Columbia River Project Water Use Plan

Lower Columbia River Fish Management Plan

Lower Columbia River Fish Population Indexing Surveys

Implementation Year 11

Reference: CLBMON-45

Final Technical Report

Study Period 2017

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CLBMON-45:
Lower Columbia River
Fish Population Indexing Survey
2017 Report

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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*]).

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 Columbia River confluence.

Fish were sampled by boat electrofishing at night within nearshore habitats. In addition to the mark-recapture indexing sites sampled since 2001, additional sample sites were randomly selected from 2011 to 2017 using a Generalized Random Tessellation Stratified (GRTS) 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. In 2017, Mountain Whitefish scales were aged by measuring inter-circuli distances and using a computer algorithm to identify and

count growth annuli. 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 (MW flows). 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 substantially from ~25,000 in 2002 to ~68,000 in 2017, and high abundances in recent years coincided with a decline in body condition and survival, suggesting density-dependence. Adult Mountain Whitefish abundance estimates were greater from 2001 to 2009 (118,000 to 233,000) than during 2010 to 2017, when estimates lower and relatively stable (81,000–105,000). Data for Walleye also suggested density-dependence with lower abundance and greater body condition in 2012 to 2015 than in previous years but near-average values in 2016 and 2017.

Ages assigned using the circuli method had considerable error for all age-classes. For this reason, ages assigned using the length-at-age model were used when calculating the age-1:2 ratio for Mountain Whitefish as an indicator of recruitment. There was no statistically significant relationship between the Mountain Whitefish age-1:2 recruitment index and the estimated annual egg loss (P=0.5). This suggests that factors other than dewatering affected the inter-annual variation in recruitment. The age-1:2 index was not calculated for Rainbow Trout because age data were not available from 2013 to 2017.

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 being consistent with density-dependent survival. The effect of egg loss in the stock-recruitment model was not statistically significant for Mountain Whitefish (P>0.7), 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=0.02) 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. However, 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)

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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 and 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 stranded 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 provided by Golder (2009a, 2010b).

Data collected under the LRFIP (2001–2006) and the current program (CLBMON-45; 2007–2017) will be used to identify changes in fish populations 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 the 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 (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 2017, 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 2 and 28 October 2017. 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 7 November 2017.

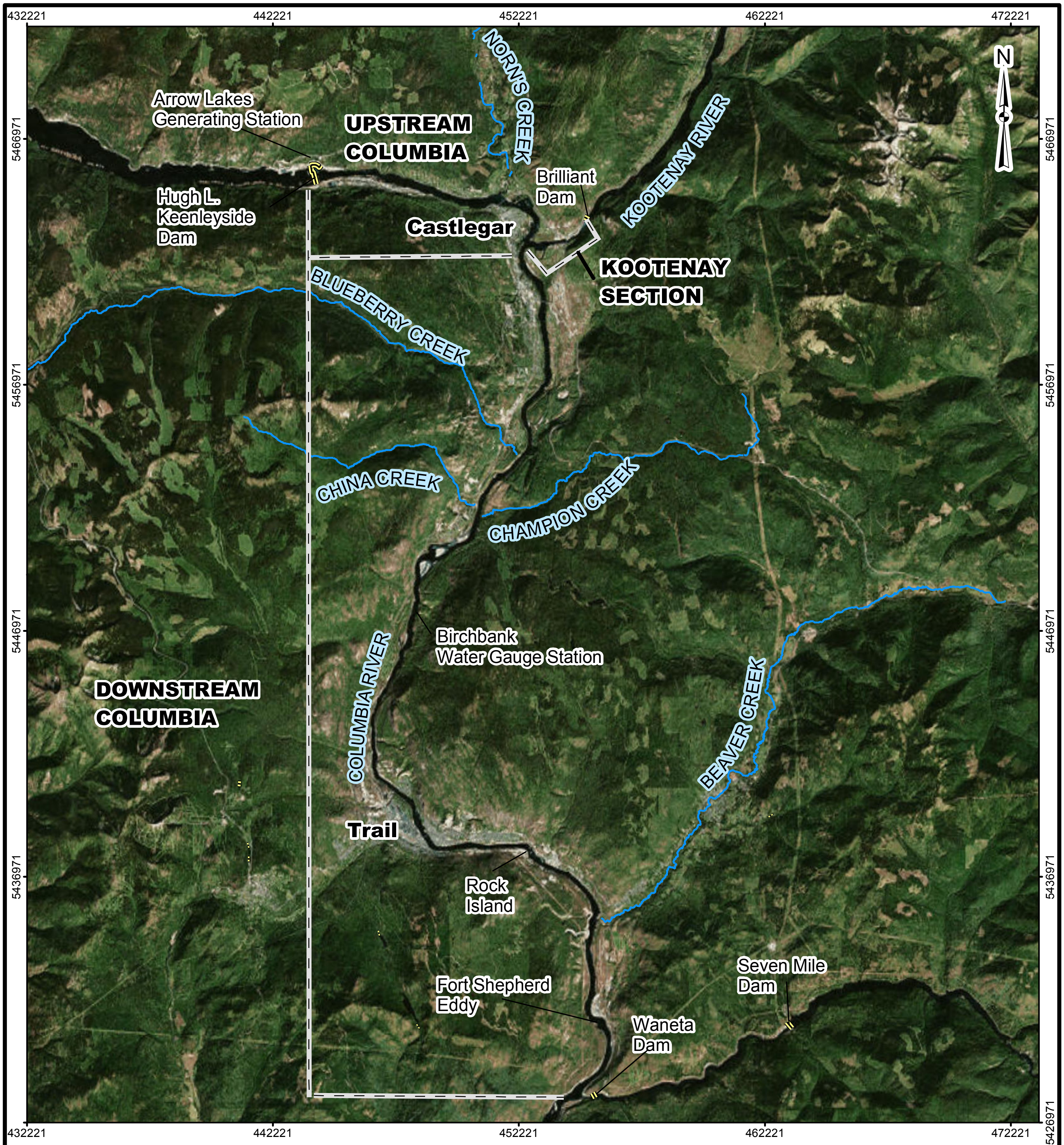
Table 1: Summary of annual study periods and number of sites sampled for boat electrofishing surveys conducted in the lower Columbia River, 2001 to 2017.

Year	Start Date	End Date	Number of Sites			Number of Sessions	Duration (in days)
			Index Sites[a]	GRTS[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

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 2017.



LEGEND

- WATERCOURSE
- DAM

REFERENCE

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

PROJECTION: UTM ZONE 11 DATUM: NAD 83

PROJECT

LARGE RIVER FISH INDEXING PROGRAM LOWER COLUMBIA RIVER

TITLE

STUDY AREA OVERVIEW

GOLDER

PROJECT	1537874/2017	FILE No.	
DESIGN	DR	14 JUN. 2016	SCALE AS SHOWN · REV. 0
GIS	JG/CD	6 JUN. 2018	FIGURE: 1
CHECK	DR	6 JUN. 2018	
REVIEW	SR	6 JUN. 2018	

Document Path: \\golder.gds\gal\burnaby\CAD-GIS\Client\ONALCR\99_PROJECTS\1537874\02_PRODUCTION\INDEXING\MXD\Report\2017\1537874_FIG_1_OVERVIEW_2017.mxd

2.0 METHODS

2.1 Data Collection

2.1.1 Discharge

Discharge data were obtained from BC Hydro's Temperature and Discharge 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 2017 (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 three kilometres downstream of the Kootenay-Columbia confluence (J. Crossman, BC Hydro, pers. comm.) during March to April 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 approximately 1.8 km upstream of the Columbia-Kootenay rivers confluence. All available temperature data were summarized to provide daily average temperatures. Spot measurements of water temperature were obtained at all sample sites at the time of sampling using a hull-mounted digital thermometer (accuracy ± 0.2°C).

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 as a means 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). Bank type length within each site was calculated using ArcView® GIS software (Appendix B, Table B2). While electrofishing, netters estimated the number of observed fish by species within each bank habitat type that were not captured. 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. 2017a). 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 5.0) electrofisher operated out of a 160 HP 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, because of logistical reasons, a site could not be completed, the distance that was actually sampled was estimated and recorded on the site form, and then used as the sampled length in the subsequent analyses.

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

Voltage was adjusted as needed to achieve an amperage output of ~1.75 A, at a frequency of 30 Hz pulsed direct current as 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). Although electrical output is variable (i.e., depending on water conductivity, water depth, and water temperature), field crews attempted to maintain electrical output at similar levels for all sites over all sessions.

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.

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 livewell 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 unique feature of the GRTS strategy is that new sites may be selected during each study year; therefore, all potential fish habitats are included within the 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 3.4.0 (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. Selected GRTS sites are presented in Appendix A, Table A2.

A single-pass boat electrofishing survey was conducted at each GRTS survey site between 30 October and 6 November 2017 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

During the current study year, scale samples from 2010 to 2017 were aged using a method that involved measuring distances between circuli on scales. Circuli are visible rings that are formed as scales grow and deposit material at the outer edge of the scale. Areas of the scale where circuli are closer together indicate slow growth during the winter and are called annuli that can be used to age fish. Age was analyzed by measuring the distance between circuli and using a computer algorithm to identify annuli and assign ages.

Digital photographs were taken of each scale using a Canon Microfilm Scanner 800II (Canon, Inc., Melville, NY). The distance from the first circulus to each subsequent circulus was measured to the nearest 0.000001 mm on the digital images using Image-Pro Plus software, vers. 7.0 (Media Cybernetics, Inc., Rockville, MD) and the built-in calibration tool. Measurements were taken along the longest axis from the center to the edge of the scale opposite to the attachment point to the body of the fish, which is equivalent to the 360° axis used by Friedland and Haas (1996) and Beamish et al. (2004). Measurements were taken from the inside edge of each circulus. The distance from the center to the first circulus was not used in analysis of inter-circuli spacing because the approximate location of the center was considered not precise enough for the analysis. Scales were measured at the ONA’s scale ageing laboratory in Penticton, BC.

Mountain Whitefish was the only species aged using the circuli method. From each year from 2010 to 2017, 200 scale samples were analyzed. Scales were randomly selected but the random selection was stratified by body length, to ensure sufficient numbers of smaller fish (age-0 and age-1) were included in the sample. The 2015 length-at-age values from Golder et al. (2016), which were representative size-at-age in a typical year, were used to stratify the estimates. These length-at-age values were <160mm for age-0, 160-263 mm for age-1 and >263 mm for age-2 and older. The random selection of 200 samples per year included 10 age-0, 30 age-1, and 160 age-2 and older based on these length-at-age values. In addition to these samples, 35 samples were analyzed from recaptured fish from various years whose true age was known due to size at initial capture and time-at-large before recapture. The recaptured fish of known age were analyzed to assess the uncertainty and bias in age assignments using the new method.

In previous years of the monitoring program, fish scales were aged using different techniques. During 2001 to 2012 study years, a subsample of Mountain Whitefish and Rainbow Trout was aged by counting growth annuli on scales following methods given in Ford and Thorley (2011a). This method is referred to as ”informed” scale ageing in plots in this report because scale agers used information about fish size and capture history (if available) when assigning ages. In 2013 and 2014, scales were not aged because previous years of the study demonstrated that the length-at-age model (Section 2.2.3) accurately assigned ages to age-0 and age-1 Mountain Whitefish and Rainbow Trout based on fork length and there was a relatively large amount of error and uncertainty in the ages assigned to age-2 and older fish based on scales.

In 2015, a subsample of scales collected from 2011 to 2015 were aged by counting growth annuli but using a new method to attempt to address some of the limitations of previous scale analyses (Golder, ONA, and Poisson 2016). In 2015, while assigning ages, scale agers did not have access to information about the sampled fish such as the fork length or capture history, as they did during the 2001 to 2012 study years. This method is referred to as “uninformed” scale ageing in plots in this report. Age analyses in 2015 also estimated the accuracy and variability in assigned ages. Accuracy was assessed by ageing samples whose true age was known because they were initially captured at age-0 or age-1 and recaptured in a subsequent year. Variability within and between agers was assessed by having each scale sample aged twice by two scale agers. As ages assigned in 2015 were relatively uncertain and inaccurate (Golder, ONA, and Poisson 2016), these methods were not repeated in subsequent years, and the circuli-based ageing method was used instead.

Analysis of the circuli and age data is described in Section 2.2.11

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 livewell (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 2017, 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 2017 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 2017 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 provided 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 2013 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 2017 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 3.5.0 (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 2018).

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 and 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 0. 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 0 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 proportion of fish in each length-class varied with year.
- The expected length bias and error for a given observer did not vary by year.

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 was constant.
- The growth coefficient (k) varied randomly with year.
- The residual variation in growth was normally distributed.

Plots of growth show the effect size (percent change) relative to a typical year in the annual estimates of the mean growth coefficient. 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, which are of interest for assessing the management questions, are considered reliable indicators of growth of 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.

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 Scale Ageing

For 200 Mountain Whitefish per year from 2010 to 2017, age was estimated from their circuli distances (Section 2.1.7) using a hand-coded algorithm. The algorithm involved a series of steps. First, the circuli distances were differenced to get the distance between circuli, which are referred to as increments. Next, a linear mixed model on the circuli number with the encounter (each capture of a particular fish) as a random effect was fitted to the increments to account for differences in scale size and/or shape. A simple moving average (of window sma1) was then fitted to the residuals from the linear mixed model (circuli increment deviations) to remove noise. Small increment deviations, which are associated with annuli, were then identified by testing whether they are smaller than their neighbours based on a second simple moving average (of window sma2) and a multiplier. Finally blocks of small increment deviations greater than a threshold size (block) were considered to be annuli. The initial circuli increment deviations below a second threshold were considered to have been laid down during the first year of life and were not included in the age (block count).

The algorithm was tuned by varying each of sma1, sma2, multiplier, block threshold and age-0 threshold within a narrow range of values and selecting the combination that minimized the age-averaged chi-squared statistic for encounters of known age. The age of an encounter was considered to be known ("certain") if the length-at-age model was able to assign it to a single age-class with a probability ≥0.98 or if a recaptured fish's age was known at first capture. Ages that are not known based on length or recapture history is referred to as "uncertain". Recaptured fish that were initially captured at age-0 or age-1, but whose length-based age had a probability of <0.98, were also considered "uncertain" true age.

Ages assigned using different methods were compared graphically to assess accuracy and precision for fish of "certain" and "uncertain" true age. Ages from 2010 to 2017 assigned using the circuli method were compared to ages assigned using the length-at-age model for the same fish. Ages of Mountain Whitefish from 2001 to 2015 assigned by annuli counts using the two methods described in Section 2.1.7 were compared to ages assigned by the length-at-age model. To assess the accuracy of the length-at-age model, length-based ages were compared to the known age for recaptured Mountain Whitefish.

2.2.12 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), because they were considered more reliable than the ages assigned using the scale circuli analysis (Section 2.2.11). 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 2017.

The proportional ratio of age-1 to age-2 Mountain Whitefish (age-1:2 ratio) for each year from 2001 to 2017 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 ($N^1_{t+2)}$) whereas the proportion of age-2 fish (N^2_{t+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.

2.2.13 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.

In the stock-recruitment model, the effect of egg loss on could act on α, β, or on the number of spawners. Due to the lack of data at low spawner densities there is little information on α, which is almost exclusively defined by its the prior distribution. It is therefore not possible to draw any useful conclusions about the effect of dewatering on α. In preliminary analyses where the effect of egg loss on spawning stock was modeled, there was no predictive value of egg loss for either Mountain Whitefish or Rainbow Trout. Therefore, the stock-recruitment model presented in this report modeled the effect of egg loss on β, to test for effects of dewatering on the stock-recruitment relationship. 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).
- β varied with 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 2017 was higher than normal during the spring (April to June) due to a spring freshet earlier than in most years (Figure 2; Appendix D, Figure D1). Discharge was within the range of values observed in previous years during spring (2000-4000 m^3/s), but the increase and subsequent decrease from peak freshet occurred approximately a month earlier than average. Discharge was low during the fall sampling period, with discharges often lower than the previous minimum daily discharge from 2001 to 2016 during October (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.

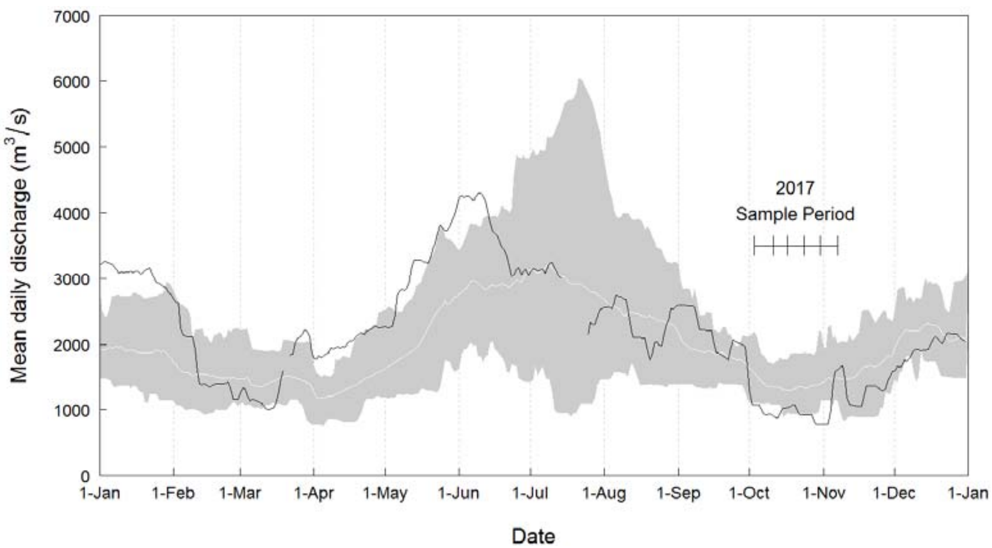


Figure 2: **Mean daily discharge (m^3/s) for the Columbia River at the Birchbank water gauging station, 2017 (black line). The shaded area represents minimum and maximum mean daily discharge values recorded at Birchbank from 2001 to 2016. The white line represents average mean daily discharge values over the same time period.**

In 2017, 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 2016 (Figure 3; Appendix D, Figure D2). One exception was higher than normal discharge during January. As was the case for the discharge at Birchbank, discharge below HLK suggested an earlier than normal increase in discharge during the spring freshet.

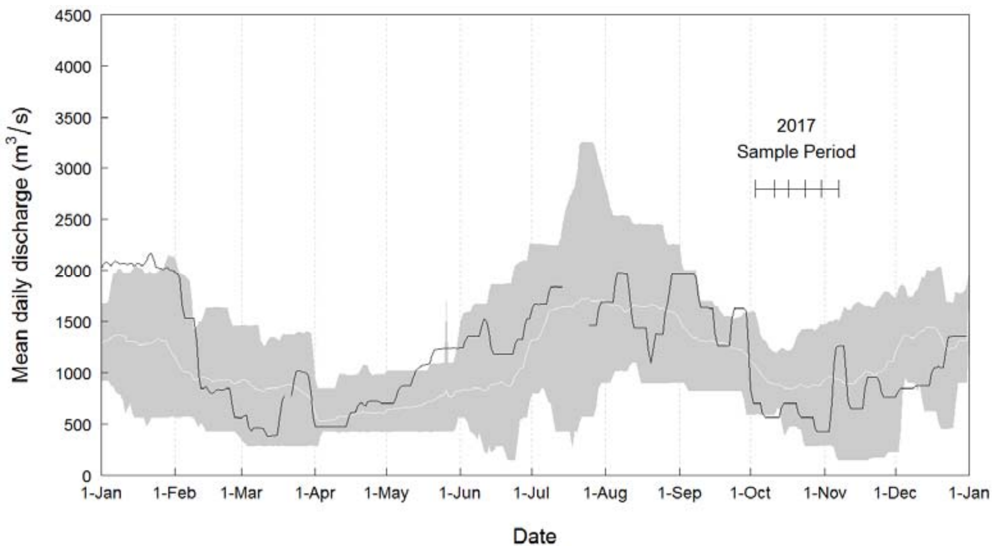


Figure 3: Mean daily discharge (m^3/s) for the Columbia River at Hugh L. Keenleyside Dam, 2017 (black line). The shaded area represents minimum and maximum mean daily discharge values recorded at the dam from 2001 to 2016. The white line represents average mean daily discharge values over the same time period.

3.1.2 Columbia River Temperature

Water temperature data for the Columbia River at Birchbank were not available for most of 2017 (March to November). Water temperature measured at Kinnaird Eddy, which is also downstream of the Kootenay-Columbia confluence, was within 0.5°C of data from Birchbank for the period in 2017 when water temperature was available for both locations (data not shown). Therefore, water temperature from Kinnaird Eddy in 2017 was considered comparable to historical data (2001–2016) from Birchbank.

In 2017, daily mean water temperature in the Columbia River was near-average for the majority of the year, except for short periods of lower than average temperature in February and during the sampling period in late October (Figure 4). Between 2001 and 2016, 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 6.8°C and 12.9°C (Appendix B, Table B3).

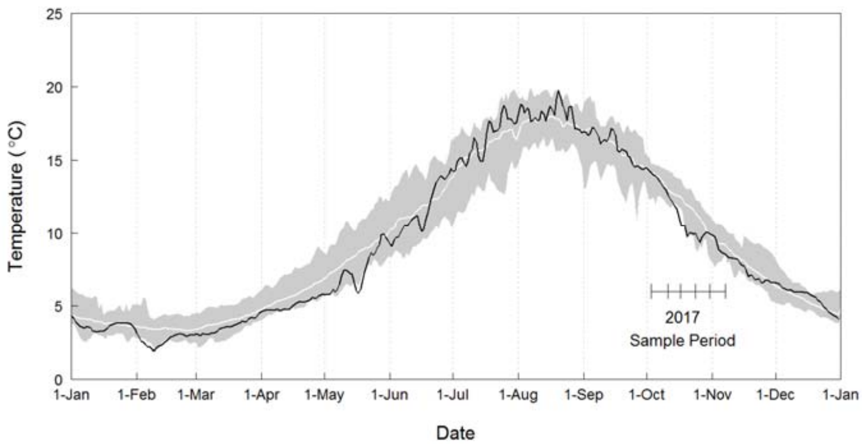


Figure 4: Mean daily water temperature (°C) for the Columbia River downstream of the confluence of the Kootenay River, 2017 (black line). The shaded area represents the minimum and maximum mean daily water temperature values from 2001 to 2016 for the Birchbank gauge station. The white line represents the average mean daily water temperature during the same time period. For 2017, water temperature data during March to April are from Kinnaird Eddy because data were not available for this period at Birchbank.

3.1.3 Kootenay River Discharge

In 2017, mean daily discharge in the Kootenay River downstream of BRD was greater than average, with peak discharge (~2900 m^3/s) approximately 900 m^3/s greater than the average from 2001 to 2016 (Figure 5; Appendix D, Figure D4). As was the case in the Columbia River, the onset of the spring freshet was approximately a month earlier than normal. Mean daily discharge was approximately 150 m^3/s lower than average (~500 m^3/s) during the sampling period in October (Figure 5).

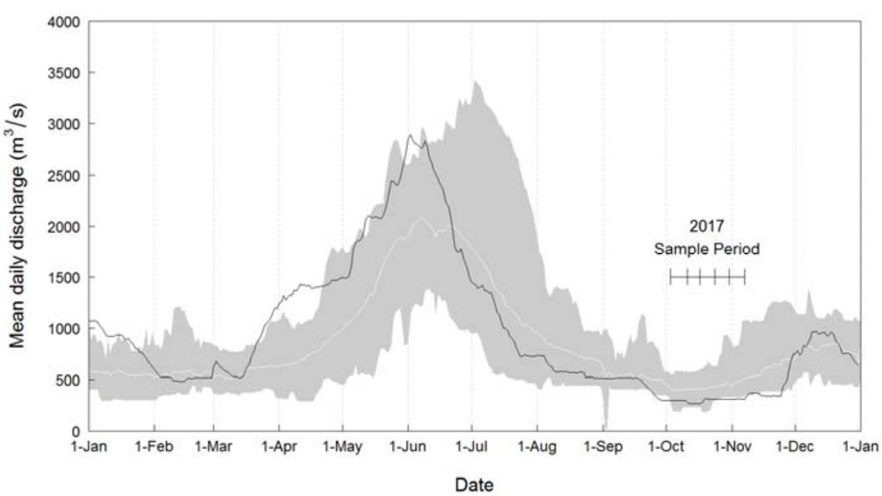


Figure 5: Mean daily discharge (m^3/s) for the Kootenay River at BRD, 2017 (black line). The shaded area represents minimum and maximum mean daily discharge values recorded at the dam from 2001 to 2016. The white line represents average mean daily discharge values over the same time period.

3.1.4 Kootenay River Temperature

Water temperature data for the Kootenay River downstream of BRD was not available from January to May of 2017. Mean daily water temperature in the Kootenay River (downstream of BRD) was approximately 1°C greater than average during August and September in 2017 but near average for the rest of the year (Figure 6). Spot temperature readings for the Kootenay River taken at the time of sampling ranged between 9.7°C and 12.9°C (Appendix B, Table B3).

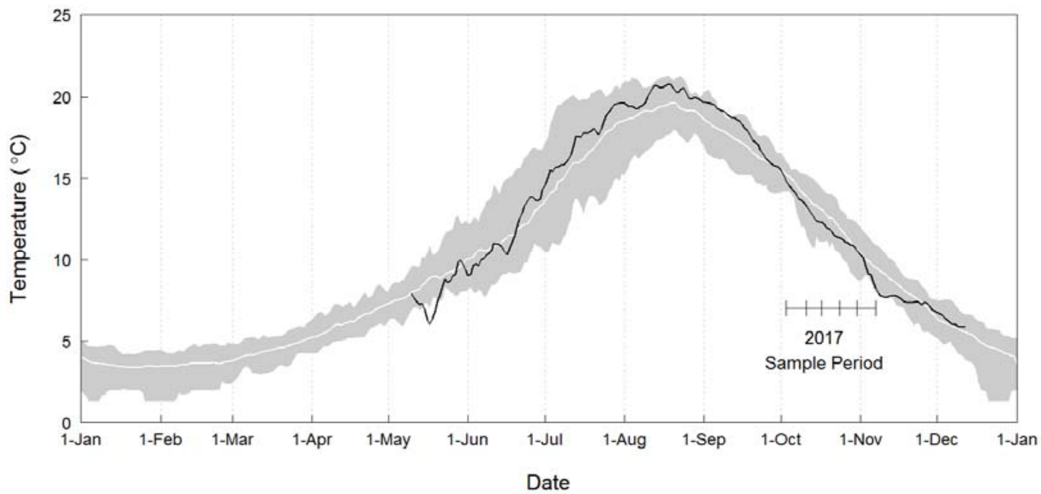


Figure 6: Mean daily water temperature (°C) for the Kootenay River downstream of BRD, 2017 (black line).The shaded area represents minimum and maximum mean daily water temperature values recorded at the dam from 2001 to 2016. The white line represents average mean daily water temperature values over 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 2017 (Attachment A; Appendix B, Table B3). Shallower sandy locations are dominantly Eurasian Watermilfoil (EVM; *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, 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.). Efforts to control the invasive EVM, and in turn, potential invasive Northern Pike habitat, started in 2017 by laying long sections of mat material in areas of high concentrations of EVM, within some of the electrofishing sites in the upstream section of the Columbia River (Golder and ONA 2018).

3.2 Catch

In total, 36,015 fish were recorded in the LCR in 2017 (Table 5). 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, 2 October to 7 November 2017. 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*)	1	<1			7	<1	8	<1
Brown Trout (*Salmo trutta*)			1	<1	1	<1	2	<1
Bull Trout (*Salvelinus confluentus*)	2	<1					2	<1
Burbot (*Lota lota*)					30	<1	30	<1
Cutthroat Trout (*Oncorhynchus clarki*)					1	<1	1	<1
Kokanee (*Oncorhynchus nerka*)	4	<1	5	<1	16	<1	25	<1
Lake Whitefish (*Coregonus clupeaformis*)	7	<1	5	<1	105	1	117	<1
Mountain Whitefish (*Prosopium wiliamsoni*)	1979	46	829	58	1689	21	4497	33
Northern Pike (*Esox lucius*)	2	<1			9	<1	11	<1
Rainbow Trout (*Oncorhynchus mykiss*)	1955	45	380	27	5189	66	7524	55
Smallmouth Bass (*Micropterus dolomieu*)					4	<1	4	<1
Walleye (*Sanders vitreus*)	343	8	205	14	852	11	1400	10
White Sturgeon (*Acipenser transmontanus*)	21	<1	4	<1	10	<1	35	<1
Yellow Perch (*Perca flavescens*)					5	<1	5	<1
Sportfish Subtotal	4314	100	1429	100	7918	100	13661	100
Non-sportfish								
Northern Pikeminnow (*Ptychocheilus oregonensis*)	64	<1	7	<1	29	<1	100	<1
Peamouth (*Mylocheilus caurinus*)	104	1	3	<1	6	<1	113	<1
Redside Shiner (*Richardsonius balteatus*)	5574	63	21	2	483	4	6078	27
Sculpin spp. (*Cottidae*)	2294	26	730	80	11898	94	14922	67
Sucker spp. (*Catostomidae*)	753	9	145	16	240	2	1138	5
Tench (*Tinca tinca*)					1	<1	1	<1
Non-Sportfish Subtotal	8789	100	907	100	12658	100	22354	100
Total	13103	100	2336	100	20576	100	36015	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), 2017;
- catch and percent composition by species, 2001 to 2017 (Appendix E, Table E1);
- catch-rates for all sportfish (Appendix E, Table E2) and non-sportfish (Appendix E, Table E3), 2017;
- length-frequency histograms by section for Mountain Whitefish (Appendix F, Figure F1), Rainbow Trout (Appendix F, Figure F2), and Walleye (Appendix F, Figure F3), 2017;
- 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 6 and represent the most appropriate 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 6). 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 2017. 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	≤159	160-253	254-288	≥289	≤155	156-358	≥359
1991	≤144	145-226	227-297	≥298	≤127	128-343	≥344
2001	≤141	142-257	258-343	≥344	≤133	134-324	≥325
2002	≤163	164-260	261-343	≥344	≤154	155-350	≥351
2003	≤160	161-263	264-353	≥354	≤161	162-343	≥344
2004	≤158	159-249	250-342	≥343	≤142	143-333	≥334
2005	≤168	169-263	264-362	≥363	≤164	165-347	≥348
2006	≤175	176-284	285-356	≥357	≤170	171-365	≥366
2007	≤171	172-279	280-338	≥339	≤166	167-375	≥376
2008	≤170	171-248	249-341	≥342	≤146	147-340	≥341
2009	≤169	170-265	266-355	≥356	≤147	148-339	≥340
2010	≤177	178-272	273-353	≥354	≤143	144-337	≥338
2011	≤163	164-269	270-349	≥350	≤156	157-344	≥345
2012	≤162	163-268	269-347	≥348	≤152	153-344	≥345
2013	≤185	186-282	283-350	≥351	≤169	170-355	≥356
2014	≤178	179-283	284-362	≥363	≤154	155-337	≥338
2015	≤167	168-277	278-366	≥367	≤167	168-334	≥335
2016	≤165	166-282	283-352	≥353	≤154	155-337	≥338
2017	≤158	159-269	270-354	≥355	≤133	134-317	≥318

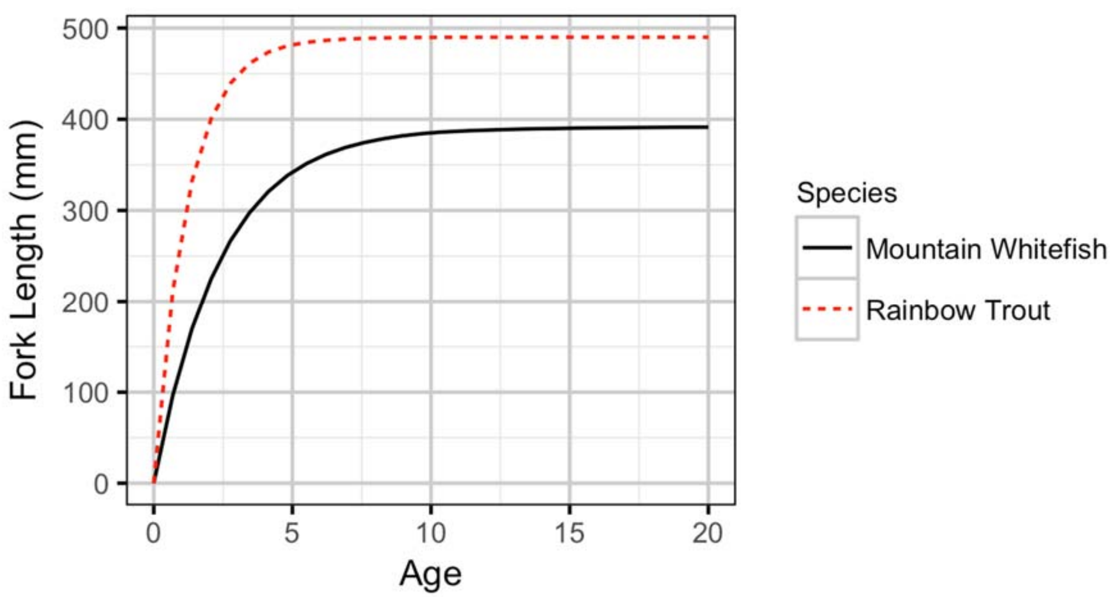


Figure 7: Growth curve showing length-at-age by species as predicted by the von Bertalanffy model for the lower Columbia River, 2001-2017.

3.3.1 Mountain Whitefish

The mean fork length of Mountain Whitefish fry (age-0) in 2017 (126 mm) was similar to most previous years, which typically ranged from 120 to 140 mm. In 2016, mean fork length (156 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 it may be that the length-at-age model overestimated the size of age-0 fish because of a small and potentially unrepresentative sample. 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.

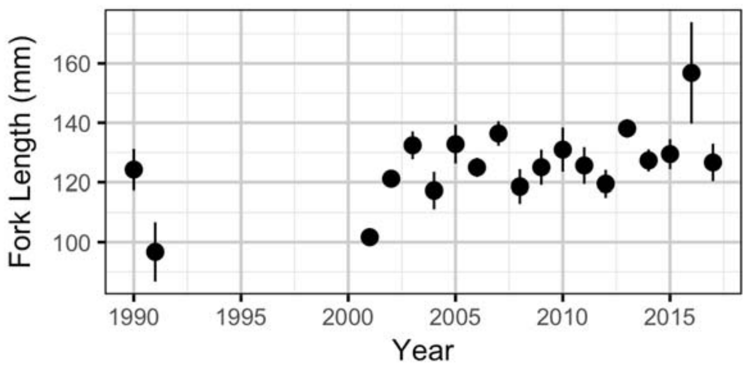


Figure 8: Mean fork length of age-0 Mountain Whitefish in the lower Columbia River, 1990 to 1991 and 2001 to 2017.

