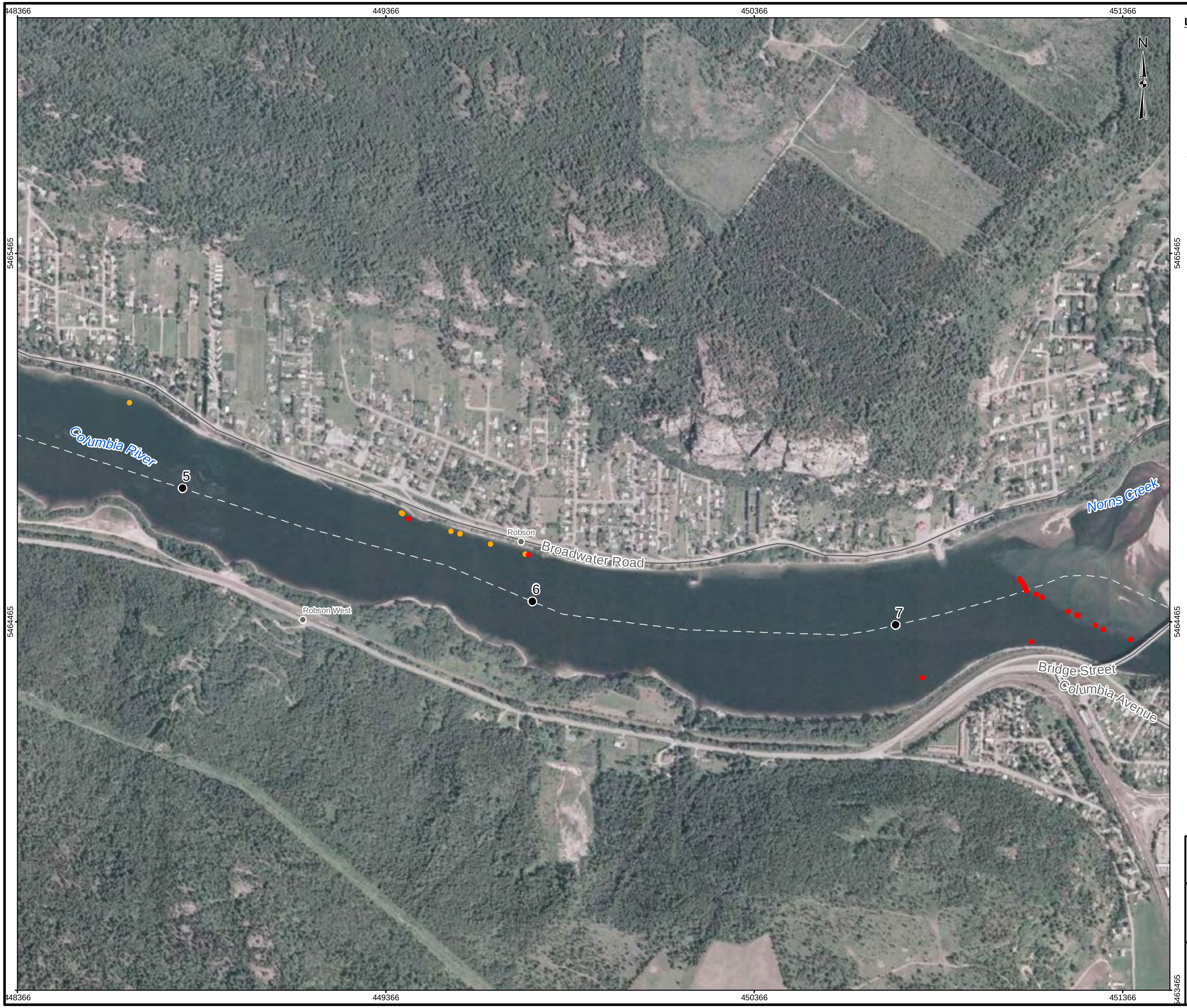

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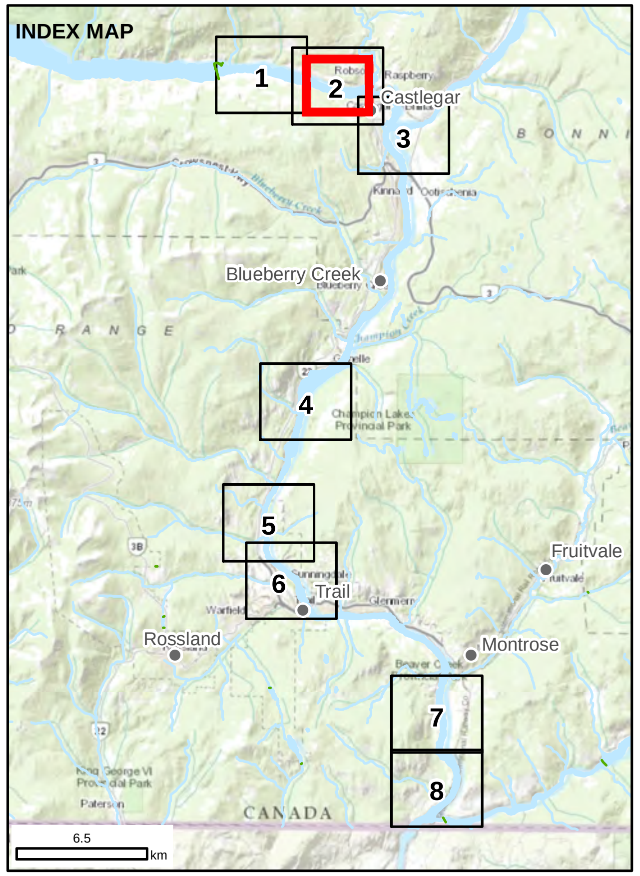
- ● RIVER KILOMETRE POSTS

FISH_OBSERVATIONS_SURVEY_2019_UTM11

MOUNTAIN WHITEFISH OBSERVATIONS

- ● ADULT
- ● JUVENILE
- - - RIVER CENTRELINE
- — ROAD



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PROJECT

LOWER COLUMBIA RIVER
GEO-REFERENCED VISUAL ENUMERATION SURVEY 2019

TITLE

MOUNTAIN WHITEFISH

GOLDER

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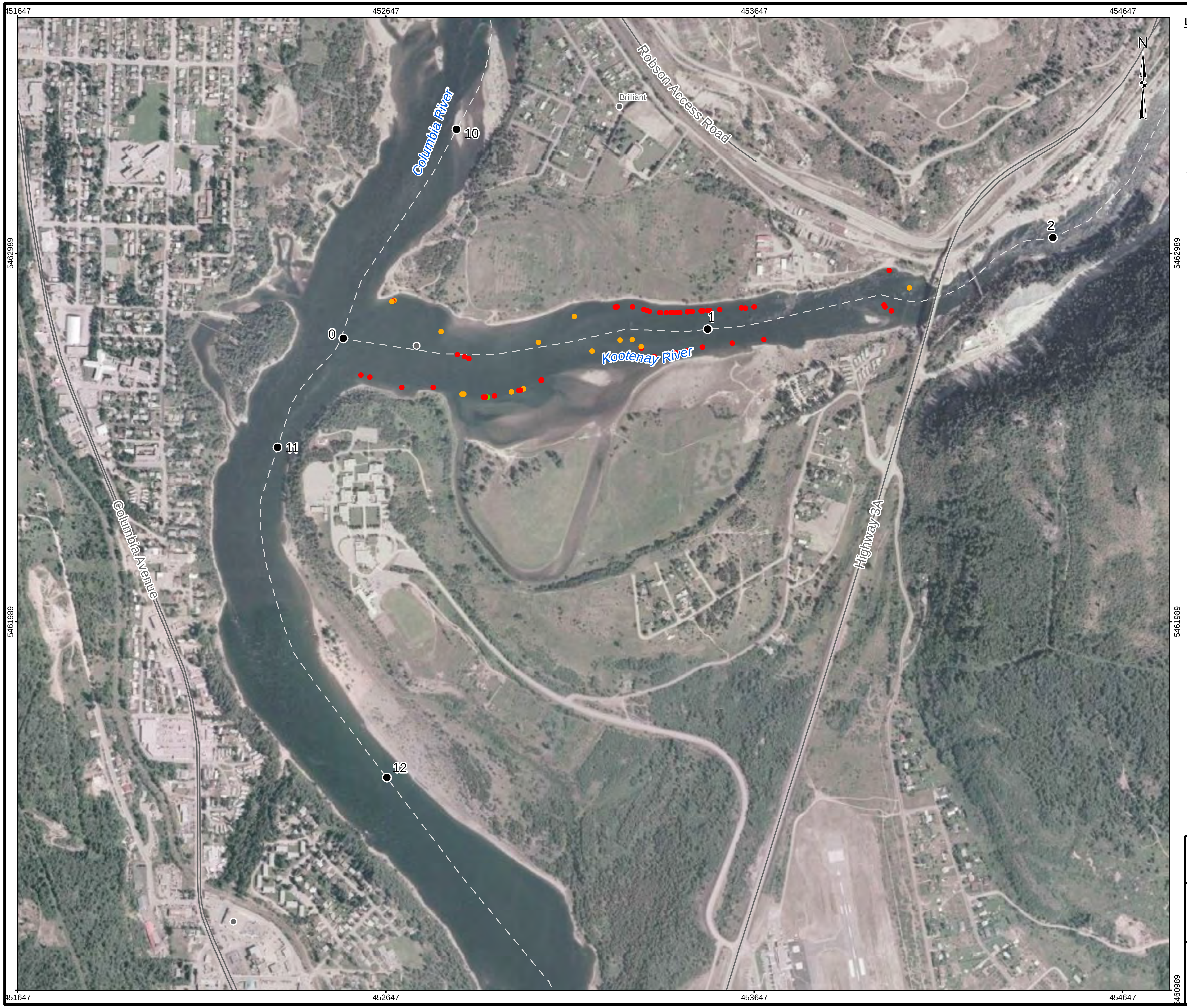

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● PLACE NAME

● RIVER KILOMETRE POSTS

FISH_OBSERVATIONS_SURVEY_2019_UTM11

MOUNTAIN WHITEFISH OBSERVATIONS

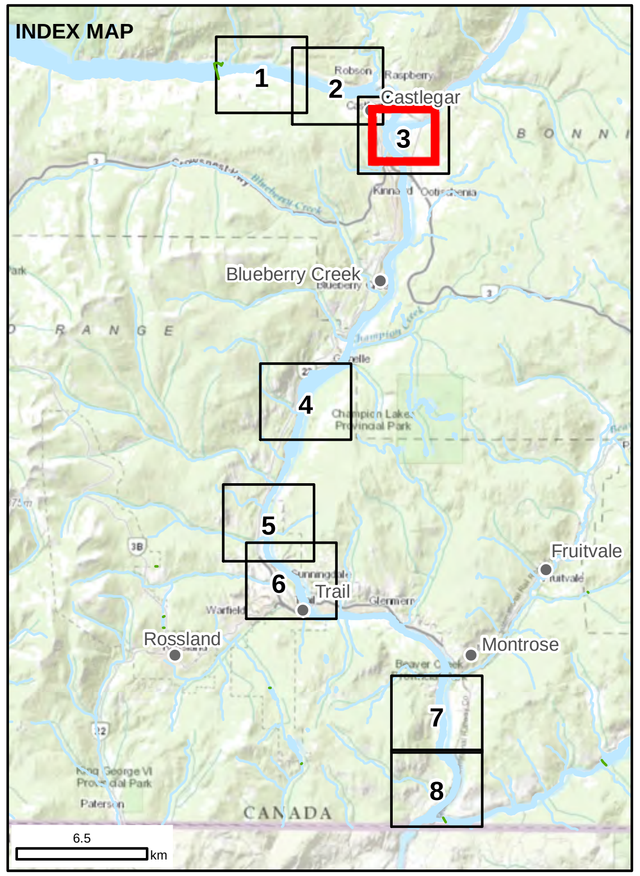
● ADULT

● JUVENILE

● FRY

- - RIVER CENTRELINE

— ROAD



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PROJECT

LOWER COLUMBIA RIVER
GEO-REFERENCED VISUAL ENUMERATION SURVEY 2019

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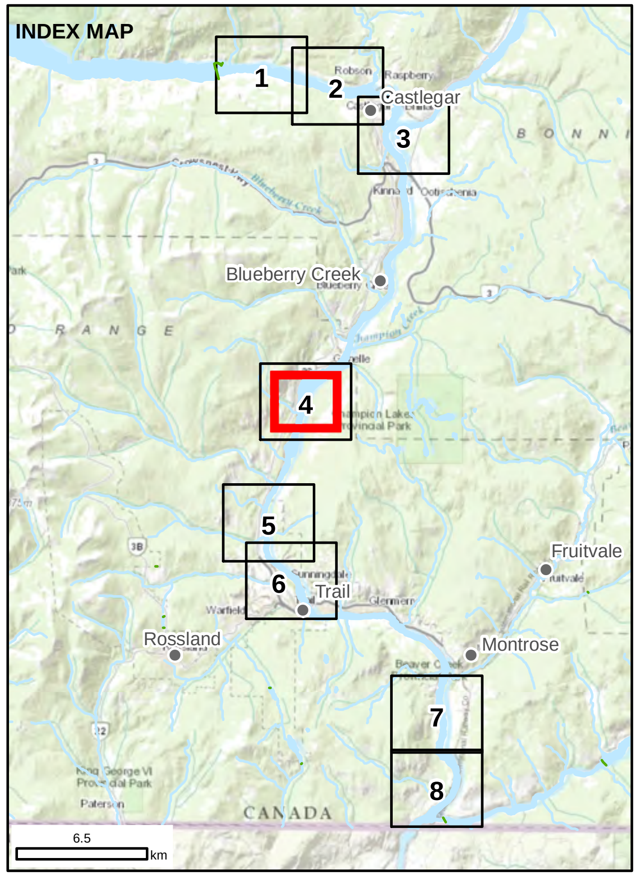
● PLACE NAME
● RIVER KILOMETRE POSTS

FISH_OBSERVATIONS_SURVEY_2019_UTM11

MOUNTAIN WHITEFISH OBSERVATIONS

● ADULT
● JUVENILE
● FRY
- - RIVER CENTRELINE
— ROAD



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PROJECT

LOWER COLUMBIA RIVER
GEO-REFERENCED VISUAL ENUMERATION SURVEY 2019

TITLE

MOUNTAIN WHITEFISH

GOLDER

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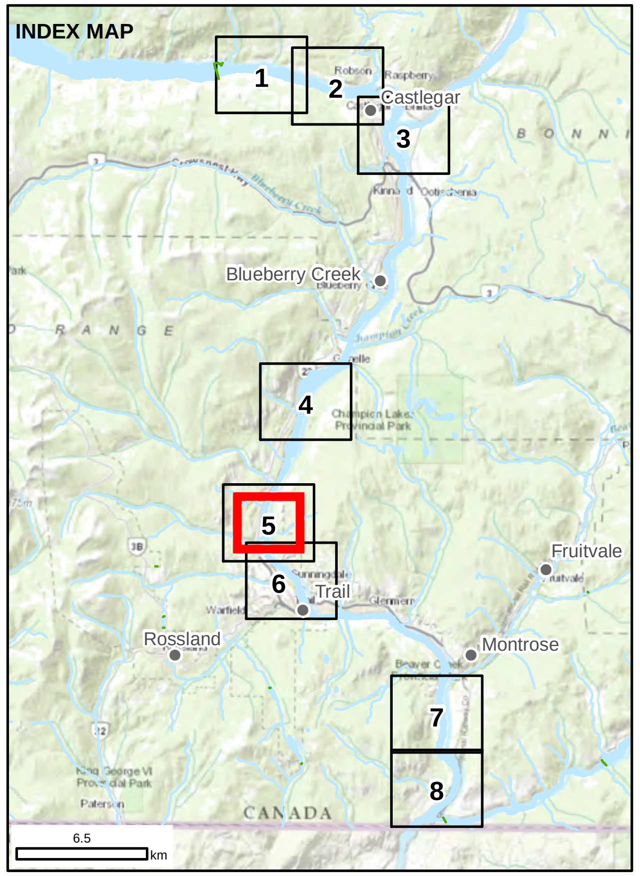
● PLACE NAME
● RIVER KILOMETRE POSTS

FISH_OBSERVATIONS_SURVEY_2019_UTM11

MOUNTAIN WHITEFISH OBSERVATIONS

● ADULT
-- RIVER CENTRELINE
— ROAD



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PROJECT
LOWER COLUMBIA RIVER
GEO-REFERENCED VISUAL ENUMERATION SURVEY 2019

TITLE
MOUNTAIN WHITEFISH

GOLDER

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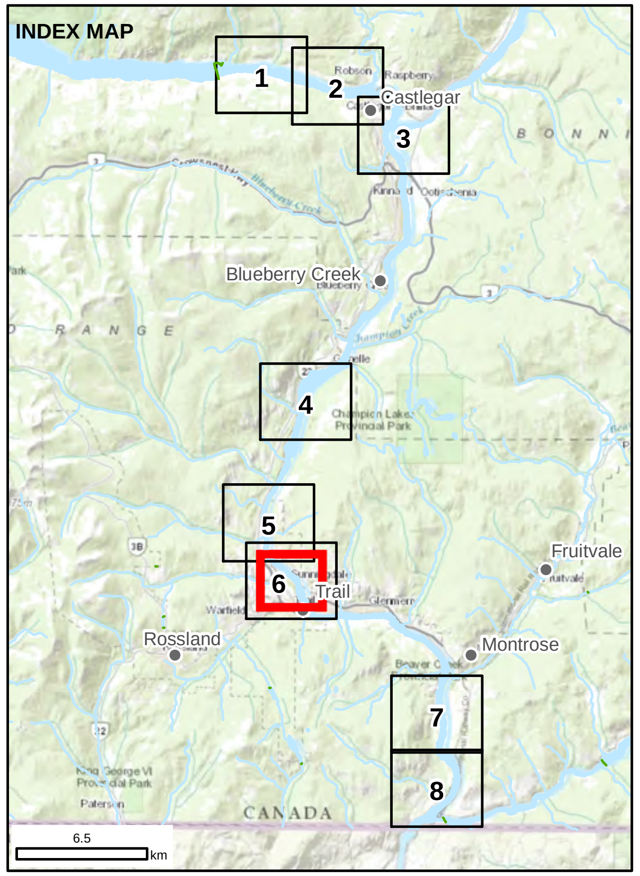
- ● RIVER KILOMETRE POSTS

