Columbia River Project Water Use Plan

Lower Columbia River Fish Management Plan

Lower Columbia River Fish Population Indexing Surveys

Implementation Year 12

Reference: CLBMON-45

Final Technical Report

Study Period 2018

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

November 2019

CLBMON-45:
Lower Columbia River
Fish Population Indexing Survey
2018 Report

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

Prepared for:
BC Hydro

November 2019

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

November 2019

Disclaimer: Okanagan Nation Alliance Fisheries Department reports frequently contain preliminary data, and conclusions based on these may be subject to change. Reports may be cited in publications but their manuscript status (MS) must be noted. Please obtain the individual author's permission before citing their work.

Citation: Golder Associates Ltd., Poisson Consulting Ltd., and Okanagan Nation Alliance. 2019. CLBMON-45 Lower Columbia River Fish Population Indexing Survey 2018 Report. Report prepared for BC Hydro Generation, Water License Requirements, Castlegar, BC. 71 pages + 8 app.

November 2019

Executive Summary

BC Hydro has conducted flow management actions to reduce egg losses in the Lower Columbia River (LCR) during the Mountain Whitefish (*Prosopium williamsoni*) and Rainbow Trout (*Oncorhynchus mykiss*) spawning seasons since the mid-1990s. These actions include decreasing flows from Hugh L. Keenleyside Dam (HLK) in early winter to encourage Mountain Whitefish spawning at lower water level elevations and to reduce egg dewatering over the winter egg incubation period. In early spring, flows are managed to provide stable or increasing water levels during the Rainbow Trout spawning season, which reduces the likelihood of Rainbow Trout eggs and other larval fish from becoming stranded during spring flow management.

In 2007, BC Hydro completed the Water Use Planning process for its hydroelectric and storage facilities on the Columbia River. The Water Use Plan Consultative Committee recommended the commissioning of the LCR Fish Population Indexing Program (CLBMON-45) to address data gaps regarding the effects of HLK operations on downstream fish communities. CLBMON-45 represents a continuation of BC Hydro's LCR Large River Fish Indexing Program (LRFIP), first established in 2001 to gather baseline information on fish distribution, life history characteristics, and population abundance data for select index species (i.e., Mountain Whitefish, Rainbow Trout, and Walleye [*Sanders vitreus*]). This report summarizes the 2018 study year, which is the 18th of 19 years of planned monitoring.

The two key management questions to be answered by CLBMON-45 are:

- 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?
- 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 study area for CLBMON-45 includes the portion of the Columbia River between HLK and the Canada-US border (approximately 56.5 km of river habitat) 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 electrofishing at night within nearshore habitats. In addition to the indexing sites sampled since 2001, additional sample sites were randomly selected in 2011 to 2018 using a Generalized Random Tessellation Stratified survey design. All captured Mountain Whitefish, Rainbow Trout, and Walleye were measured for fork length, weighed, and implanted with a Passive Integrated Transponder (PIT) tag. Hierarchical Bayesian Models (HBMs) were used to estimate temporal and spatial variation in abundance, spatial distribution, growth, survival, and body condition. A maximum likelihood model was used to estimate mean annual length-at-age based on length-frequency data. The proportional ratio of age-1:2 Mountain Whitefish was used as an indicator of recruitment to assess annual variation and the effects of egg dewatering.

For Mountain Whitefish and Rainbow Trout, a Beverton-Holt stock-recruitment model was fit to the data and egg dewatering was included as a covariate.

The estimated abundance of adult Rainbow Trout increased from ~27,000 in 2002 to ~75,000 in 2018. High abundance of Rainbow Trout in recent years coincided with a decline in body condition, growth, and survival, suggesting increased competition and density-dependence. The estimated abundance of subadult and adult Mountain Whitefish was relatively stable from 2012 to 2017. However, in 2018 the estimated abundance of age-1 Mountain Whitefish decreased by more than half while the abundance of adults increased by approximately 65%. Growth of Mountain Whitefish also decreased in recent years, with a predicted maximum growth rate of 140 mm/yr in 2017–2018. In earlier years, the maximum growth rate of Mountain Whitefish increased from 98 mm/yr in 2005 to 247 mm/yr in 2016. Walleye abundance estimates were low but relatively stable from 2012 to 2018 (17,000–29,000) compared to earlier years (26,000–69,000). The body condition of Walleye declined in recent years from a 6% effect size in 2014 to a -2% effect size in 2018.

For Mountain Whitefish, there was no statistically significant relationship between the age-1:2 recruitment index and estimated egg losses (P=0.3) across all years of the study (1999 to 2016 spawning years). The largest estimated egg loss (59%) on record occurred in the 2016 spawning year and corresponded to a large decrease in the age ratio recruitment index and a >50% decrease in the estimated abundance of age-1 Mountain Whitefish in 2018. This suggests that a 59% egg loss due to dewatering could have contributed to the large and biologically significant reduction in recruitment. However, a similar decrease in abundance of age-1 Rainbow Trout in 2018 raises the possibility that some common factor other than dewatering could have contributed to reduced recruitment of both species that year. The age-1:2 index was not calculated for Rainbow Trout because age-2 individuals could not be reliably separated from age-3 and older fish.

In stock-recruitment analyses, there was no effect of increasing abundance of adults (“stock”) on the resulting number of age-1 recruits for Mountain Whitefish or Rainbow Trout, which was interpreted as indicating that the numbers of spawners are currently sufficient to repopulate the river. The effect of egg loss in the stock-recruitment model was not statistically significant for Mountain Whitefish (P=0.4), which did not support an effect of dewatering on subsequent recruitment at the observed levels of stock abundance. The effect of egg loss on the stock-recruitment curve for Rainbow Trout was statistically significant (P=0.03) with a predicted positive effect of egg loss on the carrying capacity of age-1 recruits. However, since the percentage of Rainbow Trout egg loss was small, and unlikely to cause a detectable difference in recruitment, this unexpected result is likely due to other unmeasured variables. There were no years of data on the steeper part of the stock-recruitment curves, where decreases in spawners or egg losses would be expected to decrease subsequent recruitment. Therefore, the effects of egg losses at lower adult abundance are unknown based on these stock-recruitment models. These conclusions should be considered tentative because of the poor fit in the stock-recruitment relationships, and the possibility that sampling biases or environmental variability masked real effects of egg dewatering.

Keywords: Columbia River, Hugh L. Keenleyside Dam (HLK), Density Estimation, Fish Abundance, Hierarchical Bayesian Models (HBM)

Acknowledgements

The Lower Columbia River Fish Population Indexing Survey (CLBMON-45) is funded by BC Hydro's Columbia River Water Use Plan. The Okanagan Nation Alliance, Golder Associates Ltd., and Poisson Consulting Ltd. would like to thank the following individuals for their contributions to the program:

BC Hydro

Darin Nishi	Burnaby, BC
Phil Bradshaw	Burnaby, BC
Guy Martel	Burnaby, BC

The following members of the **Okanagan Nation Alliance Fisheries Department** contributed to the collection of data and preparation of this report.

Amy Duncan, MSc, RPBio	Biologist, Project Manager
Dave DeRosa, BSc, PAg	Biologist
Evan Smith, BSc	Technician
Eleanor Duifhuis, BSc	Technician

The following employees of **GOLDER ASSOCIATES LTD.** contributed to the collection of data and preparation of this report.

David Roscoe, MSc, RPBio	Biologist, Report Author
Dustin Ford, RPBio	Senior Fisheries Biologist
Chris King, Dipl Tech	Biological Technician, Field Lead
Shawn Redden, RPBio	Senior Fisheries Biologist, Project Director
Sima Usvyatsov, PhD	Biological Scientist, Data Analyst
Natasha Audy, Dipl Tech	Biological Technician
Carrie McAllister	Office Administrator
Ron Giles	Warehouse Technician

The following employee and subcontractor of **Poisson Consulting Ltd.** contributed to the preparation of this report.

Joseph Thorley, PhD, RPBio	Computational Biologist, Co-Author
Seb Dalgarno, MSc	Computational Biologist

TABLE OF CONTENTS

List of Tables

List of Figures

Appendices

Attachments

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. 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 2010a) to encourage spawning at lower water level elevations to reduce egg dewatering over the winter period and during the 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 during spring flow management.

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).

Data collected under the LRFIP (2001–2006) and the current program (CLBMON-45; 2007–2018) will be used to identify changes in populations of index fish species and assist in the determination of the biological and statistical significance of these changes in relation to Mountain Whitefish and Rainbow Trout spawning protection flows.

1.1 Study Objectives

The objectives of CLBMON-45 (BC Hydro 2007) are:

- to extend time series data on the abundance, distribution, and biological characteristics of nearshore and shallow water fish populations in the LCR;
- to examine long-term trends in key index fish populations (i.e., Mountain Whitefish, Walleye, and Rainbow Trout) during the continued implementation of Mountain Whitefish and Rainbow Trout flows in the LCR;
- to build upon previous investigations for the further refinement of sampling strategy, sampling program, and analytical procedures to establish a long-term monitoring program for fish populations in the LCR;
- to update the existing electronic storage and retrieval system for fish population and habitat monitoring data for the Columbia River;
- to establish linkages between other biological monitoring programs being undertaken in the LCR, in particular, the Physical Habitat and Ecological Productivity Monitoring Program (CLBMON-44); and
- to identify gaps in data and understanding of current knowledge about fish populations and procedures for sampling them, and to provide recommendations for future monitoring and fisheries investigations.

1.2 Key Management Questions

Key management questions to be addressed by CLBMON-45 are:

- 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?
- 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?

1.3 Management Hypotheses

Specific hypotheses to be tested under CLBMON-45 include:

- 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.

1.4 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.

In 2018, sample sites were distributed throughout the study area in locations similar to all other study years since 2001. In total, nine sites were sampled in the upstream section of the Columbia River (Appendix A, Figure A1), 15 sites were sampled in the downstream section of the Columbia River (Appendix A, Figures A2 and A3), and four 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 four times (i.e., 4 sessions) between 1 and 31 October 2018. Field sampling was also conducted in the late summer to fall during previous study years (Table 1).

In addition to the standard indexing program described above, 20 additional sites were randomly selected for sampling in Session 5 using a Generalized Random Tessellation Stratified (GRTS) survey (see Section 2.1.5). Session 5 was completed between 30 October and 4 November 2018.

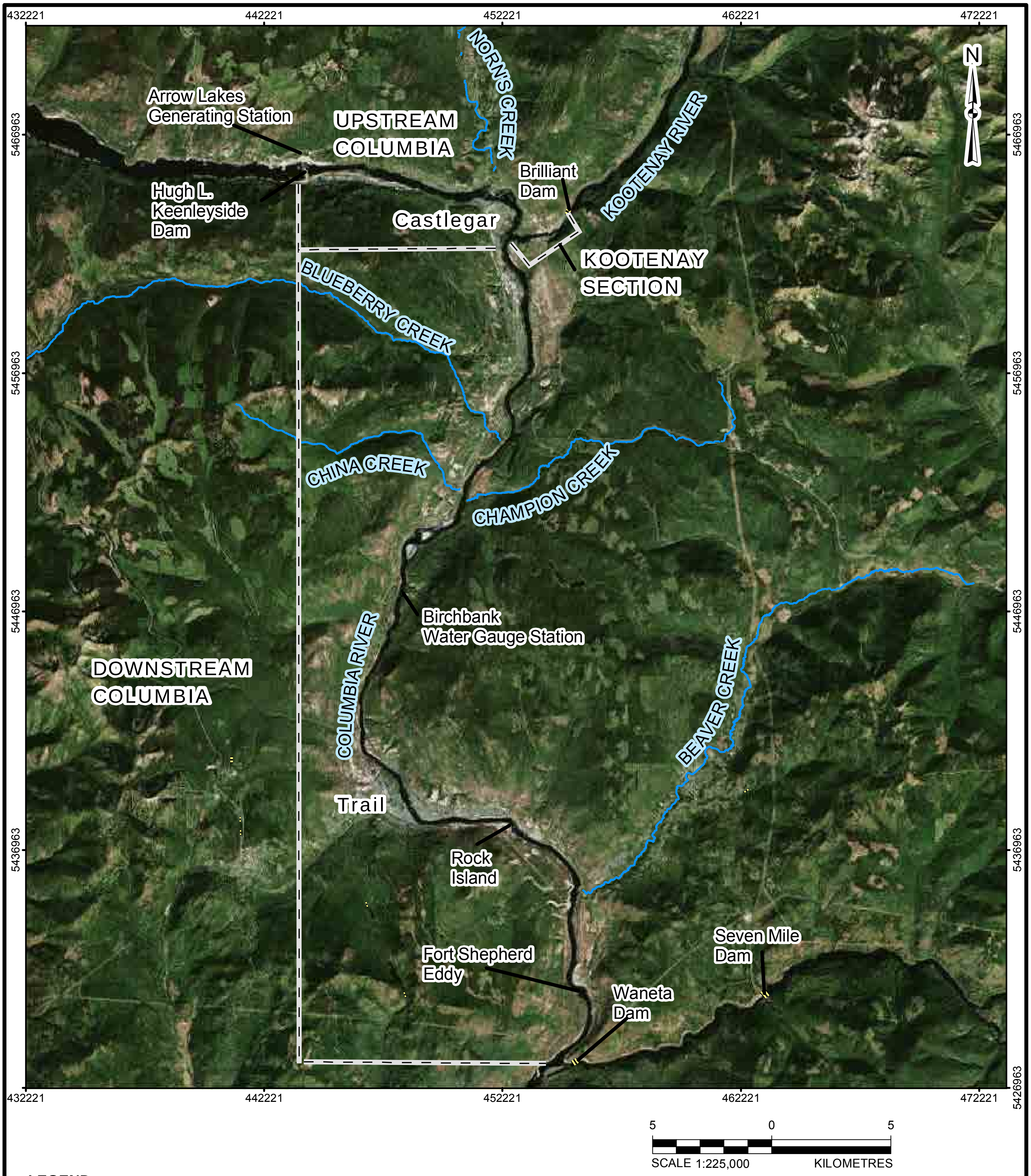
Table 1: Summary of annual study periods and number of sites sampled for boat electrofishing surveys conducted in the lower Columbia River, 2001 to 2018.

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	30 October	28	20	-	5	35
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

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 2.1.5 for details.

c. 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 2018.



LEGEND

🟨	DAM
—	WATERCOURSE

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

LARGE RIVER FISH INDEXING PROGRAM LOWER COLUMBIA RIVER

TITLE

STUDY AREA OVERVIEW

GOLDER

PROJECT		1537874/2018	FILE No.
DESIGN	DR	14 JUN. 2016	SCALE AS SHOWN REV. 0
GIS	JG/CD	6 JUN. 2019	FIGURE: 1
CHECK	DR	6 JUN. 2019	
REVIEW	SR	6 JUN. 2019	

Document Path: N:\Client\ONA\LCR\99_PROJECTS\1537874\02_PRODUCTION\INDEXING\MXD\Report\2018\1537874_FIG_1_OVERVIEW_2018.mxd

2.0 METHODS

2.1 Data Collection

2.1.1 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).

2.1.2 Water Temperature

Water temperatures for the mainstem Columbia River from 2001 to 2018 (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 2013a). 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. Water temperature data for the Kootenay River were available for 2001 to 2017 but not for 2018 because the logger had not been downloaded since December 2017. 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).

2.1.3 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

2.1.4 Fish Capture

Fish were captured and sampled using methods similar to previous years of the project (Golder et al. 2018). 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 manned by 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 new boat used in 2017 had a different amperage gauge that measured a different part of the electrical wave form than the previous boat. Amperages in 2018 ranged from 3.0 to 3.8 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; 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).

2.1.5 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 3.5.1 (R Team 2018), 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 due to 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 (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 2018 are presented in Appendix A, Table A2.

A single-pass boat electrofishing survey was conducted at each GRTS survey site between 30 October and 4 November 2018 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 2.1.6).

2.1.6 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 preferred ageing structure for Walleye (Mackay et al. 1990), which are primarily seasonal resident in the LCR and use the study area principally 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.

2.1.7 Scale Ageing

In 2018, fish were not aged using scale samples. Various techniques have been used in past years of the program to assign ages using scale samples but in all cases 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 2018 were assigned age-classes based on their fork length and the length-at-age model (Section 2.2.3). Scale-based ages assigned during previous years of the program were not used in this report.

2.1.8 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 2.1.4), 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 (see Section 4.2.4).

2.1.9 Historical Data

In addition to the data collected between 2001 and 2018, 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 2018 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 2018 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.

2.2 Data Analyses

2.2.1 Data Compilation and Validation

Data were entered directly into the LCR Fish Indexing Database (Attachment A) using Microsoft® Access 2016 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 (AVID PowerTracker VIII) 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 2018 are included in the LCR Fish Indexing Database (Attachment A).

For all figures in this report, 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).

2.2.2 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 3.5.3 (R Core Team 2018) 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 and Dalgarno 2019).

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 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 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).

2.2.3 Length-At-Age

The length-at-age analysis was conducted to 1) determine length-at-age cutoffs by life stage (fry, juvenile, or 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 MW 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, a 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), juvenile (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 was not plotted and compared because the size depends on growth during more than one year, which complicates interpretation.

2.2.4 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.

2.2.5 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 1989; 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 based on data from typical adult Walleye (300-450 mm) in the study area.

2.2.6 Site Fidelity

Site fidelity was the estimated probability of a recaptured fish being caught at the same site where it was previously encountered. Site fidelity was modelled using logistic regression and estimates were used to evaluate the extent to which sites were closed within a sample period (i.e., whether fish remained at the same site between sessions). Site fidelity estimates also were used to adjust the capture efficiencies in the analysis of mark-recapture data (see Section 2.2.7).

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.

2.2.7 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.

2.2.8 Abundance

The abundance of each index fish species was estimated using the catch data from 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 2.2.7) 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 was the point estimate from the capture efficiency model.
- The efficiency varied by visit type (mark-recapture or visual survey).
- The lineal 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 2.2.3).

2.2.9 Survival

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

2.2.10 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.

2.2.11 Age Ratios

This program's management questions regard 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). 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 2018. 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 2018 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 2013b). 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.

2.2.12 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. For the LCR, the relationship between the adults (“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):

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

where S is the estimated number of adults (stock), R is the estimated number of age-1 subadults (recruits), α is the recruits per spawner 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 high spawner abundance.

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. In stock-recruitment relationships, the spawning stock of adults is used as a proxy for reproductive potential or the number of eggs deposited (Subbey et al. 2014). 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 2013b) and from Irvine et al. (2018) for Rainbow Trout.

Key assumptions of the stock-recruitment model include:

- The prior probability for the logarithm of α was a truncated normal distribution from log(1) to log(5).
- 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.

3.0 RESULTS

3.1 Physical Habitat

3.1.1 Columbia River Discharge

Discharge in the LCR in 2018 was higher than normal during May due to a spring freshet earlier than in most years (Figure 2; Appendix D, Figure D1). The peak discharge was within the range of values observed in previous years during freshet (mean of approximately 3000 m^3/s and maximum of approximately 6000 m^3/s), but the increase and subsequent decrease from peak freshet occurred approximately a month earlier than average. Discharge was near average during the fall sampling period (Figure 2). As in previous years of the study, 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.

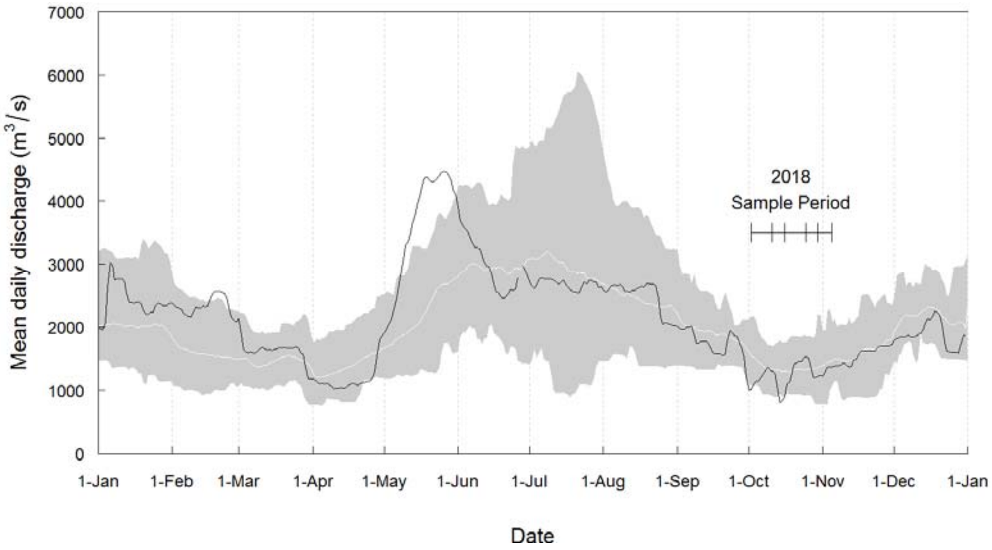


Figure 2: **Mean daily discharge (m^3/s) for the Columbia River at the Birchbank water gauging station, 2018 (black line). The shaded area represents minimum and maximum mean daily discharge values recorded at Birchbank from 2001 to 2017. The white line represents average mean daily discharge values over the same time period.**

In 2018, mean daily discharge in the Columbia River below HLK was typical for most of the year, when compared to the mean, minimum, and maximum values from 2001 to 2017 (Figure 3; Appendix D, Figure D2). One exception was higher than normal discharge during January and February. There was a small peak in discharge in late May and a second larger peak in discharge mid-July to mid-August.

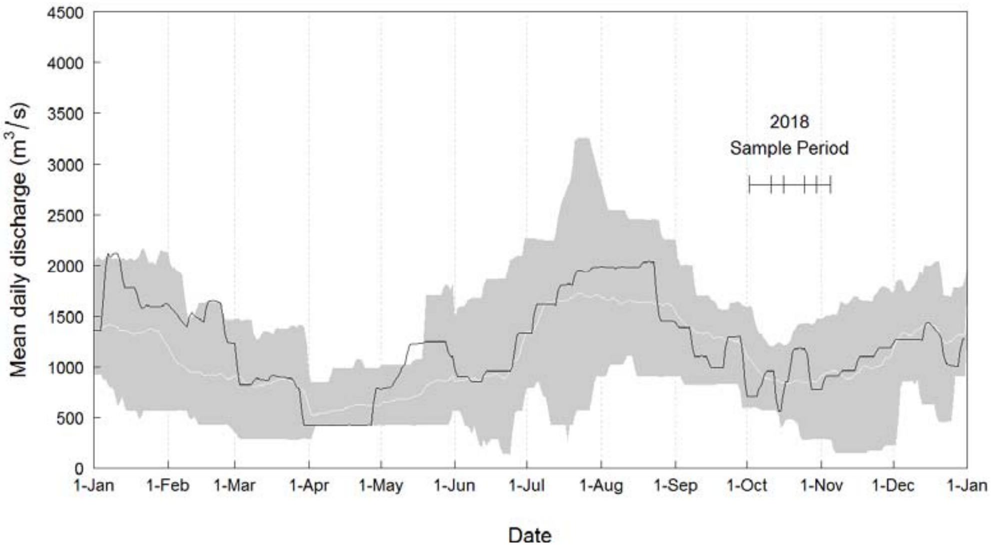


Figure 3: **Mean daily discharge (m^3/s) for the Columbia River at Hugh L. Keenleyside Dam, 2018 (black line). The shaded area represents minimum and maximum mean daily discharge values recorded at the dam from 2001 to 2017. The white line represents average mean daily discharge values over the same time period.**

3.1.2 Columbia River Temperature

In 2018, daily mean water temperature in the Columbia River was near average for the whole year (Figure 4). Between 2001 and 2017, 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. Spot temperature readings for the Columbia River taken at the time of sampling ranged between 9.3°C and 13.3°C (Appendix B, Table B3).

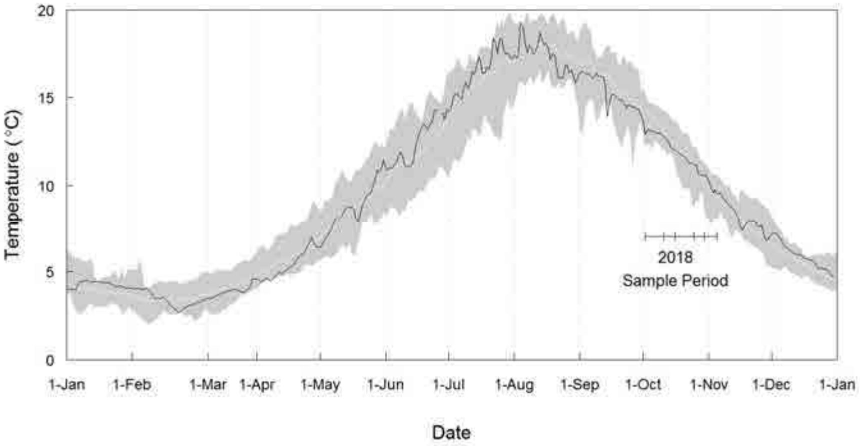


Figure 4: **Mean daily water temperature (°C) for the Columbia River downstream of the confluence of the Kootenay River, 2018 (black line). The shaded area represents the minimum and maximum mean daily water temperature values from 2001 to 2017 for the Birchbank gauge station. The white line represents the average mean daily water temperature during the same time period.**

3.1.3 Kootenay River Discharge

In 2018, peak discharge during the spring freshet (~3000 m³/s) was approximately 1000 m³/s greater than the average peak discharge from 2001 to 2017 (~2000 m³/s). In addition, the peak discharge occurred two to three weeks earlier than normal, occurring in mid-May instead of early June. The early peak discharge in the Columbia River at Birchbank in 2018 (Figure 2) was primarily related to flows from the Kootenay River (Figure 4) rather than discharge from HLK (Figure 3). Mean daily discharge during the sampling period in October was lower than average but within the range of values observed between 2001 and 2017 (Figure 5).

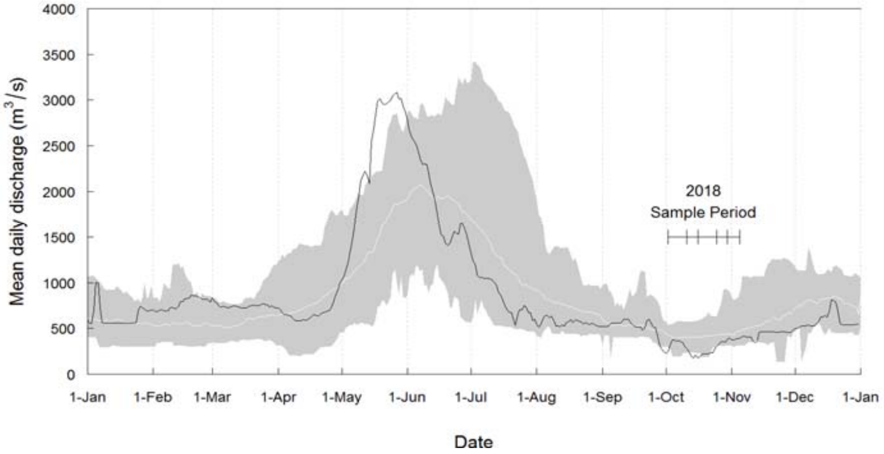


Figure 5: **Mean daily discharge (m^3/s) for the Kootenay River at BRD, 2018 (black line). The shaded area represents minimum and maximum mean daily discharge values recorded at the dam from 2001 to 2017. The white line represents average mean daily discharge values over the same time period.**

3.1.4 Kootenay River Temperature

Mean daily water temperature in the Kootenay River downstream of BRD was near average most of the year in 2018, with the exception of warmer than average temperature (approximately 1°C to 2°C greater) in July to August. The historical data from 2001 to 2017 indicate that 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 (Figure 6). Spot temperature readings for the Kootenay River taken at the time of sampling ranged between 11.4°C and 13.9°C (Appendix B, Table B3).

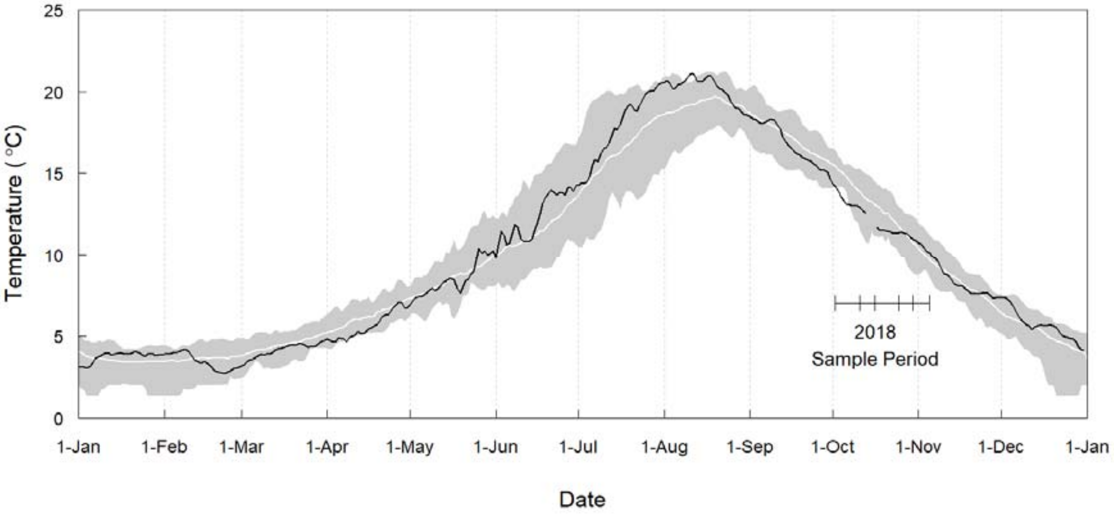


Figure 6: **Mean daily water temperature (°C) for the Kootenay River downstream of BRD, 2018 (black line). The shaded area represents minimum and maximum mean daily water temperature values recorded from 2001 to 2017. The white line represents average mean daily water temperature values over the same time period.**

3.1.5 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 2018 (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.

3.2 Catch

In total, 17,289 fish were recorded in the LCR in 2018 (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, 1 October to 4 November 2018. 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*)					4	<1	4	<1
Bull Trout (*Salvelinus confluentus*)	1	<1	1	<1			2	<1
Burbot (*Lota lota*)					15	<1	15	<1
Kokanee (*Oncorhynchus nerka*)	6	<1			2	<1	8	<1
Lake Whitefish (*Coregonus clupeaformis*)	16	<1	2	<1	96	1	114	<1
Mountain Whitefish (*Prosopium williamsoni*)	2155	56	865	63	1935	27	4955	40
Northern Pike (*Esox lucius*)	1	<1	2	<1			3	<1
Rainbow Trout (*Oncorhynchus mykiss*)	1234	32	351	25	4381	61	5966	48
Smallmouth Bass (*Micropterus dolomieu*)	1	<1			7	<1	8	<1
Walleye (*Sanders vitreus*)	425	11	149	11	698	10	1272	10
White Sturgeon (*Acipenser transmontanus*)	34	<1	13	<1	8	<1	55	<1
Yellow Perch (*Perca flavescens*)					1	<1	1	<1
Sportfish Subtotal	3873	100	1383	100	7149	100	12405	100
Non-sportfish								
Carp spp. (*Cyprinus carpio*)	1	<1					1	<1
Northern Pikeminnow (*Ptychocheilus oregonensis*)	176	10	9	2	39	1	224	5
Peamouth (*Mylocheilus caurinus*)	8	<1	1	<1			9	<1
Redside Shiner (*Richardsonius balteatus*)	86	5	24	6	266	10	376	8
Sculpin spp. (*Cottidae*)	550	31	151	38	2123	79	2824	58
Sucker spp. (*Catostomidae*)	969	54	213	53	265	10	1447	30
Tench (*Tinca tinca*)	1	<1	1	<1	1	<1	3	<1
Non-Sportfish Subtotal	1791	100	399	100	2694	100	4884	100
Total	5664	100	1782	100	9843	100	17289	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 in this report. 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), 2018;
- catch and percent composition by species, 2001 to 2018 (Appendix E, Table E1);
- catch-rates for all sportfish (Appendix E, Table E2) and non-sportfish (Appendix E, Table E3), 2018;
- length-frequency histograms by section for Mountain Whitefish (Appendix F, Figure F1), Rainbow Trout (Appendix F, Figure F2), and Walleye (Appendix F, Figure F3), 2018;
- 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.

3.3 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 7). 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 3.3.3.

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 2018. Estimates were derived from the length-at-age model (Section 2.2.3).

Year	Mountain Whitefish				Rainbow Trout		
	Age-0	Age-1	Age-2	Age-3+	Age-0	Age-1	Age-2+
1990	≤163	164–275	≥276	≥276	≤155	156–358	≥359
1991	≤144	145–226	227–296	≥297	≤127	128–342	≥343
2001	≤141	142–257	258–344	≥345	≤133	134–324	≥325
2002	≤163	164–260	261–343	≥344	≤155	156–349	≥350
2003	≤159	160–263	264–353	≥354	≤161	162–342	≥343
2004	≤158	159–249	250–342	≥343	≤142	143–332	≥333
2005	≤168	169–263	264–362	≥363	≤164	165–346	≥347
2006	≤175	176–284	285–357	≥358	≤170	171–364	≥365
2007	≤171	172–279	280–337	≥338	≤166	167–375	≥376
2008	≤170	171–248	249–341	≥342	≤146	147–339	≥340
2009	≤169	170–265	266–355	≥356	≤147	148–338	≥339
2010	≤177	178–272	273–353	≥354	≤143	144–337	≥338
2011	≤163	164–269	270–349	≥350	≤156	157–343	≥344
2012	≤162	163–268	269–347	≥348	≤152	153–344	≥345
2013	≤185	186–282	283–350	≥351	≤169	170–354	≥355
2014	≤178	179–283	284–362	≥363	≤154	155–337	≥338
2015	≤167	168–278	279–366	≥367	≤167	168–334	≥335
2016	≤165	166–283	284–352	≥353	≤154	155–336	≥337
2017	≤158	159–269	270–354	≥355	≤133	134–316	≥317
2018	≤177	178–262	263–346	≥347	≤139	140–306	≥307

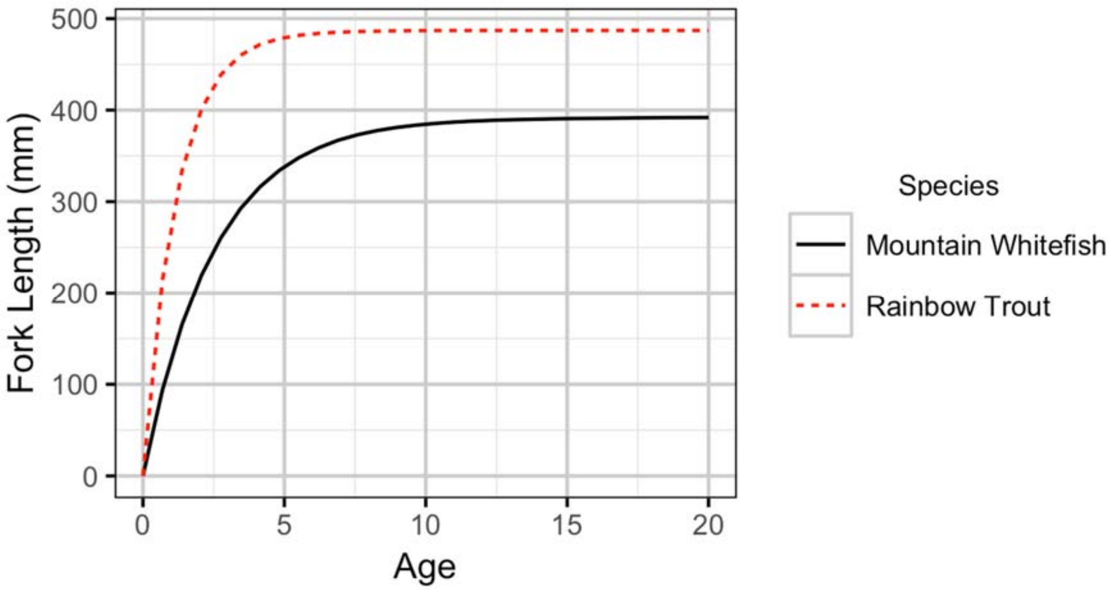


Figure 7: **Growth curve showing length-at-age by species as predicted by the von Bertalanffy model for the lower Columbia River, 2001–2018.**

3.3.1 Mountain Whitefish

The mean fork length of Mountain Whitefish fry (age-0) in 2018 (142 mm) was greater than most previous years, which typically ranged from 120 to 140 mm. In 2016, mean fork length (157 mm) of age-0 Mountain Whitefish was greater than any previous year of the study (Figure 8). However, the length-frequency plot of Mountain Whitefish suggests that very few age-0 fish were captured in 2016 (Appendix F, Figure F4) and the estimate of the mean fork length for that year is relatively uncertain. 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 of age-1, age-2, and age-3 and older age-classes is not presented because they depend on growth in more than one previous year, which complicates interpretation.

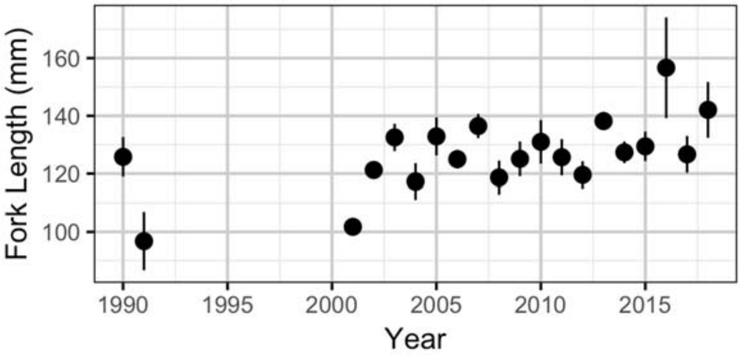


Figure 8: **Mean fork length of age-0 Mountain Whitefish in the lower Columbia River, 1990 to 1991 and 2001 to 2018.**

Analysis of growth of recaptured Mountain Whitefish indicated generally increasing annual growth between 2005 and 2016 with the exception of 2012 (Figure 9). Growth was lower in 2017 and 2018, with effect sizes of -9% and -10%, compared to an effect size of 59% 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 247 mm/yr in 2016 and decreased to approximately 140 mm/yr in 2017 and 2018 (Figure 10).

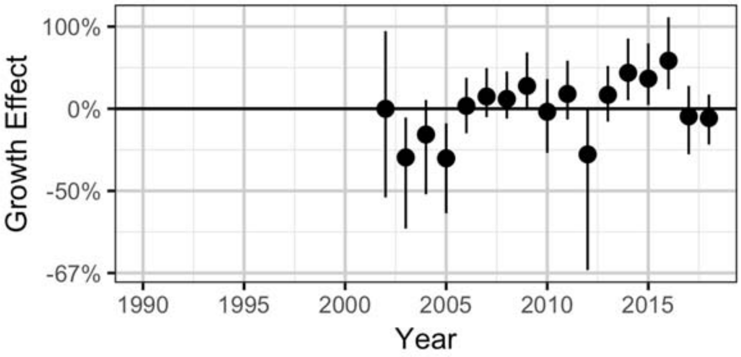


Figure 9: Estimated percent change in the von Bertalanffy growth coefficient (mean with 95% CRIs) relative to a typical year for Mountain Whitefish based on recaptured individuals in the lower Columbia River, 2001 to 2018.

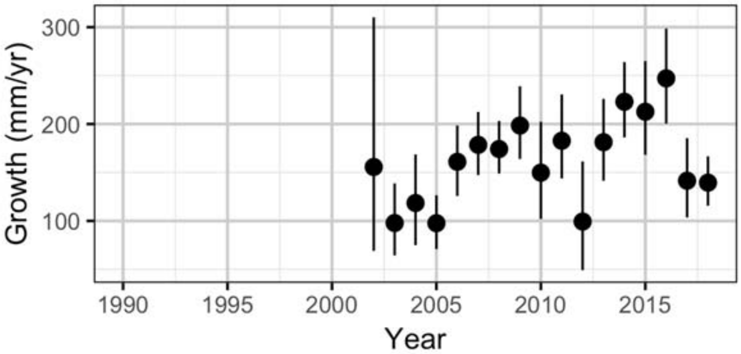


Figure 10: Predicted maximum growth rate (mean with 95% CRIs) from the von Bertalanffy model for Mountain Whitefish based on recaptured individuals in the lower Columbia River, 2001 to 2018.

3.3.2 Rainbow Trout

The length-at-age model indicated an increase in the mean length of Rainbow Trout fry (age-0) from 101 mm in 2010 to 144 mm in 2015 (Figure 11). Mean length of age-0 Rainbow Trout varied from 102 to 126 mm between 2016 and 2018 with large and overlapping credible intervals. The greater uncertainty in the estimates from 2015 to 2018 than previous years was due to lower catch of age-0 Rainbow Trout during these recent years. Catch of age-0 Rainbow Trout ranged from 1 to 5 fish per year between 2015 and 2018 and between 18 and 319 fish per year between 2001 and 2014. Mean length-at-age of fry was much lower in 1991 (88 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.

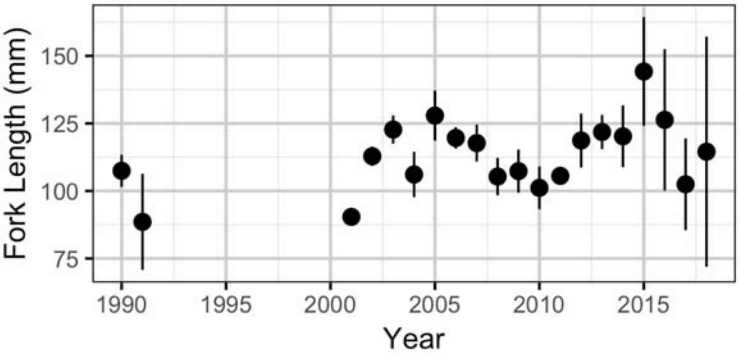


Figure 11: Mean fork length of age-0 Rainbow Trout in the lower Columbia River, 1990 to 1991 and 2001 to 2018.

Analysis of annual growth of recaptured Rainbow Trout indicated a low growth coefficient in 2003 and 2004 (-15% to -31% effect size; Figure 12). Estimates of the growth coefficient generally declined from a 55% effect size in 2006 to -38% in 2018. The predicted maximum growth during early life suggested a similar trend with a decrease from 632 mm/yr in 2006 to 256 mm/yr in 2018 (Figure 13). 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 (632 to 256 mm/yr) suggests a substantial change in growth.

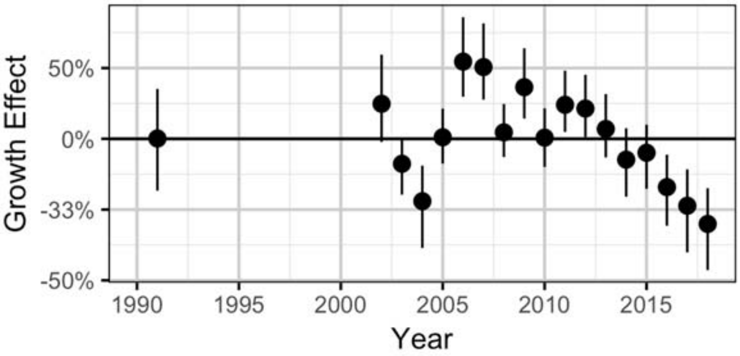


Figure 12: Estimated percent change in the von Bertalanffy growth coefficient (mean with 95% CRIs) relative to a typical year for Rainbow Trout based on recaptured individuals in the lower Columbia River, 2001 to 2018.

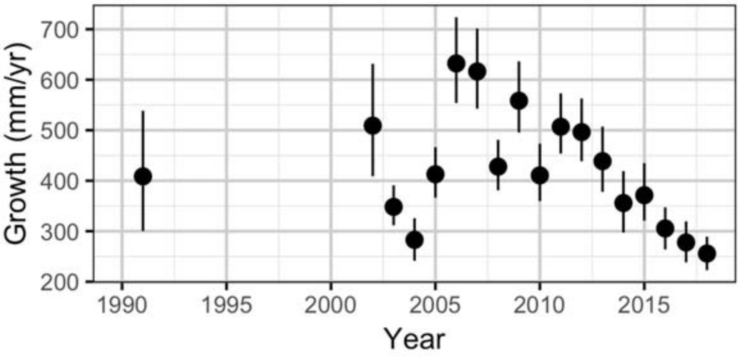


Figure 13: Predicted maximum growth rate (mean with 95% CRIs) from the von Bertalanffy model for Rainbow Trout based on recaptured individuals in the lower Columbia River, 2001 to 2018.

3.3.3 *Walleye*

Analysis of annual growth of recaptured Walleye indicated a near-average growth coefficient in 2018 with an effect size of 15%, which was within the range of effect sizes observed in most years (typical range of -25% to 30%; Figure 14). The estimated growth coefficient generally increased from 2010 (-24% effect size) until 2016 (30%), but with a very high growth coefficient (80%) 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 7) and effect size based on the model's growth coefficient (Figure 14) were calculated using only Walleye <450 mm in fork length. Predicted values of maximum growth rate during early life ranged from 45 to 77 mm, except in 2013 when the maximum growth rate was 107 mm/yr (Figure 15).

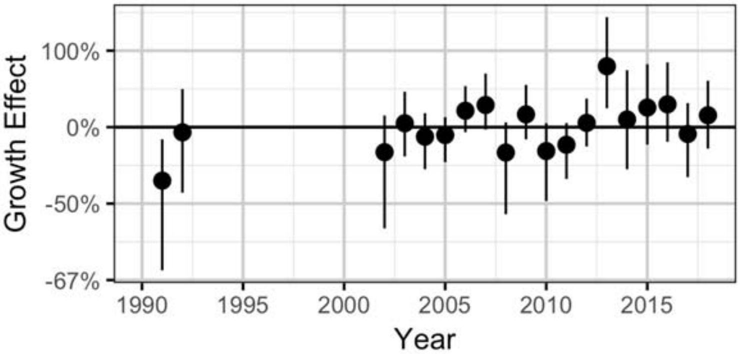


Figure 14: Estimated percent change in the von Bertalanffy growth coefficient (mean with 95% CRIs) relative to a typical year for Walleye based on recaptured individuals <450 mm in fork length in the lower Columbia River, 2001 to 2018.

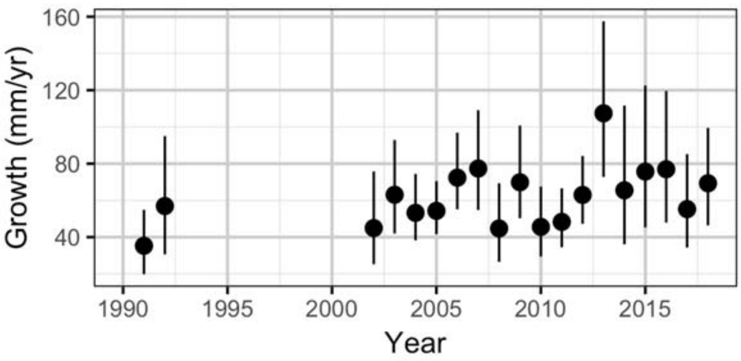


Figure 15: **Predicted maximum growth rate (mean with 95% CRIs) from the von Bertalanffy model for Walleye based on recaptured individuals in the lower Columbia River, 2001 to 2018.**

3.3.4 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 16). The inaccuracy for Mountain Whitefish varied by observer with bias of -40 to 20 mm relative to captured fish of known length (Figure 17). Inaccuracy of Rainbow Trout lengths varied between -60 and 10 mm. Inaccuracy in estimated Walleye fork lengths ranged between -80 and 20 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.