Analysis of annual growth of recaptured Mountain Whitefish indicated an increase in mean annual growth between 2003 and 2009, and variable annual growth between 2010 and 2017, although credible intervals overlapped between most estimates (Figure 9). The growth coefficient was lower in 2017 (12% effect size) than the previous three years (2014-2016; 32-42% effect size).

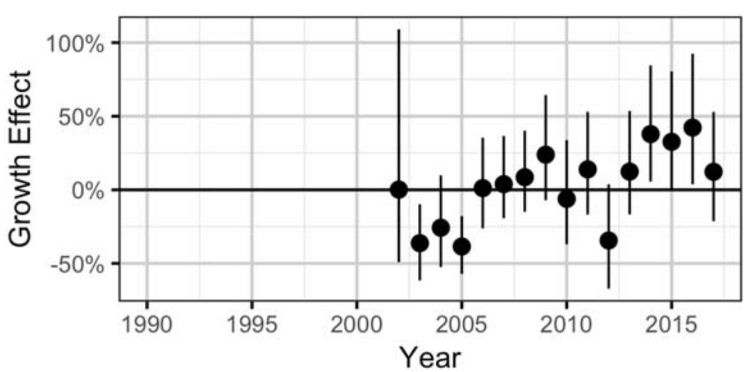


Figure 9: Estimated percent change in the von Bertalanffy growth coefficient (mean with 95% CRIs) relative to a typical year for Mountain Whitefish based on recaptured individuals in the lower Columbia River, 2001 to 2017.

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 143 mm in 2015 (Figure 10). Mean length of age-0 Rainbow Trout decreased in the last two years (2016–2017; 126 and 102 mm). 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.

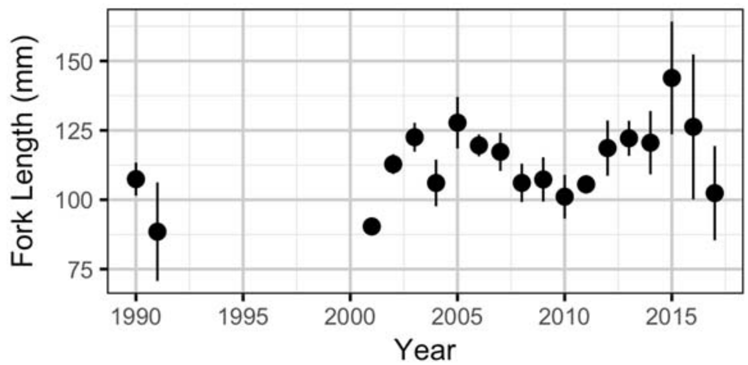


Figure 10: Mean fork length of age-0 Rainbow Trout in the lower Columbia River, 1990 to 1991 and 2001 to 2017.

Analysis of annual growth of recaptured Rainbow Trout indicated a low growth coefficient in 2003 and 2004 (-17 to -32% effect size; Figure 11). Estimates of the growth coefficient generally declined from a 48% effect size in 2006 to -30% in 2017.

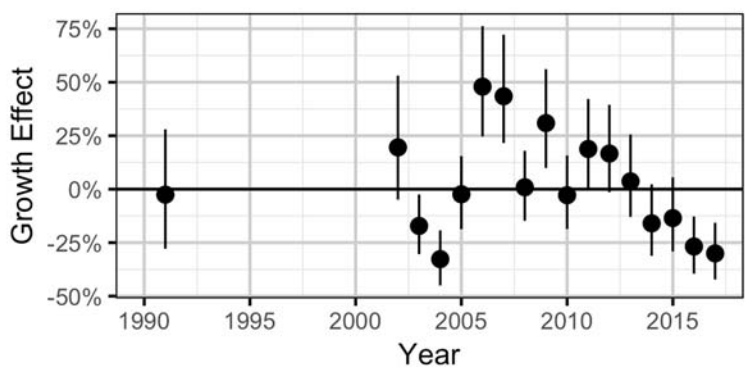


Figure 11: Estimated percent change in the von Bertalanffy growth coefficient (mean with 95% CRIs) relative to a typical year for Rainbow Trout based on recaptured individuals in the lower Columbia River, 2001 to 2017.

3.3.3 Walleye

Analysis of annual growth of recaptured Walleye indicated lower than average growth in 2017 with an effect size of -11% (Figure 12). The estimated growth coefficient generally increased from 2010 (-23% effect size) until 2016 (31%), but with a very high growth coefficient (85%) 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 12) were calculated using only Walleye <450 mm in fork length.

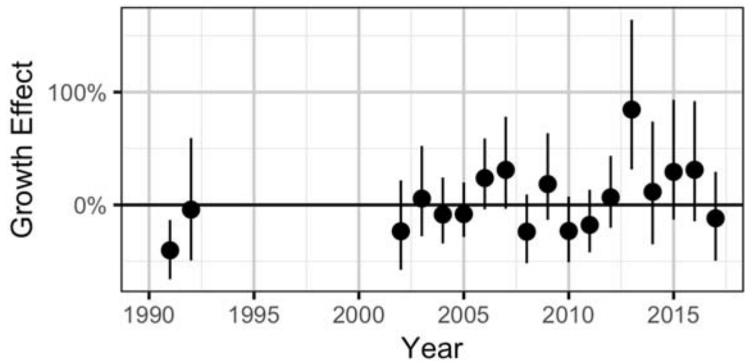


Figure 12: Estimated percent change in the von Bertalanffy growth coefficient (mean with 95% CRIs) relative to a typical year for Walleye based on recaptured individuals <450 mm in fork length in the lower Columbia River, 2001 to 2017.

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 13). The bias for Mountain Whitefish varied by observer with bias of -14 to 3% relative to captured fish of known length (Figure 14). Bias of Rainbow Trout lengths varied between -17 and 3%. Bias in estimated Walleye fork lengths ranged between -20% and 5%. Estimates of observer bias were used to correct estimated fork lengths (Appendix G, Figure G12) before classifying fish into age-classes for abundance analyses.

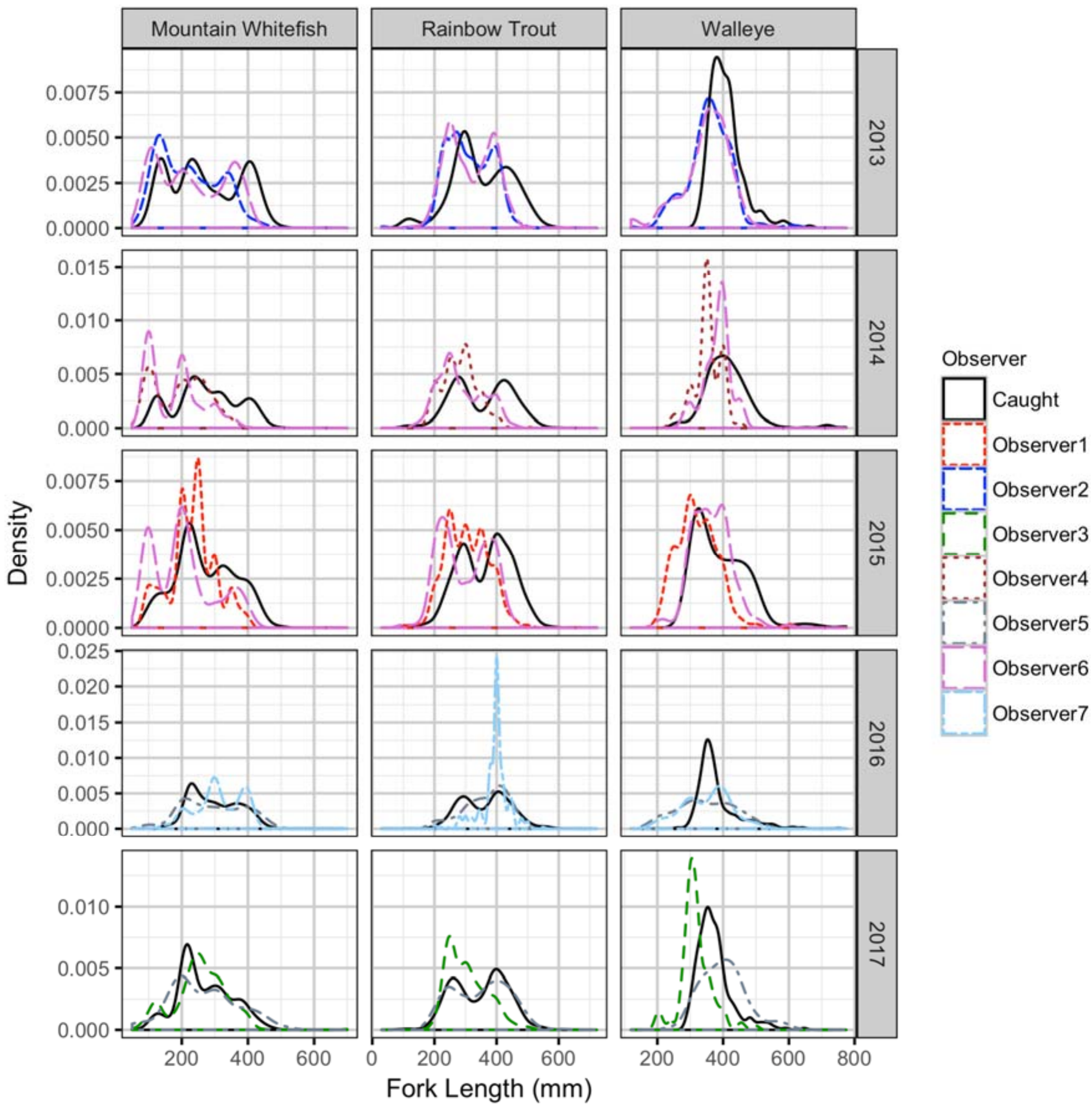


Figure 13: Fork length-density plots for measured and estimated fork lengths of fish caught or observed in the lower Columbia River, 2013-2017. The black line shows fish that were caught. Observed data from the georeferenced visual survey are shown by coloured dashed lines.

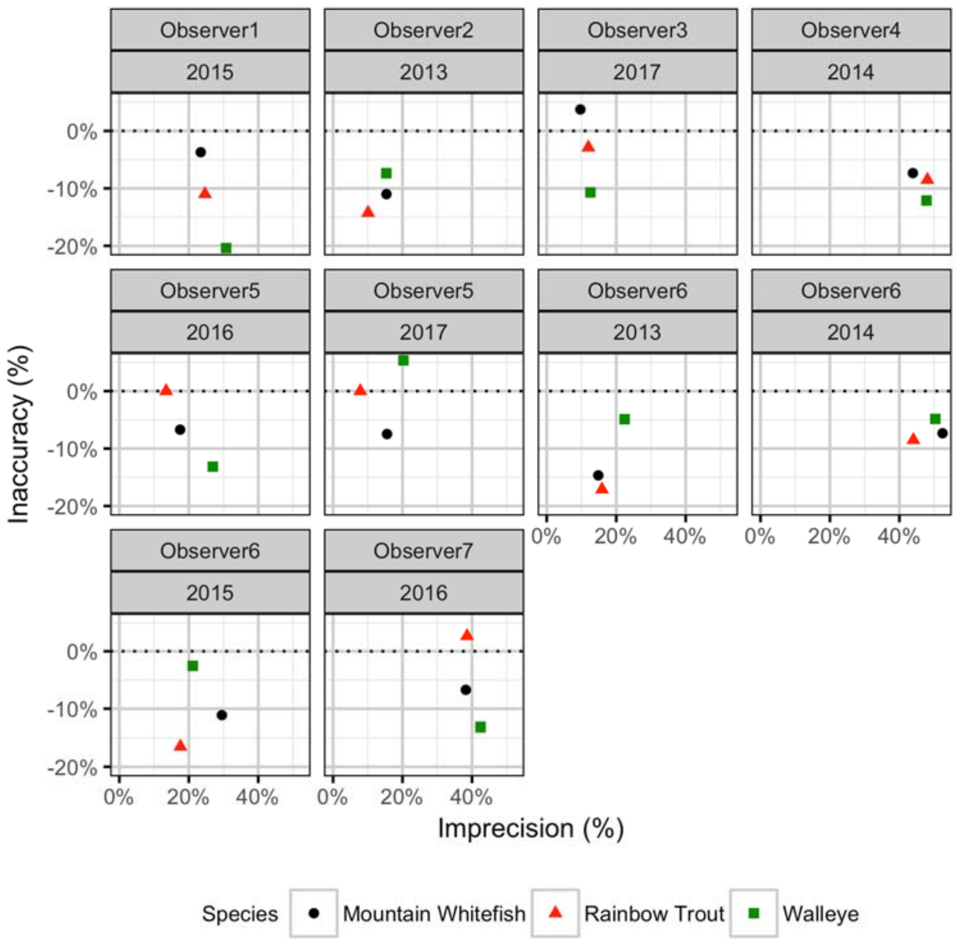


Figure 14: Fish length inaccuracy (bias) and imprecision by observer, year of observation and species. Observations use the length bias model of captured (mark-recapture surveys) compared to estimated (geo-referenced visual surveys) length-frequency distributions from the lower Columbia River, 2013–2017.

3.4 Spatial Distribution and Abundance

3.4.1 Site Fidelity

Site fidelity was greater for Rainbow Trout and Walleye (~50-75%) than for Mountain Whitefish (<50%; Figure 15). 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 ($P > 0.5$).

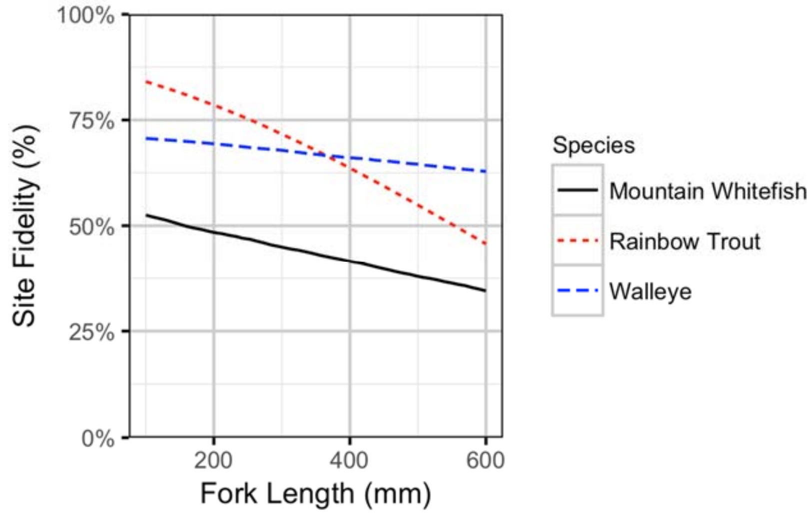


Figure 15: Site fidelity, defined as the expected probability that a fish is recaptured at the same site where it was marked, by species and fork length in the lower Columbia River, 2001 to 2017.

3.4.2 Efficiency

Estimated capture efficiency was greatest for Rainbow Trout and lowest for Mountain Whitefish (Figure 16). Capture efficiency was lower for adult than subadult 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).

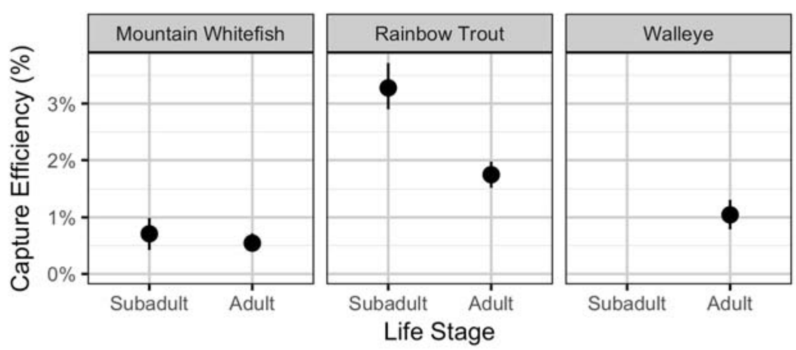


Figure 16: Capture efficiency (mean with 95% CRIs) by species from mark-recapture data from the lower Columbia River, 2001–2017.

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 (107,000–122,000) than all other years (Figure 17). Estimated subadult abundance fluctuated between 11,000 and 74,000 between 2003 and 2017, with stable values in the last five years (51,000–57,000). Estimates of adult Mountain Whitefish abundance were greater from 2001 to 2009 (118,000 to 233,000) than during 2010 to 2017, when estimates were lower and relatively stable (81,000–105,000).

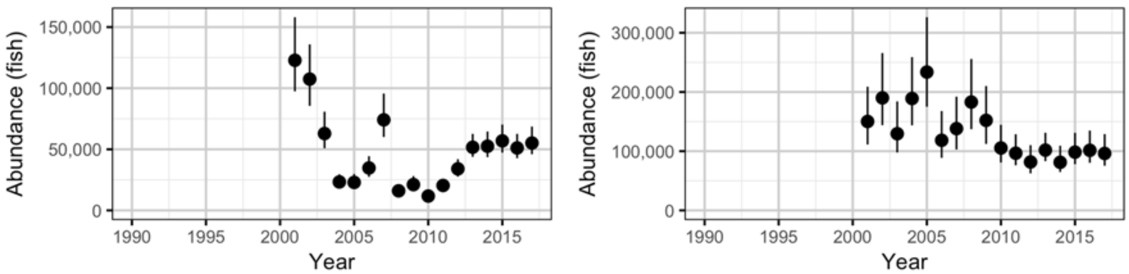


Figure 17: Abundance (means with 95% CRIs) of subadult (left) and adult (right) Mountain Whitefish at index sample sites in the lower Columbia River, 2001-2017

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 18). 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 18). 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 18) 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).

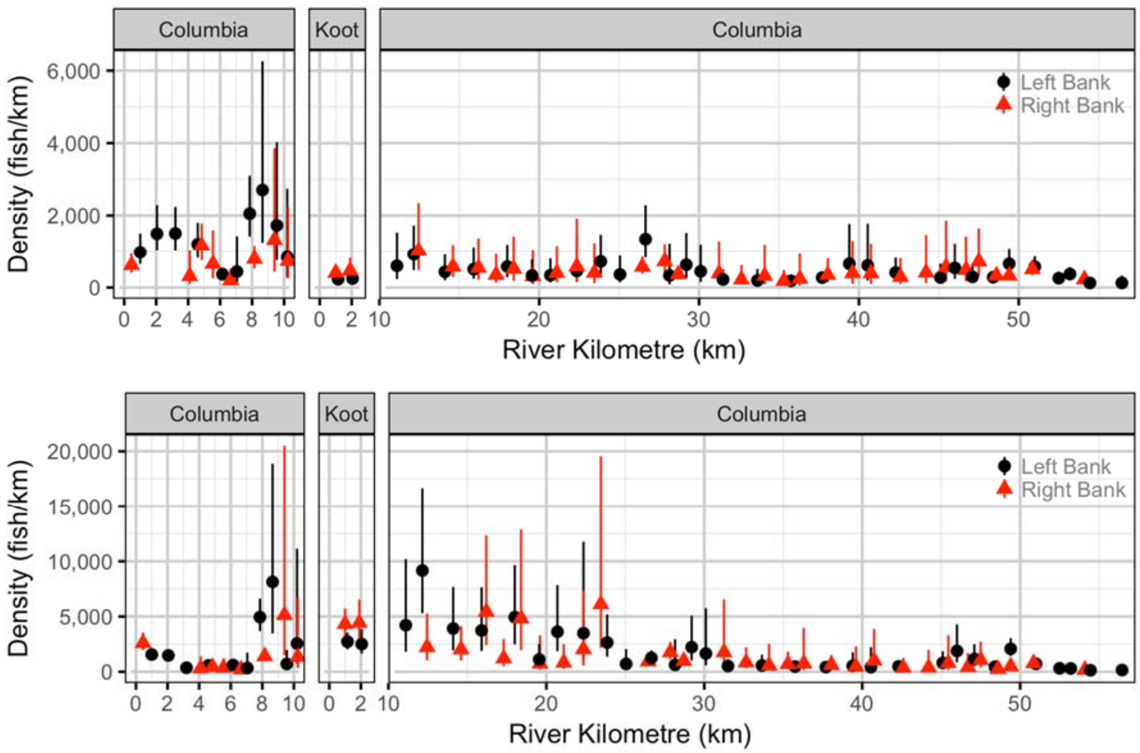


Figure 18: Density (means with 95% CRIs) of subadult (top) and adult (bottom) Mountain Whitefish by river kilometre in the lower Columbia River, 2001-2017.

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 2017 (Figure 19). Adult Rainbow Trout abundance estimates increased from ~27,000 in 2002 to ~68,000 in 2017. Rainbow Trout site-level density estimates had large credible intervals (Figure 20), particularly at sites that were only sampled between 2012 and 2017 (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 20). 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 20). 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.

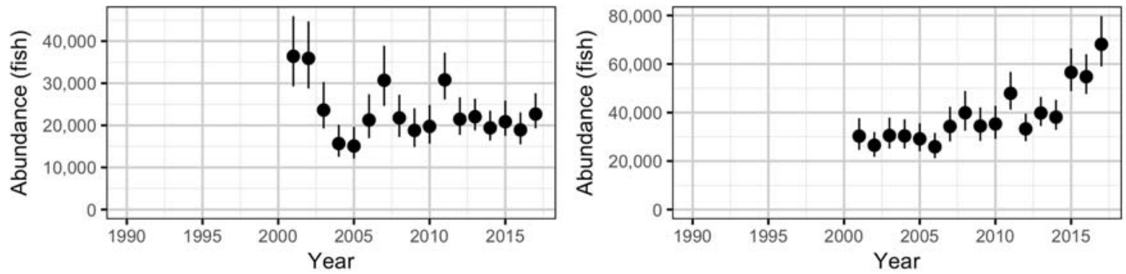


Figure 19: Abundance (means with 95% CRIs) of subadult (left) and adult (right) Rainbow Trout at index sample sites in the lower Columbia River, 2001-2017.

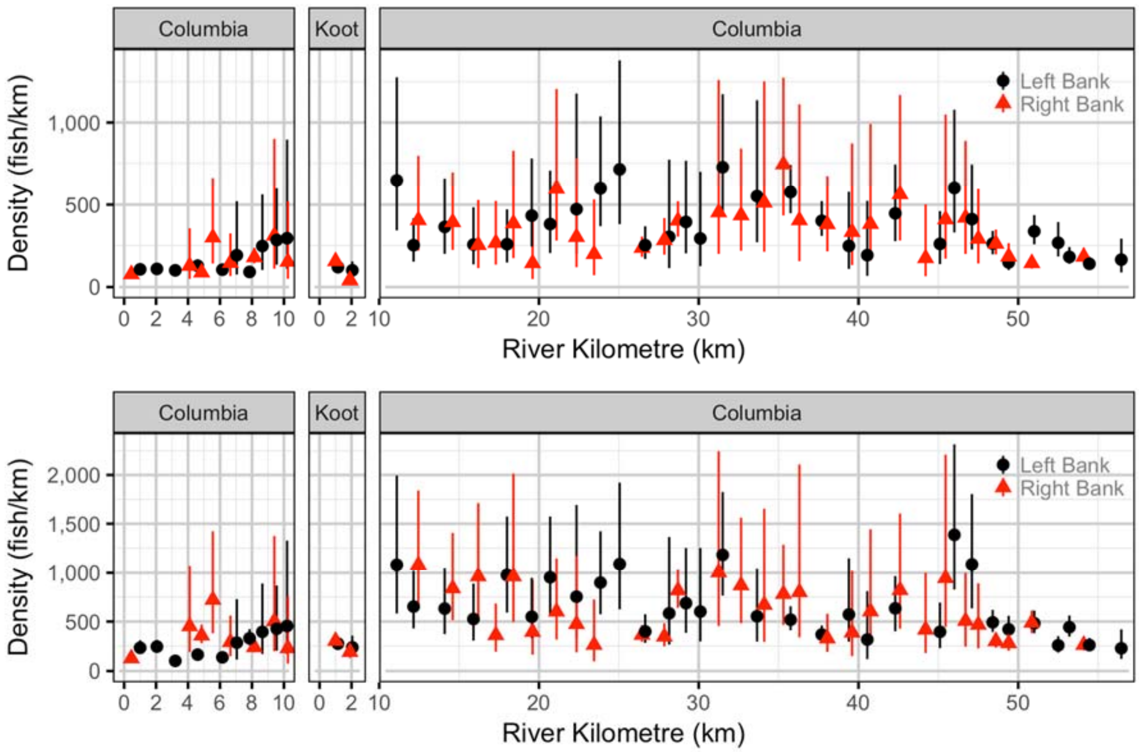


Figure 20: Density (means with 95% CRIs) of subadult (top) and adult (bottom) Rainbow Trout by river kilometre in the lower Columbia River, 2001–2017.

3.4.5 Walleye

Since 2001, Walleye abundance has fluctuated with peaks in 2003 to 2005 and in 2011 (Figure 21). Walleye abundance estimates were lower from 2012 to 2015 (17,000–23,000) than during previous years but increased slightly in 2016 and 2017 (25,000–28,000). 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 22). 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.

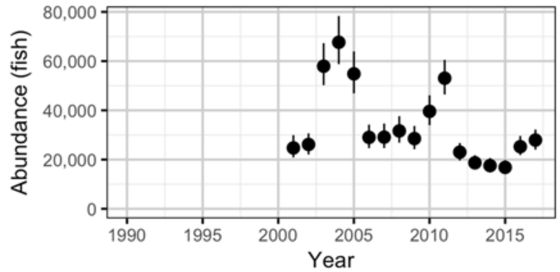


Figure 21: Abundance (means with 95% CRIs) of adult Walleye at index sample sites in the lower Columbia River, 2001–2017.

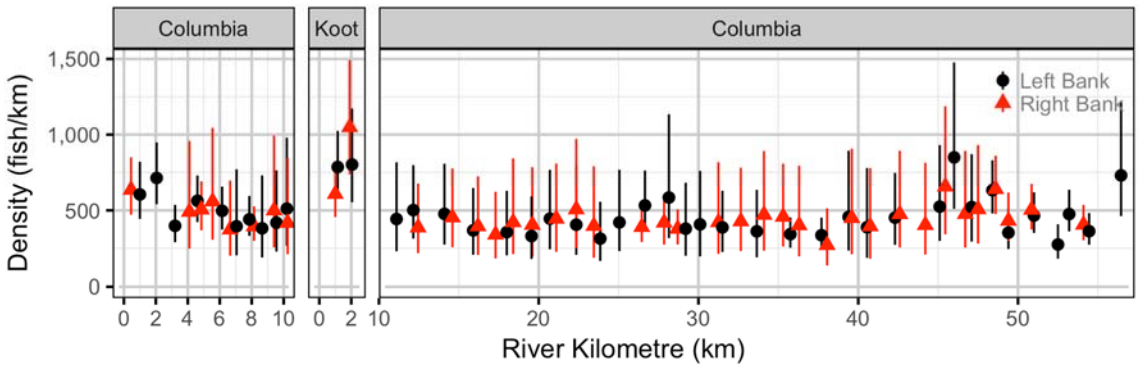


Figure 22: Density (means with 95% CRIs) of adult Walleye by river kilometre in the lower Columbia River, 2001–2017.

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 19% to 95%. Adult survival generally increased between 2002 and 2008 and was relatively stable between 2011 and 2017 (70-88%; Figure 23). 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% (Figure G8, Appendix G).

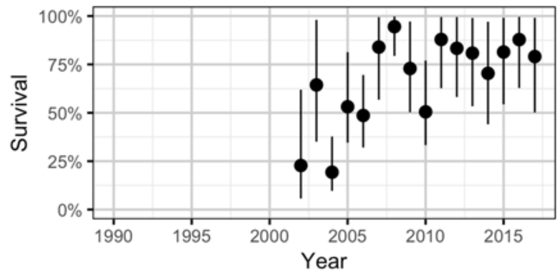


Figure 23: Survival estimates (mean with 95% CRIs) for adult Mountain Whitefish in the lower Columbia River, 2001–2017.

3.5.2 Rainbow Trout

Survival estimates of Rainbow Trout increased gradually from 32% in 2003 to 52% in 2011, but declined to 34–40% in 2012 to 2017 (Figure 24). The inter-annual capture efficiency was 7–8% (Figure G9, Appendix G).

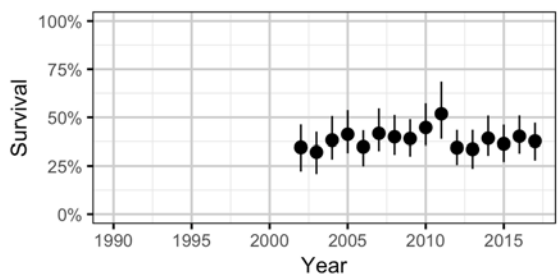


Figure 24: Survival estimates (mean with 95% CRIs) for adult Rainbow Trout in the lower Columbia River, 2001–2017.

3.5.3 Walleye

The estimated survival of Walleye was 54% in 2017, which was similar to most other years since 2001 (Figure 25). A few years, including 2004, 2006, and 2013–2014, had lower survival ranging from 37% to 46%. However, credible intervals overlapped for all years. The inter-annual capture efficiency was 3–4% (Figure G10, Appendix G).

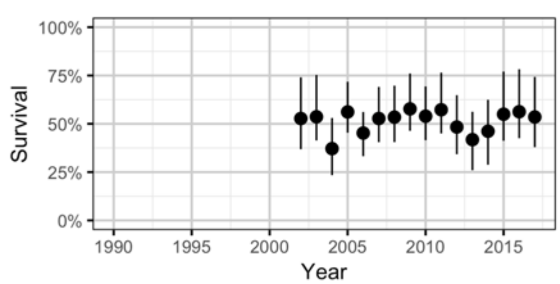


Figure 25: Survival estimates (mean with 95% CRIs) for adult Walleye in the lower Columbia River, 2001–2017.

3.6 Body Condition

3.6.1 Mountain Whitefish

The body condition of subadult Mountain Whitefish varied little (<1%) from 2008 to 2015, increased to 3% in 2016 and declined to -2% in 2017 (Figure 26; left panel). Adult Mountain Whitefish body condition was also stable between 2010 and 2017, with effect sizes of 1–3%, except in 2016 (5%; Figure 26; right panel). Adult body condition was much lower in the 1990s than between 2001 and 2017, with effect sizes of 6-16% lower than in a typical year.

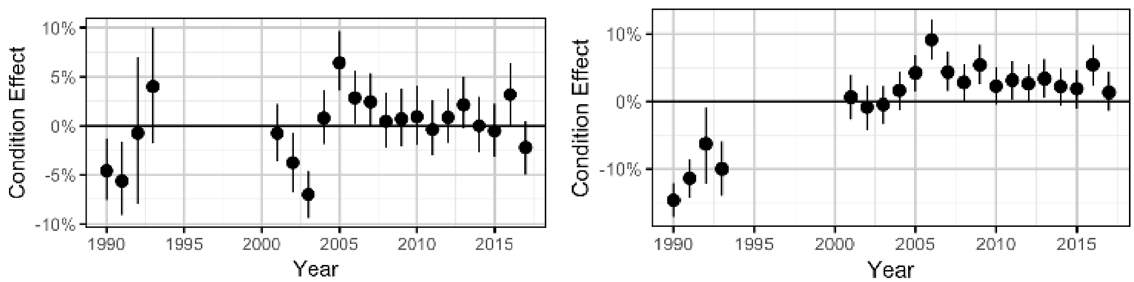


Figure 26: Body condition effect size estimates (mean with 95% CRIs) for subadult (200 mm; left panel) and adult (350 mm; right panel) Mountain Whitefish in the lower Columbia River, 1990 to 1993 and 2001 to 2017.

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 27). For subadults, body condition estimates increased from 2003 to 2006, decreased from 2006 to 2011, were similar from 2012 to 2016 and were lowest (-4% effect size) in 2017. Estimates of the body condition of adult Rainbow Trout were greater in 2002 and 2006 than in other years. Adult body condition declined from 3% in 2011 to -7% in 2017, which coincided with increasing abundance estimates (Section 3.4.4).

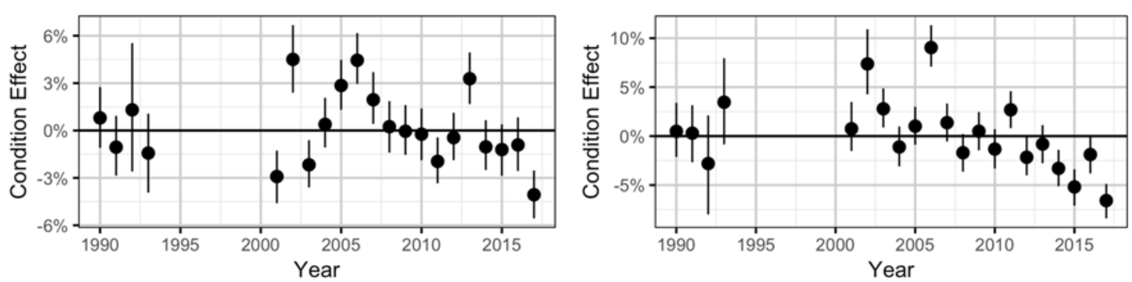


Figure 27: Body condition effect size estimates (mean with 95% CRIs) for subadult (250 mm; left panel) and adult (500 mm; right panel) Rainbow Trout in the lower Columbia River, 1990 to 1993 and 2001 to 2017.

3.6.3 Walleye

Walleye body condition fluctuated with no consistent trend since the early 1990s (Figure 29). Body condition estimates decreased gradually from 2012 to 2017 but the effect size was relatively small (5 to 1% effect size). Overall, the results suggest good body condition since 2012, but a declining trend to more typical values in the last few years (i.e. 0% effect size).

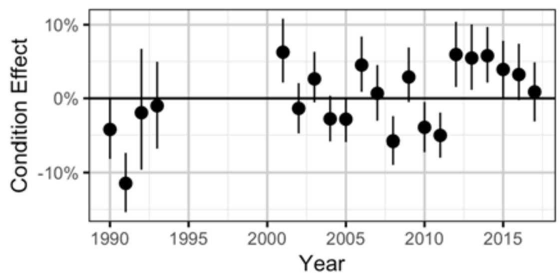


Figure 28: Body condition effect size estimates (median with 95% CRIs) by year for adult (600 mm) Walleye in the lower Columbia River, 1990 to 1993 and 2001 to 2017.

3.7 Scale Ageing

Ages were assigned to scale samples using an algorithm to identify growth annuli based on inter-circuli distances for Mountain Whitefish (Figure 29). For Mountain Whitefish of known age ("Certain" in Figure 29), age-0 fish were classified as either age-0 or age-1, whereas age-1 fish were mostly classified as age-1 but with ages ranging from 0 to 3+. Known age-2 fish were classified as age-1 to age-3+, and known age-3+ were classified as age-0 to age-3+ using the circuli method (Figure 29). After maximizing the classification accuracy of the algorithm using fish of known age, the algorithm was used to age a random sample of Mountain Whitefish captured in 2010 to 2017. For fish of uncertain true age (bottom panel; Figure 29), there was considerable disagreement between ages assigned using the circuli algorithm vs. the length-at-age model. For all four age-classes assigned by the length-at-age model (age-0, age-1, age-2, and age-3+), there was considerable variability in the ages assigned using the circuli algorithm.