FISH_OBSERVATIONS_SURVEY_2019_UTM11

MOUNTAIN WHITEFISH OBSERVATIONS

- ● ADULT
- - - RIVER CENTRELINE
- — ROAD



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SCALE 1:10,305 METRES

PROJECT

LOWER COLUMBIA RIVER
GEO-REFERENCED VISUAL ENUMERATION SURVEY 2019

TITLE

MOUNTAIN WHITEFISH

GOLDER

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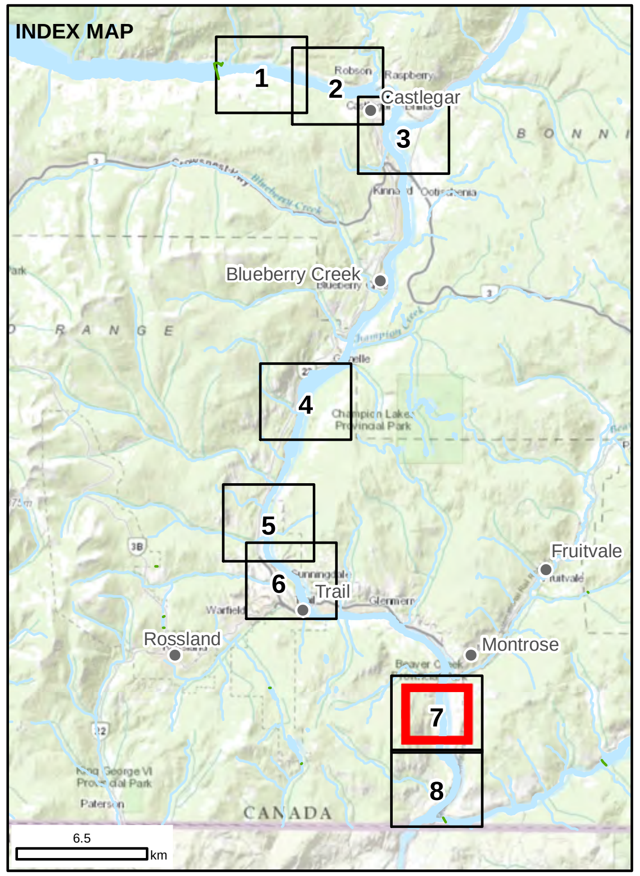
FISH_OBSERVATIONS_SURVEY_2019_UTM11

MOUNTAIN WHITEFISH OBSERVATIONS

- ● ADULT
- ● JUVENILE
- ● FRY
- - - RIVER CENTRELINE
- — ROAD



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PROJECT

LOWER COLUMBIA RIVER
GEO-REFERENCED VISUAL ENUMERATION SURVEY 2019

TITLE

MOUNTAIN WHITEFISH

GOLDER

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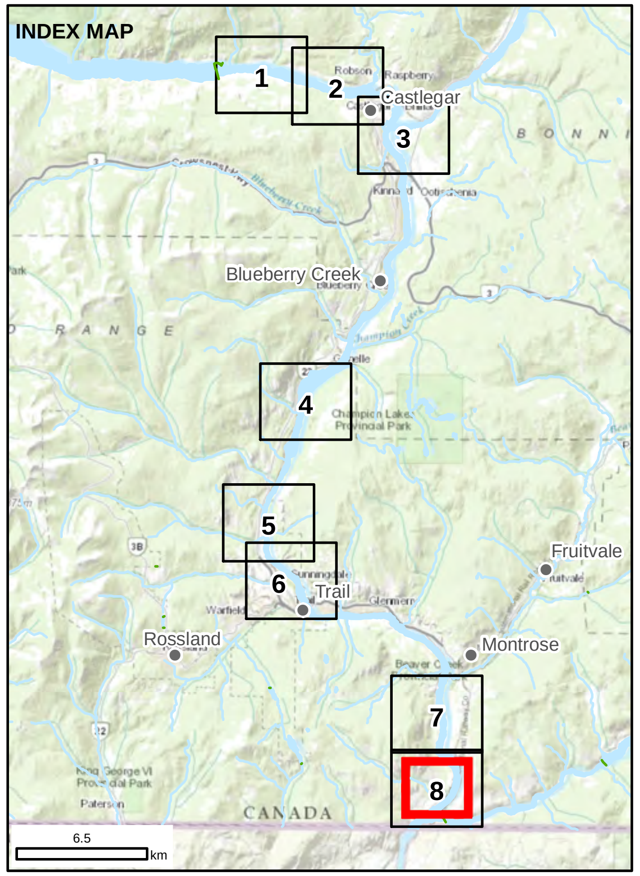
LEGEND

- ● PLACE NAME
- ● RIVER KILOMETRE POSTS

FISH_OBSERVATIONS_SURVEY_2019_UTM11

MOUNTAIN WHITEFISH OBSERVATIONS

- 🔴 ADULT
- 🟠 JUVENILE
- 🟢 FRY
- - - RIVER CENTRELINE
- — ROAD



REFERENCE

1. ROAD DATA OBTAINED FROM IHS ENERGY INC.
2. IMAGERY OBTAINED FROM BING MAPS FOR ARCGIS PUBLISHED BY MICROSOFT CORPORATION, REDMOND, WA, 2014
3. INSET: SOURCES: ESRI, HERE, GARMIN, INTERMAP, INCREMENT P CORP., GEBCO, USGS, FAO, NPS, NRCAN, GEOBASE, IGN, KADASTER NL, ORDNANCE SURVEY, ESRI JAPAN, METI, ESRI CHINA (HONG KONG), (C) OPENSTREETMAP CONTRIBUTORS, AND THE GIS USER COMMUNITY.

DATUM: NAD83 PROJECTION: UTM ZONE 11

300 0 300

SCALE 1:10,305 METRES

PROJECT

LOWER COLUMBIA RIVER
GEO-REFERENCED VISUAL ENUMERATION SURVEY 2019

TITLE

MOUNTAIN WHITEFISH

GOLDER

PROJECT		1537874/2017	FILE No.	
DESIGN	DR	09 JUN. 2017	SCALE AS SHOWN	REV. 0
GIS	JG	24 JUN. 2019	**FIGURE H1** **8 OF 8**	
CHECK	DR	24 JUN. 2019		
REVIEW	SR	24 JUN. 2019		

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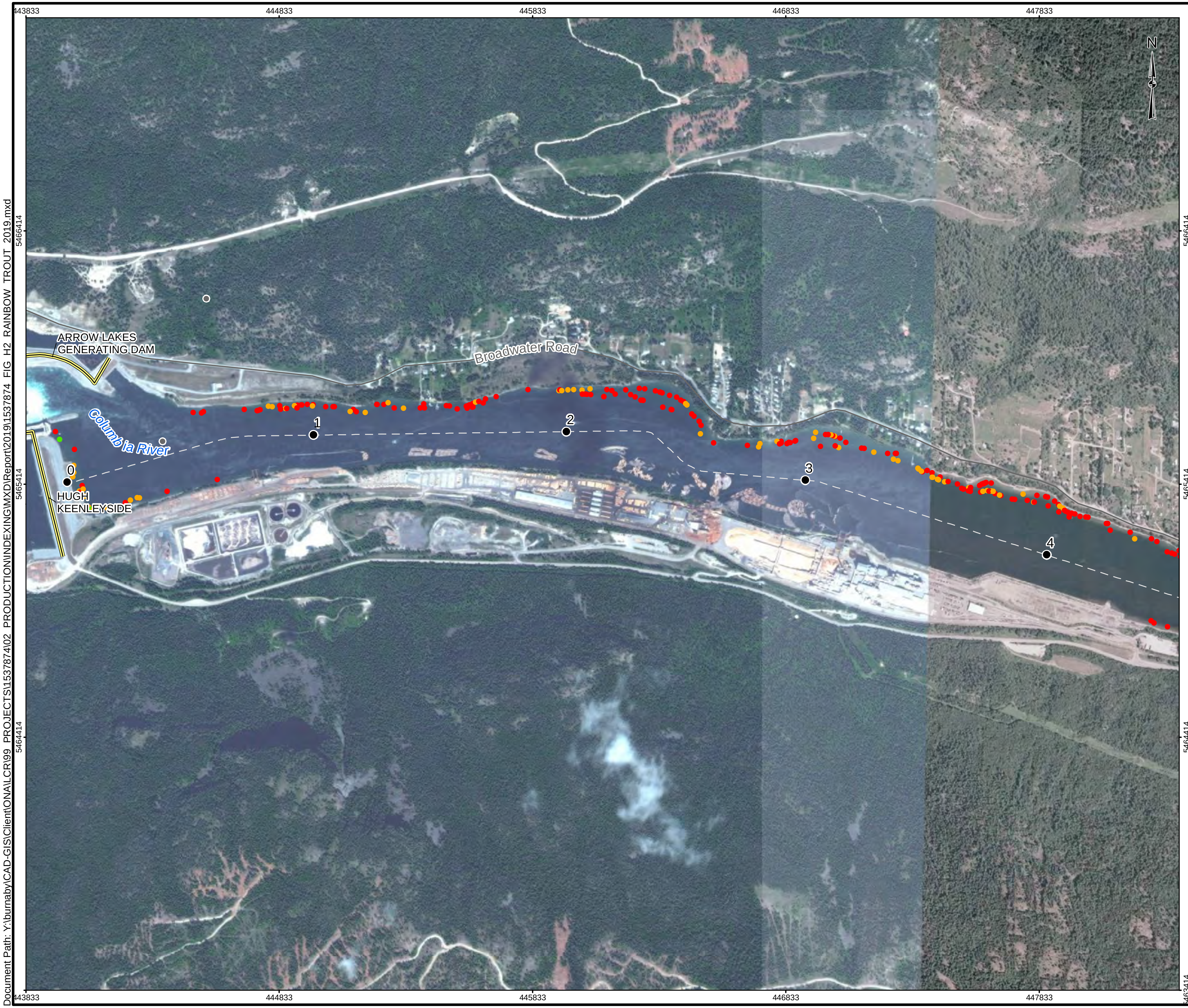


Document Path: Y:\burnaby\CAD-GIS\Client\ONA\LCR\99_PROJECTS\1537874\02_PRODUCTION\INDEXING\MXD\Report\2019\1537874_FIG_H2_RAINBOW_TROUT_2019.mxd

LEGEND

● PLACE NAME

● RIVER KILOMETRE POSTS

FISH_OBSERVATIONS_SURVEY_2019_UTM11

RAINBOW TROUT OBSERVATIONS

🟥 ADULT

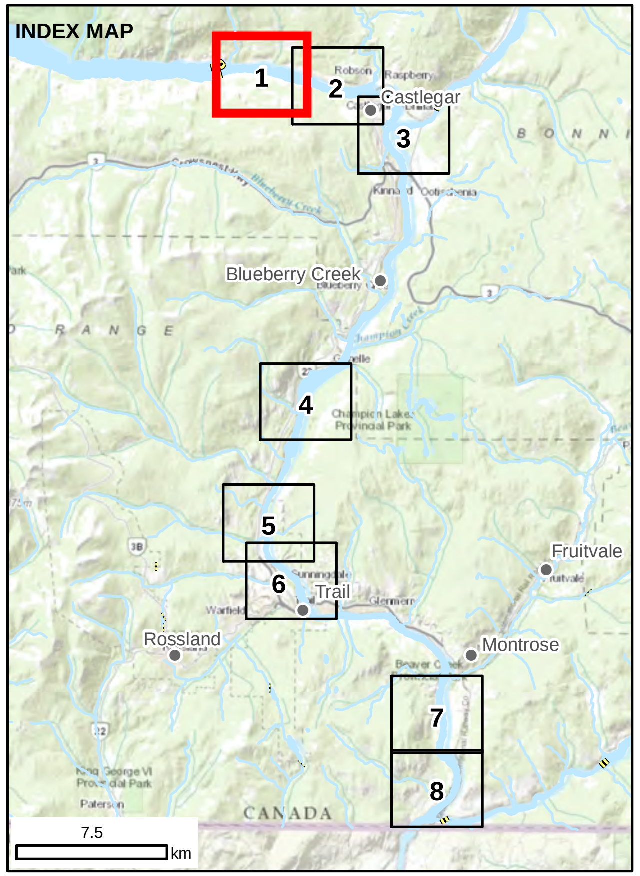
● JUVENILE

● FRY

— ROAD

- - RIVER CENTRELINE

═ DAM



REFERENCE

1. ROAD DATA OBTAINED FROM IHS ENERGY INC.
2. IMAGERY OBTAINED FROM BING MAPS FOR ARCGIS PUBLISHED BY MICROSOFT CORPORATION, REDMOND, WA, 2014.
3. INDEX MAP: SOURCES: ESRI, HERE, GARMIN, INTERMAP, INCREMENT P CORP., GEBCO, USGS, FAO, NPS, NRCAN, GEOBASE, IGN, KADASTER NL, ORDNANCE SURVEY, ESRI JAPAN, METI, ESRI CHINA (HONG KONG), (C) OPENSTREETMAP CONTRIBUTORS, AND THE GIS USER COMMUNITY.

DATUM: NAD83 PROJECTION: UTM ZONE 11

300 0 300

SCALE 1:15,000 METRES

PROJECT

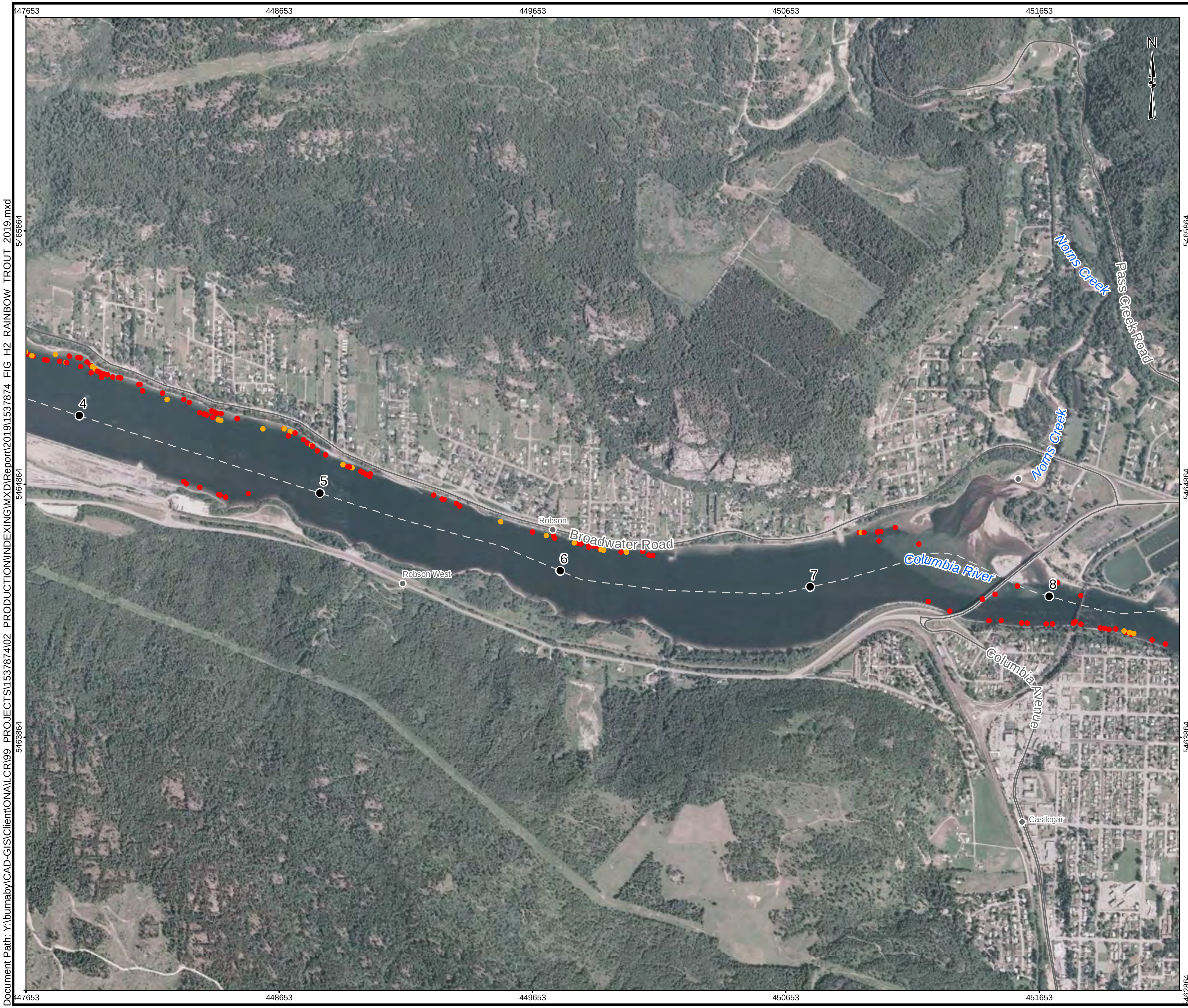
LOWER COLUMBIA RIVER
GEO-REFERENCED VISUAL ENUMERATION SURVEY 2019

TITLE

RAINBOW TROUT

GOLDER

PROJECT		1537874/2017	FILE No.	
DESIGN	DR	07 JUN. 2018	SCALE AS SHOWN	REV. 0
GIS	JG	24 JUN. 2019	**FIGURE H2** **1 OF 8**	
CHECK	DR	24 JUN. 2019		
REVIEW	SR	24 JUN. 2019		



LEGEND

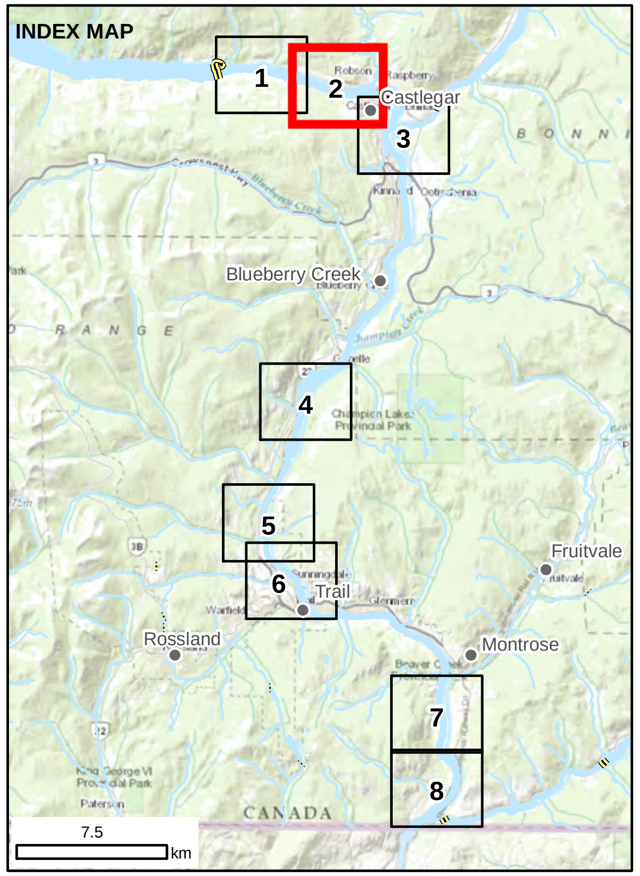
- ● PLACE NAME
- ● RIVER KILOMETRE POSTS