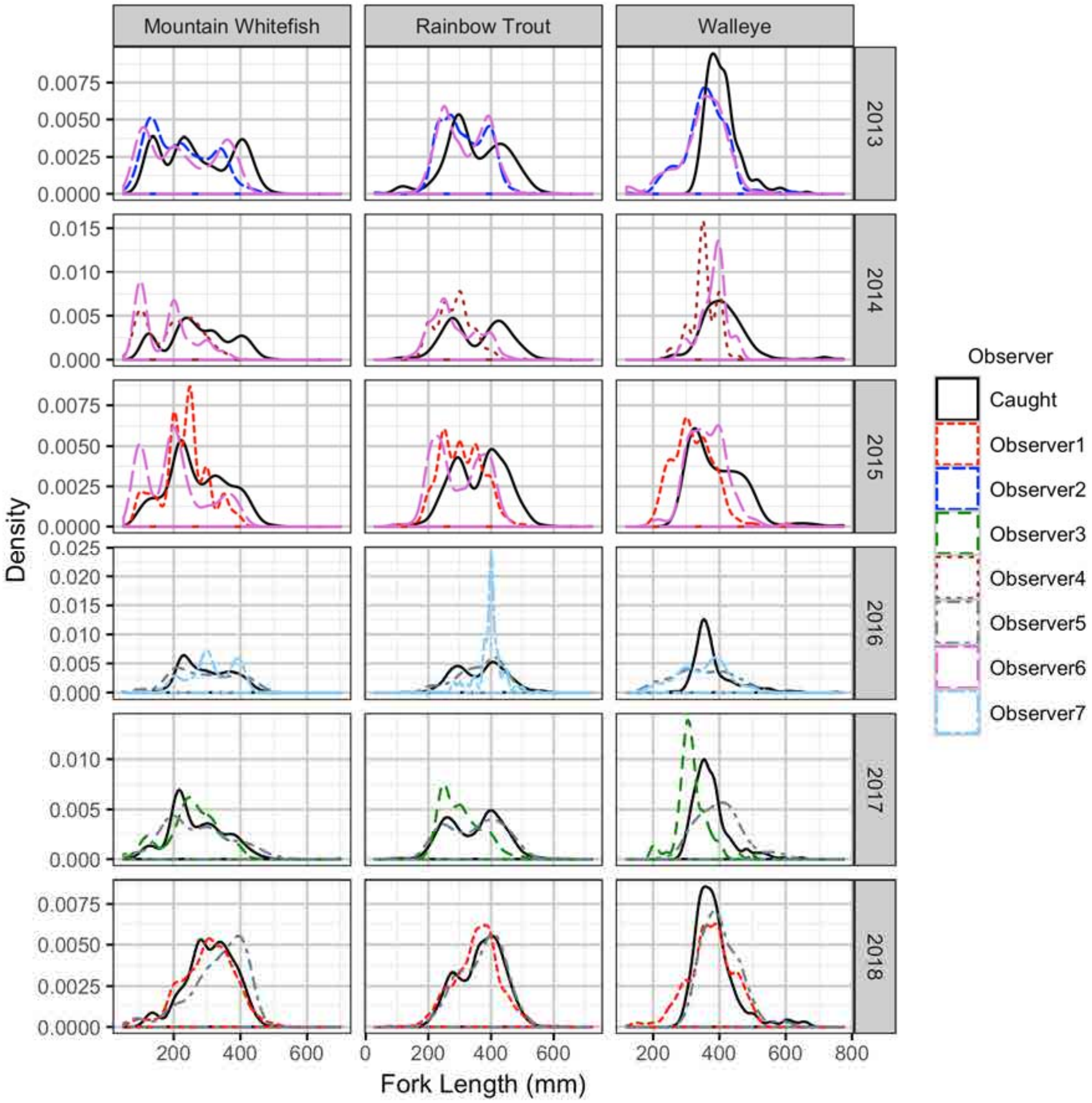


Figure 16: **Fork length-density plots for measured and estimated fork lengths of fish caught or observed in the lower Columbia River, 2013–2018. The black line shows fish that were caught. Observed data from the georeferenced visual survey are shown by coloured dashed lines.**

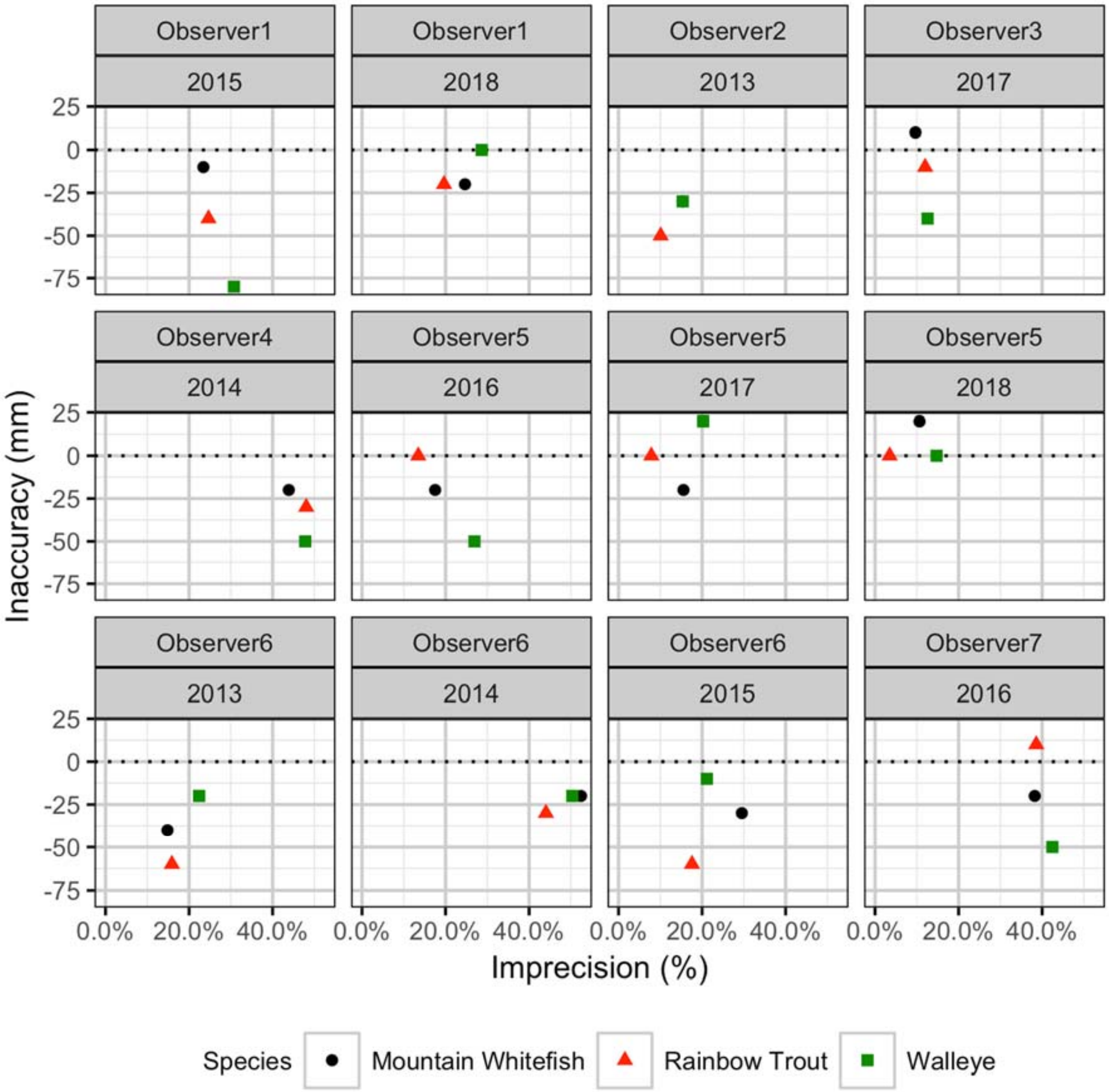


Figure 17: **Fish length inaccuracy (bias) and imprecision by observer, year of observation and species. Observations use the length bias model of captured (mark-recapture surveys) compared to estimated (geo-referenced visual surveys) length-frequency distributions from the lower Columbia River, 2013–2018.**

3.4 Spatial Distribution and Abundance

3.4.1 Site Fidelity

Site fidelity was greater for Rainbow Trout and Walleye (~50–80%) than for Mountain Whitefish (<50%; Figure 18). 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).

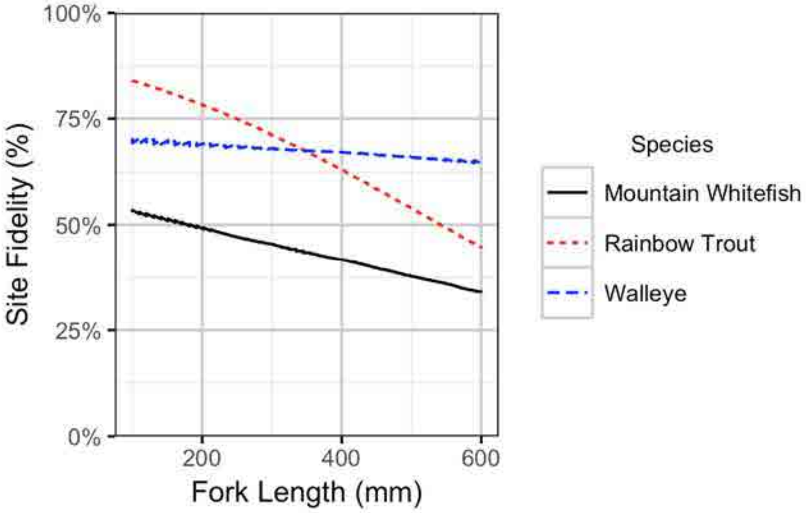


Figure 18: **Site fidelity, defined as the expected probability that a fish is recaptured at the same site where it was marked, by species and fork length in the lower Columbia River, 2001 to 2018.**

3.4.2 Efficiency

Estimated capture efficiency was greatest for Rainbow Trout (2–3%) and lowest for Mountain Whitefish (<1%; Figure 19). Capture efficiency was lower for adult (2%) than subadult (3%) 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 3.4.3–3.4.5).

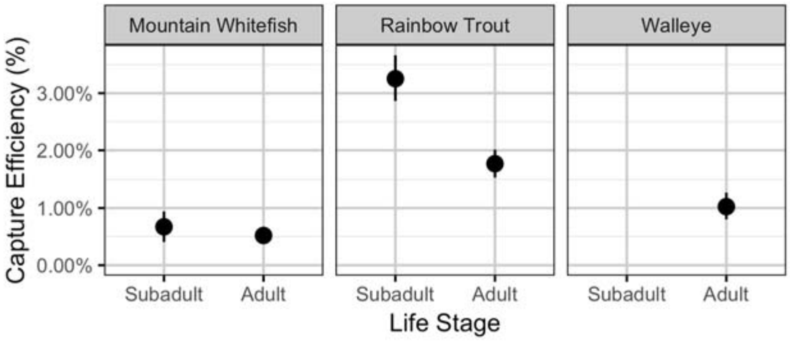


Figure 19: **Capture efficiency (mean with 95% CRIs) by species from mark-recapture data from the lower Columbia River, 2001–2018.**

3.4.3 Mountain Whitefish

The estimated abundance of subadult Mountain Whitefish in index sites in the LCR was much greater in 2001 and 2002 (112,000–128,000) than all other years (Figure 20). In 2018, the estimated abundance of subadult Mountain Whitefish (22,000) was less than half of the values from the previous five years (54,000–60,000). Estimates of adult Mountain Whitefish abundance were greater from 2001 to 2009 (118,000–233,000) than during 2010 to 2017, when estimates were lower and relatively stable (81,000–105,000). In 2018, estimated adult abundance (165,000) was greater than the recent years between 2010 and 2017 and similar to the estimated abundance in 2001 to 2009.

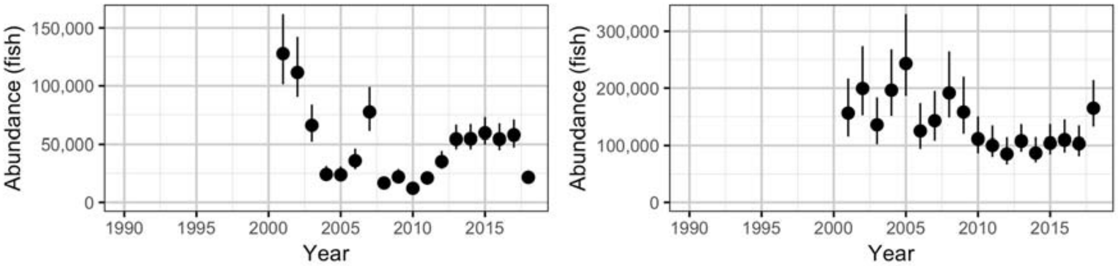


Figure 20: Abundance (means with 95% CRIs) of subadult (age-1; left panel) and adult (age-2 and older; right panel) Mountain Whitefish at index sites in the lower Columbia River, 2001–2018.

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 21). 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 21). 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 21) had larger credible intervals than estimates of subadult Mountain Whitefish. Density estimates 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), the Genelle area (RKm 27.0), and upstream of Fort Shepherd Eddy (RKm 49.0).

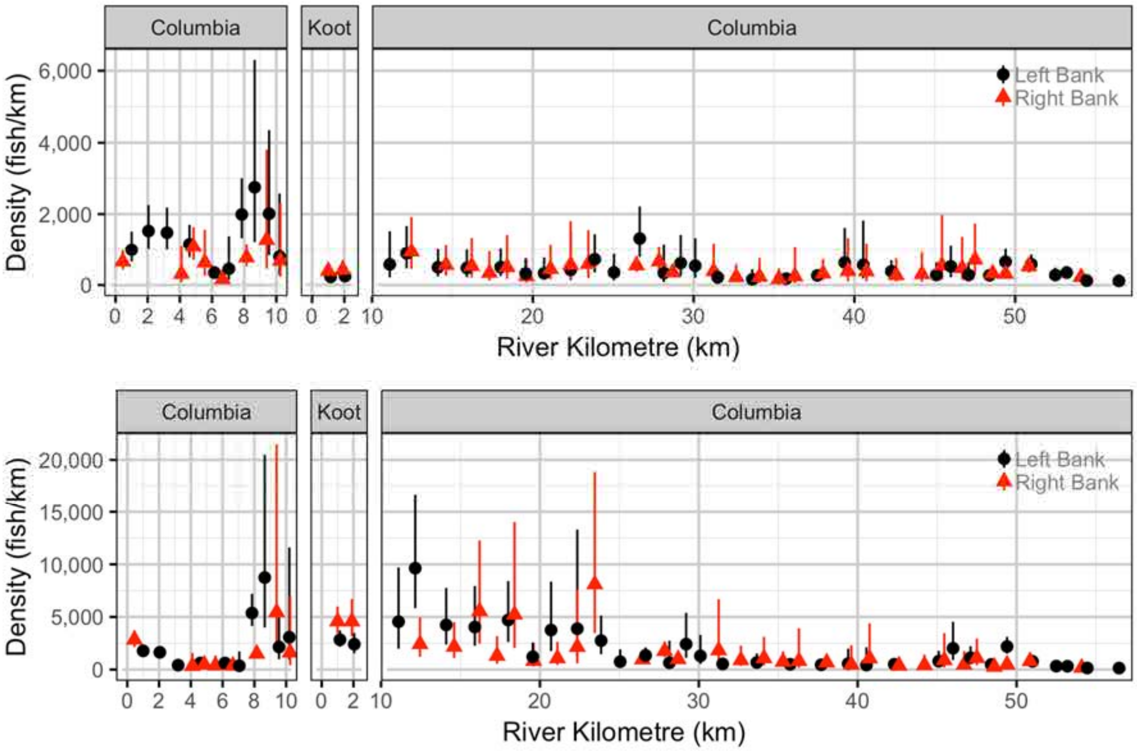


Figure 21: **Density (means with 95% CRIs) of subadult (age-1; top panel) and adult (age-2 and older; bottom panel) Mountain Whitefish by river kilometre in the lower Columbia River, 2001-2018.**

3.4.4 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 2018 (Figure 22). The estimated abundance of subadult Rainbow Trout was lower in 2018 (12,000) than the previous six years when abundance was relatively stable (19,000–23,000). Adult Rainbow Trout abundance estimates increased from ~27,000 in 2002 to ~75,000 in 2018.

Rainbow Trout site-level density estimates had large credible intervals (Figure 23), particularly at sites that were only sampled between 2012 and 2018 (GRTS sites). The analysis suggests higher densities of subadult Rainbow Trout in most sites between the Kootenay River confluence (RKm 10.6) and Beaver Creek (RKm 47.8) than in other sections of the study area (Figure 23). 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 23). Adult Rainbow Trout densities were substantially higher near the Bear Creek confluence (Site C44.7-R), between the Champion Creek and Jordan Creek confluences (Site C23.4-L), and immediately downstream of the Kootenay River confluence (both banks; Sites C10.7-R and C10.9-L) when compared to neighbouring sites.

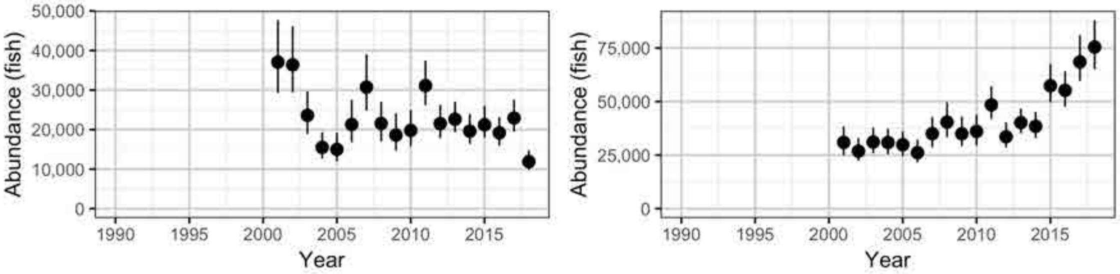


Figure 22: **Abundance (means with 95% CRIs) of subadult (age-1; left panel) and adult (age-2 and older; right panel) Rainbow Trout at index sites in the lower Columbia River, 2001–2018.**

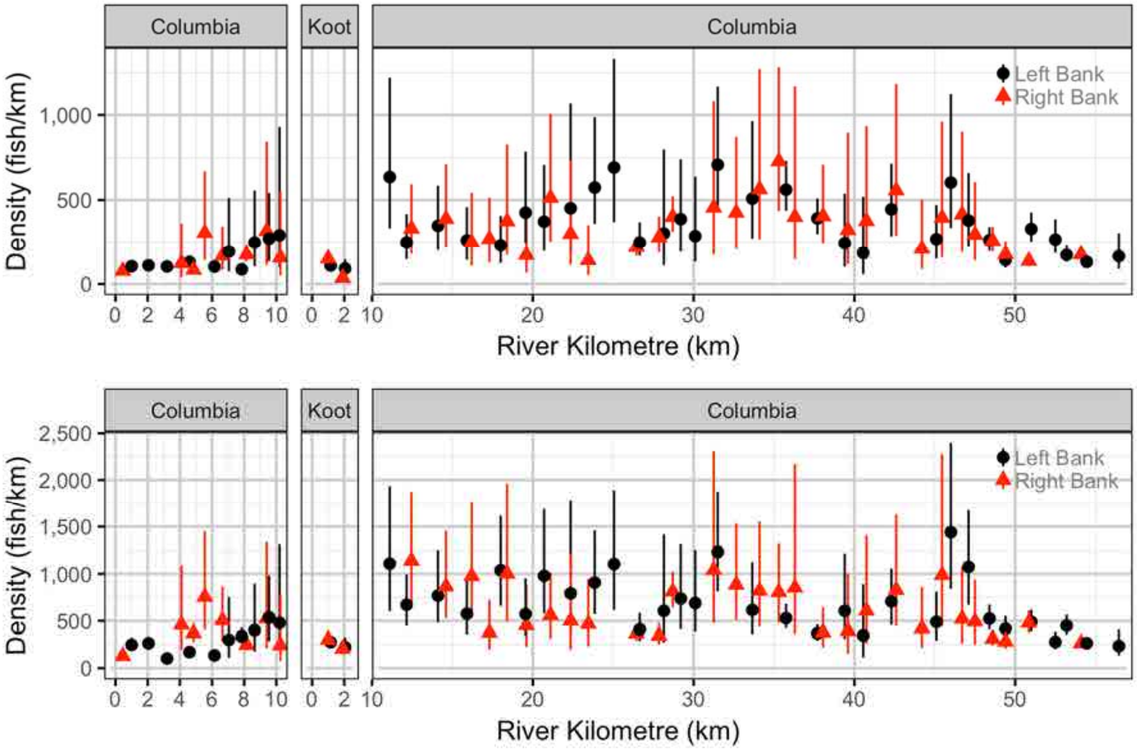


Figure 23: **Density (means with 95% CRIs) of subadult (age-1; top panel) and adult (age-2 and older; bottom panel) Rainbow Trout by river kilometre in the lower Columbia River, 2001–2018.**

3.4.5 Walleye

Since 2001, Walleye abundance has fluctuated with peaks in 2003 to 2005 and in 2011 (Figure 24). Walleye abundance estimates were lower from 2012 to 2015 (17,000–24,000) than during previous years but increased slightly in 2016 to 2018 (22,000–29,000). Density estimates for Walleye were greatest in the Kootenay River, at the three sites closest to HLK, in a small bay downstream of Bear Creek (45.6-L), and at the site adjacent to the Canada-US border (56.0-L; Figure 25). Density estimates for all other areas were similar and did not suggest differences in Walleye densities among sites. The density at sites sampled during the GRTS survey (not sampled prior to 2012) was comparable to the density at index sites.

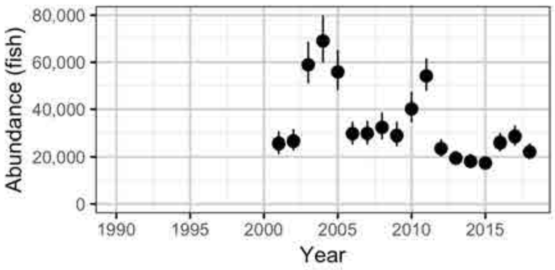


Figure 24: **Abundance (means with 95% CRIs) of adult Walleye (all age-classes) at index sample sites in the lower Columbia River, 2001–2018.**

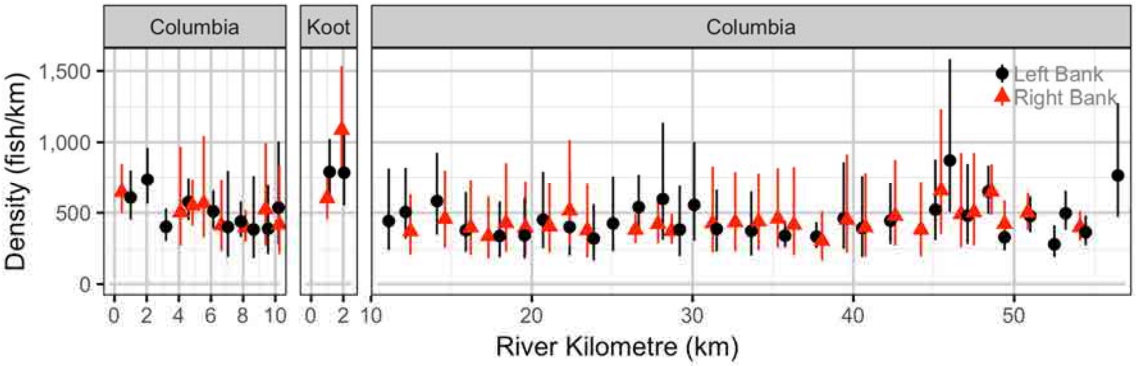


Figure 25: **Density (means with 95% CRIs) of adult Walleye (all age-classes) by river kilometre in the lower Columbia River, 2001–2018.**

3.4.6 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.

3.5 Survival

3.5.1 Mountain Whitefish

For adult Mountain Whitefish, annual survival estimates varied from 22% to 93%. Adult survival generally increased between 2002 and 2008 and was relatively stable between 2011 and 2018 (67–86%; Figure 26). Credible intervals of survival estimates were greater for Mountain Whitefish than for Rainbow Trout (Section 3.5.2). The inter-annual capture efficiency, on which the survival estimate was based, was approximately 1–4% (Appendix G, Figure G8).

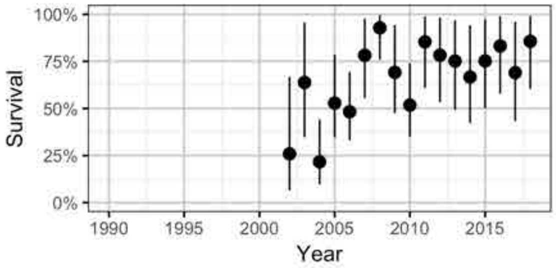


Figure 26: **Survival estimates (mean with 95% CRIs) for adult (age-2 and older) Mountain Whitefish in the lower Columbia River, 2001–2018.**

3.5.2 Rainbow Trout

Survival estimates of Rainbow Trout increased gradually from 33% in 2003 to 51% in 2011, but declined to 34–42% in 2012 to 2018 (Figure 27). The inter-annual capture efficiency was 7–8% (Appendix G, Figure G9).

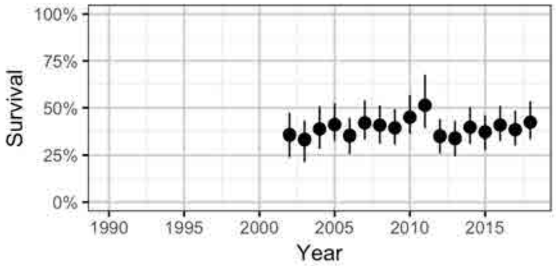


Figure 27: **Survival estimates (mean with 95% CRIs) for adult (age-2 and older) Rainbow Trout in the lower Columbia River, 2001–2018.**

3.5.3 Walleye

The estimated survival of Walleye was 51% in 2018, which was similar to most other years since 2001 (Figure 28). A few years, including 2004, 2006, and 2013–2014, had lower survival ranging from 40% to 48%. However, credible intervals overlapped for all years. The inter-annual capture efficiency was 3–4% (Appendix G, Figure G10).

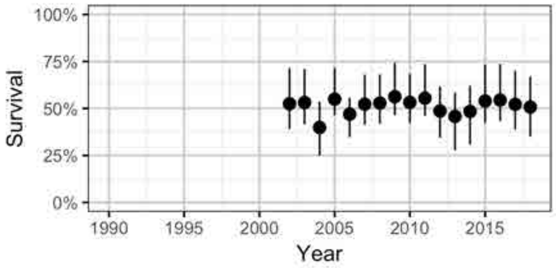


Figure 28: **Survival estimates (mean with 95% CRIs) for adult Walleye (all age-classes) in the lower Columbia River, 2001–2018.**

3.6 Body Condition

3.6.1 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 and 2018 (3%; Figure 29; left panel). Adult Mountain Whitefish body condition was also stable between 2010 and 2015, with effect sizes of 2–3%, but was greater in 2016 (5%) and lower in 2018 (0%; Figure 29; right panel). Adult body condition was much lower in the 1990s than between 2001 and 2018, with effect sizes of 6–15% lower than in a typical year.

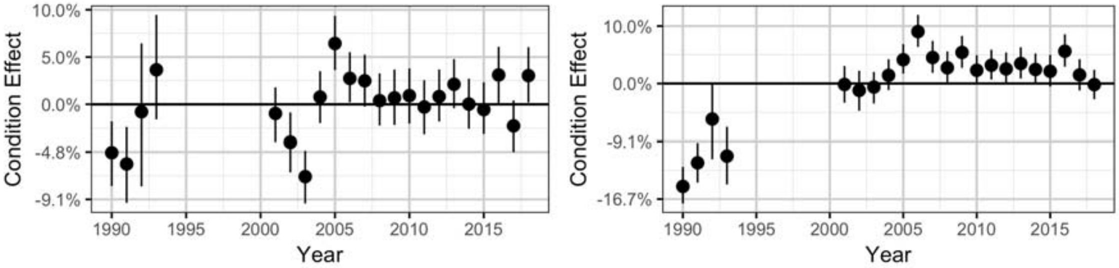


Figure 29: Body condition effect size estimates (mean with 95% CRIs) for subadult (200 mm; left panel) and adult (350 mm; right panel) Mountain Whitefish in the lower Columbia River, 1990 to 1993 and 2001 to 2018.

3.6.2 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 3.4.4).

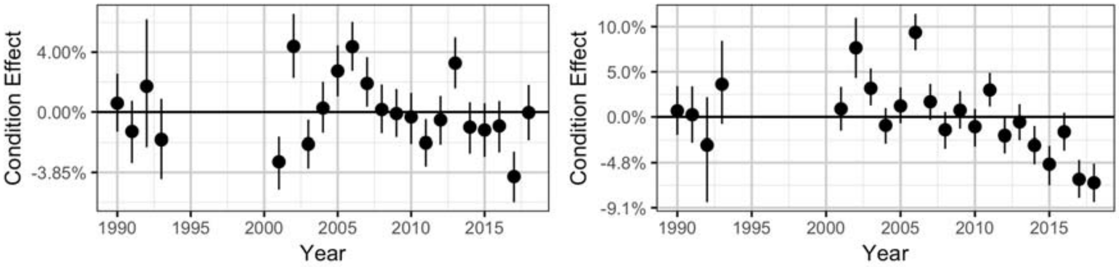


Figure 30: Body condition effect size estimates (mean with 95% CRIs) for subadult (250 mm; left panel) and adult (500 mm; right panel) Rainbow Trout in the lower Columbia River, 1990 to 1993 and 2001 to 2018.

3.6.3 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, when the effect size was -2%. Overall, the results suggest good body condition from 2012 to 2015, but a declining trend to more typical values in the last few years.

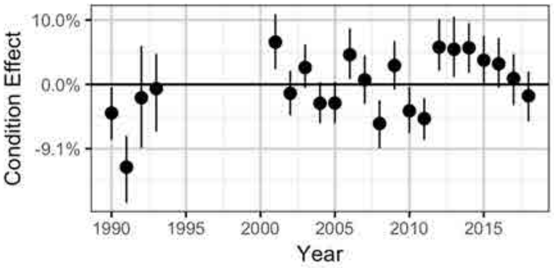


Figure 31: **Body condition effect size estimates (median with 95% CRIs) by year for adult (600 mm) Walleye in the lower Columbia River, 1990 to 1993 and 2001 to 2018.**

3.7 Age Ratios

The estimated egg loss for the 2016 spawning year was 59%, which was the largest estimated egg loss due to dewatering on record. In previous years, the estimated proportion of egg mortality due to dewatering ranged from 7% in 2010 to 46% in 2012 (Figure 32). 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 33). 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.

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 (*P*=0.3). The data suggested a negative relationship between age-1:2 ratio and egg loss (Figure 34) 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 35. The model predicts a 39% decrease in recruitment at 50% egg loss compared to the recruitment at 10% egg loss (Figure 35). At 50% egg loss, although the mean prediction was a 39% decrease (relative to 10% egg loss), the 95% credible interval for the effect on recruitment ranged from 78% decrease to a 44% 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 34). 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.

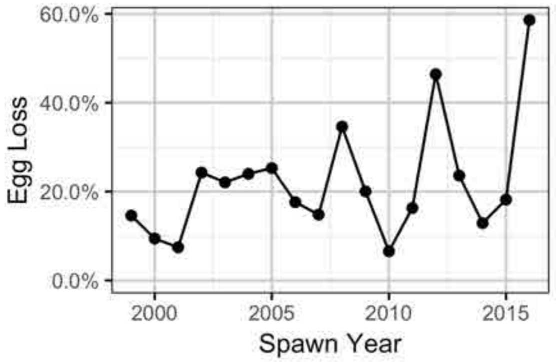


Figure 32: Estimated proportion of Mountain Whitefish egg loss due to dewatering in the lower Columbia River by spawning year, 1999 to 2016, based on the egg loss model.

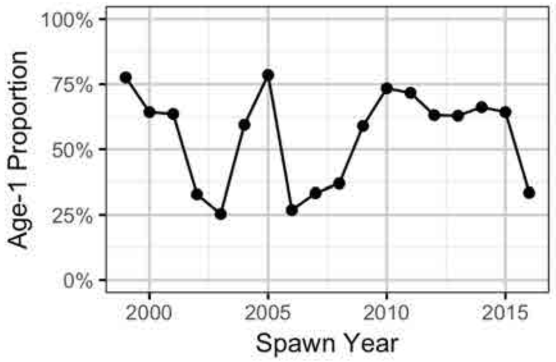


Figure 33: Proportion of age-1 to age-2 Mountain Whitefish in boat electrofishing catch in the lower Columbia River by spawning year, 1999 to 2016.

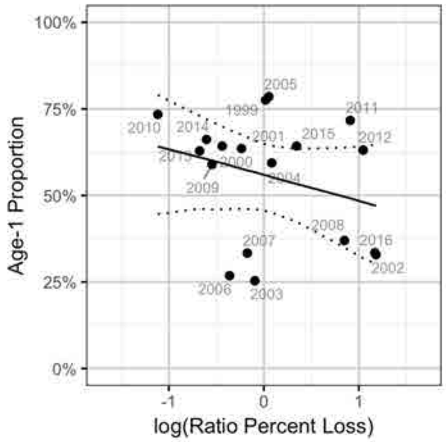


Figure 34: Relationship between the proportion of age-1 to age-2 Mountain Whitefish and the estimated proportion of Mountain Whitefish egg loss due to dewatering. Year labels represent the spawning year. The predicted relationship is indicated by the solid black line and dotted line represents the 95% CRI.

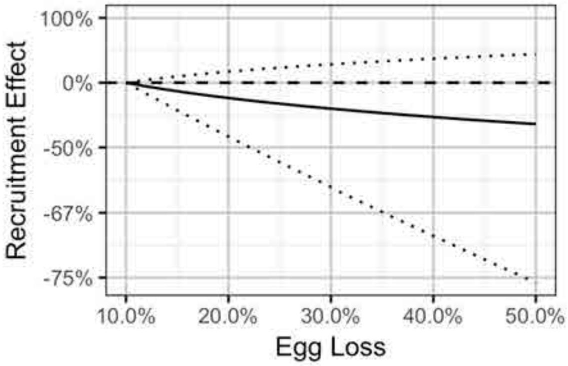


Figure 35: **Predicted percent change in age-1 Mountain Whitefish abundance by egg loss in the spawn year relative to 10% egg loss in the spawn year (with 95% CRIs).**

3.8 Stock-Recruitment Relationship

3.8.1 Mountain Whitefish

The stock-recruitment relationship indicated large variation in the recruitment for Mountain Whitefish data in the LCR (Figure 36). Based on the available data, the variability in recruitment was not related to the number of spawning adults or the estimated egg loss due to dewatering. The majority of years suggested little effect of increasing abundance of adults ("stock") on the resulting number of age-1 recruits, which is consistent with density-dependent survival and recruitment when the estimated adult population is greater than ~100,000. 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 productivity in terms of recruits per spawner 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 loss on recruitment was not statistically significant (*P*=0.4; Figure 37). 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. Therefore, the data do not support an effect of egg loss on recruitment at the range of adult abundances observed, but the effects of egg loss at lower abundance are unknown based on this analysis.

Some years with large estimates of egg loss, such as 2016 (59%) and 2008 (35%), had recruitment less than predicted by the stock recruitment curve (Figure 36). However, the second largest estimated egg loss occurred in the 2012 spawning year (46%), when the number of recruits was greater than the average recruitment predicted by the stock-recruitment curve. We cannot rule out a possible negative effect of egg loss over the range of observed abundances because of large variability in recruitment that seems to be unrelated to spawner abundance or estimated egg loss due to dewatering. The predicted relationship between carrying capacity and egg loss indicated a negative effect of egg loss on recruitment, but this relationship was not considered statistically significant because egg loss was not a significant effect in the stock-recruitment model (*P*=0.4).

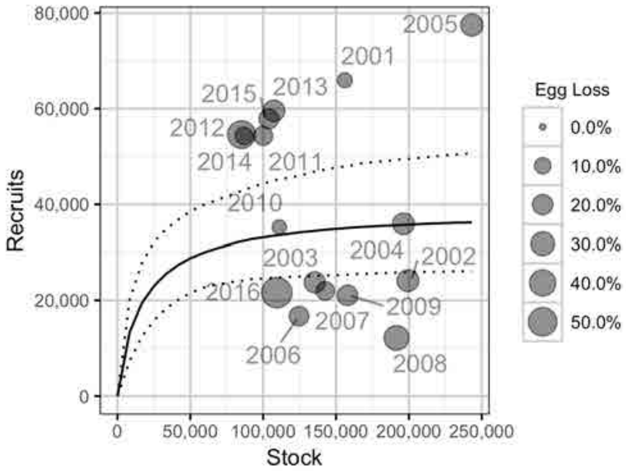


Figure 36: **Predicted stock-recruitment relationship between age-2+ spawners ("Stock") and subsequent age-1 Mountain Whitefish ("Recruits") by spawning year (with 95% CRIs). Estimated proportion of egg loss due to dewatering for each spawning year is shown by size of shaded circles.**

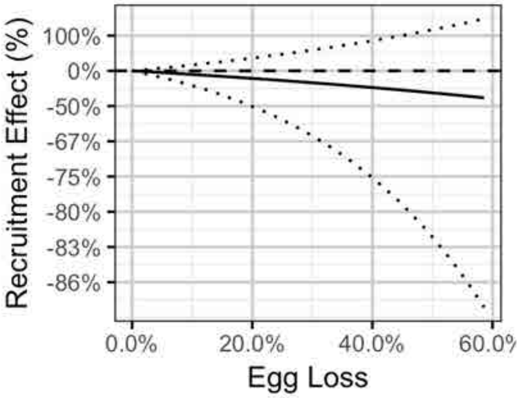


Figure 37: **Predicted carrying capacity of age-1 Mountain Whitefish recruits by percentage egg loss (with 95% CRIs).**

3.8.2 Rainbow Trout

The stock-recruitment relationship for Rainbow Trout in the LCR (Figure 38) did not suggest any effect of increasing abundance of adults ("stock") on the resulting number of age-1 recruits one year later. There were no data points on the lower part of the stock recruitment curve (<25,000 adults) where a decrease in recruitment but an increase in recruits per spawner 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 productivity in returns per spawner at low spawner abundance. The effect of egg loss on recruitment was statistically significant (*P*=0.03) and indicated a positive effect of egg loss on age-1 recruitment (Figure 39). The predicted effect size at an egg loss of 1.5% was a 100% increase in recruitment but with a credible interval of 10% to >200% (Figure 39), indicating considerable uncertainty in the relationship. Overall, observed egg losses were relatively small, with estimates of less than 2% in all years.

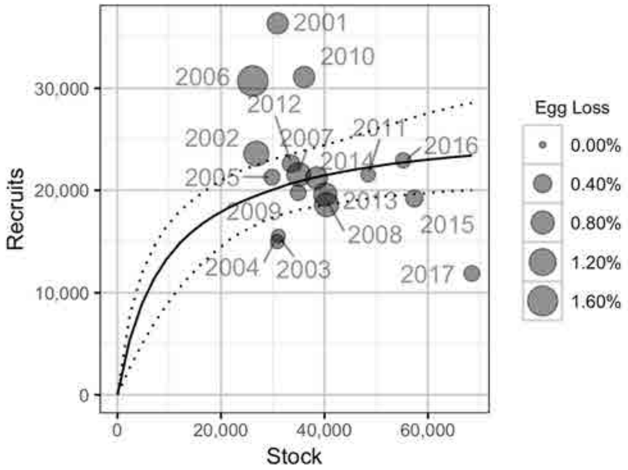


Figure 38: **Predicted stock-recruitment relationship between age-2+ spawners ("Stock") and subsequent age-1 Rainbow Trout ("Recruits") by spawning year (with 95% CRIs). Estimated proportion of egg loss due to dewatering for each spawning year is shown by size of shaded circles.**

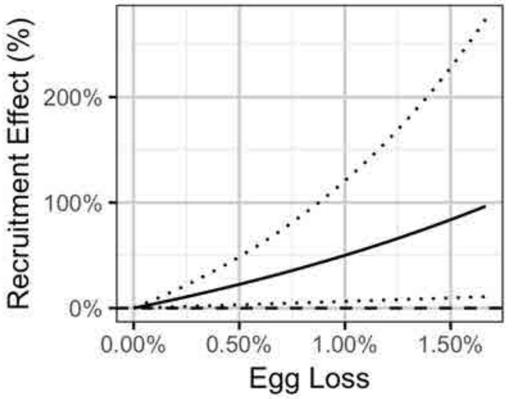


Figure 39: **Predicted carrying capacity of age-1 Rainbow Trout recruits by percentage egg loss (with 95% CRIs).**

3.9 *Other Species*

Northern Pike (*Esox Lucius*) were first observed during the LCR Fish Indexing Program in 2010, and the number of individuals captured and observed increased in successive years from 2010 to 2013 (Table 6). Catches of Northern Pike declined in 2014 and were low in 2015 to 2018 (<12 per year), which were years when a Northern Pike gill netting suppression program was conducted (Wood 2018). A total of 323 Northern Pike were removed during the gill netting program in 2014 (n=133), 2015 (n=116), 2016 (n=39), and 2017 (n=35). In 2018, at total of 27 Northern Pike were removed during the suppression program of which 22 were captured by gill-net and 5 were captured by boat electrofishing. Northern Pike removal efforts are currently ongoing within the LCR.

Since 2010, Northern Pike have been recorded during the LCR Fish Indexing Program in all three sections of the study area (Upper Columbia, Lower Columbia, and Kootenay River). However, 90% of the Northern Pike captured or observed were captured in the upper section upstream of the Columbia-Kootenay confluence. During the 2018 indexing survey, two Northern Pike were captured in the Kootenay River and one was observed in the upper section of the Columbia River. As requested by the MFLNRORD (J. Burrows, pers. comm.), all captured Northern Pike were euthanized.

Table 6: Number of Northern Pike captured and observed in the lower Columbia River Fish Population Indexing program by year.

Year	# Observed	# Captured	Total #
Prior to 2010	0	0	0
2010	3	4	7
2011	1	8	9
2012	10	1	11
2013	90	45	135
2014	16	9	25
2015	6	3	9
2016	0	4	4
2017	7	4	11
2018	1	2	3

Other aquatic invasive species captured or observed within the LCR in 2018 include two Brook Trout (*Salvelinus fontinalis*), four Brown Trout (*Salmo trutta*), one Common Carp (*Cyprinus carpio*), eight Smallmouth Bass (*Micropterus dolomieu*), three Tench (*Tinca tinca*), and one Yellow Perch (*Perca flavescens*).

In 2018, 13 Burbot were recorded at index sites in the LCR, which was similar to catches from 2013 to 2017 (6–25 Burbot per year) but lower than catches from 2003 to 2012, which ranged from 33 to 247 Burbot per year (Appendix E, Table E1).

Fifty-five White Sturgeon (40 adults and 15 immatures) were recorded (all observed; none captured) during the 2018 survey. Observational information for these fish is provided in Attachment A.

The number of sculpin (*n* = 2018) and Redside Shiner (*n* = 375) captured and observed in 2018 was lower than all previous years since 2001 (Appendix E, Table E1). In previous years, the number of sculpin ranged from 2,724 to 51,925 and the number of Redside Shiner ranged from 1,592 to 40,151. Observations of these small-bodied species are often clustered in a few locations (e.g. near HLK) and numbers are highly variable among years. Variability in the numbers observed is likely partly due to difficulty in observing these smaller fishes, especially if water surface visibility is affected by weather.

4.0 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.

The 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 mainly with the analyses of age ratio (Section 4.6) and stock-recruitment (Section 4.7). 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, which make it difficult to detect relationships without specific a priori hypotheses. Where relevant, we discuss which of the metrics (length-at-age, abundance, condition, and survival) are most likely to be affected by annual variability in the flow regime, and whether trends in fish metrics occurred in years of atypical discharge or water temperature. Assessment of the mechanisms of these relationships is speculative and not possible to assess given the observational study design of this program. 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.

The status of each of the specific management questions and hypotheses to be addressed by CLBMON-45 is summarized in the Executive Summary under Table I.

4.1 Length-at-Age and Growth

For Mountain Whitefish and Rainbow Trout, the mean length of age-0 individuals was used as an indicator of early life stage growth. 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 more intuitive and biologically meaningful 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.

4.1.1 Mountain Whitefish

There was little variation in the mean length of age-0 Mountain Whitefish during the study period, with mean fork lengths between approximately 120 and 140 mm in nearly all years (Figure 8). One exception was 2016, when mean length was larger (157 mm), but this may have been partly attributed to small and non-representative sample size that year. In 2018, the mean length of age-0 Mountain Whitefish was 142 mm, which was greater than all previous years other than 2016.

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 (Section 4.7).

The von Bertalanffy growth model based on inter-year recapture suggested generally increasing growth from 2006 to 2016 and slower growth in 2017 and 2018. The effect size for the growth coefficient was -9% to -10% in 2017–2018 compared to 59% in 2016. The predicted maximum growth rate declined from 247 mm/yr in 2016 to 140 mm/yr in 2017–2018. Water temperature in the Columbia River from February to May of 2016 was higher than had been seen over 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 and 2018. The changes in von Bertalanffy growth coefficient and predicted maximum growth during early life history in 2017 and 2018 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 (Petit and Wallace 1975; Meyer et al. 2009).

Table 7: 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	157	126	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.

4.1.2 Rainbow Trout

Mean length of age-0 Rainbow Trout declined in 2016 and 2017 and remained low in 2018 but the values were within the range observed in most previous years of the study (100–130 mm; Figure 12). Mean length had previously increased from 101 mm in 2010 to 143 mm in 2015. These trends did not agree with the trend in growth suggested by the von Bertalanffy growth coefficient, which decreased from a 55% effect size in 2006 to -38% in 2018 (Figure 13). A decrease in growth coefficient indicates a flatter growth curve and slower approach to the asymptotic size than in recent years than in the mid-2000s. The corresponding decrease for the maximum growth rate was from 632 mm/yr in 2006 to 256 mm/yr in 2018. 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., 632 mm/yr) for the entire first year of life. However, the large difference in values between 2006 (632 mm/yr) and 2018 (256 mm/yr) suggest a substantial and biologically important change in the growth of Rainbow Trout.

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 2018) and the growth model (continuous decline since 2006) 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 Rainbow Trout during the first year 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 trend in the growth based on the von Bertalanffy model coincided with increasing abundance of adult Rainbow Trout 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 period because they were not in direct competition with adults for food or other resources.

Table 8: 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		
0.84	487	409	113	267	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	Thorley 2015	Kootenay Lake, BC
0.34 – 1.0	330 – 740	288	n/a	n/a	FishBase.org	Canada, Australia, Mexico
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.

4.1.3 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 -41% to 80% across years (high variability), and the 95% CI of the 2018 estimate ranged from -22% to 61% (high uncertainty). The predicted maximum growth rate in 2018 was 69 mm/yr with a 95% CI of 46 to 99 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 grow 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 7. 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 (~300-450 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 85% effect sizes;Figure 14) and maximum growth rate (35 to 107 mm/yr; Figure 15) 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. During future study years, 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 with a large number of individuals migrating 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.

4.2 Abundance and Site Fidelity

4.2.1 Mountain Whitefish

In 2018, the estimated abundance of subadult Mountain Whitefish (22,000) was less than half of the values from the previous five years (54,000–60,000), which was attributed to poor recruitment from the 2016 spawning year (Figure 33). Poor recruitment may have been related to a large amount of egg loss (59%) due to dewatering for the 2016 cohort (Figure 32). The approximately 65% increase in estimated abundance of adults in 2018 (Figure 20) might 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 33) and coincided with relatively low levels of estimated egg loss (13–18%; Figure 32).

Differences in electrofisher settings during the first two years of the monitoring program in 2001 and 2002 may also 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 2018. 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). Therefore, there is potential for Northern Pike to influence the abundance and distribution of Mountain Whitefish in the upper LCR.

Since 2002, more than 140,000 hatchery-reared juvenile White Sturgeon were released into the Transboundary Reach section of the LCR (J. Crossman, BC Hydro, pers. comm.). 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.

One of the management questions is related to the effects of variation in flow regime on Mountain Whitefish abundance. 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 (Section 4.7) provides an alternative way to assess the effects of flow variation on recruitment.

4.2.2 Rainbow Trout

The abundance of subadult Rainbow Trout decreased between 2001 and 2005, whereas the abundance of adults was relatively stable during this time period. The estimated abundance of adults more than doubled from ~27,000 in 2002 to ~75,000 in 2018. In comparison, estimates of spawner abundance based on visual observations and an area-under-the-curve model increased more than five-fold from <2000 spawners in 1999 to >10,000 in 2015 to 2018 (Baxter 2018). 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 always 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) at very high fish densities, the electrofishing field crew becomes overwhelmed and are only able to catch or count a smaller proportion of the number of fish, which could result in underestimated abundance if the estimates of recapture rates are not precise enough to account for the change;

3) 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

4) 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 (12,000) than the previous six years when abundance was relatively stable (19,000–23,000). This coincided with a similar decrease in age-1 Mountain Whitefish in 2018. The decrease in age-1 Mountain Whitefish in 2018 may have been related to the large estimated egg loss due to dewatering for the 2016 spawning year (Section 3.7). 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.

In many years, capture efficiency of subadult Rainbow Trout decreased during each successive sample session (Appendix G, Figure G5). This result may indicate a violation of the HBM's closed population assumption. By comparison, the capture efficiency of adult Rainbow Trout remained stable within most study years. Capture efficiency between study years remained constant for both age-classes.

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.

4.2.3 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 downstream regions (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) 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. 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.

4.2.4 Other Species

The CLBMON-45 management questions refer only to the three index species; numbers of non-index species are generally too low to draw conclusions about population trends in any case. However, electrofishing results during this program clearly demonstrate the colonization of non-native Northern Pike in the study area. Northern Pike were not documented in the study area prior to 2010, but this species has been captured or observed during electrofishing surveys every year since 2010. Attempts to suppress the Northern Pike population through a targeted gill-netting program in 2014 to 2018 appear to be reasonably successful with 350 individuals removed in total (Wood 2019), and population estimates decreasing from a peak of 725 in 2014 to approximately 100 in 2017 (Baxter and Lawrence 2018). The number of Northern Pike caught and observed by boat electrofishing during this program decreased from a peak of 135 in 2013 to less than 12 per year from 2015 to 2018, which also suggests that suppression efforts decreased the population size in the study area.

Northern Pike likely originated from established populations in the Pend d'Oreille River. However, recent studies demonstrate successful spawning and recruitment of Northern Pike in the LCR. Young-of-the-year and juvenile Northern Pike have been captured in the Robson Reach of the LCR and in the Kootenay River oxbow (ONA 2016; Baxter and Lawrence 2018). In addition, otolith microchemistry analyses suggested that of 50 Northern Pike sampled in the LCR in 2014, 1 originated from the Pend d'Oreille River and 49 originated from the LCR (Baxter and Lawrence 2018).

The dramatic increase in the number of Redside Shiner recorded in the section of the Columbia River upstream of the Kootenay River in 2013 suggested a significant change in the abundance of this species. However, high abundance of Redside Shiner did not persist in 2014 to 2018, when levels were similar to previous years between 2001 and 2012. Reasons for the high abundance in 2013 are unclear but possible explanations include high recruitment of a recent year-class, an increase in habitat availability or suitability in the upper section of the LCR, or inaccurate counting by different observers between years. The high abundance of Redside Shiner observed in 2013 was similar to the high abundance of this species recorded in the early 1990s (R.L.&L. 1995).

The number of Burbot captured and observed was lower from 2013 to 2018 (6–25 Burbot per year) than between 2003 and 2012 when the number recorded per year ranged from 33 to 247, with the greatest catch in 2011 (Appendix E, Table E1). Catch rates from annual gill-netting surveys in Lake Roosevelt from 2003 to 2017 were also greatest in 2011, but otherwise did not follow the same trend as electrofishing catch in the LCR, with higher gill-net catch rates in recent years than between 2003 and 2010 (Golder 2019).

4.3 Spatial Distribution

4.3.1 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 2018 (Attachment A). Most recently, 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.

Although not statistically analyzed, the data did not suggest any large temporal changes in the spatial distributions of subadult and adult Mountain Whitefish between 2001 and 2018 (Figure 18).

4.3.2 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. Ford and Thorley (2011) suggested that these areas supported higher Rainbow Trout densities due to the more suitable habitat characteristics of these areas for this life stage and the presence of major spawning areas immediately upstream (i.e., Norn's Creek Fan, the Kootenay River, and the Genelle area; Thorley and Baxter 2012). No large changes in spatial distribution 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 generally similar to indexing sites, except at sites near the Columbia-Kootenay river confluence where densities were very high. 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. Higher densities in these areas than in index sites would result in underestimates of overall population density in the LCR and might explain the discrepancy with the spawner counts. 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.

4.3.3 Walleye

Walleye densities were high immediately downstream of HLK and BRD (Figure 25). Sculpin species and Redside Shiner are a common prey fish for Walleye based on stomach sample analyses (Ford and Thorley 2011). In 2010, results from the spatial density HBM 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 spatial distribution across index sites during the study period.