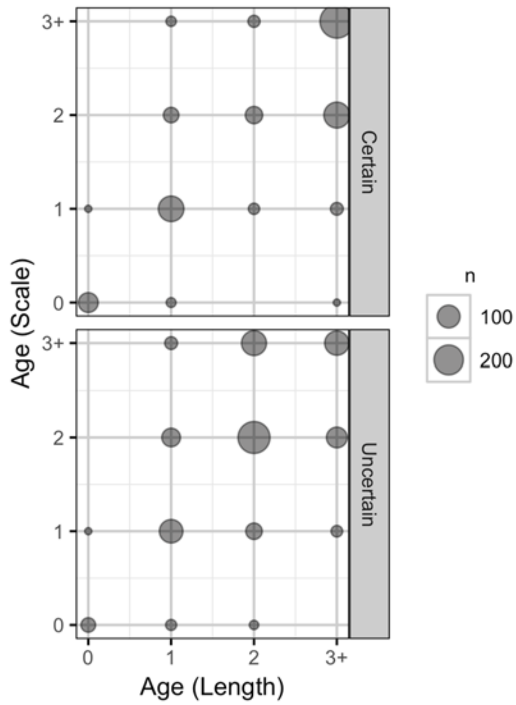


Figure 29: Estimated scale age based on inter-circuli distances of Mountain Whitefish compared to ages from the length-at-age model. Ages are compared for fish whose true age was known due to length at initial capture and recapture history (“Certain”) and fish of “Uncertain” true age. Circle size represents the number of fish (“n”).

For ages assigned using annuli counts, ages assigned using the uninformed scale ageing method were typically one year older than the known age (Figure 30). Note that ages are not always an integer for the uninformed method, because there were two blind replicates by two different scale agers for each sample and the single age shown is the average of the four assigned ages. Ages assigned using the informed scale ageing method were relatively more accurate, with the majority of age-1, age-2, and age-3 and older fish correctly aged. However, for fish of “certain” age, the low error rate of the informed method is because scale agers had access to recapture history (number of years between captures) and not necessarily more accurate annuli counts. All of the analyses assume that age-0 and age-1 can reliably be distinguished based on length, which is the basis for “known” ages for young (age-0 and age-1) and recaptured fish that were initially captured at age-0 or age-1. All three of the scale-based ageing methods had considerable variability in the age-class assigned for each age category from the length-at-age model. This likely indicates considerable error in the scale-based ageing methods, especially for the circuli and uninformed method. For this reason, ages from the length-at-age model were used when calculating the age-1:2 ratio for Mountain Whitefish as an indicator of recruitment.

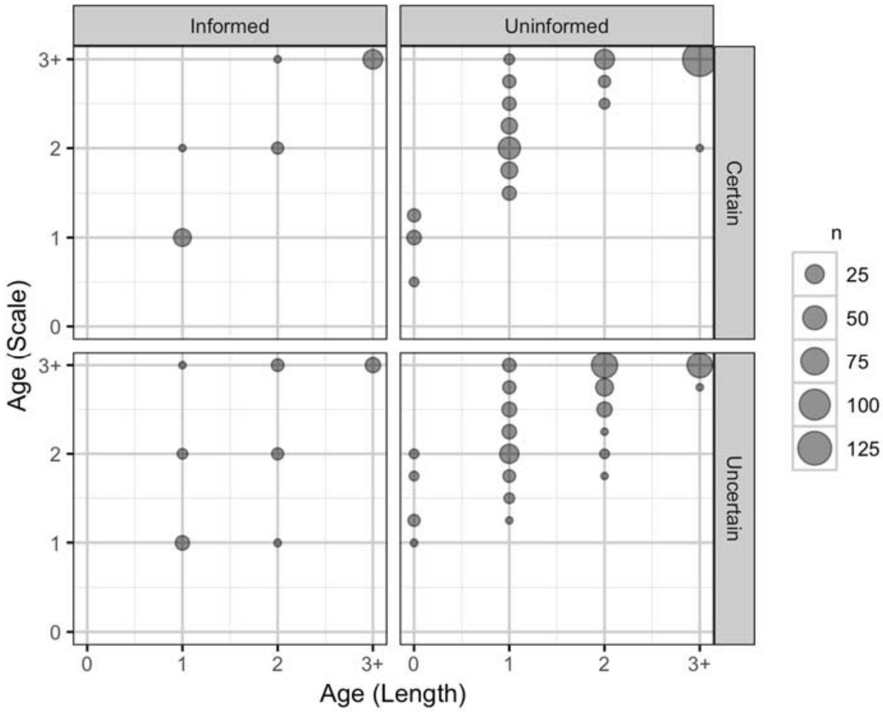


Figure 30: Comparison of scale ages from annuli counts using two methods (Golder and ONA) to ages assigned using the length-at-age model for Mountain Whitefish. Ages are compared for fish of known age due to length at initial capture and recapture history ("Certain") and fish of "Uncertain" true age. Circle size represents the number of fish ("n").

Ages assigned by the length-at-age model were relatively accurate when compared to known ages that were based on size at initial capture (age-0 or age-1) and recapture history (Figure 31). Age-2 Mountain Whitefish were correctly classified in nearly all cases with a small proportion of fish incorrectly classified as age-1. Age-3 and older Mountain Whitefish were mostly classified correctly by length, but a proportion was incorrectly classified as age-2. This indicates that length-based ages are reasonably accurate but with a small bias towards overestimating the proportion of age-2 Mountain Whitefish.

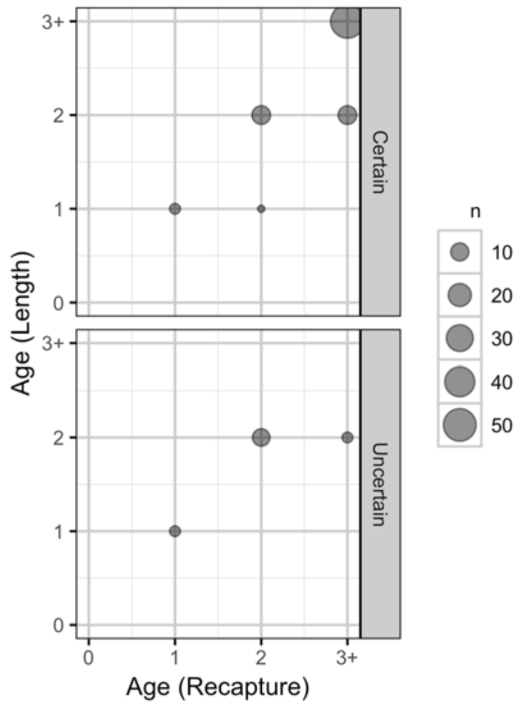


Figure 31: Comparison of ages assigned using the length-at-age model (vertical axis) to known age based on recapture history (horizontal axis) for Mountain Whitefish. All recapture ages (horizontal axis) were fish initially captured at age-0 or age-1 and recaptured in a subsequent year. Fish of "Certain" age had a probability ≥0.98 associated with the length-based age of initial capture (age-0 or age-1) where fish of "Uncertain" age had a probability <0.98, indicating uncertainty in the initial age. Circle size represents the number of fish ("n").

3.8 Age Ratios

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 78% in 2005 (Figure 32). The estimated proportion of egg mortality due to dewatering was greatest in 2008 (35%) and 2012 (46%) based on the egg loss model (Figure 33). To test for the effect of egg loss on age-1:2 ratio, the logged ratio of age-1 and 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=0.5). The data suggested a weak 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. From the 2010 to 2015 spawning years, the age-1:2 ratio recruitment index has remained relatively stable (63% to 73%), while the estimated egg loss due to dewatering varied from 7% to 46%.

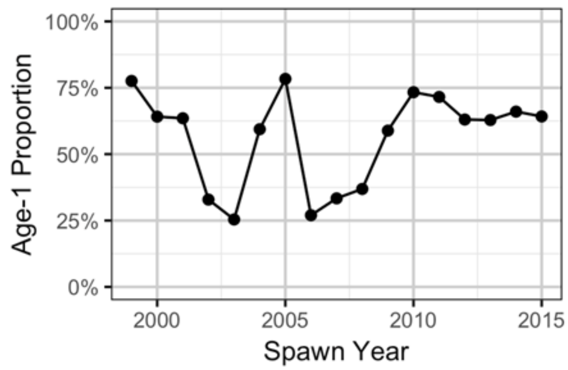


Figure 32: Proportion of age-1 to age-2 Mountain Whitefish in boat electrofishing catch in the lower Columbia River by spawning year, 1999 to 2015.

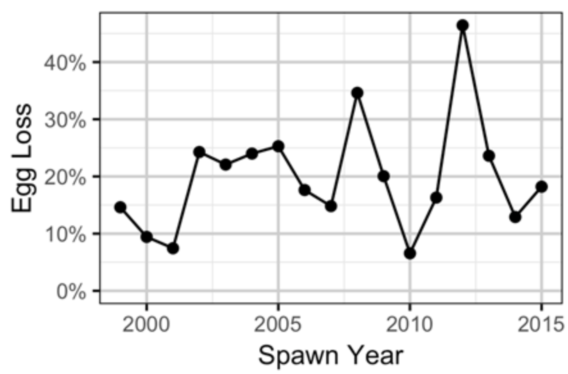


Figure 33: Estimated proportion of Mountain Whitefish egg loss due to dewatering in the lower Columbia River by spawning year, 1999 to 2015, based on the egg loss model.

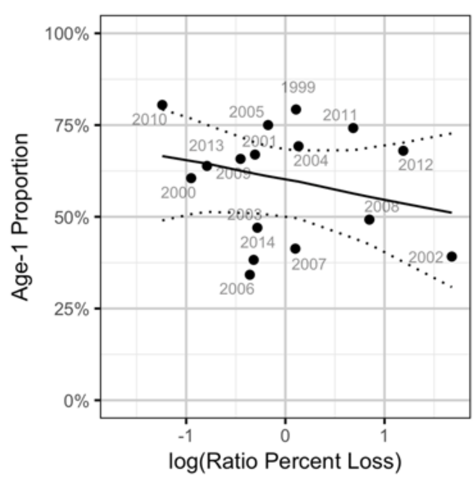


Figure 34: Relationship between the proportion of age-1 to age-2 Mountain Whitefish and the estimated proportion of Mountain Whitefish egg loss due to dewatering. Year labels represent the spawning year. The predicted relationship is indicated by the solid black line and dotted line represents the 95%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

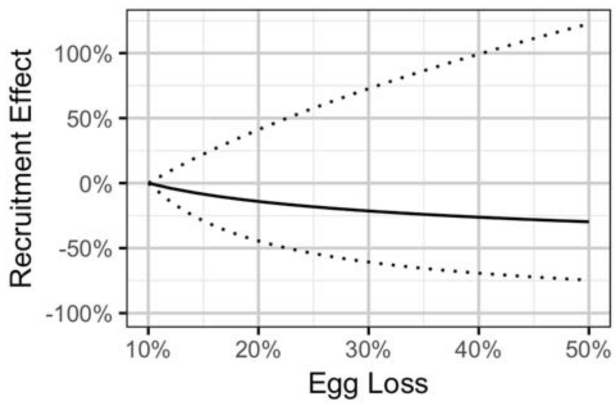


Figure 35: Predicted percent change in age-1 Mountain Whitefish abundance by egg loss in the spawn year relative to 10% egg loss in the spawn year (with 95% CRIs).

3.9 Stock-Recruitment Relationship

3.9.1 Mountain Whitefish

The Beverton-Holt stock-recruitment curve indicated large variation in the recruitment for Mountain Whitefish data in the LCR (Figure 36).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 impact of egg loss due to dewatering was modeled as an effect on the β parameter. The effect of egg loss was not significant (P>0.7), which does not support an effect of egg loss on recruitment. 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.

The largest estimated egg loss occurred for the 2012 spawning year (46%) but the number of recruits was greater than the average recruitment predicted by the stock-recruitment curve (Figure 36). On the other hand, 2008 had the next greatest estimated egg loss (35%) and had fewer than half the estimated number of recruits than predicted by the recruitment curve, which supports a potential negative effect of egg dewatering on recruitment. Thus, 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>0.7).

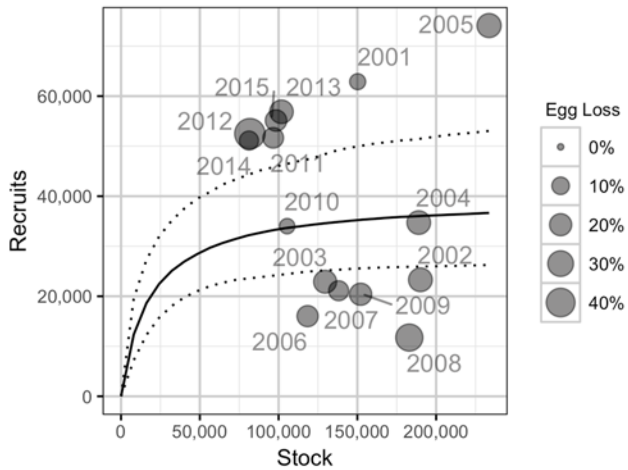


Figure 36: Predicted stock-recruitment relationship between age-2+ spawners (“Stock”) and subsequent age-1 Mountain Whitefish (“Recruits”) by spawning year (with 95% CRIs). Estimated proportion of egg loss due to dewatering for each spawning year is shown by size of shaded circles.

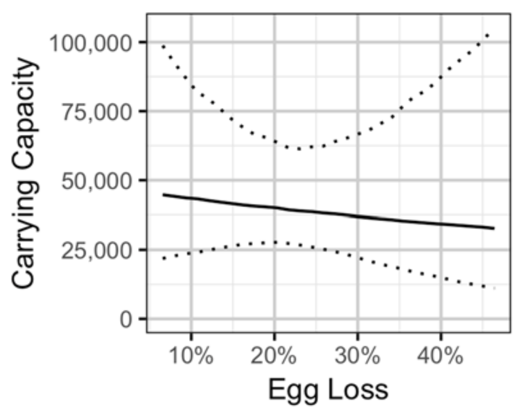


Figure 37: Predicted carrying capacity of age-1 Mountain Whitefish recruits by percentage egg loss (with 95% CRIs).

3.9.2 Rainbow Trout

The Beverton-Holt stock-recruitment curve 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 β was statistically significant (P>0.02) and indicated a negative effect of egg loss on the strength of density-dependence. Decreasing density-dependence resulted in a positive effect of egg loss on the carrying capacity of age-1 recruits (Figure 39). The predicted mean carrying capacity increased from 25,000 recruits at 0.4% egg loss to 50,000 recruits at 1.6%, although there was a large degree of uncertainty, especially for egg loss greater than 0.8% (Figure 39). For instance, with an egg loss of 1.2%, the 95% credible interval for carrying capacity ranged from 25,000 to 125,000 recruits, which reflects large uncertainty in the stock recruitment relationship and the effects of egg loss. Overall, observed egg losses were relatively small, with estimates of less than 2% in all years.

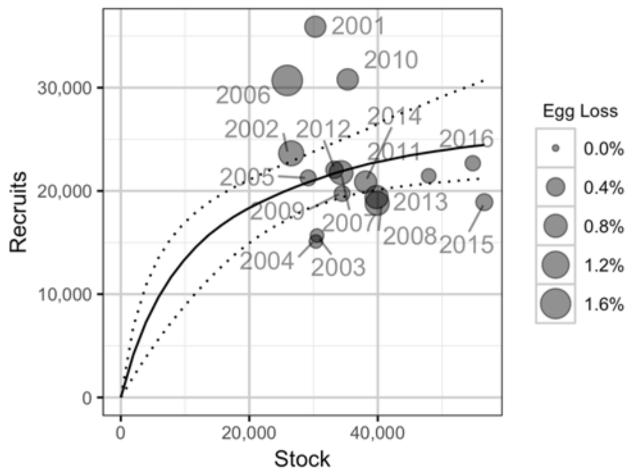


Figure 38: Predicted stock-recruitment relationship between age-2+ spawners ("Stock") and subsequent age-1 Rainbow Trout ("Recruits") by spawning year (with 95% CRIs). Estimated proportion of egg loss due to dewatering for each spawning year is shown by size of shaded circles.

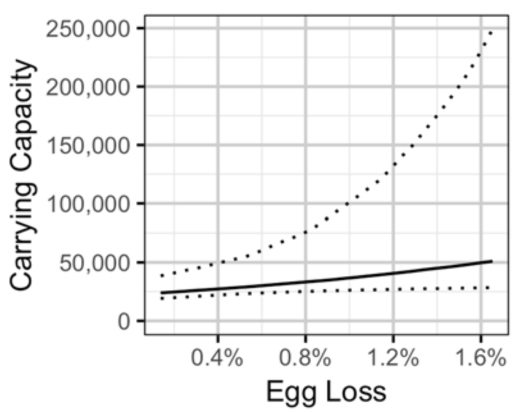


Figure 39: Predicted carrying capacity of age-1 recruits by percentage egg loss (with 95% CRIs).

3.10 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 7). Catches of Northern Pike declined in 2014 and were low in 2015 to 2017 (<12 per year), which were years when a Northern Pike gill netting suppression program was conducted by Mountain Water Research for the Ministry of Forests, Land, Natural Resources Operations, and Rural Development (MFLNRORD) and Teck Metals Ltd. (Baxter and Lawrence 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). Northern Pike removal efforts are currently ongoing within the LCR.

During the LCR Fish Indexing Program in 2016, all Northern Pike were captured in the Columbia River upstream of the Kootenay River confluence. In 2017 only two of the eleven Northern Pike were captured or observed in this reach. All other Northern Pike were captured or observed in the lower reach 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

Other aquatic invasive species captured or observed within the LCR in 2017 include eight Brook Trout (*Salvelinus fontinalis*), two Brown Trout (*Salmo trutta*), four Smallmouth Bass (*Micropterus dolomieu*), one Tench (*Tinca tinca*), and five Yellow Perch (*Perca flavescens*).

In 2017, 25 Burbot were recorded at index sites in the LCR, which was similar to catches from 2013 to 2016 (6-20 Burbot per year) but lower than catches from 2003 to 2013, which ranged from 39 to 247 Burbot per year (Appendix E, Table E1).

Thirty-five White Sturgeon (17 adults and 18 immatures) were recorded (all observed; none captured) during the 2017 survey. Observational information for these fish is provided in Attachment A.

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 4.7) and stock-recruitment (Section 4.8). 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. Thus, the growth coefficient was 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 120 and 140 mm in nearly all years (Figure 8). One exception was 2016, when mean length was larger (156 mm), but this may have been partly attributed to small and non-representative sample size that year.

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. Refinement of the length-at-age model in 2017 allowed age-2 and age-3 and older Mountain Whitefish to be separated, whereas in previous years age-2 and older Mountain Whitefish were grouped together. 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 recaptures had a growth coefficient in 2017 that was similar to the long-term average (Figure 9). In 2014 to 2016, growth coefficients were 33% to 42% greater than a typical year. 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.

4.1.2 Rainbow Trout

Mean length of age-0 Rainbow Trout declined in 2016 and 2017 but the values were within the range observed in most previous years of the study (100–130 mm; Figure 10). Mean length had previously increased from 101 mm in 2010 to 143 mm in 2015. Thesetrends did not agree with the trend in growth suggested by the von Bertalanffy growth coefficient, which decreased from a 48% effect size in 2006 to -30% in 2017 (Figure 11). 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 different trends suggested by length-at-age and the growth model could reflect differences in growth between life stages because mean length of age-0 fish reflects growth during early life history, whereas the growth coefficient represents the rate of approach to the asymptotic length independent of size, but may be influenced in this case more by adult fish that were more commonly recaptured. The decreasing trend in the growth coefficient coincided with increasing abundance of adult Rainbow Trout and may reflect density-dependence and reduced growth due to intra-specific competition. Favourable environmental conditions that led to increasing abundance from 2010 to 2017 may also have contributed to increasing length-at-age for age-0 Rainbow Trout (2010-2015) that were not in direct competition with adults for food or other resources.

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 -40% to 85% across years (high variability), and the 95% CL of the 2017 estimate ranged from -50% to 29% (high uncertainty). 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- for Walleye were not realistic and the von Bertalanffy curve was not presented in Figure 7. However, the growth coefficient can be used as relative indicator 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 to 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 12) 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 numbers 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

Estimates of abundance of Mountain Whitefish were stable, with very little variation for juveniles between 2014 and 2017 and for adults from 2010 to 2017 (Figure 17). In earlier years of the program, abundance estimates of subadult Mountain Whitefish decreased markedly (>70%) between 2001 and 2005. If subadult Mountain Whitefish density truly declined between 2001 and 2005, one would expect either adult Mountain Whitefish densities to decline between 2002 and 2006 or adult Mountain Whitefish survival to increase between 2001 and 2005. Neither adult abundance nor survival changed enough over that time period to support a >70% reduction in the abundance of subadult Mountain Whitefish. This discrepancy could be partly explained by migration of Mountain Whitefish out of the study area, and the subsequent effect on survival and abundance estimates, which is discussed in further detail in Section 4.4.1.

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 that were not supported by trends in adult abundance and survival. Pulse frequencies used were 120 or 60 Hz in 2001 and 2002, 60 or 30 Hz in 2003, and 30 Hz from 2004 to 2017. Higher pulse frequencies are more effective for catching smaller-bodied fish that higher 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 2011a) 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 abundance of adults more than doubled from ~27,000 in 2002 to ~68,000 in 2017. 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 2017 (Irvine et al. 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.

Increasing adult abundance (spawner survey and indexing) during periods of declining or similar subadult abundance (indexing study) is also reflected in the annual length frequency plots, which show increasing proportion of larger fish during the study period (Appendix F, Figure F5). The high abundance estimates of subadult Rainbow Trout in 2001 and 2002 could be related to the higher pulse frequency used while electrofishing those years, which would be expected to be more efficient for capturing smaller fish, as discussed for Mountain Whitefish in Section 4.2.1.

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 each study year. 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 growing Northern Pike population through a targeted gill-netting program in 2014 to 2017 appear to be reasonably successful with 323 individuals removed in total, 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 in from a peak of 135 in 2013 to less than 12 per year from 2015 to 2017, 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 2017, 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 among 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 2017 (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 2016 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 2018).

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 water-milfoil) between 2001 and 2017 (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 2017 (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 (2011a) 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 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 (Figure 22). Sculpin species and Redside Shiner are a common prey fish for Walleye based on stomach sample analyses (Ford and Thorley 2011a). 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 2011a). In addition, Walleye densities are probably higher immediately downstream of HLK because they are feeding on fish entrained at the dam. Walleye densities also were high in the Kootenay River downstream of BRD to the confluence of the Columbia, likely for the same reason.

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 (19-95%) but has been ≥70% since 2011 (Figure 23). 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 density estimates, the estimates generated were not compatible with survival estimates. For instance, it is not possible for an adult population of ~120,000 fish in 2014 to be supported by a subadult population in 2013 of 56,000 fish with only 25% subadult survival (14,000 fish to be recruited to the adult population) and adult survival of 29% (34,800 fish remaining in the adult population). This indicates 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.

Subadult survival was not estimated in 2015 to 2017 because the estimates provide no information on inter-annual variation.

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. 2017b). 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 32% to 52% 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 40% during 2012 to 2016. Lower survival during recent years coincided with high abundances, as indicated by mark-recapture estimates (Section 3.4.4) and spawner surveys (Irvine et al. 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 54% in 2017 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 26) between 2010 and 2017. 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 2017 (Figure 26). 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 2017 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 2017 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-Rusello 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 (2001–2017).

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 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-Rusello 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 2017 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 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; Ford and Thorley 2011b).

4.5.3 Walleye

Body condition of Walleye was greater in 2012 to 2016 than in most previous years but decreased in 2017. The years with high body condition (2012 to 2016) 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 Scale Ageing

Mountain Whitefish scales were aged by measuring inter-circuli distances and using a computer algorithm to identify and count growth annuli. The objective was to develop a more dependable, repeatable, and objective ageing method than traditional methods, where scale agers visually identify and count annuli. Analyses in this report show that traditional annuli counts can be reasonably reliable, at least for age-3 and younger Mountain Whitefish, but there can be considerable variation between scale agers, and sometimes significant variation and error (Figure 30). Subjectivity in interpreting fish scales that leads to ageing bias or imprecision has also been noted for many other species (Campana 2001). The circuli algorithm in this report provides an objective and repeatable method but unfortunately is imprecise and had considerable ageing error even for age-1 Mountain Whitefish that can be reliably aged using traditional annuli counts or length-frequency models. Improvement of accuracy and precision of the circuli method may be possible but would likely require additional information to be measured or extracted from the scale (e.g. circuli width, shading, spawning checks) and a very large sample size.

Due to the error and uncertainty in the current circuli-based ages, the ages assigned using the length-at-age model were used in analysis of the age-1:2 ratio as a recruitment indicator (Section 4.7). An advantage of length-based ageing is that it is objective and repeatable. In addition, using length-based ages allows for a consistent ageing technique to be used for all years of the study, instead of using ages from different techniques and scale agers from different years of the program, which could introduce bias into the age-1:2 ratio. Comparison of length-based ages to ages that were known due to recapture history suggested relatively good accuracy of the length-at-age model, with a small bias towards overestimating the proportion of age-2 Mountain Whitefish. Unless circuli-based ageing accuracy and precision can be improved, using ages from the length-at-age model when calculating the age-1:2 ratio is recommended for future study years.

4.7 Age Ratios

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. 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 78% between the 1999 and 2015 spawning years, which suggests substantial inter-annual variation in recruitment during the monitoring period. There was no significant relationship between the age-1:2 ratio recruitment index and the estimated annual egg loss. The weak, non-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 the period of study.

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 2017. 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.

4.8 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 2017 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 in the model was not 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 the β parameter was significant, with a predicted positive effect of egg loss on the carrying capacity of age-1 recruits. 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 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.

4.9 Summary

The sampling program conducted since 2001 provides a high-quality, long-term dataset to address the first management question, which regards 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 2017, 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 also suggested density-dependence with lower abundance and greater body condition in 2012 to 2016 but near-average values in 2017. The estimated abundance of Mountain Whitefish abundance declined since 2001 but was relatively stable during the most recent eight years (2010-2017). Length-at-age of fry and body condition of Mountain Whitefish also 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 significant relationship between the age-1:2 recruitment index and estimated egg losses. 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 significantly different flow regimes, which would help address the management question regarding the effects of variability in the flow regime on fish populations.

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Appendix A - Maps

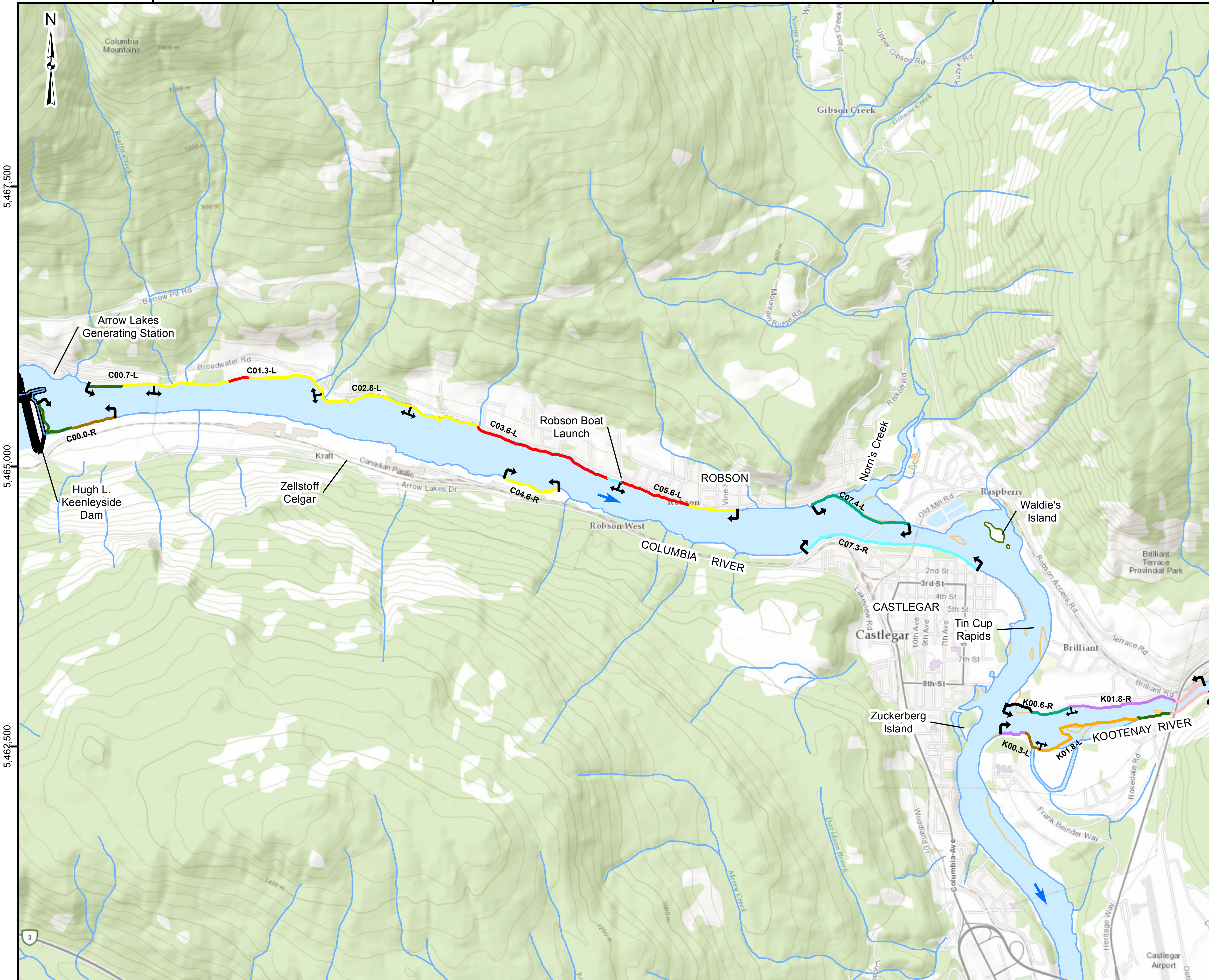
Table A1 Locations and distances from Hugh L. Keenleyside Dam of boat electrofishing index sites in the lower Columbia River, 2017.

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.