FISH_OBSERVATIONS_SURVEY_2019_UTM11

RAINBOW TROUT OBSERVATIONS

- ● ADULT
- ● JUVENILE
- — ROAD
- - - RIVER CENTRELINE

INDEX MAP



REFERENCE

1. ROAD DATA OBTAINED FROM IHS ENERGY INC.
2. IMAGERY OBTAINED FROM BING MAPS FOR ARCGIS
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CORP., GEBCO, USGS, FAO, NPS, NRCAN, GEOBASE, IGN, KADASTER NL,
ORDNANCE SURVEY, ESRI JAPAN, METI, ESRI CHINA (HONG KONG), (C)
OPENSTREETMAP CONTRIBUTORS, AND THE GIS USER COMMUNITY.
DATUM: NAD83 PROJECTION: UTM ZONE 11

300 0 300

SCALE 1:15,000 METRES

PROJECT

LOWER COLUMBIA RIVER
GEO-REFERENCED VISUAL ENUMERATION SURVEY 2019

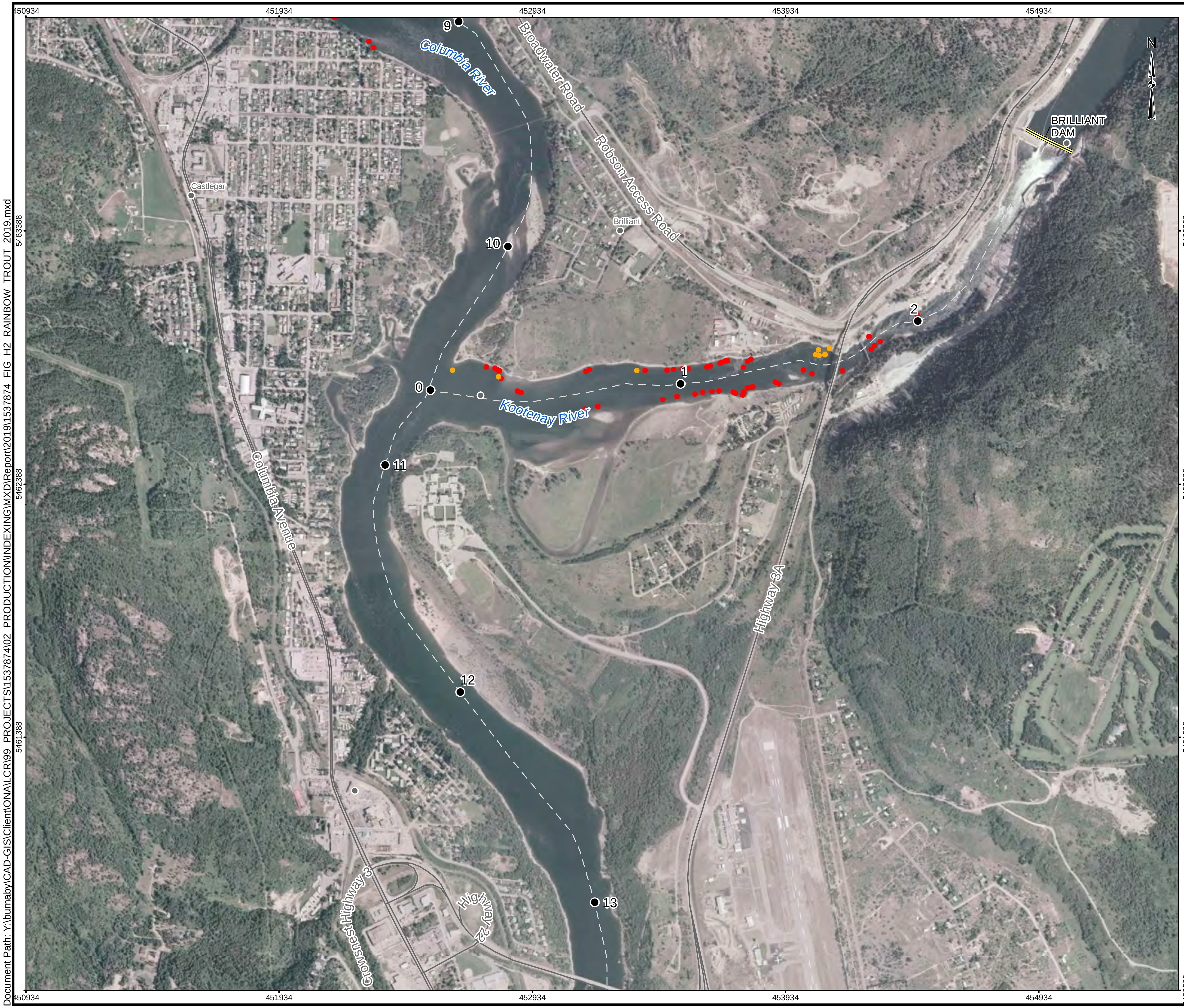
TITLE

RAINBOW TROUT

GOLDER

PROJECT		1537874/2017	FILE No.	
DESIGN	DR	07 JUN. 2018	SCALE AS SHOWN	REV. 0
GIS	JG	24 JUN. 2019	**FIGURE H2** **2 OF 8**	
CHECK	DR	24 JUN. 2019		
REVIEW	SR	24 JUN. 2019		

Document Path: Y:\burnaby\CAD-GIS\Client\ONALCR\99 PROJECTS\1537874\02 PRODUCTION\INDEXING\MXD\Report\2019\1537874 FIG H2 RAINBOW TROUT 2019.mxd



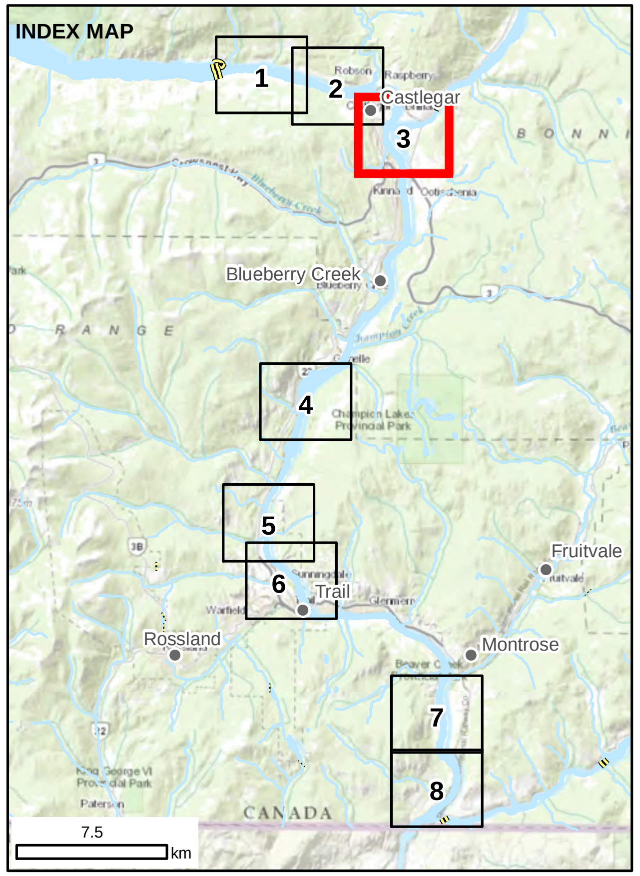
LEGEND

- ● PLACE NAME
- ● RIVER KILOMETRE POSTS

FISH_OBSERVATIONS_SURVEY_2019_UTM11

RAINBOW TROUT OBSERVATIONS

- ● ADULT
- ● JUVENILE
- — ROAD
- - - RIVER CENTRELINE
- ═ DAM



REFERENCE

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DATUM: NAD83 PROJECTION: UTM ZONE 11

300 0 300

SCALE 1:15,000 METRES

PROJECT

LOWER COLUMBIA RIVER
GEO-REFERENCED VISUAL ENUMERATION SURVEY 2019

TITLE

RAINBOW TROUT

GOLDER

PROJECT		1537874/2017	FILE No.	
DESIGN	DR	07 JUN. 2018	SCALE AS SHOWN	REV. 0
GIS	JG	24 JUN. 2019	**FIGURE H2** **3 OF 8**	
CHECK	DR	24 JUN. 2019		
REVIEW	SR	24 JUN. 2019		

Document Path: Y:\burnaby\CAD-GIS\Client\ONA\LCR\99 PROJECTS\1537874\02 PRODUCTION\INDEXING\MXD\Report\2019\1537874 FIG H2 RAINBOW TROUT 2019.mxd

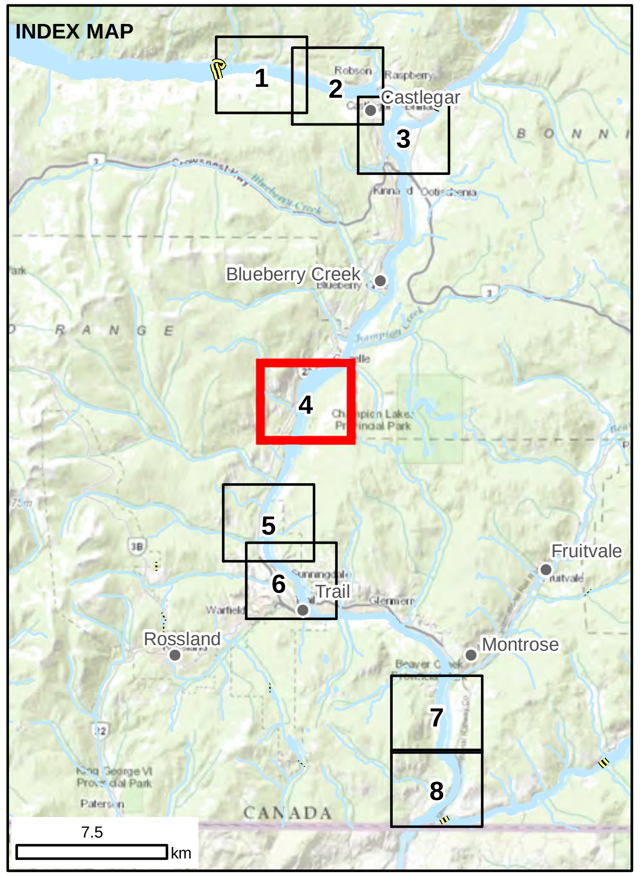
LEGEND

● PLACE NAME
● RIVER KILOMETRE POSTS

FISH_OBSERVATIONS_SURVEY_2019_UTM11

RAINBOW TROUT OBSERVATIONS

● ADULT
● JUVENILE
— ROAD
- - RIVER CENTRELINE



REFERENCE

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CORP., GEBCO, USGS, FAO, NPS, NRCAN, GEOBASE, IGN, KADASTER NL,
ORDNANCE SURVEY, ESRI JAPAN, METI, ESRI CHINA (HONG KONG), (C)
OPENSTREETMAP CONTRIBUTORS, AND THE GIS USER COMMUNITY.
DATUM: NAD83 PROJECTION: UTM ZONE 11

300 0 300

SCALE 1:15,000 METRES

PROJECT

LOWER COLUMBIA RIVER
GEO-REFERENCED VISUAL ENUMERATION SURVEY 2019

TITLE

RAINBOW TROUT

PROJECT		1537874/2017	FILE No.	
DESIGN	DR	07 JUN. 2018	SCALE AS SHOWN	REV. 0
GIS	JG	24 JUN. 2019	**FIGURE H2 4 OF 8**	
CHECK	DR	24 JUN. 2019		
REVIEW	SR	24 JUN. 2019		

GOLDER

Document Path: Y:\burnaby\CAD-GIS\Client\ONA\LCR\99 PROJECTS\1537874\02 PRODUCTION\INDEXING\MXD\Report\2019\1537874 FIG H2 RAINBOW TROUT 2019.mxd

LEGEND

● PLACE NAME

● RIVER KILOMETRE POSTS

FISH_OBSERVATIONS_SURVEY_2019_UTM11

RAINBOW TROUT OBSERVATIONS

● ADULT

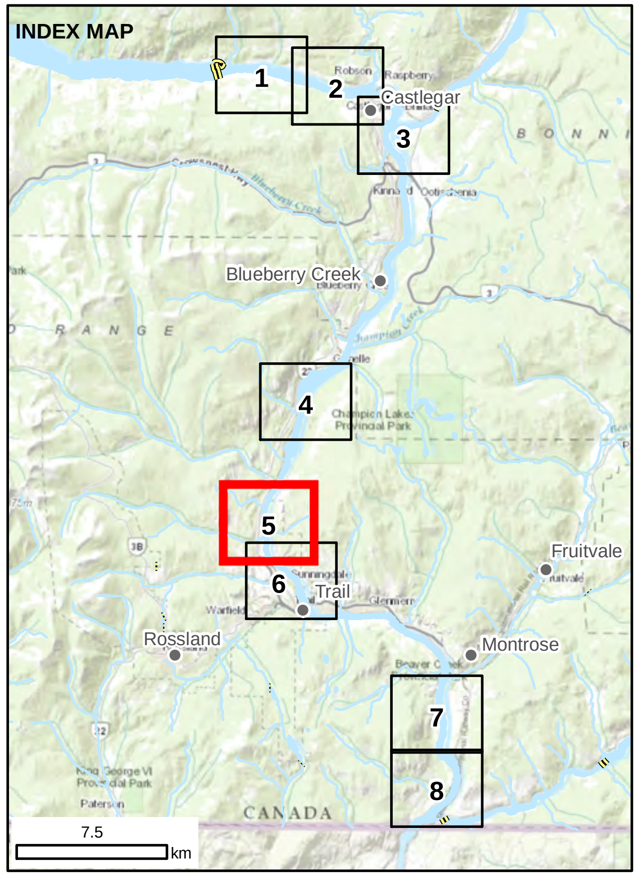
● JUVENILE

● FRY

— ROAD

– – RIVER CENTRELINE

INDEX MAP



REFERENCE

1. ROAD DATA OBTAINED FROM IHS ENERGY INC.
2. IMAGERY OBTAINED FROM BING MAPS FOR ARCGIS
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DATUM: NAD83 PROJECTION: UTM ZONE 11

300 0 300

SCALE 1:15,000 METRES

PROJECT

LOWER COLUMBIA RIVER
GEO-REFERENCED VISUAL ENUMERATION SURVEY 2019

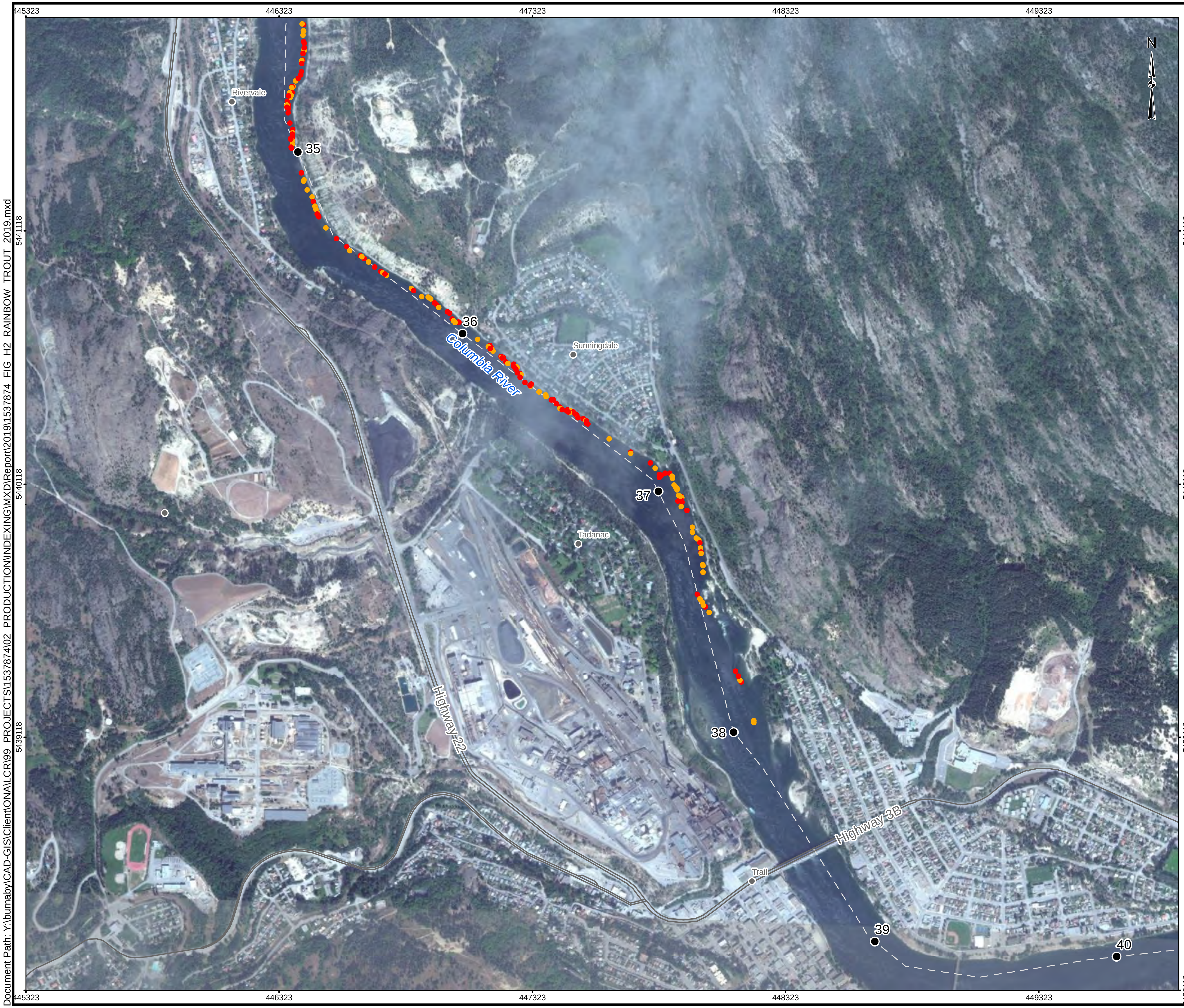
TITLE

RAINBOW TROUT

GOLDER

PROJECT		1537874/2017	FILE No.	
DESIGN	DR	07 JUN. 2018	SCALE AS SHOWN	REV. 0
GIS	JG	24 JUN. 2019	**FIGURE H2** **5 OF 8**	
CHECK	DR	24 JUN. 2019		
REVIEW	SR	24 JUN. 2019		