4.4 Survival

4.4.1 Mountain Whitefish

Estimated survival of adult Mountain Whitefish varied throughout all study years (22–93%) but has been >65% since 2011 (Figure 26). 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 58,000 subadults in 2017 would be recruited into the 2018 adult population (29,000 recruits), in addition to the 88,000 surviving adults (103,000 adults in 2018 and 86% survival), which yields a predicted adult population of 117,000. This prediction is substantially lower than the 2018 population estimate of 165,000. However, in other years such as 2017, the population estimate (103,000) agreed well with the predicted population (102,600) 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 estimated by the site fidelity model. The site fidelity model estimates the probability that a recaptured fish is caught at the same site as encountered previously, as opposed to being recaptured at a different site. Consequently, if a fish moved from the shallow water margins, where sampling occurred, into the main channel, or moved into an area of the river where sampling was not conducted, 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.

4.4.2 Rainbow Trout

Adult survival ranged from 33% to 51% 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 2018. Lower survival during recent years coincided with high abundances, as indicated by mark-recapture estimates (Section 3.4.4) and spawner surveys (Baxter 2018), 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.

4.4.3 Walleye

The estimated survival of Walleye was 51% in 2018, which was similar to most other years since 2001. Some years that had lower survival, such as 2004 (37% 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.

4.5 Body Condition

4.5.1 Mountain Whitefish

The body condition of subadult and adult Mountain Whitefish was fairly stable (≤5% change; Figure 29) between 2010 and 2018. Across all years when data were available, the effect sizes for the body condition of adult Mountain Whitefish varied from -15% to 9% (compared to a typical year) between 1990 and 2018 (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 2018 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 2018 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 (2001–2018).

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 the 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.

4.5.2 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. Thus, the results do not suggest that variations in flow regime 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 4.5.1 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 4.1), which also declined during this period. The recent high abundance, low body condition, and low growth also coincided with lower adult survival estimates, which suggests that low body condition and growth may lead to lower survival of Rainbow Trout in the LCR. These trends suggest that the population may be near 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). 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. 2019).

4.5.3 Walleye

Body condition of Walleye was greater in 2012 to 2014 than in most previous years but decreased from 2015 to 2018. 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.

4.6 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 2016 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. The data indicated a negative relationship between estimated egg loss and age-1:2 ratio but the relationship was not statistically significant. The large credible intervals around the relationship (Figures 34 and 35) show that a negative effect of egg loss on Mountain Whitefish recruitment is the most likely, but it is possible there is no effect of egg loss, given the data. The non-statistically significant relationship between age-1:2 ratio and egg loss (Figure 34) and large variability in this recruitment index was likely because there were many of other factors, such as population dynamics, environmental conditions, and ecological interactions that influenced survival and recruitment more than egg dewatering during most study years.

The most recent sampling year (2018) 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 54,000–60,000 in the previous five years to 22,000 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 4.2.2). Therefore, some common factor 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.

4.7 Stock-Recruitment Relationship

For both Mountain Whitefish and Rainbow Trout, the stock-recruitment analysis indicated no relationship between the estimated number of adults and age-1 recruits, and large variability in the number of recruits produced by a particular number of adults. 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, which does not support an effect of egg loss on recruitment in the LCR. 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 loss. Therefore, the data do not support an effect of egg loss on recruitment at the range of adult abundances observed, but the effects of egg loss at lower abundance are unknown based on this analysis.

For Rainbow Trout, the effect of egg loss on recruitment was statistically significant, with a predicted positive effect of egg loss on the carrying capacity of age-1 recruits. The predicted effect size at an egg loss of 1.5% was a 100% increase in age-1 recruits but with a credible interval of 10% to >200%, indicating considerable uncertainty in the relationship. This unexpected relationship cannot be directly due to egg loss as the dewatering rates are low (<2% in all years) and the relationship is positive. Instead it must be because egg loss is correlated with some other unmeasured factor that increases recruitment. 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. This conclusion should be considered tentative because of the poor fit in the stock-recruitment relationship, 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.

4.8 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 2018, 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 2018 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 2018, the estimated abundance of age-1 Mountain Whitefish decreased by more than half while the estimated abundance of adults increased by approximately 65%. Length-at-age of fry and body condition of Mountain Whitefish suggested relatively little change during the monitoring period.

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 2016 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 >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.

5.0 RECOMMENDATIONS

The following recommendations for future years of the study are provided:

- If BC Hydro wants to improve methods to monitor annual variation in recruitment of age-1 Mountain Whitefish and Rainbow Trout, then new methodologies targeting this age-class could be trialled. Methods could include: 1) using small-boat or raft electrofisher to target shallow, channel margin habitats; 2) using a higher pulse frequency (60 Hz) that is more effective for smaller fish than current settings (30 Hz), as long as sampled areas have few large adult fish that are susceptible to injury by high frequency electrofishing.
- The feasibility of implementing alternative, experimental flow regimes for a single spawning season instead of the current Mountain Whitefish and Rainbow Trout protection flows should be examined. This would provide an opportunity to monitor changes in the parameters of interest under different flow regimes, which would help address the management question regarding the effects of variability in the flow regime on fish populations.

6.0 REFERENCES

Ash, G., W. Luedke, and B. Herbert. 1981. Fisheries inventory and impacts assessment in relation to the proposed Murphy Creek Project on the Columbia River, B.C. Prepared for BC Hydro by R.L.&L. Environmental Services Ltd. (Revised January 1984). 329 pp.

Baker, T., R. Lafferty, and T.J. Quinn II. 1991. A general growth model for mark-recapture data. Fisheries Research 11: 257–281.

Baxter, J.T.A. 2018. Lower Columbia River Rainbow Trout spawning assessment – 2018 data report. Final data report prepared for BC Hydro, Castlegar, BC. 15 pp + 1 app.

Baxter, J.T.A. and D.J. Doutaz. 2017. Lower Columbia River Invasive Northern Pike Suppression - 2016 Update. Report prepared for Teck Trail Operations. 16 pp.

Baxter, J. and C. Lawrence. 2018. Lower Columbia River Invasive Northern Pike Suppression - 2017 Update. Report prepared for Teck Trail Operations. 12 pp.

BC Hydro. 2005. Columbia River Project, Water Use Plan. 41 pp. + 1 app.

BC Hydro. 2007. Columbia River Project Water Use Plan, Monitoring Program Terms of Reference – Lower Columbia Fish Management Plan (CLBMON-45 Lower Columbia River Fish Indexing Surveys). 18 pp.

Bradford, M. J., J. Korman and P. S. Higgins. 2005. Using confidence intervals to estimate the response of salmon populations (*Oncorhynchus* spp.) to experimental habitat alterations. Canadian Journal of Fisheries and Aquatic Sciences 62: 2716-2726.

Boyer, J. K. 2016. Spawning and early life history of Mountain Whitefish in the Madison River, Montana. Master's thesis. Montana State University, Bozeman.

Carpenter, B., A. Gelman, M.D. Hoffman, D. Lee, B. Goodrich, M. Betancourt, M. Brubaker, J. Guo, P. Li, and A. Riddell. 2017. Stan: A Probabilistic Programming Language. Journal of Statistical Software 76 (1).

Cox, S. 2000. Angling quality, effort response, and exploitation in recreational fisheries: field and modelling studies on British Columbia Rainbow Trout (*Oncorhynchus mykiss*) lakes. Doctoral dissertation. University of British Columbia, Vancouver.

Columbia River Integrated Environmental Monitoring Program (CRIEMP). 2005. 2005 Environmental Status Report – Public update on the environmental health of the Columbia River from Hugh Keenleyside Dam to the border. 15 pp.

Dolan, C.R., and L.E. Miranda. 2003. Immobilization thresholds of electrofishing relative to fish size. Transactions of the American Fisheries Society 132: 969-976.

Environment Canada. 2012. Metal mining technical guidance for environmental effects monitoring. Environment Canada, Ottawa, Ontario. 550 pp.

Fabens, A.J. 1965. Properties and fitting of the von Bertalanffy growth curve. Growth. 1965 Sep; 29:265-289.

Fetherman, E.R., D.L. Winkelman, M.R. Baerwald, and G.J. Schisler. 2014. Survival and reproduction of *Myxobolus cerebralis*-resistant Rainbow Trout introduced to the Colorado River and increased resistance of age-0 progeny. PloS one 9: e96954.

Ford, B.S., P.S. Higgins, A.F. Lewis, K.L. Cooper, T.A. Watson, C.M. Gee, G.L. Ennis, and R.L. Sweeting. 1995. Literature reviews of the life history, habitat requirements and mitigation/compensation strategies for thirteen sport fish species in the Peace, Liard, and Columbia River drainages of British Columbia. Canadian Manuscript Report of Fisheries and Aquatic Sciences 2321: xxiv + 342 pp.

Ford, D. And J.L. Thorley. 2011. CLBMON-45 Lower Columbia River Fish Population Indexing Surveys – 2010 Investigations. Report prepared for BC Hydro Generations, Water Licence Requirements, Castlegar, BC. Golder Report No. 10-1492-0102F: 54 pp. + 5 app.

Forney, J.L. 1977. Evidence of Inter- and Intraspecific Competition as Factors Regulating Walleye (*Stizostedion vitreum vitreum*) Biomass in Oneida Lake, New York. Journal of the Fisheries Research Board of Canada 34: 1812-1820.

Gale, M. K., S.G. Hinch and M.R. Donaldson. 2013. The role of temperature in the capture and release of fish. Fish and Fisheries 14: 1-33.

Godfrey, H. 1955. On the ecology of the Skeena River whitefishes Coregonus and Prosopium. Journal of the Fisheries Research Board of Canada 12: 488-527.

Golder Associates Ltd. 2002. Lower Columbia River Fish Community Indexing Program. 2001 Phase 1 investigations. Report prepared for BC Hydro, Burnaby, B.C. Golder Report No. 012-8007F: 52 pp. + 6 app.

Golder Associates Ltd. 2003. Large River Fish Indexing Program – Lower Columbia River 2002 Phase 2 Investigations. Report prepared for B.C. Hydro, Burnaby, B.C. Golder Report No. 022-8023F: 47 pp. + 5 app.

Golder Associates Ltd. 2004. Large River Fish Indexing Program – Lower Columbia River 2003 Phase 3 Investigations. Report prepared for B.C. Hydro, Burnaby, B.C. Golder Report No. 03-1480-021F: 54 pp. + 6 app.

Golder Associates Ltd. 2005. Large River Fish Indexing Program – Lower Columbia River 2004 Phase 4 Investigations. Report prepared for B.C. Hydro, Burnaby, B.C. Golder Report No. 04-1480-047F: 57 pp. + 6 app.

Golder Associates Ltd. 2006. Large River Fish Indexing Program – Lower Columbia River 2005 Phase 5 Investigations. Report prepared for B.C. Hydro, Burnaby, B.C. Golder Report No. 05-1480-034F: 56 pp. + 6 app.

Golder Associates Ltd. 2007. Large River Fish Indexing Program – Lower Columbia River 2006 Phase 6 Investigations. Report prepared for B.C. Hydro, Burnaby, B.C. Golder Report No. 06-1480-031F: 70 pp. + 6 app.

Golder Associates Ltd. 2009a. Large River Fish Indexing Program – Lower Columbia River 2008 Phase 8 Investigations. Report prepared for B.C. Hydro, Burnaby, B.C. Golder Report No. 08-1480-046F: 58 pp. + 6 app.

Golder Associates Ltd. 2009b. Monitoring of juvenile white sturgeon habitat use and movements of sonic-tagged sturgeon: 2008 investigations. Report prepared for BC Hydro, Revelstoke, B.C. Golder Report No. 08-1480-0030F: 34 pp. + 3 app.

Golder Associates Ltd. 2009c. Lower Columbia River whitefish life history and egg mat monitoring program: 2008 - 2009 investigations data report. Report prepared for BC Hydro, Castlegar, BC Golder Report No. 08-1480-0054F: 42 pp. + 6 app.

Golder Associates Ltd. 2010a. Lower Columbia River Whitefish Life History and Egg Mat Monitoring Program: 2009 – 2010 Investigations Data Report. Report prepared for BC Hydro, Castlegar, B.C. Golder Report No. 08-1480-054F: 59 pp. + 7 app.

Golder Associates Ltd. 2010b. Large River Fish Indexing Program – Lower Columbia River 2009 Phase 9 Investigations. Report prepared for B.C. Hydro, Castlegar, B.C. Golder Report No. 09-1480-049F: 80 pp. + 6 app.

Golder Associates Ltd. 2012. Lower Columbia River whitefish life history and egg mat monitoring program: Year 4 data report. Report prepared for BC Hydro, Castlegar, BC. Golder Report No. 11-1492-0111F: 48 pp. + 3 app.

Golder Associates Ltd. 2013a. Fish and Egg Stranding Monitoring for Waneta Expansion Project-Year Two Report prepared for Columbia Power Corporation, Castlegar, BC. Golder Report No. 11-1492-0130: 30 pp. + 1 App.

Golder Associates Ltd. 2013b. Lower Columbia River whitefish spawning ground topography survey: Year 3 summary report. Report prepared for BC Hydro, Castlegar, BC Golder Report No. 10-1492-0142F: 68 pp. + 3 app.

Golder Associates Ltd. 2019. Lake Roosevelt Burbot Stock Assessment 2018. Report prepared for Colville Confederated Tribes. 84 pp + apps.

Golder Associates Ltd. and W.J. Gazey Research. 2019. Peace River Large Fish Indexing Survey - 2018 investigations. Report prepared for BC Hydro, Vancouver, British Columbia. Golder Report No. 1670320. 118 pp + 8 app.

Golder Associates Ltd. and Okanagan Nation Alliance. 2018. Lower Columbia River Aquatic Invasive Species Reduction Program. Report for Environmental Damages Fund Program, Environment and Climate Change Canada. 24 pp.

Golder Associates Ltd., Poisson Consulting Ltd., and Okanagan Nation Alliance. 2017. CLBMON-16 Middle Columbia River Fish Population Indexing Survey 2016 Report. Report prepared for BC Hydro Generation, Water License Requirements, Castlegar, BC. 65 pp. + 9 app.

Golder Associates Ltd., Okanagan Nation Alliance, and Poisson Consulting Ltd. 2018. CLBMON-45 Lower Columbia River Fish Population Indexing Survey 2017 Report. Report prepared for BC Hydro Generation, Water License Requirements, Castlegar, BC. 70 pages + 8 app.

Golder Associates Ltd., Poisson Consulting Ltd., and Okanagan Nation Alliance. 2019. CLBMON-16 Middle Columbia River Fish Population Indexing Survey 2018 Report. Report prepared for BC Hydro Generation, Water License Requirements, Revelstoke, BC. 75 pages + 9 app.

Greenland, S., S.J. Senn, K.J. Rothman, J.B Carlin, C. Poole, S.N. Goodman, and D.G. Altman. 2016. Statistical tests, P values, confidence intervals, and power: a guide to misinterpretations. European Journal of Epidemiology 31: 337-350.

Hartman, K.J. and J.F., Margraf. 1992. Effects of Prey and Predator Abundances on Prey Consumption and Growth of Walleyes in Western Lake Erie. Transactions of the American Fisheries Society, 121:245 – 260.

He, J. X., J. R. Bence, J. E. Johnson, D. F. Clapp and M. P. Ebener. 2008. Modeling Variation in Mass-Length Relations and Condition Indices of Lake Trout and Chinook Salmon in Lake Huron: a Hierarchical Bayesian Approach. Transactions of the American Fisheries Society 137: 801-817.

Hutchinson, W. F. 2008. The dangers of ignoring stock complexity in fishery management: the case of the North Sea cod. Biology Letters 4: 693–695.

Imre, I, J.W.A. Grant, and E.R. Keeley. 2002. The effect of visual isolation on territory size and population density of juvenile rainbow trout (Oncorhynchus mykiss). Canadian Journal of Fisheries and Aquatic Sciences 59: 303-309.

Irvine, R.L., J.T.A. Baxter and J.L. Thorley. 2015. WLR Monitoring Study No. CLBMON-46 (Year 7) Lower Columbia River Rainbow Trout Spawning Assessment. Columbia River Water Use Plan. BC Hydro, Castlegar. A Mountain Water Research and Poisson Consulting Ltd Final Report.

Irvine, R.L., J.T.A. Baxter, and J.L. Thorley. 2018. WLR Monitoring Study No. CLBMON-46 (Year 10) Lower Columbia River Rainbow Trout Spawning Assessment. Columbia River Water Use Plan. BC Hydro, Castlegar, BC. A Mountain Water Research and Poisson Consulting Ltd. Final Report.

Kéry, M. 2010. Introduction to WinBUGS for Ecologists: A Bayesian Approach to Regression, ANOVA, Mixed Models and Related Analyses. Elsevier, Boston.

Kéry, M. and M. Schaub. 2011. Bayesian population analysis using WinBUGS – a hierarchical perspective. Academic Press, Burlington.

Kincaid, T.M. and A.R. Olsen. 2016. spsurvey: Spatial Survey Design and Analysis. R package version 3.3.

Korman, J. 2009. Early life history dynamics of rainbow trout in a large regulated river. Doctoral dissertation. University of British Columbia, Vancouver.

Lester, N.P., B.J. Shuter, and P.A. Abrams. 2004. Interpreting the von Bertalanffy model of somatic growth in fishes: the cost of reproduction. Proceedings of the Royal Society of London B: Biological Sciences 271: 1625-1631.

Lin, J. 1991. Divergence Measures Based on the Shannon Entropy. IEEE Transactions on Information Theory 37: 145–151.

Lorenzen, K. 2008. Fish population regulation beyond “stock and recruitment”: the role of density-dependent growth in the recruited stock. Bulletin of Marine Science 83: 181-196.

MacDonald Environmental Services Ltd. 1997. Lower Columbia River from Birchbank to the International Border: Water Quality Assessment and Recommended Objectives. Technical Report prepared for Environment Canada and British Columbia Ministry of Environment, Lands and Parks. 115 pp. + apps.

Macdonald, P. 2012. Mixdist: Finite Mixture Distribution Models. R package version 0.5-5. https://CRAN.R-project.org/package=mixdist.

Macdonald, P.D.M. and T.J. Pitcher. 1979. Age-groups from size-frequency data: a versatile and efficient method of analysing distribution mixtures. Journal of the Fisheries Research Board of Canada 36: 987-1001.

Mackay, W.C., G.R. Ash and H.J. Norris. 1990. Fish ageing methods for Alberta. R.L. & L. Environmental Services Ltd. in association with Alberta and Wildlife Division and University of Alberta, Edmonton. 133 pp.

McPhail, J.D. 2007. The Freshwater Fishes of British Columbia. University of Alberta Press, Edmonton, AB.

Meyer, K. A., F. S. Elle, and J. A. Lamansky Jr. 2009. Environmental factors related to the distribution, abundance, and life history characteristics of mountain whitefish in Idaho. North American Journal of Fisheries Management 29: 753-767.

Munkittrick, K.R., C.J. Arens, R.B. Lowell, and G.P. Kaminski. 2009. A review of potential methods of determining critical effect size for designing environmental monitoring programs. Environmental Toxicology and Chemistry 28: 1361-1371.

Myers, R.A. 1998. When do environment-recruitment correlations work? Reviews in Fish Biology and Fisheries 8: 285-305.

Myers, R.A. 2001. Stock and recruitment: generalizations about maximum reproductive rate, density dependence, and variability using meta-analytic approaches. ICES Journal of Marine Science 58: 937-951.

Myers, R. A., and N.J. Barrowman. 1996. Is fish recruitment related to spawner abundance? Fishery Bulletin 94: 707-724.

Nener, J., D. Kieser, J.A.J. Thompson, W.L. Lockhart, D.A. Metner, and R. Roome. 1995. Monitoring of Mountain Whitefish Prosopium williamsoni from the Columbia River system near Castlegar, British Columbia: Health parameters and contaminants in 1992. Canadian Manuscript Report of Fisheries and Aquatic Sciences 2036, 89 pp.

Ohnishi, S., T. Yamakawa, H. Okamura, and T. Akamine. 2012. A note on the von Bertalanffy growth function concerning the allocation of surplus energy to reproduction. Fishery Bulletin 110: 223-229.

Okanagan Nation Alliance. 2016. Lower Columbia River Juvenile Northern Pike (*Esox lucius*) Assessment. Prepared for Columbia Basin Trust. 14 pp.

Olson-Russello, M.A., J. Schleppe, H. Larratt, K. Hawes. 2015. Monitoring Study No. CLBMON-44 (Year 7) Lower Columbia River Physical Habitat and Ecological Productivity, Study Period: 2014. Report Prepared for BC Hydro, Castlegar, British Columbia. 103 p. Report Prepared by: Ecoscape Environmental Consultants Ltd.

Pettit, S.W., and R.L. Wallace. 1975. Age, growth, and movement of Mountain Whitefish, *Prosopium williamsoni* (Girard), in the North Fork Clearwater River, Idaho. Transactions of the American Fisheries Society 104: 68-76.

Plewes, R., H. Larratt, and M.A. Olson-Russello. 2017. Monitoring Study No. CLBMON-44 (Year 9) Lower Columbia River Physical Habitat and Ecological Productivity, Study Period: 2016. Report Prepared for BC Hydro, Castlegar, British Columbia. 62 pgs + Appendices. Report Prepared by: Ecoscape Environmental Consultants Ltd.

Plummer, M. 2015. {JAGS} version 4.0.1 user manual.

http://sourceforge.net/projects/mcmc-jags/files/Manuals/4.x/

Porath, M.T., and E.J. Peters. 1997. Use of Walleye Relative Weights (Wr) to Assess Prey Availability. North American Journal of Fisheries Management 17: 628-637.

Quince, C., P.A. Abrams, B.J. Shuter, and N.P. Lester. 2008. Biphasic growth in fish I: theoretical foundations. Journal of Theoretical Biology 254: 197-206.

Ratz H.J. and J. Lloret. 2003. Variation in fish condition between Atlantic cod (*Gadus morhua*) stocks, the effect on their productivity and management implications. Fisheries Research 60: 369-380.

R Team. 2018. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria. http://www.R-project.org

R.L. & L. Environmental Services Ltd. 1991. Lower Columbia Development. Lower Columbia River Fisheries Inventory – 1990 Studies. Volume I Main Report. Submitted to BC Hydro Environmental Resources. (Revised March 1992). 170pp. + 7 app.

R.L. & L. Environmental Services Ltd. 1995. Columbia Basin Developments – Lower Columbia River. Fisheries Inventory Program 1990 to 1994. Report Prepared for BC Hydro, Environmental Affairs, Vancouver, B.C., by R.L. & L. Environmental Services Ltd., Castlegar, B.C. R.L. & L. Report No. 381- 95F: 147 pp. + 7 app.

R.L. & L. Environmental Services Ltd. 1997. Lower Columbia River mountain whitefish monitoring program. 1994-1996 investigations. Draft Report prepared for BC Hydro, Kootenay Power Supply/Power Facilities. R.L. & L. Report No. 514D: 101 pp. + 8 app.

R.L. & L. Environmental Services Ltd. 2000. 13 October 2000. Memo to Colin Spence, MOE, from Louise Porto, R.L.&L. Environmental Services. Re: White Sturgeon Mortality.

Scott, W.B. and E.J. Crossman 1973. Freshwater Fishes of Canada. Bulletin 184. ISBN 0-660-10239-0. Fisheries Research Board of Canada, Ottawa.

Seals, J., J. McCormick, and R. French. 2014. Growth, condition, and age structure of Redband Trout in the lower Deschutes River, Oregon. Technical report prepared by the Oregon Department of Fish and Wildlife, The Dalles, OR. 20 pp.

https://www.dfw.state.or.us/fish/local_fisheries/deschutes/docs/Monitoring_Report_for_Deschutes_River_Rainbow_Trout_2014_Final_2.pdf

Stevens, D. L., Jr. and A. R. Olsen 2004. Spatially-balanced sampling of natural resources. Journal of American Statistical Association 99: 262-278.

Subbey, S., J. A. Devine, U. Schaarschmidt, and R.D.M. Nash. 2014. Modelling and Forecasting Stock-Recruitment: Current and Future Perspectives. ICES Journal of Marine Science 71: 2307–2322.

Thorley, J.L. 2015. Kootenay Lake Gerrard Rainbow Trout Condition and Growth Analysis 2014. A Poisson Consulting Analysis Report. URL: http://www.poissonconsulting.ca/f/723490014.

Thorley, J.L. and S. Dalgarno. 2019. Lower Columbia River Fish Population Indexing Analysis 2018. A Poisson Consulting Analysis Report. URL: http://www.poissonconsulting.ca/f/1169613097.

Thorley, J. L. and J. T. A. Baxter. 2012. Lower Columbia River Rainbow Trout Spawning Assessment 2011: WLR Monitoring Study No. CLBMON-46 (Year 4). Columbia River Water Use Plan. BC Hydro, Castlegar. Mountain Water Research and Poisson Consulting Ltd.

Tornqvist, L., P. Vartia, and Y.O. Vartia. 1985. How Should Relative Changes Be Measured? The American Statistician 39: 43-46.

von Bertalanffy, L. 1938. A quantitative theory of organic growth. Human Biology 10: 181–213.

Walters, C. J., and D. Ludwig. 1981. Effects of measurement errors on the assessment of stock-recruitment relationships. Canadian Journal of Fisheries and Aquatic Sciences 38: 704-710.

Walters, C.J., and S.J.D. Martell. 2004. Fisheries Ecology and Management. Princeton University Press, Princeton, N.J.

Wood Environment and Infrastructure Solutions (Wood). 2018. Columbia River Northern Pike Suppression 2018. Report Prepared for Columbia Basin Trust, Castlegar, BC and the BC Ministry of Forests, Lands, Natural Resource Operations and Rural Development, Nelson, BC. Wood Report No: VE52702.2018. 32 pp + 3 App.

Wydoski, R.S. and D.H. Bennett. 1981. Forage species in lakes and reservoirs of the western United States. Transactions of the American Fisheries Society 110: 764-771.

Appendix A - Maps

Table A1 Locations and distances from Hugh L. Keenleyside Dam of boat electrofishing index sites in the lower Columbia River, 2018.

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.

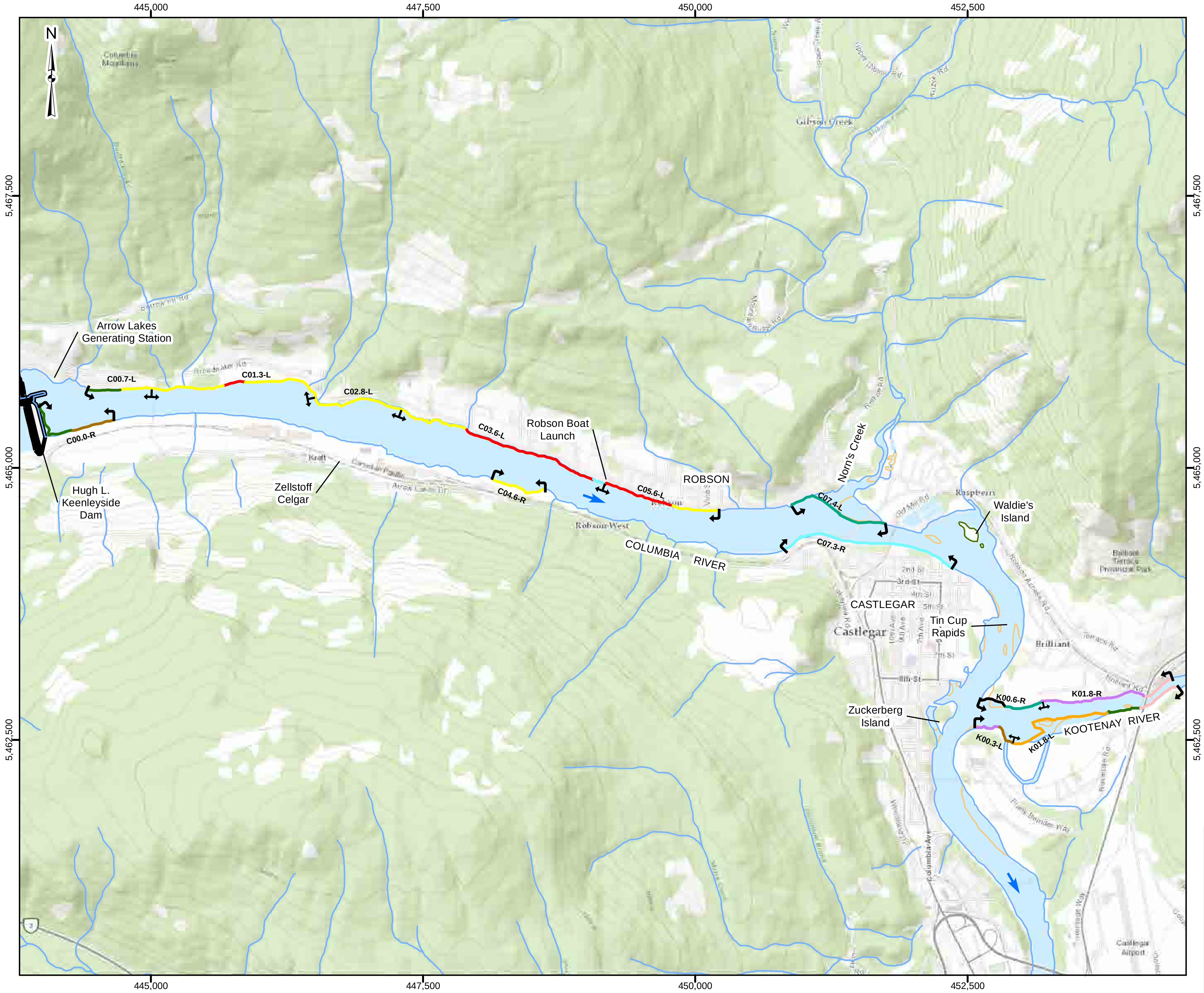
[c] LDB=Left bank as viewed facing downstream; RDB=Right bank as viewed facing downstream.

Table A2 Locations of selected sites and available sites included in the Generalized Random Tessellation Stratified (GRTS) survey, 2018.

Site Designation	Location (km)[a]	Bank[b]	Upstream UTM Coordinates			Downstream UTM Coordinates			Sites Selected in 2018
			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	
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	X
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	
C10.8-R	10.8	RDB	11U	452154	5462718	11U	452154	5462718	
C10.9-L	10.9	LDB	11U	452584	5462607	11U	453290	5460373	
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	X
C13.4-R	13.4	RDB	11U	453103	5460426	11U	453221	5458057	
C14.8-L	14.8	LDB	11U	453321	5459007	11U	453210	5456890	X
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	X
C18.0-R	18.0	RDB	11U	452358	5456216	11U	452351	5455401	
C18.8-R	18.8	RDB	11U	452351	5455401	11U	452122	5454012	X
C19.0-L	19.0	LDB	11U	452622	5455322	11U	452444	5454183	
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	
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	
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	X
C26.2-L	26.2	MID	11U	448938	5449626	11U	448938	5449626	X
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	
C30.6-L	30.6	LDB	11U	447491	5446079	11U	446746	5444432	
C32.0-R	32.0	RDB	11U	446817	5444824	11U	446256	5443655	
C32.4-L	32.4	LDB	11U	446746	5444432	11U	446353	5442572	X
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	
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	
C40.0-R	40.0	RDB	11U	448995	5438083	11U	450459	5438222	
C41.1-L	41.1	LDB	11U	450090	5438405	11U	452466	5438365	X
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	X
C44.6-L	44.6	LDB	11U	453245	5437597	11U	454179	5437228	X
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	X
C47.2-R	47.2	RDB	11U	455141	5435856	11U	455017	5434942	
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.



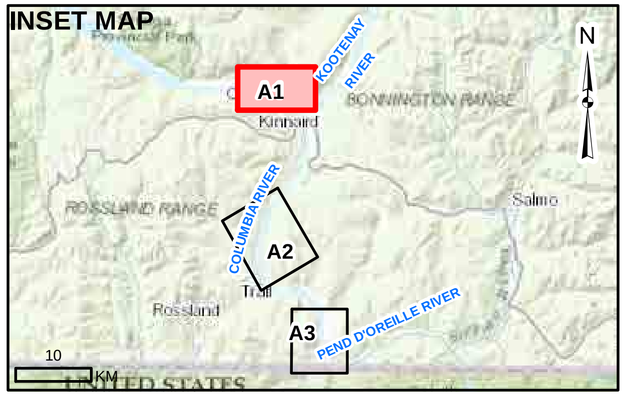
LEGEND

● 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), SWISSTOPO, © OPENSTREETMAP CONTRIBUTORS, AND THE GIS USER COMMUNITY.

PROJECTION: UTM ZONE 11 DATUM: NAD 83

600 0 600
SCALE 1:35,000 METRES

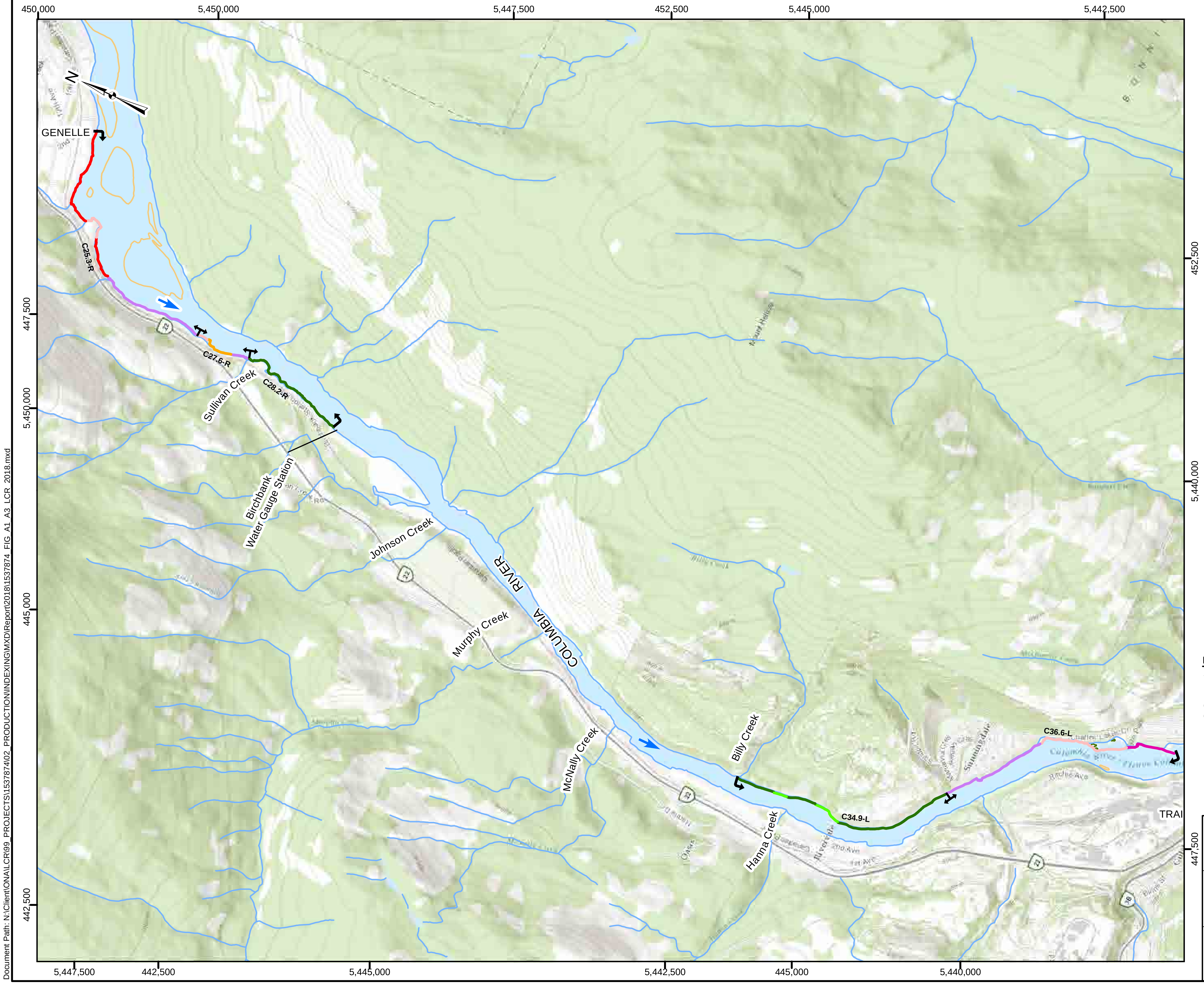
PROJECT
LARGE RIVER FISH INDEXING PROGRAM
LOWER COLUMBIA RIVER

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	24 JUN. 2019		
CHECK	DR	24 JUN. 2019		
REVIEW	SR	24 JUN. 2019		

Document Path: N:\Client\ONAL\CR\99_PROJECTS\1537874\02_PRODUCTION\INDEXING\MXD\Report\2018\1537874_FIG_A1_A3_LCR_2018.mxd

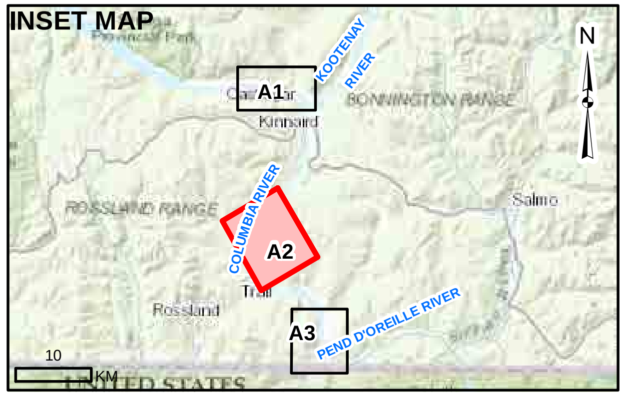


LEGEND

●	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



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), SWISSTOPO, © OPENSTREETMAP CONTRIBUTORS, AND THE GIS USER COMMUNITY.

PROJECTION: UTM ZONE 11 DATUM: NAD 83

600 0 600

SCALE 1:35,000 METRES

PROJECT

LARGE RIVER FISH INDEXING PROGRAM
LOWER COLUMBIA RIVER

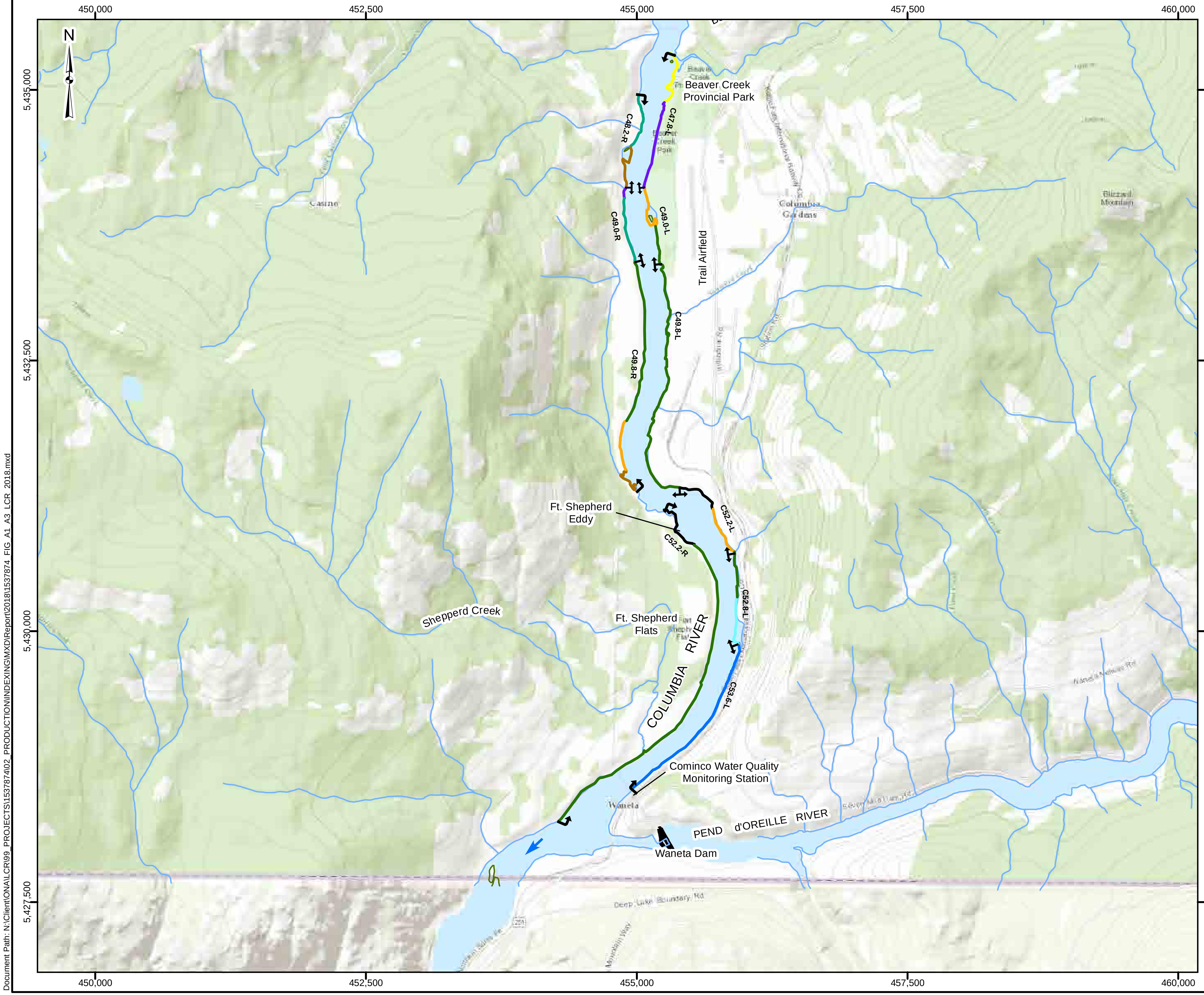
TITLE

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	24 JUN. 2019		
CHECK	DR	24 JUN. 2019		
REVIEW	SR	24 JUN. 2019		

Document Path: N:\Client\ONA\LCR\99_PROJECTS\1537874\02_PRODUCTION\INDEXING\MXD\Report\2018\1537874_FIG_A1_A3_LCR_2018.mxd



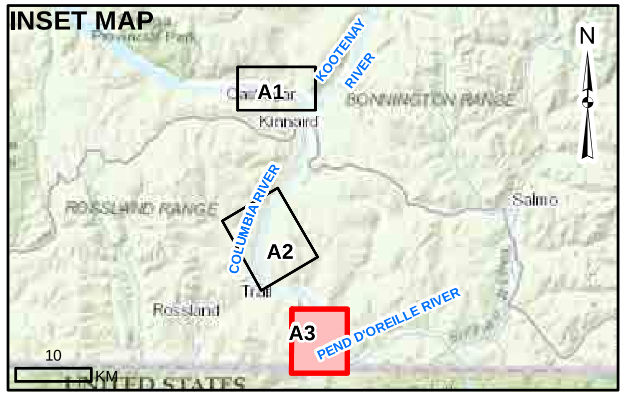
LEGEND

● 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), SWISSTOPO, © OPENSTREETMAP CONTRIBUTORS, AND THE GIS USER COMMUNITY.

PROJECTION: UTM ZONE 11 DATUM: NAD 83

600 0 600

SCALE 1:35,000 METRES

PROJECT

LARGE RIVER FISH INDEXING PROGRAM
LOWER COLUMBIA RIVER

TITLE

LOWER SECTION OF STUDY AREA
SAMPLE SITE LOCATIONS

PROJECT No. 1537874			SCALE AS SHOWN	REV. 0
DESIGN	DR	14 JUN. 2016	FIGURE: A3	
GIS	JG/CD	24 JUN. 2019		
CHECK	DR	24 JUN. 2019		
REVIEW	SR	24 JUN. 2019		

GOLDER

Document Path: N:\Client\ONA\LCR\99_PROJECTS\1537874\02_PRODUCTION\INDEXING\MXD\Report\2018\1537874 FIG A1 A3 LCR 2018.mxd

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, 01 October to 31 October 2018.

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	K01.8-R	1	5.0	13.9	150	Partly cloudy	High	High	Medium	0	0	0	0	0	80	20
Kootenay	K01.8-R	2	2.0	12.9	150	Clear	High	High	High	10	0	0	0	0	80	10
Kootenay	K01.8-R	3	9.0	11.5	140	Partly cloudy	High	High	High	10	0	0	0	0	35	55
Kootenay	K01.8-R	4	4.0	11.5	140	Partly cloudy	High	High	High	10	0	0	0	0	50	40
Kootenay	K01.8-L	1	5.0	13.9	150	Partly cloudy	High	High	Medium	0	0	0	0	0	65	35
Kootenay	K01.8-L	2	2.0	12.9	150	Clear	High	High	High	15	0	0	0	0	70	15
Kootenay	K01.8-L	3	6.0	11.4	140	Partly cloudy	High	High	High	0	0	0	0	0	65	35
Kootenay	K01.8-L	4	6.0	11.4	150	Partly cloudy	High	High	High	0	0	0	0	0	70	30
Kootenay	K00.6-R	1	5.0	13.7	150	Partly cloudy	High	High	Medium	5	0	0	10	0	80	5
Kootenay	K00.6-R	2	1.0	12.8		Clear	High	High	High	10	0	0	10	0	80	0
Kootenay	K00.6-R	3	8.0	11.4	140	Partly cloudy	High	High	High	10	0	0	10	0	80	0
Kootenay	K00.6-R	4	3.0	11.4	140	Clear	High	High	High	15	0	0	0	0	80	5
Kootenay	K00.3-L	1	5.0	13.9	150	Partly cloudy	High	High	High	15	0	0	0	0	60	25
Kootenay	K00.3-L	2	1.0	12.9	150	Clear	High	High	High	35	0	0	0	0	25	40
Kootenay	K00.3-L	3	10.0	11.7	140	Clear	High	High	High	40	0	0	0	0	0	60
Kootenay	K00.3-L	4	3.0	11.5	140	Clear	High	High	High	30	0	0	0	0	30	40
Lower	C53.6-L	1	7.0	13.1	130	Partly cloudy	High	High	High	30	0	0	0	0	20	50
Lower	C53.6-L	2	3.0	12.2	130	Clear	High	High	High	40	0	0	0	0	40	20
Lower	C53.6-L	3	6.0	11.4	140	Partly cloudy	High	High	High	50	0	0	0	0	20	30
Lower	C53.6-L	4	6.0	10.5	140	Mostly cloudy	High	High	High	45	0	0	0	0	0	55
Lower	C52.8-L	1	8.0	13.2	130	Partly cloudy	High	High	High	20	0	0	0	0	30	50
Lower	C52.8-L	2	4.0	12.1	130	Clear	High	High	High	25	0	0	0	0	50	25
Lower	C52.8-L	3	6.0	11.2	140	Partly cloudy	High	High	High	30	0	0	0	0	60	10
Lower	C52.8-L	4	7.0	10.5	140	Mostly cloudy	High	High	High	15	0	0	0	0	25	60
Lower	C52.2-R	1	7.0	13.2	140	Overcast	High	High	High	10	0	0	0	0	65	25
Lower	C52.2-R	2	4.0	12.5	130	Clear	High	High	High	10	0	0	0	0	80	10
Lower	C52.2-R	3	2.0	12.0	130	Clear	High	High	High	5	0	0	0	0	80	15
Lower	C52.2-R	4	7.0	11.3	130	Overcast	Medium	High	High	0	0	0	0	0	85	15
Lower	C52.2-L	1	8.0	13.2	130	Mostly cloudy	High	High	High	15	0	0	1	0	75	9
Lower	C52.2-L	2	3.0	12.3	130	Clear	High	High	High	20	0	0	0	0	30	50
Lower	C52.2-L	3	7.0	11.3	140	Mostly cloudy	High	High	High	15	0	0	0	0	60	25
Lower	C52.2-L	4	8.0	10.6	140	Mostly cloudy	High	High	High	10	0	0	0	0	50	40
Lower	C49.8-R	1	7.0	13.2	140	Partly cloudy	High	High	High	10	0	0	2	0	80	8
Lower	C49.8-R	2	7.0	12.5	130	Clear	High	High	High	15	0	0	0	0	80	5
Lower	C49.8-R	3	6.0	11.9	130	Clear	High	High	High	0	0	0	0	0	80	20
Lower	C49.8-R	4	8.0	11.3	130	Overcast	Medium	High	High	5	0	0	0	0	75	20
Lower	C49.8-L	1	9.0	13.2	130	Mostly cloudy	High	High	High	0	0	0	1	0	75	24
Lower	C49.8-L	2	5.0	12.2	130	Clear	High	High	High	0	0	0	1	0	85	14
Lower	C49.8-L	3	7.0	11.4	140	Partly cloudy	High	High	High	10	0	0	0	0	70	20
Lower	C49.8-L	4	7.0	10.6	140	Mostly cloudy	High	High	High	0	0	0	0	0	75	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.

Continued...