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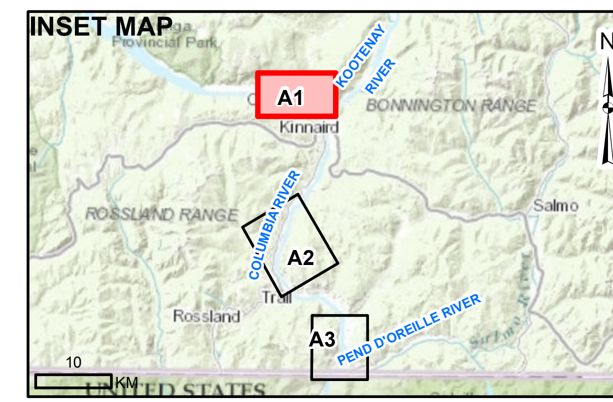
LEGEND

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

BANK HABITAT TYPE

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

INSET MAP



REFERENCE

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

PROJECTION: UTM ZONE 11 DATUM: NAD 83

600 0 600

SCALE 1:35,000 METRES

PROJECT

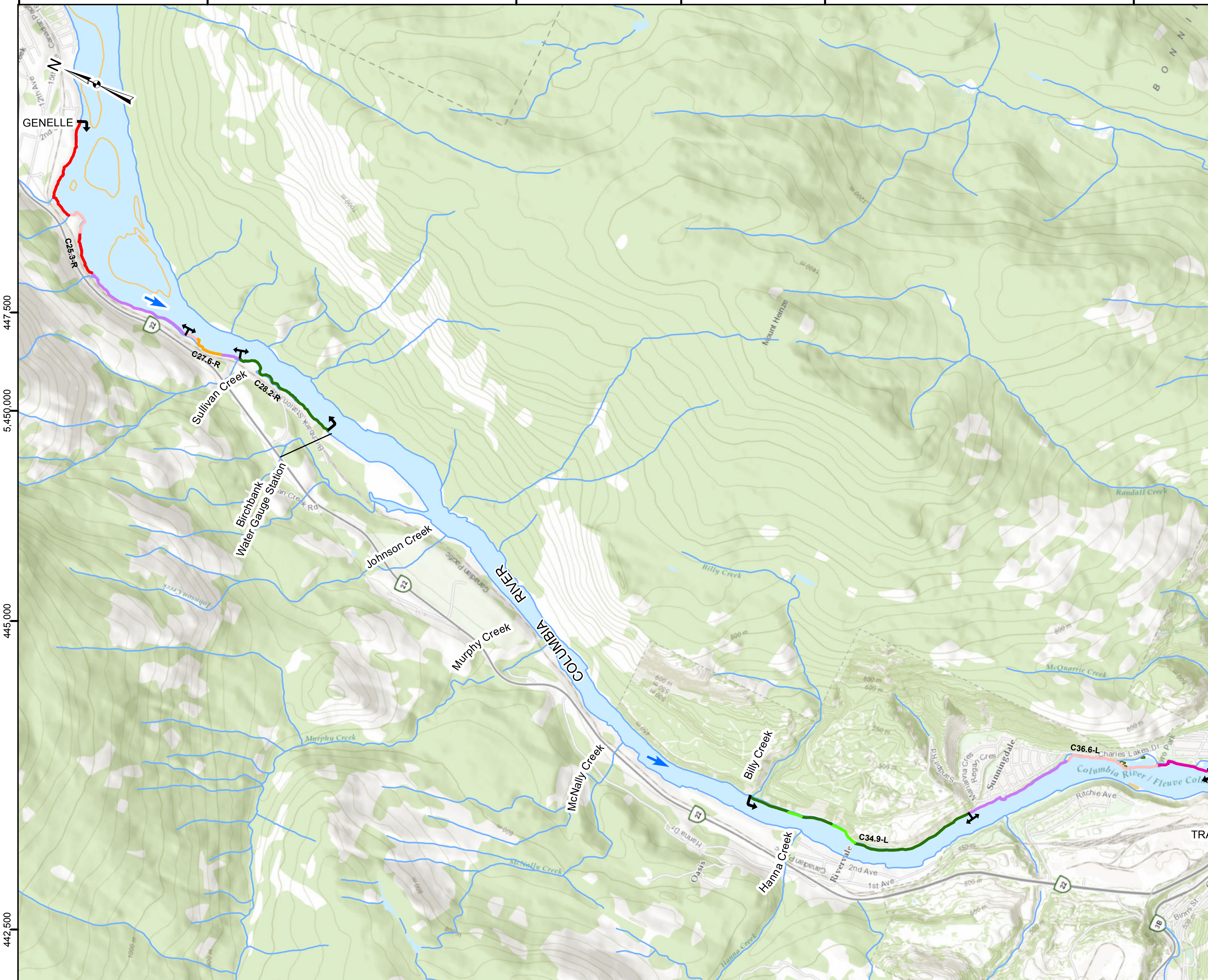
LARGE RIVER FISH INDEXING PROGRAM
LOWER COLUMBIA RIVER

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	6 JUN. 2018		
CHECK	DR	6 JUN. 2018		
REVIEW	SR	6 JUN. 2018		



LEGEND

RIVER KILOMETRE DOWNSTREAM OF HUGH L. KEENLEYSIDE DAM

C00.0-R BOAT ELECTROSHOCKING SITE

FLOW DIRECTION

WATERCOURSE

BREAKWATER

DAM SECTION

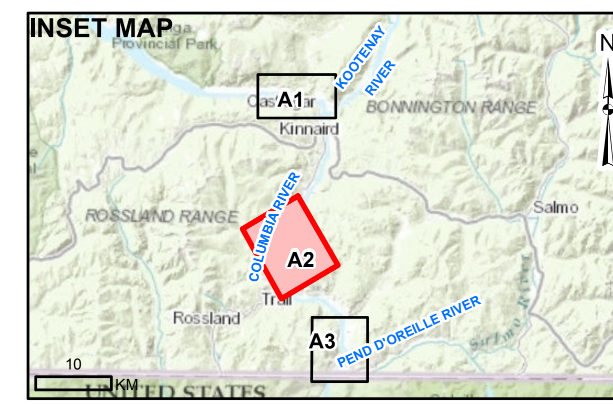
ISLAND

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, DELORME, INTERMAP, INCREMENT P CORP., GEBCO, USGS, FAO, NPS, NRCAN, GEOBASE, IGN, KADASTER NL, ORDNANCE SURVEY, ESRI JAPAN, METI, ESRI CHINA (HONG KONG), SWISSTOPO, MAPMYINDIA, © 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	6 JUN. 2018		
CHECK	DR	6 JUN. 2018		
REVIEW	SR	6 JUN. 2018		

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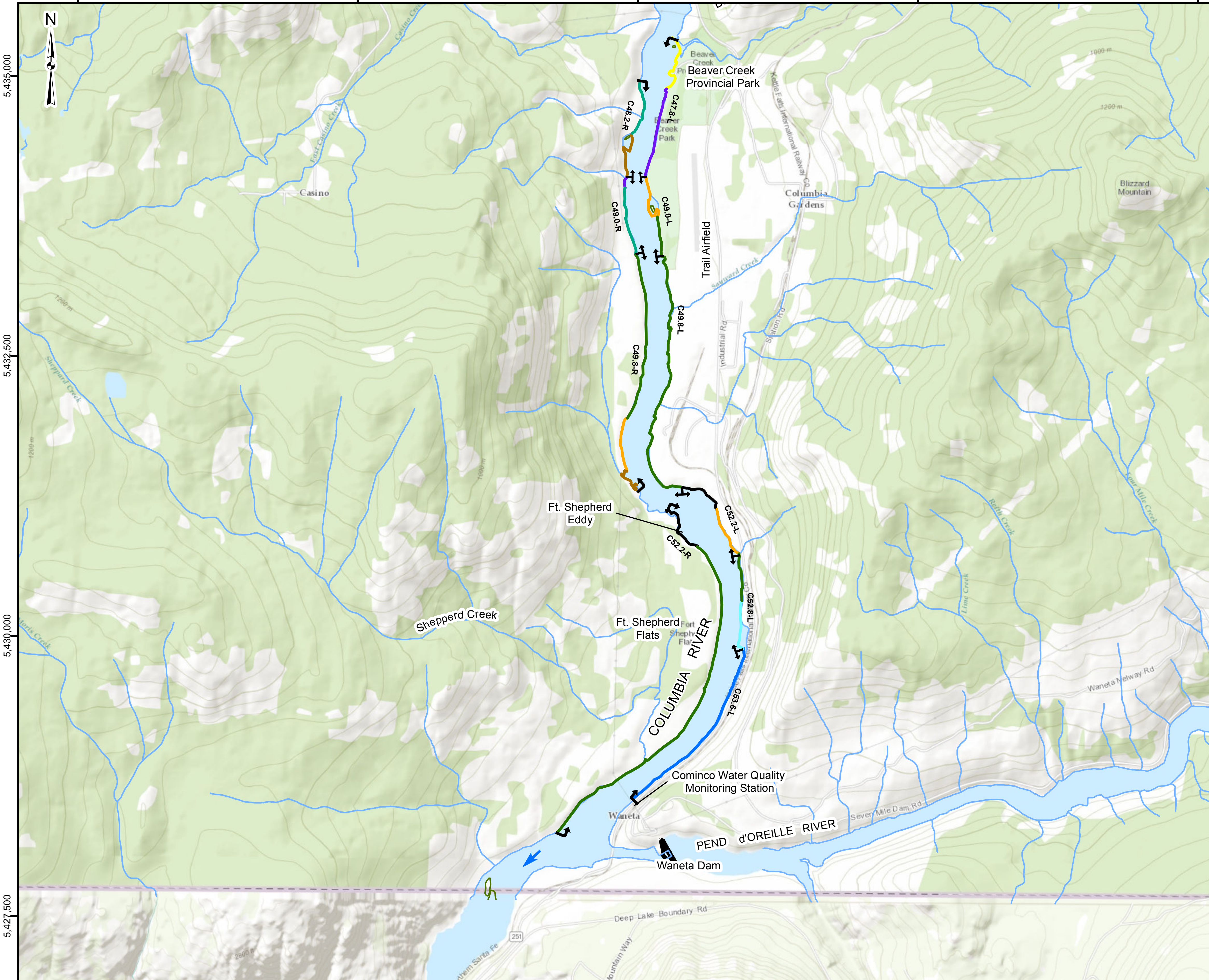


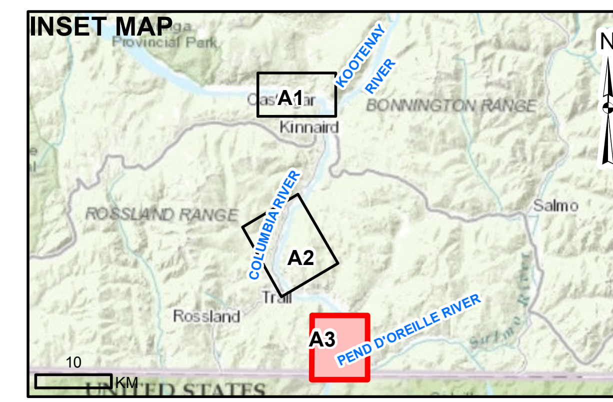
LEGEND

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

BANK HABITAT TYPE

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

INSET MAP



REFERENCE

SERVICE LAYER CREDITS: SOURCES: ESRI, HERE, DELORME, INTERMAP, INCREMENT P CORP., GEBCO, USGS, FAO, NPS, NRCAN, GEOBASE, IGN, KADASTER NL, ORDNANCE SURVEY, ESRI JAPAN, METI, ESRI CHINA (HONG KONG), SWISSTOPO, MAPMYINDIA, © 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

GOLDER

PROJECT No. 1537874			SCALE AS SHOWN	REV. 0
DESIGN	DR	14 JUN. 2016	**FIGURE: A3**	
GIS	JG/CD	6 JUN. 2018		
CHECK	DR	6 JUN. 2018		
REVIEW	SR	6 JUN. 2018		

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Appendix B – Habitat Summary Information

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

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

Continued.

Table B1 Concluded.

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

Velocity Classifications:

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

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

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

[a] See Appendix A, Figures A1 to A3 for sample site locations.
[b] See Appendix B, Table B1 for bank habitat type descriptions.

Table B3 Summary of habitat variables recorded at boat electroshocking index sites in the Lower Columbia River, 02 October to 28 October 2017.

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	12.9	180	Clear	High	High	High	30	0	0	0	0	50	20
Kootenay	K01.8-R	2	10.0	11.3	180	Overcast	High	High	High	10	0	0	0	0	50	40
Kootenay	K01.8-R	3	6.0	10.5	180	Partly cloudy	High	High	High	20	0	0	0	0	60	20
Kootenay	K01.8-R	4	8.0	9.7	170	Partly cloudy	High	High	High	20	0	0	0	0	70	10
Kootenay	K01.8-L	1	5.0	12.9	180	Overcast	High	High	High	0	0	0	0	0	85	15
Kootenay	K01.8-L	2	7.0	11.3	180	Overcast	High	High	High	10	0	0	0	0	70	20
Kootenay	K01.8-L	3	1.0	10.5	180	Clear	High	High	High	15	0	0	0	0	75	10
Kootenay	K01.8-L	4	6.0	9.7	170	Partly cloudy	High	High	High	20	0	0	0	0	65	15
Kootenay	K00.6-R	1	5.0	12.9	180	Partly cloudy	High	High	High	0	0	0	80	0	20	0
Kootenay	K00.6-R	2	8.0	11.3	180	Overcast	High	High	High	0	0	0	20	0	80	0
Kootenay	K00.6-R	3	5.0	10.1	180	Clear	High	High	High	10	0	0	10	0	70	10
Kootenay	K00.6-R	4	5.0	9.7	170	Clear	High	High	High	0	0	0	10	0	80	10
Kootenay	K00.3-L	1	5.0	12.9	180	Overcast	High	High	High	0	0	0	0	0	20	80
Kootenay	K00.3-L	2	6.0	11.3	180	Overcast	High	High	High	25	0	0	0	0	15	60
Kootenay	K00.3-L	3	2.0	10.5	180	Clear	High	High	High	40	0	0	0	0	20	40
Kootenay	K00.3-L	4	4.0	10.1	170	Clear	High	High	High	35	0	0	0	0	20	45
Lower	C53.6-L	1	4.0	12.5	150	Clear	High	High	High	40	0	0	0	10	0	50
Lower	C53.6-L	2	4.0	11.7	160	Partly cloudy	High	High	High	25	0	0	0	0	30	45
Lower	C53.6-L	3	3.0	9.3	160	Overcast	High	High	High	25	0	0	0	0	25	50
Lower	C53.6-L	4	4.0	8.5	160	Clear	High	High	High	40	0	0	0	0	40	20
Lower	C52.8-L	1	6.0	12.5	150	Clear	High	High	High	25	0	0	0	0	20	55
Lower	C52.8-L	2	4.0	11.7	160	Partly cloudy	High	High	High	15	0	0	0	0	0	85
Lower	C52.8-L	3	3.0	9.3	160	Overcast	High	High	High	20	0	0	0	0	40	40
Lower	C52.8-L	4	3.0	8.5	160	Clear	High	High	High	40	0	0	0	0	40	20
Lower	C52.2-R	1	1.0	12.3	160	Clear	High	High	High	30	0	10	0	0	40	20
Lower	C52.2-R	2	6.0	10.9	160	Overcast	High	High	High	0	0	0	0	0	80	20
Lower	C52.2-R	3	3.0	9.0	150	Clear	High	High	High	10	0	0	0	0	80	10
Lower	C52.2-R	4	3.0	8.9	160	Clear	High	High	High	0	0	0	0	0	50	50
Lower	C52.2-L	1	5.0	12.5	150	Clear	High	High	High	15	0	0	0	0	10	75
Lower	C52.2-L	2	4.0	11.7	160	Partly cloudy	High	High	High	25	0	0	0	0	0	75
Lower	C52.2-L	3	3.0	9.3	160	Overcast	High	High	High	15	0	0	0	0	20	65
Lower	C52.2-L	4	3.0	8.5	160	Clear	High	High	High	25	0	0	0	0	20	55
Lower	C49.8-R	1	6.0	12.9	140	Clear	High	High	High	50	0	10	2	0	38	0
Lower	C49.8-R	2	7.0	10.9	160	Overcast	High	High	High	0	0	0	0	0	80	20
Lower	C49.8-R	3	8.0	9.3	150	Partly cloudy	High	High	High	10	0	0	1	0	80	9
Lower	C49.8-R	4	2.0	8.9	160	Clear	High	High	High	10	0	0	1	0	80	9
Lower	C49.8-L	1	5.0	12.5	150	Clear	High	High	High	20	0	0	1	0	39	40
Lower	C49.8-L	2	6.0	11.7	160	Partly cloudy	High	High	High	10	0	0	2	0	60	28
Lower	C49.8-L	3	4.0	9.3	160	Partly cloudy	High	High	High	0	0	0	0	0	80	20
Lower	C49.8-L	4	5.0	8.5	160	Clear	High	High	High	0	0	5	0	0	85	10

[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	7.0	12.9	140	Clear	High	High	High	80	0	0	0	0	20	0
Lower	C49.0-R	2	8.0	10.9	160	Mostly cloudy	High	High	High	25	0	0	0	0	50	25
Lower	C49.0-R	3	9.0	9.3	150	Partly cloudy	High	High	High	20	0	0	0	0	50	30
Lower	C49.0-R	4	5.0	8.9	160	Clear	High	High	High	10	0	0	0	0	60	30
Lower	C49.0-L	1	7.0	12.5	150	Clear	High	High	High	0	0	0	0	0	90	10
Lower	C49.0-L	2	6.0	11.7	160	Partly cloudy	High	High	High	0	0	0	0	0	90	10
Lower	C49.0-L	3	3.0	9.3	160	Overcast	High	High	High	20	0	0	0	0	70	10
Lower	C49.0-L	4	6.0	8.5	160	Clear	High	High	High	0	0	0	0	0	90	10
Lower	C48.2-R	1	7.0	12.9	150	Partly cloudy	High	High	High	30	0	10	30	0	30	0
Lower	C48.2-R	2	10.0	10.9	160	Overcast	High	High	High	0	0	0	10	0	80	10
Lower	C48.2-R	3	9.0	9.5	150	Partly cloudy	High	High	High	0	0	0	10	0	80	10
Lower	C48.2-R	4	9.0	8.9	160	Clear	High	High	High	0	0	0	5	0	80	15
Lower	C47.8-L	1	8.0	12.9	150	Clear	High	High	High	20	0	0	5	0	25	50
Lower	C47.8-L	2	9.0	11.7	160	Mostly cloudy	High	High	High	0	0	0	10	0	60	30
Lower	C47.8-L	3	4.0	9.3	160	Overcast	High	High	High	0	0	0	5	0	35	60
Lower	C47.8-L	4	9.0	8.5	160	Clear	High	High	High	0	0	0	5	0	55	40
Middle	C36.6-L	1	2.0	12.5	160	Clear	High	High	High	30	0	0	2	0	18	50
Middle	C36.6-L	2	4.0	11.7	150	Clear	High	High	High	25	0	0	0	0	25	50
Middle	C36.6-L	3	8.0	9.9	160	Partly cloudy	High	High	High	15	0	0	2	0	70	13
Middle	C36.6-L	4	3.0	8.5	160	Clear	High	High	High	30	0	0	2	0	38	30
Middle	C34.9-L	1	4.0	12.9	150	Clear	High	High	High	35	0	0	0	0	20	45
Middle	C34.9-L	2	4.0	11.7	150	Clear	High	High	High	25	0	0	0	0	0	75
Middle	C34.9-L	3	9.0	9.9	140	Overcast	High	High	High	40	0	0	0	0	30	30
Middle	C34.9-L	4	5.0	8.9	160	Clear	High	High	High	25	0	0	0	0	25	50
Middle	C28.2-R	1	5.0	12.9	140	Clear	High	High	High	20	0	0	0	0	70	10
Middle	C28.2-R	2	4.0	11.7	150	Clear	High	High	High	0	0	0	0	0	70	30
Middle	C28.2-R	3	9.0	9.9	140	Overcast	High	High	High	0	0	0	0	0	70	30
Middle	C28.2-R	4	5.0	8.9	160	Overcast	High	High	High	10	0	0	0	0	80	10
Middle	C27.6-R	1	7.0	12.9	140	Clear	High	High	High	30	0	0	0	0	20	50
Middle	C27.6-R	2	9.0	11.7	150	Clear	High	High	High	10	0	0	0	0	20	70
Middle	C27.6-R	3	9.0	10.3	140	Overcast	High	High	High	10	0	0	0	0	50	40
Middle	C27.6-R	4	7.0	8.9	160	Overcast	High	High	High	20	0	0	0	0	35	45
Middle	C25.3-R	1	8.0	12.9	140	Clear	High	High	High	25	0	0	0	0	0	75
Middle	C25.3-R	2	12.0	11.7	150	Overcast	High	High	High	30	0	10	0	0	30	30
Middle	C25.3-R	3	9.0	9.9	140	Overcast	High	High	High	5	0	0	0	0	10	85
Middle	C25.3-R	4	9.0	8.9	160	Overcast	High	High	High	15	0	0	0	0	15	70
Upper	C07.4-L	1	15.0	12.3	130	Overcast	High	Low	High	0	0	0	15	0	60	25
Upper	C07.4-L	2	7.0	10.1	150	Overcast	High	High	High	0	0	0	10	0	70	20
Upper	C07.4-L	3	6.0	7.2	150	Partly cloudy	High	Low	High	0	0	0	20	0	70	10
Upper	C07.4-L	4	4.0	7.6	140	Clear	High	High	High	0	0	0	20	0	70	10

[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
Upper	C07.3-R	1	12.0	12.1	140	Overcast	High	High	High	50	0	0	5	0	35	10
Upper	C07.3-R	2	7.0	10.1	160	Overcast	High	High	High	50	0	0	0	0	25	25
Upper	C07.3-R	3	7.0	6.8	160	Overcast	High	High	High	30	0	0	0	0	35	35
Upper	C07.3-R	4	4.0	7.6	150	Clear	High	High	High	0	30	0	0	0	30	40
Upper	C05.6-L	1	2.0	12.5	140	Clear	High	Low	High	20	0	0	25	0	20	35
Upper	C05.6-L	2	1.0	10.5	130	Clear	High	Low	High	0	70	0	5	0	0	25
Upper	C05.6-L	3	9.0	6.8	160	Overcast	High	Low	High	0	2	0	10	0	40	48
Upper	C05.6-L	4	1.0	8.0	140	Clear	High	Low	High	0	2	0	55	0	30	13
Upper	C04.6-R	1	3.0	12.5	140	Clear	High	Low	High	0	0	0	100	0	0	0
Upper	C04.6-R	2	1.0	10.2	130	Clear	High	Low	High	0	0	0	100	0	0	0
Upper	C04.6-R	3	10.0	7.2	160	Overcast	High	Low	High	0	0	0	90	0	0	10
Upper	C04.6-R	4	1.0	8.0	140	Clear	High	Low	High	0	0	0	100	0	0	0
Upper	C03.6-L	1	5.0	12.5	130	Clear	High	Low	High	10	0	0	30	0	30	30
Upper	C03.6-L	2	2.0	10.5	130	Clear	High	Low	High	5	0	0	55	0	30	10
Upper	C03.6-L	3	6.0	8.0	140	Overcast	Medium	Low	Medium	0	0	0	40	0	40	20
Upper	C03.6-L	4	3.0	8.0	140	Clear	High	Low	High	0	0	0	55	0	30	15
Upper	C02.8-L	1	5.0	12.5	130	Clear	High	Low	High	0	0	0	65	0	20	15
Upper	C02.8-L	2	5.0	10.5	130	Clear	High	Low	High	0	0	0	60	0	40	0
Upper	C02.8-L	3	5.0	7.9	140	Overcast	Medium	Low	Medium	0	0	0	20	0	70	10
Upper	C02.8-L	4	4.0	8.0	140	Clear	High	Low	High	0	0	0	60	0	40	0
Upper	C01.3-L	1	6.0	12.5	130	Clear	High	Low	High	0	0	0	10	0	80	10
Upper	C01.3-L	2	6.0	10.1	130	Clear	High	Low	High	0	0	0	30	0	60	10
Upper	C01.3-L	3	6.0	7.9	140	Overcast	Medium	Low	High	0	0	0	25	0	50	25
Upper	C01.3-L	4	6.0	8.0	140	Clear	High	Low	High	0	0	0	15	0	70	15
Upper	C00.7-L	1	7.0	12.5	130	Clear	High	Low	High	20	0	0	0	0	40	40
Upper	C00.7-L	2	7.0	10.5	140	Clear	High	Low	High	15	0	0	0	0	20	65
Upper	C00.7-L	3	7.0	7.9	140	Overcast	Medium	Low	High	20	0	0	0	0	70	10
Upper	C00.7-L	4	8.0	8.0	140	Clear	High	Low	High	15	0	0	0	0	85	0
Upper	C00.0-R	1	9.0	12.5	130	Clear	High	Low	High	25	0	0	0	0	25	50
Upper	C00.0-R	2	9.0	10.5	140	Clear	High	Low	High	30	0	0	0	0	20	50
Upper	C00.0-R	3	10.0	7.9	140	Overcast	Medium	Low	High	0	0	0	0	0	60	40
Upper	C00.0-R	4	9.0	8.0	140	Clear	High	Low	High	25	0	0	0	0	60	15

[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 Concluded.

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	C01.3-L	1	6.0	12.5	130	Clear	High	Low	High	0	0	0	10	0	80	10
Upper	C01.3-L	2	6.0	10.1	130	Clear	High	Low	High	0	0	0	30	0	60	10
Upper	C01.3-L	3	6.0	7.9	140	Overcast	Medium	Low	High	0	0	0	25	0	50	25
Upper	C01.3-L	4	6.0	8.0	140	Clear	High	Low	High	0	0	0	15	0	70	15
Upper	C00.7-L	1	7.0	12.5	130	Clear	High	Low	High	20	0	0	0	0	40	40
Upper	C00.7-L	2	7.0	10.5	140	Clear	High	Low	High	15	0	0	0	0	20	65
Upper	C00.7-L	3	7.0	7.9	140	Overcast	Medium	Low	High	20	0	0	0	0	70	10
Upper	C00.7-L	4	8.0	8.0	140	Clear	High	Low	High	15	0	0	0	0	85	0
Upper	C00.0-R	1	9.0	12.5	130	Clear	High	Low	High	25	0	0	0	0	25	50
Upper	C00.0-R	2	9.0	10.5	140	Clear	High	Low	High	30	0	0	0	0	20	50
Upper	C00.0-R	3	10.0	7.9	140	Overcast	Medium	Low	High	0	0	0	0	0	60	40
Upper	C00.0-R	4	9.0	8.0	140	Clear	High	Low	High	25	0	0	0	0	60	15

[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, 02 October to 28 October 2017.

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		40											21		**61**
	C00.0-R	Northern Pikeminnow													1		**1**
	C00.0-R	Peamouth		5											4		**9**
	C00.0-R	Rainbow Trout		63											23		**86**
	C00.0-R	Redside Shiner		190											5035		**5225**
	C00.0-R	Sculpin spp.		371											225		**596**
	C00.0-R	Sucker spp.		1											1		**2**
	C00.0-R	Walleye		9											2		**11**
	Site C00.0-R Total		**0**	**679**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**5312**	**0**	**5991**
	C00.7-L	Brook Trout															**0**
	C00.7-L	Mountain Whitefish		26							43						**69**
	C00.7-L	Northern Pikeminnow		5													**5**
	C00.7-L	Peamouth		7							12						**19**
	C00.7-L	Rainbow Trout		29							51						**80**
	C00.7-L	Redside Shiner		25							30						**55**
	C00.7-L	Sculpin spp.		110							25						**135**
	C00.7-L	Sucker spp.		1							50						**51**
	C00.7-L	Walleye		1							6						**7**
	C00.7-L	White Sturgeon		1													**1**
	Site C00.7-L Total		**0**	**205**	**0**	**0**	**0**	**0**	**0**	**0**	**217**	**0**	**0**	**0**	**0**	**0**	**422**
	C01.3-L	Bull Trout															**0**
	C01.3-L	Mountain Whitefish	47								204						**251**
	C01.3-L	Northern Pikeminnow									10						**10**
	C01.3-L	Peamouth	10								34						**44**
	C01.3-L	Rainbow Trout	50								235						**285**
	C01.3-L	Redside Shiner	20								61						**81**
	C01.3-L	Sculpin spp.	52								228						**280**
	C01.3-L	Sucker spp.	21								65						**86**
	C01.3-L	Walleye	3								34						**37**
	C01.3-L	White Sturgeon									2						**2**
	Site C01.3-L Total		**203**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**873**	**0**	**0**	**0**	**0**	**0**	**1076**
	C02.8-L	Mountain Whitefish									72						**72**
	C02.8-L	Northern Pike									1						**1**
	C02.8-L	Peamouth									4						**4**
	C02.8-L	Rainbow Trout									78						**78**
	C02.8-L	Redside Shiner									58						**58**
	C02.8-L	Sculpin spp.									130						**130**
	C02.8-L	Sucker spp.									35						**35**
	C02.8-L	Walleye									16						**16**
	C02.8-L	White Sturgeon									3						**3**
	Site C02.8-L Total		**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**397**	**0**	**0**	**0**	**0**	**0**	**397**
	C03.6-L	Lake Whitefish									4						**4**
	C03.6-L	Mountain Whitefish	96			8					82						**186**
	C03.6-L	Northern Pikeminnow	4			5											**9**
	C03.6-L	Peamouth	12								1						**13**
	C03.6-L	Rainbow Trout	149			9					133						**291**
	C03.6-L	Redside Shiner	23			25					10						**58**
	C03.6-L	Sculpin spp.	140			55					75						**270**
	C03.6-L	Sucker spp.	116			27					71						**214**
	C03.6-L	Walleye	22			5					21						**48**
	C03.6-L	White Sturgeon									1						**1**
	Site C03.6-L Total		**562**	**0**	**0**	**134**	**0**	**0**	**0**	**0**	**398**	**0**	**0**	**0**	**0**	**0**	**1094**
	C04.6-R	Mountain Whitefish									6						**6**
	C04.6-R	Northern Pike															**0**
	C04.6-R	Peamouth									1						**1**
	C04.6-R	Rainbow Trout									44						**44**
	C04.6-R	Redside Shiner									6						**6**
	C04.6-R	Sculpin spp.									29						**29**
	C04.6-R	Sucker spp.									24						**24**
	C04.6-R	Walleye									9						**9**
	C04.6-R	White Sturgeon									1						**1**
	Site C04.6-R Total		**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**120**	**0**	**0**	**0**	**0**	**0**	**120**
	C05.6-L	Mountain Whitefish	55								16						**71**
	C05.6-L	Northern Pikeminnow	27								5						**32**
	C05.6-L	Peamouth	7								3						**10**
	C05.6-L	Rainbow Trout	83								43						**126**
	C05.6-L	Redside Shiner	7								70						**77**
	C05.6-L	Sculpin spp.	85								55						**140**
	C05.6-L	Sucker spp.	83								93						**176**
	C05.6-L	Walleye	22								6						**28**
	Site C05.6-L Total		**369**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**291**	**0**	**0**	**0**	**0**	**0**	**660**
	C07.3-R	Bull Trout															**0**
	C07.3-R	Kokanee				1											**1**
	C07.3-R	Lake Whitefish				2											**2**
	C07.3-R	Mountain Whitefish				250											**250**
	C07.3-R	Northern Pikeminnow				2											**2**
	C07.3-R	Rainbow Trout				266											**266**
	C07.3-R	Sculpin spp.				600											**600**
	C07.3-R	Sucker spp.				32											**32**
	C07.3-R	Walleye				39											**39**
	C07.3-R	White Sturgeon				5											**5**
	Site C07.3-R Total		**0**	**0**	**0**	**1197**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1197**
	C07.4-L	Kokanee												1			**1**
	C07.4-L	Lake Whitefish												1			**1**
	C07.4-L	Mountain Whitefish												471			**471**
	C07.4-L	Northern Pikeminnow												4			**4**
	C07.4-L	Peamouth												4			**4**
	C07.4-L	Rainbow Trout												160			**160**
	C07.4-L	Redside Shiner												4			**4**
	C07.4-L	Sculpin spp.												49			**49**
	C07.4-L	Sucker spp.												97			**97**
	C07.4-L	Walleye												17			**17**
	C07.4-L	White Sturgeon												8			**8**
	Site C07.4-L Total		**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**816**	**0**	**0**	**816**
Upstream Columbia River Total			**1134**	**884**	**0**	**1331**	**0**	**0**	**0**	**0**	**2296**	**0**	**0**	**816**	**5312**	**0**	**11773**
Kootenay	K00.3-L	Brown Trout															**0**
	K00.3-L	Mountain Whitefish								20					9		**29**
	K00.3-L	Rainbow Trout								12					3		**15**
	K00.3-L	Sculpin spp.													1		**1**
	K00.3-L	Sucker spp.								16							**16**
	K00.3-L	Walleye								6					6		**12**
	Site K00.3-L Total		**0**	**0**	**0**	**0**	**0**	**0**	**0**	**54**	**0**	**0**	**0**	**0**	**19**	**0**	**73**

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

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

Continued...

Table B4 Continued.

Section	Site[a]	Species	Bank Habitat Type[a]														Total
			A1	A2	A3	A4	A5	A6	A1+A2	A2+A3	D1	D2	D3	D1+D2	BW	Eddy	
	K00.6-R	Mountain Whitefish												82		15	**97**
	K00.6-R	Northern Pikeminnow														1	**1**
	K00.6-R	Peamouth														1	**1**
	K00.6-R	Rainbow Trout												22		30	**52**
	K00.6-R	Redside Shiner												3			**3**
	K00.6-R	Sculpin spp.												25		20	**45**
	K00.6-R	Sucker spp.												63		20	**83**
	K00.6-R	Walleye												9		29	**38**
	Site K00.6-R Total		**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**204**	**0**	**116**	**320**
	K01.8-L	Kokanee		2								1					**3**
	K01.8-L	Lake Whitefish										3					**3**
	K01.8-L	Mountain Whitefish		78			18					209					**305**
	K01.8-L	Northern Pikeminnow		1													**1**
	K01.8-L	Prickly Sculpin															**0**
	K01.8-L	Rainbow Trout		40			5					94					**139**
	K01.8-L	Redside Shiner		3			1										**4**
	K01.8-L	Sculpin spp.		91			7					505					**603**
	K01.8-L	Sucker spp.		6								35					**41**
	K01.8-L	Walleye		21			1					48					**70**
	K01.8-L	White Sturgeon										1					**1**
	Site K01.8-L Total		**0**	**242**	**0**	**0**	**32**	**0**	**0**	**0**	**0**	**896**	**0**	**0**	**0**	**0**	**1170**
	K01.8-R	Kokanee								1							**1**
	K01.8-R	Lake Whitefish								2							**2**
	K01.8-R	Mountain Whitefish					13			157							**170**
	K01.8-R	Northern Pikeminnow					1			4							**5**
	K01.8-R	Peamouth								2							**2**
	K01.8-R	Rainbow Trout					28			76							**104**
	K01.8-R	Redside Shiner					14										**14**
	K01.8-R	Sculpin spp.					5			76							**81**
	K01.8-R	Sucker spp.								5							**5**
	K01.8-R	Walleye					8			22							**30**
	K01.8-R	White Sturgeon					1			2							**3**
	Site K01.8-R Total		**0**	**0**	**0**	**0**	**70**	**0**	**0**	**347**	**0**	**0**	**0**	**0**	**0**	**0**	**417**
Kootenay Total			**0**	**242**	**0**	**0**	**102**	**0**	**0**	**401**	**0**	**896**	**0**	**204**	**19**	**116**	**1980**
Downstream Columbia River	C25.3-R	Northern Pike								5							**5**
	C25.3-R	Lake Whitefish	1							6							**7**
	C25.3-R	Sucker spp.	4							4							**8**
	C25.3-R	Walleye	6				3			18							**27**
	C25.3-R	Mountain Whitefish	12				2			72							**86**
	C25.3-R	Rainbow Trout	115				6			155							**276**
	C25.3-R	Sculpin spp.	133				3			39							**175**
	C25.3-R	Redside Shiner	344				10			5							**359**
	Site C25.3-R Total		**615**	**0**	**0**	**0**	**24**	**0**	**0**	**304**	**0**	**0**	**0**	**0**	**0**	**0**	**943**
	C27.6-R	Kokanee										1					**1**
	C27.6-R	Mountain Whitefish					1			6	12	37					**56**
	C27.6-R	Rainbow Trout					10			43	4	36					**93**
	C27.6-R	Sculpin spp.					24			22	15	8					**69**
	C27.6-R	Sucker spp.					1			3	1	6					**11**
	C27.6-R	Walleye					7			3		4					**14**
	Site C27.6-R Total		**0**	**0**	**0**	**0**	**43**	**0**	**0**	**77**	**32**	**92**	**0**	**0**	**0**	**0**	**244**
	C28.2-R	Kokanee		1													**1**
	C28.2-R	Mountain Whitefish		40													**40**
	C28.2-R	Northern Pikeminnow		1													**1**
	C28.2-R	Rainbow Trout		148													**148**
	C28.2-R	Redside Shiner		5													**5**
	C28.2-R	Sculpin spp.		262													**262**
	C28.2-R	Sucker spp.		13													**13**
	C28.2-R	Walleye		11													**11**
	Site C28.2-R Total		**0**	**481**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**481**
	C34.9-L	Kokanee			1												**1**
	C34.9-L	Mountain Whitefish		38	9												**47**
	C34.9-L	Northern Pikeminnow		2	2												**4**
	C34.9-L	Rainbow Trout		297	102												**399**
	C34.9-L	Sculpin spp.		369	68												**437**
	C34.9-L	Smallmouth Bass		1													**1**
	C34.9-L	Sucker spp.		5	3												**8**
	C34.9-L	Tench															**0**
	C34.9-L	Walleye		12	8												**20**
	Site C34.9-L Total		**0**	**724**	**193**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**917**
	C36.6-L	Lake Whitefish					1						1				**2**
	C36.6-L	Mountain Whitefish					16			16			33				**65**
	C36.6-L	Northern Pikeminnow					1			2							**3**
	C36.6-L	Rainbow Trout					121			179			34				**334**
	C36.6-L	Sculpin spp.					94			318			60				**472**
	C36.6-L	Sucker spp.					5			4			3				**12**
	C36.6-L	Walleye					13			16			15				**44**
	Site C36.6-L Total		**0**	**0**	**0**	**0**	**251**	**0**	**0**	**535**	**0**	**0**	**146**	**0**	**0**	**0**	**932**
	C47.8-L	Brook Trout															**0**
	C47.8-L	Kokanee							2								**2**
	C47.8-L	Lake Whitefish							4		2						**6**
	C47.8-L	Mountain Whitefish							21		13						**34**
	C47.8-L	Northern Pike															**0**
	C47.8-L	Northern Pikeminnow									1						**1**
	C47.8-L	Rainbow Trout							85		39						**124**
	C47.8-L	Redside Shiner							25		9						**34**
	C47.8-L	Sculpin spp.							584		85						**669**
	C47.8-L	Sucker spp.							6		25						**31**
	C47.8-L	Walleye							12		4						**16**
	Site C47.8-L Total		**0**	**0**	**0**	**0**	**0**	**0**	**739**	**0**	**178**	**0**	**0**	**0**	**0**	**0**	**917**
	C48.2-R	Brook Trout															**0**
	C48.2-R	Kokanee													1		**1**
	C48.2-R	Lake Whitefish												1			**1**
	C48.2-R	Mountain Whitefish												24	8		**32**
	C48.2-R	Northern Pikeminnow												5	1		**6**
	C48.2-R	Rainbow Trout												75	29		**104**
	C48.2-R	Redside Shiner												52	3		**55**
	C48.2-R	Sculpin spp.												65	47		**112**
	C48.2-R	Sucker spp.												33	6		**39**
	C48.2-R	Walleye												24	7		**31**
	Site C48.2-R Total		**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**279**	**102**	**0**	**381**