Document Path: Y:\burnaby\CAD-GIS\Client\ONA\LCR\99_PROJECTS\1537874\02_PRODUCTION\INDEXING\MXD\Report\2019\1537874_FIG_H2_RAINBOW_TROUT_2019.mxd



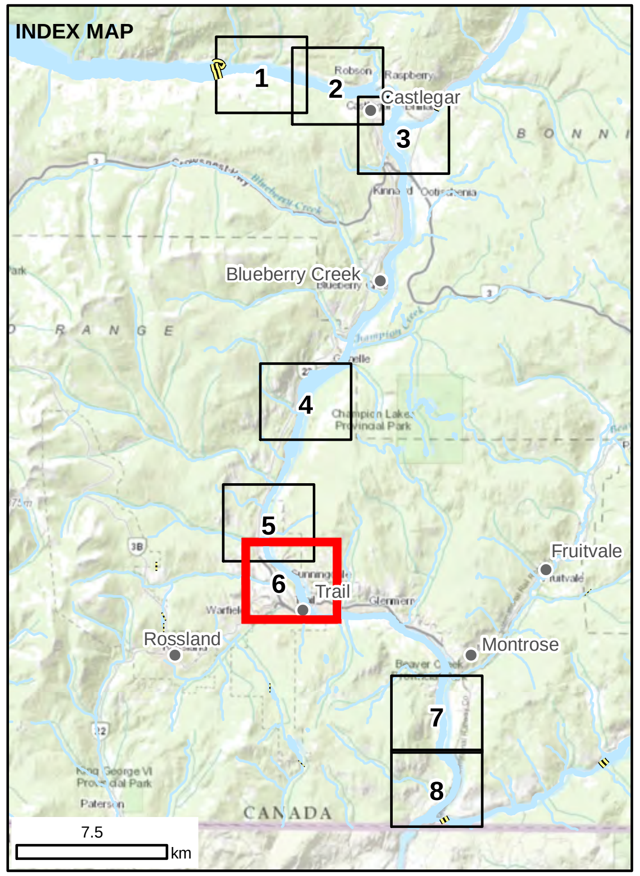
LEGEND

- ● PLACE NAME
- ● RIVER KILOMETRE POSTS

FISH_OBSERVATIONS_SURVEY_2019_UTM11

RAINBOW TROUT OBSERVATIONS

- 🟥 ADULT
- 🟧 JUVENILE
- — ROAD
- - - RIVER CENTRELINE



REFERENCE

1. ROAD DATA OBTAINED FROM IHS ENERGY INC.
2. IMAGERY OBTAINED FROM BING MAPS FOR ARCGIS
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CORP., GEBCO, USGS, FAO, NPS, NRCAN, GEOBASE, IGN, KADASTER NL,
ORDNANCE SURVEY, ESRI JAPAN, METI, ESRI CHINA (HONG KONG), (C)
OPENSTREETMAP CONTRIBUTORS, AND THE GIS USER COMMUNITY.
DATUM: NAD83 PROJECTION: UTM ZONE 11

300 0 300
SCALE 1:15,000 METRES

PROJECT

LOWER COLUMBIA RIVER
GEO-REFERENCED VISUAL ENUMERATION SURVEY 2019

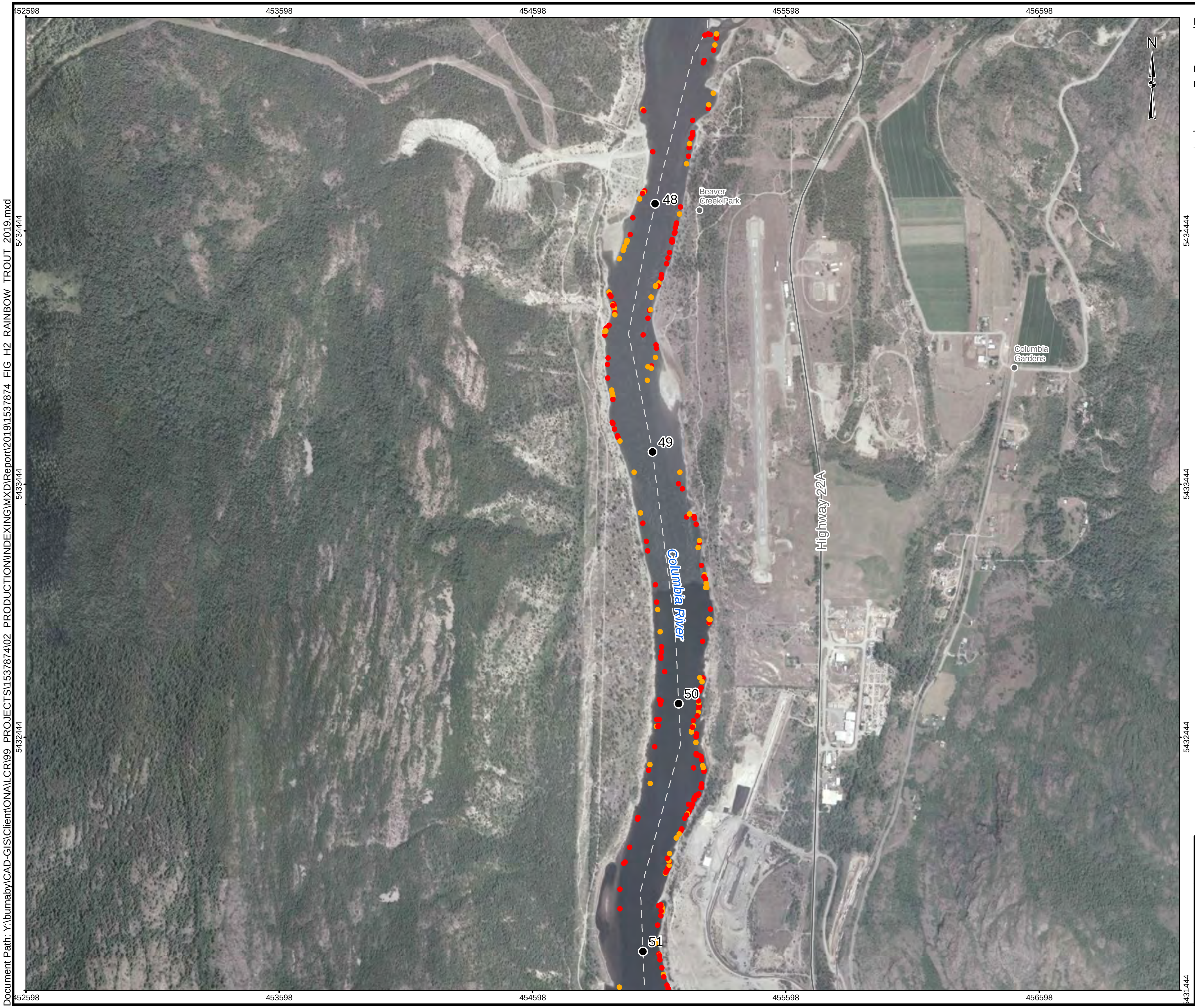
TITLE

RAINBOW TROUT

GOLDER

PROJECT		1537874/2017	FILE No.	
DESIGN	DR	07 JUN. 2018	SCALE AS SHOWN	REV. 0
GIS	JG	24 JUN. 2019	**FIGURE H2 6 OF 8**	
CHECK	DR	24 JUN. 2019		
REVIEW	SR	24 JUN. 2019		

Document Path: Y:\burnaby\CAD-GIS\Client\ONA\LCR\99_PROJECTS\1537874\02_PRODUCTION\INDEXING\MXD\Report\2019\1537874_FIG_H2_RAINBOW_TROUT_2019.mxd



Document Path: Y:\burnaby\CAD-GIS\Client\ONA\LCR\99 PROJECTS\1537874\02 PRODUCTION\INDEXING\MXD\Report\2019\1537874 FIG H2 RAINBOW TROUT 2019.mxd

LEGEND

● PLACE NAME

● RIVER KILOMETRE POSTS

FISH_OBSERVATIONS_SURVEY_2019_UTM11

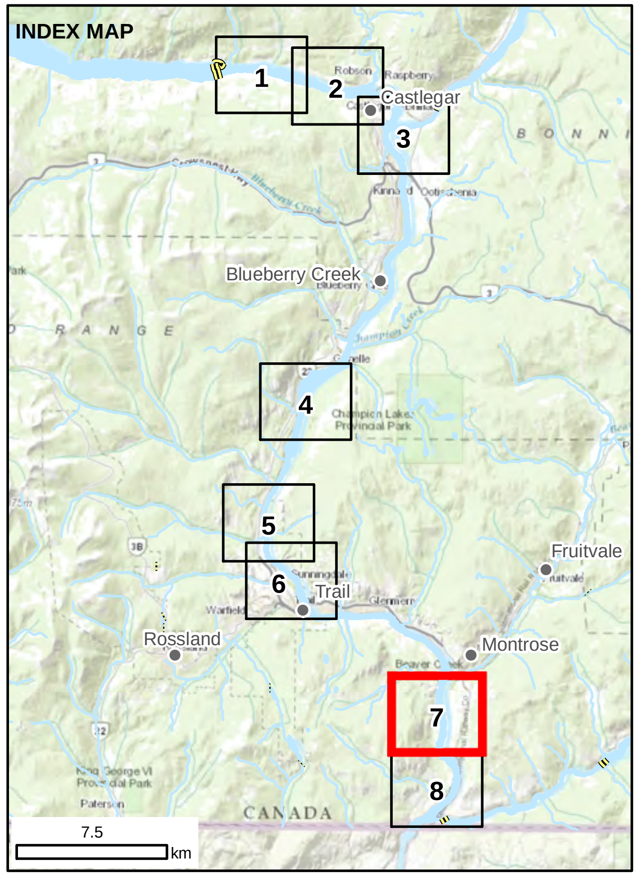
RAINBOW TROUT OBSERVATIONS

🟥 ADULT

● JUVENILE

— ROAD

- - RIVER CENTRELINE



REFERENCE

1. ROAD DATA OBTAINED FROM IHS ENERGY INC.
2. IMAGERY OBTAINED FROM BING MAPS FOR ARCGIS PUBLISHED BY MICROSOFT CORPORATION, REDMOND, WA, 2014.
3. INDEX MAP: SOURCES: ESRI, HERE, GARMIN, INTERMAP, INCREMENT P CORP., GEBCO, USGS, FAO, NPS, NRCAN, GEOBASE, IGN, KADASTER NL, ORDNANCE SURVEY, ESRI JAPAN, METI, ESRI CHINA (HONG KONG), (C) OPENSTREETMAP CONTRIBUTORS, AND THE GIS USER COMMUNITY.

DATUM: NAD83 PROJECTION: UTM ZONE 11

300 0 300

SCALE 1:15,000 METRES

PROJECT

LOWER COLUMBIA RIVER
GEO-REFERENCED VISUAL ENUMERATION SURVEY 2019

TITLE

RAINBOW TROUT

GOLDER

PROJECT		1537874/2017	FILE No.
DESIGN	DR	07 JUN. 2018	SCALE AS SHOWN / REV. 0
GIS	JG	24 JUN. 2019	**FIGURE H2 7 OF 8**
CHECK	DR	24 JUN. 2019	
REVIEW	SR	24 JUN. 2019	

LEGEND

● PLACE NAME

● RIVER KILOMETRE POSTS

FISH_OBSERVATIONS_SURVEY_2019_UTM11

RAINBOW TROUT OBSERVATIONS

● ADULT

● JUVENILE

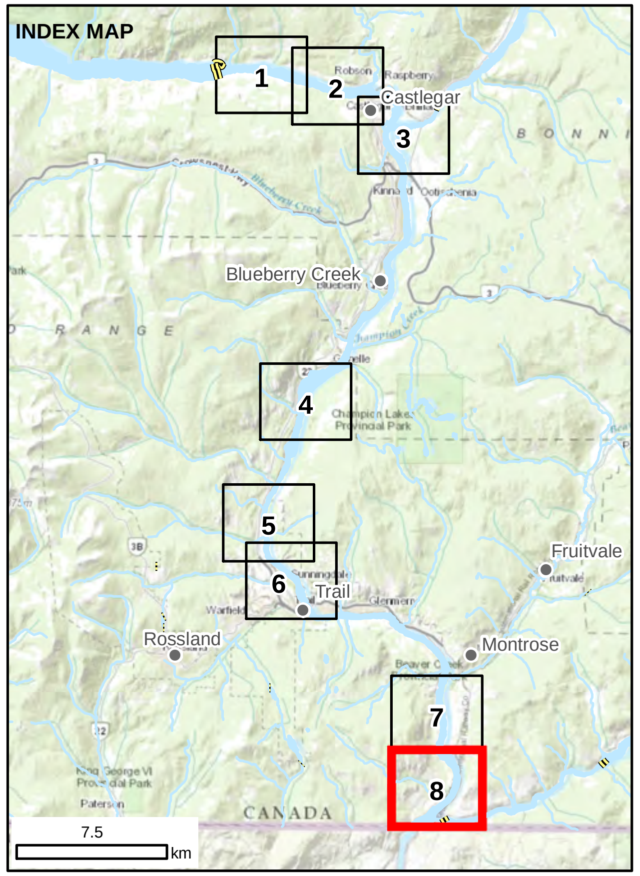
● FRY

— ROAD

– – RIVER CENTRELINE

▬ DAM

INDEX MAP



REFERENCE

1. ROAD DATA OBTAINED FROM IHS ENERGY INC.
2. IMAGERY OBTAINED FROM BING MAPS FOR ARCGIS
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3. INDEX MAP: SOURCES: ESRI, HERE, GARMIN, INTERMAP, INCREMENT P
CORP., GEBCO, USGS, FAO, NPS, NRCAN, GEOBASE, IGN, KADASTER NL,
ORDNANCE SURVEY, ESRI JAPAN, METI, ESRI CHINA (HONG KONG), (C)
OPENSTREETMAP CONTRIBUTORS, AND THE GIS USER COMMUNITY.
DATUM: NAD83 PROJECTION: UTM ZONE 11

300 0 300

SCALE 1:15,000 METRES

PROJECT

LOWER COLUMBIA RIVER
GEO-REFERENCED VISUAL ENUMERATION SURVEY 2019

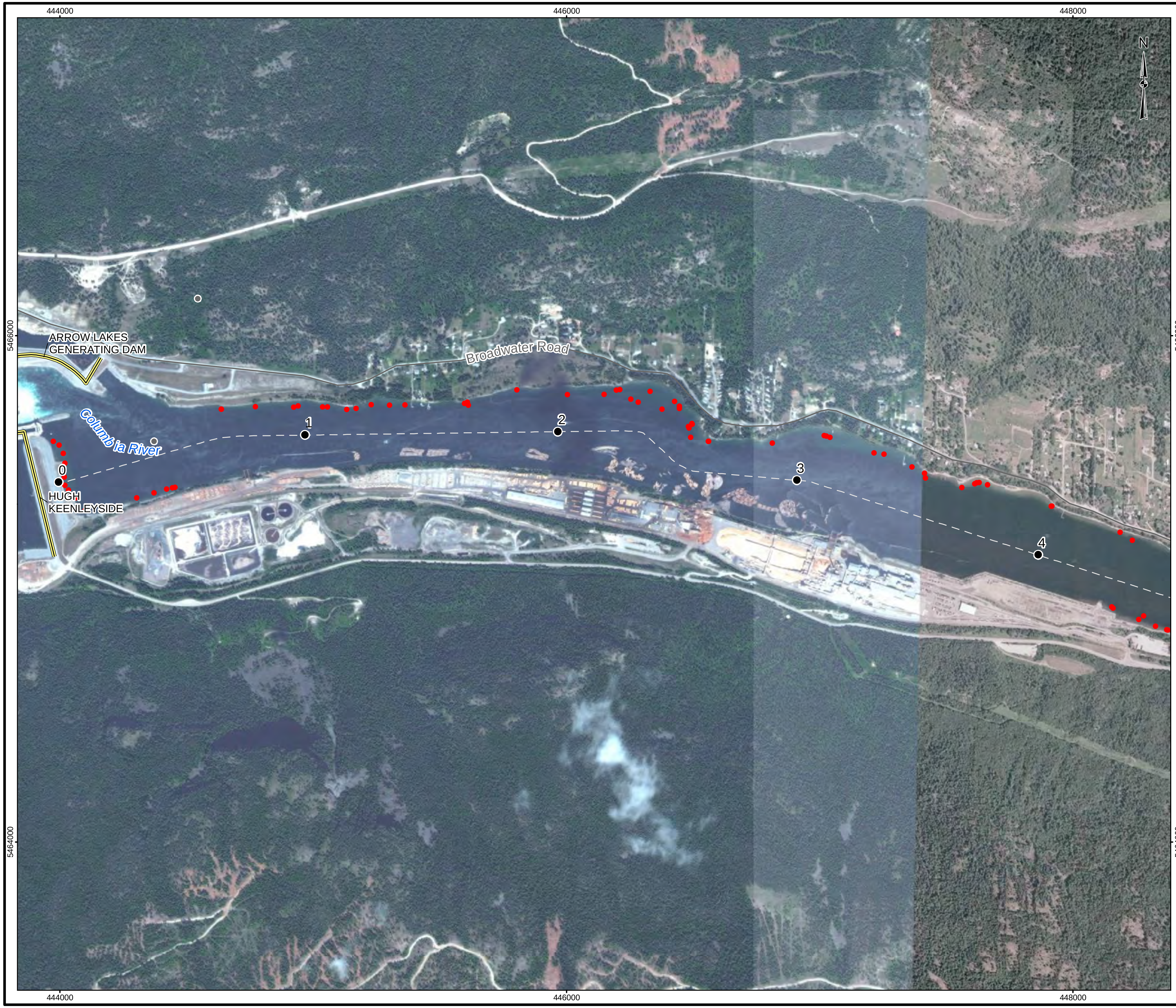
TITLE

RAINBOW TROUT

GOLDER

PROJECT		1537874/2017	FILE No.	
DESIGN	DR	07 JUN. 2018	SCALE AS SHOWN	REV. 0
GIS	JG	24 JUN. 2019	**FIGURE H2** **8 OF 8**	
CHECK	DR	24 JUN. 2019		
REVIEW	SR	24 JUN. 2019		