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
Lower	C49.0-R	1	9.0	13.3	140	Overcast	High	High	High	15	0	0	0	0	60	25
Lower	C49.0-R	2	8.0	12.6	130	Clear	High	High	High	0	0	0	0	0	65	35
Lower	C49.0-R	3	7.0	12.1	130	Clear	High	High	High	0	0	0	0	0	60	40
Lower	C49.0-R	4	9.0	11.3	130	Overcast	High	High	High	0	0	0	0	0	65	35
Lower	C49.0-L	1	9.0	13.2	130	Partly cloudy	High	High	High	0	0	0	0	0	90	10
Lower	C49.0-L	2	7.0	12.3	130	Clear	High	High	High	0	0	0	0	0	90	10
Lower	C49.0-L	3	8.0	11.4	140	Partly cloudy	High	High	High	0	0	0	0	0	90	10
Lower	C49.0-L	4	8.0	10.6	140	Partly cloudy	High	High	High	0	0	0	0	0	90	10
Lower	C48.2-R	1	10.0	13.0	140	Overcast	High	High	High	0	0	0	10	0	80	10
Lower	C48.2-R	2	9.0	12.6	130	Clear	High	High	High	0	0	0	5	0	80	15
Lower	C48.2-R	3	10.0	12.0	130	Clear	High	High	High	0	0	0	5	0	80	15
Lower	C48.2-R	4	10.0	11.3	130	Overcast	High	High	High	0	0	0	0	0	90	10
Lower	C47.8-L	1	11.0	13.2	130	Partly cloudy	High	High	High	0	0	0	10	0	80	10
Lower	C47.8-L	2	8.0	12.2	140	Clear	High	High	High	0	0	0	10	0	60	30
Lower	C47.8-L	3	10.0	11.4	140	Mostly cloudy	High	High	High	0	0	0	5	0	80	15
Lower	C47.8-L	4	10.0	10.5	140	Mostly cloudy	High	High	High	20	0	0	0	0	40	40
Middle	C36.6-L	1	0.0	13.0	120	Clear	High	High	High	15	0	0	0	0	20	65
Middle	C36.6-L	2	5.0	12.7	130	Clear	High	High	High	15	0	0	1	0	50	34
Middle	C36.6-L	3	0.0	11.6	140	Clear	Medium	High	High	20	0	0	5	0	55	20
Middle	C36.6-L	4	4.0	10.6	140	Overcast	High	High	High	10	0	0	0	0	20	70
Middle	C34.9-L	1	2.0	13.2	120	Clear	High	High	High	10	0	0	0	0	30	60
Middle	C34.9-L	2	7.0	12.8	130	Clear	High	High	High	25	0	0	0	0	30	45
Middle	C34.9-L	3	0.0	12.0	140	Clear	Medium	High	High	25	0	0	0	0	50	25
Middle	C34.9-L	4	4.0	10.7	140	Overcast	High	High	High	15	0	0	0	0	20	65
Middle	C28.2-R	1	3.0	13.3	120	Clear	High	High	High	0	0	0	0	0	90	10
Middle	C28.2-R	2	8.0	12.8	130	Clear	High	High	High	0	0	0	0	0	60	40
Middle	C28.2-R	3	4.0	12.2	140	Clear	High	High	High	0	0	0	0	0	80	20
Middle	C28.2-R	4	6.0	10.6	140	Overcast	High	High	High	0	0	0	0	0	80	20
Middle	C27.6-R	1	7.0	13.2	120	Clear	High	High	High	10	0	0	0	0	60	30
Middle	C27.6-R	2	9.0	12.8	130	Clear	Medium	High	High	20	0	0	0	0	30	50
Middle	C27.6-R	3	8.0	12.2	140	Clear	High	High	High	15	0	0	0	0	30	55
Middle	C27.6-R	4	6.0	10.6	140	Mostly cloudy	High	High	High	10	0	0	0	0	60	30
Middle	C25.3-R	1	8.0	13.3	120	Clear	High	High	High	10	0	0	0	0	30	60
Middle	C25.3-R	2	12.0	12.9	130	Clear	High	High	High	15	0	0	0	0	30	55
Middle	C25.3-R	3	10.0	12.3	130	Clear	High	High	High	10	0	0	0	0	35	55
Middle	C25.3-R	4	9.0	10.6	130	Overcast	High	High	High	15	0	0	0	0	25	60
Upper	C07.4-L	1	8.0	12.5	110	Partly cloudy	High	Low	High	0	0	0	25	0	60	15
Upper	C07.4-L	2	9.0	12.7	120	Clear	High	High	High	0	0	0	25	0	65	10
Upper	C07.4-L	3	10.0	11.9	120	Clear	High	High	High	0	0	0	20	0	65	15
Upper	C07.4-L	4	10.0	10.9	120	Overcast	High	Medium	High	0	0	0	10	0	80	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	C07.3-R	1	6.0	12.9	110	Partly cloudy	High	High	High	20	0	0	0	0	30	50
Upper	C07.3-R	2	5.0	12.9	120	Clear	High	High	High	25	0	0	0	0	40	35
Upper	C07.3-R	3	4.0	12.0	120	Clear	High	High	High	50	0	0	0	0	30	20
Upper	C07.3-R	4	7.0	10.8	120	Mostly cloudy	High	High	High	25	0	0	0	0	50	25
Upper	C05.6-L	1	7.0	13.0	120	Overcast	High	Low	High	0	5	0	80	0	10	5
Upper	C05.6-L	2	1.0	12.7	120	Clear	High	Low	High	10	2	0	55	0	20	13
Upper	C05.6-L	3	-1.0	11.9	120	Clear	Medium	Low	High	0	0	0	35	0	20	45
Upper	C05.6-L	4	9.0	11.3	120	Clear	High	Low	High	0	0	0	25	0	25	50
Upper	C04.6-R	1	7.0	13.0	120	Overcast	Medium	Low	Medium	0	0	0	100	0	0	0
Upper	C04.6-R	2	6.0	12.8	120	Clear	High	Low	High	0	0	0	90	0	10	0
Upper	C04.6-R	3	-1.0	12.1	120	Clear	Medium	Low	High	0	0	0	95	0	5	0
Upper	C04.6-R	4	7.0	11.3	120	Partly cloudy	High	Low	High	0	0	0	90	0	10	0
Upper	C03.6-L	1	8.0	12.9	120	Overcast	Medium	Low	High	0	0	0	65	0	20	15
Upper	C03.6-L	2	7.0	12.8	120	Clear	High	Low	High	0	0	0	55	0	35	10
Upper	C03.6-L	3	0.0	11.9	120	Clear	Medium	Low	High	0	0	0	65	0	20	15
Upper	C03.6-L	4	4.0	11.3	120	Partly cloudy	High	Low	High	5	0	0	65	0	25	5
Upper	C02.8-L	1	8.0	13.0	120	Overcast	High	Low	High	0	0	0	80	0	15	5
Upper	C02.8-L	2	7.0	12.8	120	Clear	High	Low	High	0	0	0	80	0	15	5
Upper	C02.8-L	3	3.0	11.9	120	Clear	High	Low	High	0	0	0	90	0	10	0
Upper	C02.8-L	4	5.0	11.2	120	Partly cloudy	High	Low	High	0	0	0	15	0	80	5
Upper	C01.3-L	1	7.0	13.0	120	Overcast	Medium	Low	High	0	0	0	80	0	15	5
Upper	C01.3-L	2	9.0	12.8	120	Clear	High	Low	High	0	0	0	40	0	50	10
Upper	C01.3-L	3	5.0	11.9	120	Clear	High	Low	High	0	0	0	25	0	50	25
Upper	C01.3-L	4	6.0	11.1	120	Partly cloudy	High	Low	High	0	0	0	5	0	80	15
Upper	C00.7-L	1	12.5	13.0	120	Overcast	High	Low	High	10	0	0	0	0	70	20
Upper	C00.7-L	2	10.0	12.8	120	Clear	High	Low	High	25	0	0	0	0	65	10
Upper	C00.7-L	3	8.0	12.1	120	Clear	High	Low	High	15	0	0	0	0	75	10
Upper	C00.7-L	4	6.0	11.3	120	Partly cloudy	High	Low	High	15	0	0	0	0	70	15
Upper	C00.0-R	1	14.0	13.0	120	Overcast	High	Low	High	20	0	0	0	0	70	10
Upper	C00.0-R	2	11.0	12.8	120	Clear	High	Low	High	15	0	0	0	0	60	25
Upper	C00.0-R	3	9.0	12.0	120	Clear	High	Low	High	10	0	0	0	0	70	20
Upper	C00.0-R	4	6.0	11.3	120	Partly cloudy	High	Low	High	0	0	0	0	0	40	60

[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, 01 October to 31 October 2018.

Section	Site[a]	Species	Bank Habitat Type[a]														Total
			A1	A2	A3	A4	A5	A6	A1+A2	A2+A3	D1	D2	D3	D1+D2	BW	Eddy	
Upstream Columbia River	C00.0-R	Mountain Whitefish		232											52		**284**
	C00.0-R	Peamouth		3													**3**
	C00.0-R	Rainbow Trout		42											15		**57**
	C00.0-R	Redside Shiner		6											52		**58**
	C00.0-R	Sculpin spp.		5											121		**126**
	C00.0-R	Sucker spp.		4											2		**6**
	C00.0-R	Walleye		7											8		**15**
	C00.0-R	White Sturgeon													5		**5**
	Site C00.0-R Total		**0**	**299**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**255**	**0**	**554**
	C00.7-L	Bull Trout									1						**1**
	C00.7-L	Mountain Whitefish		15							159						**174**
	C00.7-L	Northern Pikeminnow		2													**2**
	C00.7-L	Peamouth		2													**2**
	C00.7-L	Rainbow Trout		15							36	1					**52**
	C00.7-L	Redside Shiner		2													**2**
	C00.7-L	Sculpin spp.		5							2						**7**
	C00.7-L	Smallmouth Bass									1						**1**
	C00.7-L	Sucker spp.		7							3						**10**
	C00.7-L	Walleye		6							7						**13**
	C00.7-L	White Sturgeon		1							1						**2**
	Site C00.7-L Total		**0**	**55**	**0**	**0**	**0**	**0**	**0**	**0**	**210**	**1**	**0**	**0**	**0**	**0**	**266**
	C01.3-L	Kokanee	1								2						**3**
	C01.3-L	Mountain Whitefish	67								395						**462**
	C01.3-L	Northern Pikeminnow	6								11						**17**
	C01.3-L	Peamouth									3						**3**
	C01.3-L	Rainbow Trout	39								276						**315**
	C01.3-L	Sculpin spp.									22						**22**
	C01.3-L	Sucker spp.	51								164						**215**
	C01.3-L	Tench									1						**1**
	C01.3-L	Walleye	17								95						**112**
	Site C01.3-L Total		**181**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**969**	**0**	**0**	**0**	**0**	**0**	**1150**
	C02.8-L	Carp spp.									1						**1**
	C02.8-L	Mountain Whitefish									101						**101**
	C02.8-L	Northern Pikeminnow									3						**3**
	C02.8-L	Rainbow Trout									62						**62**
	C02.8-L	Redside Shiner									1						**1**
	C02.8-L	Sculpin spp.									6						**6**
	C02.8-L	Sucker spp.									112						**112**
	C02.8-L	Walleye									29						**29**
	C02.8-L	White Sturgeon									7						**7**
	Site C02.8-L Total		**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**322**	**0**	**0**	**0**	**0**	**0**	**322**
	C03.6-L	Kokanee	1														**1**
	C03.6-L	Lake Whitefish	1								2						**3**
	C03.6-L	Mountain Whitefish	60			4					82						**146**
	C03.6-L	Northern Pikeminnow	11			75					1						**87**
	C03.6-L	Rainbow Trout	95			6					92						**193**
	C03.6-L	Redside Shiner				3											**3**
	C03.6-L	Sculpin spp.	1			71											**72**
	C03.6-L	Sucker spp.	100			8					117						**225**
	C03.6-L	Walleye	52			4					38						**94**
	C03.6-L	White Sturgeon									5						**5**
	Site C03.6-L Total		**321**	**0**	**0**	**171**	**0**	**0**	**0**	**0**	**337**	**0**	**0**	**0**	**0**	**0**	**829**
	C04.6-R	Mountain Whitefish									13						**13**
	C04.6-R	Northern Pikeminnow									3						**3**
	C04.6-R	Rainbow Trout									57						**57**
	C04.6-R	Sculpin spp.									2						**2**
	C04.6-R	Sucker spp.									48						**48**
	C04.6-R	Walleye									37						**37**
	Site C04.6-R Total		**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**160**	**0**	**0**	**0**	**0**	**0**	**160**
	C05.6-L	Mountain Whitefish	17								14						**31**
	C05.6-L	Northern Pikeminnow	42								15						**57**
	C05.6-L	Rainbow Trout	44								30						**74**
	C05.6-L	Redside Shiner	22														**22**
	C05.6-L	Sculpin spp.	281								5						**286**
	C05.6-L	Sucker spp.	43								44						**87**
	C05.6-L	Walleye	34								19						**53**
	Site C05.6-L Total		**483**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**127**	**0**	**0**	**0**	**0**	**0**	**610**
	C07.3-R	Lake Whitefish				2											**2**
	C07.3-R	Mountain Whitefish				212											**212**
	C07.3-R	Rainbow Trout				169											**169**
	C07.3-R	Sculpin spp.				23											**23**
	C07.3-R	Sucker spp.				18											**18**
	C07.3-R	Walleye				39											**39**
	C07.3-R	White Sturgeon				1											**1**
	Site C07.3-R Total		**0**	**0**	**0**	**464**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**464**
	C07.4-L	Kokanee												2			**2**
	C07.4-L	Lake Whitefish												9			**9**
	C07.4-L	Mountain Whitefish												621			**621**
	C07.4-L	Northern Pike												1			**1**
	C07.4-L	Northern Pikeminnow												1			**1**
	C07.4-L	Rainbow Trout												112			**112**
	C07.4-L	Sculpin spp.												1			**1**
	C07.4-L	Sucker spp.												196			**196**
	C07.4-L	Walleye												21			**21**
	C07.4-L	White Sturgeon												14			**14**
	Site C07.4-L Total		**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**978**	**0**	**0**	**978**
Upstream Columbia River Total			**985**	**354**	**0**	**635**	**0**	**0**	**0**	**0**	**2125**	**1**	**0**	**978**	**255**	**0**	**5333**
Kootenay	K00.3-L	Mountain Whitefish								17					3		**20**
	K00.3-L	Rainbow Trout								16					3		**19**
	K00.3-L	Sculpin spp.													5		**5**
	K00.3-L	Sucker spp.								4					1		**5**
	K00.3-L	Walleye								12					2		**14**
	Site K00.3-L Total		**0**	**0**	**0**	**0**	**0**	**0**	**0**	**49**	**0**	**0**	**0**	**0**	**14**	**0**	**63**

[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 Concluded.

Section	Site[a]	Species	A1	A2	A3	A4	A5	A6	A1+A2	A2+A3	D1	D2	D3	D1+D2	BW	Eddy	Total
			Bank Habitat Type[a]														
	K00.6-R	Bull Trout														1	**1**
	K00.6-R	Mountain Whitefish												148		11	**159**
	K00.6-R	Northern Pike														2	**2**
	K00.6-R	Rainbow Trout												48		10	**58**
	K00.6-R	Redside Shiner														1	**1**
	K00.6-R	Sculpin spp.												12		3	**15**
	K00.6-R	Sucker spp.												59		20	**79**
	K00.6-R	Tench														1	**1**
	K00.6-R	Walleye												12		25	**37**
	Site K00.6-R Total		**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**279**	**0**	**74**	**353**
	K01.8-L	Lake Whitefish										1					**1**
	K01.8-L	Mountain Whitefish		111			3					225					**339**
	K01.8-L	Northern Pikeminnow		3			1					4					**8**
	K01.8-L	Peamouth		1													**1**
	K01.8-L	Rainbow Trout		53			4					95					**152**
	K01.8-L	Redside Shiner					9										**9**
	K01.8-L	Sculpin spp.		36								25					**61**
	K01.8-L	Sucker spp.		6			1					88					**95**
	K01.8-L	Walleye		27								41					**68**
	K01.8-L	White Sturgeon		1								7					**8**
	Site K01.8-L Total		**0**	**238**	**0**	**0**	**18**	**0**	**0**	**0**	**0**	**486**	**0**	**0**	**0**	**0**	**742**
	K01.8-R	Lake Whitefish								1							**1**
	K01.8-R	Mountain Whitefish					16			333							**349**
	K01.8-R	Northern Pikeminnow								1							**1**
	K01.8-R	Rainbow Trout					21			101							**122**
	K01.8-R	Redside Shiner					4			10							**14**
	K01.8-R	Sculpin spp.								70							**70**
	K01.8-R	Sucker spp.					1			33							**34**
	K01.8-R	Walleye					1			29							**30**
	K01.8-R	White Sturgeon								5							**5**
	Site K01.8-R Total		**0**	**0**	**0**	**0**	**43**	**0**	**0**	**583**	**0**	**0**	**0**	**0**	**0**	**0**	**626**
Kootenay Total			**0**	**238**	**0**	**0**	**61**	**0**	**0**	**632**	**0**	**486**	**0**	**279**	**14**	**74**	**1784**
Downstream Columbia River	C25.3-R	Kokanee	1														**1**
	C25.3-R	Northern Pikeminnow	1														**1**
	C25.3-R	Lake Whitefish	5							6							**11**
	C25.3-R	Sucker spp.	5				2			6							**13**
	C25.3-R	Walleye	13				9			16							**38**
	C25.3-R	Mountain Whitefish	26				1			81							**108**
	C25.3-R	Rainbow Trout	99				6			78							**183**
	C25.3-R	Sculpin spp.	155							2							**157**
	C25.3-R	Redside Shiner	254														**254**
	Site C25.3-R Total		**559**	**0**	**0**	**0**	**18**	**0**	**0**	**189**	**0**	**0**	**0**	**0**	**0**	**0**	**766**
	C27.6-R	Mountain Whitefish					1			18		20					**39**
	C27.6-R	Rainbow Trout					6			34		13					**53**
	C27.6-R	Sculpin spp.					2			2							**4**
	C27.6-R	Sucker spp.								2							**2**
	C27.6-R	Walleye					1			4		2					**7**
	Site C27.6-R Total		**0**	**0**	**0**	**0**	**10**	**0**	**0**	**60**	**0**	**35**	**0**	**0**	**0**	**0**	**105**
	C28.2-R	Lake Whitefish		1													**1**
	C28.2-R	Mountain Whitefish		47													**47**
	C28.2-R	Rainbow Trout		164													**164**
	C28.2-R	Sculpin spp.		56													**56**
	C28.2-R	Smallmouth Bass		1													**1**
	C28.2-R	Sucker spp.		14													**14**
	C28.2-R	Walleye		23													**23**
	Site C28.2-R Total		**0**	**306**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**306**
	C34.9-L	Mountain Whitefish		56	10												**66**
	C34.9-L	Rainbow Trout		280	84												**364**
	C34.9-L	Redside Shiner		5													**5**
	C34.9-L	Sculpin spp.		120	20												**140**
	C34.9-L	Sucker spp.		4	4												**8**
	C34.9-L	Walleye		17	5												**22**
	C34.9-L	White Sturgeon		1													**1**
	Site C34.9-L Total		**0**	**483**	**123**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**606**
	C36.6-L	Lake Whitefish											4				**4**
	C36.6-L	Mountain Whitefish					7			49			25				**81**
	C36.6-L	Northern Pikeminnow								1							**1**
	C36.6-L	Rainbow Trout					127			159			11				**297**
	C36.6-L	Redside Shiner					4										**4**
	C36.6-L	Sculpin spp.					12			82							**94**
	C36.6-L	Sucker spp.					1			1							**2**
	C36.6-L	Walleye					12			13			3				**28**
	Site C36.6-L Total		**0**	**0**	**0**	**0**	**163**	**0**	**0**	**305**	**0**	**0**	**43**	**0**	**0**	**0**	**511**
	C47.8-L	Brook Trout									1						**1**
	C47.8-L	Brown Trout									1						**1**
	C47.8-L	Lake Whitefish							1		5						**6**
	C47.8-L	Mountain Whitefish							11		24						**35**
	C47.8-L	Northern Pikeminnow							1								**1**
	C47.8-L	Rainbow Trout							132		169						**301**
	C47.8-L	Sculpin spp.							67		12						**79**
	C47.8-L	Sucker spp.							11		33						**44**
	C47.8-L	Tench									1						**1**
	C47.8-L	Walleye							25		31						**56**
	C47.8-L	Yellow Perch									1						**1**
	Site C47.8-L Total		**0**	**0**	**0**	**0**	**0**	**0**	**248**	**0**	**278**	**0**	**0**	**0**	**0**	**0**	**526**
	C48.2-R	Lake Whitefish												5			**5**
	C48.2-R	Mountain Whitefish												31	5		**36**
	C48.2-R	Rainbow Trout												69	68		**137**
	C48.2-R	Walleye												29	24		**53**
	Site C48.2-R Total		**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**134**	**97**	**0**	**231**
	C49.0-L	Burbot		2													**2**
	C49.0-L	Lake Whitefish		4													**4**
	C49.0-L	Mountain Whitefish		80								8					**88**
	C49.0-L	Rainbow Trout		45								72					**117**
	C49.0-L	Redside Shiner										1					**1**
	C49.0-L	Sculpin spp.		60								27					**87**
	C49.0-L	Sucker spp.		21								1					**22**
	C49.0-L	Walleye		3								7					**10**
	Site C49.0-L Total		**0**	**215**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**116**	**0**	**0**	**0**	**0**	**331**

[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 Concluded.

Section	Site[a]	Species	Bank Habitat Type[a]														Total
			A1	A2	A3	A4	A5	A6	A1+A2	A2+A3	D1	D2	D3	D1+D2	BW	Eddy	
	C49.0-R	Brown Trout							1								**1**
	C49.0-R	Lake Whitefish												4			**4**
	C49.0-R	Mountain Whitefish							1			1		21			**23**
	C49.0-R	Rainbow Trout		2					26			1		52			**81**
	C49.0-R	Redside Shiner												1			**1**
	C49.0-R	Sculpin spp.							5					40			**45**
	C49.0-R	Sucker spp.							1					2			**3**
	C49.0-R	Walleye							11					8			**19**
	C49.0-R	White Sturgeon												1			**1**
	Site C49.0-R Total		**0**	**2**	**0**	**0**	**0**	**0**	**45**	**0**	**0**	**2**	**0**	**129**	**0**	**0**	**178**
	C49.8-L	Burbot		1													**1**
	C49.8-L	Lake Whitefish		5													**5**
	C49.8-L	Mountain Whitefish		139													**139**
	C49.8-L	Rainbow Trout		341													**341**
	C49.8-L	Sculpin spp.		510													**510**
	C49.8-L	Sucker spp.		15													**15**
	C49.8-L	Walleye		56													**56**
	Site C49.8-L Total		**0**	**1067**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1067**
	C49.8-R	Burbot		1								1					**2**
	C49.8-R	Mountain Whitefish		105								12			4		**121**
	C49.8-R	Rainbow Trout		101								49			66		**216**
	C49.8-R	Sculpin spp.		130								5			10		**145**
	C49.8-R	Sucker spp.		21								2			8		**31**
	C49.8-R	Walleye		19								15			17		**51**
	Site C49.8-R Total		**0**	**377**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**84**	**0**	**0**	**105**	**0**	**566**
	C52.2-L	Brown Trout														1	**1**
	C52.2-L	Burbot										1					**1**
	C52.2-L	Lake Whitefish										3					**3**
	C52.2-L	Mountain Whitefish										24				1	**25**
	C52.2-L	Northern Pikeminnow														1	**1**
	C52.2-L	Rainbow Trout										9				84	**93**
	C52.2-L	Sucker spp.										4					**4**
	C52.2-L	Walleye										2				15	**17**
	Site C52.2-L Total		**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**43**	**0**	**0**	**0**	**102**	**145**
	C52.2-R	Brown Trout		1													**1**
	C52.2-R	Burbot		3													**3**
	C52.2-R	Lake Whitefish		22												3	**25**
	C52.2-R	Mountain Whitefish		91													**91**
	C52.2-R	Rainbow Trout		165												107	**272**
	C52.2-R	Sculpin spp.		5													**5**
	C52.2-R	Sucker spp.		11												4	**15**
	C52.2-R	Walleye		38												9	**47**
	Site C52.2-R Total		**0**	**336**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**123**	**459**
	C52.8-L	Burbot		1		1											**2**
	C52.8-L	Lake Whitefish		1		3											**4**
	C52.8-L	Mountain Whitefish		1		17											**18**
	C52.8-L	Northern Pikeminnow		1													**1**
	C52.8-L	Rainbow Trout		7		90											**97**
	C52.8-L	Walleye		4		30											**34**
	Site C52.8-L Total		**0**	**15**	**0**	**141**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**156**
	C53.6-L	Burbot						2									**2**
	C53.6-L	Lake Whitefish						2									**2**
	C53.6-L	Mountain Whitefish						10									**10**
	C53.6-L	Rainbow Trout						83									**83**
	C53.6-L	Smallmouth Bass						1									**1**
	C53.6-L	Walleye						33									**33**
	Site C53.6-L Total		**0**	**0**	**0**	**0**	**0**	**131**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**131**
Downstream Columbia River Total			**559**	**2801**	**123**	**141**	**191**	**131**	**293**	**554**	**278**	**280**	**43**	**263**	**202**	**225**	**6084**
Grand Total			**1544**	**3393**	**123**	**776**	**252**	**131**	**293**	**1186**	**2403**	**767**	**43**	**1520**	**471**	**299**	**13201**

[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 Analysis 2018

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 data were prepared for analysis using R version 3.5.3 (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 $\pm$ 1.96 $\cdot$ 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 3.5.3 (R Core Team 2018) and the mbr family of packages.

Model Code

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]] + (bWeightLength + 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 ~ dunif(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)]) * eEfficiency[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(0, 5^-2)

```

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

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

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

    eFidelity[i] ~ dnorm(Fidelity[i], FidelitySD[i]^-2) T(FidelityLower[i], F
idelityUpper[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
  for (i in 2:nVisitType) {
    bEfficiencyVisitType[i] ~ dnorm(0, 2^-2)
  }

  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[Ann
ual[i]] + bDensitySiteAnnual[Site[i],Annual[i]]

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

    logit(eEfficiency[i]) <- logit(Efficiency[i]) + bEfficiencyVisitType[Visi
tType[i]]

    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.

Stock-Recruitment

```
.model {

  bAlpha ~ dnorm(1, 2^-2) T(log(1), log(5))
  bBeta ~ dnorm(-10, 5^-2)
  bEggLoss ~ dnorm(0, 2^-2)

  sRecruits ~ dnorm(0, 1^-2) T(0,)
  for(i in 1:length(Stock)){
    log(eAlpha[i]) <- bAlpha
    log(eBeta[i]) <- bBeta
    eLogRecruits[i] <- log((eAlpha[i] * Stock[i]) / (1 + eBeta[i] * Stock[i])
) + bEggLoss * EggLoss[i]
    Recruits[i] ~ dlnorm(eLogRecruits[i], sRecruits^-2)
  }
..
```

Block 7.

Age-Ratios

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

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