[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-L	Lake Whitefish		9													**9**
	C49.0-L	Mountain Whitefish		49								6					**55**
	C49.0-L	Rainbow Trout		59								24					**83**
	C49.0-L	Sculpin spp.		68								46					**114**
	C49.0-L	Sucker spp.		7													**7**
	C49.0-L	Walleye		9								2					**11**
	C49.0-L	White Sturgeon		1													**1**
	Site C49.0-L Total		**0**	**202**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**78**	**0**	**0**	**0**	**0**	**280**
	C49.0-R	Kokanee							1								**1**
	C49.0-R	Lake Whitefish												6			**6**
	C49.0-R	Mountain Whitefish							3					22			**25**
	C49.0-R	Rainbow Trout							11	5				50			**66**
	C49.0-R	Redside Shiner												5			**5**
	C49.0-R	Sculpin spp.							11					315			**326**
	C49.0-R	Sucker spp.							2					4			**6**
	C49.0-R	Walleye							6	3				12			**21**
	Site C49.0-R Total		**0**	**0**	**0**	**0**	**0**	**0**	**34**	**8**	**0**	**0**	**0**	**414**	**0**	**0**	**456**
	C49.8-L	Brown Trout															**0**
	C49.8-L	Burbot		3													**3**
	C49.8-L	Kokanee		1													**1**
	C49.8-L	Lake Whitefish		15													**15**
	C49.8-L	Mountain Whitefish		101													**101**
	C49.8-L	Rainbow Trout		210													**210**
	C49.8-L	Sculpin spp.		2777													**2777**
	C49.8-L	Smallmouth Bass															**0**
	C49.8-L	Sucker spp.		10													**10**
	C49.8-L	Walleye		42													**42**
	Site C49.8-L Total		**0**	**3159**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**3159**
	C49.8-R	Brook Trout															**0**
	C49.8-R	Burbot		2								2					**4**
	C49.8-R	Lake Whitefish										2			1		**3**
	C49.8-R	Longnose Sucker															**0**
	C49.8-R	Mountain Whitefish		99								23			5		**127**
	C49.8-R	Rainbow Trout		124								74			65		**263**
	C49.8-R	Redside Shiner		10													**10**
	C49.8-R	Sculpin spp.		1071								342			120		**1533**
	C49.8-R	Smallmouth Bass															**0**
	C49.8-R	Sucker spp.		5								4			17		**26**
	C49.8-R	Walleye		26								19			19		**64**
	C49.8-R	White Sturgeon		1								1					**2**
	C49.8-R	Yellow Perch													1		**1**
	Site C49.8-R Total		**0**	**1338**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**467**	**0**	**0**	**228**	**0**	**2033**
	C52.2-L	Brook Trout															**0**
	C52.2-L	Burbot										1					**1**
	C52.2-L	Lake Whitefish										8					**8**
	C52.2-L	Mountain Whitefish										6				18	**24**
	C52.2-L	Rainbow Trout										28				65	**93**
	C52.2-L	Sculpin spp.										20				107	**127**
	C52.2-L	Walleye										2				7	**9**
	C52.2-L	White Sturgeon										1					**1**
	Site C52.2-L Total		**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**66**	**0**	**0**	**0**	**197**	**263**
	C52.2-R	Brook Trout															**0**
	C52.2-R	Burbot		15													**15**
	C52.2-R	Kokanee		1												1	**2**
	C52.2-R	Lake Whitefish		12												1	**13**
	C52.2-R	Mountain Whitefish		66												7	**73**
	C52.2-R	Northern Pikeminnow		2													**2**
	C52.2-R	Rainbow Trout		183												109	**292**
	C52.2-R	Sculpin spp.		535													**535**
	C52.2-R	Sucker spp.		7												6	**13**
	C52.2-R	Walleye		40												6	**46**
	C52.2-R	White Sturgeon		2												1	**3**
	Site C52.2-R Total		**0**	**863**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**131**	**994**
	C52.8-L	Burbot				2											**2**
	C52.8-L	Kokanee				2											**2**
	C52.8-L	Lake Whitefish				2											**2**
	C52.8-L	Mountain Whitefish		2		13											**15**
	C52.8-L	Northern Pikeminnow				1											**1**
	C52.8-L	Rainbow Trout		11		109											**120**
	C52.8-L	Sculpin spp.		3		50											**53**
	C52.8-L	Smallmouth Bass															**0**
	C52.8-L	Sucker spp.				3											**3**
	C52.8-L	Walleye		5		16											**21**
	C52.8-L	White Sturgeon				1											**1**
	Site C52.8-L Total		**0**	**21**	**0**	**199**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**220**
	C53.6-L	Lake Whitefish						2									**2**
	C53.6-L	Mountain Whitefish						10									**10**
	C53.6-L	Rainbow Trout						86									**86**
	C53.6-L	Sculpin spp.						115									**115**
	C53.6-L	Sucker spp.						2									**2**
	C53.6-L	Walleye						21									**21**
	Site C53.6-L Total		**0**	**0**	**0**	**0**	**0**	**236**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**236**
Downstream Columbia River Total			**615**	**6788**	**193**	**199**	**318**	**236**	**773**	**924**	**210**	**703**	**146**	**693**	**330**	**328**	**12456**
Grand Total			**1749**	**7914**	**193**	**1530**	**420**	**236**	**773**	**1325**	**2506**	**1599**	**146**	**1713**	**5661**	**444**	**26209**

[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 2017

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).

The data were prepared for analysis using R version 3.3.3 (R Core Team 2017).

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 $\widehat{R} \leq 1.05$ (Kery and Schaub 2011, 40) and ESS ≥ 150 for each of the monitored parameters (Kery and Schaub 2011, 61). Where $\widehat{R}$ 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 3.5.0 (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));
  }
..
```

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]:(Ye
ar[i] + dYears[i] - 1)])))
    Growth[i] ~ dnorm(max(eGrowth[i], 0), exp(sGrowth)^-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])
  }
..
```

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 * Sampled
Length[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])
  }
..
```

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])
  }
..
```

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])
  }
.
```

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, 5^-2)
  for(i in 1:length(Stock)){
    log(eAlpha[i]) <- bAlpha
    log(eBeta[i]) <- bBeta + bEggLoss * EggLoss[i]
    eRecruits[i] <- (eAlpha[i] * Stock[i]) / (1 + eBeta[i] * Stock[i])
    Recruits[i] ~ dlnorm(log(eRecruits[i]), exp(sRecruits)^-2)
  }
..
```