Document Path: Y:\burnaby\CAD-GIS\Client\ONA\LCR\99 PROJECTS\1537874\02 PRODUCTION\INDEXING\MXD\Report\2019\1537874 FIG H2 RAINBOW TROUT 2019.mxd



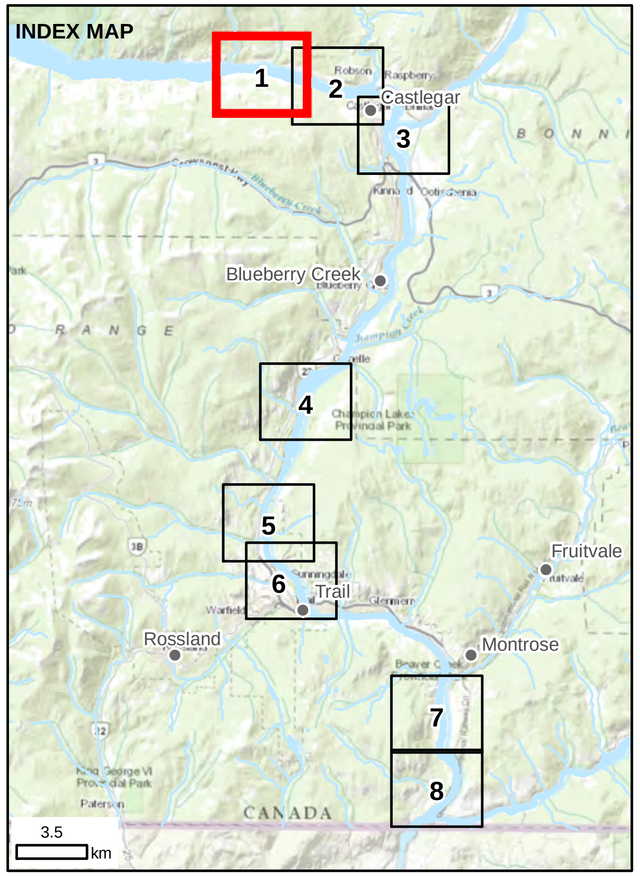
LEGEND

- ● PLACE NAME
- ● RIVER KILOMETRE POSTS

FISH_OBSERVATIONS_SURVEY_2019_UTM11

WALLEYE OBSERVATIONS

- 🔴 ADULT
- 🟠 JUVENILE
- 🟢 FRY
- ── ROAD
- – – RIVER CENTRELINE
- ═ DAM



REFERENCE

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2. IMAGERY OBTAINED FROM BING MAPS FOR ARCGIS PUBLISHED BY MICROSOFT CORPORATION, REDMOND, WA, 2014.
3. INDEX MAP: SOURCES: ESRI, HERE, GARMIN, INTERMAP, INCREMENT P CORP., GEBCO, USGS, FAO, NPS, NRCAN, GEOBASE, IGN, KADASTER NL, ORDNANCE SURVEY, ESRI JAPAN, METI, ESRI CHINA (HONG KONG), (C) OPENSTREETMAP CONTRIBUTORS, AND THE GIS USER COMMUNITY.

DATUM: NAD83 PROJECTION: UTM ZONE 11

300 0 300

SCALE 1:15,000 METRES

PROJECT

LOWER COLUMBIA RIVER
GEO-REFERENCED VISUAL ENUMERATION SURVEY 2019

TITLE

WALLEYE

GOLDER

PROJECT		1537874/2017	FILE No.	
DESIGN	DR	07 JUN. 2018	SCALE AS SHOWN	REV. 0
GIS	JG	24 JUN. 2019	**FIGURE H3** **1 OF 8**	
CHECK	DR	24 JUN. 2019		
REVIEW	SR	24 JUN. 2019		

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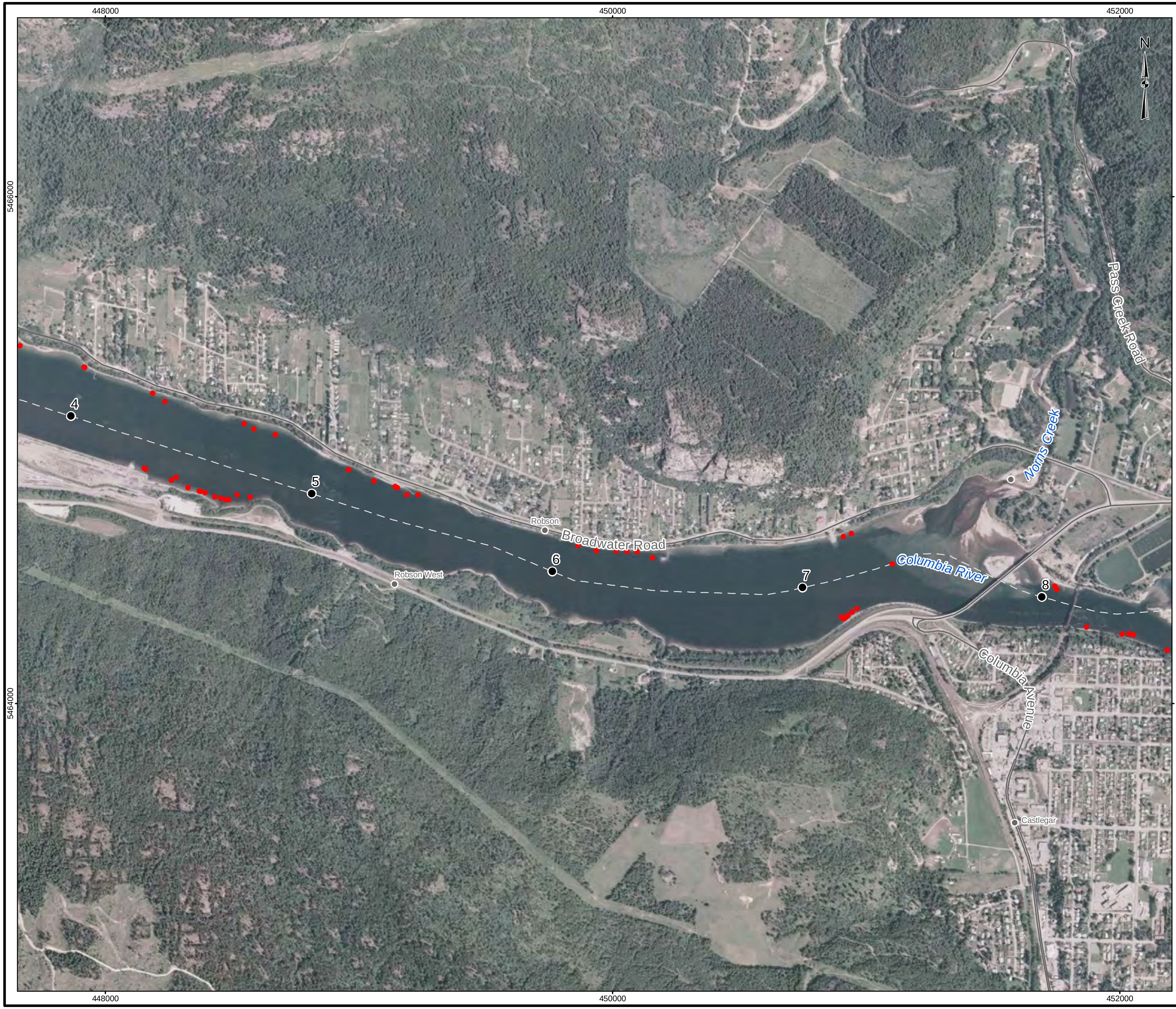

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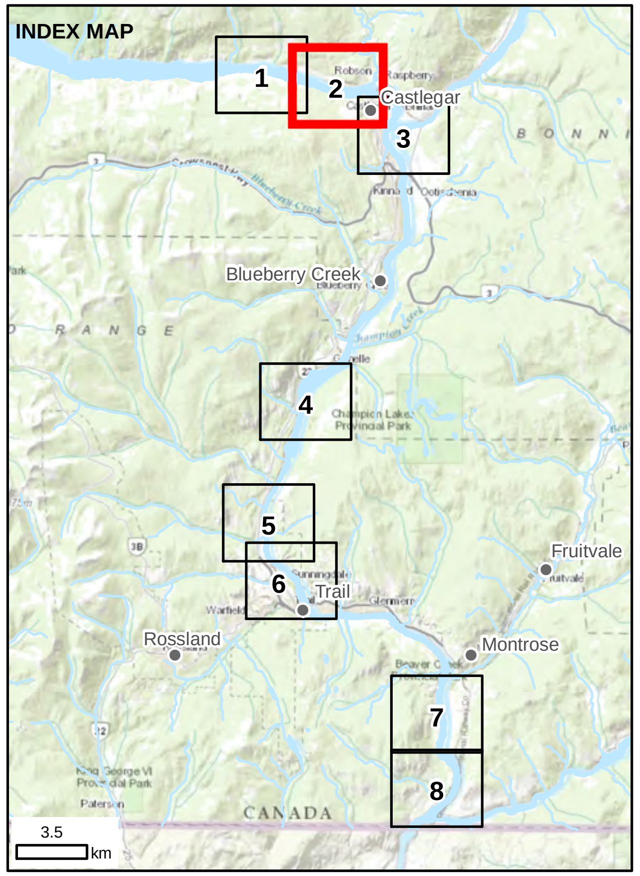
LEGEND

- ● PLACE NAME
- ● RIVER KILOMETRE POSTS

FISH_OBSERVATIONS_SURVEY_2019_UTM11

WALLEYE OBSERVATIONS

- ● ADULT
- ● JUVENILE
- ● FRY
- — ROAD
- – – RIVER CENTRELINE
- ═ DAM



REFERENCE

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DATUM: NAD83 PROJECTION: UTM ZONE 11

300 0 300

SCALE 1:15,000 METRES

PROJECT

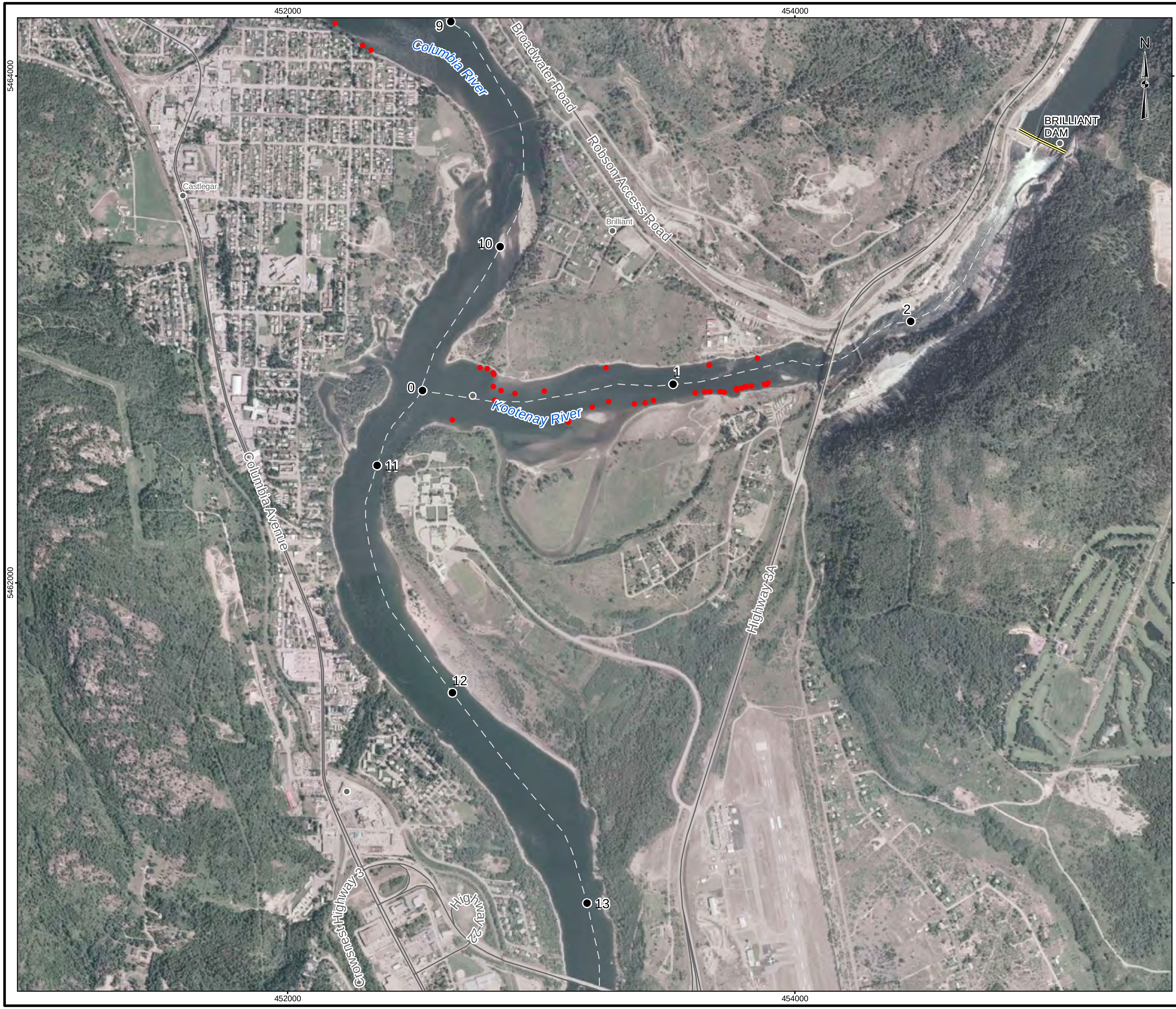
LOWER COLUMBIA RIVER
GEO-REFERENCED VISUAL ENUMERATION SURVEY 2019

TITLE

WALLEYE

GOLDER

PROJECT		1537874/2017	FILE No.	
DESIGN	DR	07 JUN. 2018	SCALE AS SHOWN	REV. 0
GIS	JG	24 JUN. 2019	**FIGURE H3 2 OF 8**	
CHECK	DR	24 JUN. 2019		
REVIEW	SR	24 JUN. 2019		



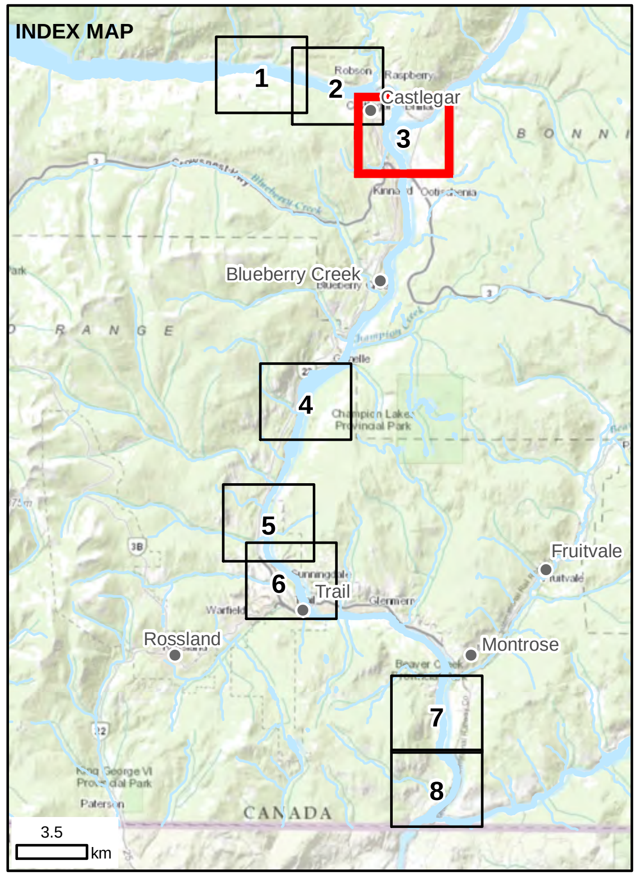
LEGEND

- ● PLACE NAME
- ● RIVER KILOMETRE POSTS

FISH_OBSERVATIONS_SURVEY_2019_UTM11

WALLEYE OBSERVATIONS

- ● ADULT
- ● JUVENILE
- ● FRY
- — ROAD
- - - RIVER CENTRELINE
- ═ DAM



REFERENCE

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DATUM: NAD83 PROJECTION: UTM ZONE 11

300 0 300

SCALE 1:15,000 METRES

PROJECT

LOWER COLUMBIA RIVER
GEO-REFERENCED VISUAL ENUMERATION SURVEY 2019

TITLE

WALLEYE

GOLDER

PROJECT		1537874/2017	FILE No.
DESIGN	DR	07 JUN. 2018	SCALE AS SHOWN / REV. 0
GIS	JG	24 JUN. 2019	FIGURE H3 3 OF 8
CHECK	DR	24 JUN. 2019	
REVIEW	SR	24 JUN. 2019	

Document Path: Y:\burnaby\CAD-GIS\Client\ONALCR\99_PROJECTS\1537874\02_PRODUCTION\INDEXING\MXD\Report\2019\1537874_FIG_H3_WALLEYE_2019.mxd