```
  }
..
```

Block 8.

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	5.4481708	0.0099010	550.217864	5.4277038	5.4674031	0.0007
bWeightDayte	-0.0176867	0.0018633	-9.517441	-0.0213734	-0.0141445	0.0007
bWeightLength	3.1579282	0.0233766	135.080079	3.1093590	3.2040653	0.0007
bWeightLengthDayte	-0.0122878	0.0050029	-2.457204	-0.0221361	-0.0026500	0.0093
sWeight	-1.9095091	0.0060218	-317.076006	-1.9208347	-1.8977600	0.0007
sWeightLengthYear	-2.2657732	0.1913599	-11.805313	-2.6206595	-1.8801177	0.0007
sWeightYear	-3.1215164	0.1734585	-17.942536	-3.4339287	-2.7488788	0.0007

Table 3. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged

14178	7	3	500	2	393	1.011	TRUE

Rainbow Trout

Table 4. Model coefficients.

term	estimate	sd	zscore	lower	upper	pvalue
bWeight	5.9948771	0.0062049	966.160917	5.9819110	6.0072682	7e-04
bWeightDayte	-0.0044249	0.0012834	-3.475668	-0.0069787	-0.0019914	7e-04
bWeightLength	2.9215460	0.0125398	232.960088	2.8962627	2.9453204	7e-04
bWeightLengthDayte	0.0377059	0.0038700	9.744408	0.0301796	0.0451479	7e-04
sWeight	-2.2655650	0.0058125	-389.785952	-2.2774300	-2.2545811	7e-04
sWeightLengthYear	-2.9060607	0.1892851	-15.342687	-3.2594914	-2.5229922	7e-04
sWeightYear	-3.6317633	0.1684327	-21.507633	-3.9415447	-3.2894396	7e-04

Table 5. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
14589	7	3	500	2	374	1.009	TRUE

Walleye

Table 6. Model coefficients.

term	estimate	sd	zscore	lower	upper	pvalue
bWeight	6.2919286	0.0080132	785.139922	6.2739150	6.3064459	0.0007
bWeightDayte	0.0161593	0.0014148	11.389367	0.0134151	0.0188725	0.0007
bWeightLength	3.2304215	0.0191397	168.779806	3.1904598	3.2675943	0.0007
bWeightLengthDayte	-0.0107375	0.0083310	-1.277545	-0.0272052	0.0058224	0.1947
sWeight	-2.3681131	0.0073079	-324.012600	-2.3819666	-2.3535583	0.0007
sWeightLengthYear	-2.5323101	0.1992700	-12.680344	-2.8975376	-2.1164227	0.0007
sWeightYear	-3.3305458	0.1668623	-19.908489	-3.6302314	-2.9748845	0.0007

Table 7. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
9205	7	3	500	2	393	1.014	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	-0.9259595	0.1086078	-8.559326	-1.149029	-0.7297757	7e-04
bLinf	392.6903086	3.2148232	122.202222	386.888094	399.3993119	7e-04
sGrowth	2.4601904	0.0443263	55.511488	2.377194	2.5493541	7e-04
sKYear	-1.0848023	0.2570075	-4.222173	-1.557970	-0.5837363	7e-04

Table 10. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
259	4	3	500	20	543	1.013	TRUE

Rainbow Trout

Table 11. Model coefficients.

term	estimate	sd	zscore	lower	upper	pvalue
bK	-0.1744708	0.0762919	-2.306990	-0.3307308	-0.0225079	2e-02
bLinf	487.0687845	2.7075093	179.890601	481.9086684	492.4080715	7e-04
sGrowth	3.3811271	0.0206856	163.459867	3.3411191	3.4218987	7e-04
sKYear	-1.2416744	0.1924957	-6.405807	-1.5677043	-0.8305064	7e-04

Table 12. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
1158	4	3	500	20	400	1.011	TRUE

Walleye

Table 13. Model coefficients.

term	estimate	sd	zscore	lower	upper	pvalue
bK	-2.539502	0.2502549	-10.147884	-3.001751	-2.0618755	7e-04
bLinf	754.315450	84.3008026	9.083864	628.631688	949.4953241	7e-04
sGrowth	2.866226	0.0460119	62.295651	2.778109	2.9608715	7e-04
sKYear	-1.157805	0.2545813	-4.530802	-1.636968	-0.6447953	7e-04

Table 14. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
263	4	3	500	40	222	1.006	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	-0.1552880	0.1792936	-0.8567948	-0.4959377	0.1981948	0.388
bLength	-0.1105809	0.1946158	-0.5319073	-0.4760564	0.2944789	0.592

Table 17. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
117	2	3	500	1	847	1.002	TRUE

Rainbow Trout

Table 18. Model coefficients.

term	estimate	sd	zscore	lower	upper	pvalue
bFidelity	0.7654122	0.0796299	9.626364	0.6143531	0.9178480	7e-04
bLength	-0.3300007	0.0769163	-4.272205	-0.4739996	-0.1766411	7e-04

Table 19. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
756	2	3	500	1	774	1.001	TRUE

Walleye

Table 20. Model coefficients.

term	estimate	sd	zscore	lower	upper	pvalue
bFidelity	0.7258183	0.1486066	4.9023664	0.4342957	1.0092428	0.0007
bLength	-0.0188939	0.1390122	-0.1504418	-0.2987952	0.2483826	0.8800

Table 21. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
220	2	3	500	1	942	1.003	TRUE

Length-At-Age

Mountain Whitefish

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

Year	Age0	Age1	Age2
1990	163	275	NA
1991	144	226	296
2001	141	257	344
2002	163	260	343
2003	159	263	353
2004	158	249	342
2005	168	263	362
2006	175	284	357
2007	171	279	337
2008	170	248	341
2009	169	265	355
2010	177	272	353
2011	163	269	349
2012	162	268	347
2013	185	282	350
2014	178	283	362
2015	167	278	366
2016	165	283	352
2017	158	269	354
2018	177	262	346

Rainbow Trout

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

Year	Age0	Age1
1990	155	358
1991	127	342
2001	133	324
2002	155	349
2003	161	342
2004	142	332
2005	164	346

2006	170	364
2007	166	375
2008	146	339
2009	147	338
2010	143	337
2011	156	343
2012	152	344
2013	169	354
2014	154	337
2015	167	334
2016	154	336
2017	133	316
2018	139	306

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	-4.1804013	0.1042621	-40.087541	-4.3845229	-3.9700036	0.0007
bEfficiencySampledLength	0.3721012	0.1235324	3.044773	0.1361591	0.6260196	0.0027
bSurvival	0.8463913	0.4231537	2.100816	0.1262261	1.8068358	0.0253
sSurvivalYear	0.2442526	0.3452415	0.739245	-0.4118839	0.9193125	0.4587

Table 26. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
17	4	3	500	100	1052	1.005	TRUE

Rainbow Trout

Table 27. Model coefficients.

term	estimate	sd	zscore	lower	upper	pvalue
bEfficiency	-2.5293162	0.0910345	-27.7736502	-2.7044300	-2.3480069	0.0007
bEfficiencySampledLength	0.0111727	0.0715640	0.1401614	-0.1288650	0.1565815	0.8907
bSurvival	-0.4348034	0.1118249	-3.8860616	-0.6559384	-0.2061208	0.0007
sSurvivalYear	-1.2570805	1.0270840	-1.4226367	-4.9922516	-0.6119388	0.0007

Table 28. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
17	4	3	500	100	261	1.017	TRUE

Walleye

Table 29. Model coefficients.

term	estimate	sd	zscore	lower	upper	pvalue
bEfficiency	-3.3757879	0.1030395	-32.8019436	-3.5811971	-3.1708020	0.0007
bEfficiencySampledLength	0.0587105	0.0826296	0.7621854	-0.0929374	0.2316543	0.4440
bSurvival	0.0628850	0.1358752	0.5602158	-0.1683843	0.3885211	0.5440
sSurvivalYear	-1.0997005	1.9896128	-0.9160875	-8.2747079	-0.2785067	0.0040

Table 30. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
17	4	3	500	200	285	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`	Log SD of effect of `Session` within `Annual` on `logit(eEfficiency)`
`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	-4.9972025	0.2168087	-23.144160	-5.50063	-4.6570936	0.0007
sEfficiencySessionAnnual	-0.9461967	1.1534489	-1.110064	-4.39114	0.0966403	0.0907

Table 33. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
1359	2	3	500	100	172	1.011	TRUE

Adult

Table 34. Model coefficients.

term	estimate	sd	zscore	lower	upper	pvalue
bEfficiency	-5.254932	0.1430929	-36.755286	-5.550742	-4.9969882	7e-04
sEfficiencySessionAnnual	-2.049795	1.1473121	-1.939951	-5.029096	-0.5983976	7e-04

Table 35. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
1545	2	3	500	200	356	1.01	TRUE

Rainbow Trout

Subadult

Table 36. Model coefficients.

term	estimate	sd	zscore	lower	upper	pvalue
bEfficiency	-3.3923810	0.0654085	-51.880249	-3.524317	-3.2695877	7e-04
sEfficiencySessionAnnual	-0.9259046	0.1647731	-5.624789	-1.263903	-0.6153031	7e-04

Table 37. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
1558	2	3	500	100	1214	1.005	TRUE

Adult

Table 38. Model coefficients.

term	estimate	sd	zscore	lower	upper	pvalue
bEfficiency	-4.019309	0.0710880	-56.58399	-4.162507	-3.8854350	7e-04
sEfficiencySessionAnnual	-1.805271	0.8881719	-2.28053	-4.395410	-0.9157114	7e-04

Table 39. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
1629	2	3	500	100	244	1.009	TRUE

Walleye

Table 40. Model coefficients.

term	estimate	sd	zscore	lower	upper	pvalue
bEfficiency	-4.5702137	0.1218943	-37.523799	-4.8186384	-4.3526356	0.0007
sEfficiencySessionAnnual	-0.5577893	0.2079586	-2.704928	-0.9992889	-0.1707303	0.0013

Table 41. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
1673	2	3	500	100	1191	1.004	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	5.4406580	0.1874181	29.013274	5.0405099	5.7930340	0.0007
bEfficiencyVisitType2	1.4556995	0.0806910	18.040699	1.2955386	1.6214112	0.0007
sDensityAnnual	-0.3775397	0.1736743	-2.125087	-0.6879389	-0.0297508	0.0387
sDensitySite	-0.2804839	0.1087247	-2.544630	-0.4863189	-0.0637620	0.0120
sDensitySiteAnnual	-0.8244691	0.0611086	-13.458192	-0.9419095	-0.7030915	0.0007
sDispersion	-0.7661634	0.0449215	-17.069776	-0.8547301	-0.6842493	0.0007
sDispersionVisitType2	0.6067664	0.0927844	6.551051	0.4258833	0.7808791	0.0007

Table 44. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
2551	7	3	500	200	242	1.009	TRUE

Adult

Table 45. Model coefficients.

term	estimate	sd	zscore	lower	upper	pvalue
bDensity	6.3926287	0.1626779	39.271714	6.0770985	6.7111804	0.0007
bEfficiencyVisitType2	1.7286939	0.0804946	21.492578	1.5693144	1.8887179	0.0007
sDensityAnnual	-1.0772117	0.1991107	-5.379547	-1.4486766	-0.6795237	0.0007
sDensitySite	0.1034875	0.0951208	1.059008	-0.0796085	0.2881605	0.2853
sDensitySiteAnnual	-0.9089343	0.0653335	-13.926549	-1.0397152	-0.7879970	0.0007
sDispersion	-0.6528188	0.0346453	-18.859430	-0.7171653	-0.5855589	0.0007
sDispersionVisitType2	0.4805907	0.0803911	5.973736	0.3199828	0.6406288	0.0007

Table 46. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
2551	7	3	500	200	285	1.008	TRUE

Rainbow Trout

Subadult

Table 47. Model coefficients.

term	estimate	sd	zscore	lower	upper	pvalue
bDensity	4.8366559	0.1161441	41.651809	4.6119463	5.0539153	7e-04
bEfficiencyVisitType 2	1.4215737	0.0776402	18.346412	1.2804333	1.5847675	7e-04
sDensityAnnual	-1.1758941	0.2012193	-5.774457	-1.5226979	-0.7263475	7e-04
sDensitySite	-0.3802453	0.0972301	-3.875574	-0.5617739	-0.1774587	7e-04
sDensitySiteAnnual	-0.8930931	0.0557025	-16.052414	-1.0040788	-0.7882411	7e-04
sDispersion	-0.9650807	0.0398708	-24.228399	-1.0473340	-0.8914979	7e-04
sDispersionVisitType 2	0.6569666	0.0897573	7.266721	0.4830828	0.8315600	7e-04

Table 48. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
2551	7	3	500	200	494	1.008	TRUE

Adult

Table 49. Model coefficients.

term	estimate	sd	zscore	lower	upper	pvalue
bDensity	5.4942462	0.1140338	48.164683	5.2728280	5.7120537	7e-04
bEfficiencyVisitType 2	1.2869357	0.0602682	21.380955	1.1664900	1.4055163	7e-04
sDensityAnnual	-1.0927513	0.1848807	-5.862344	-1.4319721	-0.7008315	7e-04
sDensitySite	-0.4651834	0.0931610	-4.958562	-0.6378218	-0.2822007	7e-04
sDensitySiteAnnual	-1.2089195	0.0693396	-17.453081	-1.3503149	-1.0796723	7e-04
sDispersion	-1.0166974	0.0437112	-23.290154	-1.1051124	-0.9356607	7e-04
sDispersionVisitType 2	0.5491976	0.0927775	5.949737	0.3708907	0.7335595	7e-04

Table 50. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
2551	7	3	500	200	538	1.006	TRUE

Walleye

Table 51. Model coefficients.

term	estimate	sd	zscore	lower	upper	pvalue
bDensity	5.4321978	0.1158070	46.940936	5.2043312	5.6606843	7e-04

bEfficiencyVisitType2	1.1735932	0.0756155	15.543691	1.0203961	1.3285330	7e-04
sDensityAnnual	-0.8466866	0.1806938	-4.642299	-1.1679495	-0.4744504	7e-04
sDensitySite	-1.0459901	0.1388762	-7.514605	-1.3137513	-0.7765578	7e-04
sDensitySiteAnnual	-1.3244656	0.0846409	-15.702992	-1.5117795	-1.1702710	7e-04
sDispersion	-0.8224011	0.0390031	-21.050567	-0.8956316	-0.7446447	7e-04
sDispersionVisitType2	0.5073740	0.0931255	5.432866	0.3154596	0.6789489	7e-04

Table 52. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
2551	7	3	500	200	682	1.008	TRUE

Stock-Recruitment

Table 53. Parameter descriptions.

Parameter	Description
`bAlpha`	Intercept for `log(eAlpha)`
`bBeta`	Intercept for `log(eBeta)`
`bEggLoss`	Effect of `EggLoss` on `bBeta`
`eAlpha`	`eRecruits` per `Stock` at low `Stock` density
`eBeta`	Expected density-dependence
`EggLoss`	Calculated proportional egg loss
`eRecruits`	Expected `Recruits`
`Recruits`	Number of Age-1 recruits
`sRecruits`	Log SD of residual variation in `Recruits`
`Stock`	Number of Age-2+ spawners

Mountain Whitefish

Table 54. Model coefficients.

term	estimate	sd	zscore	lower	upper	pvalue
bAlpha	0.9003438	0.4528069	1.9298312	0.0575934	1.5750652	0.0007
bBeta	-9.6517720	0.5478618	-17.7067921	-10.7832662	-8.8115021	0.0007
bEggLoss	-0.1312203	0.1693046	-0.7867717	-0.4716888	0.2092525	0.4187
sRecruits	0.6146288	0.1334134	4.7609870	0.4290761	0.9387169	0.0007

Table 55. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
16	4	3	500	50	1262	1.002	TRUE

Rainbow Trout

Table 56. Model coefficients.

term	estimate	sd	zscore	lower	upper	pvalue
bAlpha	1.0563379	0.3949465	2.567620	0.1819702	1.5837393	0.0007
bBeta	-9.1223234	0.5321613	-17.294711	-10.4142573	-8.4729122	0.0007
bEggLoss	0.1661576	0.0742890	2.248995	0.0252849	0.3241453	0.0280
sRecruits	0.2746352	0.0594218	4.793799	0.1976847	0.4334546	0.0007

Table 57. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
17	4	3	500	50	532	1.006	TRUE

Age-Ratios

Table 58. 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

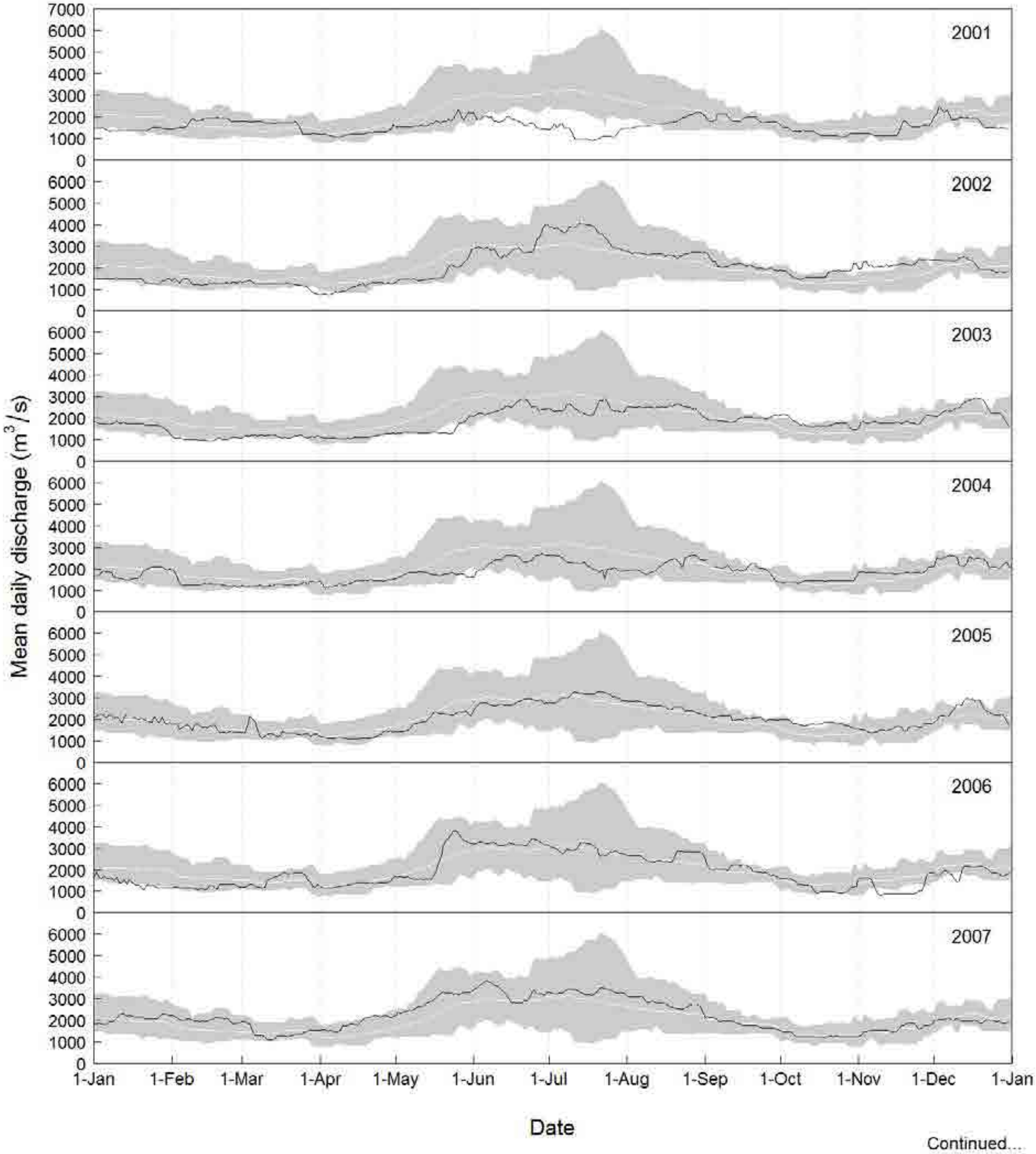
Table 59. Model coefficients.

term	estimate	sd	zscore	lower	upper	pvalue
bProbAge1	0.2409373	0.2021096	1.155502	-0.1779642	0.6160426	0.2400
bProbAge1Loss	-0.3070399	0.2870403	-1.052766	-0.8735155	0.2271430	0.2920
sProbAge1	0.8203105	0.1706548	4.943255	0.5839656	1.2571520	0.0007

Table 60. Model summary.

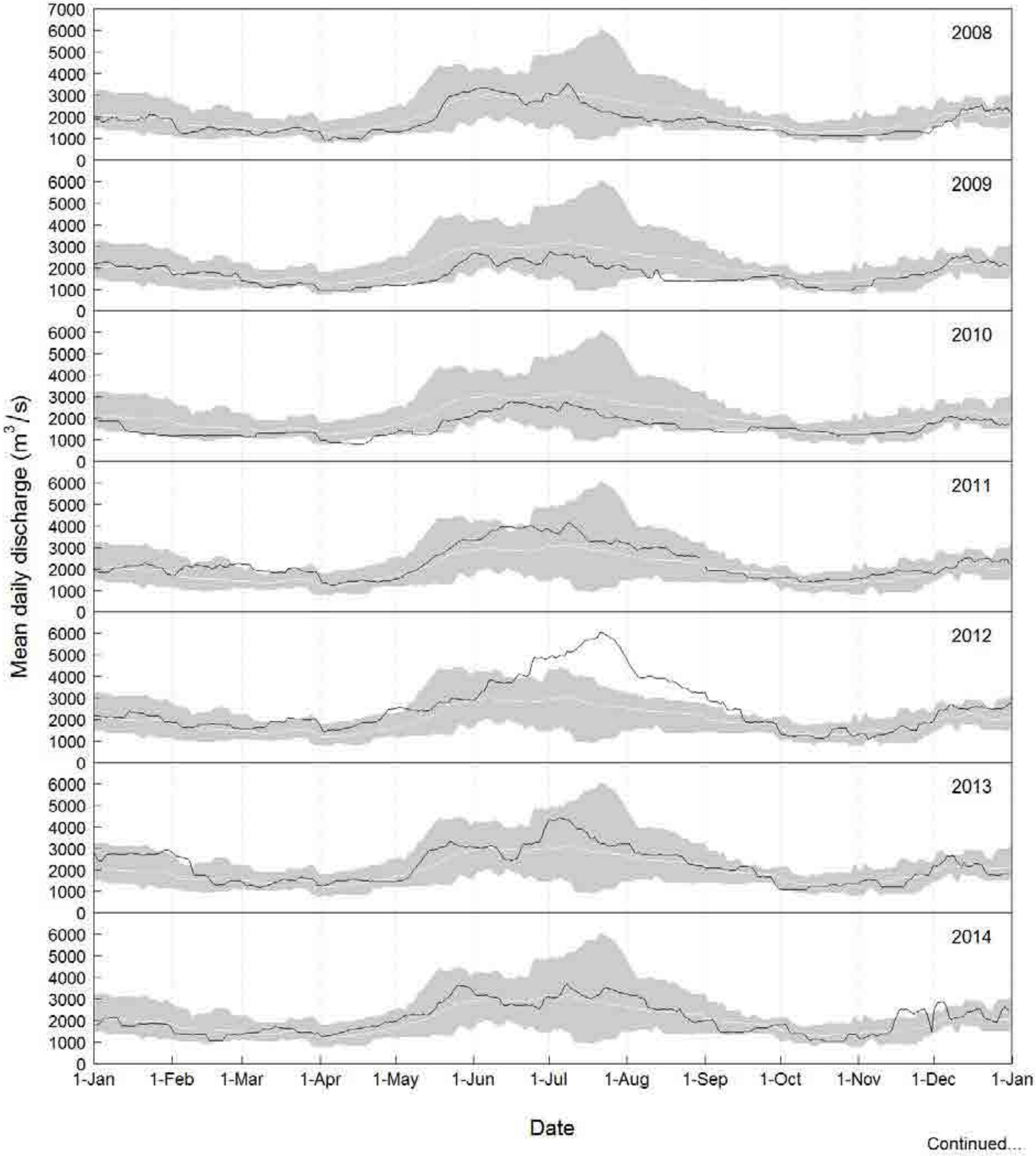
n	K	nchains	niters	nthin	ess	rhat	converged
18	3	3	500	1	668	1.006	TRUE

Appendix D – Discharge, Temperature, and Elevation Data



Continued...

Figure D1. Mean daily discharge (m³/s) for the Columbia River at the Birchbank water gauging station (black line), 2001 to 2018. The shaded area represents minimum and maximum mean daily discharge recorded at Birchbank during other study years between 2001 and 2018. The white line represents average mean daily discharge over the same time period.



Continued...

Figure D1. Continued.

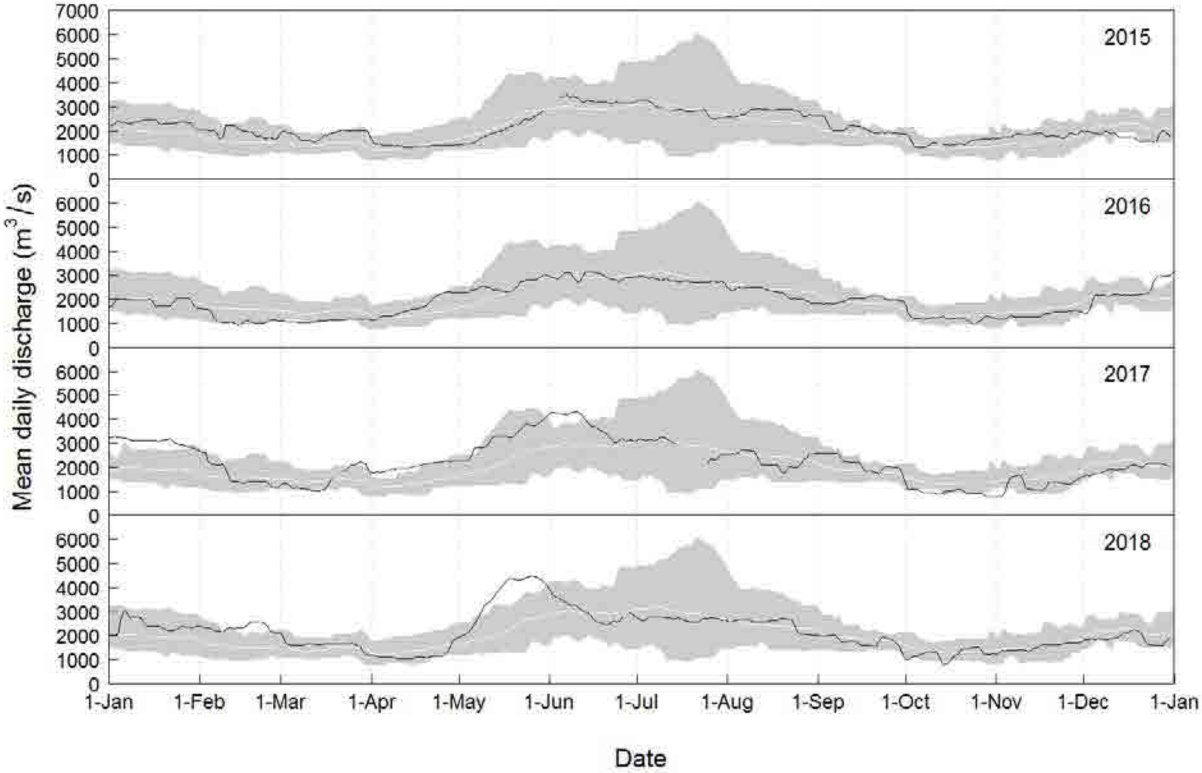
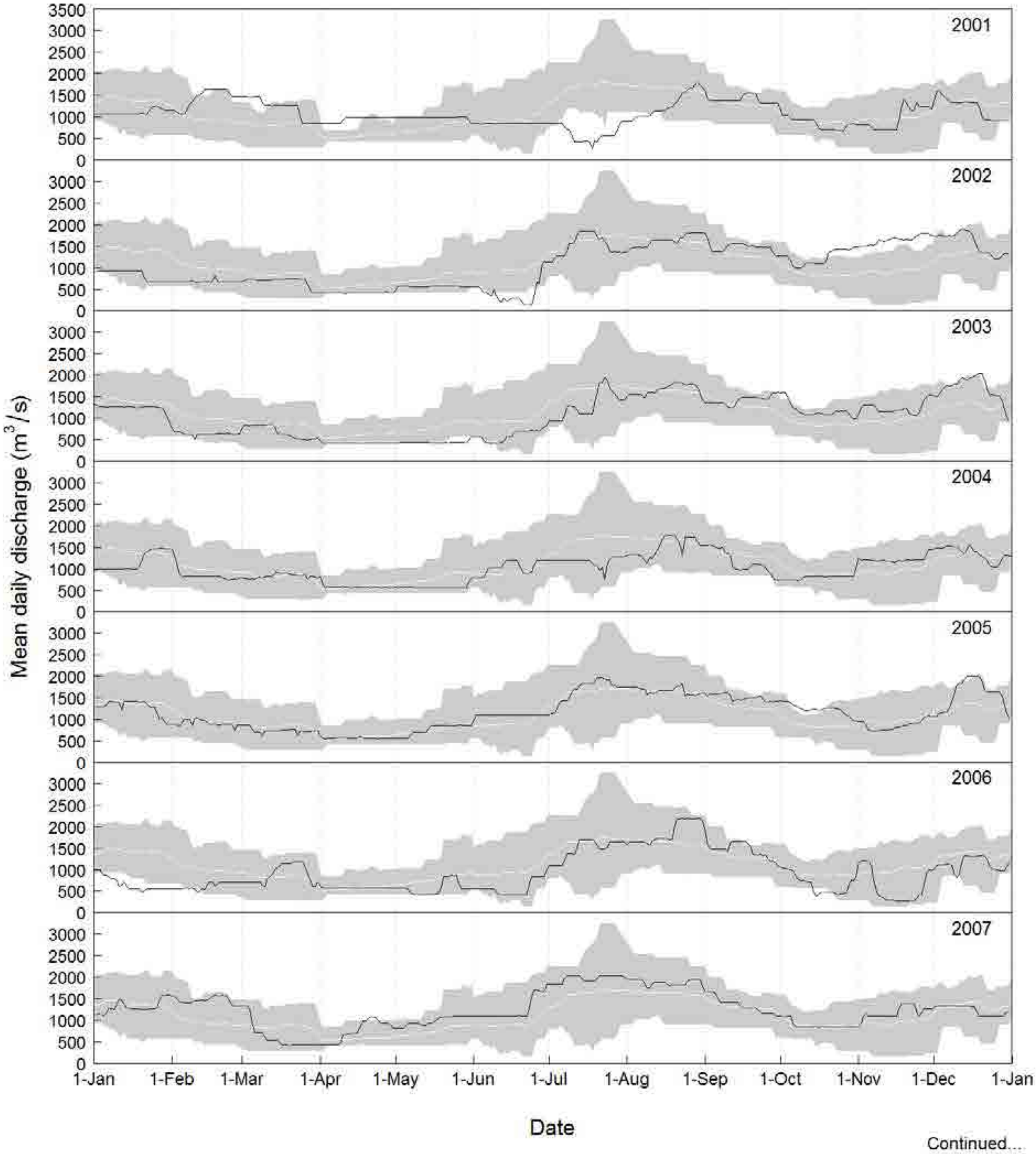
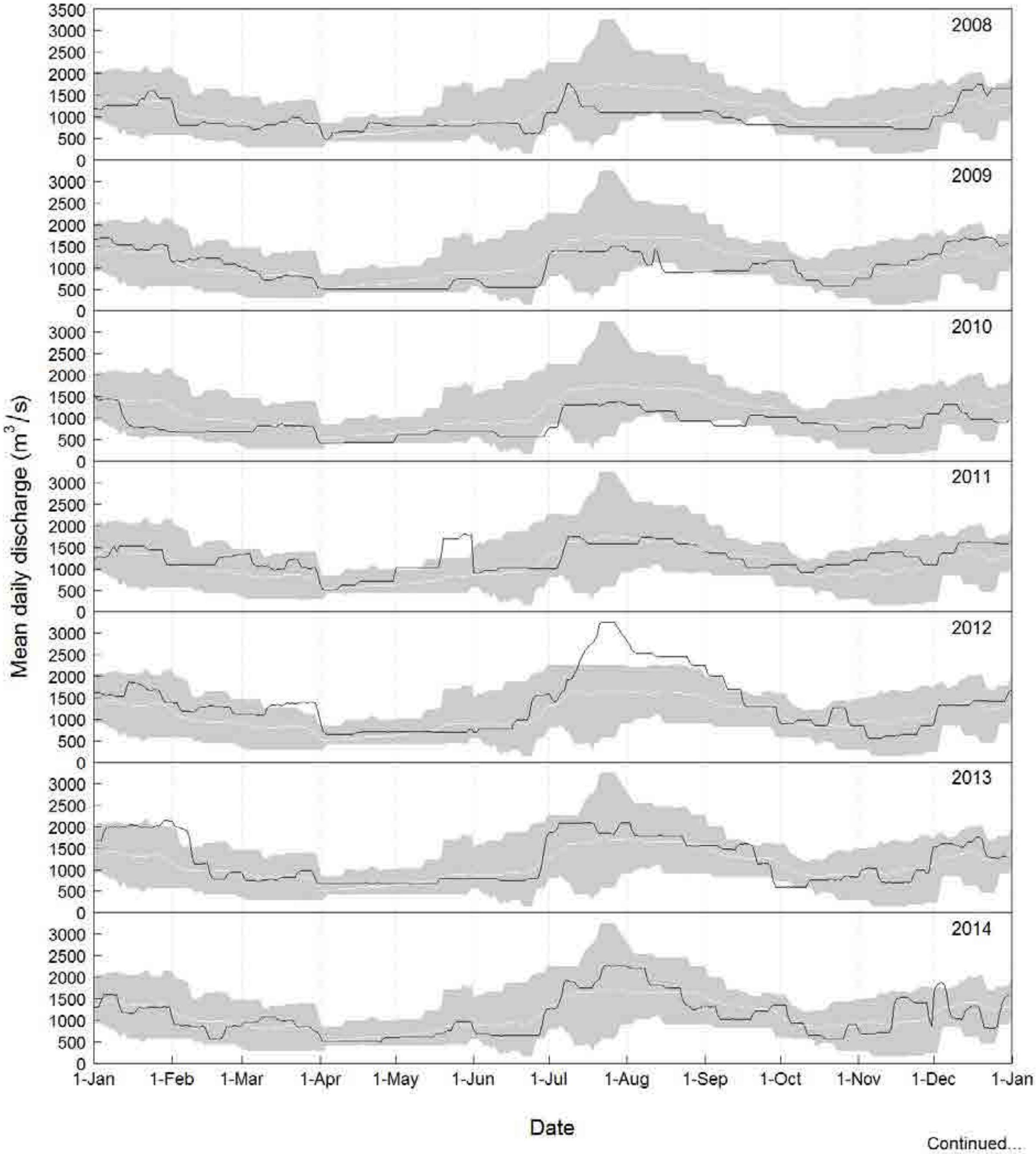


Figure D1. Concluded.



Continued...

Figure D2. Mean daily discharge (m³/s) for the Columbia River at Hugh L. Keenleyside Dam (HLK), 2001 to 2018 (black line). The shaded area represents minimum and maximum mean daily discharge recorded at HLK during other study years between 2001 and 2018. The white line represents average mean daily discharge over the same time period.