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)
  }
..
```

Results

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	5.4294212	0.0104229	520.916540	5.4097270	5.4492954	0.0007
bWeightDayte	-0.0159965	0.0019319	-8.273691	-0.0197489	-0.0122547	0.0007
bWeightLength	3.1589240	0.0248477	127.123133	3.1085492	3.2068216	0.0007
bWeightLengthDayte	-0.0078296	0.0052733	-1.450593	-0.0176503	0.0026358	0.1547
sWeight	-1.9074108	0.0061874	-308.315251	-1.9192942	-1.8957215	0.0007
sWeightLengthYear	-2.2877071	0.2067677	-11.032237	-2.6563198	-1.8565276	0.0007
sWeightYear	-3.1270272	0.1756062	-17.766849	-3.4643990	-2.7675448	0.0007

Table 3. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
13422	7	3	500	2	358	1.006	TRUE

Rainbow Trout

Table 4. Model coefficients.

term	estimate	sd	zscore	lower	upper	pvalue
bWeight	5.9791123	0.0059613	1002.959006	5.9662992	5.9905083	0.0007
bWeightDayte	-0.0037758	0.0013122	-2.902873	-0.0064961	-0.0013717	0.0013
bWeightLength	2.9255780	0.0118616	246.595286	2.9008210	2.9479510	0.0007
bWeightLengthDayte	0.0384326	0.0039495	9.755974	0.0308850	0.0463159	0.0007
sWeight	-2.2538561	0.0062821	-358.769320	-2.2664328	-2.2413489	0.0007
sWeightLengthYear	-3.0158107	0.1961825	-15.327172	-3.3700589	-2.5985948	0.0007
sWeightYear	-3.6355060	0.1671642	-21.687819	-3.9169343	-3.2706035	0.0007

Table 5. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged

13671	7	3	500	1	234	1.005	TRUE

Walleye

Table 6. Model coefficients.

term	estimate	sd	zscore	lower	upper	pvalue
bWeight	6.2898298	0.0077988	806.505412	6.2742873	6.3055566	0.0007
bWeightDayte	0.0163324	0.0014428	11.331798	0.0134977	0.0191421	0.0007
bWeightLength	3.2298520	0.0209100	154.475415	3.1867992	3.2727126	0.0007
bWeightLengthDayte	-0.0132222	0.0086535	-1.541439	-0.0309711	0.0033237	0.1053
sWeight	-2.3651037	0.0075800	-312.016650	-2.3795661	-2.3498578	0.0007
sWeightLengthYear	-2.5023394	0.1986423	-12.570806	-2.8826675	-2.0771975	0.0007
sWeightYear	-3.3033678	0.1720936	-19.149392	-3.5926969	-2.9368921	0.0007

Table 7. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
8876	7	3	500	1	238	1.011	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	-0.8886555	0.1124476	-7.929429	-1.124709	-0.6700452	0.0007
bLinf	392.0554701	3.3943312	115.560885	385.992525	399.4185467	0.0007
sGrowth	2.5056451	0.0473208	52.955425	2.416305	2.6015461	0.0007
sKYear	-1.1074394	0.2848052	-3.885767	-1.671213	-0.5295446	0.0013

Table 10. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
234	4	3	500	20	627	1.004	TRUE

Rainbow Trout

Table 11. Model coefficients.

term	estimate	sd	zscore	lower	upper	pvalue
bK	-0.1652507	0.0734300	-2.249802	-0.3133925	-0.0134686	0.0333
bLinf	490.0335024	2.9089229	168.464706	484.4790208	495.7201166	0.0007
sGrowth	3.3786477	0.0216482	156.096301	3.3375430	3.4225138	0.0007
sKYear	-1.3629170	0.1930054	-7.025804	-1.7035313	-0.9577791	0.0007

Table 12. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
1061	4	3	500	20	477	1.004	TRUE

Walleye

Table 13. Model coefficients.

term	estimate	sd	zscore	lower	upper	pvalue
bK	-2.549841	0.2642482	-9.675154	-3.044665	-2.058332	0.0007
bLinf	751.584259	88.5302441	8.648111	626.812966	960.982689	0.0007
sGrowth	2.879025	0.0468696	61.413981	2.789731	2.969387	0.0007
sKYear	-1.105929	0.2687935	-4.093901	-1.608352	-0.569811	0.0013

Table 14. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
254	4	3	500	40	184	1.005	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	-0.1681327	0.1917864	-0.8653585	-0.5569344	0.2141905	0.3947
bLength	-0.0989941	0.1850241	-0.5236471	-0.4525534	0.2541279	0.6133

Table 17. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
115	2	3	500	1	963	1.004	TRUE

Rainbow Trout

Table 18. Model coefficients.

term	estimate	sd	zscore	lower	upper	pvalue
bFidelity	0.7971779	0.0787477	10.135053	0.6500068	0.9494468	7e-04
bLength	-0.3188989	0.0790255	-4.093261	-0.4815628	-0.1772360	7e-04

Table 19. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
727	2	3	500	1	782	1.005	TRUE

Walleye

Table 20. Model coefficients.

term	estimate	sd	zscore	lower	upper	pvalue
bFidelity	0.688804	0.1433271	4.8394646	0.4161226	0.9739216	7e-04
bLength	-0.035624	0.1451421	-0.2579797	-0.3346848	0.2363574	8e-01

Table 21. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
216	2	3	500	1	788	1	TRUE

Length-At-Age

Mountain Whitefish

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

Year	Age0	Age1	Age2
1990	159	253	288
1991	144	226	297
2001	141	257	343
2002	163	260	343

2003	160	263	353
2004	158	249	342
2005	168	263	362
2006	175	284	356
2007	171	279	338
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	277	366
2016	165	282	352
2017	158	269	354

Rainbow Trout

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

Year	Age0	Age1
1990	155	358
1991	127	343
2001	133	324
2002	154	350
2003	161	343
2004	142	333
2005	164	347
2006	170	365
2007	166	375
2008	146	340
2009	147	339
2010	143	337
2011	156	344
2012	152	344
2013	169	355
2014	154	337
2015	167	334
2016	154	337
2017	133	317

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	-4.2446253	0.1159913	-36.624695	-4.4823947	-4.0346703	0.0007
bEfficiencySampledLength	0.4838203	0.1289041	3.762524	0.2397391	0.7548392	0.0007
bSurvival	0.9930812	0.4906920	2.111555	0.1403570	2.1629080	0.0240
sSurvivalYear	0.4267963	0.3395373	1.247323	-0.2306143	1.0868005	0.2067

Table 26. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
16	4	3	500	20	309	1.011	TRUE

Rainbow Trout

Table 27. Model coefficients.

term	estimate	sd	zscore	lower	upper	pvalue
bEfficiency	-2.5152846	0.0950245	-26.484951	-2.7066001	-2.3324168	0.0007
bEfficiencySampledLength	0.0095463	0.0781437	0.1393196	-0.1381551	0.1688784	0.8933
bSurvival	-0.4648874	0.1244426	-3.7236758	-0.7057194	-0.2139384	0.0007
sSurvivalYear	-1.1833806	0.7035404	-1.8780897	-3.3992595	-0.5055175	0.0007

Table 28. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
16	4	3	500	20	356	1.013	TRUE

Walleye

Table 29. Model coefficients.

term	estimate	sd	zscore	lower	upper	pvalue
bEfficiency	-3.3746728	0.1066350	-31.6284314	-3.582299	-3.165135	0.0007
bEfficiencySampledLength	0.0722225	0.0908089	0.8042139	-0.099594	0.2536344	0.4253

bSurvival	0.0752269	0.1561675	0.5612343	-0.190561	0.4284746	0.5893
sSurvivalYear	-0.9238995	1.0595874	-1.1130358	-4.527790	-0.180671	0.0173

Table 30. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
16	4	3	500	40	254	1.033	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	-4.941610	0.2182581	-22.726014	-5.459583	-4.6046780	0.0007
sEfficiencySessionAnnual	-1.023467	1.1297632	-1.162838	-4.219376	0.0912245	0.0907

Table 33. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
1299	2	3	500	100	217	1.017	TRUE

Adult

Table 34. Model coefficients.

term	estimate	sd	zscore	lower	upper	pvalue
bEfficiency	-5.207899	0.1490366	-34.97314	-5.519861	-4.9309168	7e-04

sEfficiencySessionAnnual	-1.992512	1.1615237	-1.91703	-5.088239	-0.6557197	7e-04

Table 35. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
1468	2	3	500	100	237	1.014	TRUE

Rainbow Trout

Subadult

Table 36. Model coefficients.

term	estimate	sd	zscore	lower	upper	pvalue
bEfficiency	-3.3845947	0.0663431	-51.009127	-3.511163	-3.2539976	7e-04
sEfficiencySessionAnnual	-0.9316827	0.1633991	-5.746617	-1.283852	-0.6348329	7e-04

Table 37. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
1487	2	3	500	50	1278	1.004	TRUE

Adult

Table 38. Model coefficients.

term	estimate	sd	zscore	lower	upper	pvalue
bEfficiency	-4.031955	0.0686749	-58.707182	-4.169615	-3.905716	7e-04
sEfficiencySessionAnnual	-2.003418	0.8916414	-2.486169	-4.397031	-1.049144	7e-04

Table 39. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
1545	2	3	500	100	252	1.015	TRUE

Walleye

Adult

Table 40. Model coefficients.

term	estimate	sd	zscore	lower	upper	pvalue
bEfficiency	-4.5514548	0.1248230	-36.509723	-4.835597	-4.3221467	7e-04
sEfficiencySessionAnnual	-0.5398251	0.2158204	-2.548474	-1.003360	-0.1761849	4e-03

Table 41. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
1601	2	3	500	50	1224	1.005	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	5.4765903	0.1861413	29.407587	5.1026572	5.8323686	0.0007
bEfficiencyVisitType 2	1.4860960	0.0801141	18.548050	1.3344746	1.6503053	0.0007
sDensityAnnual	-0.3789589	0.1843361	-2.004608	-0.7057124	0.0122872	0.0587
sDensitySite	-0.3014650	0.1053811	-2.867956	-0.5094493	-0.0862499	0.0013
sDensitySiteAnnual	-0.8258834	0.0629434	-13.143671	-0.9504982	-0.7041190	0.0007
sDispersion	-0.7542474	0.0458290	-16.472246	-0.8469796	-0.6673892	0.0007
sDispersionVisitType 2	0.5072713	0.0949927	5.354164	0.3241520	0.6973576	0.0007

Table 44. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
2391	7	3	500	200	219	1.008	TRUE

Adult

Table 45. Model coefficients.

term	estimate	sd	zscore	lower	upper	pvalue
bDensity	6.2920251	0.1661460	37.906648	5.9587938	6.6104837	0.0007
bEfficiencyVisitType2	1.8182092	0.0898705	20.266968	1.6446940	1.9949233	0.0007
sDensityAnnual	-1.0424453	0.2058076	-5.020928	-1.4065557	-0.6015453	0.0007
sDensitySite	0.1118483	0.0975265	1.188015	-0.0766389	0.3110734	0.2227
sDensitySiteAnnual	-0.9021927	0.0648302	-13.923568	-1.0276214	-0.7742620	0.0007
sDispersion	-0.6333482	0.0345890	-18.301069	-0.7020864	-0.5656565	0.0007
sDispersionVisitType2	0.5364494	0.0836070	6.381720	0.3701216	0.6951912	0.0007

Table 46. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
2391	7	3	500	100	156	1.019	TRUE

Rainbow Trout

Subadult

Table 47. Model coefficients.

term	estimate	sd	zscore	lower	upper	pvalue
bDensity	4.8482784	0.1101237	44.002798	4.6164097	5.0487444	7e-04
bEfficiencyVisitType2	1.5145148	0.0794431	19.108376	1.3721645	1.6754129	7e-04
sDensityAnnual	-1.2885872	0.2095606	-6.138977	-1.6901852	-0.8703518	7e-04
sDensitySite	-0.3538945	0.0995714	-3.547526	-0.5445650	-0.1626558	7e-04
sDensitySiteAnnual	-0.8838403	0.0560701	-15.788300	-0.9980944	-0.7810704	7e-04
sDispersion	-0.9522129	0.0415707	-22.955099	-1.0363156	-0.8755609	7e-04
sDispersionVisitType2	0.5865835	0.0946903	6.176692	0.3967560	0.7602344	7e-04

Table 48. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
2391	7	3	500	100	260	1.007	TRUE

Adult

Table 49. Model coefficients.

term	estimate	sd	zscore	lower	upper	pvalue
bDensity	5.4427109	0.1195159	45.505604	5.1951437	5.6676320	7e-04
bEfficiencyVisitType 2	1.3055565	0.0657781	19.877116	1.1741961	1.4379650	7e-04
sDensityAnnual	-1.1997397	0.1936541	-6.152570	-1.5440803	-0.7983087	7e-04
sDensitySite	-0.4379821	0.0975582	-4.437252	-0.6142232	-0.2303591	7e-04
sDensitySiteAnnual	-1.2203696	0.0729850	-16.774980	-1.3683662	-1.0880160	7e-04
sDispersion	-1.0144820	0.0475458	-21.354124	-1.1164392	-0.9266665	7e-04
sDispersionVisitType 2	0.5819554	0.0962208	6.050765	0.3978520	0.7699114	7e-04

Table 50. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
2391	7	3	500	100	251	1.012	TRUE

Walleye

Adult

Table 51. Model coefficients.

term	estimate	sd	zscore	lower	upper	pvalue
bDensity	5.4307042	0.1258833	43.106649	5.1724770	5.6656843	7e-04
bEfficiencyVisitType 2	1.2318520	0.0802977	15.329270	1.0713218	1.3844783	7e-04
sDensityAnnual	-0.8157032	0.1843167	-4.421948	-1.1569998	-0.4333404	7e-04
sDensitySite	-1.0547288	0.1435021	-7.377644	-1.3425560	-0.7928187	7e-04
sDensitySiteAnnual	-1.3424684	0.0924602	-14.518714	-1.5360284	-1.1713057	7e-04
sDispersion	-0.8126212	0.0400443	-20.305996	-0.8936627	-0.7371643	7e-04
sDispersionVisitType 2	0.5085584	0.1009985	5.039459	0.3083867	0.6986985	7e-04

Table 52. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
2391	7	3	500	100	249	1.015	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	0.8139611	0.4446271	1.8384688	0.0695496	1.5512923	0.0007
bBeta	-9.7597367	0.5537169	-17.6694263	-10.8393829	-8.8183202	0.0007
bEggLoss	0.0860254	0.2179828	0.3908444	-0.3726391	0.5233172	0.6787
sRecruits	-0.4619553	0.2177265	-2.0973882	-0.8410797	0.0023342	0.0533

Table 55. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
15	4	3	500	50	1252	1.001	TRUE

Rainbow Trout

Table 56. Model coefficients.

term	estimate	sd	zscore	lower	upper	pvalue
bAlpha	0.9040279	0.4368077	2.011898	0.0715993	1.5797639	0.0007
bBeta	-9.3898676	0.6571494	-14.431341	-10.8339241	-8.5409575	0.0007
bEggLoss	-0.2074621	0.1598935	-1.485111	-0.6006027	-0.0320101	0.0240
sRecruits	-1.4767867	0.2035237	-7.211967	-1.8300063	-1.0273612	0.0007

Table 57. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
16	4	3	500	50	310	1.004	TRUE

Scale Age

Table 58. The optimal parameter values for aging fish from their circuli distances.

sma1	sma2	multiplier	block	age0
3	12	0.2	4	40

Age-Ratios

Table 59. 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

Mountain Whitefish

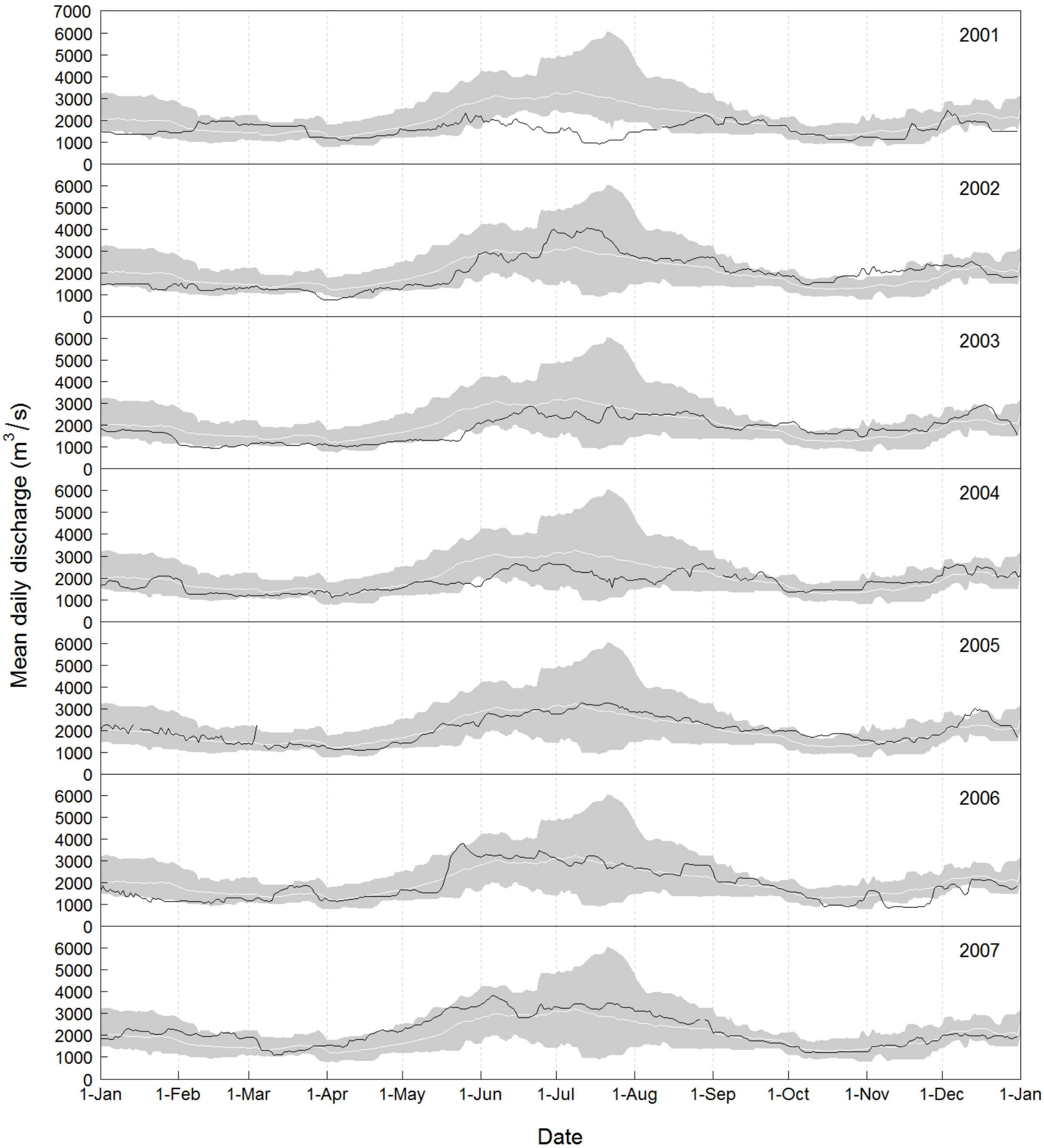
Table 60. Model coefficients.

term	estimate	sd	zscore	lower	upper	pvalue
bProbAge1	0.2764236	0.2186040	1.2242454	-0.1768765	0.6933735	0.1960
bProbAge1Loss	-0.2193412	0.3303882	-0.6362767	-0.8510240	0.4972314	0.4773
sProbAge1	0.8401563	0.1967772	4.4300797	0.5952813	1.3401481	0.0007

Table 70. Model summary.

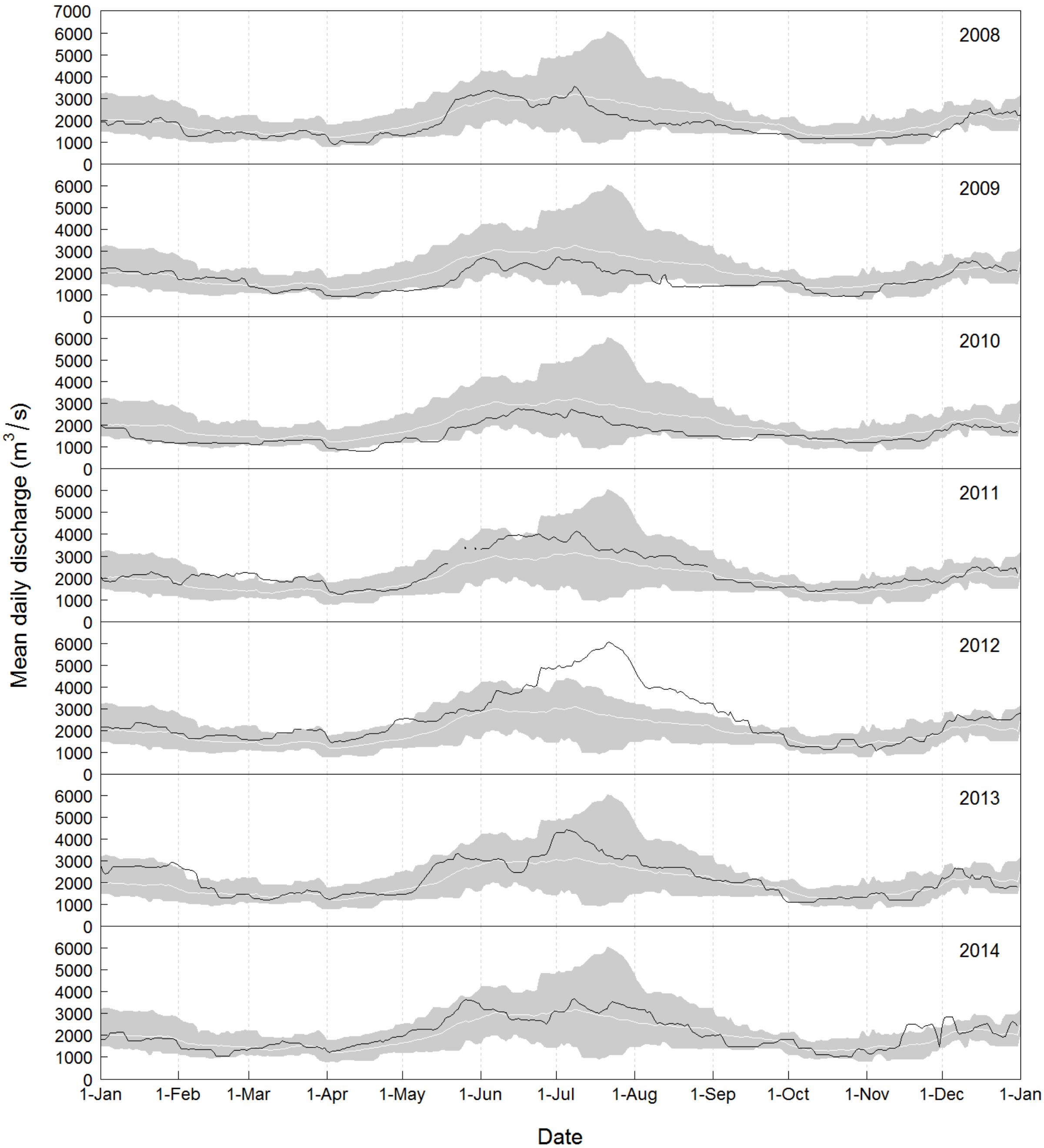
n	K	nchains	niters	nthin	ess	rhat	converged
17	3	3	500	1	471	1.003	TRUE

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 2017. The shaded area represents minimum and maximum mean daily discharge recorded at Birchbank during other study years between 2001 and 2017. The white line represents average mean daily discharge over the same time period.



Continued...

Figure D1. Continued.

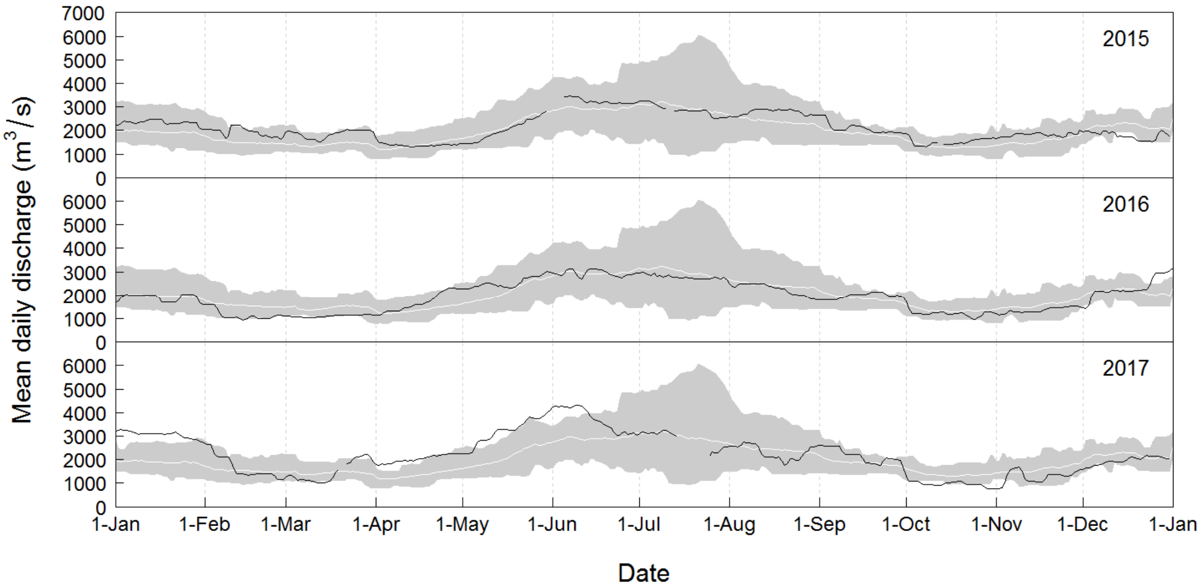


Figure D1. Concluded.

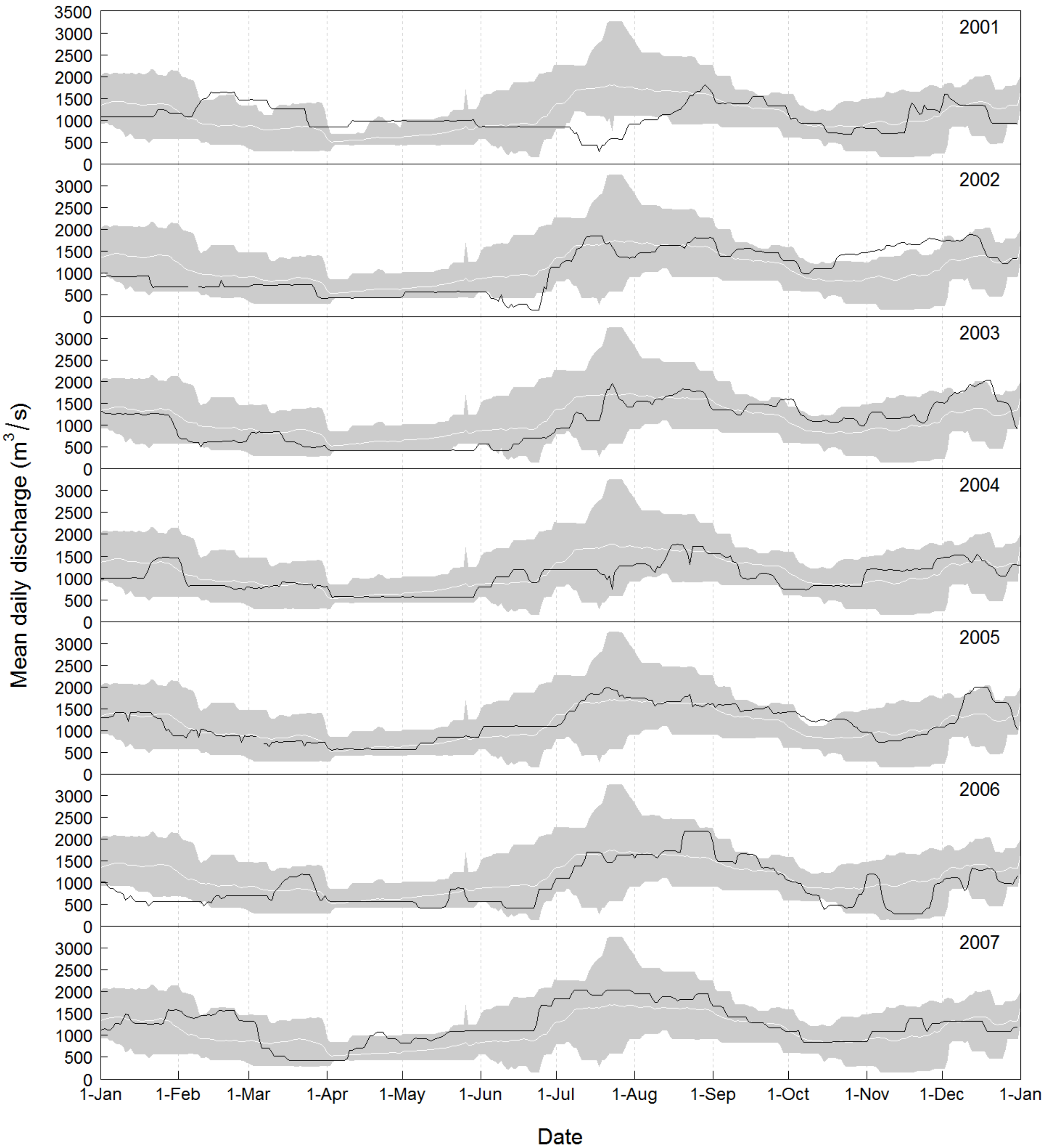


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Figure D2. Mean daily discharge (m³/s) for the Columbia River at Hugh L. Keenleyside Dam (HLK), 2001 to 2017 (black line). The shaded area represents minimum and maximum mean daily discharge recorded at HLK during other study years between 2001 and 2017. The white line represents average mean daily discharge over the same time period.

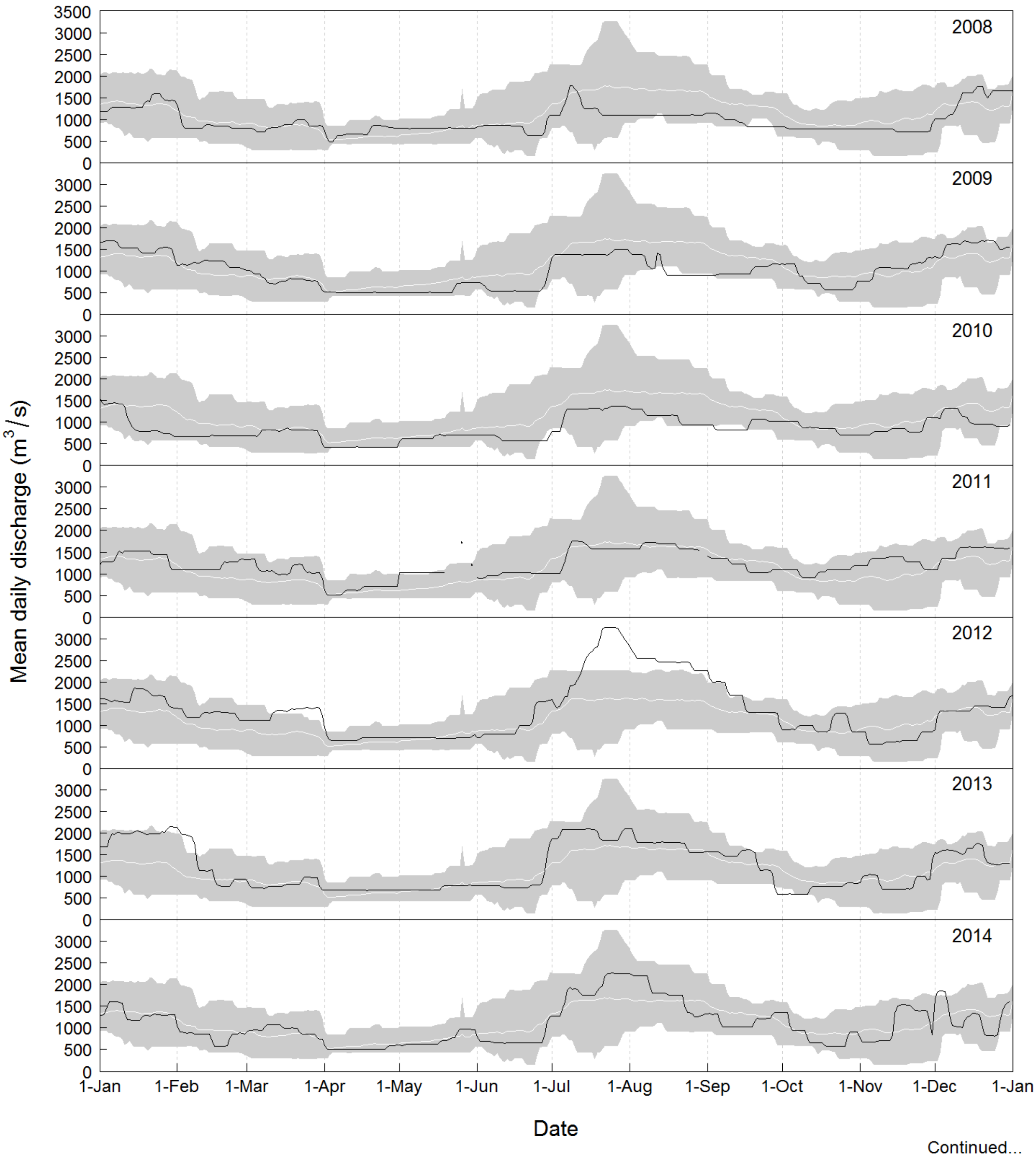

Figure D2. Continued.

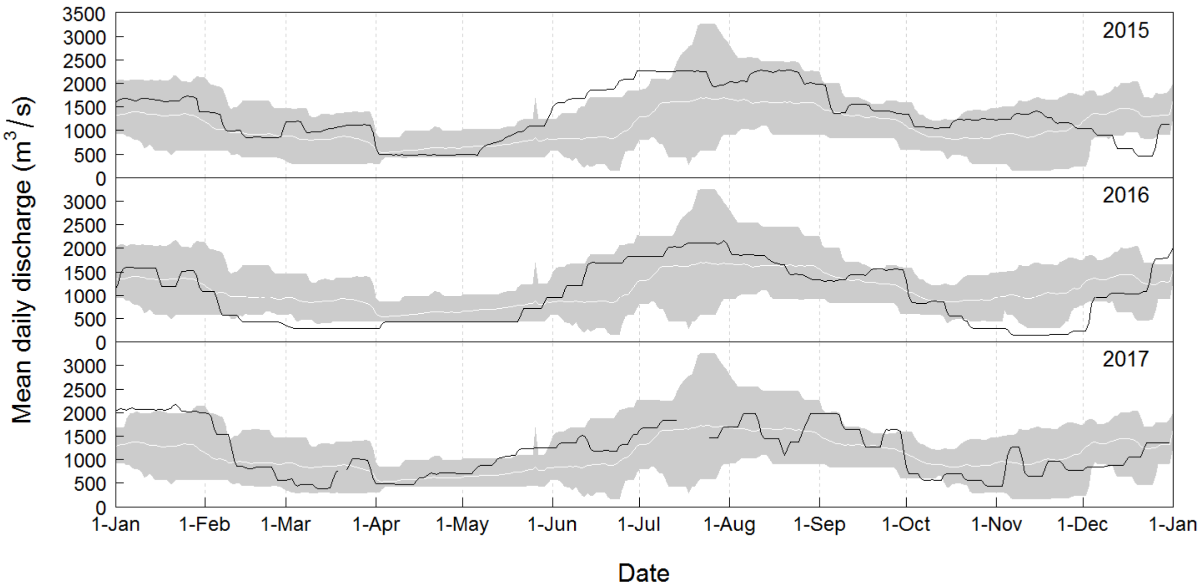

Figure D2. Concluded.

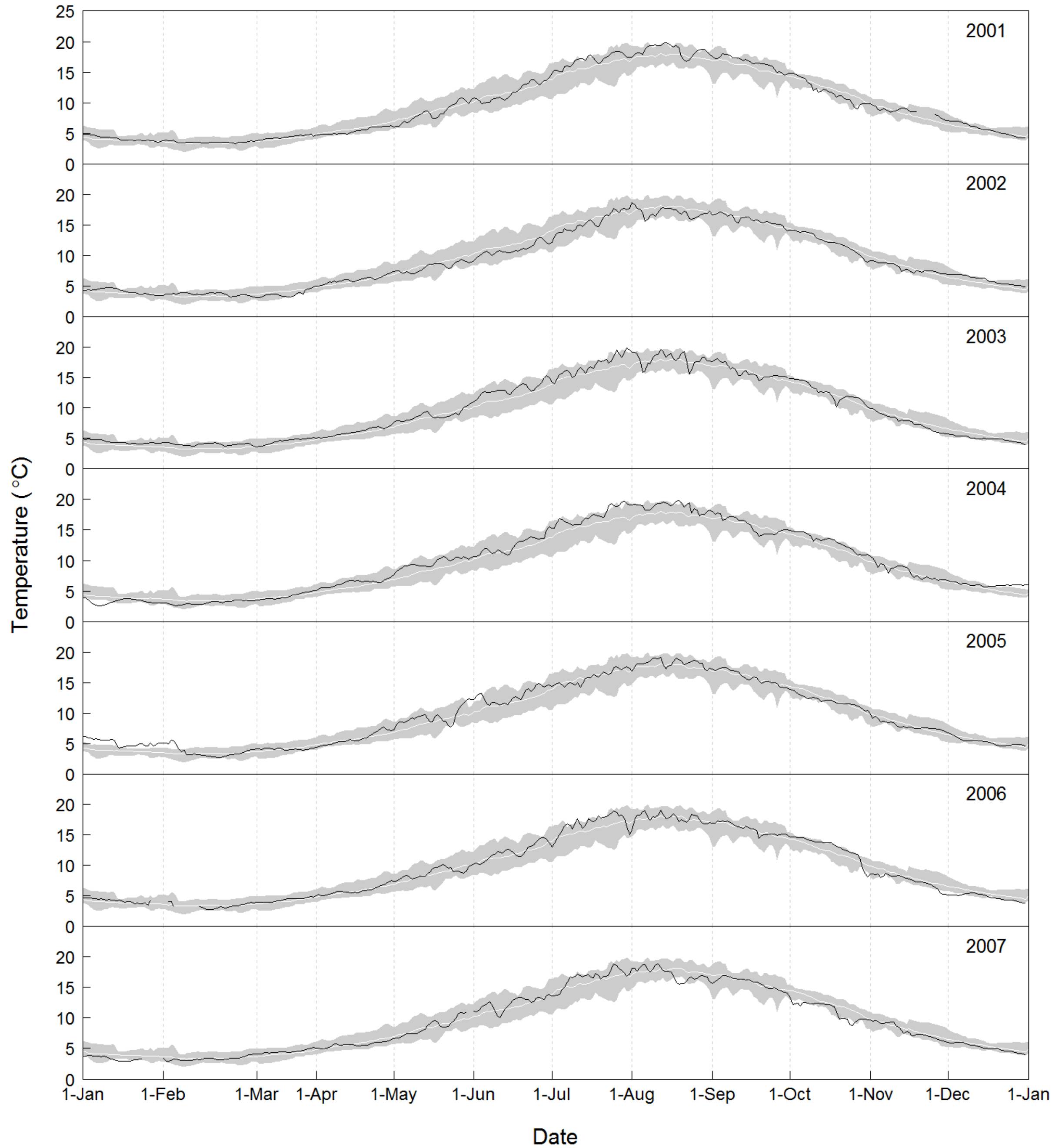

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Figure D3. Mean daily water temperatures (°C) for the Columbia River (black line), 2001 to 2017. Data from all years except 2012 and March-April 2017 were recorded at the Birchbank water gauging station. Data from 2012 were recorded near Fort Shepherd.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

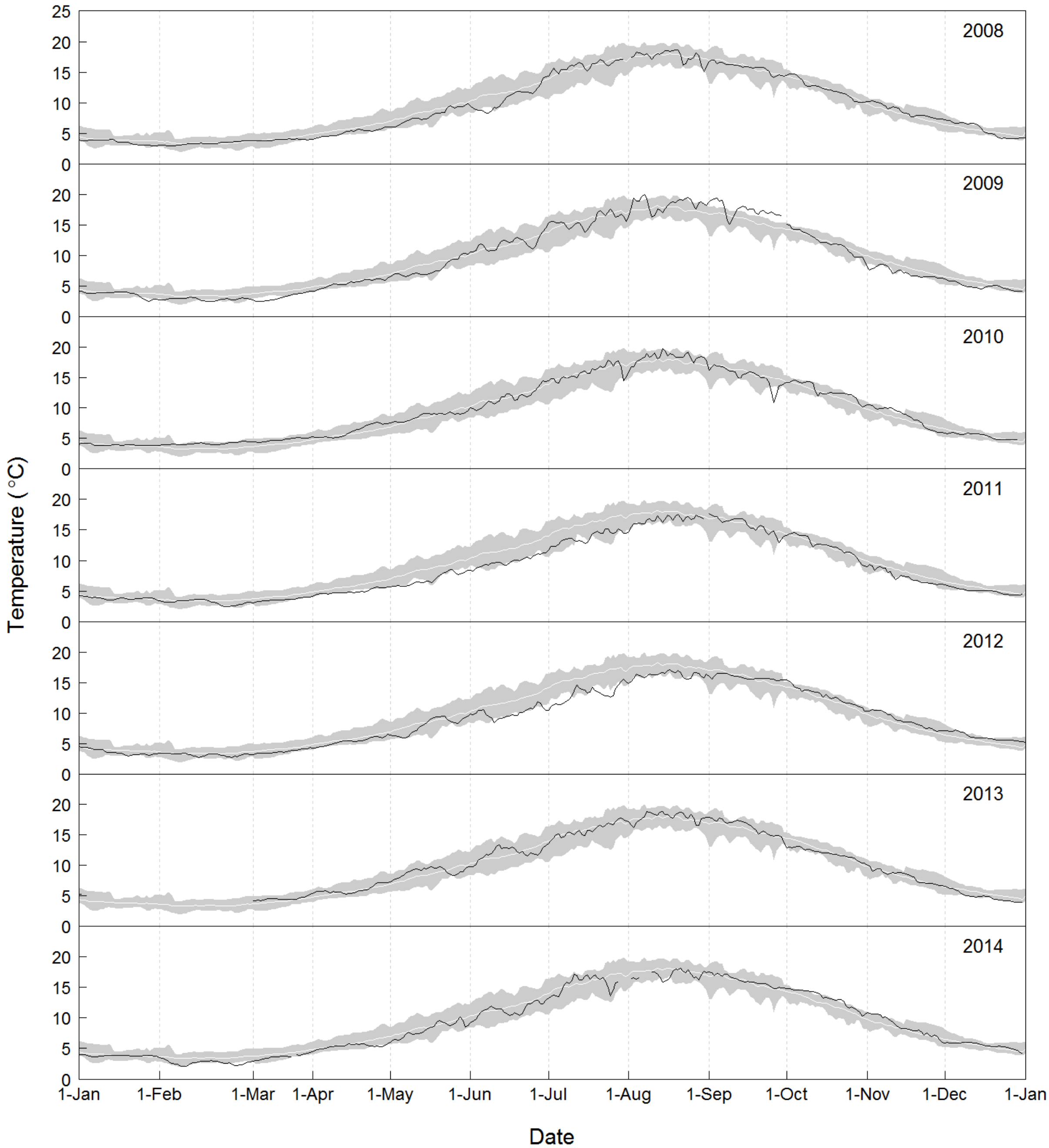

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Figure D3. Continued.

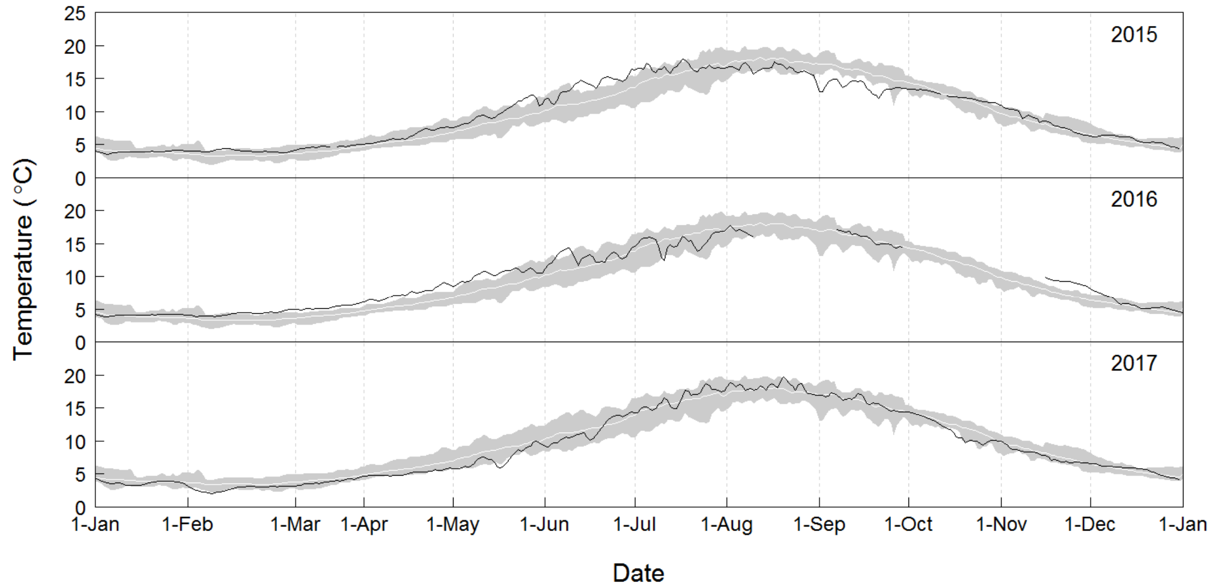

Figure D3. Concluded.

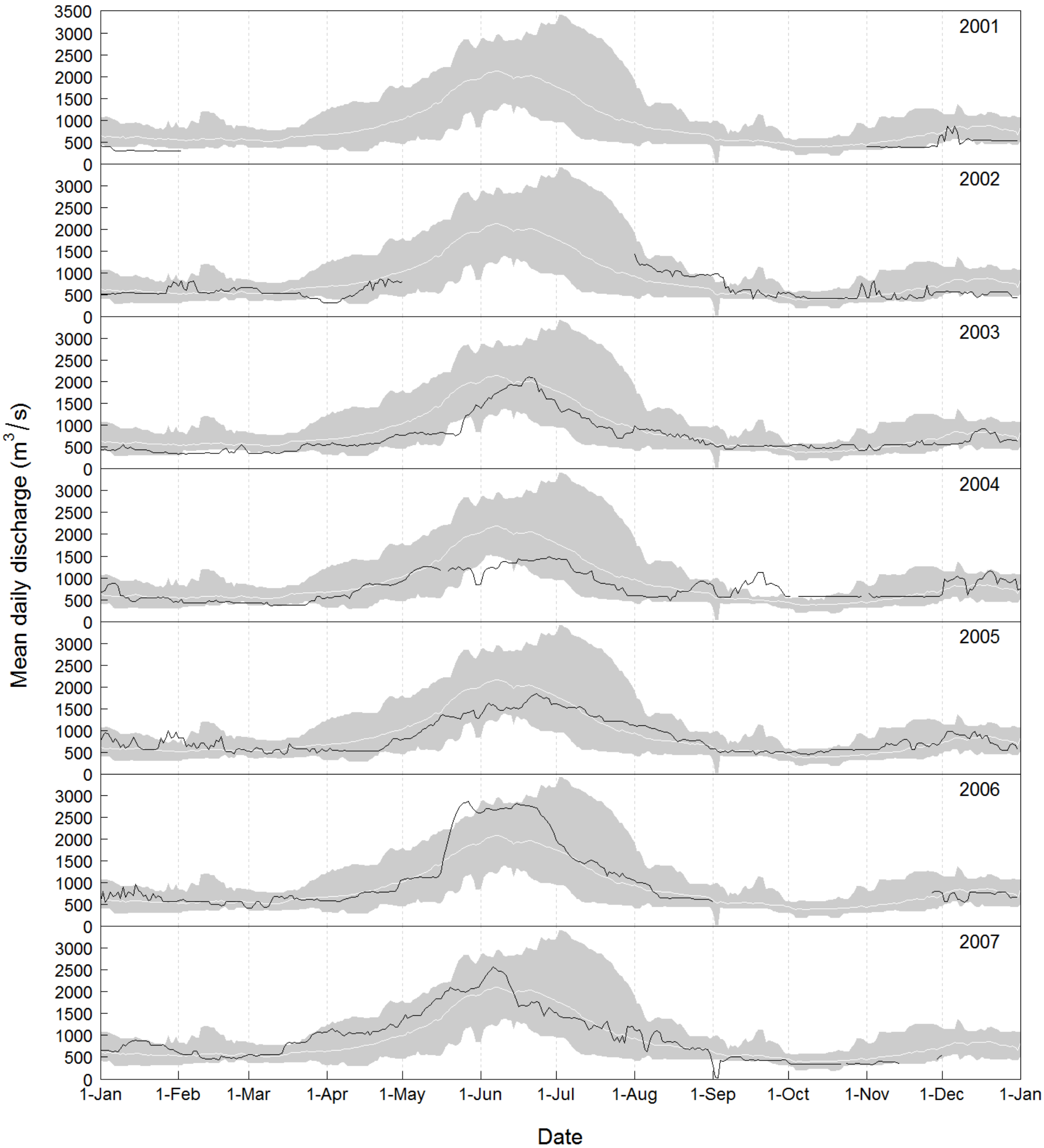

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Figure D4. Mean daily discharge (m³/s) for the Kootenay River at Brilliant Dam (BRD), 2001 to 2017 (black line). The shaded area represents minimum and maximum mean daily discharge recorded at BRD during other study years between 2001 and 2017. The white line represents average mean daily discharge over the same time period.

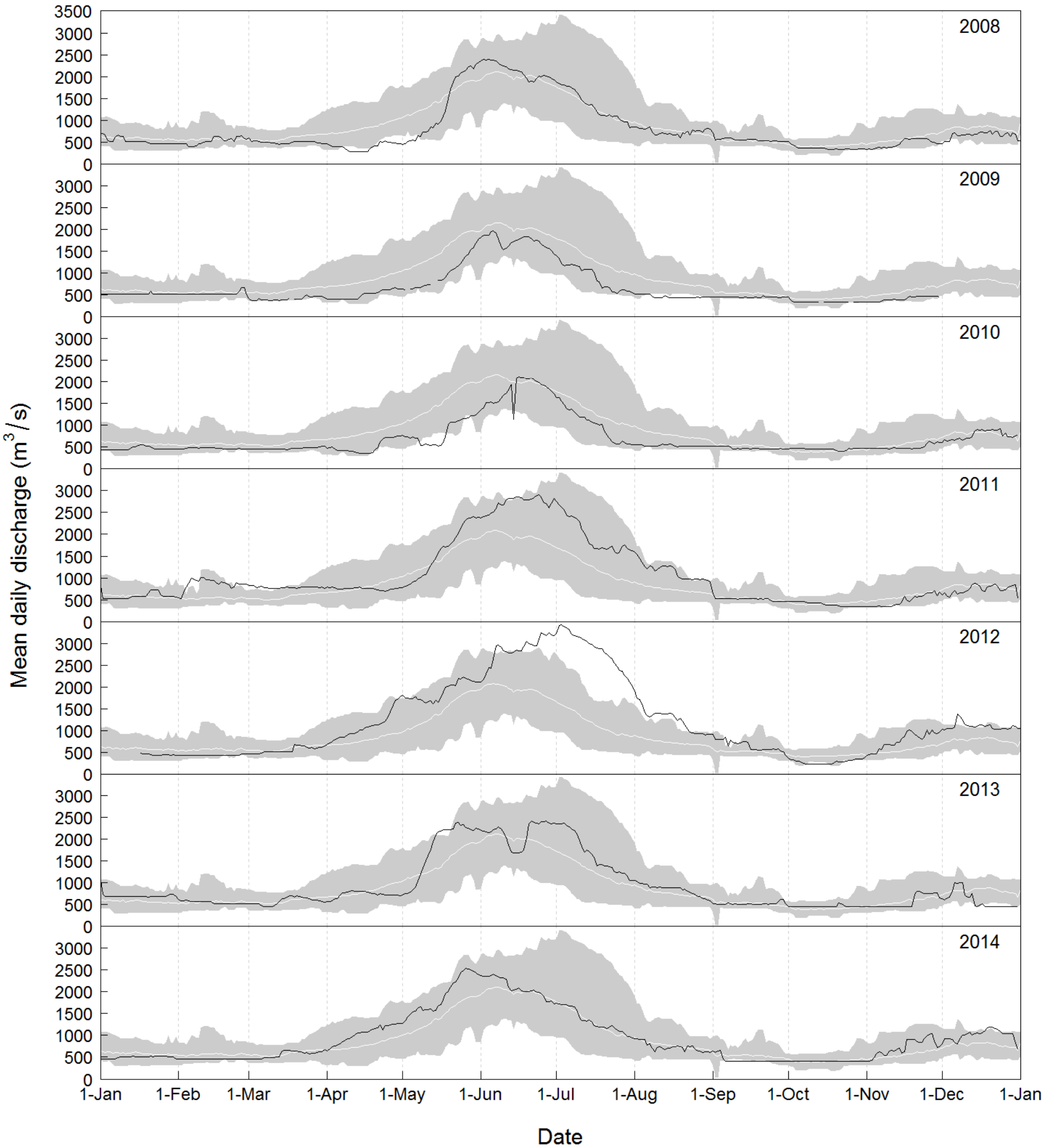

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Figure D4. Continued.

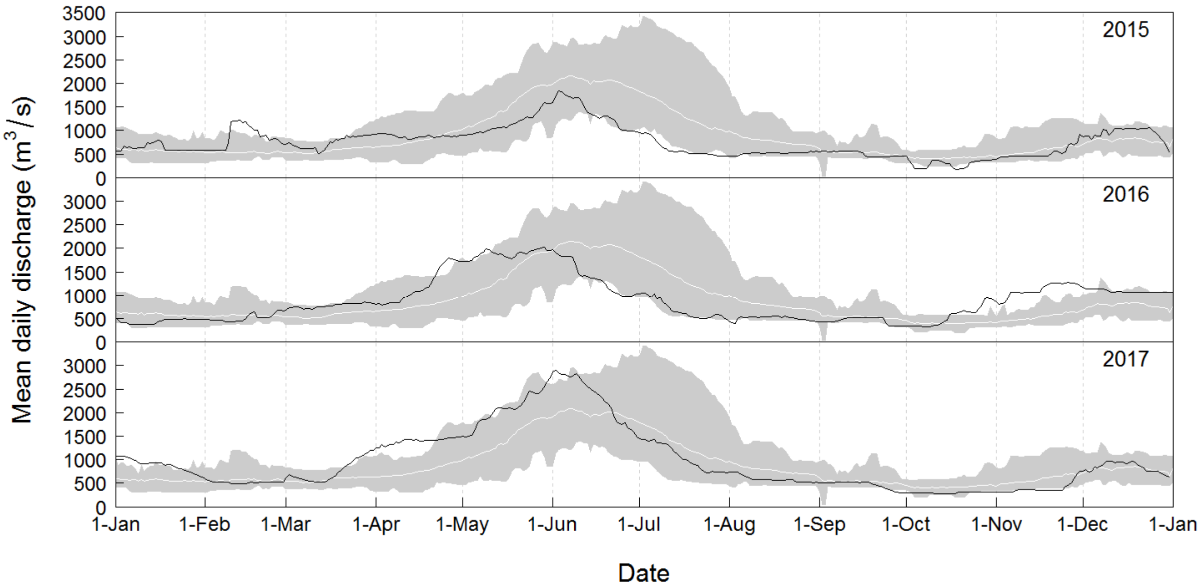

Figure D4. Concluded.

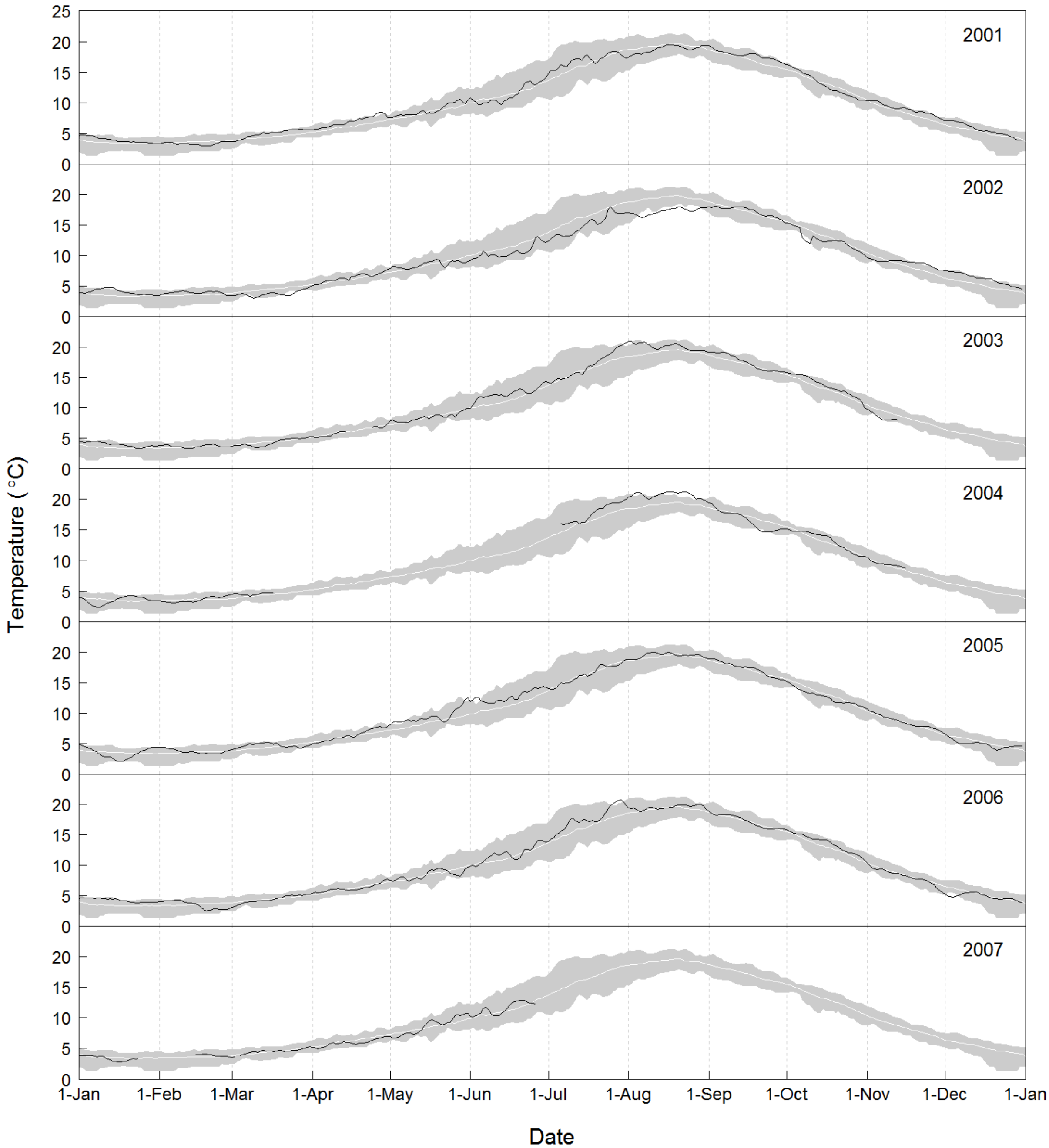

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Figure D5. Mean daily water temperatures (°C) for the Kootenay River at Brilliant Dam (BRD), 2001 to 2017 (black line). The shaded area represents minimum and maximum mean daily water temperatures recorded at BRD during other study years between 2001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

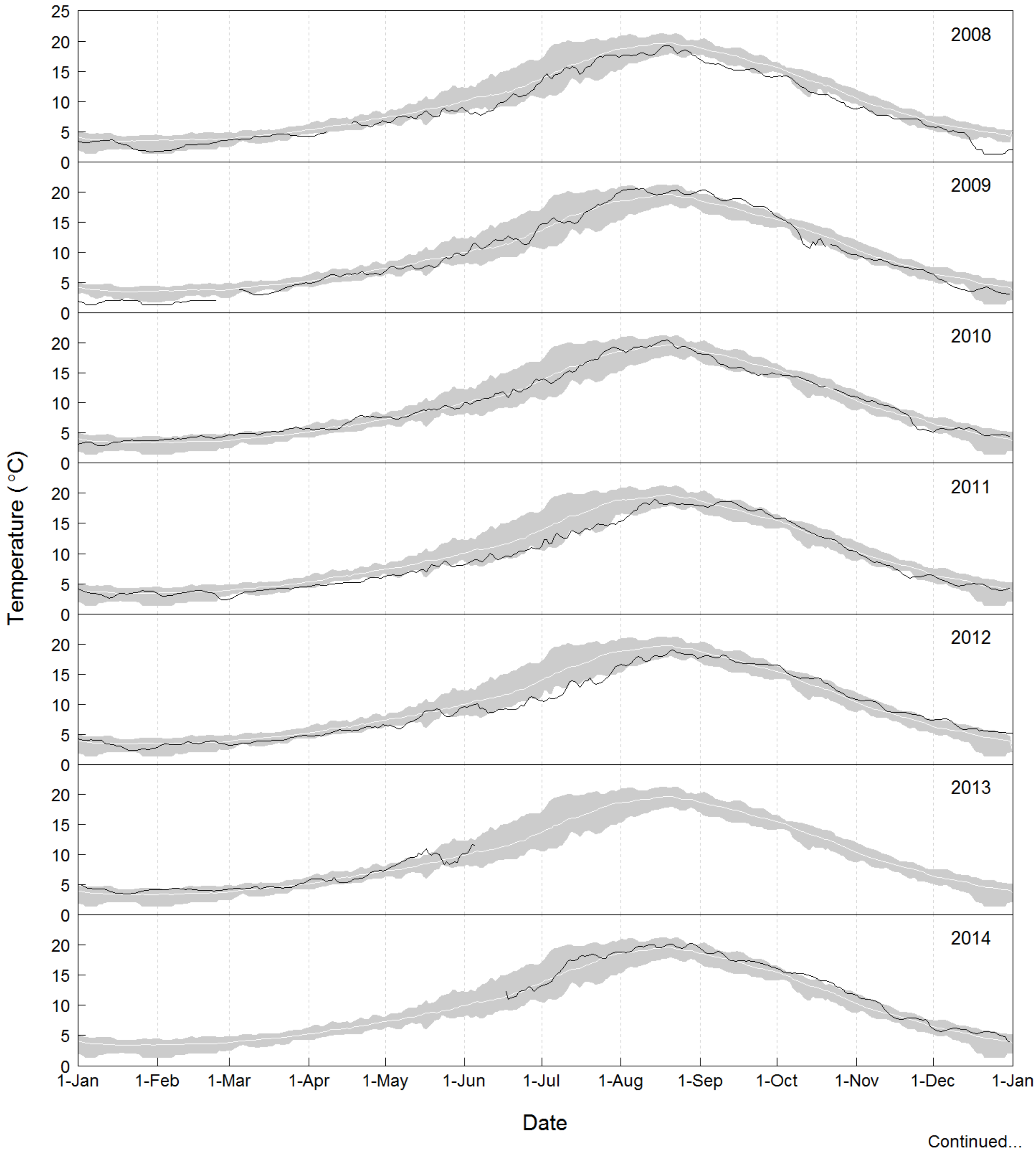


Figure D5. Continued.

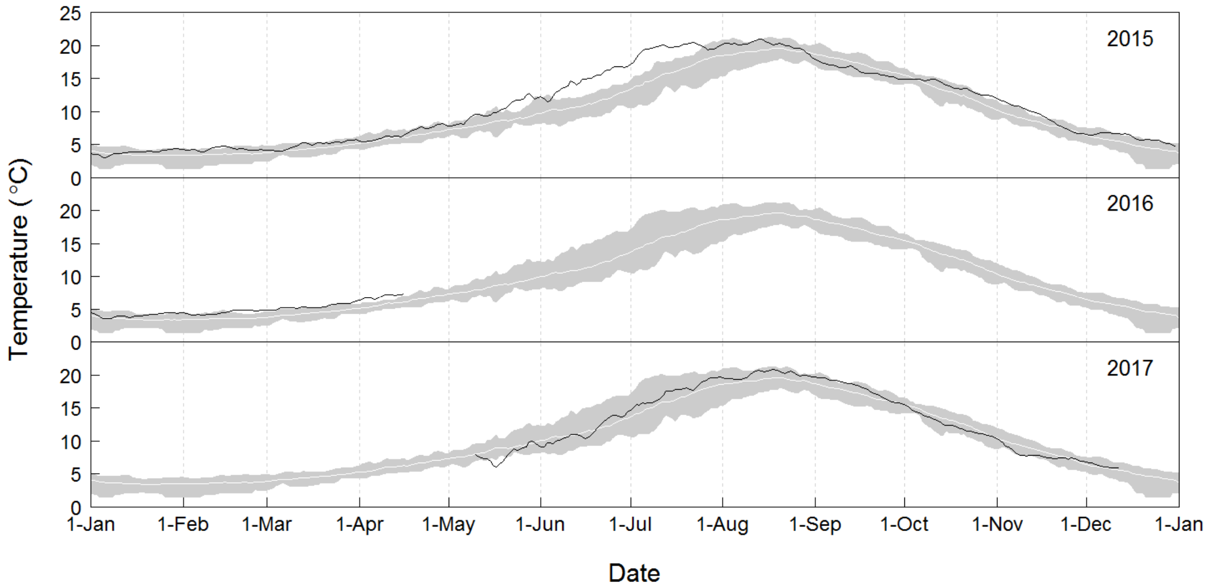


Figure D5. Concluded.

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 2017. 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		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]	%[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	155	<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	46	<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	165	<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	1374	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	11 125	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	2680	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	98 345	42	11
Northern Pike																			7	<1	9	<1	11	<1	125	1	25	<1	9	<1	4	<1	8	<1	198	<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	92 604	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	106	<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	25 806	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	238	<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	55	<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	232 946	100	26
Non-sportfish																																					
Carp spp.	2	<1					1	<1	1	<1	3	<1	1	<1	2	<1			3	<1									1	<1					14	<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	12 380	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	1574	<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	120 137	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	391 029	63	46
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	99 636	16	12
Tench											1	<1	5	<1	1	<1			2	<1					2	<1	1	<1			1	<1	1	<1	14	<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	624 840	100	73
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		857 786		

[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, 02 October to 07 November 2017.

Section	Session	Site	Date	Time Sampled (s)	Length Sampled (km)	Number Caught (CPUE = no. fish/km/hr)																													
						Brook Trout		Brown Trout		Bull Trout		Burbot		Cutthroat Trout		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	No.	CPUE