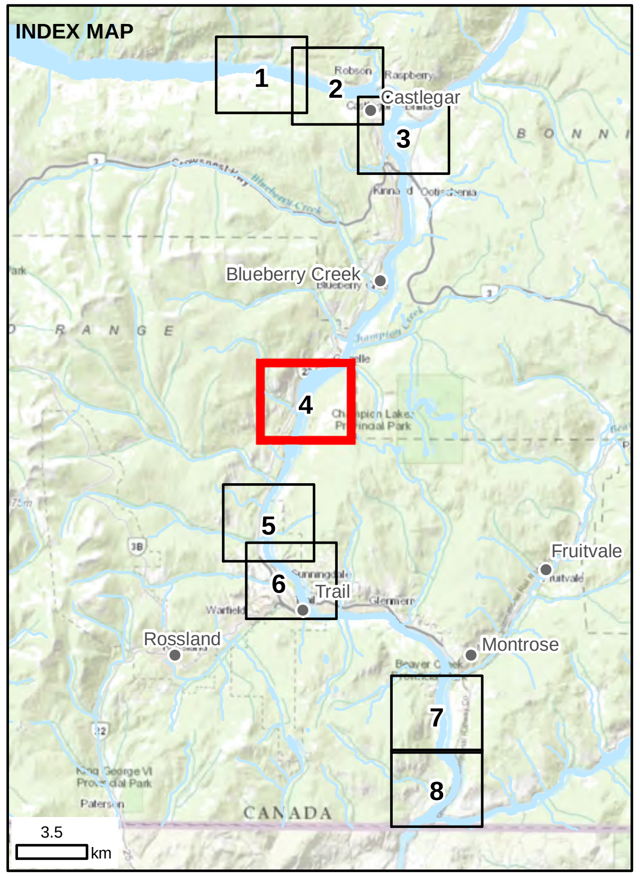
LEGEND

● PLACE NAME
● RIVER KILOMETRE POSTS

FISH_OBSERVATIONS_SURVEY_2019_UTM11

WALLEYE OBSERVATIONS

● ADULT
● JUVENILE
● FRY
— ROAD
- - RIVER CENTRELINE
═ DAM



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DATUM: NAD83 PROJECTION: UTM ZONE 11

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SCALE 1:15,000 METRES

PROJECT
LOWER COLUMBIA RIVER
GEO-REFERENCED VISUAL ENUMERATION SURVEY 2019

TITLE

WALLEYE

GOLDER

PROJECT		1537874/2017	FILE No.	
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GIS	JG	24 JUN. 2019	**FIGURE H3 4 OF 8**	
CHECK	DR	24 JUN. 2019		
REVIEW	SR	24 JUN. 2019		

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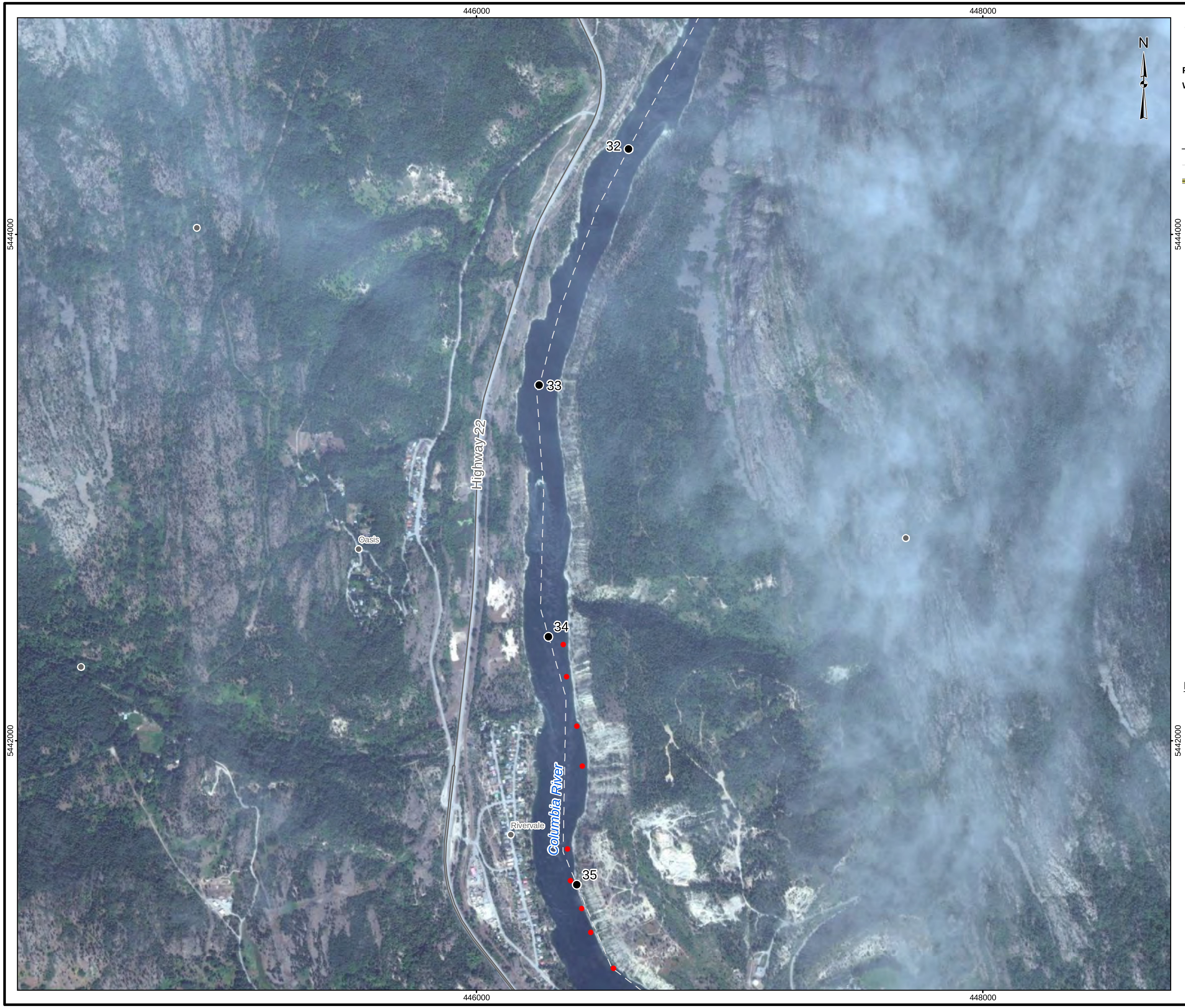

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FISH_OBSERVATIONS_SURVEY_2019_UTM11

WALLEYE OBSERVATIONS

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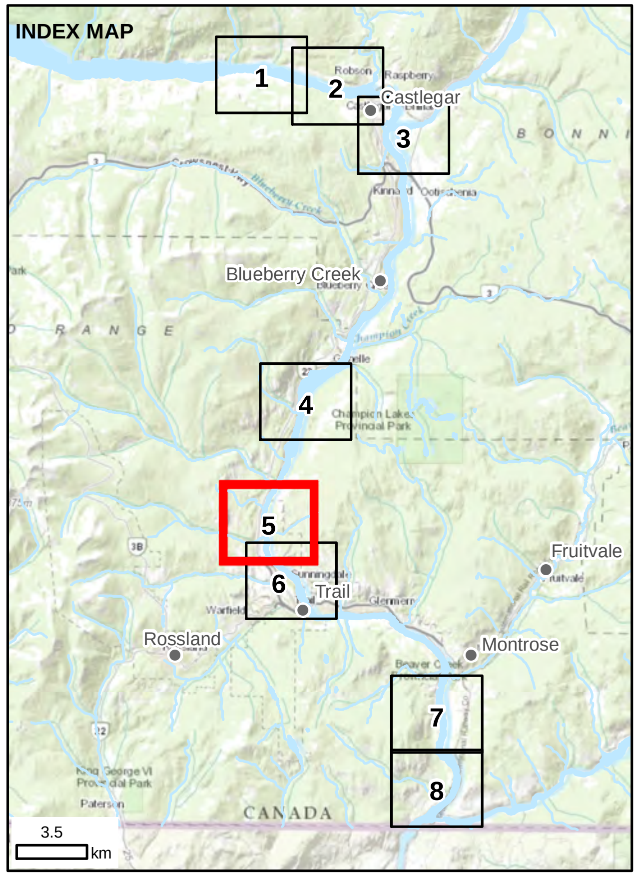

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FISH_OBSERVATIONS_SURVEY_2019_UTM11

WALLEYE OBSERVATIONS

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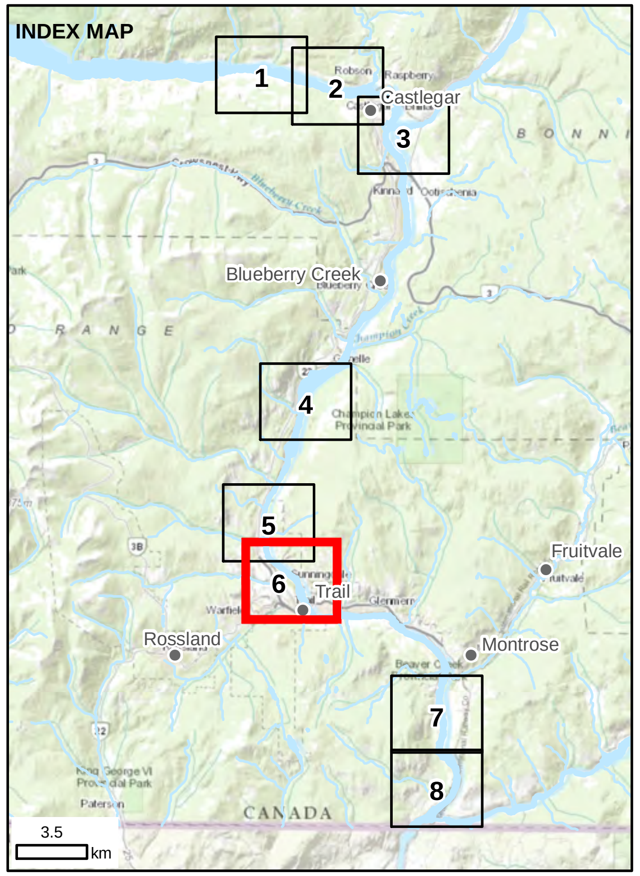

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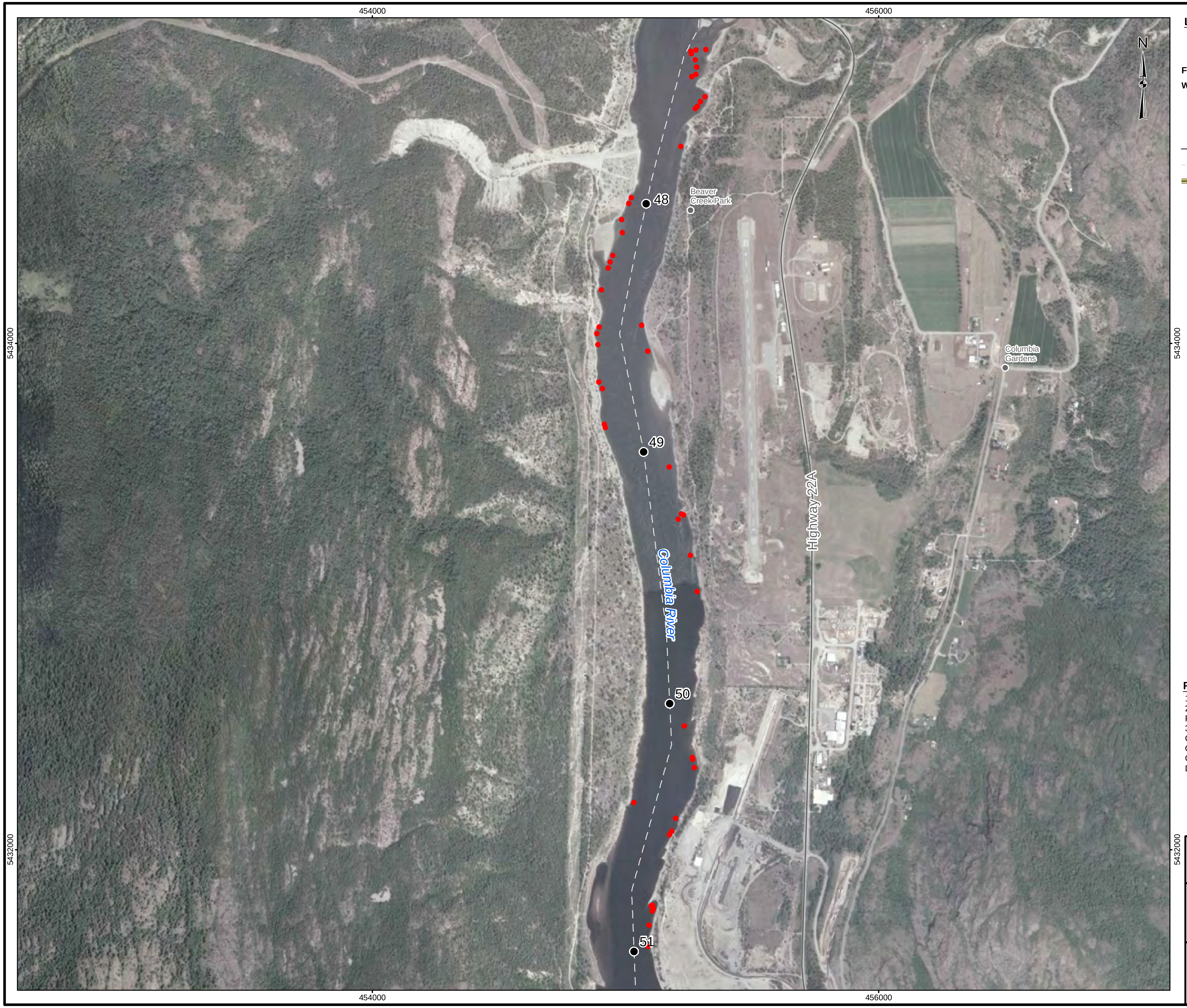

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FISH_OBSERVATIONS_SURVEY_2019_UTM11

WALLEYE OBSERVATIONS

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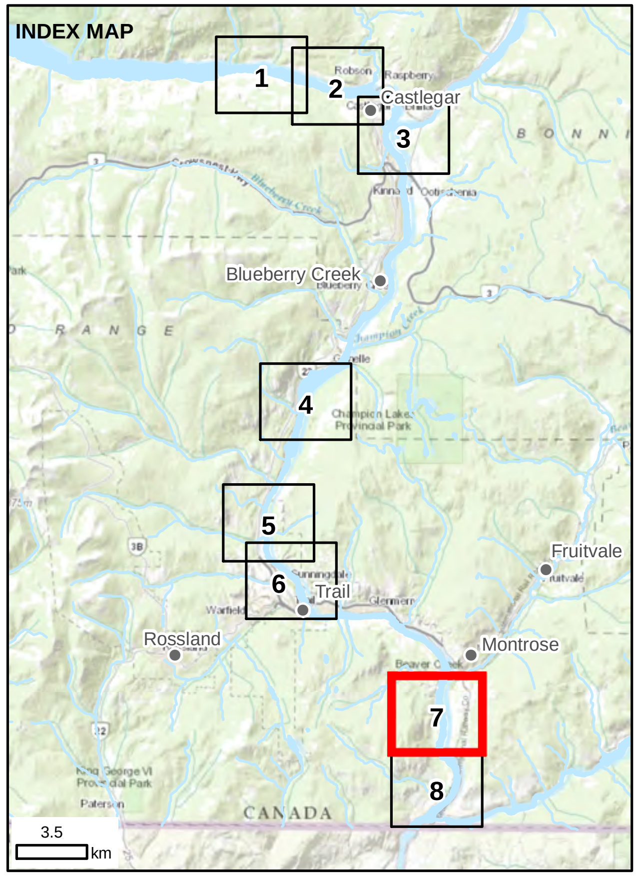

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FISH_OBSERVATIONS_SURVEY_2019_UTM11

WALLEYE OBSERVATIONS

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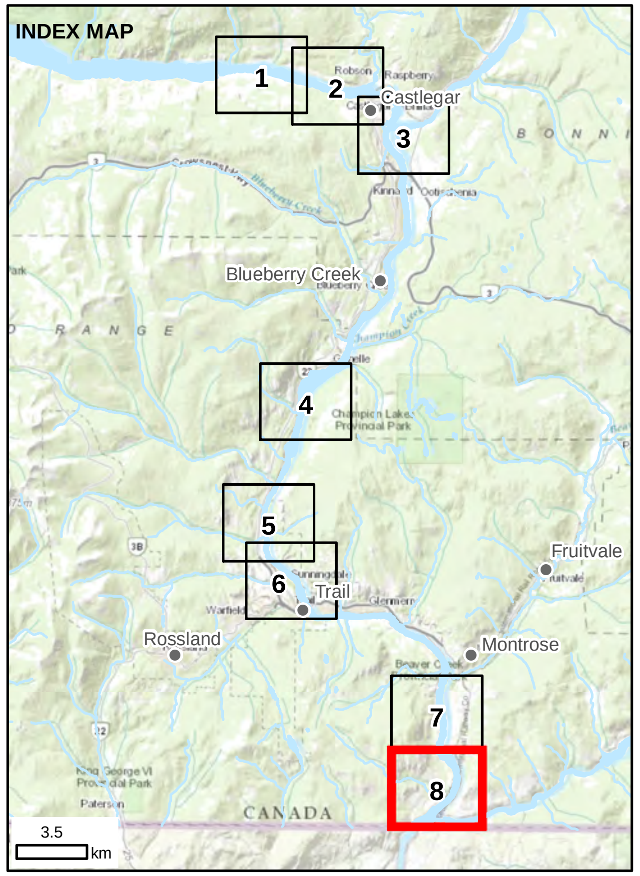

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REVIEW	SR	24 JUN. 2019	

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Appendix 3 – Management Question #2

1.0 INTRODUCTION

In the mid-1990s, BC Hydro initiated water management from Hugh L. Keenleyside Dam (HLK) during the Mountain Whitefish (*Prosopium williamsoni*) and Rainbow Trout (*Oncorhynchus mykiss*) spawning seasons to reduce egg losses downstream of the dam. Throughout the Mountain Whitefish spawning season (December to February), BC Hydro decreases flow from HLK during the peak spawning period (24 December to 21 January; Golder 2010a) to encourage spawning at lower water level elevations and to reduce egg dewatering over the winter and early spring when annual minimum flows typically occur. Subsequently, flows are managed (within the constraints of the Columbia River Treaty and flood protection considerations) to provide stable or increasing water levels during the middle of the Rainbow Trout spawning season (early April to late June) to protect Rainbow Trout spawners by reducing the likelihood that Rainbow Trout eggs (and other larval fishes) are dewatered. These operational strategies are referred to as the Mountain Whitefish and Rainbow Trout flow regimes.

BC Hydro implemented a Water Use Plan (WUP; BC Hydro 2005) for the Columbia River in 2007. As part of the WUP, the Columbia River Water Use Plan Consultative Committee recommended the establishment of the Lower Columba River (LCR) Fish Indexing Program (CLBMON-45) to address data gaps regarding the effects of water management at HLK (particularly during the Mountain Whitefish and Rainbow Trout spawning seasons) on downstream fish populations. The LCR Fish Indexing Program represents a continuation of the Large River Fish Indexing Program (LRFIP), a program initiated by BC Hydro in 2001 to develop a reliable and cost-effective method of indexing the fish community downstream of HLK.