Continued...

Figure D2. Continued.

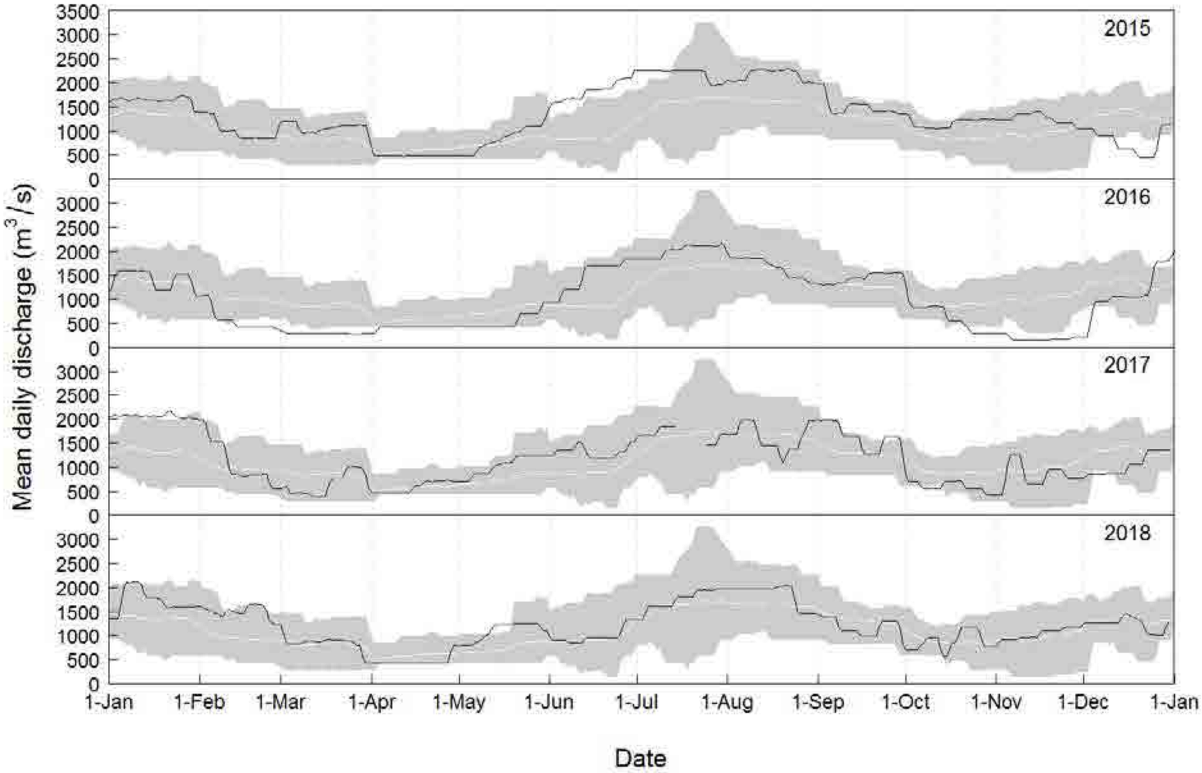
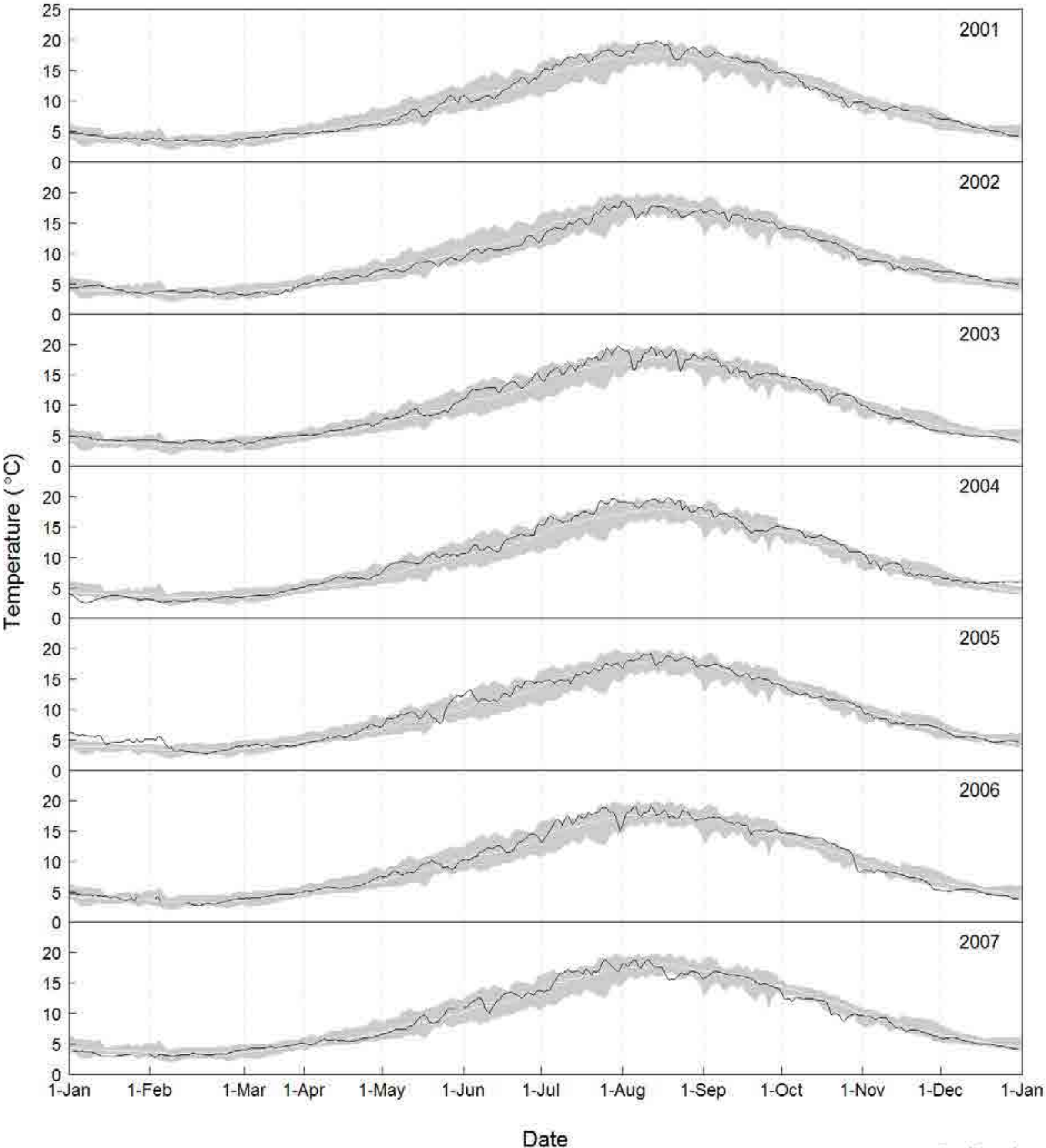


Figure D2. Concluded.



Continued...

Figure D3. Mean daily water temperatures (°C) for the Columbia River (black line), 2001 to 2018. 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 2018. The white line represents average mean daily water temperature over the same time period.

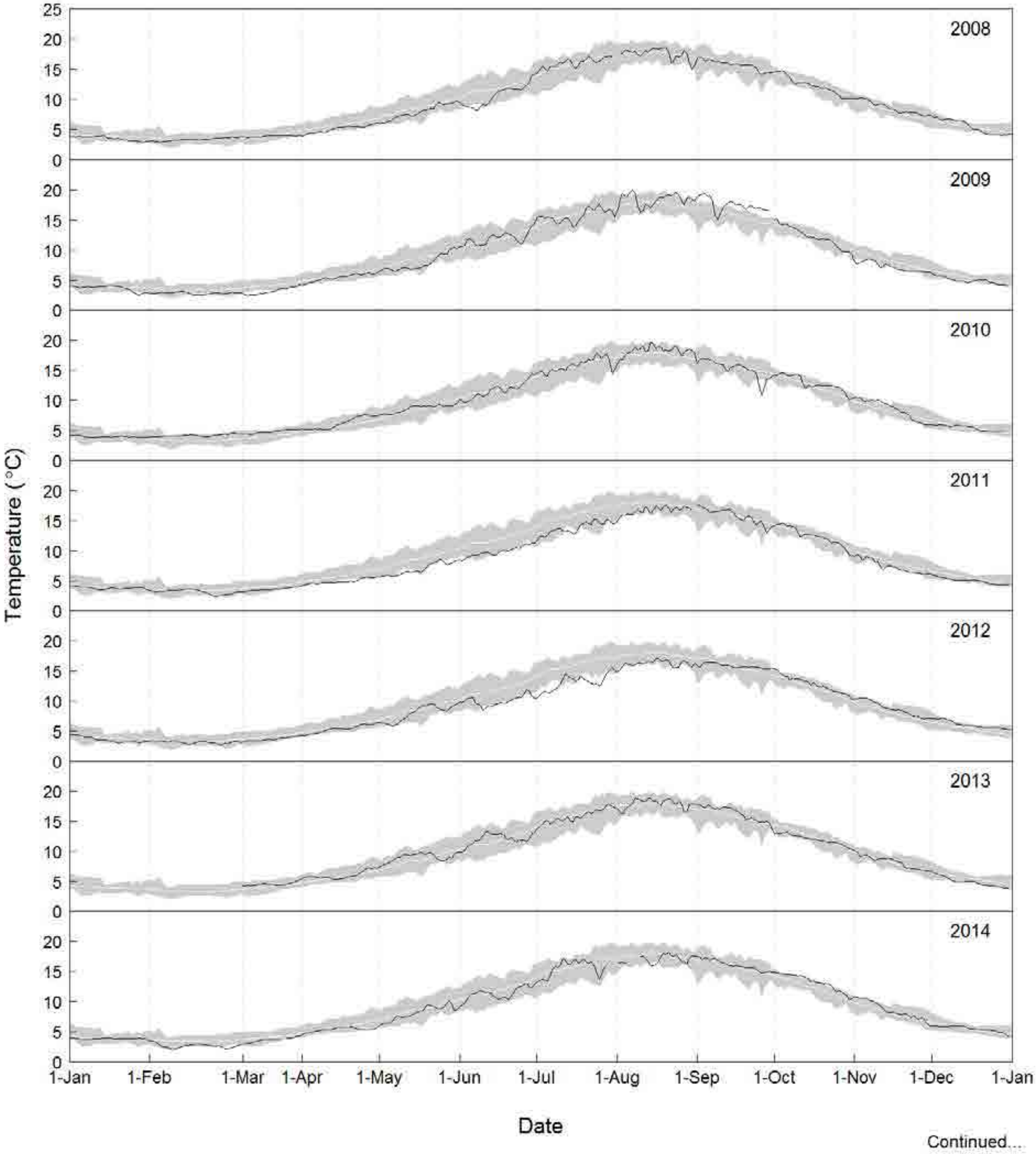


Figure D3. Continued.

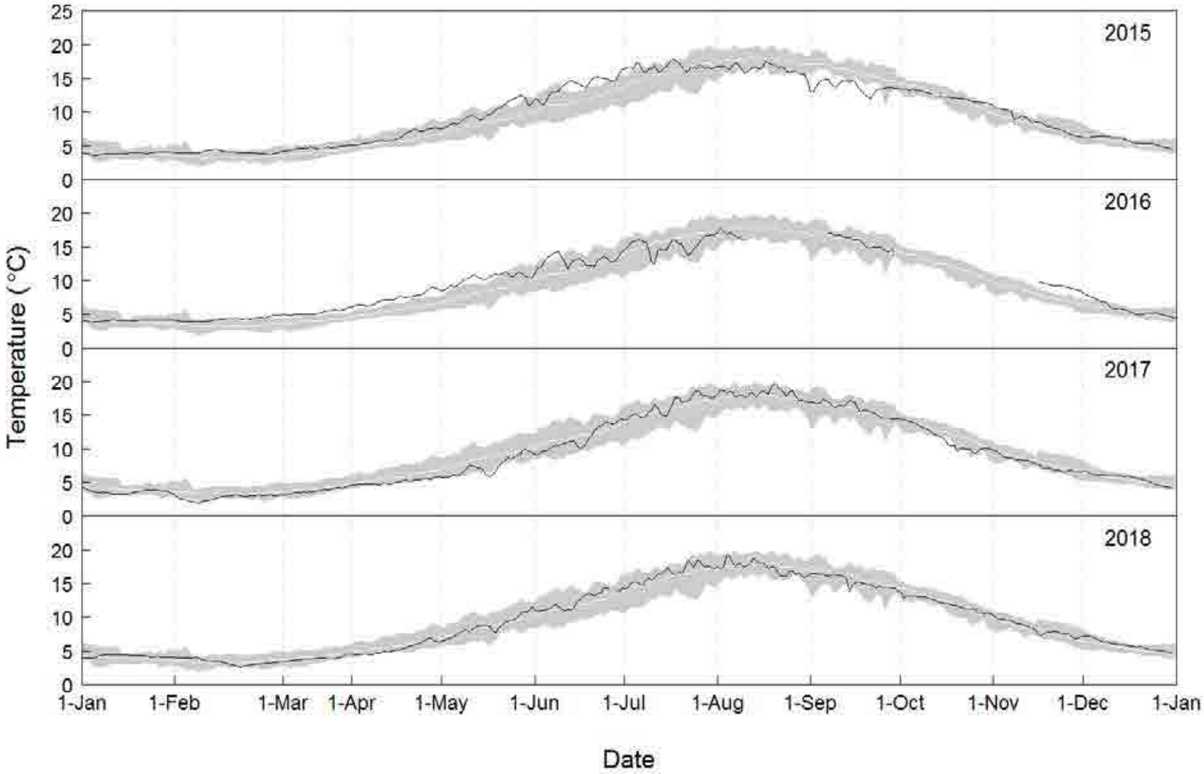
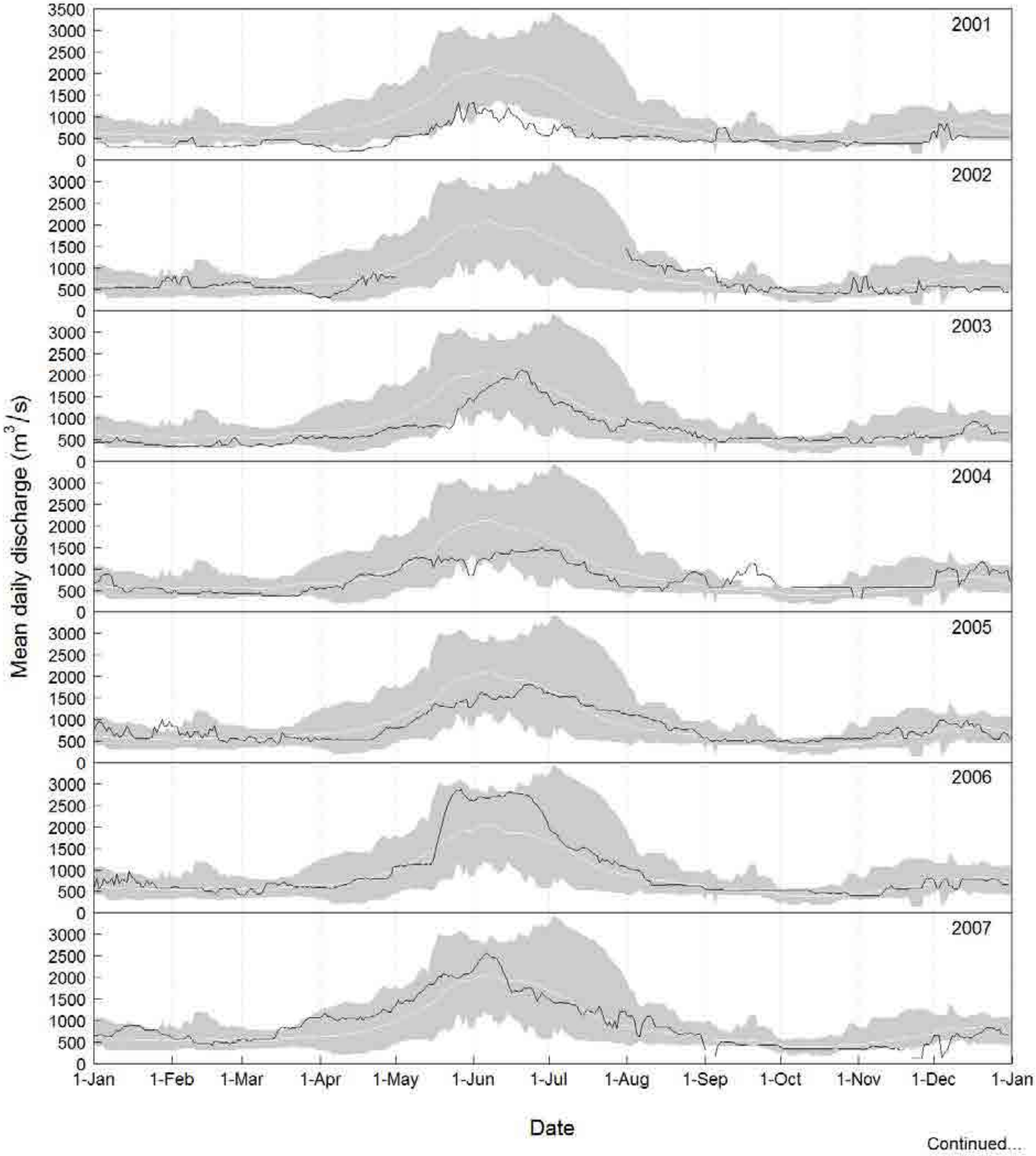
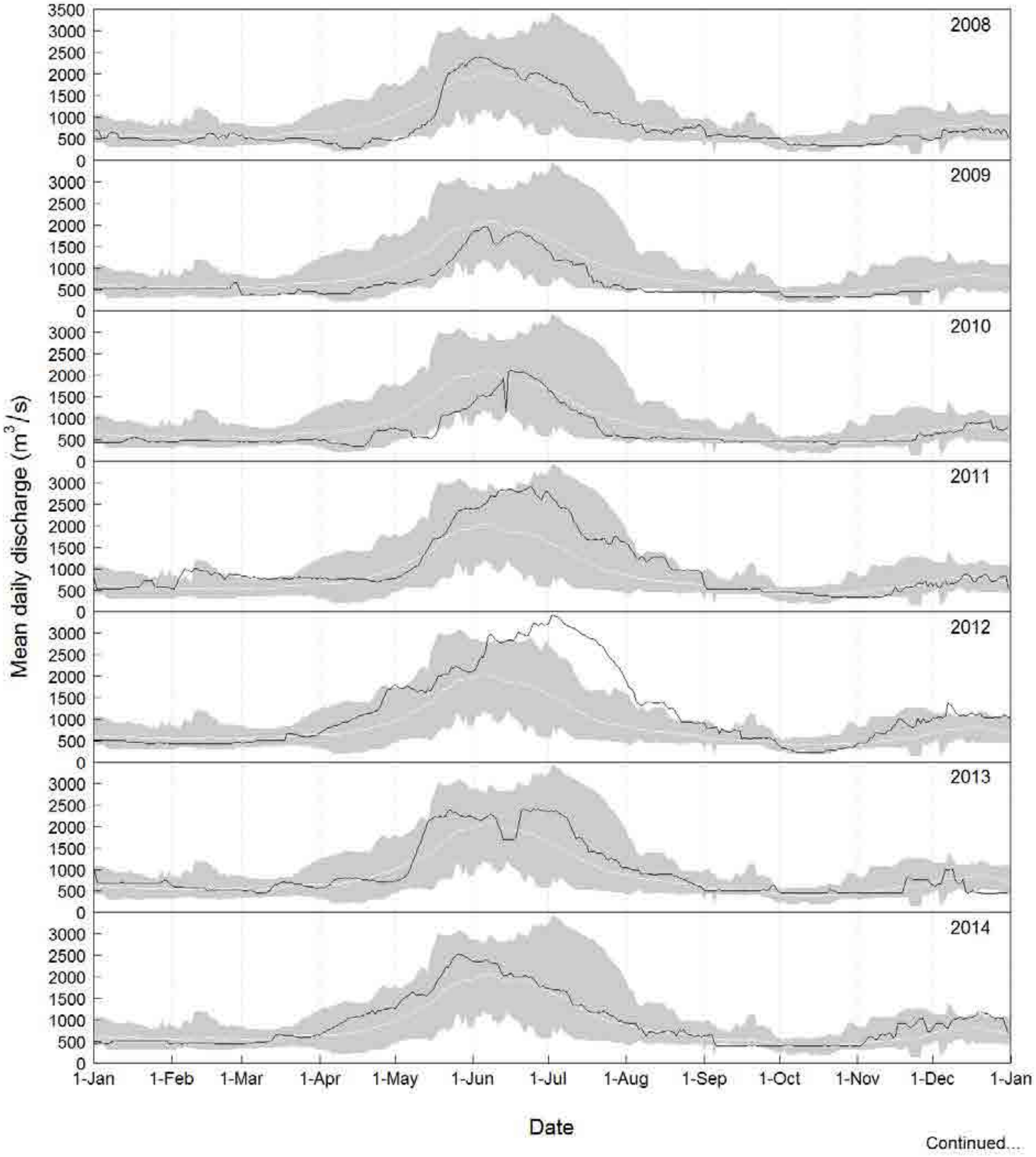


Figure D3. Concluded.



Continued…

Figure D4. Mean daily discharge (m³/s) for the Kootenay River at Brilliant Dam (BRD), 2001 to 2018 (black line). The shaded area represents minimum and maximum mean daily discharge recorded at BRD during other study years between 2001 and 2018. The white line represents average mean daily discharge over the same time period.



Continued...

Figure D4. Continued.

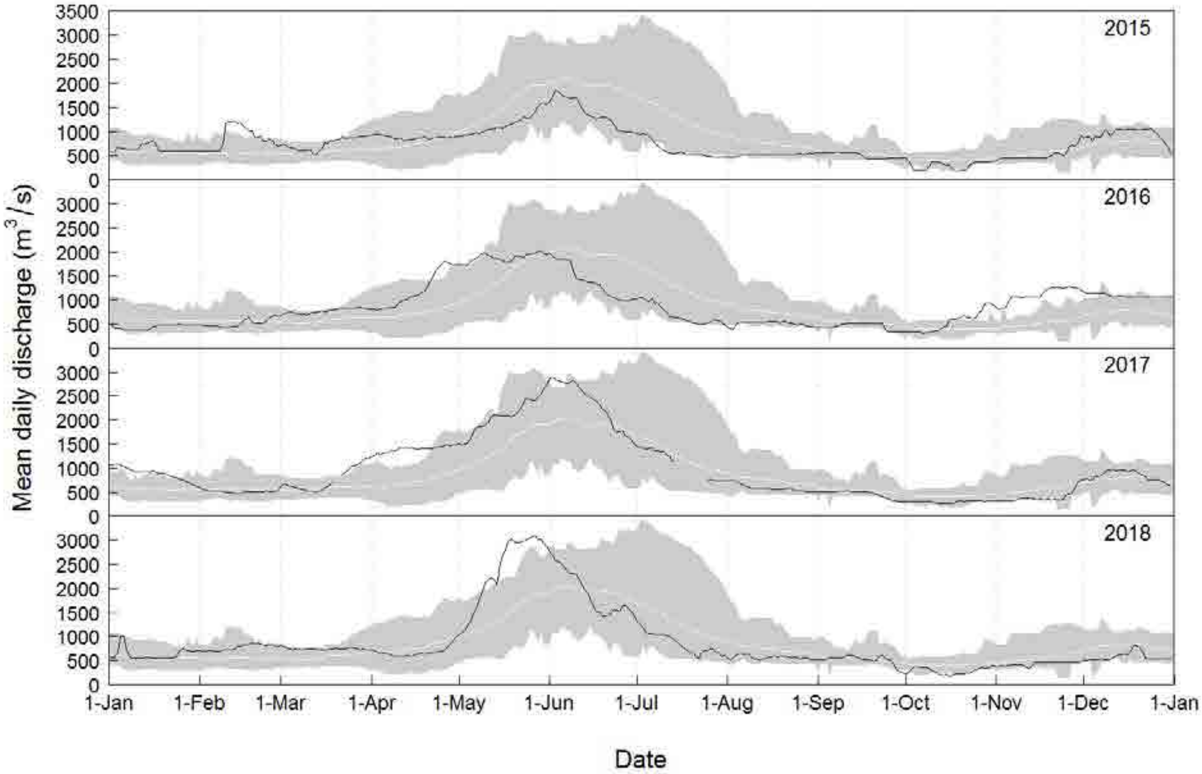
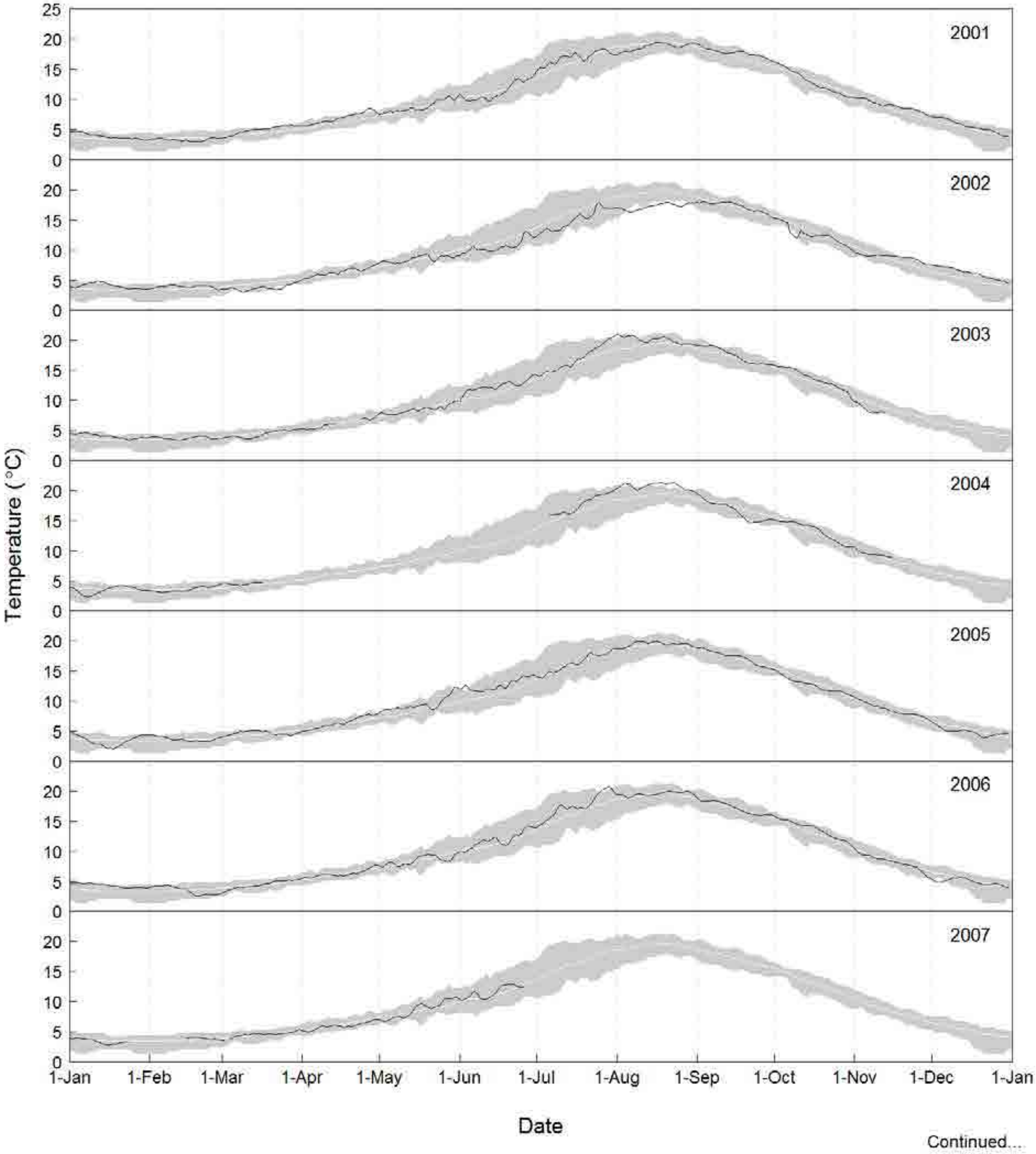
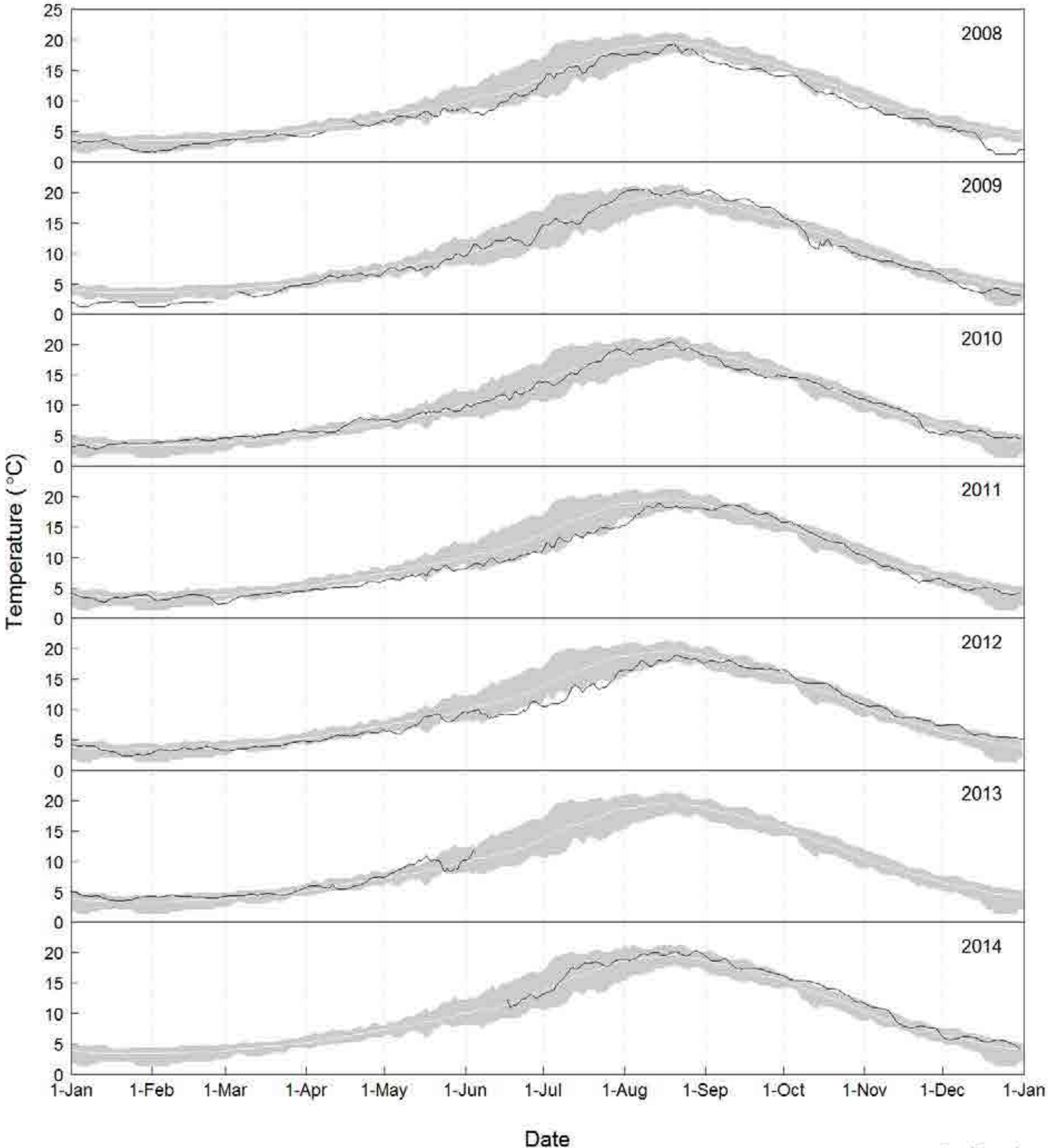


Figure D4. Concluded.



Continued...

Figure D5. Mean daily water temperatures (°C) for the Kootenay River at Brilliant Dam (BRD), 2001 to 2018 (black line). The shaded area represents minimum and maximum mean daily water temperatures recorded at BRD during other study years between 2001 and 2017. The white line represents average mean daily water temperature over the same time period.



Continued...

Figure D5. Continued.

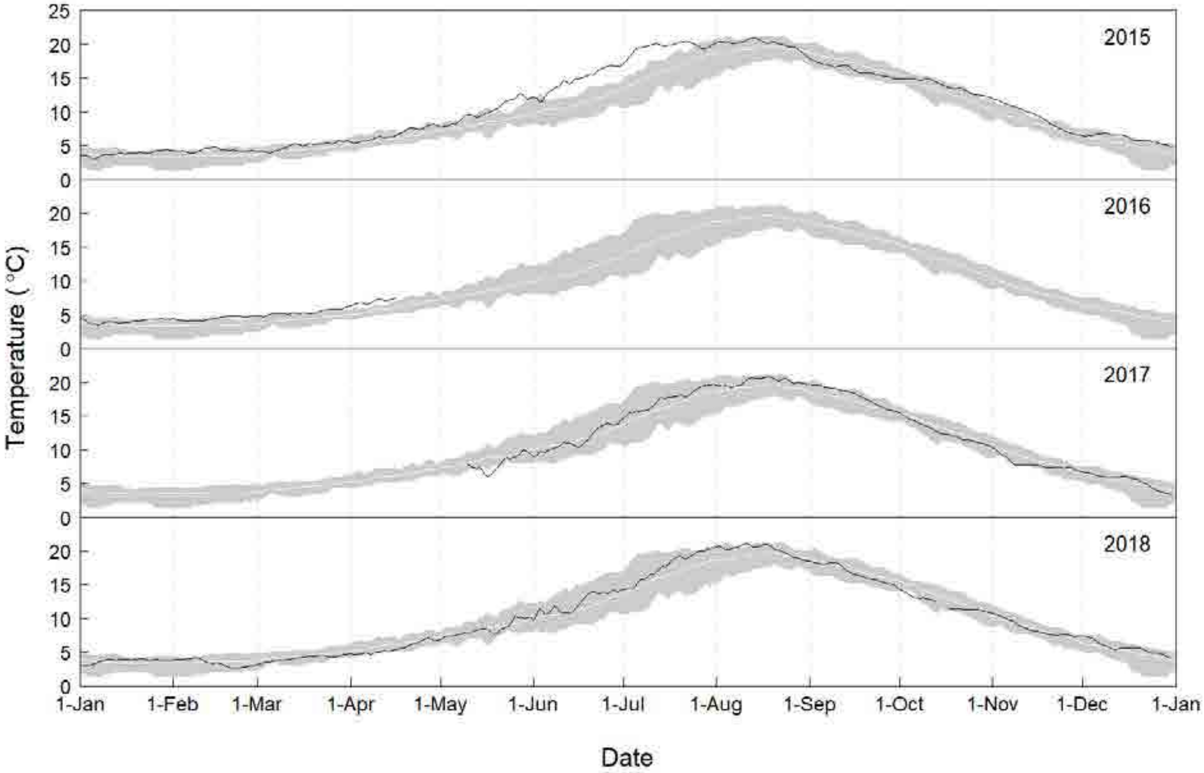


Figure D5. Concluded.

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 2018. 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		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]	%[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	156	<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	50	<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	167	<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	1387	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	
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	11 132	5	1
Lake Trout			1	<1											1	<1											1	<1									3	<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	2770	1	
Largemouth Bass																											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	102 175	42	12
Northern Pike																			7	<1	9	<1	11	<1	125	1	25	<1	9	<1	4	<1	8	<1	3	<1	201	<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	96 806	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	
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	26 857	11	3
White Sturgeon	14	<1	6	<1	18	<1	6	<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	287	<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	56	<1	
Sportfish subtotal	28 471	100	24 152	100	27 835	100	15 709	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	242 202	100	27
Non-sportfish																																							
Carp spp.	2	<1					1	<1	1	<1	3	<1	1	<1	2	<1			3	<1									1	<1					1	<1	15	<1	
Dace spp.	2	<1					3	<1	15	<1	17	<1	1	<1	1	<1			13	<1	3	<1	1	<1													56	<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	12 564	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	1583	<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	120 512	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	393 047	63	45
Sucker spp.[e]	6508	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	100 939	16	12
Tench											1	<1	5	<1	1	<1			2	<1					2	<1	1	<1			1	<1	1	<1	3	<1	17	<1	
Non-sportfish subtotal	18 406	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	628 733	100	72
All species	46 877		46 786		56 012		55 730		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		870 935		

[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, 01 October to 04 November 2018.

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		Rainbow Trout		Smallmouth Bass		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	01-Oct-18	1315	0.94													60	***174.74***			19	***55.34***			3	***8.74***					82	***238.82***
		C00.7-L	01-Oct-18	717	0.59													47	***399.97***			18	***153.18***									65	***553.15***
		C01.3-L	02-Oct-18	2167	1.6													105	***109.02***			111	***115.25***			20	***20.77***					236	***245.04***
		C02.8-L	02-Oct-18	1015	0.88													45	***181.37***			15	***60.46***			3	***12.09***	1	***4.03***			64	***257.95***
		C03.6-L	03-Oct-18	2281	2.09													59	***44.55***			63	***47.57***			18	***13.59***					140	***105.72***
		C04.6-R	03-Oct-18	837	0.52																	21	***173.7***			7	***57.9***					28	***231.6***
		C05.6-L	03-Oct-18	1191	1.1													14	***38.47***			15	***41.22***			2	***5.5***					31	***85.18***
		C07.3-R	03-Oct-18	932	1.7													46	***104.52***			60	***136.33***			3	***6.82***					109	***247.66***
		C07.4-L	03-Oct-18	1061	1													142	***481.81***			37	***125.54***			4	***13.57***	3	***10.18***			186	***631.1***
	Session Summary			**1280**	**10.4**	**0**	***0***	**0**	***0***	**0**	***0***	**0**	***0***	**0**	***0***	**0**	***0***	**518**	***140.08***	**0**	***0***	**359**	***97.09***	**0**	***0***	**60**	***16.23***	**4**	***1.08***	**0**	***0***	**941**	***254.48***
	2	C00.0-R	10-Oct-18	1000	0.94													80	***306.38***			11	***42.13***									91	***348.51***
		C00.7-L	10-Oct-18	710	0.59													16	***137.5***			13	***111.72***	1	***8.59***	1	***8.59***	1	***8.59***			32	***275.01***
		C01.3-L	10-Oct-18	1927	1.6									3	***3.5***			100	***116.76***			84	***98.08***			39	***45.54***					226	***263.88***
		C02.8-L	10-Oct-18	914	0.88													23	***102.94***			25	***111.9***			9	***40.28***	3	***13.43***			60	***268.55***
		C03.6-L	11-Oct-18	2439	2.09									1	***0.71***			33	***23.31***			60	***42.37***			21	***14.83***	1	***0.71***			116	***81.92***
		C04.6-R	11-Oct-18	739	0.52													1	***9.37***			8	***74.95***			7	***65.58***					16	***149.89***
		C05.6-L	11-Oct-18	1425	1.1													8	***18.37***			25	***57.42***			21	***48.23***					54	***124.02***
		C07.3-R	11-Oct-18	983	1.7													45	***96.94***			27	***58.17***			14	***30.16***					86	***185.27***
		C07.4-L	11-Oct-18	962	1									2	***7.48***	8	***29.94***	208	***778.38***	1	***3.74***	16	***59.88***			9	***33.68***	3	***11.23***			247	***924.32***
	Session Summary			**1233**	**10.4**	**0**	***0***	**0**	***0***	**0**	***0***	**0**	***0***	**6**	***1.68***	**8**	***2.25***	**514**	***144.3***	**1**	***0.28***	**269**	***75.52***	**1**	***0.28***	**121**	***33.97***	**8**	***2.25***	**0**	***0***	**928**	***260.53***
	3	C00.0-R	17-Oct-18	1306	0.92													65	***194.75***			21	***62.92***			4	***11.98***	3	***8.99***			93	***278.65***
		C00.7-L	17-Oct-18	817	0.59					1	***7.47***							58	***433.17***			8	***59.75***			2	***14.94***					69	***515.32***
		C01.3-L	17-Oct-18	2337	1.6													74	***71.25***			61	***58.73***			20	***19.26***					155	***149.23***
		C02.8-L	17-Oct-18	1021	0.88													19	***76.13***			7	***28.05***			7	***28.05***	2	***8.01***			35	***140.24***
		C03.6-L	18-Oct-18	2791	2.09													24	***14.81***			35	***21.6***			14	***8.64***	3	***1.85***			76	***46.9***
		C04.6-R	18-Oct-18	840	0.52																	13	***107.14***			11	***90.66***					24	***197.8***
		C05.6-L	18-Oct-18	1388	1.1													5	***11.79***			12	***28.29***			5	***11.79***					22	***51.87***
		C07.3-R	18-Oct-18	923	1.7													29	***66.53***			45	***103.24***			11	***25.24***					85	***195.02***
		C07.4-L	18-Oct-18	1010	1													134	***477.62***			30	***106.93***			6	***21.39***	2	***7.13***			172	***613.07***
	Session Summary			**1381**	**10.4**	**0**	***0***	**0**	***0***	**1**	***0.25***	**0**	***0***	**0**	***0***	**0**	***0***	**408**	***102.27***	**0**	***0***	**232**	***58.15***	**0**	***0***	**80**	***20.05***	**10**	***2.51***	**0**	***0***	**731**	***183.23***
	4	C00.0-R	24-Oct-18	1253	0.94													79	***241.46***			6	***18.34***			8	***24.45***	2	***6.11***			95	***290.37***
		C00.7-L	24-Oct-18	730	0.59													53	***443***			13	***108.66***			10	***83.58***	1	***8.36***			77	***643.6***
		C01.3-L	25-Oct-18	2183	1.6													183	***188.62***			59	***60.81***			33	***34.01***					275	***283.44***
		C02.8-L	25-Oct-18	969	0.88													14	***59.1***			15	***63.33***			10	***42.22***	1	***4.22***			40	***168.87***
		C03.6-L	25-Oct-18	2626	2.09											3	***1.97***	30	***19.68***			35	***22.96***			41	***26.89***	1	***0.66***			110	***72.15***
		C04.6-R	24-Oct-18	772	0.52													12	***107.61***			15	***134.52***			12	***107.61***					39	***349.74***
		C05.6-L	24-Oct-18	1345	1.1													4	***9.73***			22	***53.53***			25	***60.83***					51	***124.1***
		C07.3-R	26-Oct-18	1064	1.69											2	***4***	92	***184.19***			37	***74.08***			11	***22.02***	1	***2***			143	***286.29***
		C07.4-L	26-Oct-18	935	1											1	***3.85***	137	***527.49***			29	***111.66***			2	***7.7***	6	***23.1***			175	***673.8***
	Session Summary			**1320**	**10.4**	**0**	***0***	**0**	***0***	**0**	***0***	**0**	***0***	**0**	***0***	**6**	***1.57***	**604**	***158.39***	**0**	***0***	**231**	***60.58***	**0**	***0***	**152**	***39.86***	**12**	***3.15***	**0**	***0***	**1005**	***263.55***
	5	C06.0-R	04-Nov-18	1550	1.49											2	***3.12***	15	***23.38***			112	***174.58***			14	***21.82***					143	***222.91***
		C09.2-L	04-Nov-18	482	0.81													101	***931.3***			43	***396.5***			2	***18.44***					146	***1346.24***
	Session Summary			**1016**	**2.3**	**0**	***0***	**0**	***0***	**0**	***0***	**0**	***0***	**0**	***0***	**2**	***3.08***	**116**	***178.71***	**0**	***0***	**155**	***238.79***	**0**	***0***	**16**	***24.65***	**0**	***0***	**0**	***0***	**289**	***445.22***
Section Total All Samples				**48957**	**43.95**	**0**		**0**		**1**		**0**		**6**		**16**		**2160**		**1**		**1246**		**1**		**429**		**34**		**0**		**3894**	
Section Average All Samples				**1288**	**1.16**	**0**	***0***	**0**	***0***	**0**	***0.06***	**0**	***0***	**0**	***0.38***	**0**	***1.02***	**57**	***137.37***	**0**	***0.06***	**33**	***79.24***	**0**	***0.06***	**11**	***27.28***	**1**	***2.16***	**0**	***0***	**102**	***247.64***
Section Standard Error of Mean						**0**	***0***	**0**	***0***	**0.03**	***0.2***	**0**	***0***	**0.1**	***0.22***	**0.23**	***0.8***	**8.43**	***36.01***	**0.03**	***0.1***	**4.33**	***10.75***	**0.03**	***0.23***	**1.66**	***4.11***	**0.22**	***0.84***	**0**	***0***	**11.06**	***42.83***

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		Rainbow Trout		Smallmouth Bass		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
Kootenay River	1	K00.3-L	04-Oct-18	155	0.44													10	***527.86***			1	***52.79***			4	***211.14***					15	***791.79***
		K00.6-R	04-Oct-18	577	0.6													26	***270.36***			9	***93.59***			4	***41.59***					39	***405.55***
		K01.8-L	04-Oct-18	1407	1.87													97	***132.72***			36	***49.26***			12	***16.42***					145	***198.4***
		K01.8-R	03-Oct-18	1053	1.3													90	***236.69***			18	***47.34***			4	***10.52***					112	***294.54***
	Session Summary			**798**	**4.2**	**0**	***0***	**0**	***0***	**0**	***0***	**0**	***0***	**0**	***0***	**0**	***0***	**223**	***239.53***	**0**	***0***	**64**	***68.74***	**0**	***0***	**24**	***25.78***	**0**	***0***	**0**	***0***	**311**	***334.05***
	2	K00.3-L	12-Oct-18	180	0.44													5	***227.27***			9	***409.09***			3	***136.36***					17	***772.73***
		K00.6-R	12-Oct-18	657	0.6					1	***9.13***							54	***493.15***	1	***9.13***	18	***164.38***			8	***73.06***					82	***748.86***
		K01.8-L	12-Oct-18	1656	1.87													118	***137.18***			38	***44.18***			25	***29.06***	3	***3.49***			184	***213.9***
		K01.8-R	11-Oct-18	1275	1.3													108	***234.57***			47	***102.08***			12	***26.06***	1	***2.17***			168	***364.89***
	Session Summary			**942**	**4.2**	**0**	***0***	**0**	***0***	**1**	***0.91***	**0**	***0***	**0**	***0***	**0**	***0***	**285**	***259.33***	**1**	***0.91***	**112**	***101.91***	**0**	***0***	**48**	***43.68***	**4**	***3.64***	**0**	***0***	**451**	***410.37***
	3	K00.3-L	18-Oct-18	311	0.44																	5	***131.54***			6	***157.85***					11	***289.39***
		K00.6-R	22-Oct-18	646	0.6													40	***371.52***	1	***9.29***	20	***185.76***			13	***120.74***					74	***687.31***
		K01.8-L	22-Oct-18	1784	1.87											1	***1.08***	45	***48.56***			33	***35.61***			15	***16.19***	3	***3.24***			97	***104.67***
		K01.8-R	22-Oct-18	1033	1.28											1	***2.72***	43	***117.07***			32	***87.12***			10	***27.23***	2	***5.45***			88	***239.59***
	Session Summary			**944**	**4.2**	**0**	***0***	**0**	***0***	**0**	***0***	**0**	***0***	**0**	***0***	**2**	***1.82***	**128**	***116.22***	**1**	***0.91***	**90**	***81.72***	**0**	***0***	**44**	***39.95***	**5**	***4.54***	**0**	***0***	**270**	***245.16***
	4	K00.3-L	27-Oct-18	229	0.44													5	***178.64***			4	***142.91***			1	***35.73***					10	***357.28***
		K00.6-R	27-Oct-18	646	0.6													39	***362.23***			11	***102.17***			12	***111.46***					62	***575.85***
		K01.8-L	26-Oct-18	1616	1.87													79	***94.11***			45	***53.61***			16	***19.06***	2	***2.38***			142	***169.16***
		K01.8-R	27-Oct-18	1319	1.27													108	***232.1***			25	***53.73***			4	***8.6***	2	***4.3***			139	***298.72***
	Session Summary			**952**	**4.2**	**0**	***0***	**0**	***0***	**0**	***0***	**0**	***0***	**0**	***0***	**0**	***0***	**231**	***207.98***	**0**	***0***	**85**	***76.53***	**0**	***0***	**33**	***29.71***	**4**	***3.6***	**0**	***0***	**353**	***317.83***
Section Total All Samples				**14544**	**16.79**	**0**		**0**		**1**		**0**		**0**		**2**		**867**		**2**		**351**		**0**		**149**		**13**		**0**		**1385**	
Section Average All Samples				**909**	**1.05**	**0**	***0***	**0**	***0***	**0**	***0.24***	**0**	***0***	**0**	***0***	**0**	***0.47***	**54**	***204.51***	**0**	***0.47***	**22**	***82.79***	**0**	***0***	**9**	***35.15***	**1**	***3.07***	**0**	***0***	**87**	***326.69***
Section Standard Error of Mean						**0**	***0***	**0**	***0***	**0.06**	***0.57***	**0**	***0***	**0**	***0***	**0.09**	***0.18***	**10.16**	***37.36***	**0.09**	***0.79***	**3.76**	***23.07***	**0**	***0***	**1.57**	***15.68***	**0.29**	***0.47***	**0**	***0***	**14.53**	***57.92***