Columbia River U/S	1	C00.0-R	05-Oct-17	1082	0.94															47	166.36			16	56.63			7	24.78					70	247.77
		C00.7-L	05-Oct-17	526	0.59															32	371.21			24	278.4			1	11.6	1	11.6			58	672.81
		C01.3-L	05-Oct-17	1152	1.6															94	183.59			97	189.45			14	27.34	1	1.95			206	402.34
		C02.8-L	05-Oct-17	903	0.88															57	258.23	1	4.53	56	253.7			12	54.36	1	4.53			127	575.35
		C03.6-L	06-Oct-17	2398	2.09															81	58.18			114	81.89			24	17.24					219	157.31
		C04.6-R	06-Oct-17	631	0.52															4	43.89			15	164.57			5	54.86	1	10.97			25	274.29
		C05.6-L	06-Oct-17	1285	1.1															27	68.77			37	94.23			5	12.73					69	175.73
		C07.3-R	06-Oct-17	979	1.68															95	207.94			85	186.05			14	30.64	2	4.38			196	429.01
		C07.4-L	06-Oct-17	946	1															165	627.91			21	79.92			8	30.44					194	738.27
	Session Summary			**1100**	**10.4**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**602**	**189.44**	**1**	**0.31**	**465**	**146.33**	**0**	**0**	**90**	**28.32**	**6**	**1.89**	**0**	**0**	**1164**	**366.29**
	2	C00.0-R	13-Oct-17	899	0.94															10	42.6			31	132.06			2	8.52					43	183.18
		C00.7-L	13-Oct-17	682	0.59															23	205.78			42	375.76			2	17.89					67	599.43
		C01.3-L	13-Oct-17	1683	1.6															87	116.31			96	128.34			11	14.71	1	1.34			195	260.7
		C02.8-L	13-Oct-17	784	0.88															14	73.05			11	57.4			5	26.09					30	156.54
		C03.6-L	14-Oct-17	2300	2.09													3	2.25	61	45.68			102	76.39			25	18.72					191	143.04
		C04.6-R	14-Oct-17	580	0.52																			22	262.6			4	47.75					26	310.34
		C05.6-L	14-Oct-17	1202	1.1															38	103.46			55	149.75			10	27.23					103	280.44
		C07.3-R	15-Oct-17	808	1.6													1	2.78	118	328.59			128	356.44			19	52.91	1	2.78			267	743.5
		C07.4-L	15-Oct-17	1073	1															215	721.34			59	197.95			3	10.07					277	929.36
	Session Summary			**1112**	**10.3**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**4**	**1.26**	**566**	**177.9**	**0**	**0**	**546**	**171.61**	**0**	**0**	**81**	**25.46**	**2**	**0.63**	**0**	**0**	**1199**	**376.86**
	3	C00.0-R	19-Oct-17	1077	0.94															13	46.23			35	124.46			6	21.34					54	192.02
		C00.7-L	19-Oct-17	578	0.59															13	137.24			16	168.91			3	31.67					32	337.81
		C01.3-L	19-Oct-17	1158	1.6					1	1.94									76	147.67			78	151.55			27	52.46					182	353.63
		C02.8-L	19-Oct-17	857	0.88															7	33.41			5	23.87			3	14.32	1	4.77			16	76.38
		C03.6-L	19-Oct-17	2164	2.09													1	0.8	33	26.27			57	45.37			12	9.55					103	81.99
		C04.6-R	20-Oct-17	564	0.52																	1	12.27	13	159.57			1	12.27					15	184.12
		C05.6-L	20-Oct-17	1051	1.1															5	15.57			55	171.27			6	18.68					66	205.52
		C07.3-R	20-Oct-17	1023	1.7					1	2.07					1	2.07			37	76.59			53	109.71			9	18.63	1	2.07			102	211.14
		C07.4-L	20-Oct-17	1121	1											1	3.21			113	362.89			50	160.57			3	9.63	4	12.85			171	549.15
	Session Summary			**1066**	**10.4**	**0**	**0**	**0**	**0**	**2**	**0.65**	**0**	**0**	**0**	**0**	**2**	**0.65**	**1**	**0.32**	**297**	**96.44**	**1**	**0.32**	**362**	**117.55**	**0**	**0**	**70**	**22.73**	**6**	**1.95**	**0**	**0**	**741**	**240.62**
	4	C00.0-R	27-Oct-17	1062	0.94															29	104.58			33	119			4	14.42					66	238.01
		C00.7-L	27-Oct-17	653	0.59	1	9.34													35	327.04			25	233.6			4	37.38					65	607.37
		C01.3-L	27-Oct-17	1878	1.6															79	94.65			112	134.19			16	19.17					207	248
		C02.8-L	27-Oct-17	864	0.88															30	142.05			30	142.05			3	14.2	1	4.73			64	303.03
		C03.6-L	28-Oct-17	2088	2.09															82	67.65			137	113.02			24	19.8	1	0.82			244	201.29
		C04.6-R	28-Oct-17	603	0.52															2	22.96			23	264.06			4	45.92					29	332.95
		C05.6-L	28-Oct-17	1127	1.1															20	58.08			37	107.45			14	40.65					71	206.18
		C07.3-R	26-Oct-17	922	1.63													1	2.4	77	184.45			58	138.94			10	23.95	1	2.4			147	352.13
		C07.4-L	27-Oct-17	961	1													1	3.75	162	606.87			54	202.29			8	29.97	4	14.98			229	857.86
	Session Summary			**1129**	**10.3**	**1**	**0.31**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**2**	**0.62**	**516**	**159.74**	**0**	**0**	**509**	**157.58**	**0**	**0**	**87**	**26.93**	**7**	**2.17**	**0**	**0**	**1122**	**347.35**
	5	C05.1-R	30-Oct-17	950	0.99															1	3.83			68	260.29			11	42.11					80	306.22
		C06.0-R	30-Oct-17	1548	1.49											2	3.12			1	1.56			23	35.9			7	10.93					33	51.51
	Session Summary			**1249**	**2.5**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**2**	**2.31**	**0**	**0**	**2**	**2.31**	**0**	**0**	**91**	**104.92**	**0**	**0**	**18**	**20.75**	**0**	**0**	**0**	**0**	**113**	**130.28**
Section Total All Samples				**42162**	**43.97**	**1**		**0**		**2**		**0**		**0**		**4**		**7**		**1983**		**2**		**1973**		**0**		**346**		**21**		**0**		**4339**	
Section Average All Samples				**1110**	**1.16**	**0**	**0.07**	**0**	**0**	**0**	**0.15**	**0**	**0**	**0**	**0**	**0**	**0.3**	**0**	**0.52**	**52**	**146.27**	**0**	**0.15**	**52**	**145.53**	**0**	**0**	**9**	**25.52**	**1**	**1.55**	**0**	**0**	**114**	**320.05**
Section Standard Error of Mean						**0.03**	**0.25**	**0**	**0**	**0.04**	**0.07**	**0**	**0**	**0**	**0**	**0.06**	**0.13**	**0.09**	**0.14**	**8.39**	**29.02**	**0.04**	**0.34**	**5.7**	**13.48**	**0**	**0**	**1.15**	**2.31**	**0.16**	**0.64**	**0**	**0**	**12.97**	**36.13**

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		Cutthroat Trout		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	No.	CPUE
Kootenay River	1	K00.3-L	07-Oct-17	235	0.44															2	69.63			3	104.45			2	69.63					7	243.71
		K00.6-R	06-Oct-17	607	0.6															16	158.15			12	118.62			14	138.39					42	415.16
		K01.8-L	07-Oct-17	1416	1.84															94	129.88			41	56.65			34	46.98					169	233.51
		K01.8-R	06-Oct-17	1298	1.3															63	134.41			15	32			13	27.73	1	2.13			92	196.28
	Session Summary			**889**	**4.2**	**0**	*0*	**0**	*0*	**0**	*0*	**0**	*0*	**0**	*0*	**0**	*0*	**0**	*0*	**175**	*168.73*	**0**	*0*	**71**	*68.46*	**0**	*0*	**63**	*60.74*	**1**	*0.96*	**0**	*0*	**310**	*298.89*
	2	K00.3-L	14-Oct-17	273	0.44															9	269.73			9	269.73									18	539.46
		K00.6-R	14-Oct-17	588	0.6															30	306.12			24	244.9			12	122.45					66	673.47
		K01.8-L	14-Oct-17	1478	1.87													2	2.61	110	143.28			39	50.8			27	35.17					178	231.85
		K01.8-R	14-Oct-17	1316	1.3													2	4.21	64	134.67			47	98.9			5	10.52	1	2.1			119	250.41
	Session Summary			**914**	**4.2**	**0**	*0*	**0**	*0*	**0**	*0*	**0**	*0*	**0**	*0*	**0**	*0*	**4**	*3.75*	**213**	*199.75*	**0**	*0*	**119**	*111.6*	**0**	*0*	**44**	*41.26*	**1**	*0.94*	**0**	*0*	**381**	*357.3*
	3	K00.3-L	21-Oct-17	247	0.44			1	33.12											9	298.12			3	99.37			7	231.87					20	662.5
		K00.6-R	21-Oct-17	615	0.6															36	351.22			14	136.59			13	126.83					63	614.63
		K01.8-L	21-Oct-17	1510	1.87											2	2.55	1	1.27	104	132.59			53	67.57			26	33.15					186	237.14
		K01.8-R	20-Oct-17	1248	1.3											2	4.44			59	130.92			31	68.79			11	24.41					103	228.55
	Session Summary			**905**	**4.2**	**0**	*0*	**1**	*0.95*	**0**	*0*	**0**	*0*	**0**	*0*	**4**	*3.79*	**1**	*0.95*	**208**	*197*	**0**	*0*	**101**	*95.66*	**0**	*0*	**57**	*53.99*	**0**	*0*	**0**	*0*	**372**	*352.33*
	4	K00.3-L	26-Oct-17	208	0.44															20	786.71			8	314.69			5	196.68					33	1298.08
		K00.6-R	26-Oct-17	541	0.6															46	510.17			8	88.72			12	133.09					66	731.98
		K01.8-L	26-Oct-17	1243	1.87											1	1.55			97	150.23			36	55.76			17	26.33	1	1.55			152	235.41
		K01.8-R	26-Oct-17	1101	1.3															71	178.58			39	98.09			7	17.61	1	2.52			118	296.79
	Session Summary			**773**	**4.2**	**0**	*0*	**0**	*0*	**0**	*0*	**0**	*0*	**0**	*0*	**1**	*1.11*	**0**	*0*	**234**	*259.47*	**0**	*0*	**91**	*100.91*	**0**	*0*	**41**	*45.46*	**2**	*2.22*	**0**	*0*	**369**	*409.17*
Section Total All Samples				**13924**	**16.81**	**0**		**1**		**0**		**0**		**0**		**5**		**5**		**830**		**0**		**382**		**0**		**205**		**4**		**0**		**1432**	
Section Average All Samples				**870**	**1.05**	**0**	*0*	**0**	*0.25*	**0**	*0*	**0**	*0*	**0**	*0*	**0**	*1.23*	**0**	*1.23*	**52**	*204.31*	**0**	*0*	**24**	*94.03*	**0**	*0*	**13**	*50.46*	**0**	*0.98*	**0**	*0*	**90**	*352.5*
Section Standard Error of Mean						**0**	*0*	**0.06**	*2.07*	**0**	*0*	**0**	*0*	**0**	*0*	**0.18**	*0.32*	**0.18**	*0.3*	**9.09**	*45.98*	**0**	*0*	**4.21**	*20.9*	**0**	*0*	**2.34**	*17.8*	**0.11**	*0.24*	**0**	*0*	**14.89**	*74.57*

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		Cutthroat Trout		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	No.	CPUE
Columbia River D/S	1	C25.3-R	03-Oct-17	1932	2.73															33	22.52			95	64.84			13	8.87					141	96.24
		C27.6-R	03-Oct-17	371	0.61															19	302.24			46	731.74			1	15.91					66	1049.89
		C28.2-R	03-Oct-17	769	1.13															5	20.71			52	215.43									57	236.14
		C34.9-L	04-Oct-17	2127	2.14															21	16.61			159	125.75	1	0.79	3	2.37					184	145.53
		C36.6-L	04-Oct-17	1601	2.39													1	0.94	28	26.34			118	111.02			14	13.17					161	151.47
		C47.8-L	04-Oct-17	1236	1.44											1	2.02	2	4.05	19	38.43			63	127.43			10	20.23					95	192.15
		C48.2-R	02-Oct-17	786	0.99															14	64.77			32	148.05			7	32.38					53	245.2
		C49.0-L	04-Oct-17	480	0.93															20	161.29			23	185.48									43	346.77
		C49.0-R	02-Oct-17	480	0.72											1	10.42	1	10.42	16	166.67			25	260.42			6	62.5					49	510.42
		C49.8-L	04-Oct-17	1699	2.45													1	0.86	49	42.38			89	76.97			8	6.92					147	127.13
		C49.8-R	03-Oct-17	1319	2.39													1	1.14	42	47.96			88	100.49	1	1.14	23	26.27	2	2.28			157	179.29
		C52.2-L	04-Oct-17	737	0.89	1	5.49													6	32.93			21	115.26			1	5.49	1	5.49			30	164.65
		C52.2-R	03-Oct-17	2048	3.79							1	0.46					1	0.46	44	20.41			129	59.83			20	9.28					195	90.44
		C52.8-L	05-Oct-17	586	0.89															6	41.42			21	144.96	1	6.9	4	27.61	1	6.9			33	227.79
		C53.6-L	05-Oct-17	1072	1.42															2	4.73			33	78.04			4	9.46					39	92.23
	Session Summary			**1150**	**24.9**	**1**	***0.13***	**0**	***0***	**0**	***0***	**1**	***0.13***	**0**	***0***	**2**	***0.25***	**7**	***0.88***	**324**	***40.73***	**0**	***0***	**994**	***124.97***	**3**	***0.38***	**114**	***14.33***	**4**	***0.5***	**0**	***0***	**1450**	***182.29***
	2	C25.3-R	10-Oct-17	1526	2.73													3	2.59	38	32.84			62	53.58			11	9.51					114	98.51
		C27.6-R	10-Oct-17	314	0.61															30	563.85			18	338.31			9	169.16					57	1071.32
		C28.2-R	10-Oct-17	766	1.13															22	91.5			42	174.68			8	33.27					72	299.45
		C34.9-L	10-Oct-17	2047	2.14															20	16.44			145	119.16			11	9.04					176	144.64
		C36.6-L	11-Oct-17	1657	2.39															11	10			111	100.9			27	24.54					149	135.45
		C47.8-L	11-Oct-17	1100	1.44											1	2.27			7	15.91	1	2.27	41	93.18			8	18.18					58	131.82
		C48.2-R	12-Oct-17	824	1.01											1	4.33			10	43.26			34	147.07			10	43.26					55	237.91
		C49.0-L	11-Oct-17	479	0.93													3	24.24	21	169.71			30	242.44			6	48.49					60	484.88
		C49.0-R	12-Oct-17	575	0.72													1	8.7	11	95.65			26	226.09			10	86.96					48	417.39
		C49.8-L	11-Oct-17	1683	2.45			1	0.87							1	0.87	4	3.49	37	32.3			64	55.88	1	0.87	29	25.32					137	119.61
		C49.8-R	12-Oct-17	1483	2.39															59	59.93			78	79.22			36	36.57					173	175.72
		C52.2-L	12-Oct-17	764	0.89															16	84.71			35	185.31			5	26.47					56	296.49
		C52.2-R	12-Oct-17	2176	3.79							2	0.87			2	0.87	3	1.31	28	12.22			94	41.03			37	16.15	1	0.44			167	72.9
		C52.8-L	12-Oct-17	670	0.89															3	18.11			42	253.56			24	144.89					69	416.57
		C53.6-L	12-Oct-17	1083	1.52															3	6.56			47	102.78			14	30.62					64	139.96
	Session Summary			**1143**	**25**	**0**	***0***	**1**	***0.13***	**0**	***0***	**2**	***0.25***	**0**	***0***	**5**	***0.63***	**14**	***1.76***	**316**	***39.81***	**1**	***0.13***	**869**	***109.48***	**1**	***0.13***	**245**	***30.87***	**1**	***0.13***	**0**	***0***	**1455**	***183.31***
	3	C25.3-R	16-Oct-17	1422	2.7													1	0.94	33	30.94			79	74.07			5	4.69					118	110.64
		C27.6-R	16-Oct-17	313	0.61															21	395.96			23	433.67									44	829.62
		C28.2-R	16-Oct-17	1037	1.13															23	70.66			46	141.32			6	18.43					75	230.41
		C34.9-L	16-Oct-17	1934	2.09															9	8.02			116	103.31			5	4.45					130	115.78
		C36.6-L	16-Oct-17	1636	2.39															14	12.89			106	97.59			8	7.37					128	117.85
		C47.8-L	18-Oct-17	967	1.44	1	2.59													6	15.51			28	72.39			6	15.51					41	106
		C48.2-R	17-Oct-17	853	1.01															4	16.71			29	121.18			7	29.25					40	167.14
		C49.0-L	18-Oct-17	443	0.93													4	34.95	13	113.59			16	139.81			1	8.74					34	297.09
		C49.0-R	17-Oct-17	544	0.72															3	27.57			10	91.91			6	55.15					19	174.63
		C49.8-L	18-Oct-17	1638	2.45													4	3.59	34	30.5			76	68.18			14	12.56					128	114.82
		C49.8-R	17-Oct-17	1382	2.39	1	1.09					2	2.18							27	29.43			85	92.64			24	26.16			1	1.09	140	152.59
		C52.2-L	18-Oct-17	849	0.89							1	4.76							10	47.64			39	185.81			1	4.76					51	242.98
		C52.2-R	17-Oct-17	2183	3.79							2	0.87					4	1.74	12	5.22			82	35.68			9	3.92	2	0.87			111	48.3
		C52.8-L	18-Oct-17	710	0.89							1						2		8				60				7						78	
		C53.6-L	19-Oct-17	1136	1.52													2	4.17	8	16.68			41	85.48			13	27.1					64	133.43
	Session Summary			**1136**	**24.9**	**2**	***0.25***	**0**	***0***	**0**	***0***	**6**	***0.76***	**0**	***0***	**0**	***0***	**17**	***2.16***	**225**	***28.64***	**0**	***0***	**836**	***106.4***	**0**	***0***	**112**	***14.25***	**2**	***0.25***	**1**	***0.13***	**1201**	***152.85***

Table E2 Concluded.

Section	Session	Site	Date	Time Sampled (s)	Length Sampled (km)	Brook Trout No.	Brook Trout CPUE	Brown Trout No.	Brown Trout CPUE	Bull Trout No.	Bull Trout CPUE	Burbot No.	Burbot CPUE	Cutthroat Trout No.	Cutthroat Trout CPUE	Kokanee No.	Kokanee CPUE	Lake Whitefish No.	Lake Whitefish CPUE	Mountain Whitefish No.	Mountain Whitefish CPUE	Northern Pike No.	Northern Pike CPUE	Rainbow Trout No.	Rainbow Trout CPUE	Smallmouth Bass No.	Smallmouth Bass CPUE	Walleye No.	Walleye CPUE	White Sturgeon No.	White Sturgeon CPUE	Yellow Perch No.	Yellow Perch CPUE	All Species No.	All Species CPUE
						Number Caught (CPUE = no. fish/km/hr)																													
Columbia River D/S	4	C25.3-R	23-Oct-17	1583	2.73													3	*2.5*	24	*19.99*	5	*4.17*	99	*82.47*			9	*7.5*					140	*116.62*
		C27.6-R	23-Oct-17	334	0.61											1	*17.67*			6	*106.02*			28	*494.75*			7	*123.69*					42	*742.12*
		C28.2-R	23-Oct-17	802	1.13											1	*3.97*			6	*23.83*			55	*218.48*			5	*19.86*					67	*266.15*
		C34.9-L	23-Oct-17	2081	2.14											1	*0.81*			12	*9.7*			103	*83.26*			11	*8.89*					127	*102.66*
		C36.6-L	24-Oct-17	1679	2.34													1	*0.92*	25	*22.91*			106	*97.13*			13	*11.91*					145	*132.86*
		C47.8-L	25-Oct-17	1040	1.44	2	*4.81*											4	*9.62*	12	*28.85*			35	*84.13*			14	*33.65*					67	*161.06*
		C48.2-R	24-Oct-17	864	1.01	1	*4.13*											1	*4.13*	9	*37.13*			36	*148.51*			25	*103.14*					72	*297.03*
		C49.0-L	25-Oct-17	494	0.93													2	*15.67*	27	*211.57*			34	*266.42*			7	*54.85*	1	*7.84*			71	*556.35*
		C49.0-R	24-Oct-17	547	0.72													4	*36.56*	9	*82.27*			11	*100.55*			5	*45.7*					29	*265.08*
		C49.8-L	25-Oct-17	1641	2.45							3	*2.69*					6	*5.37*	41	*36.71*			68	*60.89*			24	*21.49*					142	*127.15*
		C49.8-R	24-Oct-17	1545	2.39							2	*1.95*					2	*1.95*	66	*64.35*			96	*93.59*			33	*32.17*					199	*194.01*
		C52.2-L	25-Oct-17	691	0.85													8	*49.03*	2	*12.26*			20	*122.58*			2	*12.26*					32	*196.14*
		C52.2-R	25-Oct-17	2392	3.77	1	*0.4*					10	*3.99*					5	*2*	11	*4.39*			72	*28.74*			9	*3.59*					108	*43.11*
		C52.8-L	26-Oct-17	620	0.89							1	*6.52*			2	*13.05*			3	*19.57*			52	*339.25*			6	*39.14*					64	*417.54*
		C53.6-L	26-Oct-17	1168	1.52															2	*4.06*			20	*40.56*			5	*10.14*					27	*54.75*
	Session Summary			**1165**	**24.9**	**4**	***0.5***	**0**	***0***	**0**	***0***	**16**	***1.99***	**0**	***0***	**5**	***0.62***	**36**	***4.47***	**255**	***31.65***	**5**	***0.62***	**835**	***103.62***	**0**	***0***	**175**	***21.72***	**1**	***0.12***	**0**	***0***	**1332**	***165.3***
	5	C10.7-R	31-Oct-17	898	0.91													1	*4.41*	6	*26.43*			84	*370.05*			5	*22.03*					96	*422.92*
		C13.4-R	31-Oct-17	1530	2.52											2	*1.87*	8	*7.47*	41	*38.28*			166	*155*			18	*16.81*	1	*0.93*			236	*220.35*
		C14.8-L	30-Oct-17	1931	2.26													1	*0.82*	109	*89.92*	1	*0.82*	65	*53.62*			11	*9.07*			3	*2.47*	190	*156.73*
		C15.8-R	31-Oct-17	844	0.82											1	*5.2*			36	*187.26*	1	*5.2*	74	*384.93*			6	*31.21*					118	*613.8*
		C16.6-R	31-Oct-17	1592	1.44									1	*1.57*					33	*51.82*			78	*122.49*			9	*14.13*					121	*190.01*
		C20.1-L	01-Nov-17	1160	1.27															28	*68.42*			88	*215.04*			20	*48.87*					136	*332.34*
		C20.4-R	01-Nov-17	1162	1.47													1	*2.11*	33	*69.55*	1	*2.11*	114	*240.26*			4	*8.43*			1	*2.11*	154	*324.56*
		C23.4-L	01-Nov-17	749	0.93															24	*124.04*			67	*346.27*			7	*36.18*					98	*506.48*
		C25.3-L	01-Nov-17	1217	1.88													1	*1.57*	79	*124.3*			67	*105.42*			17	*26.75*					164	*258.05*
		C27.5-L	02-Nov-17	1202	1.31							1	*2.29*							17	*38.87*			104	*237.77*			24	*54.87*	1	*2.29*			147	*336.08*
		C29.6-L	03-Nov-17	609	1.11													10	*53.26*	35	*186.39*			59	*314.21*			4	*21.3*					108	*575.16*
		C32.0-R	03-Nov-17	1304	1.37															12	*24.18*			60	*120.91*			11	*22.17*					83	*167.26*
		C32.4-L	03-Nov-17	1562	2															9	*10.37*			137	*157.87*			12	*13.83*					158	*182.07*
		C36.9-R	03-Nov-17	1622	2.27											1	*0.98*	7	*6.84*	23	*22.49*			75	*73.33*			8	*7.82*					114	*111.46*