In 2001, the LRFIP gathered baseline information on fish distribution, life history characteristics, and population abundance of fish species present in the LCR (Golder 2002). Between 2002 and 2006 (Golder 2003, 2004, 2005, 2006, 2007), the program was refined, based on the results of previous study years, to provide a systematic and repetitive index of fish population parameters for three index species: Mountain Whitefish, Rainbow Trout, and Walleye (*Sanders vitreus*). A detailed summary of the life history requirements for these three species was prepared by Golder (2009, 2010b).

The current study year (2019) is the final year of planned monitoring under the WUP. The final reports for monitoring programs under the WUP are summary reports in a less technical format than a conventional scientific technical report. Technical details are provided in appendices with a separate appendix for each management question of the program. Appendix 3 provides the details of the background, methods, results, and interpretation relevant to the program's second of two management questions, which was:

- What is the effect of inter-annual variability in the Whitefish and Rainbow Trout flow regimes on the abundance, growth rate, survival rate, body condition, and spatial distribution of subadult and adult Whitefish, Rainbow Trout and Walleye in the LCR?

This management question is addressed in this appendix using data collected from 2001 to 2019 during the LRFIP (2001–2006) and CLBMON-45 (2007–2019).

The Mountain Whitefish and Rainbow Trout flow regimes, also referred to as "spawning protection flows", are intended to reduce mortality of eggs due to dewatering. Effects of the flow regimes on the growth, body condition, adult survival, and spatial distribution are possible, but are not the main intent of the spawning protection flows. Therefore, when answering management question #2, the focus was to assess the effects of variation in the flow regime on the subsequent recruitment and abundance of Mountain Whitefish and Rainbow Trout. As spawning, rearing, and recruitment of Walleye is thought to occur primarily or entirely outside of the study area, effects of flow variability and related egg dewatering were not assessed for this species. For fish population metrics that are less directly linked to the spawning protection flows, including growth, body condition, adult survival, and distribution, potential effects of flow variability and discharge reductions are discussed in Appendix 2. Statistical analyses were not conducted to assess the effect of flow variability on these variables.

2.0 Study Area and Study Period

The study area and period for management question #2 were the same as presented for management question #1. Refer to Section 2.0 of Appendix 2 for details about the study area and period.

3.0 METHODS

3.1 Data Collection

Field methods and data collection to address management question #2 were the same as presented for management question #1. Refer to Section 3.1 of Appendix 2 for details about data collection.

3.2 Data Analyses

Data entry and validation methods were the same as presented in Section 3.2.1 of Appendix 2. Details of the statistical analyses conducted to address management question #2 are presented in the following section.

3.2.1 Hierarchical Bayesian Analyses

Metrics used to assess management question #2 were analyzed using Hierarchical Bayesian Models (HBMs). The book ‘Bayesian Population Analysis using WinBUGS: A hierarchical perspective’ by Kéry and Schaub (2011) provides an excellent reference for hierarchical Bayesian methods. In short, a hierarchical Bayesian approach:

- Allows complex models to be logically defined using the BUGS language (Kéry and Schaub 2011: 41).
- Permits the incorporation of prior information (Kéry and Schaub 2011: 41).
- Readily handles missing values.
- Provides readily interpretable parameter estimates whose reliability does not depend on the sample size.
- Allows derived quantities to be calculated (Kéry and Schaub 2011: 41).
- Enables the efficient modelling of spatial and temporal variations and correlations (Kéry and Schaub 2011: 78-82).
- Permits the separation of ecological and observational processes (Kéry and Schaub 2011: 44).

The analyses were implemented using R version 4.0.0 (R Core Team 2020) and the mbr family of packages. Models were fit using JAGS (Plummer 2015) and STAN (Carpenter et al. 2017). The technical aspects of the analyses, including the general approach, model definitions, and the resultant parameter estimates are provided in Appendix C of Appendix 2. In addition, the statistical methodology, sample code, parameter estimates, and figures of results are available online (Thorley 2020).

The parameters are summarized in terms of the point estimate, standard deviation (sd), the z-score, lower and upper 95% confidence/credible limits (CLs) and the p-value (Kéry and Schaub 2011, 37, 42). The z-scores were used to calculate p-values for each of the parameter estimates. Lower and upper 95% confidence limits are used to describe uncertainty in maximum likelihood estimates. Credible limits are the Bayesian equivalent of confidence limits. The range from the lower CL to the upper CL is referred to as a credible/confidence interval (CI). For maximum likelihood models, the point estimate is the maximum likelihood estimate (MLE), the standard deviation is the standard error, the z-score is MLE/sd, and the 95% CLs are the MLE±1.96×sd. For Bayesian models, the estimate is the median (50th percentile) of the MCMC samples, the z-score is mean/sd and the 95% CLs are the 2.5th and 97.5th percentiles. A p-value of 0.05 indicates that the lower or upper 95% CL is 0. Where relevant, model adequacy was confirmed by examination of residual plots for the full model(s).

The results were displayed graphically by plotting the modeled relationships between a particular variable (e.g., year) and the response variable with the remaining variables held constant. Continuous and discrete fixed variables were held constant at their mean and first level values, respectively, while random variables were 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 was expressed in terms of the effect size (i.e., percent change in the response variable) with 95% CIs (Bradford et al. 2005).

If the model assumptions are correct, there is 95% probability that the actual underlying values lie within the credible intervals (CIs). An estimate is statistically significant if its 95% CIs do not include zero. If two values have non-overlapping CIs, then the difference between them is by definition statistically significant. However, estimates can have overlapping CIs but the difference between them can still be statistically significantly different. For example, the estimates of abundance depend on the differences between years, as well as the abundance in a typical year. As uncertainty in the abundance in a typical year affects all the estimates, it can cause the CIs to overlap even if the differences between years are significantly different. If it is important to establish the statistical significance of a difference or trend where the CIs overlap, this can be determined from the posterior probability distributions.

Statistical significance does not indicate biological importance. For example, a difference may be statistically significant but so small as to be of no consequence for the population. Conversely, the uncertainty in a difference may include zero thus rendering the difference statistically insignificant while also admitting the possibility of a large and potentially impactful effect. For further information on the limitations of statistical significance, see Greenland et al. (2016).

3.2.3 Age Ratios

This program’s second management question regards the effect of variability on the flow regime, which can result in variable amounts of egg mortality due to dewatering, on abundance of fish in the LCR. The abundance of fish in the LCR is determined in part by the number of eggs that hatch, survive, and are recruited to the subadult and adult populations. To monitor inter-annual changes in recruitment, ratios of age-1:age-2 fish were calculated and used as an index of annual recruitment. The age ratio analysis used ages assigned based on the length-at-age model (Section 2.2.3 of Appendix 2). Age ratio analyses were conducted for Mountain Whitefish, which was the only species for which there were data regarding the proportion of age-1 and age-2 fish from 2001 to 2019. The age ratio could not be assessed for Rainbow Trout because age-2 individuals could not be reliably distinguished from age-3 and older based on their fork lengths.

The proportional ratio of age-1 to age-2 Mountain Whitefish (age-1:2 ratio) for each year from 2001 to 2019 was obtained from the length-at-age models. Years with strong recruitment are expected to result in greater age-1:2 ratios than years with weaker recruitment and this ratio does not depend on estimates of capture efficiency and is not affected by violations of the assumptions of the mark-recapture models.

The age-1:2 ratio for a given spawning year (r_t) was calculated based on the abundance of age-1 (N^1) and age-2 (N^2) fish two years after the spawning year ($t + 2$):

$$r_t = \frac{N_{t+2}^1}{N_{t+2}^1 + N_{t+2}^2}$$

Mountain Whitefish in the LCR spawn in November and December, hatch primarily in March and April of the following year (referred to as the hatch year), and are therefore age-1 two years after the spawning year ($t + 2$). To test for effects of egg loss from dewatering on the recruitment index (r_t), the ratio of estimated egg loss (L_t) affecting each spawning year was calculated:

$$L_t = \log(Q_t/Q_{t-1})$$

This ratio was used to represent egg loss because the losses during the spawning year (Q_t) are expected to affect the proportion of age-1 fish two years later ($N_{t+2)}^1$) whereas the proportion of age-2 fish (N_{t+2}^2) is expected to be affected by egg losses three years prior (Q_{t-1}). The ratio was logged to ensure it was symmetrical about zero (Tornqvist et al. 1985). Annual egg loss estimates were obtained from the Mountain Whitefish Egg Stranding Model, which estimates egg dewatering and mortality using hourly hydrological data, bathymetry, and information regarding spawning timing and location (Golder 2013). The relationship between the recruitment index, r_t, and egg losses, L_t, was estimated using a hierarchical Bayesian logistic regression (Kéry 2010) loss model. Key assumptions of the final model include the following:

- The log odds of the proportion of age-1 fish varied linearly with the log of the ratio of the percent egg losses.
- The residual variation was normally distributed.

The relationship between egg dewatering and subsequent recruitment is expected to depend on stock abundance (Subbey et al. 2014) which might be changing over the course of the study. Consequently, preliminary analyses allowed the slope of the regression line to change through time. The change was not significant and was therefore removed from the final model. The effect of dewatering on Mountain Whitefish recruitment was expressed in terms of the predicted percent change in age-1 Mountain Whitefish abundance by egg loss in the spawn year relative to 10% egg loss in the spawn year. The egg loss in the previous year was fixed at 10%. The percent change could not be calculated relative to 0% in the spawn or previous year because L_t is undefined in either case.

3.2.4 Fecundity and Egg Deposition

The number of eggs produced per spawning female, known as the fecundity, and the total number of eggs deposited by the population per spawning year were calculated to be used in the stock-recruitment analysis (Section 3.2.5).

The relationship between fecundity (F) and body weight (W) for Mountain Whitefish was estimated from data collected by Boyer et al. (2017) for the Madison River, Montana. The data were analysed using an allometric model of the form: $F = \alpha W^{\beta}$, where α and β are estimated coefficients. The model assumed that the residual variation in fecundity was log-normally distributed.

For Rainbow Trout, the fecundity (F) in year t of an adult female Rainbow Trout was calculated from the expected weight (W) in grams using the equation: $F_t = 3.8 \times W_t^{0.9}$. This equation was developed using data from Rainbow Trout in Kootenay Lake (Andrusak and Thorley 2019).

The weights used in fecundity calculations were the year-specific expected weights from an average-length fish from the condition model (Section 3.2.11 of Appendix 2).

The total egg deposition (E_t) in year t was calculated from the estimated fecundity (F_t) and adult abundance (A_t), assuming that the population was 50% female, using the equation: $E_t = F_t \times A_t \times 0.5$.

3.2.5 Stock-Recruitment Relationship

Understanding the relationship between the number of spawning adults, which is sometimes referred to as the “stock,” and the resulting number of individuals recruited to the catchable population of fish (“recruitment”) is one of the most important issues in fisheries biology and management (Myers 2001). At low spawner abundance, recruitment is expected to be driven by density-independent factors and the number of recruits will increase with the number of spawners. At high spawner abundance, density-dependent factors such as competition for limited resources can result in a decrease in per capita recruitment with increasing numbers of spawners. Stock-recruitment relationships often use the number of spawners as a proxy for the reproductive output of the population (Subbey et al. 2014) but this approach does not account for differences in body size and fecundity of the population. Estimates of egg production or deposition may provide a more accurate estimate of reproductive output of the population. For the LCR, the relationship between the estimated number of eggs deposited (“stock”) and the resultant number of subadults the following year (“recruitment”) was estimated using a Bayesian Beverton-Holt stock-recruitment model (Walters and Martell 2004):

$$R = \frac{\alpha E}{1 + \beta E}$$

where E is the estimated number of eggs deposited, R is the estimated number of age-1 subadults (recruits), α is the recruits per egg (survival from egg to age-1) at low density and β determines the density-dependence. The ratio of α to β defines the carrying capacity, which is the predicted maximum value of the mean number of recruits at large values of egg deposition.

With respect to the Mountain Whitefish and Rainbow Trout protection flows, it is important to understand if and when egg losses due to dewatering affect the number of recruits in the LCR. Mortality of incubating eggs due to dewatering could affect density-dependent mortality of eggs or rearing juveniles, which would change the stock-recruitment curve compared to in the absence of dewatering. To test for effects of egg loss, the estimated proportional egg loss was included as a predictor variable affecting the number of recruits in the stock-recruitment model. Egg loss estimates were obtained from the Mountain Whitefish Egg Stranding Model (Golder 2013) and from Irvine et al. (2018) for Rainbow Trout.
Key assumptions of the stock-recruitment model include:

- The egg to recruit survival at low numbers of egg deposition was likely less than 1% (the prior distribution of α was a zero truncated normal distribution with a standard deviation of 0.005).
- The expected log number of recruits was affected by the proportional egg loss.
- The residual variation in the number of recruits was log-normally distributed.

The stock-recruitment relationship was calculated for Mountain Whitefish and Rainbow Trout. Age ratio and stock-recruit results are presented in terms of the spawning year. For Rainbow Trout, which spawn from March to July and hatch in June to August in the LCR (Irvine et al. 2015), the spawning year is the same as the hatch year. For Mountain Whitefish, spawning occurs mostly in November to December in the LCR and hatch occurs mostly between March and April; therefore, the hatch year is one year greater than the corresponding spawning year. For both species, the age-0 life stage is defined as the first year beginning on the hatch date.

4.0 RESULTS

4.1 Age Ratios

The estimated proportion of egg mortality due to dewatering ranged from 7% in 2010 to 59% in 2016 (Figure 1). The age-1:2 ratio for Mountain Whitefish was used as an indicator of annual recruitment strength and ranged from a minimum of 25% for the 2003 spawning year to a maximum of 79% in 2005 (Figure 2). For the 2016 spawning year, which corresponds to catch of age-1 and age-2 individuals during the 2018 survey, the age-1:2 ratio decreased to 33%, which was substantially lower than the previous six years when the ratio ranged from 64% to 73%. The decrease in age-1:2 ratio for the 2016 spawning year coincided with the large estimated egg loss that year, when an estimated 59% of eggs were dewatered. However, the age-1:2 ratio remained low (44%) in 2017 when the egg loss estimate was only 14%.

To test for the effect of egg loss on the age-1:2 ratio, the logged ratio of age-1 egg loss to age-2 egg loss was used as the predictor variable to account for both age-1 egg loss one year prior and age-2 egg loss two years prior. There was no statistically significant relationship between the age-1:2 ratio and estimated egg losses from the 1999 to 2017 spawn years (P=0.5). The data suggested a negative relationship between age-1:2 ratio and logged egg loss ratio (Figure 3) but large variability resulted in a non-significant regression slope. Although this relationship was not significant, the effect size of egg loss on recruitment is shown in Figure 4. The model predicts a 24% decrease in recruitment at 50% egg loss compared to the recruitment at 10% egg loss (Figure 4). At 50% egg loss, although the mean prediction was a 24% decrease (relative to 10% egg loss), the 95% credible interval for the effect on recruitment ranged from a 67% decrease to a 65% increase, which indicates considerable uncertainty in the relationship. This uncertainty was due to highly variable recruitment at similar levels of egg loss. For instance, recruitment was either high (2011 and 2012) or low (2002, 2008, and 2016) during the greatest levels of egg loss (Figure 3). This suggests that there was not a consistent negative effect of egg loss on the age-1:2 recruitment index based on the available data, and that factors other than egg loss are contributing to the large variability in age-1:2 ratio.

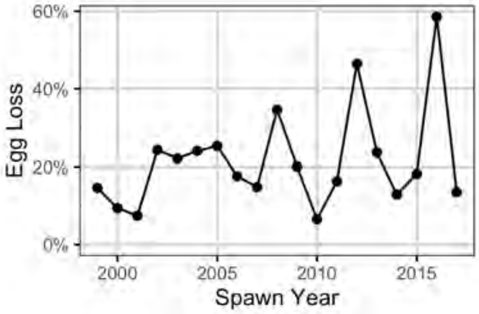

Figure 1: Estimated proportion of Mountain Whitefish egg loss due to dewatering in the lower Columbia River by spawning year, 1999 to 2017, based on the egg loss model.

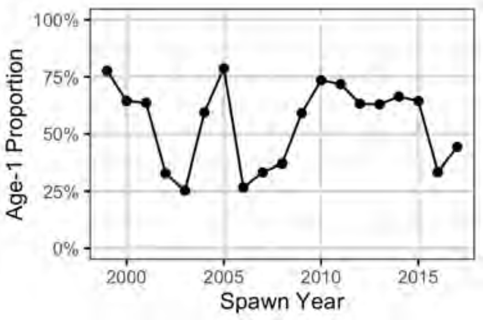

Figure 2: Proportion of age-1 to age-2 Mountain Whitefish in boat electrofishing catch in the lower Columbia River by spawning year, 1999 to 2017.

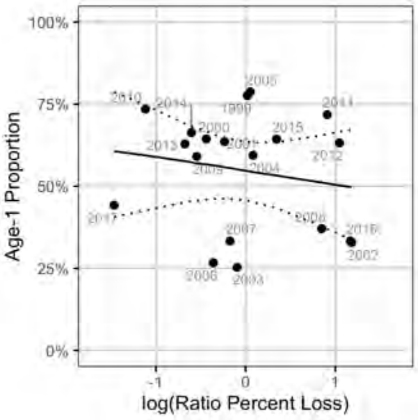

Figure 3: Relationship between the proportion of age-1 to age-2 Mountain Whitefish and the estimated proportion of Mountain Whitefish egg loss due to dewatering. Year labels represent the spawning year. The predicted relationship is indicated by the solid black line and dotted line represents the 95% CI.

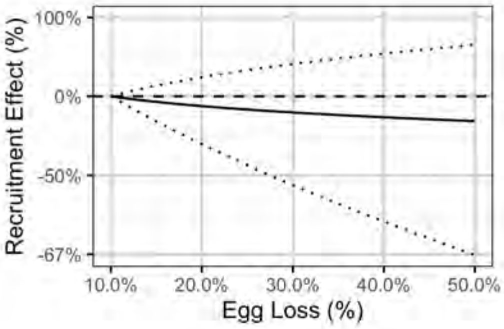

Figure 4: Predicted percent change in age-1 Mountain Whitefish abundance by egg loss in the spawn year relative to 10% egg loss in the spawn year (with 95% CIs).