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		Rainbow Trout		Smallmouth Bass		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	1	C25.3-R	04-Oct-18	1627	2.73													27	***21.88***			39	***31.61***			6	***4.86***					72	***58.36***
		C27.6-R	04-Oct-18	298	0.61													14	***277.26***			10	***198.04***			1	***19.8***					25	***495.1***
		C28.2-R	04-Oct-18	851	1.13													18	***67.39***			28	***104.82***			6	***22.46***					52	***194.67***
		C34.9-L	05-Oct-18	1994	2.14													27	***22.78***			148	***124.86***			3	***2.53***					178	***150.17***
		C36.6-L	05-Oct-18	1550	2.39													36	***34.98***			103	***100.09***			3	***2.92***					142	***137.99***
		C47.8-L	09-Oct-18	1157	1.44													12	***25.93***			88	***190.15***			7	***15.13***					107	***231.2***
		C48.2-R	05-Oct-18	859	1.01													13	***53.94***			39	***161.83***			5	***20.75***					57	***236.52***
		C49.0-L	09-Oct-18	527	0.93													17	***124.87***			31	***227.7***									48	***352.57***
		C49.0-R	05-Oct-18	347	0.72													6	***86.46***			19	***273.78***			4	***57.64***					29	***417.87***
		C49.8-L	09-Oct-18	1577	2.45													19	***17.7***			66	***61.5***			9	***8.39***					94	***87.59***
		C49.8-R	05-Oct-18	1185	2.39													39	***49.57***			86	***109.32***			10	***12.71***					135	***171.6***
		C52.2-L	09-Oct-18	867	0.89			1	***4.67***							1	***4.67***	8	***37.32***			26	***121.3***			2	***9.33***					38	***177.29***
		C52.2-R	05-Oct-18	1985	3.79											8	***3.83***	24	***11.48***			89	***42.59***			9	***4.31***					130	***62.21***
		C52.8-L	09-Oct-18	584	0.89											1	***6.93***	6	***41.56***			40	***277.05***			10	***69.26***					57	***394.8***
		C53.6-L	10-Oct-18	1126	1.52							1	***2.1***			1	***2.1***	4	***8.41***			29	***61***			9	***18.93***					44	***92.55***
	Session Summary			**1102**	**25**	**0**	***0***	**1**	***0.13***	**0**	***0***	**1**	***0.13***	**0**	***0***	**11**	***1.44***	**270**	***35.28***	**0**	***0***	**841**	***109.89***	**0**	***0***	**84**	***10.98***	**0**	***0***	**0**	***0***	**1208**	***157.85***
	2	C25.3-R	12-Oct-18	1908	2.73											3	***2.07***	14	***9.68***			53	***36.63***			8	***5.53***					78	***53.91***
		C27.6-R	12-Oct-18	348	0.61													2	***33.92***			8	***135.67***			2	***33.92***					12	***203.5***
		C28.2-R	12-Oct-18	848	1.13													6	***22.54***			29	***108.95***			5	***18.78***					40	***150.28***
		C34.9-L	12-Oct-18	1887	2.14													15	***13.37***			46	***41.01***			1	***0.89***	1	***0.89***			63	***56.16***
		C36.6-L	13-Oct-18	1524	2.39													9	***8.9***			86	***85***			10	***9.88***					105	***103.78***
		C47.8-L	15-Oct-18	1243	1.44													6	***12.07***			66	***132.74***			12	***24.14***			1	***2.01***	85	***170.96***
		C48.2-R	13-Oct-18	1018	1.01											1	***3.5***	7	***24.51***			16	***56.02***			12	***42.02***					36	***126.05***
		C49.0-L	15-Oct-18	496	0.93											1	***7.8***	14	***109.26***			8	***62.43***			1	***7.8***					24	***187.3***
		C49.0-R	13-Oct-18	317	0.72													8	***126.18***			13	***205.05***			1	***15.77***					22	***347***
		C49.8-L	15-Oct-18	1911	2.45													42	***32.29***			70	***53.82***			13	***10***					125	***96.11***
		C49.8-R	13-Oct-18	1375	2.39							2	***2.19***					26	***28.48***			42	***46.01***			8	***8.76***					78	***85.45***
		C52.2-L	15-Oct-18	758	0.89							1	***5.34***			1	***5.34***	1	***5.34***			12	***64.04***									15	***80.05***
		C52.2-R	13-Oct-18	2157	3.79							2	***0.88***			1	***0.44***	24	***10.57***			43	***18.94***			10	***4.4***					80	***35.23***
		C52.8-L	16-Oct-18	599	0.89							1	***6.75***					2	***13.51***			21	***141.81***			11	***74.28***					35	***236.35***
		C53.6-L	16-Oct-18	1134	1.52							1	***2.09***			1	***2.09***					16	***33.42***	1	***2.09***	5	***10.44***					24	***50.13***
	Session Summary			**1168**	**25**	**0**	***0***	**0**	***0***	**0**	***0***	**7**	***0.86***	**0**	***0***	**8**	***0.99***	**176**	***21.7***	**0**	***0***	**529**	***65.22***	**1**	***0.12***	**99**	***12.21***	**1**	***0.12***	**1**	***0.12***	**822**	***101.34***
	3	C25.3-R	16-Oct-18	1508	2.73											2	***1.75***	31	***27.11***			29	***25.36***			9	***7.87***					71	***62.09***
		C27.6-R	16-Oct-18	343	0.58													5	***90.48***			10	***180.96***			3	***54.29***					18	***325.73***
		C28.2-R	16-Oct-18	757	1.13																	29	***122.05***	1	***4.21***	6	***25.25***					36	***151.51***
		C34.9-L	16-Oct-18	2157	2.14													11	***8.58***			87	***67.85***			7	***5.46***					105	***81.89***
		C36.6-L	16-Oct-18	1567	2.39											4	***3.84***	16	***15.38***			35	***33.64***			5	***4.81***					60	***57.67***
		C47.8-L	23-Oct-18	1290	1.44	1	***1.94***	1	***1.94***							1	***1.94***	8	***15.5***			59	***114.34***			14	***27.13***					84	***162.79***
		C48.2-R	19-Oct-18	1044	1.01											1	***3.41***	6	***20.48***			28	***95.6***			16	***54.63***					51	***174.12***
		C49.0-L	23-Oct-18	484	0.93											3	***23.99***	24	***191.95***			42	***335.91***			6	***47.99***					75	***599.84***
		C49.0-R	19-Oct-18	386	0.72											4	***51.81***	4	***51.81***			12	***155.44***			3	***38.86***	1	***12.95***			24	***310.88***
		C49.8-L	23-Oct-18	1718	2.45											3	***2.57***	43	***36.78***			79	***67.57***			16	***13.68***					141	***120.6***
		C49.8-R	19-Oct-18	1269	2.39													21	***24.93***			55	***65.28***			14	***16.62***					90	***106.83***
		C52.2-L	23-Oct-18	869	0.89											1	***4.65***	8	***37.24***			31	***144.3***			6	***27.93***					46	***214.12***
		C52.2-R	19-Oct-18	2105	3.79			1	***0.45***							7	***3.16***	16	***7.22***			65	***29.33***			11	***4.96***					100	***45.12***
		C52.8-L	24-Oct-18	611	0.89													3				10				5						18	
		C53.6-L	24-Oct-18	1177	1.52													2	***4.02***			23	***46.28***			12	***24.15***					37	***74.45***
	Session Summary			**1152**	**25**	**1**	***0.12***	**2**	***0.25***	**0**	***0***	**0**	***0***	**0**	***0***	**26**	***3.25***	**198**	***24.75***	**0**	***0***	**594**	***74.25***	**1**	***0.12***	**133**	***16.62***	**1**	***0.12***	**0**	***0***	**956**	***119.5***

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		Rainbow Trout		Smallmouth Bass		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	30-Oct-18	1485	2.73									1	0.89	6	5.33	36	31.97			62	55.06			15	13.32					120	106.56
		C27.6-R	30-Oct-18	396	0.61													18	268.26			25	372.58			1	14.9					44	655.74
		C28.2-R	30-Oct-18	854	1.13											1	3.73	23	85.8			78	290.98			6	22.38					108	402.89
		C34.9-L	30-Oct-18	2022	2.14													13	10.82			83	69.05			11	9.15					107	89.02
		C36.6-L	31-Oct-18	1706	2.34													20	18.04			73	65.83			10	9.02					103	92.88
		C47.8-L	29-Oct-18	1394	1.44											5	8.97	9	16.14			88	157.82			23	41.25					125	224.18
		C48.2-R	25-Oct-18	886	1.01											3	12.07	10	40.23			54	217.24			20	80.46					87	350
		C49.0-L	29-Oct-18	502	0.93							2	15.42					33	254.47			36	277.6			3	23.13					74	570.62
		C49.0-R	25-Oct-18	494	0.72			1	10.12									5	50.61			37	374.49			11	111.34					54	546.56
		C49.8-L	29-Oct-18	1811	2.45							1	0.81			2	1.62	35	28.4			126	102.23			18	14.6					182	147.67
		C49.8-R	25-Oct-18	1264	2.39													35	41.71			33	39.33			19	22.64					87	103.68
		C52.2-L	29-Oct-18	864	0.89													8	37.45			24	112.36			9	42.13					41	191.95
		C52.2-R	25-Oct-18	2375	3.79							1	0.4			9	3.6	27	10.8			75	30			17	6.8					129	51.59
		C52.8-L	30-Oct-18	730	0.89							1	5.54			3	16.62	7	38.79			26	144.07			8	44.33					45	249.35
		C53.6-L	30-Oct-18	1160	1.52													4	8.17			15	30.63			7	14.29					26	53.09
	Session Summary			**1196**	**25**	**0**	*0*	**1**	*0.12*	**0**	*0*	**5**	*0.6*	**1**	*0.12*	**29**	*3.49*	**283**	*34.07*	**0**	*0*	**835**	*100.54*	**0**	*0*	**178**	*21.43*	**0**	*0*	**0**	*0*	**1332**	*160.37*
	5	C11.5-R	04-Nov-18	1369	1.87											7	9.84	78	109.69			145	203.9			4	5.62					234	329.06
		C13.4-L	03-Nov-18	1144	1.39													106	239.98			125	282.99			12	27.17					243	550.13
		C14.8-L	03-Nov-18	1738	2.26													141	129.23			118	108.15			14	12.83	1	0.92			274	251.13
		C17.0-L	03-Nov-18	1561	1.91													120	144.89			148	178.7			16	19.32					284	342.91
		C18.8-R	04-Nov-18	1512	1.61													23	34.01			74	109.44			7	10.35					104	153.8
		C20.4-R	02-Nov-18	1200	1.47									1	2.04	3	6.12	28	57.14			51	104.08			5	10.2					88	179.59
		C22.9-R	02-Nov-18	922	1.22							1	3.2			2	6.4	194	620.89			46	147.22			5	16	2	6.4			250	800.11
		C25.3-L	02-Nov-18	1128	1.88											1	1.7	75	127.32			97	164.67			26	44.14	3	5.09			202	342.92
		C26.2-L	02-Nov-18	462	0.95											2	16.4	91	746.41			68	557.76			8	65.62					169	1386.19
		C29.6-L	01-Nov-18	731	1.11											1	4.44	9	39.93			65	288.39	1	4.44	14	62.11					90	399.3
		C32.4-L	01-Nov-18	1710	2													12	12.63			81	85.26			12	12.63					105	110.53
		C33.3-R	01-Nov-18	1528	1.61	1	1.46											40	58.53			149	218.04			11	16.1					201	294.14
		C36.9-R	02-Nov-18	1830	2.27											2	1.73	18	15.6			107	92.73			18	15.6					145	125.66
		C41.1-L	31-Oct-18	2020	2.41											1	0.74	36	26.62			147	108.71			17	12.57					201	148.64
		C43.7-R	31-Oct-18	664	1.34											3	12.14	14	56.64			40	161.84			6	24.28					63	254.9
		C44.6-L	31-Oct-18	706	1.01							1	5.05					7	35.34			47	237.29			8	40.39					63	318.07
		C46.4-L	31-Oct-18	1074	1.59													19	40.05			96	202.38			11	23.19					126	265.63
		C56.0-L	30-Oct-18	1059	0.94																	9	32.55	4	14.47	12	43.4					25	90.41
	Session Summary			**1242**	**28.8**	**1**	*0.1*	**0**	*0*	**0**	*0*	**2**	*0.2*	**1**	*0.1*	**22**	*2.21*	**1011**	*101.75*	**0**	*0*	**1613**	*162.34*	**5**	*0.5*	**206**	*20.73*	**6**	*0.6*	**0**	*0*	**2867**	*288.55*
Section Total All Samples				**91643**	**128.88**	**2**		**4**		**0**		**15**		**2**		**96**		**1938**		**0**		**4412**		**7**		**700**		**8**		**1**		**7185**	
Section Average All Samples				**1175**	**1.65**	**0**	*0.05*	**0**	*0.1*	**0**	*0*	**0**	*0.36*	**0**	*0.05*	**1**	*2.28*	**25**	*46.07*	**0**	*0*	**57**	*104.89*	**0**	*0.17*	**9**	*16.64*	**0**	*0.19*	**0**	*0.02*	**92**	*170.81*
Section Standard Error of Mean						**0.02**	*0.03*	**0.03**	*0.14*	**0**	*0*	**0.05**	*0.25*	**0.02**	*0.03*	**0.23**	*0.81*	**3.71**	*13.4*	**0**	*0*	**4.36**	*11.26*	**0.06**	*0.2*	**0.63**	*2.41*	**0.05**	*0.19*	**0.01**	*0.03*	**7.27**	*23.59*
All Sections Total All Samples				**155144**	**189.62**	*2*	*0*	*4*	*0*	*2*	*0*	*15*	*0*	*8*	*0*	*114*	*0.01*	*4965*	*0.61*	*3*	*0*	*6009*	*0.74*	*8*	*0*	*1278*	*0.16*	*55*	*0.01*	*1*	*0*	*12464*	*1.53*
All Sections Average All Samples						*0*	*0.03*	*0*	*0.06*	*0*	*0.03*	*0*	*0.24*	*0*	*0.13*	*1*	*1.84*	*38*	*80.2*	*0*	*0.05*	*46*	*97.06*	*0*	*0.13*	*10*	*20.64*	*0*	*0.89*	*0*	*0.02*	*94*	*201.33*
All Sections Standard Error of Mean						*0.01*	*0.02*	*0.01*	*0.09*	*0.01*	*0.09*	*0.03*	*0.15*	*0.03*	*0.06*	*0.16*	*0.54*	*3.71*	*14.86*	*0.01*	*0.1*	*3.12*	*8*	*0.03*	*0.14*	*0.64*	*2.85*	*0.08*	*0.29*	*0.01*	*0.02*	*5.61*	*20.42*

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, 01 October to 04 November 2018.

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.		Tench		All Species	
						No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE
Columbia River U/S	1	C00.0-R	01-Oct-18	1315	0.9371516							52	151.9	18	52.58	2	5.84			72	210.33
		C00.7-L	01-Oct-18	717	0.5932888											1	8.46			1	8.46
		C01.3-L	02-Oct-18	2167	1.601247									20	20.75	66	68.47			86	89.22
		C02.8-L	02-Oct-18	1015	0.8821294									3	12.06	23	92.48			26	104.54
		C03.6-L	03-Oct-18	2281	2.087279											36	27.22			36	27.22
		C04.6-R	03-Oct-18	837	0.5174685											6	49.87			6	49.87
		C05.6-L	03-Oct-18	1191	1.100858									30	82.37	15	41.19			45	123.56
		C07.3-R	03-Oct-18	932	1.704862									23	52.11	5	11.33			28	63.44
		C07.4-L	03-Oct-18	1061	0.9981754									1	3.4	48	163.16			49	166.56
	Session Summary			**1280**	**10.4**	**0**	**0**	**0**	**0**	**0**	**0**	**52**	**14.06**	**95**	**25.69**	**202**	**54.63**	**0**	**0**	**349**	**94.38**
	2	C00.0-R	10-Oct-18	1000	0.9371516					3	11.52			3	11.52	4	15.37			10	38.41
		C00.7-L	10-Oct-18	710	0.5932888			1	8.55					2	17.09	1	8.55			4	34.19
		C01.3-L	10-Oct-18	1927	1.601247			6	7	1	1.17					90	105			97	113.17
		C02.8-L	10-Oct-18	914	0.8821294			2	8.93							37	165.21			39	174.14
		C03.6-L	11-Oct-18	2439	2.087279			11	7.78			2	1.41	21	14.85	64	45.26			98	69.3
		C04.6-R	11-Oct-18	739	0.5174685			1	9.41							23	216.52			24	225.94
		C05.6-L	11-Oct-18	1425	1.100858			25	57.37			2	4.59	55	126.22	31	71.14			113	259.32
		C07.3-R	11-Oct-18	983	1.704862											4	8.59			4	8.59
		C07.4-L	11-Oct-18	962	0.9981754			1	3.75							43	161.21			44	164.96
	Session Summary			**1233**	**10.4**	**0**	**0**	**47**	**13.19**	**4**	**1.12**	**4**	**1.12**	**81**	**22.74**	**297**	**83.38**	**0**	**0**	**433**	**121.56**
	3	C00.0-R	17-Oct-18	1306	0.9171516									55	165.3					55	165.3
		C00.7-L	17-Oct-18	817	0.5932888					2	14.85	2	14.85			8	59.42			12	89.12
		C01.3-L	17-Oct-18	2337	1.601247			11	10.58	2	1.92			2	1.92	43	41.37			58	55.8
		C02.8-L	17-Oct-18	1021	0.8821294	1	4	1	4			1	4	3	11.99	32	127.91			38	151.89
		C03.6-L	18-Oct-18	2791	2.087279			32	19.77			1	0.62	21	12.98	82	50.67			136	84.04
		C04.6-R	18-Oct-18	840	0.5174685			1	8.28					2	16.56	13	107.67			16	132.51
		C05.6-L	18-Oct-18	1388	1.100858			26	61.26					1	2.36	27	63.61			54	127.23
		C07.3-R	18-Oct-18	923	1.704862											5	11.44			5	11.44
		C07.4-L	18-Oct-18	1010	0.9981754											45	160.69			45	160.69
	Session Summary			**1381**	**10.4**	**1**	**0.25**	**71**	**17.8**	**4**	**1**	**4**	**1**	**84**	**21.05**	**255**	**63.92**	**0**	**0**	**419**	**105.02**
	4	C00.0-R	24-Oct-18	1253	0.9371516							6	18.39	50	153.29					56	171.68
		C00.7-L	24-Oct-18	730	0.5932888			1	8.31					5	41.56					6	49.87
		C01.3-L	25-Oct-18	2183	1.601247											16	16.48	1	1.03	17	17.51
		C02.8-L	25-Oct-18	969	0.8821294											20	84.23			20	84.23
		C03.6-L	25-Oct-18	2626	2.087279			44	28.9					30	19.7	43	28.24			117	76.84
		C04.6-R	24-Oct-18	772	0.5174685			1	9.01							6	54.07			7	63.08
		C05.6-L	24-Oct-18	1345	1.100858			6	14.59			20	48.63	200	486.27	14	34.04			240	583.53
		C07.3-R	26-Oct-18	1064	1.694862											4	7.99			4	7.99
		C07.4-L	26-Oct-18	935	0.9981754											60	231.44			60	231.44
	Session Summary			**1320**	**10.4**	**0**	**0**	**52**	**13.64**	**0**	**0**	**26**	**6.82**	**285**	**74.74**	**163**	**42.74**	**1**	**0.26**	**527**	**138.2**
	5	C06.0-R	04-Nov-18	1550	1.48665			6	9.37					5	7.81	40	62.49			51	79.68