4.2 Stock-Recruitment Relationship

4.2.1 Mountain Whitefish

The stock-recruitment relationship indicated large variation in the recruitment for Mountain Whitefish data in the LCR (Figure 5). Based on the available data, the variability in recruitment was not related to the number of adults or the estimated egg loss due to dewatering. The majority of years suggested little effect of increasing the estimated number of eggs deposited by adults ("stock") on the resulting number of age-1 recruits, which is consistent with density-dependent survival, where egg survival is lower at high numbers of spawners (Figure 6). An exception was the 2005 spawning year that had the greatest number of adults and greater recruitment than all other years. There were no years with data that allowed assessment of the shape of the curve at small stock size. Therefore, the egg survival at low stock abundance and the number of spawners below which the number of recruits is predicted to decrease is not known based on this analysis.

The effect of egg dewatering mortality on recruitment was uncertain and not statistically significant (*P*=0.7; Figure 7). However, the stock-recruitment curve did not have any data on the lower part of the curve where decreased stock or increased egg loss would be expected to result in a large decrease in recruitment. Estimates of the effect of egg dewatering mortality showed high uncertainty with the possible effect size ranging from a 135% increase to a 67% decrease in recruitment when egg dewatering mortality was 40%. The most likely effect (i.e., predicted mean value) was a 15% decrease in recruitment when egg dewatering mortality was 40%. Therefore, the data were most consistent with a small negative effect of egg dewatering mortality on recruitment, but a large negative or positive effect cannot be ruled out.

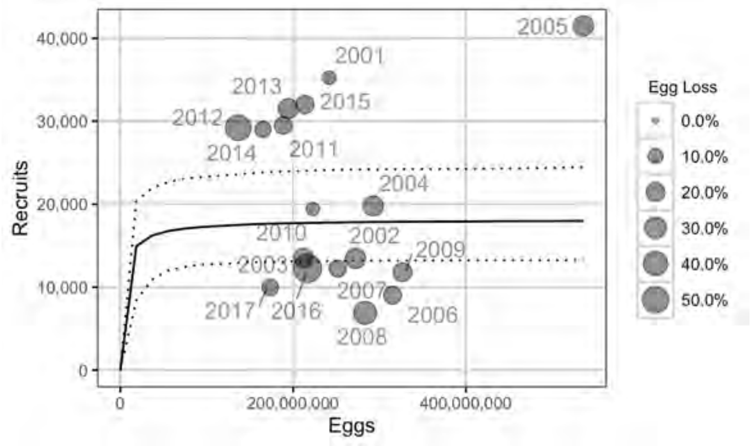

Figure 5: Predicted stock-recruitment relationship between age-2+ spawners ("Stock") and subsequent age-1 Mountain Whitefish ("Recruits") by spawning year (with 95% CIs). Estimated proportion of egg loss due to dewatering for each spawning year is shown by size of shaded circles.

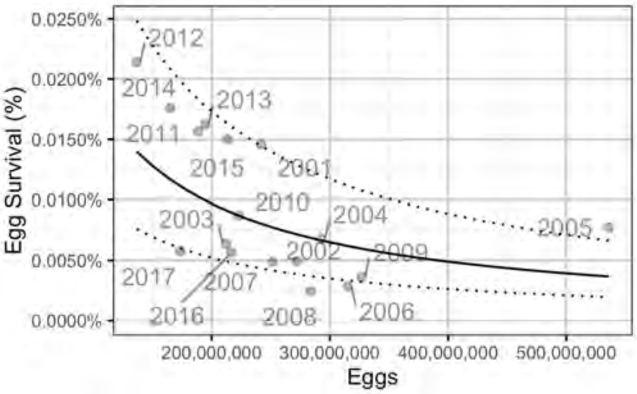

Figure 6: Predicted egg to age-1 survival by total egg deposition (with 95% CIs) for Mountain Whitefish.

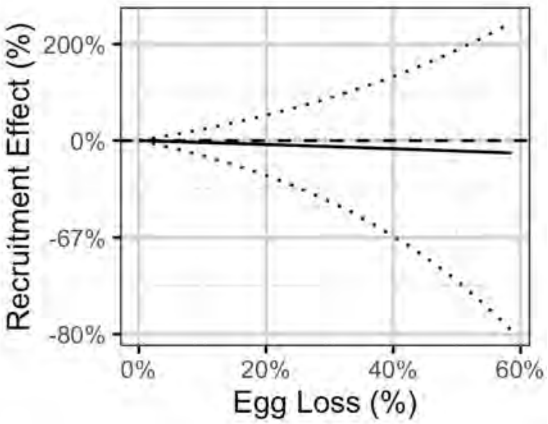

Figure 7: Predicted carrying capacity of age-1 Mountain Whitefish recruits by percentage egg loss (with 95% CIs).

3.8.2 *Rainbow Trout*

The stock-recruitment model for Rainbow Trout predicted little effect of increasing number of eggs deposited by spawners ("stock") on the resulting number of age-1 recruits (Figure 8). However, the actual recruitment decreased with increasing number of eggs, especially in 2017 and 2018 when the estimated number of eggs was the greatest, and recruitment was the lowest (Figure 8).There were no data points on the lower part of the stock-recruitment curve (< 10 million eggs) where a decrease in recruitment but an increase in egg survival is predicted by the curve. As with Mountain Whitefish, no data are available to inform the number of spawners (or egg deposition) required to reach the carrying capacity for recruits, or the egg survival rate at low spawner abundance. The effect of egg loss on recruitment was positive but not statistically significant (*P*=0.06) (Figure 10). The predicted effect size at an egg loss of 1.0% was a 46% increase in recruitment (Figure 10). However, at an egg loss of 1.0%, the credible interval showed that the effect size could be anywhere between a 1% decrease and a 127% increase in recruitment, given the data. This indicates considerable uncertainty in the effect of egg loss on recruitment of Rainbow Trout. Overall, observed egg losses were relatively small, with estimates of less than 1.0% in 16 of 18 years, and a maximum estimated egg loss of 1.6%, which occurred in 2016.

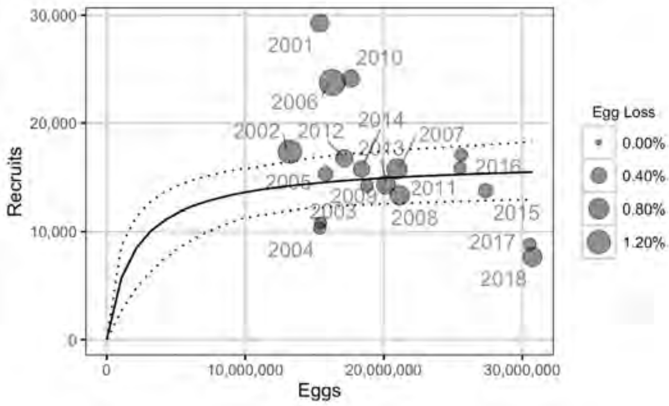

Figure 8: **Predicted stock-recruitment relationship between age-2+ spawners ("Stock") and subsequent age-1 Rainbow Trout ("Recruits") by spawning year (with 95% CIs). Estimated proportion of egg loss due to dewatering for each spawning year is shown by size of shaded circles.**

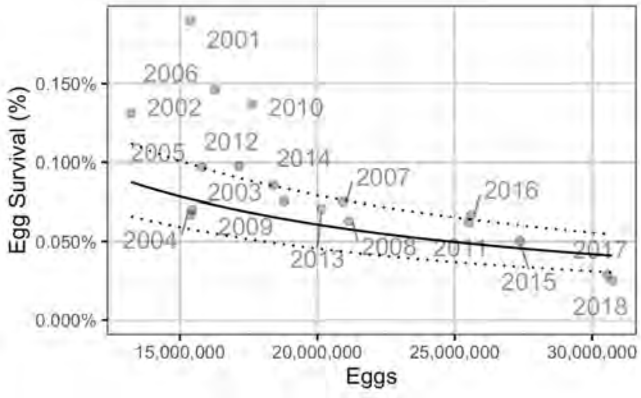

Figure 9: **Predicted egg to age-1 survival by total egg deposition (with 95% CIs) for Rainbow Trout.**

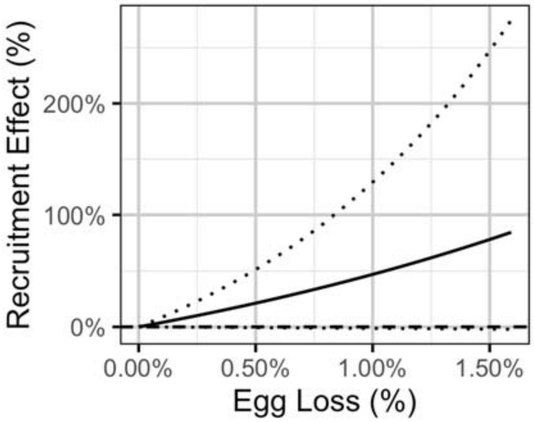

Figure 10: **Predicted carrying capacity of age-1 Rainbow Trout recruits by percentage egg loss (with 95% CIs).**

5.0 DISCUSSION

The program's second management question is whether variability in the Mountain Whitefish or Rainbow Trout flow regimes is related to fish population metrics. The most important aspect of flow regime variability that could affect fish populations is reduction in discharge that could dewater incubating eggs or early life stages. The effect of discharge reductions on Mountain Whitefish and Rainbow Trout populations is addressed with the analyses of age ratio (Section 4.1) and stock-recruitment (Section 4.2). Variability in the flow regime could also affect populations of the index species in other ways, such as effects on availability or suitability of habitat, water temperature, or ecological interactions. These types of effects could be occurring across a range of spatial and temporal scales in the LCR and may differ among species and life stages, making it difficult to detect relationships without specific a priori hypotheses. Both flow regulation, including the Mountain Whitefish and Rainbow Trout protection flows, and natural variability due to weather affect the flow regime in the LCR. Therefore, variability in the flow regime is based on the resulting hydrograph from both natural and operational processes.

5.1 Age Ratios

The proportional ratio of age-1:2 Mountain Whitefish was used as an indicator of recruitment to assess the effects of egg dewatering. Greater egg dewatering is expected to reduce subsequent recruitment of age-1 Mountain Whitefish, which would be reflected by lower age-1:2 ratios. The age-1:2 ratio ranged from 25% to 79% between the 1999 and 2017 spawning years, which suggests substantial inter-annual variation in recruitment during the monitoring period. Across all years of available data, there was no statistically significant relationship between the age-1:2 ratio recruitment index and the estimated annual egg loss ratio. The data indicated a negative relationship between estimated egg loss ratio and age-1:2 ratio but the relationship was uncertain and not statistically significant. The large credible intervals around the relationship (Figures 4 and 5) show that a negative effect of egg loss on Mountain Whitefish recruitment is the most likely, but it is possible there is a large negative or positive effect of egg dewatering, given the data. The non-statistically significant relationship between age-1:2 ratio and egg loss ratio (Figure 3) and large variability in this recruitment index was likely because of other factors, such as environmental conditions and ecological interactions, that influenced survival and recruitment more than egg dewatering during most study years.

The 2016 spawning year had a large decline in the recruitment index (33% compared to 64%–73% in previous six years) and coincided with the largest estimated egg loss on record (59%). This suggests that 59% egg loss due to dewatering could have had a negative effect on the recruitment of Mountain Whitefish. The abundance estimate of age-1 Mountain Whitefish decreased from 29,000–32,000 in the previous five years to 12,000 in 2018, suggesting a biologically significant change in recruitment. However, there was also a decrease in recruitment of age-1 Rainbow Trout in 2018, which could not have been related to the discharge reductions that affected Mountain Whitefish recruitment in 2018 because that cohort of Rainbow Trout was not yet spawned (Section 5.2.2 of Appendix 2). In addition, the recruitment index for Mountain Whitefish remained low in the 2017 spawning year (44%), even though egg dewatering was much lower (13%) than in 2016. These results suggest that factors other than egg dewatering could have contributed to the decrease in age-1 recruits of both Mountain Whitefish and Rainbow Trout in 2018.

Mark-recapture population estimates of subadults could also be used to assess recruitment and the effects of egg dewatering. However, capture efficiencies for subadult Mountain Whitefish are low (<1%) and the mark-recapture estimates are based on several untested assumptions, such as no migration out of the study area between capture sessions. If assumptions are violated or low recapture rates are not accurately reflecting changes in capture efficiency, then it could mask trends in subadult abundance and make it difficult to detect the effects of dewatering. Because the age-1:2 ratio is based on proportions of ages in the catch, this recruitment index would not be affected by undetected changes in capture efficiency, and therefore is likely a more robust method to assess the effects of egg dewatering in the LCR. This approach could also be used for Rainbow Trout in the LCR but currently age data are only available for Rainbow Trout from 2001 to 2012, whereas scales were collected and but not analyzed for Rainbow Trout from 2013 to 2018. Using length-based ages for the age-1:2 ratio is not possible for Rainbow Trout because the length-at-age model cannot distinguish age-2 and age-3 fish, and therefore all age-2 and older fish are grouped in a single category.

5.2 Stock-Recruitment Relationship

For both Mountain Whitefish and Rainbow Trout, the stock-recruitment analysis indicated no relationship between the estimated number of eggs deposited by spawners and age-1 recruits, and large variability in the number of recruits produced by a particular number of eggs. The lack of relationship between stock and recruitment was interpreted as being consistent with density-dependent survival and recruitment at all of the observed stock sizes. Smaller stock sizes may not have resulted in lower recruitment because the lowest observed number of adults between 2001 and 2018 was still sufficient to fully seed the habitat with eggs or fry, resulting in similar numbers of recruits as with greater stock size.

In other words, it may appear that there is no relationship between spawners and recruitment if the range of spawner abundance observed is not sufficiently large (Myers and Barrowman 1996). Alternatively, errors in the measurement of either stock or recruits can mask real relationships and make recruitment appear independent of spawning stock size (Walters and Ludwig 1981). In the LCR, it could be that imprecise estimates of abundance, especially for age-1 fish that have lower recapture rates, could be masking trends in abundance and relationships between adults and age-1 recruits.

For Mountain Whitefish, the effect of egg loss on recruitment was negative but not statistically significant. However, the only data points were on the relatively flat part of the estimated stock-recruitment curve, where a decrease in spawners or egg loss due to dewatering would not be predicted to decrease the resulting recruits substantially. Based on the estimated stock-recruitment curve, years with substantially fewer adults and/or larger egg loss would be needed to detect a decrease in recruitment related to egg dewatering. Predictions of the effect of egg dewatering from the stock-recruitment indicated a high degree of uncertainty in the relationship between egg dewatering and recruitment. These predictions showed that the data were most consistent with a small negative effect of egg dewatering mortality on recruitment but a large negative or positive effect cannot be ruled out.

For Rainbow Trout, estimated egg losses were small between 2001 and 2018, with estimates less than 1.0% in 16 of 18 years, and the greatest observed egg loss of 1.6%. The stock-recruitment model predicted a positive effect of egg loss on recruitment of age-1 Rainbow Trout (Figure 11) but the effect was not statistically significant and had large estimates of uncertainty.

Egg mortality due to dewatering cannot realistically have a positive causal effect on recruitment of juveniles. The unexpected positive effect of egg loss on recruitment was likely due to other, unmeasured factors that are correlated with both egg dewatering and recruitment success. For instance, lower water levels during the spawning season could be associated with lower amounts of subsequent egg dewatering, but have some other negative effect on spawning and recruitment success, such as less available spawning habitat and greater competition than during higher water levels.

Based on the available data, there is no evidence of negative effects of egg losses less than 2% on recruitment of Rainbow Trout in the LCR. Although the data do not support an effect of egg loss on recruitment at the range of adult abundances observed, the effects of egg loss at lower abundance, or higher levels of egg loss (>1.6%) are unknown based on this analysis.

Conclusions regarding the effect of egg dewatering drawn from the stock-recruitment analyses should be considered uncertain because of the poor fit of modeled relationships, and the possibility that sampling biases or environmental variability masked real effects of egg dewatering. Poor fit of stock-recruitment models with fisheries data is common in the literature for marine and freshwater environments. Failure of these models has been attributed to numerous possible factors, such as errors in measurement (Walters and Ludwig 1981), incorrect spatio-temporal scales (Hutchinson 2008), or environmental variability (Myers 1998). In the LCR, estimates of capture efficiency and abundance of age-1 Mountain Whitefish and age-1 Rainbow Trout are hindered by small numbers of recaptured fish. This is partly because this age class is not as effectively sampled as larger fish by the boat electrofisher and because a large proportion of this life stage likely uses shallow habitat not sampled during this program. Low and uncertain estimates of capture efficiency mean that changes in abundance of age-1 fish may not be detected by abundance estimates. For this reason, the age-1:2 ratio is considered a more reliable test of the effect of egg loss than the stock-recruitment analysis.

5.3 Summary

The **second management question** for this monitoring program pertains to the effects of inter-annual flow variability on fish population metrics of the index species. One of the ways that flow variability can affect fish populations is through egg dewatering during discharge reductions. The effect of egg dewatering on fish abundance was assessed through the analysis of age ratios as a recruitment index and through stock-recruitment models that included egg loss as a covariate. For **Mountain Whitefish**, there was no statistically significant relationship between the age-1:2 recruitment index and estimated egg losses across all years of the study (1999 to 2017 spawning years). However, the large estimated egg loss (59%) in the 2016 spawning year corresponded to a large decrease in the age ratio recruitment index and a greater than 50% decrease in the estimated abundance of age-1 Mountain Whitefish. Egg loss was not a significant covariate in the stock-recruitment model for Mountain Whitefish.

The stock-recruitment analysis had large variability in Mountain Whitefish recruitment for a particular level of egg loss or spawner abundance, which resulted in weak predictive ability and suggested that other unknown factors likely have a large influence on recruitment in the LCR.

For **Rainbow Trout**, there was no evidence of negative effects of egg losses on recruitment at the observed levels of egg loss, which were less than 2% in all years. These conclusions for both Mountain Whitefish and Rainbow Trout should be considered tentative because of the poor fit in modelled relationships, and the possibility that sampling biases or environmental variability masked real effects of egg dewatering.

Flow variability in the LCR is expected to have less of an effect on **Walleye** than Rainbow Trout and Mountain Whitefish because the abundance of Walleye is thought to depend on spawning and early life history survival outside of the study area. In addition, effects of flow variability on invertebrate productivity, if they occur, would not have direct effects on food availability that could impact the condition or growth of a piscivorous species like Walleye.

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