		C09.2-L	04-Nov-18	482	0.81											12	110.65			12	110.65
	Session Summary			**1016**	**2.3**	**0**	**0**	**6**	**9.24**	**0**	**0**	**0**	**0**	**5**	**7.7**	**52**	**80.11**	**0**	**0**	**63**	**97.06**
Section Total All Samples				**48957**	**43.9564888**	**1**		**176**		**8**		**86**		**550**		**969**		**1**		**1791**	
Section Average All Samples				**1288**	**1.16**	**0**	**0.06**	**5**	**11.19**	**0**	**0.51**	**2**	**5.47**	**14**	**34.97**	**26**	**61.62**	**0**	**0.06**	**47**	**113.88**
Section Standard Error of Mean						**0.03**	**0.11**	**1.65**	**2.27**	**0.11**	**0.49**	**1.45**	**4.17**	**5.63**	**13.96**	**3.93**	**10.15**	**0.03**	**0.03**	**7.76**	**16.73**

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.		Tench		All Species	
						No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE
Kootenay River	1	K00.6-R	04-Oct-18	577	0.5956581											37	***387.55***			37	***387.55***
		K01.8-L	04-Oct-18	1407	1.871003			1	***1.37***	1	***1.37***			1	***1.37***	47	***64.27***			50	***68.38***
		K01.8-R	03-Oct-18	1053	1.296347											21	***55.38***			21	***55.38***
	Session Summary			**1012**	**3.8**	**0**	***0***	**1**	***0.94***	**1**	***0.94***	**0**	***0***	**1**	***0.94***	**105**	***98.29***	**0**	***0***	**108**	***101.1***
	2	K00.3-L	12-Oct-18	180	0.4362984											1	***45.84***			1	***45.84***
		K00.6-R	12-Oct-18	657	0.5956581									12	***110.39***	15	***137.98***			27	***248.37***
		K01.8-L	12-Oct-18	1656	1.871003									33	***38.34***	15	***17.43***			48	***55.77***
		K01.8-R	11-Oct-18	1275	1.296347			1	***2.18***			3	***6.53***	35	***76.23***	1	***2.18***			40	***87.12***
	Session Summary			**942**	**4.2**	**0**	***0***	**1**	***0.91***	**0**	***0***	**3**	***2.73***	**80**	***72.79***	**32**	***29.12***	**0**	***0***	**116**	***105.55***
	3	K00.3-L	18-Oct-18	311	0.4362984											1	***26.53***			1	***26.53***
		K00.6-R	22-Oct-18	646	0.5956581									3	***28.07***	16	***149.69***			19	***177.76***
		K01.8-L	22-Oct-18	1784	1.871003			6	***6.47***			9	***9.71***	20	***21.57***	8	***8.63***			43	***46.38***
		K01.8-R	22-Oct-18	1033	1.276347							11	***30.03***	35	***95.57***	2	***5.46***			48	***131.06***
	Session Summary			**944**	**4.2**	**0**	***0***	**6**	***5.45***	**0**	***0***	**20**	***18.16***	**58**	***52.66***	**27**	***24.52***	**0**	***0***	**111**	***100.79***
	4	K00.3-L	27-Oct-18	229	0.4362984									5	***180.16***	3	***108.09***			8	***288.25***
		K00.6-R	27-Oct-18	646	0.5956581							1	***9.36***			11	***102.91***	1	***9.36***	13	***121.62***
		K01.8-L	26-Oct-18	1616	1.871003			1	***1.19***					7	***8.33***	25	***29.77***			33	***39.29***
		K01.8-R	27-Oct-18	1319	1.266347											10	***21.55***			10	***21.55***
	Session Summary			**952**	**4.2**	**0**	***0***	**1**	***0.9***	**0**	***0***	**1**	***0.9***	**12**	***10.8***	**49**	***44.12***	**1**	***0.9***	**64**	***57.62***
Section Total All Samples				**14389**	**16.3109276**	**0**		**9**		**1**		**24**		**151**		**213**		**1**		**399**	
Section Average All Samples				**959**	**1.09**	**0**	***0***	**1**	***2.07***	**0**	***0.23***	**2**	***5.52***	**10**	***34.75***	**14**	***49.02***	**0**	***0.23***	**27**	***91.83***
Section Standard Error of Mean						**0**	***0***	**0.4**	***0.44***	**0.07**	***0.09***	**0.91**	***2.09***	**3.55**	***14.05***	**3.54**	***25.4***	**0.07**	***0.62***	**4.51**	***28.26***

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.		Tench		All Species	
						No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE
Columbia River D/S	1	C25.3-R	04-Oct-18	1627	2.726756							10	8.11			5	4.06			15	12.17
		C27.6-R	04-Oct-18	298	0.6127803									2	39.43	2	39.43			4	78.86
		C28.2-R	04-Oct-18	851	1.131481									20	74.77	12	44.86			32	119.64
		C34.9-L	05-Oct-18	1994	2.135852									30	25.36	2	1.69			32	27.05
		C36.6-L	05-Oct-18	1550	2.394963									10	9.7	1	0.97			11	10.67
		C47.8-L	09-Oct-18	1157	1.439314									20	43.24	21	45.4			41	88.63
		C49.0-L	09-Oct-18	527	0.9297056									35	257.17	7	51.43			42	308.6
		C49.0-R	05-Oct-18	347	0.7195221											1	14.42			1	14.42
		C49.8-L	09-Oct-18	1577	2.4466									40	37.32	5	4.67			45	41.99
		C49.8-R	05-Oct-18	1185	2.39062											10	12.71			10	12.71
		C52.2-L	09-Oct-18	867	0.8889672											4	18.68			4	18.68
		C52.2-R	05-Oct-18	1985	3.79006											6	2.87			6	2.87
	Session Summary			**1164**	**21.6**	**0**	**0**	**0**	**0**	**0**	**0**	**10**	**1.43**	**157**	**22.48**	**76**	**10.88**	**0**	**0**	**243**	**34.79**
	2	C25.3-R	12-Oct-18	1908	2.726756							4	2.77	17	11.76	2	1.38			23	15.91
		C28.2-R	12-Oct-18	848	1.131481									1	3.75					1	3.75
		C34.9-L	12-Oct-18	1887	2.135852											2	1.79			2	1.79
		C36.6-L	13-Oct-18	1524	2.394963									10	9.86	1	0.99			11	10.85
		C47.8-L	15-Oct-18	1243	1.439314									22	44.27	10	20.12	1	2.01	33	66.4
		C49.0-L	15-Oct-18	496	0.9297056							1	7.81	5	39.03	6	46.84			12	93.68
		C49.0-R	13-Oct-18	317	0.7195221									10	157.83	2	31.57			12	189.4
		C49.8-L	15-Oct-18	1911	2.4466									115	88.55	7	5.39			122	93.94
		C49.8-R	13-Oct-18	1375	2.39062									75	82.14	15	16.43			90	98.57
		C52.2-R	13-Oct-18	2157	3.79006											3	1.32			3	1.32
		C52.8-L	16-Oct-18	599	0.8927717			1	6.73											1	6.73
	Session Summary			**1297**	**21**	**0**	**0**	**1**	**0.13**	**0**	**0**	**5**	**0.66**	**255**	**33.7**	**48**	**6.34**	**1**	**0.13**	**310**	**40.97**
	3	C25.3-R	16-Oct-18	1508	2.726756			1	0.88			200	175.1	60	52.53	2	1.75			263	230.26
		C34.9-L	16-Oct-18	2157	2.135852									75	58.61	2	1.56			77	60.17
		C36.6-L	16-Oct-18	1567	2.394963			1	0.96			4	3.84	47	45.09					52	49.88
		C47.8-L	23-Oct-18	1290	1.439314									12	23.27	1	1.94			13	25.21
		C49.0-L	23-Oct-18	484	0.9297056									17	136.01	1	8			18	144.01
		C49.0-R	19-Oct-18	386	0.7195221							1	12.96	30	388.86					31	401.82
		C49.8-L	23-Oct-18	1718	2.4466									55	47.11	3	2.57			58	49.68
		C49.8-R	19-Oct-18	1269	2.39062									70	83.07	5	5.93			75	89
		C52.2-R	19-Oct-18	2105	3.79006									5	2.26	4	1.8			9	4.06
	Session Summary			**1387**	**19**	**0**	**0**	**2**	**0.27**	**0**	**0**	**205**	**28**	**371**	**50.68**	**18**	**2.46**	**0**	**0**	**596**	**81.42**
	4	C25.3-R	30-Oct-18	1485	2.726756							40	35.56	80	71.12	4	3.56			124	110.24
		C27.6-R	30-Oct-18	396	0.6127803									2	29.67					2	29.67
		C28.2-R	30-Oct-18	854	1.131481									35	130.4	2	7.45			37	137.85
		C34.9-L	30-Oct-18	2022	2.135852							5	4.17	35	29.18	2	1.67			42	35.01
		C36.6-L	31-Oct-18	1706	2.344963									27	24.3					27	24.3
		C47.8-L	29-Oct-18	1394	1.439314			1	1.79					25	44.86	12	21.53			38	68.18
		C49.0-L	29-Oct-18	502	0.9297056									30	231.41	8	61.71			38	293.11
		C49.0-R	25-Oct-18	494	0.7195221									5	50.64					5	50.64
		C49.8-L	29-Oct-18	1811	2.4466									300	243.75					300	243.75
		C49.8-R	25-Oct-18	1264	2.39062											1	1.19			1	1.19
		C52.2-L	29-Oct-18	864	0.8889672			1	4.69											1	4.69
		C52.2-R	25-Oct-18	2375	3.79006											2	0.8			2	0.8
	Session Summary			**1264**	**21.6**	**0**	**0**	**2**	**0.26**	**0**	**0**	**45**	**5.93**	**539**	**71.07**	**31**	**4.09**	**0**	**0**	**617**	**81.36**
	5	C11.5-R	04-Nov-18	1369	1.87			1	1.41					10	14.06	3	4.22			14	19.69
		C13.4-L	03-Nov-18	1144	1.392									30	67.82					30	67.82
		C14.8-L	03-Nov-18	1738	2.26			3	2.75					50	45.83	1	0.92			54	49.49
		C17.0-L	03-Nov-18	1561	1.906			2	2.42					120	145.2	5	6.05			127	153.67
		C18.8-R	04-Nov-18	1512	1.61324									15	22.14					15	22.14
		C20.4-R	02-Nov-18	1200	1.474			1	2.04					70	142.47	4	8.14			75	152.65
		C22.9-R	02-Nov-18	922	1.221			15	47.97					10	31.98	50	159.89			75	239.84
		C25.3-L	02-Nov-18	1128	1.88			11	18.67					10	16.98	21	35.65			42	71.3
		C26.2-L	02-Nov-18	462	0.95									21	172.25					21	172.25
		C29.6-L	01-Nov-18	731	1.10546									15	66.82					15	66.82
		C32.4-L	01-Nov-18	1710	1.997									100	105.42	1	1.05			101	106.48
		C33.3-R	01-Nov-18	1528	1.613			1	1.46			1	1.46	30	43.82	5	7.3			37	54.04
		C36.9-R	02-Nov-18	1830	2.27									250	216.65	1	0.87			251	217.52
		C41.1-L	31-Oct-18	2020	2.41									20	14.79					20	14.79
		C43.7-R	31-Oct-18	664	1.3446											1	4.03			1	4.03
		C44.6-L	31-Oct-18	706	1.01									40	201.95					40	201.95
		C46.4-L	31-Oct-18	1074	1.59									10	21.08					10	21.08
	Session Summary			**1253**	**27.9**	**0**	**0**	**34**	**3.5**	**0**	**0**	**1**	**0.1**	**801**	**82.49**	**92**	**9.47**	**0**	**0**	**928**	**95.56**
Section Total All Samples				**77180**	**111.0405805**	**0**		**39**		**0**		**266**		**2123**		**265**		**1**		**2694**	
Section Average All Samples				**1265**	**1.82**	**0**	**0**	**1**	**1**	**0**	**0**	**4**	**6.82**	**35**	**54.41**	**4**	**6.79**	**0**	**0.03**	**44**	**69.04**
Section Standard Error of Mean						**0**	**0**	**0.31**	**0.84**	**0**	**0**	**3.33**	**2.92**	**6.85**	**10.2**	**0.97**	**3.14**	**0.02**	**0.03**	**7.85**	**11.42**
All Sections Total All Samples				**140526**	**171.3079969**	**1**	**0**	**224**	**0.03**	**9**	**0**	**376**	**0.06**	**2824**	**0.42**	**1447**	**0.22**	**3**	**0**	**4884**	**0.73**
All Sections Average All Samples						**0**	**0.02**	**2**	**3.82**	**0**	**0.15**	**3**	**6.41**	**25**	**48.14**	**13**	**24.67**	**0**	**0.05**	**43**	**83.26**
All Sections Standard Error of Mean						**0.01**	**0.04**	**0.6**	**0.92**	**0.04**	**0.17**	**1.85**	**2.1**	**4.25**	**7.48**	**1.72**	**5.66**	**0.02**	**0.08**	**4.98**	**9.13**

Appendix F – Life History

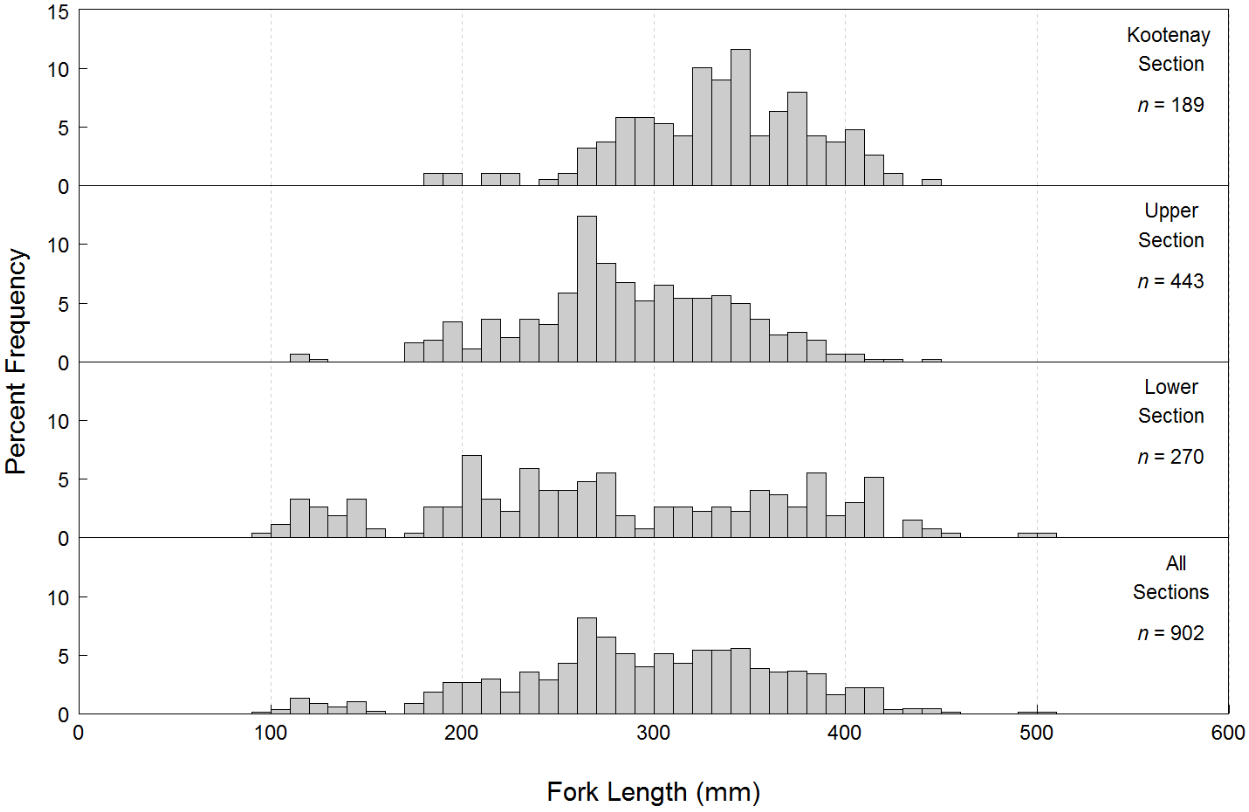


Figure F1. Length-frequency distributions by site for Mountain Whitefish captured by boat electroshocking in sampled sections of the lower Columbia River, 1 to 31 October 2018.

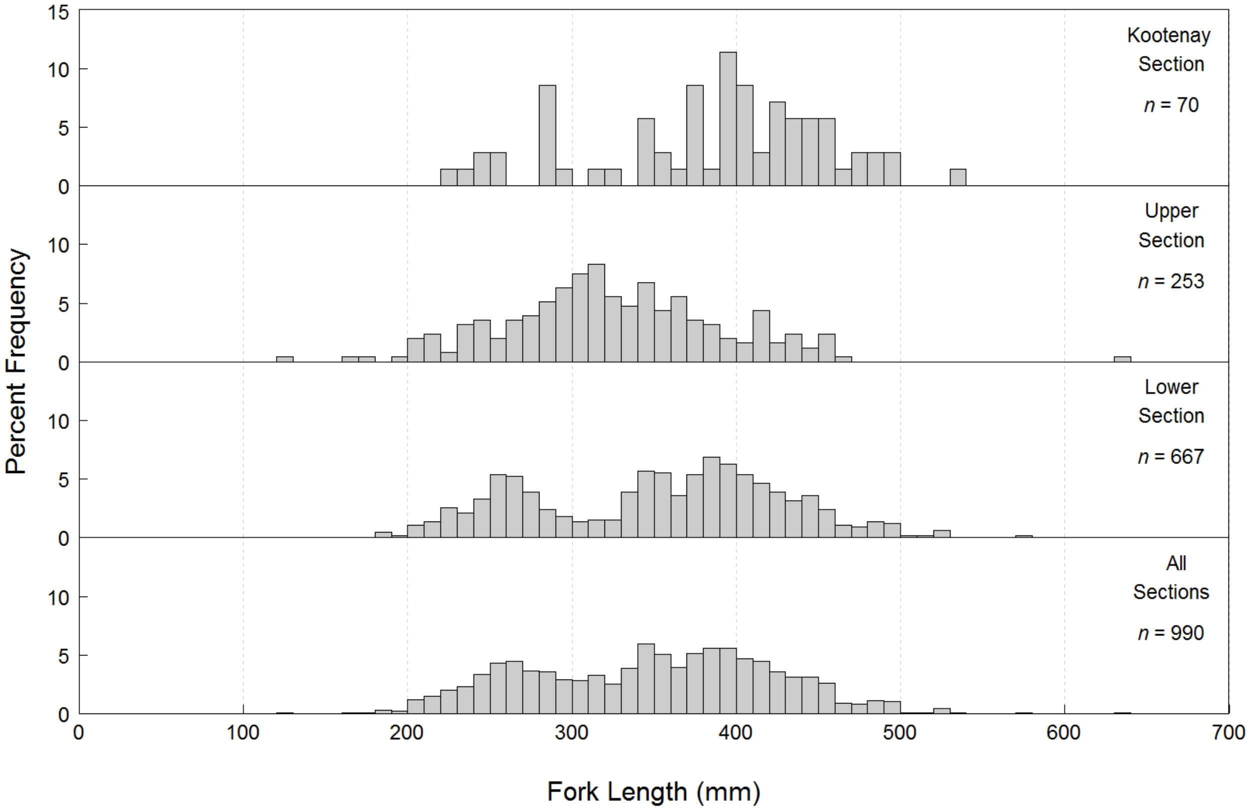


Figure F2. Length-frequency distributions by site for Rainbow Trout captured by boat electroshocking in sampled sections of the lower Columbia River, 1 to 31 October 2018.

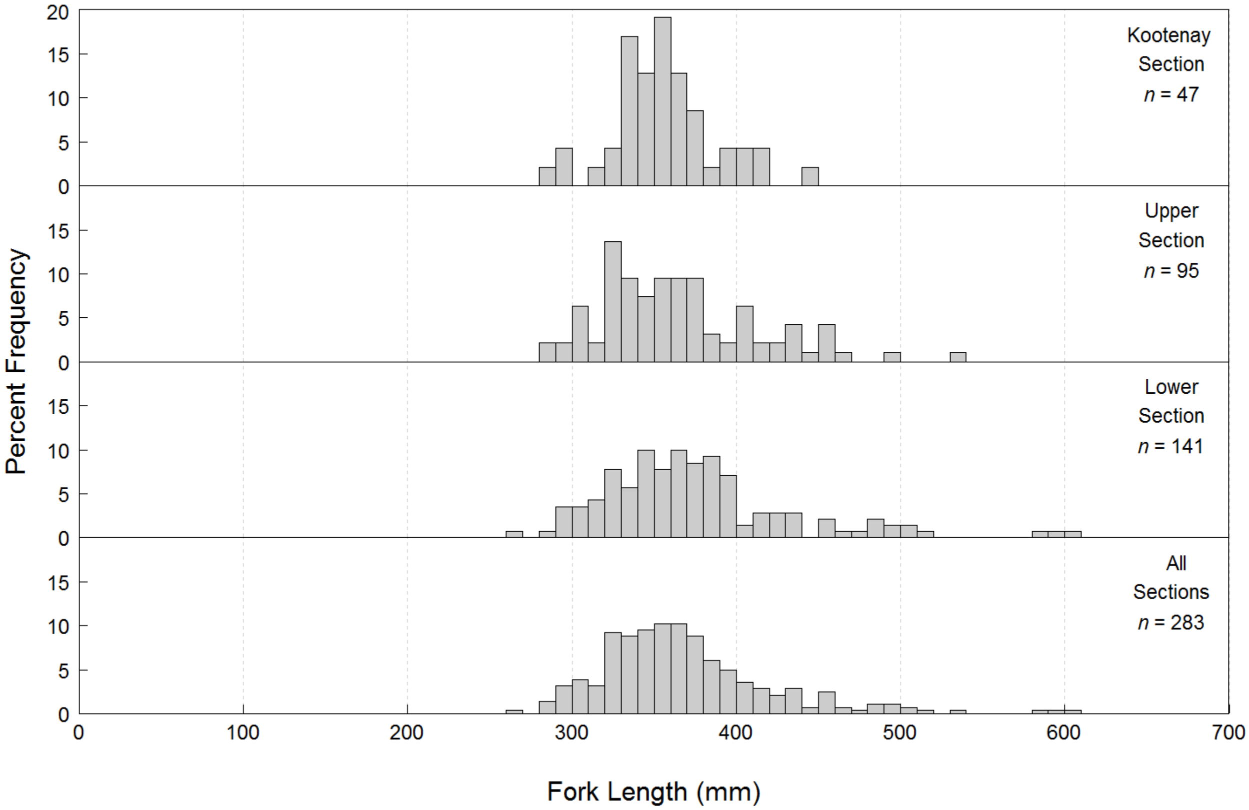
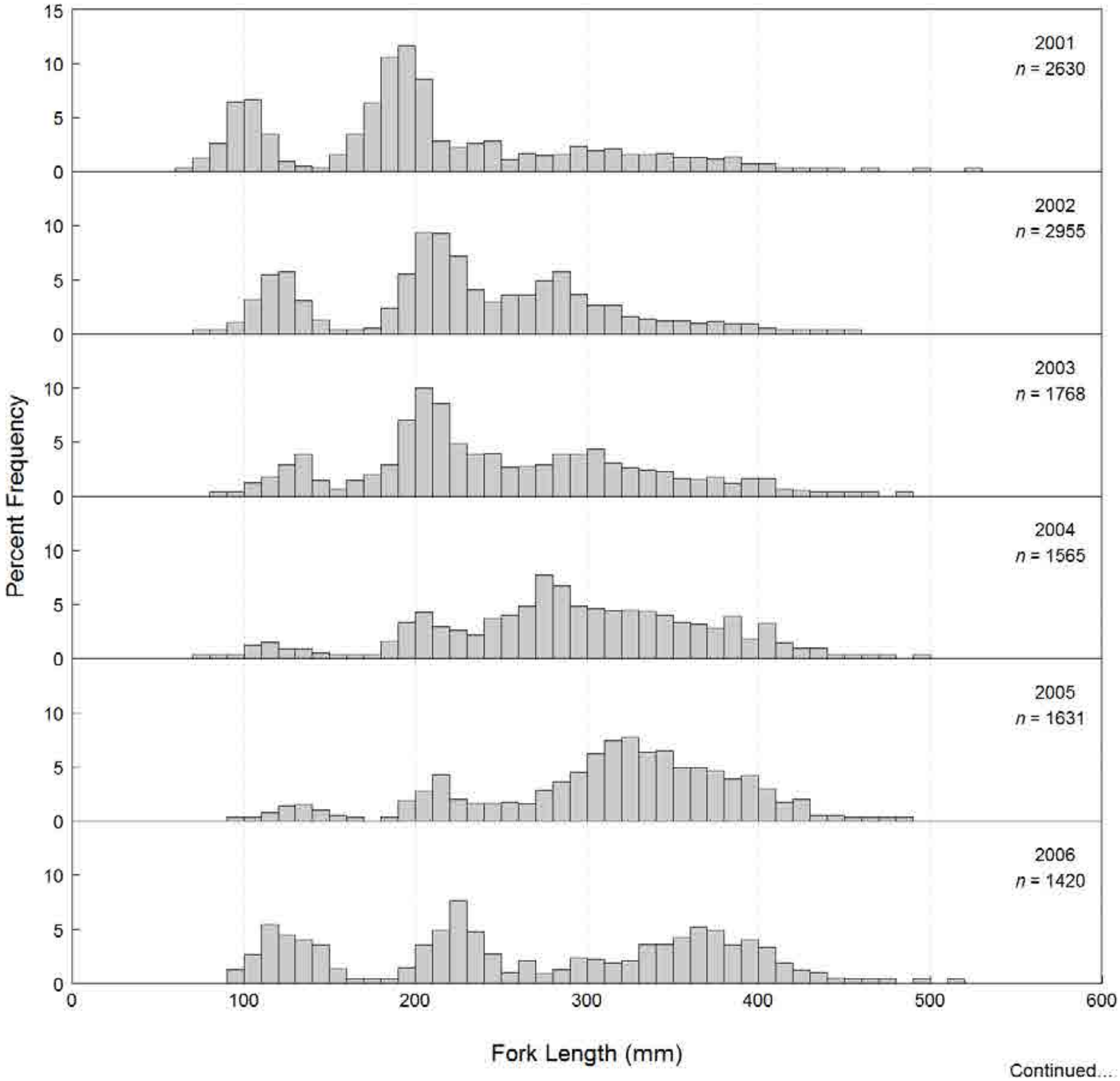


Figure F3. Length-frequency distributions by site for Walleye captured by boat electroshocking in sampled sections of the lower Columbia River, 1 to 31 October 2018.



Continued...

Figure F4. Length-frequency distributions by year for Mountain Whitefish captured by boat electroshocking in sampled sections of the lower Columbia River, 2001 to 2018.

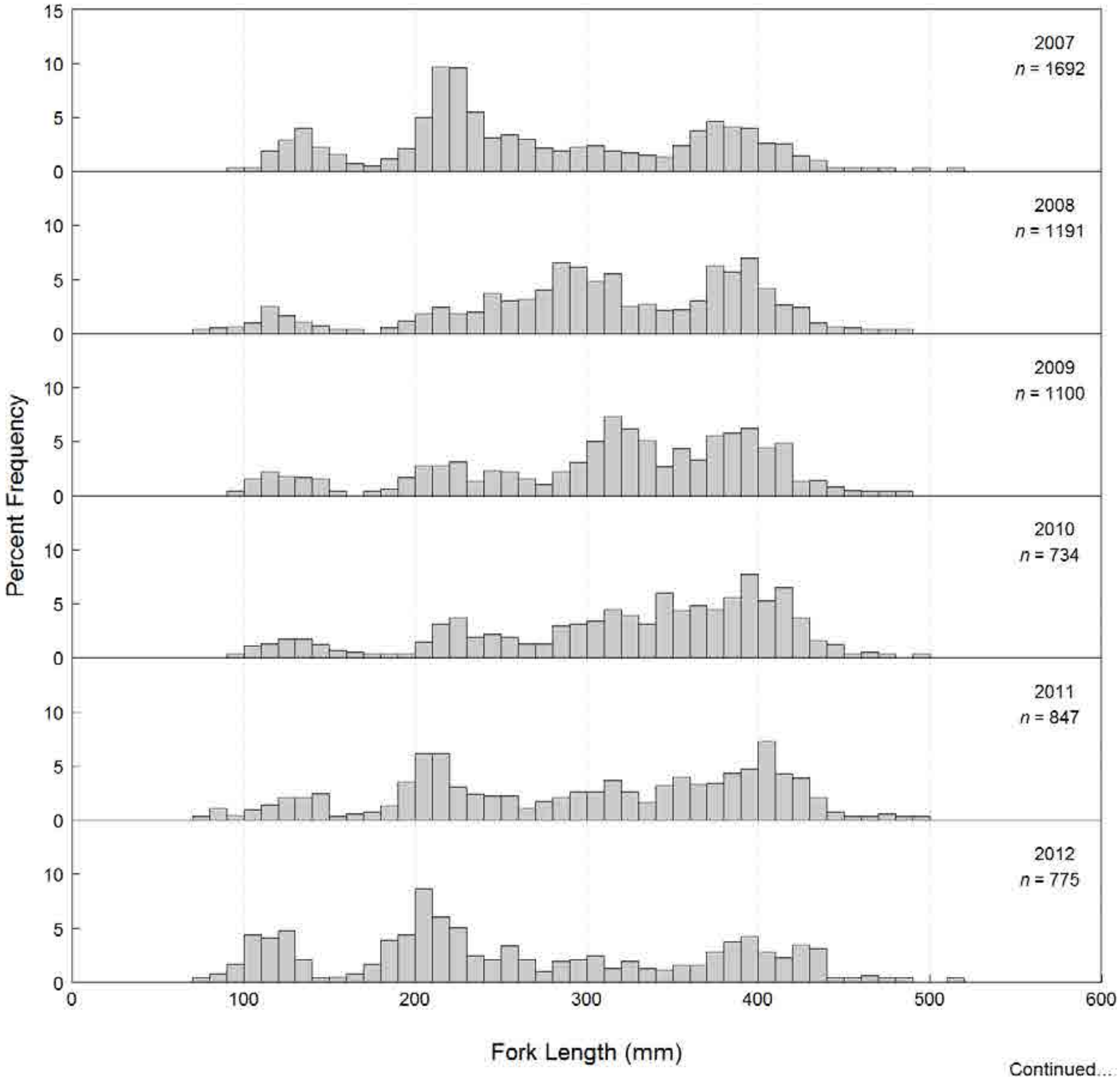


Figure F4. Continued.

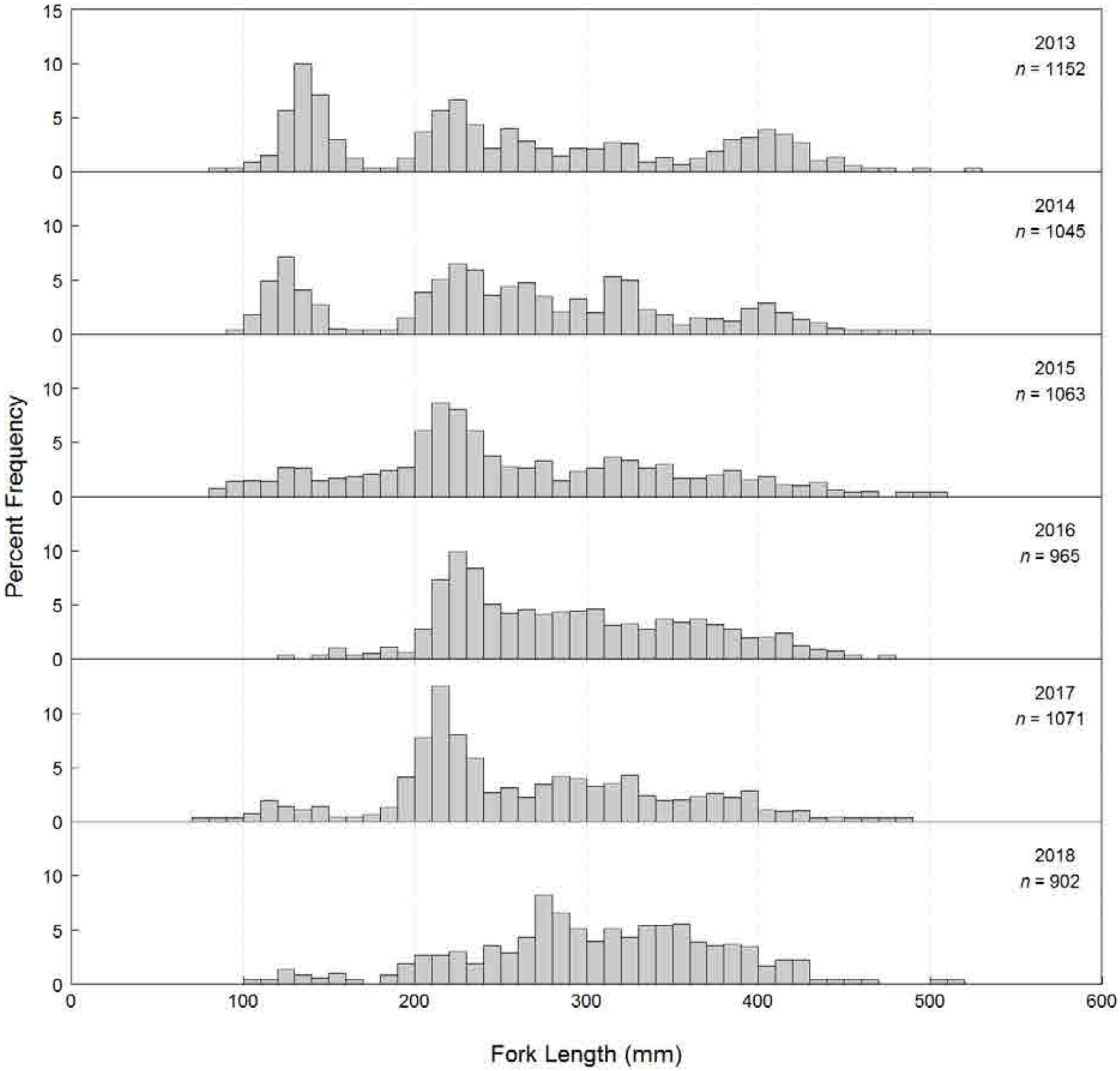
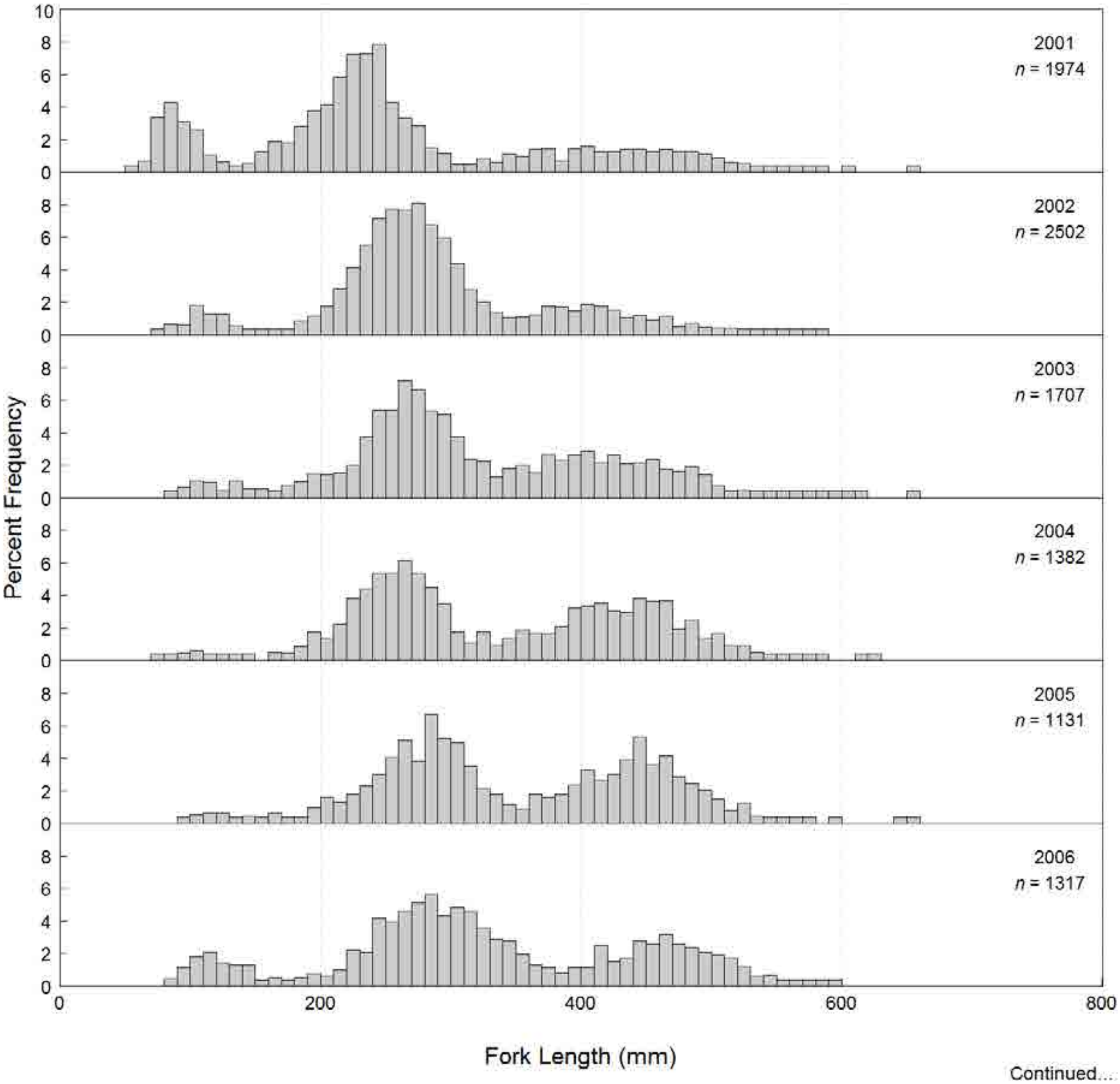
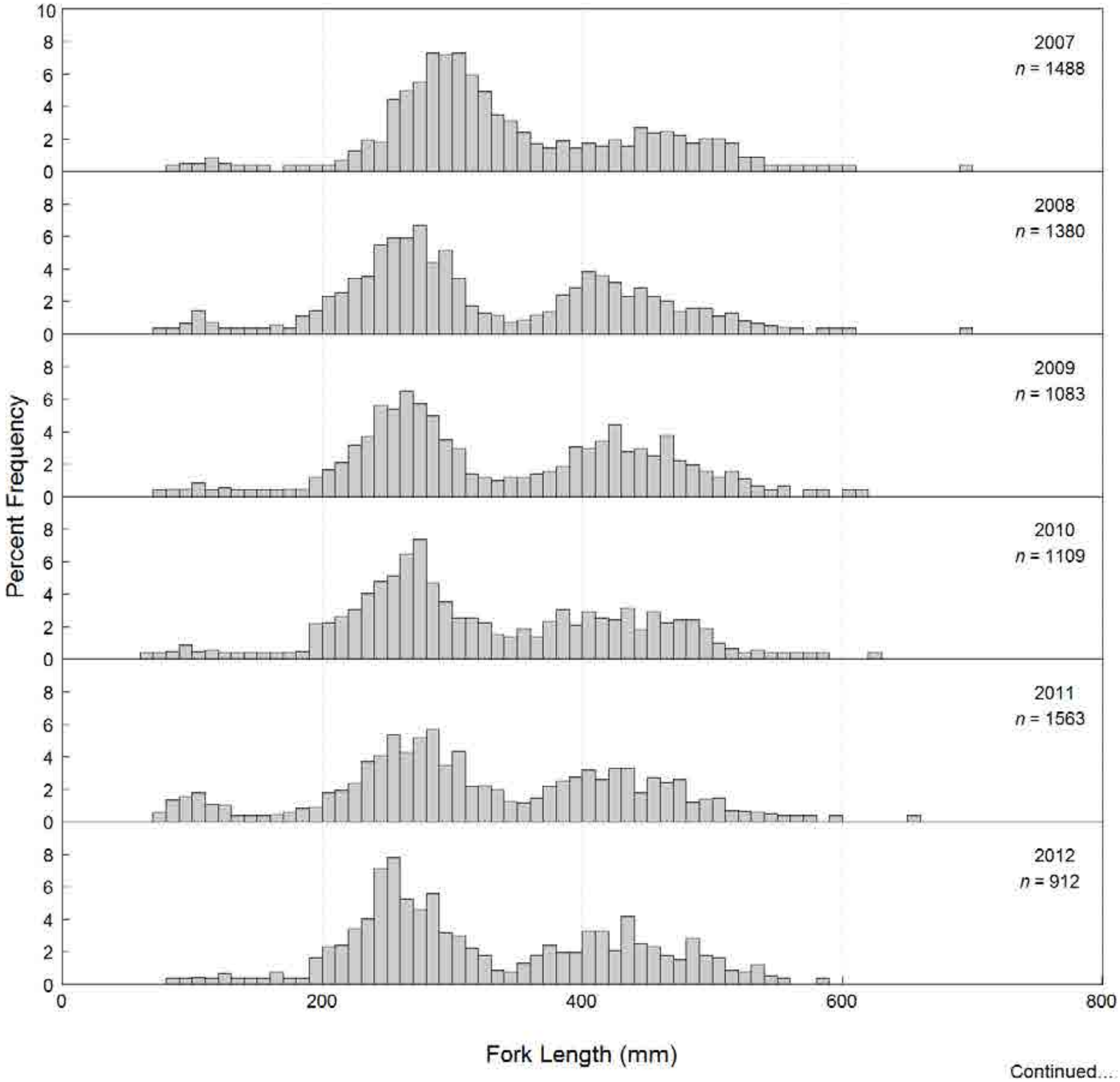


Figure F4. Concluded.



Continued...

Figure F5. Length-frequency distributions by year for Rainbow Trout captured by boat electroshocking in sampled sections of the lower Columbia River, 2001 to 2018.



Continued...

Figure F5. Continued.

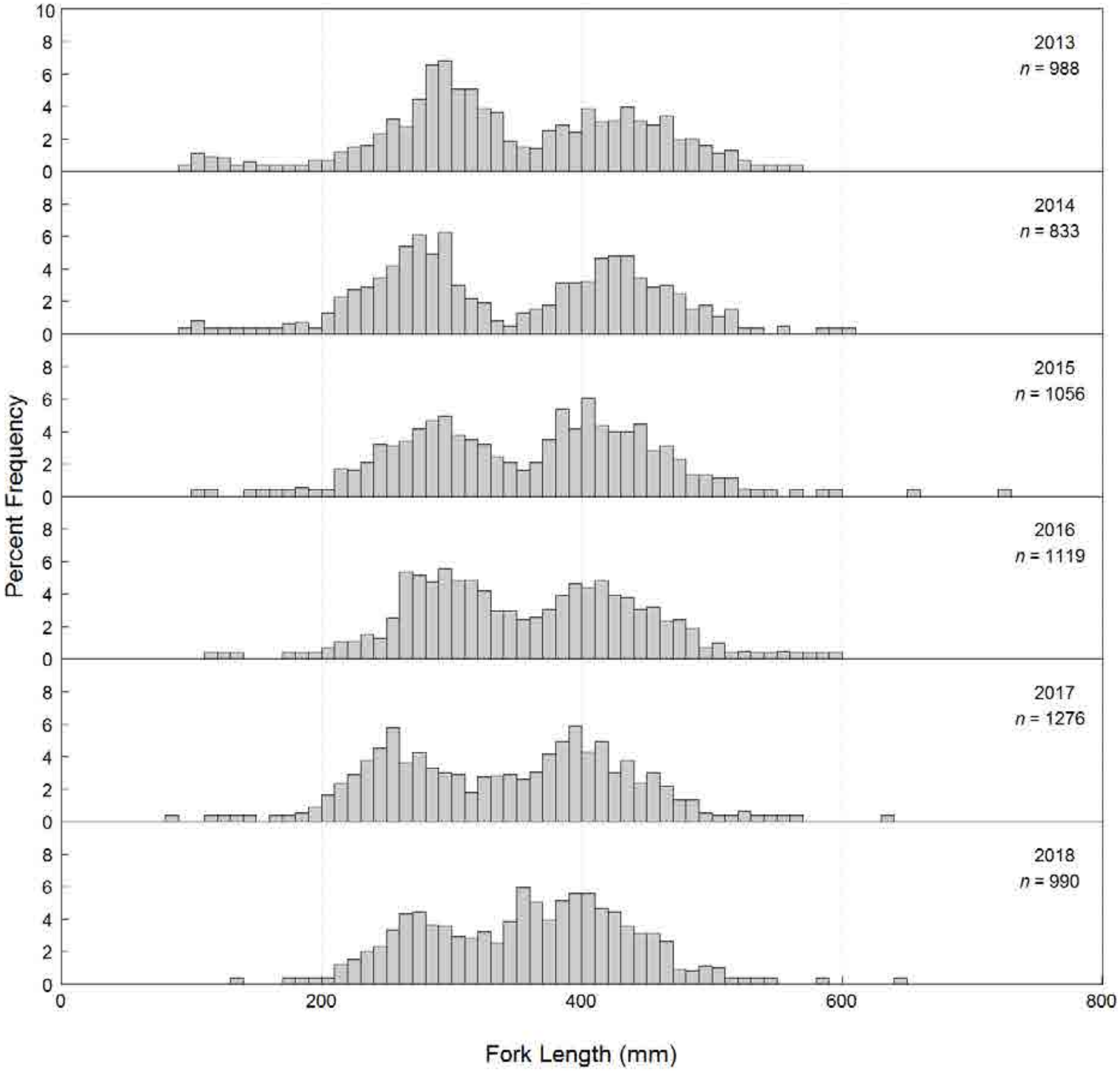


Figure F5. Concluded.

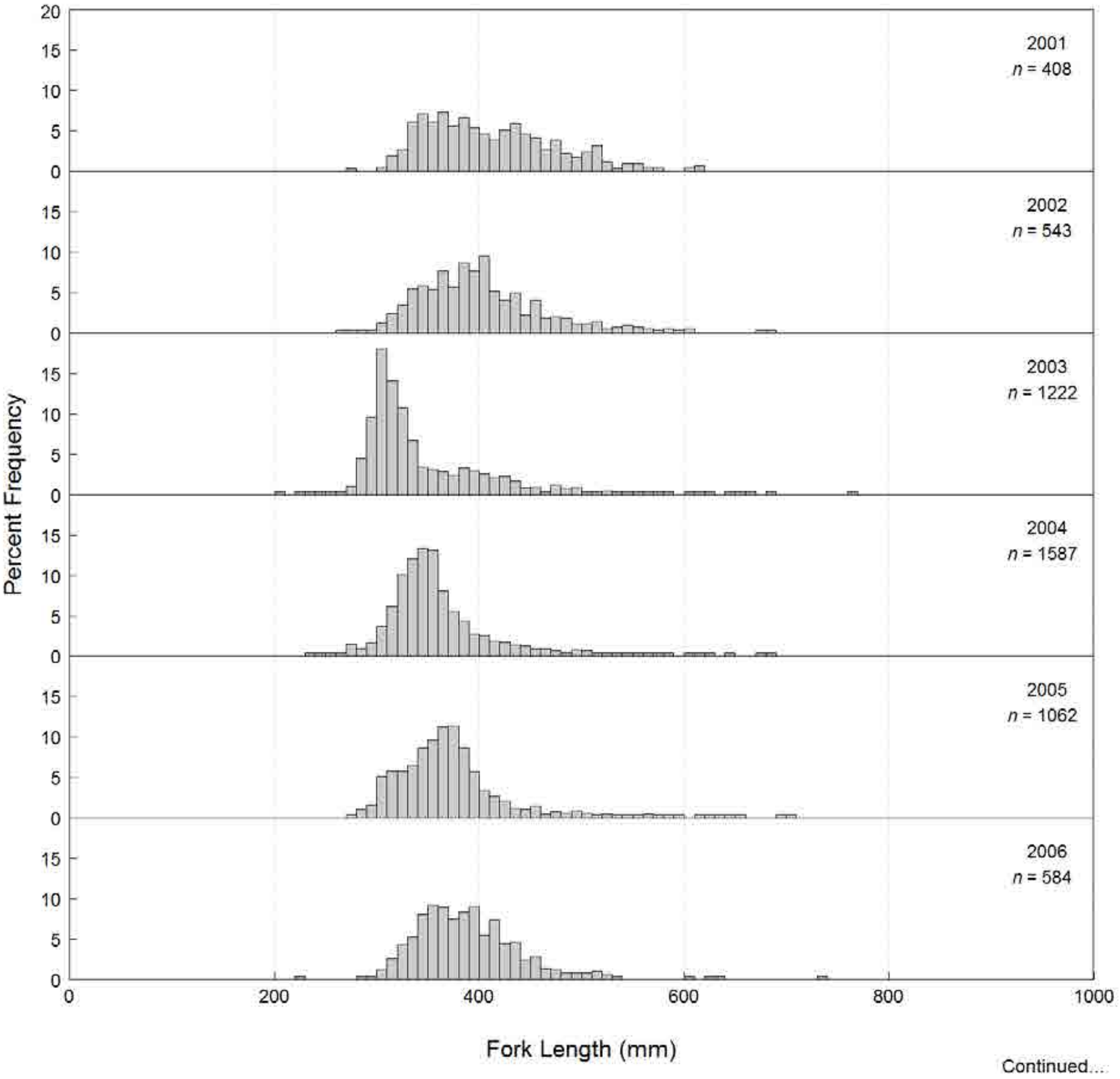
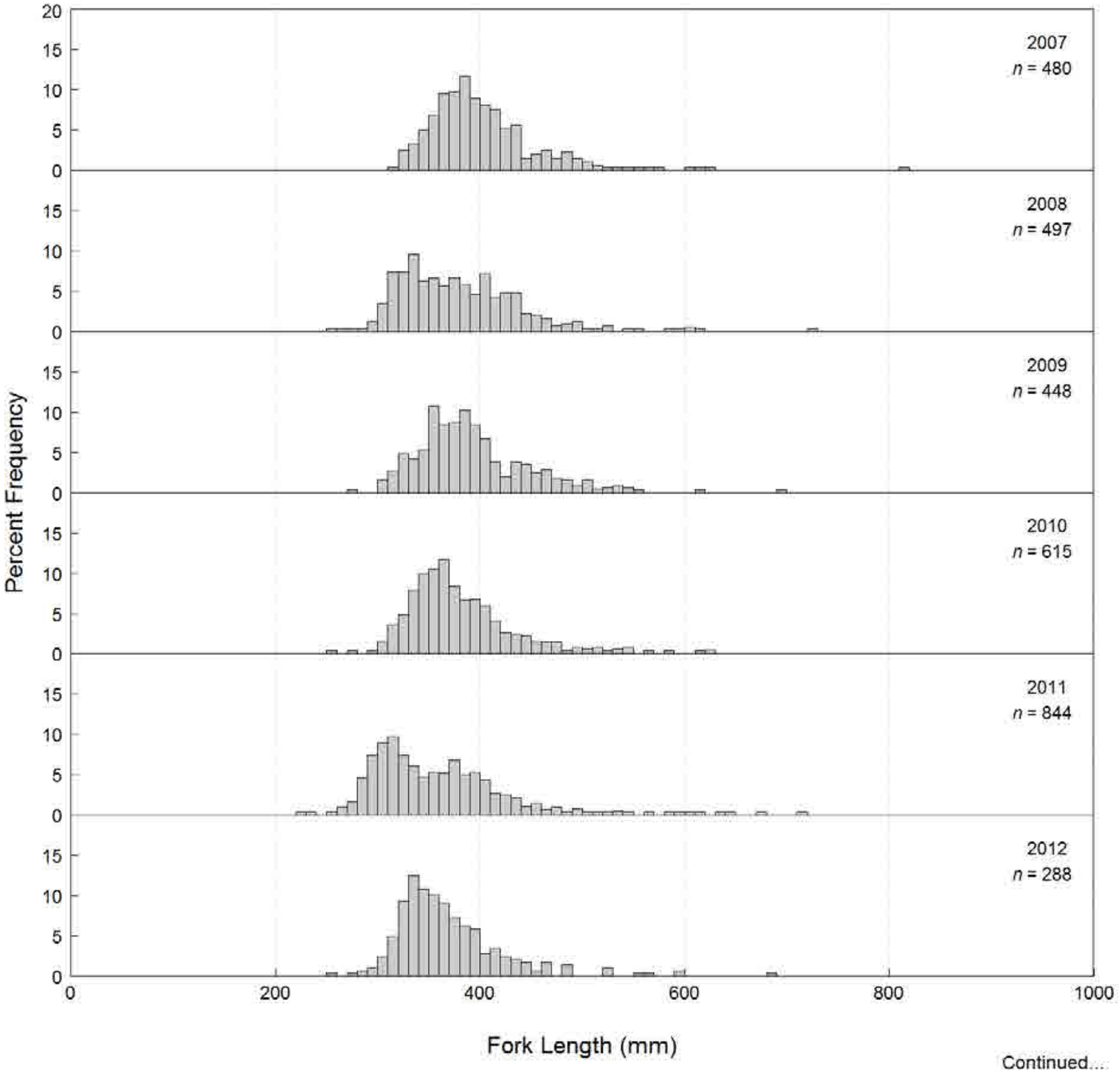


Figure F6. Length-frequency distributions by year for Walleye captured by boat electroshocking in sampled sections of the lower Columbia River, 2001 to 2018.



Continued…

Figure F6. Continued.

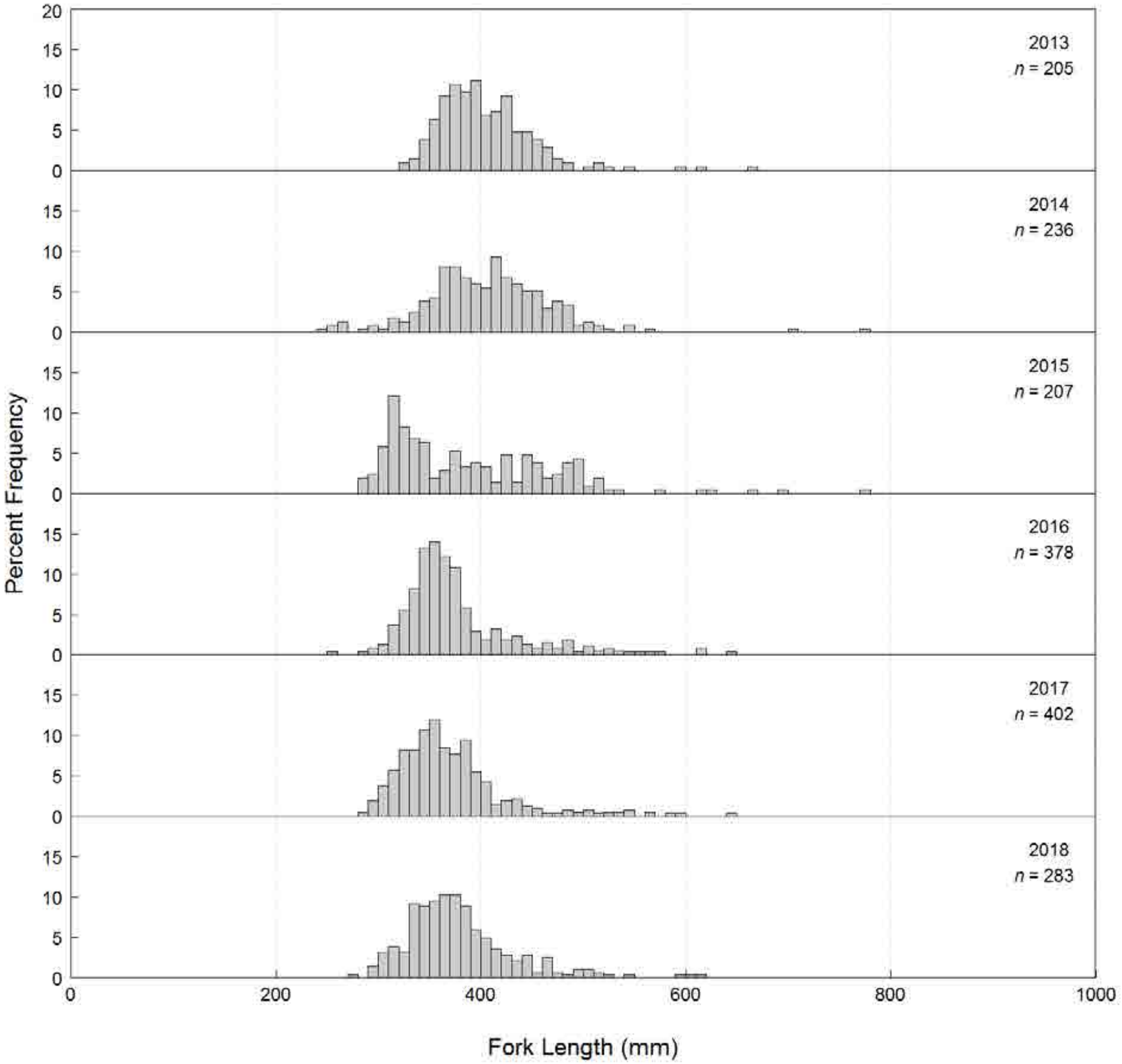
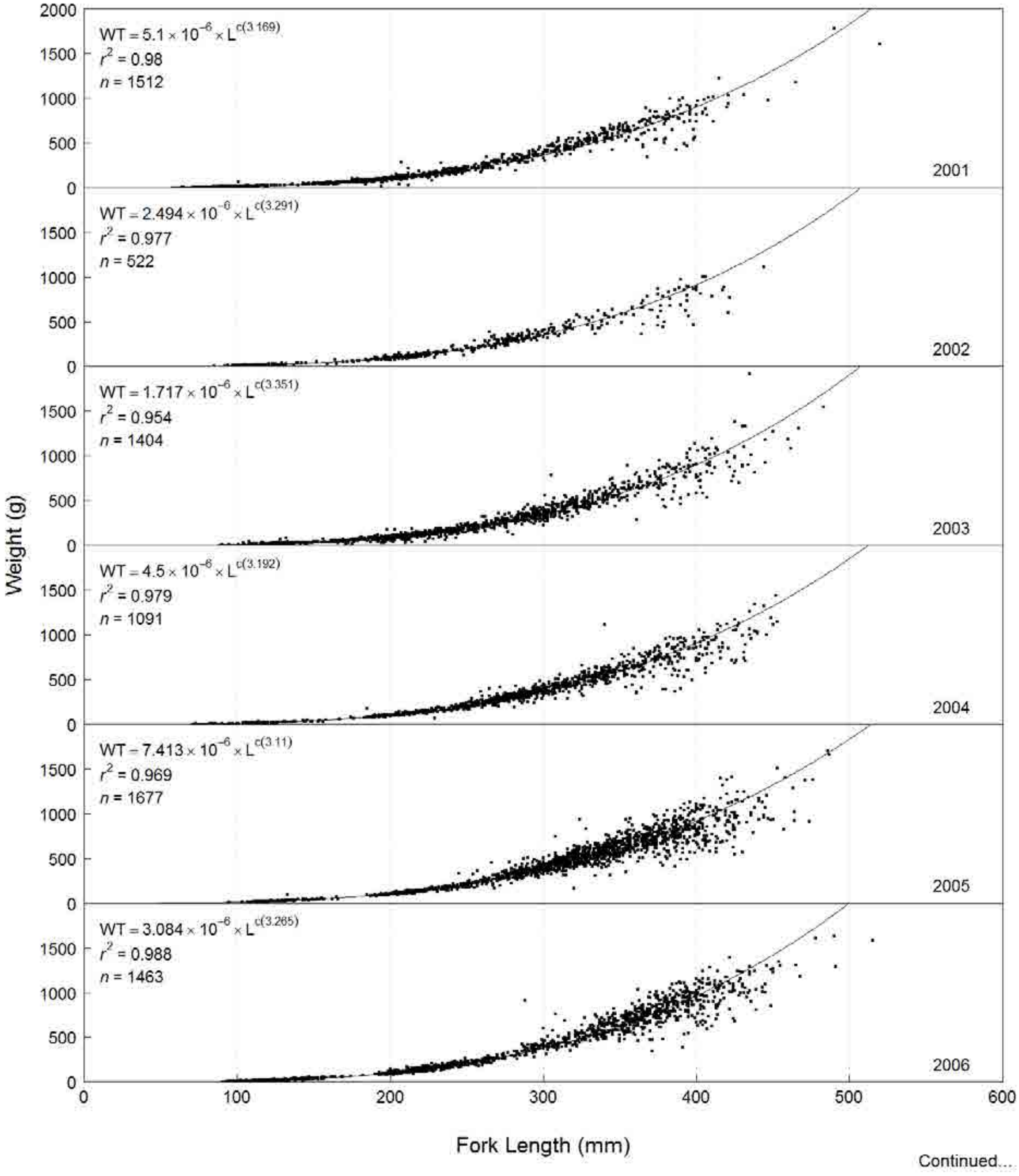
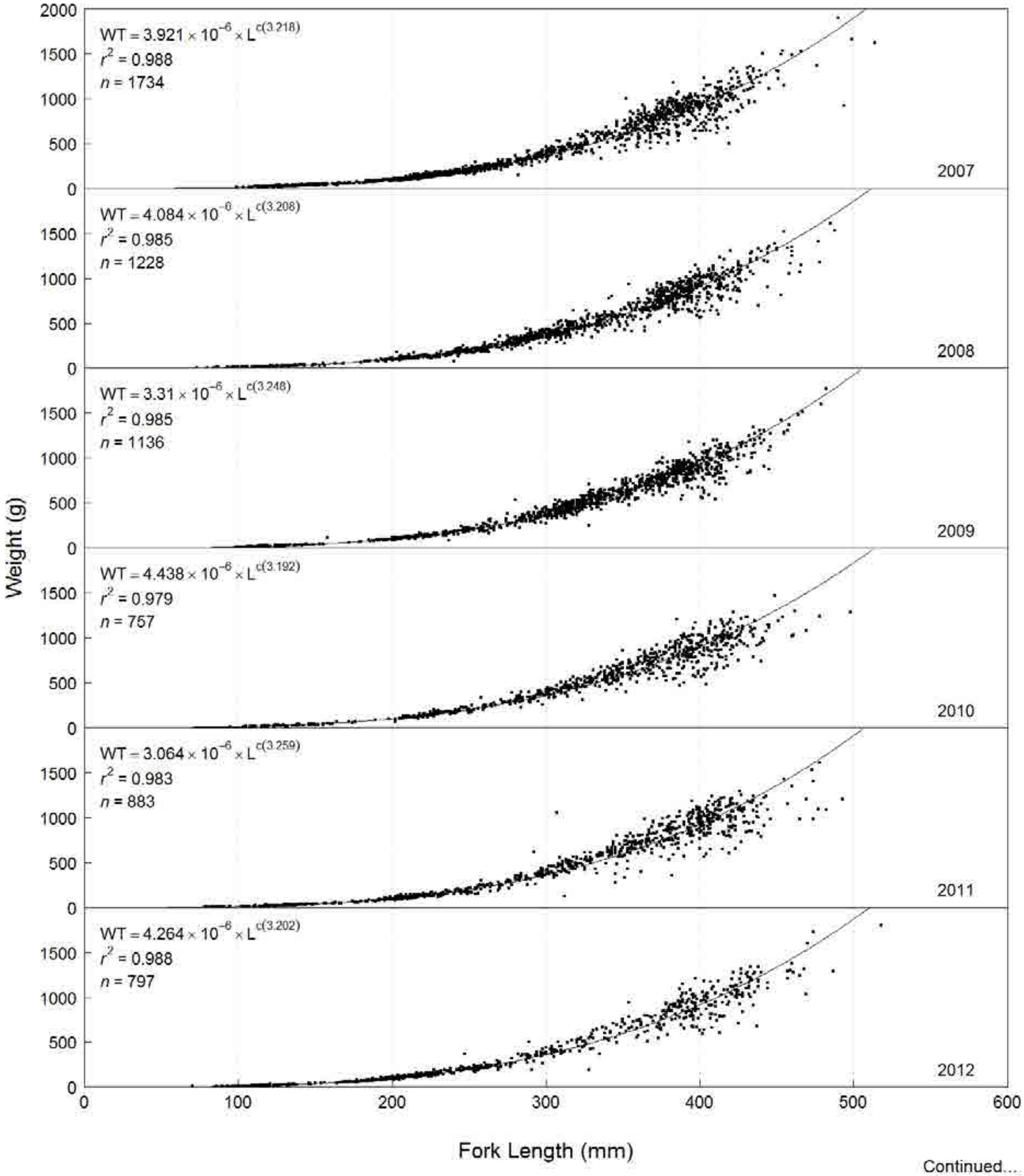


Figure F6. Concluded.



Continued...

Figure F7. Length-weight regressions for Mountain Whitefish captured by boat electroshocking in the lower Columbia River, 2001 to 2018.



Continued...

Figure F7. Continued.

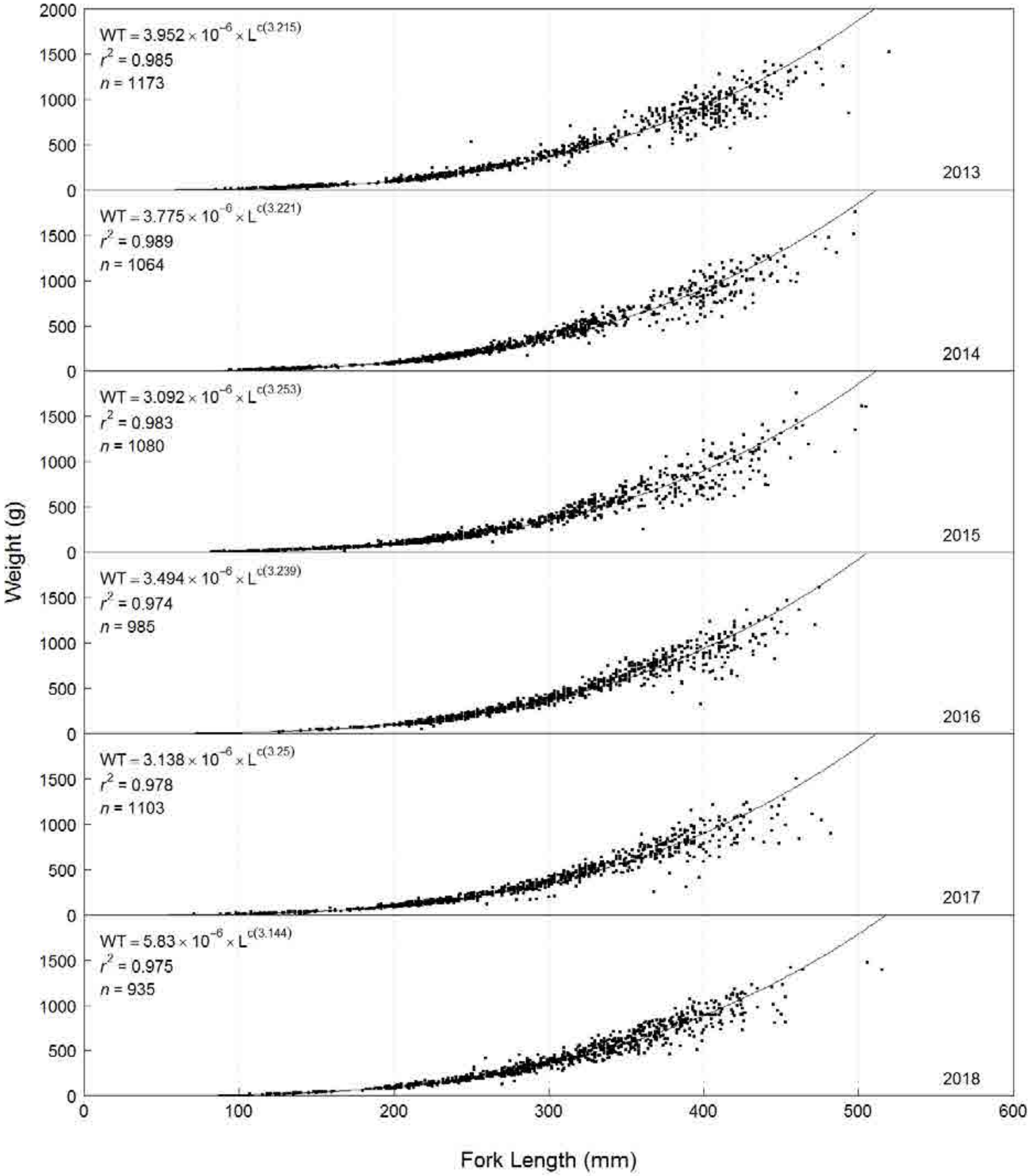
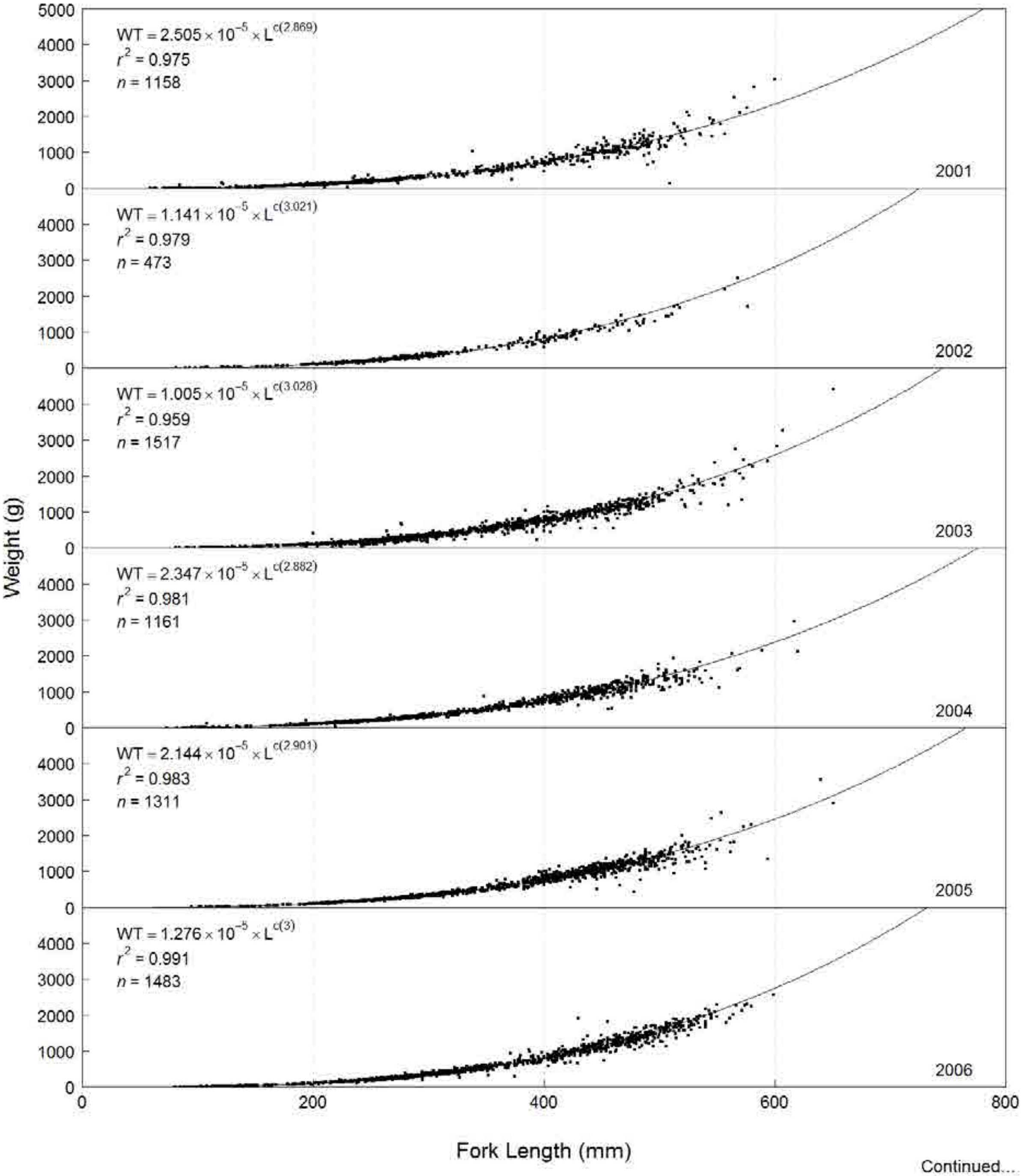


Figure F7. Concluded.



Continued...

Figure F8. Length-weight regressions for Rainbow Trout captured by boat electroshocking in the lower Columbia River, 2001 to 2018.

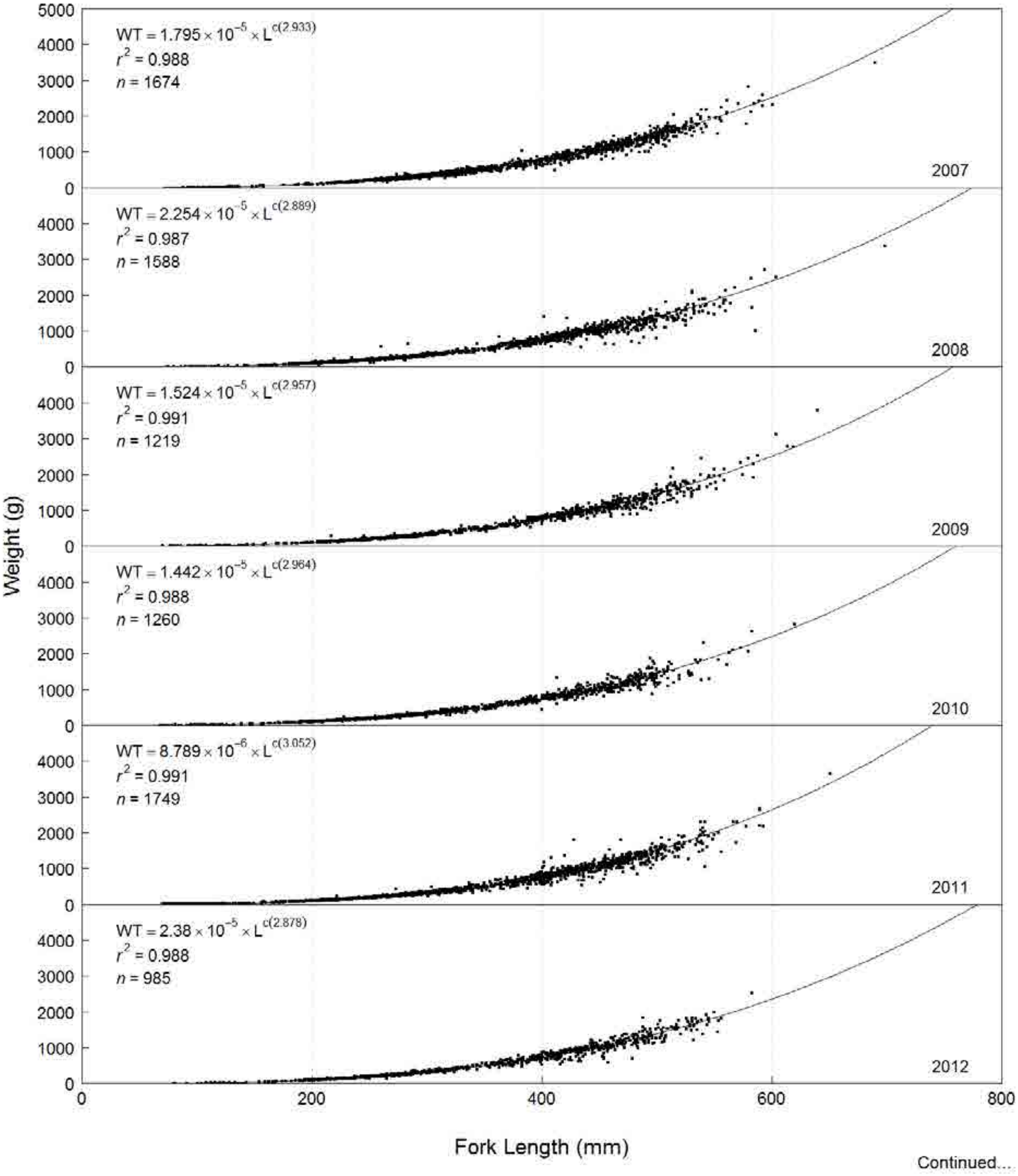


Figure F8. Continued.

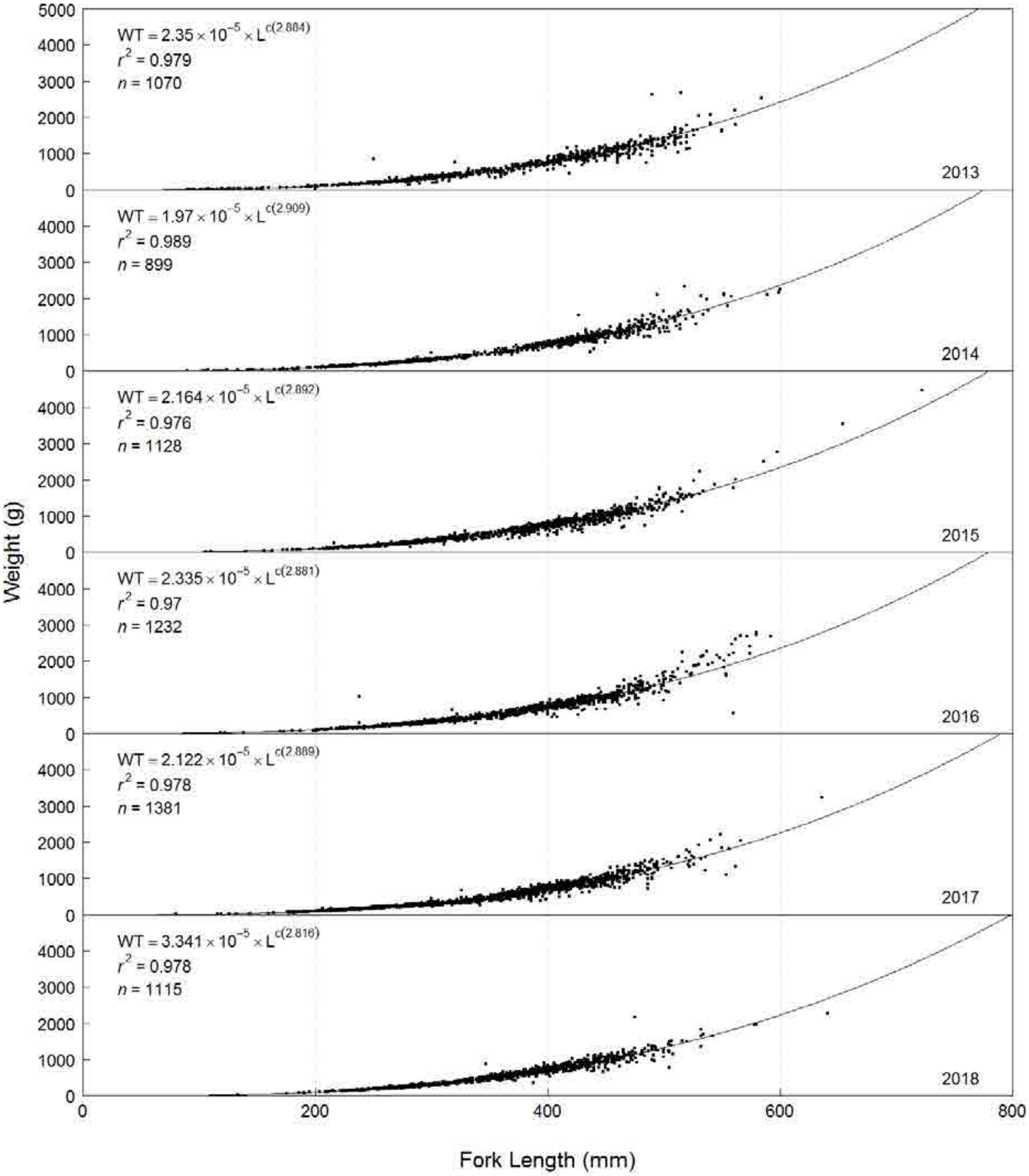
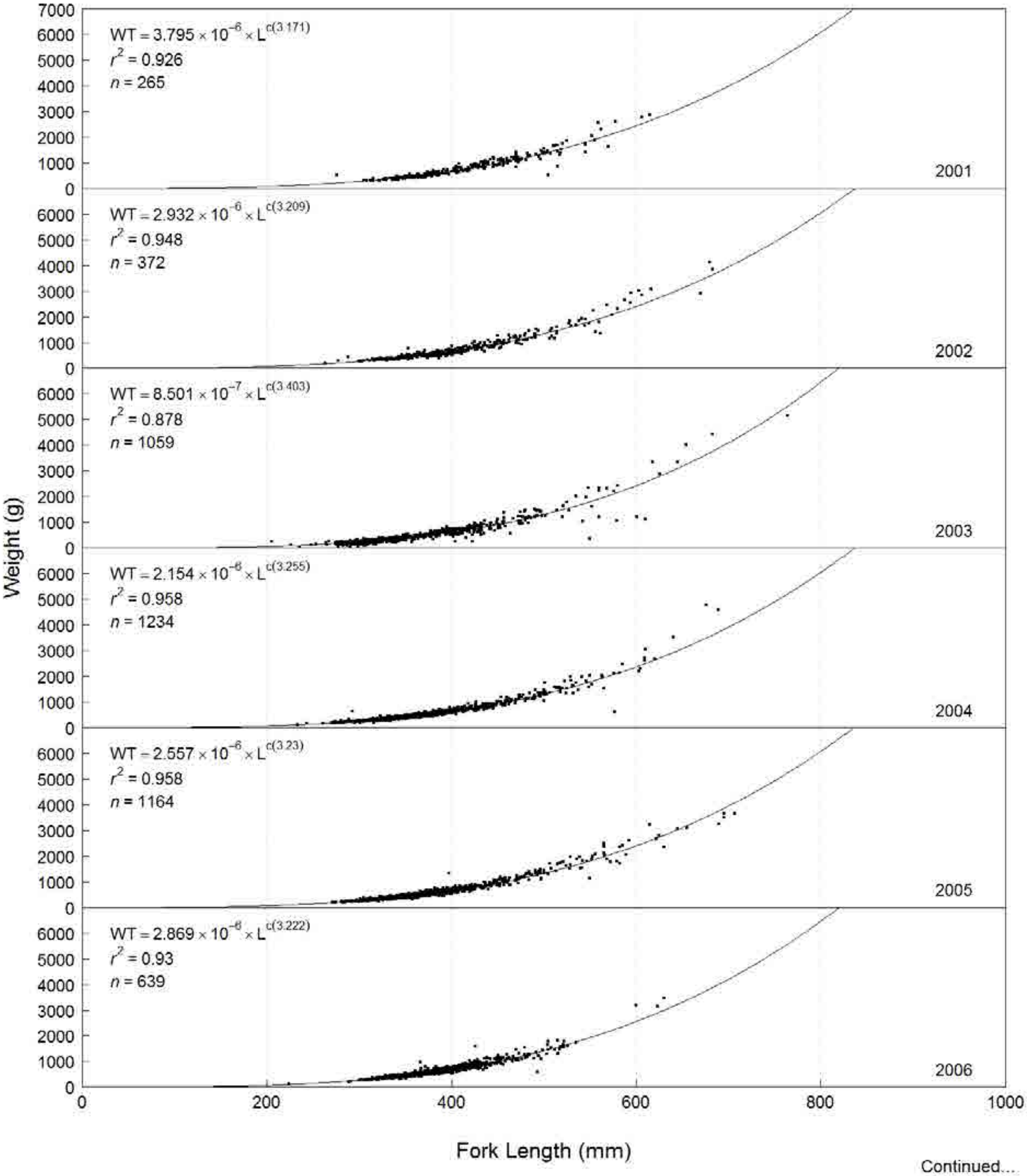
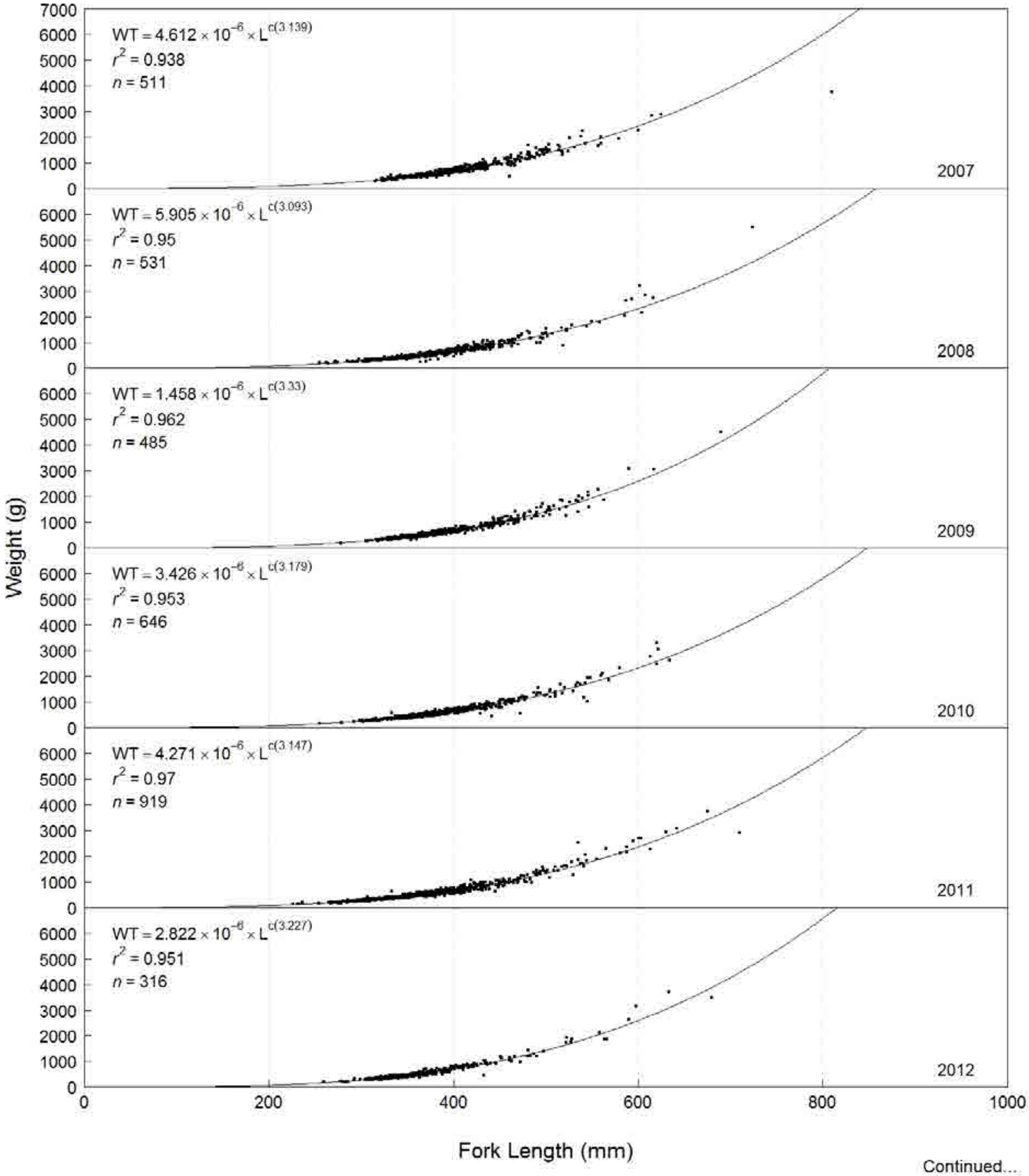


Figure F8. Concluded.



Continued...

Figure F9. Length-weight regressions for Walleye captured by boat electroshocking in the lower Columbia River, 2001 to 2018.



Continued...

Figure F9. Continued.

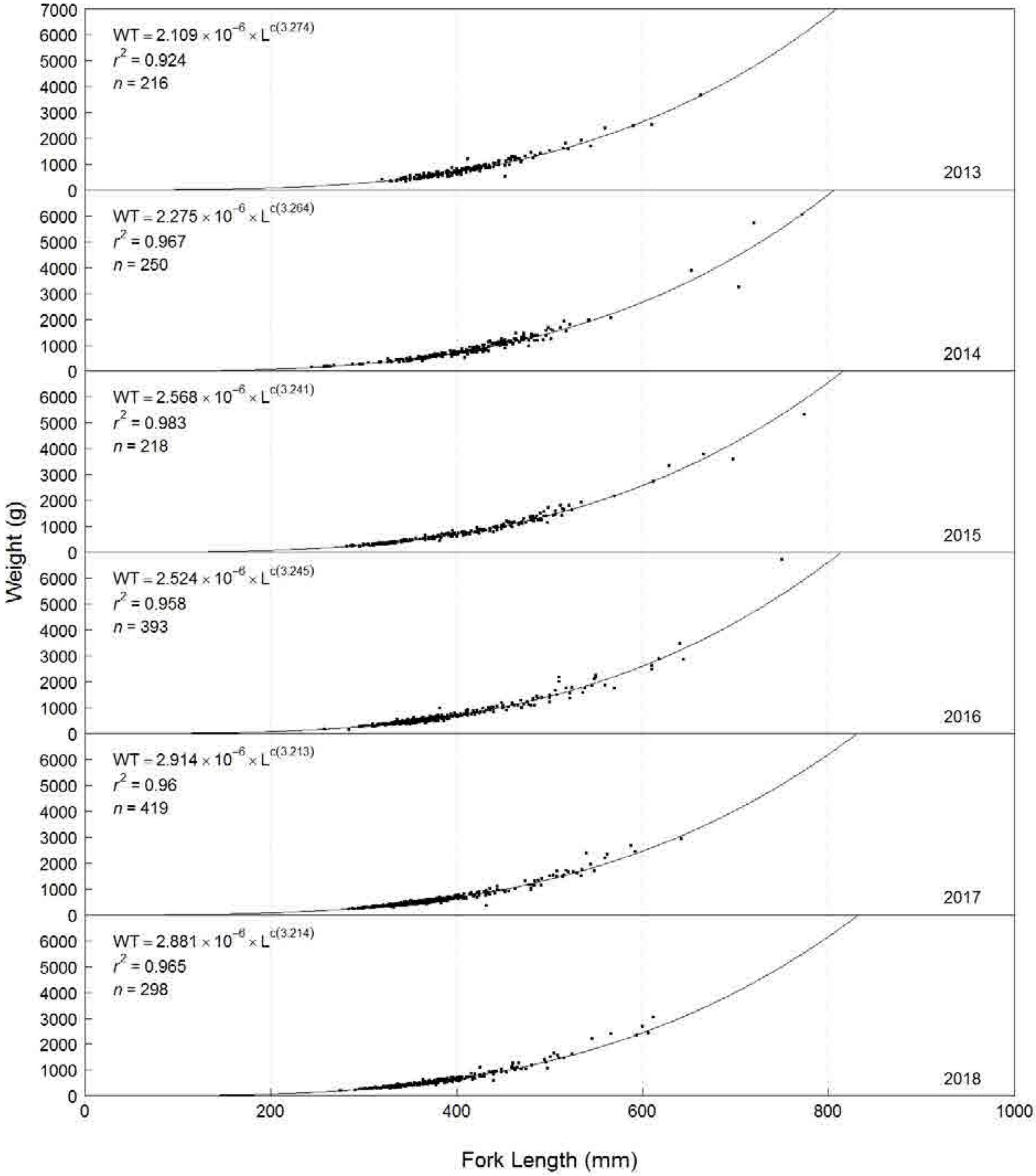


Figure F9. Concluded.

Appendix G – Additional Results

Appendix G: Additional Figures

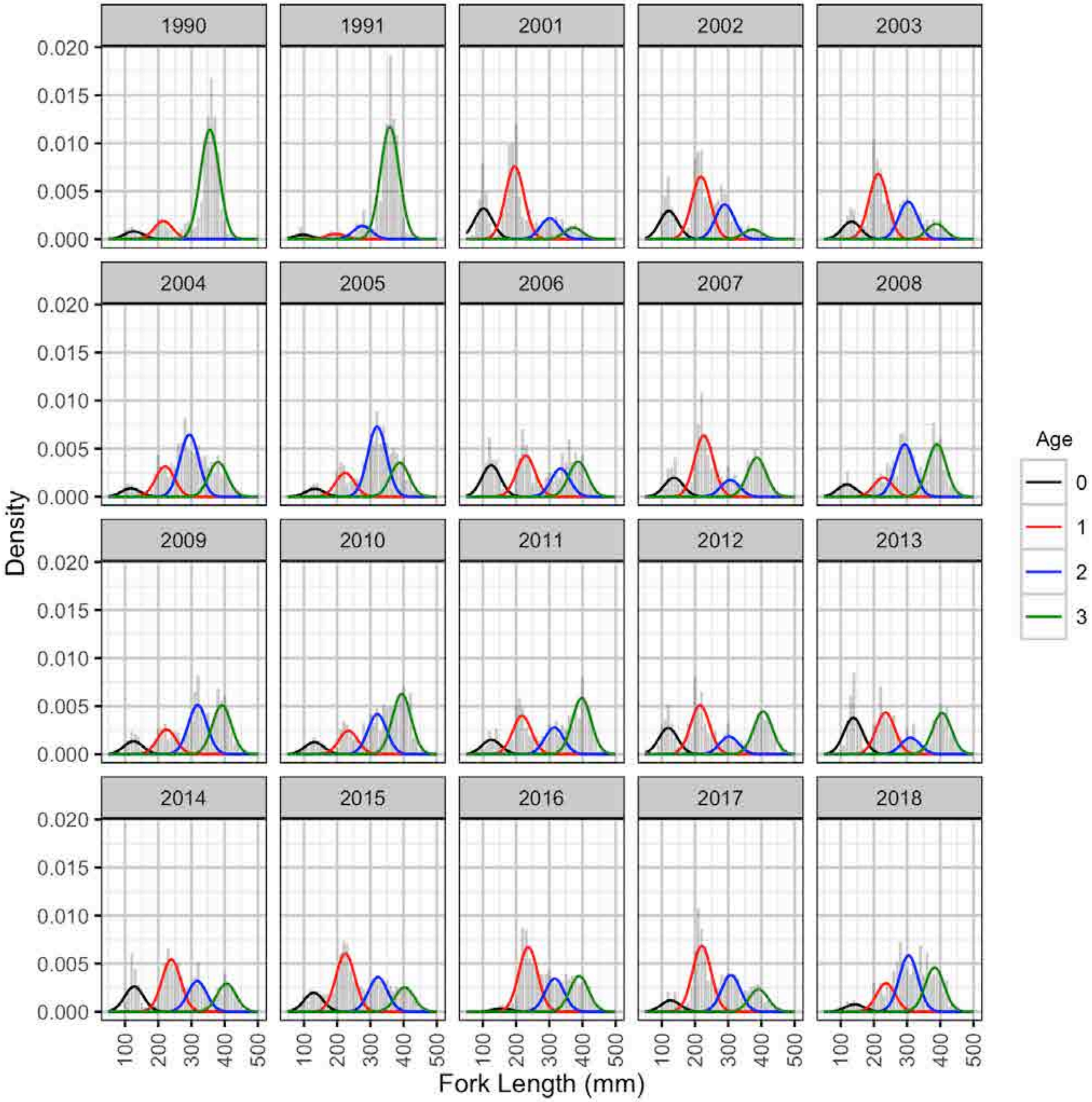


Figure G1: Predicted length-density plot for Mountain Whitefish by life stage and year.

Appendix G: Additional Figures

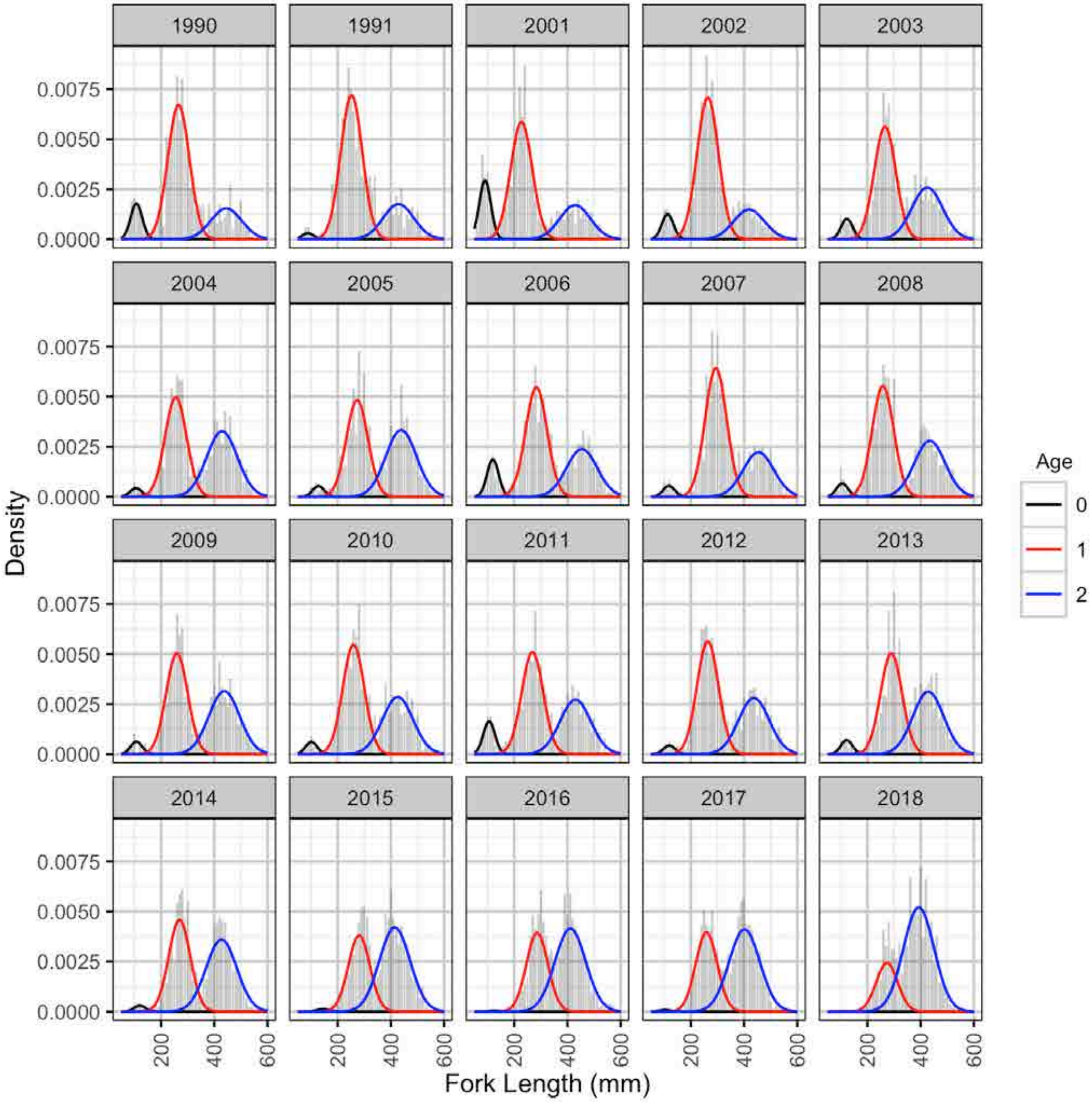


Figure G2: Predicted length-density plot for Rainbow Trout by life stage and year.

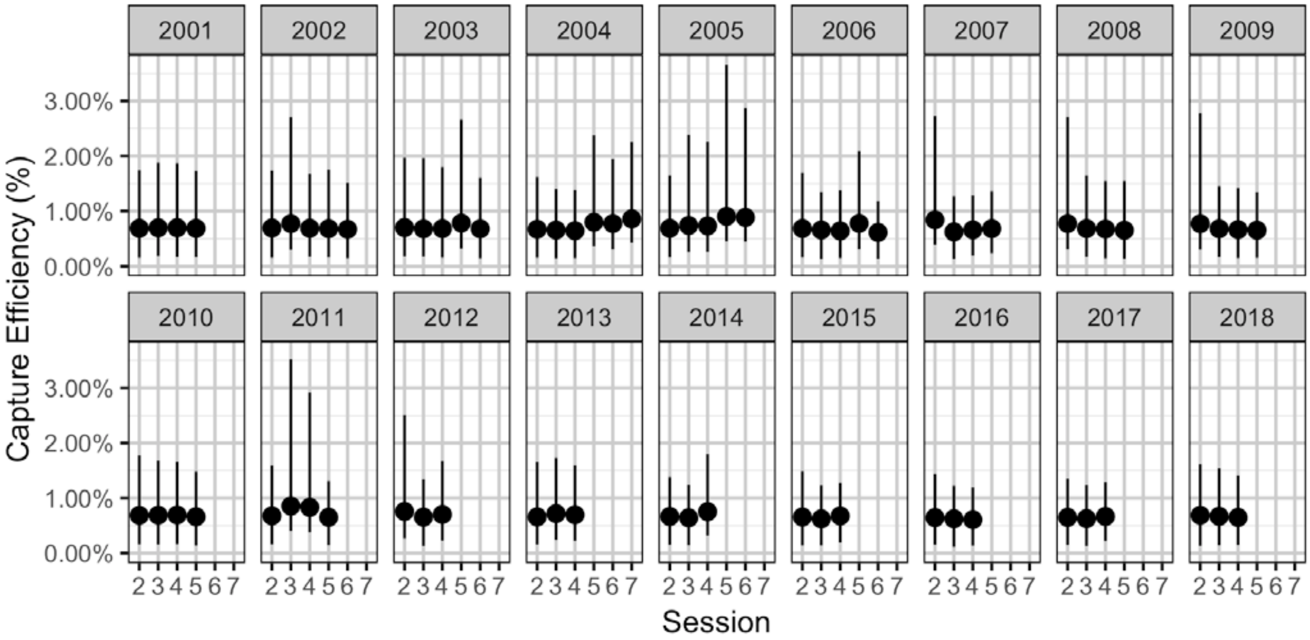


Figure G3: Capture efficiency (mean with 95% credible intervals) of subadult Mountain Whitefish by year and sample session in the lower Columbia River, 2001–2018.

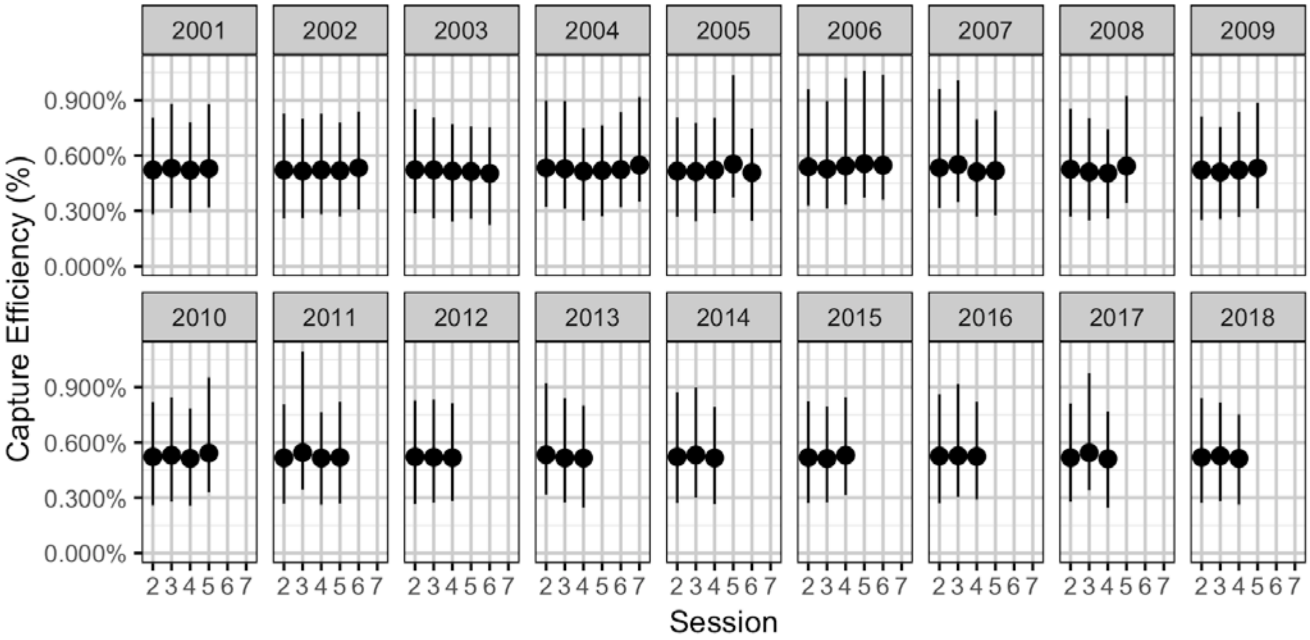


Figure G4: Capture efficiency (mean with 95% credible intervals) of adult Mountain Whitefish by year and sample session in the lower Columbia River, 2001–2018.

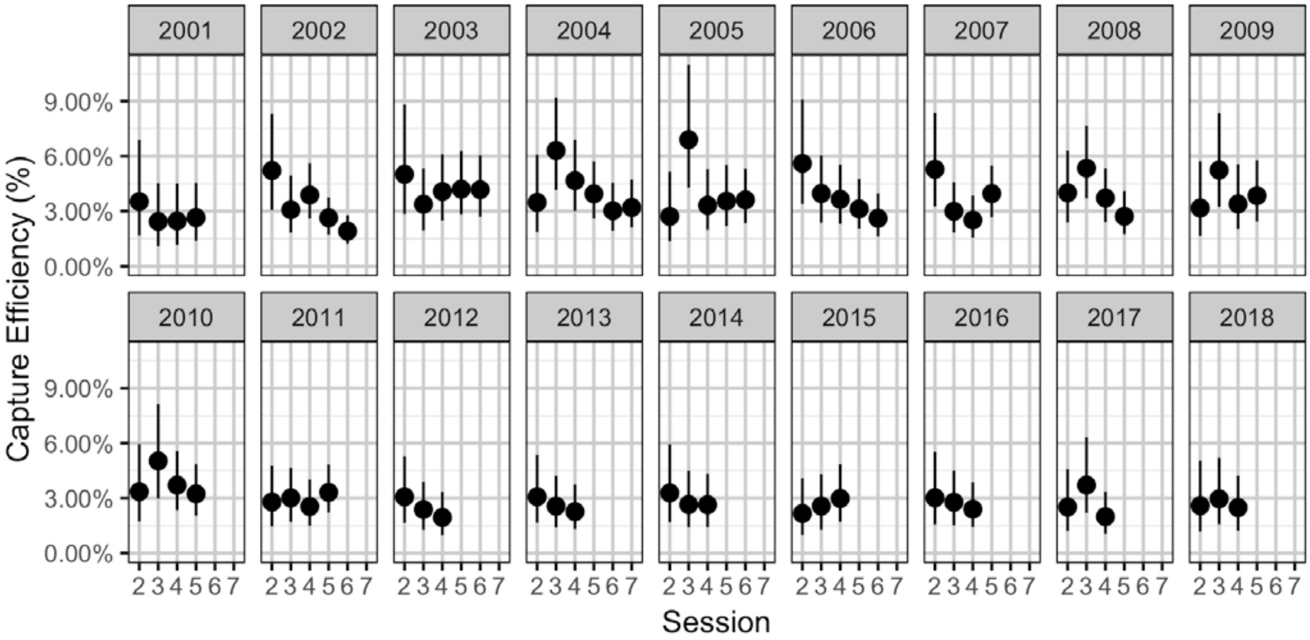


Figure G5: *Capture efficiency (mean with 95% credible intervals) of subadult Rainbow Trout by year and sample session in the lower Columbia River, 2001–2018.*

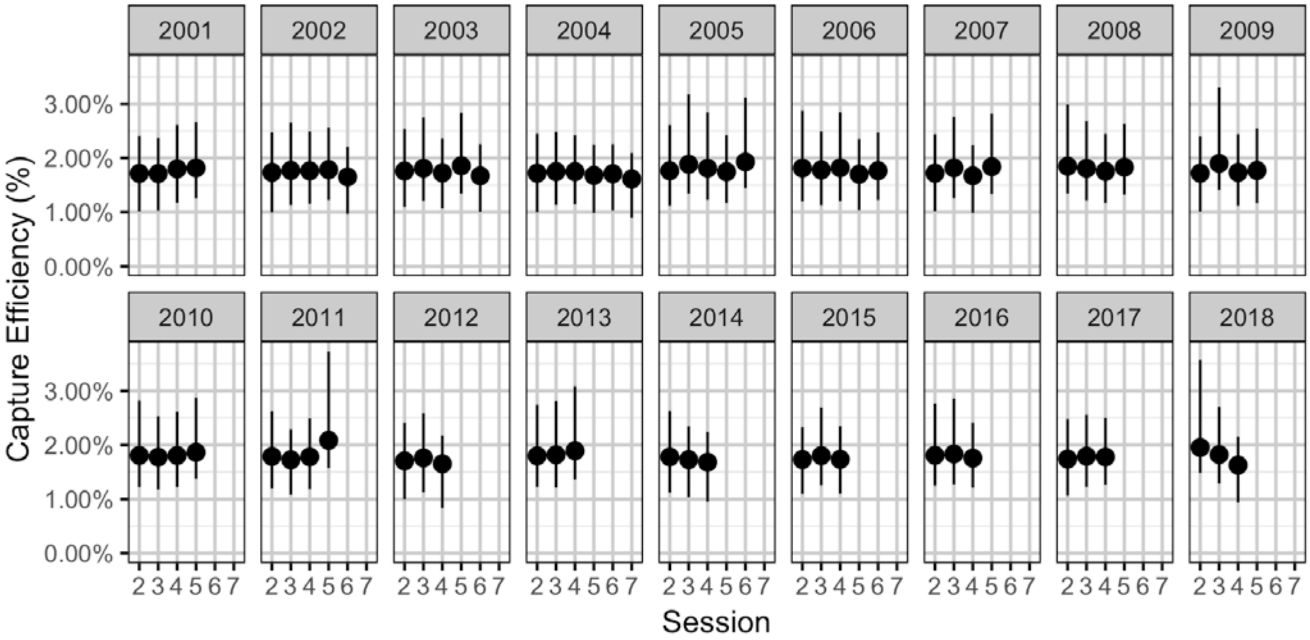


Figure G6: *Capture efficiency (mean with 95% credible intervals) of adult Rainbow Trout by year and sample session in the lower Columbia River, 2001–2018.*

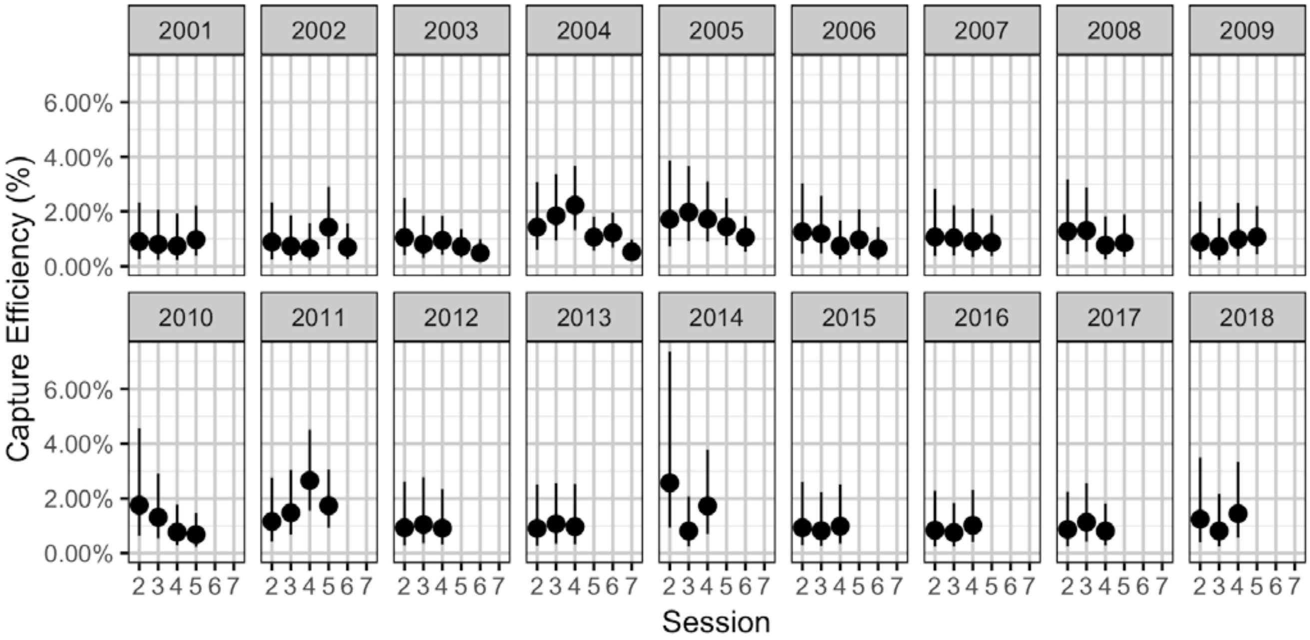


Figure G7: Capture efficiency (mean with 95% credible intervals) of adult Walleye by year and sample session in the lower Columbia River, 2001–2018.

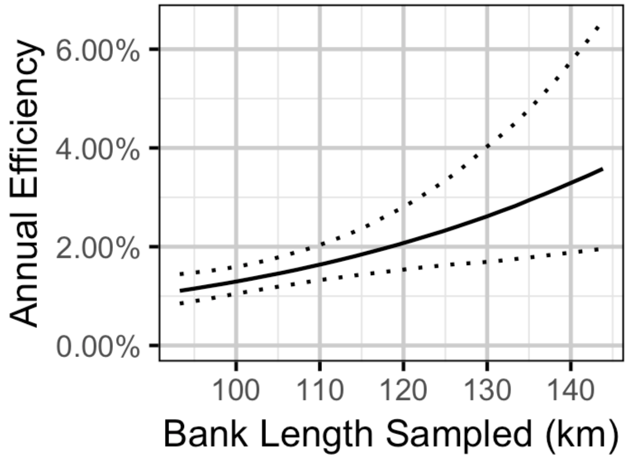


Figure G8: Predicted annual efficiency of capture for adult Mountain Whitefish by amount of bank length sampled (km).

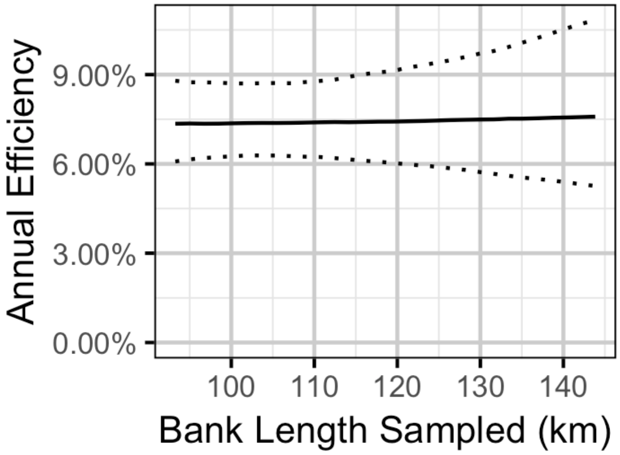


Figure G9: Predicted annual efficiency of capture for adult Rainbow Trout by amount of bank length sampled (km).

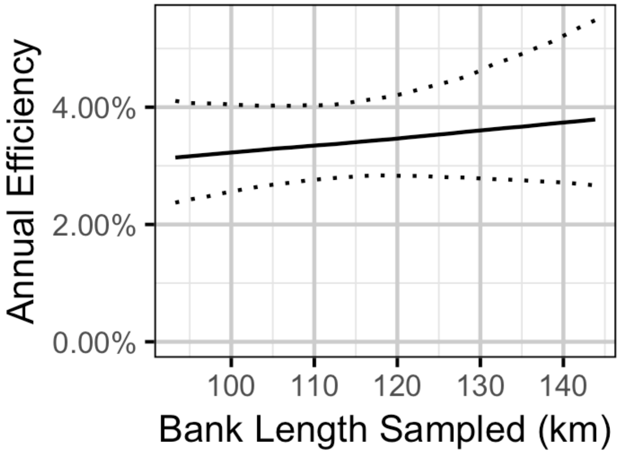


Figure G10: Predicted annual efficiency of capture for Walleye by amount of bank length sampled (km).

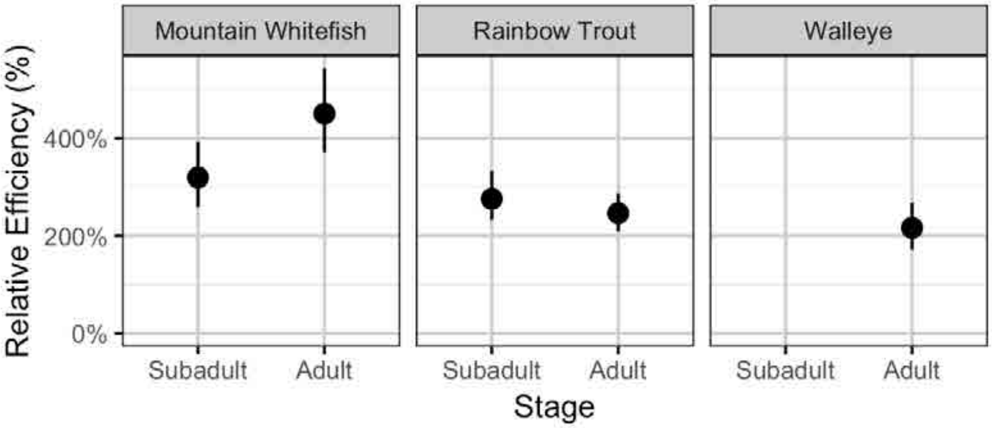


Figure G11: Predicted relative efficiency of capture vs counting for each species by life stage.

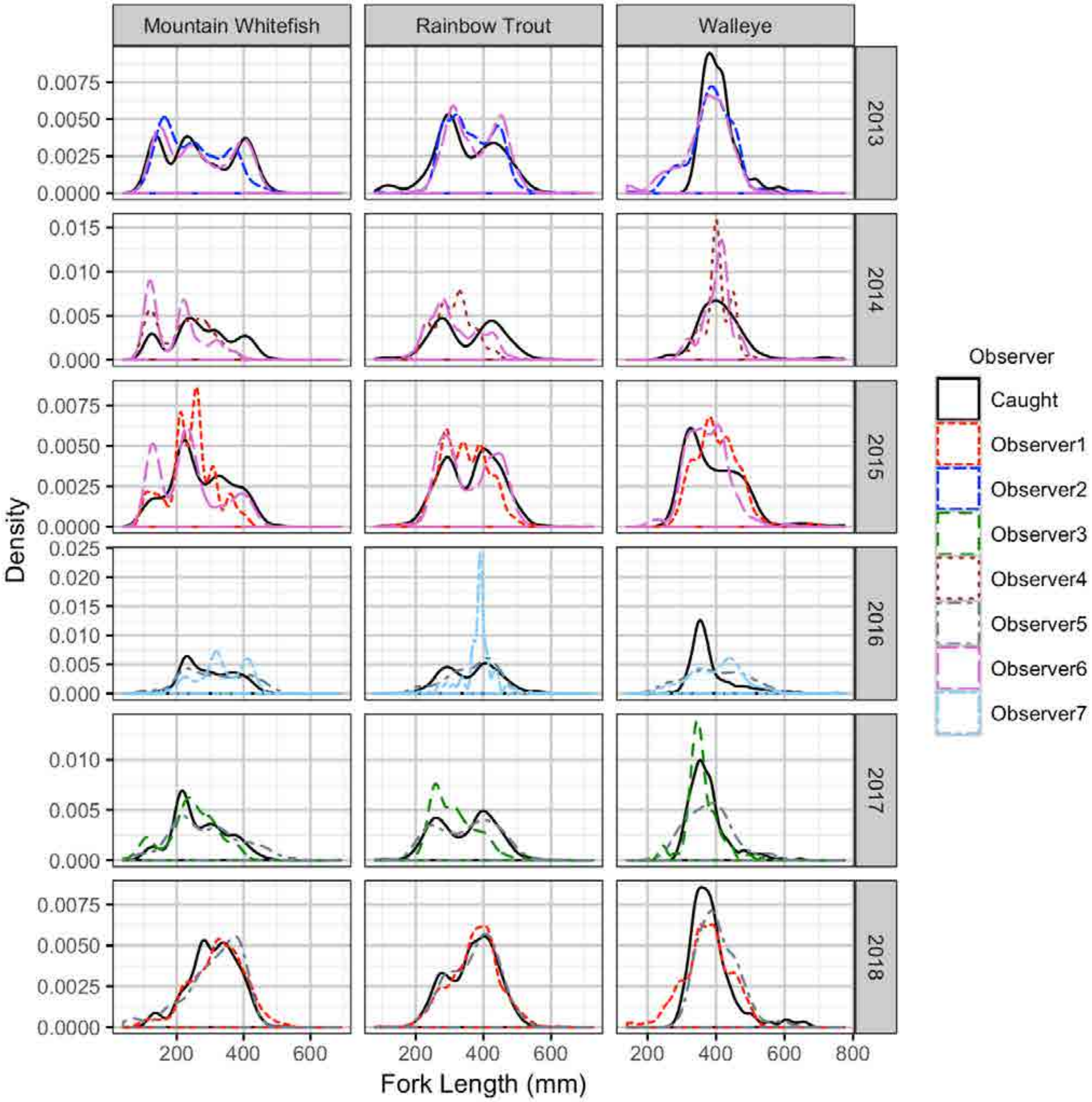


Figure G12: Corrected fork length-density plots for measured and estimated fork lengths of fish caught or observed in the lower Columbia River, 2013–2018. The black line shows fish that were caught. Observed data are shown by coloured dashed lines.

Appendix H – Spatial Distribution Maps