		C41.1-L	06-Nov-17	1752	2.41							1	*0.85*					1	*0.85*	24	*20.46*			131	*111.69*			12	*10.23*					169	*144.09*
		C41.5-R	06-Nov-17	2068	2.16													1	*0.81*	15	*12.09*			176	*141.84*			22	*17.73*					214	*172.47*
		C46.2-R	06-Nov-17	782	1.01															25	*113.95*			45	*205.11*			10	*45.58*					80	*364.64*
		C46.4-L	07-Nov-17	939	1.59							3	*7.23*							21	*50.64*			90	*217.01*			8	*19.29*					122	*294.17*
	Session Summary			**1274**	**28.7**	**0**	***0***	**0**	***0***	**0**	***0***	**5**	***0.49***	**1**	***0.1***	**4**	***0.39***	**31**	***3.05***	**570**	***56.12***	**3**	***0.3***	**1680**	***165.41***	**0**	***0***	**208**	***20.48***	**2**	***0.2***	**4**	***0.39***	**2508**	***246.93***
Section Total All Samples				**91841**	**128.54**	**7**		**1**		**0**		**30**		**1**		**16**		**105**		**1690**		**9**		**5214**		**4**		**854**		**10**		**5**		**7946**	
Section Average All Samples				**1177**	**1.65**	**0**	***0.17***	**0**	***0.02***	**0**	***0***	**0**	***0.71***	**0**	***0.02***	**0**	***0.38***	**1**	***2.5***	**22**	***40.21***	**0**	***0.21***	**67**	***124.07***	**0**	***0.1***	**11**	***20.32***	**0**	***0.24***	**0**	***0.12***	**102**	***189.08***
Section Standard Error of Mean						**0.04**	***0.11***	**0.01**	***0.01***	**0**	***0***	**0.15**	***0.17***	**0.01**	***0.02***	**0.06**	***0.32***	**0.25**	***1.15***	**2.07**	***10.07***	**0.07**	***0.09***	**4.42**	***13.51***	**0.03**	***0.09***	**0.96**	***3.46***	**0.05**	***0.15***	**0.04**	***0.04***	**5.99**	***23.28***
All Sections Total All Samples				**147927**	**189.32**	***8***	***0***	***2***	***0***	***2***	***0***	***30***	***0***	***1***	***0***	***25***	***0***	***117***	***0.02***	***4503***	***0.58***	***11***	***0***	***7569***	***0.97***	***4***	***0***	***1405***	***0.18***	***35***	***0***	***5***	***0***	***13717***	***1.76***
All Sections Average All Samples						***0***	***0.14***	***0***	***0.03***	***0***	***0.03***	***0***	***0.51***	***0***	***0.02***	***0***	***0.42***	***1***	***1.99***	***34***	***76.41***	***0***	***0.19***	***57***	***128.43***	***0***	***0.07***	***11***	***23.84***	***0***	***0.59***	***0***	***0.08***	***104***	***232.75***
All Sections Standard Error of Mean						***0.02***	***0.1***	***0.01***	***0.25***	***0.01***	***0.02***	***0.09***	***0.1***	***0.01***	***0.01***	***0.04***	***0.2***	***0.16***	***0.7***	***3.17***	***12.8***	***0.04***	***0.11***	***3.34***	***9.26***	***0.01***	***0.05***	***0.72***	***3.33***	***0.06***	***0.22***	***0.03***	***0.03***	***5.45***	***20.03***

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, 02 October to 07 November 2017.

Section	Session	Site	Date	Time Sampled (s)	Length Sampled (km)	Number Caught (CPUE = no. fish/km/hr)													
						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
Columbia River U/S	1	C00.0-R	05-Oct-17	1082	0.9371516	1	*3.55*	4	*14.2*	5140	*18248.56*	51	*181.07*	1	*3.55*			5197	*18450.92*
		C00.7-L	05-Oct-17	526	0.5932888			6	*69.22*	12	*138.43*	10	*115.36*	1	*11.54*			29	*334.54*
		C01.3-L	05-Oct-17	1152	1.601247	4	*7.81*	4	*7.81*	6	*11.71*	58	*113.19*	15	*29.27*			87	*169.79*
		C02.8-L	05-Oct-17	903	0.8821294					28	*126.54*	15	*67.79*	10	*45.19*			53	*239.53*
		C03.6-L	06-Oct-17	2398	2.087279					38	*27.33*	35	*25.17*	43	*30.93*			116	*83.43*
		C04.6-R	06-Oct-17	631	0.5174685			1	*11.03*					7	*77.18*			8	*88.2*
		C05.6-L	06-Oct-17	1285	1.100858	4	*10.18*			77	*195.96*	12	*30.54*	50	*127.24*			143	*363.92*
		C07.3-R	06-Oct-17	979	1.684862							110	*240.08*	10	*21.83*			120	*261.9*
		C07.4-L	06-Oct-17	946	0.9981754									19	*72.44*			19	*72.44*
	Session Summary			**1100**	**10.4**	**9**	***2.83***	**15**	***4.72***	**5301**	***1668.15***	**291**	***91.57***	**156**	***49.09***	**0**	***0***	**5772**	***1816.36***
	2	C00.0-R	13-Oct-17	899	0.9371516					25	*106.83*	30	*128.19*	1	*4.27*			56	*239.29*
		C00.7-L	13-Oct-17	682	0.5932888			8	*71.18*	10	*88.97*	25	*222.43*					43	*382.58*
		C01.3-L	13-Oct-17	1683	1.601247			15	*20.04*	10	*13.36*	48	*64.12*	26	*34.73*			99	*132.25*
		C02.8-L	13-Oct-17	784	0.8821294			4	*20.82*			15	*78.08*	5	*26.03*			24	*124.93*
		C03.6-L	14-Oct-17	2300	2.087279	5	*3.75*	6	*4.5*	10	*7.5*	75	*56.24*	76	*56.99*			172	*128.98*
		C04.6-R	14-Oct-17	580	0.5174685					6	*71.97*	10	*119.95*	6	*71.97*			22	*263.88*
		C05.6-L	14-Oct-17	1202	1.100858	13	*35.37*	7	*19.04*			30	*81.62*	27	*73.46*			77	*209.49*
		C07.3-R	15-Oct-17	808	1.604862	1	*2.78*					30	*83.29*	14	*38.87*			45	*124.93*
		C07.4-L	15-Oct-17	1073	0.9981754	2	*6.72*	2	*6.72*	4	*13.44*	24	*80.67*	37	*124.36*			69	*231.92*
	Session Summary			**1112**	**10.3**	**21**	***6.6***	**42**	***13.2***	**65**	***20.43***	**287**	***90.21***	**192**	***60.35***	**0**	***0***	**607**	***190.79***
	3	C00.0-R	19-Oct-17	1077	0.9371516			3	*10.7*	20	*71.34*	155	*552.85*					178	*634.89*
		C00.7-L	19-Oct-17	578	0.5932888			5	*52.49*	3	*31.49*	35	*367.43*					43	*451.42*
		C01.3-L	19-Oct-17	1158	1.601247	6	*11.65*	12	*23.3*			19	*36.89*	22	*42.71*			59	*114.55*
		C02.8-L	19-Oct-17	857	0.8821294									7	*33.33*			7	*33.33*
		C03.6-L	19-Oct-17	2164	2.087279									22	*17.53*			22	*17.53*
		C04.6-R	20-Oct-17	564	0.5174685							17	*209.7*	3	*37.01*			20	*246.7*
		C05.6-L	20-Oct-17	1051	1.100858	10	*31.11*					55	*171.13*	30	*93.34*			95	*295.59*
		C07.3-R	20-Oct-17	1023	1.704862	1	*2.06*					160	*330.26*	2	*4.13*			163	*336.45*
		C07.4-L	20-Oct-17	1121	0.9981754	2	*6.43*	2	*6.43*			25	*80.43*	18	*57.91*			47	*151.21*
	Session Summary			**1066**	**10.4**	**19**	***6.17***	**22**	***7.14***	**23**	***7.47***	**466**	***151.32***	**104**	***33.77***	**0**	***0***	**634**	***205.87***
	4	C00.0-R	27-Oct-17	1062	0.9371516			2	*7.23*	40	*144.69*	360	*1302.18*					402	*1454.1*
		C00.7-L	27-Oct-17	653	0.5932888	5	*46.46*			30	*278.77*	65	*604*	50	*464.61*			150	*1393.84*
		C01.3-L	27-Oct-17	1878	1.601247			13	*15.56*	65	*77.81*	155	*185.56*	23	*27.53*			256	*306.47*
		C02.8-L	27-Oct-17	864	0.8821294					30	*141.7*	100	*472.34*	13	*61.4*			143	*675.45*
		C03.6-L	28-Oct-17	2088	2.087279	4	*3.3*	7	*5.78*	10	*8.26*	160	*132.16*	73	*60.3*			254	*209.81*
		C04.6-R	28-Oct-17	603	0.5174685							2	*23.07*	8	*92.3*			10	*115.37*
		C05.6-L	28-Oct-17	1127	1.100858	5	*14.51*	3	*8.7*			43	*124.77*	69	*200.21*			120	*348.2*
		C07.3-R	26-Oct-17	922	1.634862							300	*716.49*	6	*14.33*			306	*730.82*
		C07.4-L	27-Oct-17	961	0.9981754									23	*86.32*			23	*86.32*
	Session Summary			**1129**	**10.4**	**14**	***4.29***	**25**	***7.67***	**175**	***53.66***	**1185**	***363.32***	**265**	***81.25***	**0**	***0***	**1664**	***510.19***
	5	C05.1-R	30-Oct-17	950	0.993	1	*3.82*			10	*38.16*	35	*133.57*	22	*83.96*			68	*259.5*
		C06.0-R	30-Oct-17	1548	1.48665							30	*46.93*	14	*21.9*			44	*68.83*
	Session Summary			**1249**	**2.5**	**1**	***1.15***	**0**	***0***	**10**	***11.53***	**65**	***74.94***	**36**	***41.51***	**0**	***0***	**112**	***129.13***
Section Total All Samples				**42162**	**43.9794888**	**64**		**104**		**5574**		**2294**		**753**		**0**		**8789**	
Section Average All Samples				**1110**	**1.16**	**2**	***4.72***	**3**	***7.67***	**147**	***411.05***	**60**	***169.17***	**20**	***55.53***	**0**	***0***	**231**	***648.14***
Section Standard Error of Mean						**0.49**	***1.71***	**0.65**	***2.88***	**134.99**	***479.21***	**12.96**	***41.29***	**3.37**	***12.96***	**0**	***0***	**134.99**	***480.17***

Table E3 Continued.

Section	Session	Site	Date	Time Sampled (s)	Length Sampled (km)	Number Caught (CPUE = no. fish/km/hr)													
						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
Kootenay River	1	K00.6-R	06-Oct-17	607	0.5956581							30	298.7	22	219.05			52	517.75
		K01.8-L	07-Oct-17	1416	1.841003							74	102.19	10	13.81			84	116
		K01.8-R	06-Oct-17	1298	1.296347	2	4.28	1	2.14	2	4.28	6	12.84	4	8.56			15	32.09
	Session Summary			**1107**	**3.7**	**2**	**1.76**	**1**	**0.88**	**2**	**1.76**	**110**	**96.68**	**36**	**31.64**	**0**	**0**	**151**	**132.72**
	2	K00.3-L	14-Oct-17	273	0.4362984							1	30.22	1	30.22			2	60.45
		K00.6-R	14-Oct-17	588	0.5956581	1	10.28	1	10.28	3	30.84			27	277.52			32	328.91
		K01.8-L	14-Oct-17	1478	1.871003					4	5.21	369	480.37	9	11.72			382	497.3
		K01.8-R	14-Oct-17	1316	1.296347					3	6.33	24	50.65					27	56.98
	Session Summary			**914**	**4.2**	**1**	**0.94**	**1**	**0.94**	**10**	**9.38**	**394**	**369.49**	**37**	**34.7**	**0**	**0**	**443**	**415.44**
	3	K00.3-L	21-Oct-17	247	0.4362984									4	133.62			4	133.62
		K00.6-R	21-Oct-17	615	0.5956581							15	147.41	22	216.2			37	363.61
		K01.8-L	21-Oct-17	1510	1.871003	1	1.27					101	128.7	18	22.94			120	152.91
		K01.8-R	20-Oct-17	1248	1.296347	3	6.68	1	2.23	7	15.58	51	113.48	1	2.23			63	140.19
	Session Summary			**905**	**4.2**	**4**	**3.79**	**1**	**0.95**	**7**	**6.63**	**167**	**158.17**	**45**	**42.62**	**0**	**0**	**224**	**212.15**
	4	K00.3-L	26-Oct-17	208	0.4362984									11	436.36			11	436.36
		K00.6-R	26-Oct-17	541	0.5956581									12	134.06			12	134.06
		K01.8-L	26-Oct-17	1243	1.871003							60	92.88	4	6.19			64	99.07
		K01.8-R	26-Oct-17	1101	1.296347					2	5.04							2	5.04
	Session Summary			**773**	**4.2**	**0**	**0**	**0**	**0**	**2**	**2.22**	**60**	**66.53**	**27**	**29.94**	**0**	**0**	**89**	**98.69**
Section Total All Samples				**13689**	**16.3309276**	**7**		**3**		**21**		**731**		**145**		**0**		**907**	
Section Average All Samples				**913**	**1.09**	**0**	**1.69**	**0**	**0.72**	**1**	**5.07**	**49**	**176.5**	**10**	**35.01**	**0**	**0**	**60**	**218.99**
Section Standard Error of Mean						**0.24**	**0.81**	**0.11**	**0.69**	**0.54**	**2.19**	**24.31**	**34.66**	**2.3**	**34.32**	**0**	**0**	**24.59**	**45.05**

Table E3 Concluded.

Section	Session	Site	Date	Time Sampled (s)	Length Sampled (km)	Number Caught (CPUE = no. fish/km/hr)													
						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
Columbia River D/S	1	C25.3-R	03-Oct-17	1932	2.726756					65	44.42	15	10.25	4	2.73			84	57.4
		C27.6-R	03-Oct-17	371	0.6127803							29	459.22	1	15.84			30	475.06
		C28.2-R	03-Oct-17	769	1.131481					5	20.69	32	132.4					37	153.08
		C34.9-L	04-Oct-17	2127	2.135852	3	2.38					157	124.41	1	0.79			161	127.58
		C36.6-L	04-Oct-17	1601	2.394963	1	0.94					52	48.82					53	49.76
		C47.8-L	04-Oct-17	1236	1.439314							59	119.39	16	32.38			75	151.77
		C48.2-R	02-Oct-17	786	0.993599	1	4.61			45	207.43	7	32.27	11	50.71			64	295.02
		C49.0-L	04-Oct-17	480	0.9297056							34	274.28	3	24.2			37	298.48
		C49.0-R	02-Oct-17	480	0.7195221					5	52.12	26	271.01	1	10.42			32	333.55
		C49.8-L	04-Oct-17	1699	2.4466							77	66.69					77	66.69
		C49.8-R	03-Oct-17	1319	2.39062					10	11.42	83	94.76	8	9.13			101	115.31
		C52.2-L	04-Oct-17	737	0.8889672							27	148.36					27	148.36
		C52.2-R	03-Oct-17	2048	3.79006	1	0.46					35	16.23	4	1.86			40	18.55
		C52.8-L	05-Oct-17	586	0.8927717							3	20.64	2	13.76			5	34.41
		C53.6-L	05-Oct-17	1072	1.41784							35	82.9	2	4.74			37	87.64
	Session Summary			**1150**	**24.9**	**6**	**0.75**	**0**	**0**	**130**	**16.34**	**671**	**84.36**	**53**	**6.66**	**0**	**0**	**860**	**108.12**
	2	C25.3-R	10-Oct-17	1526	2.726756					171	147.94	60	51.91	4	3.46			235	203.32
		C27.6-R	10-Oct-17	314	0.6127803									8	149.68			8	149.68
		C28.2-R	10-Oct-17	766	1.131481							30	124.61	5	20.77			35	145.38
		C34.9-L	10-Oct-17	2047	2.135852							160	131.74	6	4.94	1	0.82	167	137.51
		C36.6-L	11-Oct-17	1657	2.394963							125	113.39	6	5.44			131	118.84
		C47.8-L	11-Oct-17	1100	1.439314					25	56.85	420	955					445	1011.85
		C48.2-R	12-Oct-17	824	1.008599					4	17.33			8	34.65			12	51.98
		C49.0-L	11-Oct-17	479	0.9297056							25	202.1	3	24.25			28	226.35
		C49.0-R	12-Oct-17	575	0.7195221							45	391.56	4	34.81			49	426.37
		C49.8-L	11-Oct-17	1683	2.4466							900	786.86	5	4.37			905	791.23
		C49.8-R	12-Oct-17	1483	2.39062							270	274.17	8	8.12			278	282.29
		C52.2-L	12-Oct-17	764	0.8889672							50	265.03					50	265.03
		C52.2-R	12-Oct-17	2176	3.79006									1	0.44			1	0.44
		C52.8-L	12-Oct-17	670	0.8927717									1	6.02			1	6.02
		C53.6-L	12-Oct-17	1083	1.51784							30	65.7					30	65.7
	Session Summary			**1143**	**25**	**0**	**0**	**0**	**0**	**200**	**25.2**	**2115**	**266.46**	**59**	**7.43**	**1**	**0.13**	**2375**	**299.21**
	3	C25.3-R	16-Oct-17	1422	2.701756					50	46.85	60	56.22					110	103.07
		C27.6-R	16-Oct-17	313	0.6127803							40	750.78	1	18.77			41	769.55
		C28.2-R	16-Oct-17	1037	1.131481	1	3.07					50	153.41	4	12.27			55	168.75
		C34.9-L	16-Oct-17	1934	2.085852	1	0.89					55	49.08	1	0.89			57	50.87
		C36.6-L	16-Oct-17	1636	2.394963	2	1.84					5	4.59	1	0.92			8	7.35
		C47.8-L	18-Oct-17	967	1.439314	1	2.59			5	12.93	100	258.65	10	25.87			116	300.04
		C48.2-R	17-Oct-17	853	1.008599	5	20.92					65	271.99	11	46.03			81	338.94
		C49.0-L	18-Oct-17	443	0.9297056							20	174.82	1	8.74			21	183.56
		C49.0-R	17-Oct-17	544	0.7195221							75	689.8					75	689.8
		C49.8-L	18-Oct-17	1638	2.4466							950	853.39					950	853.39
		C49.8-R	17-Oct-17	1382	2.39062							300	326.89	3	3.27			303	330.16
		C52.2-R	17-Oct-17	2183	3.79006	1	0.44					300	130.53	1	0.44			302	131.4
		C53.6-L	19-Oct-17	1136	1.51784							50	104.39					50	104.39
	Session Summary			**1191**	**23.2**	**11**	**1.43**	**0**	**0**	**55**	**7.17**	**2070**	**269.7**	**33**	**4.3**	**0**	**0**	**2169**	**282.59**
	4	C25.3-R	23-Oct-17	1583	2.726756					73	60.88	40	33.36					113	94.24
		C27.6-R	23-Oct-17	334	0.6127803									1	17.59			1	17.59
		C28.2-R	23-Oct-17	802	1.131481							150	595.08	4	15.87			154	610.94
		C34.9-L	23-Oct-17	2081	2.135852							65	52.65					65	52.65
		C36.6-L	24-Oct-17	1679	2.344963							290	265.16	5	4.57			295	269.74
		C47.8-L	25-Oct-17	1040	1.439314					4	9.62	90	216.45	5	12.02			99	238.09
		C48.2-R	24-Oct-17	864	1.008599					6	24.79	40	165.25	9	37.18			55	227.21
		C49.0-L	25-Oct-17	494	0.9297056							35	274.35					35	274.35
		C49.0-R	24-Oct-17	547	0.7195221							180	1646.43	1	9.15			181	1655.58
		C49.8-L	25-Oct-17	1641	2.4466							850	762.17	5	4.48			855	766.65
		C49.8-R	24-Oct-17	1545	2.39062							880	857.72	8	7.8			888	865.52
		C52.2-L	25-Oct-17	691	0.8489672							50	306.83					50	306.83
		C52.2-R	25-Oct-17	2392	3.76506							200	79.95	7	2.8			207	82.74
		C52.8-L	26-Oct-17	620	0.8927717	1	6.5					50	325.19					51	331.7
	Session Summary			**1165**	**23.4**	**1**	**0.13**	**0**	**0**	**83**	**10.96**	**2920**	**385.61**	**45**	**5.94**	**0**	**0**	**3049**	**402.64**
	5	C10.7-R	31-Oct-17	898	0.914							320	1403.56	5	21.93			325	1425.49
		C13.4-R	31-Oct-17	1530	2.52							800	746.97	1	0.93			801	747.9
		C14.8-L	30-Oct-17	1931	2.26	2	1.65					950	783.67	11	9.07			963	794.4
		C15.8-R	31-Oct-17	844	0.81669	3	15.67	3	15.67			300	1566.84	3	15.67			309	1613.84
		C16.6-R	31-Oct-17	1592	1.437	2	3.15	1	1.57			170	267.52	2	3.15			175	275.39
		C20.1-L	01-Nov-17	1160	1.26591	1	2.45	2	4.9			200	490.31	8	19.61			211	517.28
		C20.4-R	01-Nov-17	1162	1.474	2	4.2			10	21.02	480	1008.88	6	12.61			498	1046.71
		C23.4-L	01-Nov-17	749	0.93	1	5.17					170	878.59	5	25.84			176	909.6
		C25.3-L	01-Nov-17	1217	1.88					5	7.87	40	62.94	2	3.15			47	73.95
		C27.5-L	02-Nov-17	1202	1.30968							100	228.68	4	9.15			104	237.83
		C29.6-L	03-Nov-17	609	1.10546							20	106.95					20	106.95
		C32.0-R	03-Nov-17	1304	1.37							115	231.74	2	4.03			117	235.77
		C32.4-L	03-Nov-17	1562	1.997							30	34.62	2	2.31			32	36.93
		C36.9-R	03-Nov-17	1622	2.27							350	342.21					350	342.21
		C41.1-L	06-Nov-17	1752	2.41							15	12.79					15	12.79
		C41.5-R	06-Nov-17	2068	2.162							2	1.61					2	1.61
		C46.2-R	06-Nov-17	782	1.015							50	226.78					50	226.78
		C46.4-L	07-Nov-17	939	1.59							10	24.11					10	24.11
	Session Summary			**1274**	**28.7**	**11**	**1.08**	**6**	**0.59**	**15**	**1.48**	**4122**	**405.84**	**51**	**5.02**	**0**	**0**	**4205**	**414.02**
Section Total All Samples				**89114**	**125.2254887**	**29**		**6**		**483**		**11898**		**241**		**1**		**12658**	
Section Average All Samples				**1188**	**1.67**	**0**	**0.7**	**0**	**0.15**	**6**	**11.69**	**159**	**287.92**	**3**	**5.83**	**0**	**0.02**	**169**	**306.31**
Section Standard Error of Mean						**0.1**	**0.37**	**0.05**	**0.22**	**2.72**	**3.64**	**27.84**	**42.82**	**0.41**	**2.32**	**0.01**	**0.01**	**27.8**	**42.78**
All Sections Total All Samples				**144965**	**185.5359051**	**100**	**0.01**	**113**	**0.02**	**6078**	**0.81**	**14923**	**2**	**1139**	**0.15**	**1**	**0**	**22354**	**2.99**
All Sections Average All Samples						**1**	**1.71**	**1**	**1.94**	**47**	**104.13**	**117**	**255.67**	**9**	**19.51**	**0**	**0.02**	**175**	**382.98**
All Sections Standard Error of Mean						**0.17**	**0.58**	**0.22**	**0.94**	**40.14**	**142.48**	**17.51**	**28.89**	**1.24**	**6.29**	**0.01**	**0.01**	**43.21**	**144.84**

Appendix F – Life History

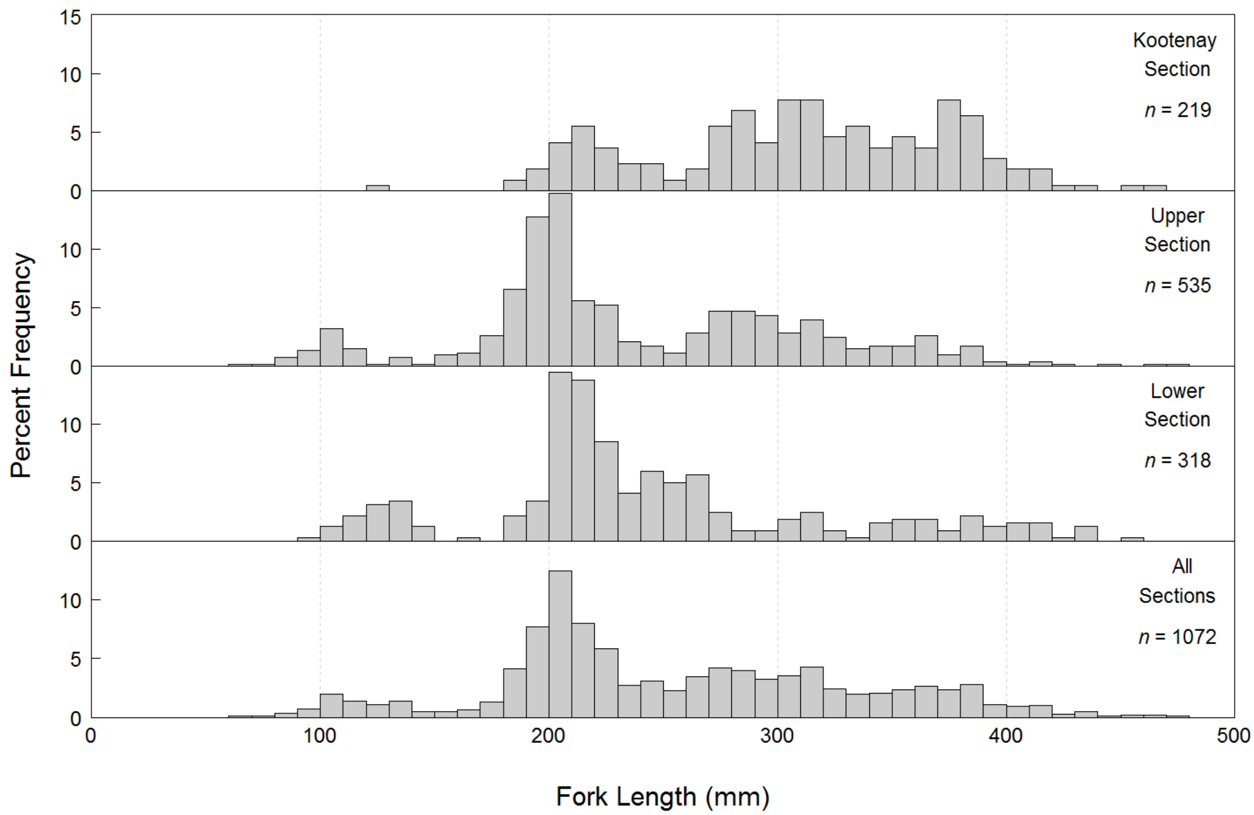


Figure F1. Length-frequency distributions by site for Mountain Whitefish captured by boat electroshocking in sampled sections of the lower Columbia River, 2 October to 7 November 2017.

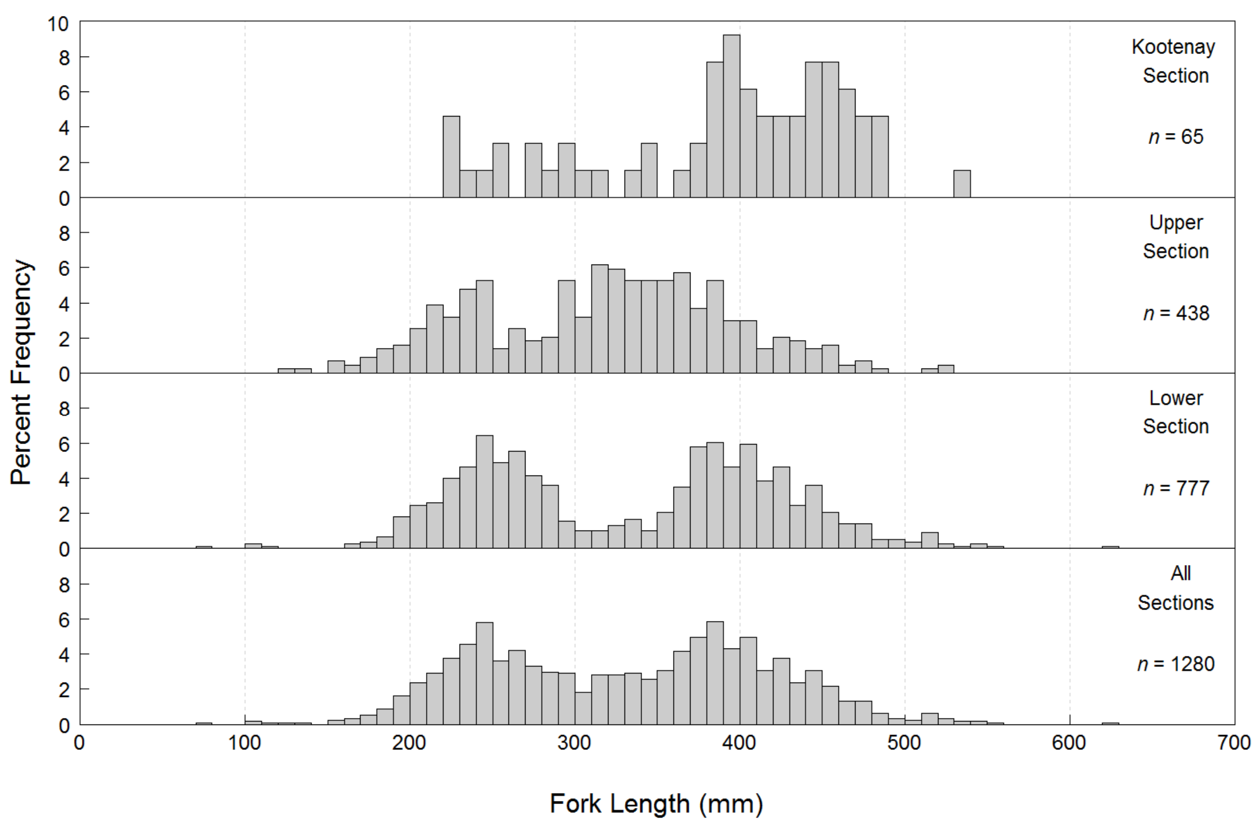


Figure F2. Length-frequency distributions by site for Rainbow Trout captured by boat electroshocking in sampled sections of the lower Columbia River, 2 October to 7 November 2017.

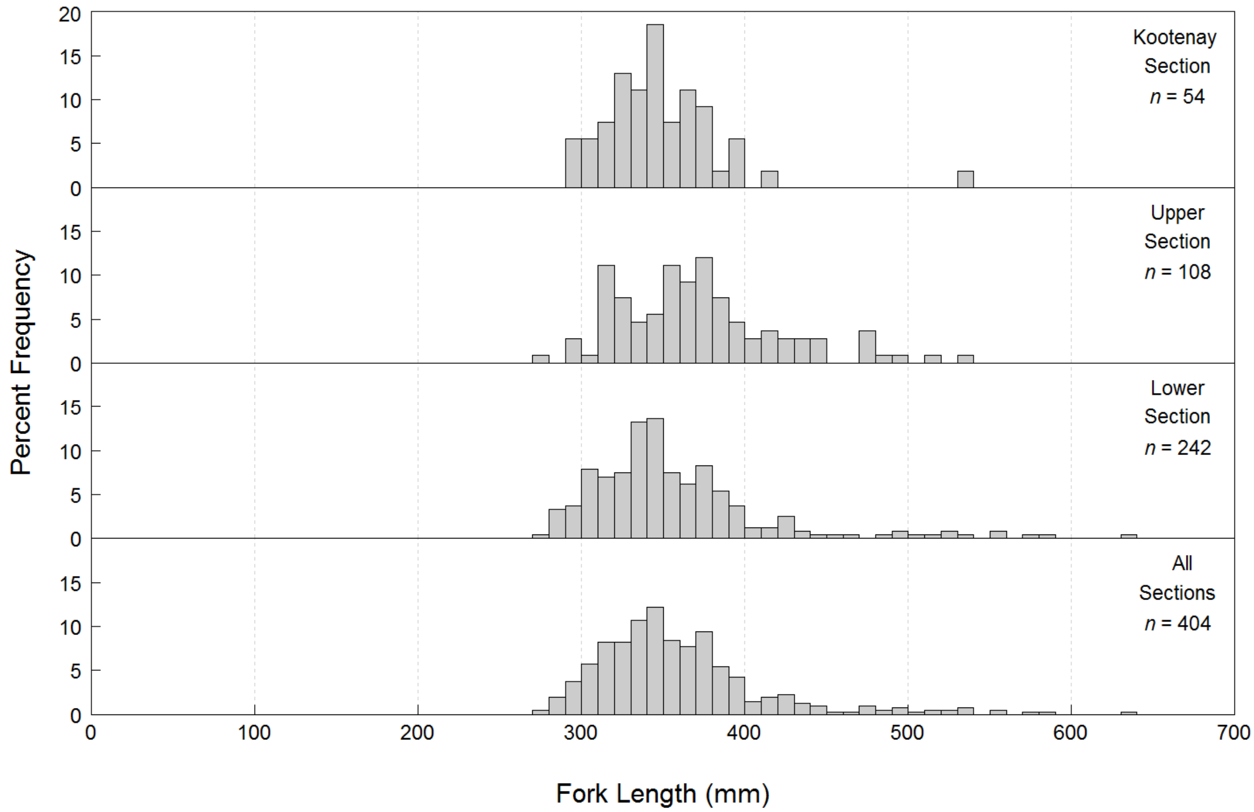
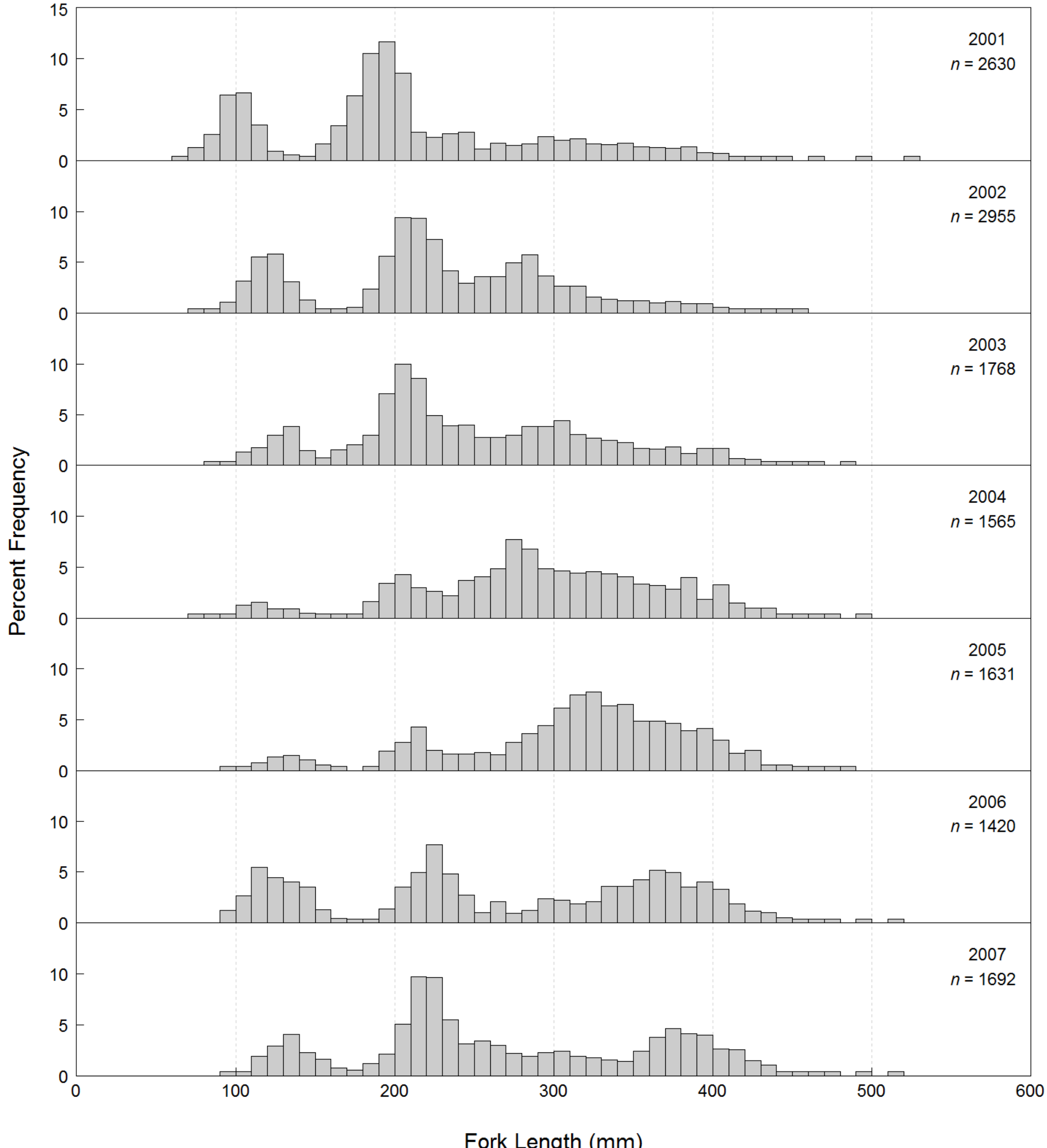


Figure F3. Length-frequency distributions by site for Walleye captured by boat electroshocking in sampled sections of the lower Columbia River, 2 October to 7 November 2017.



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 2017.

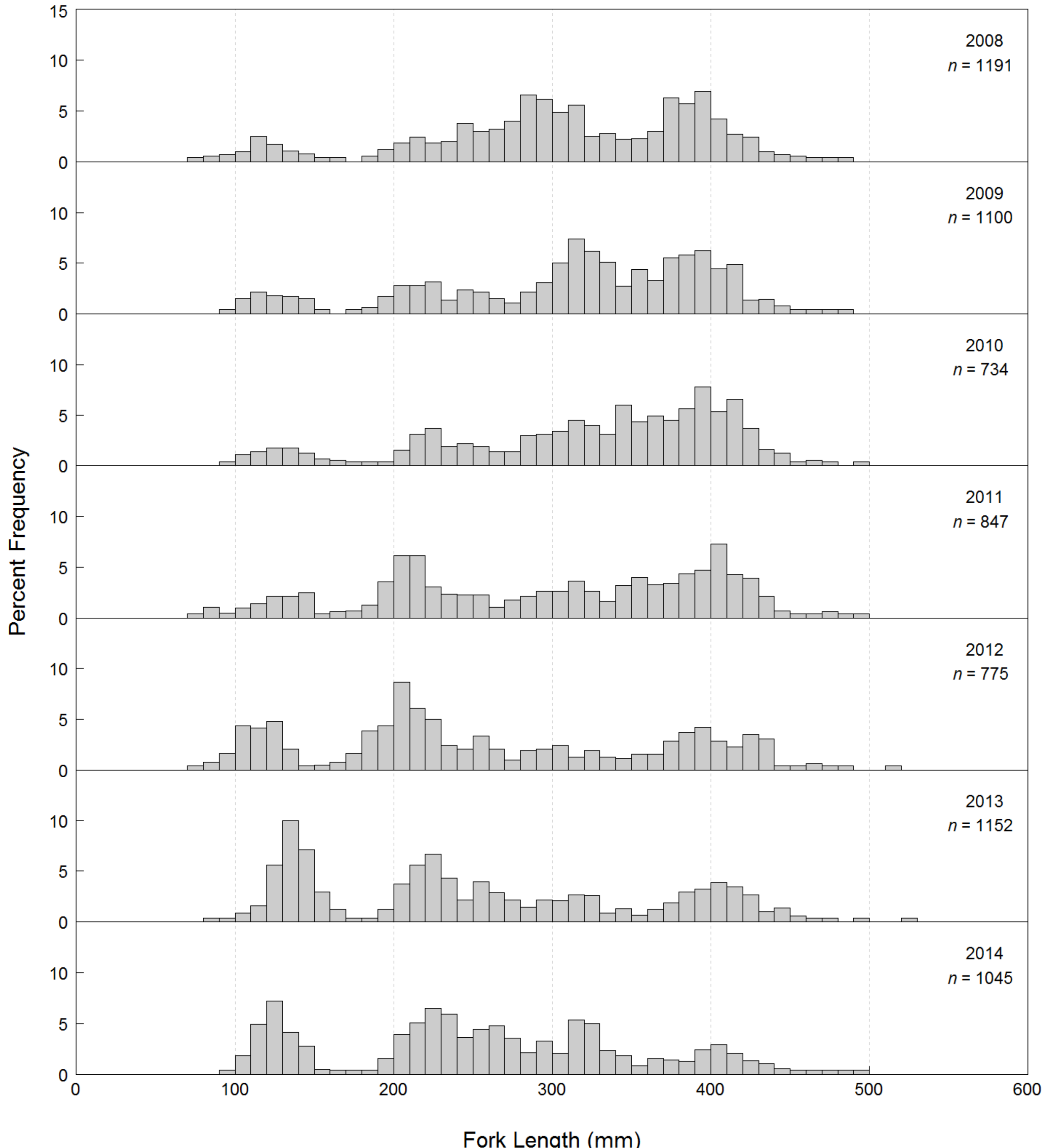


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Figure F4. Continued.

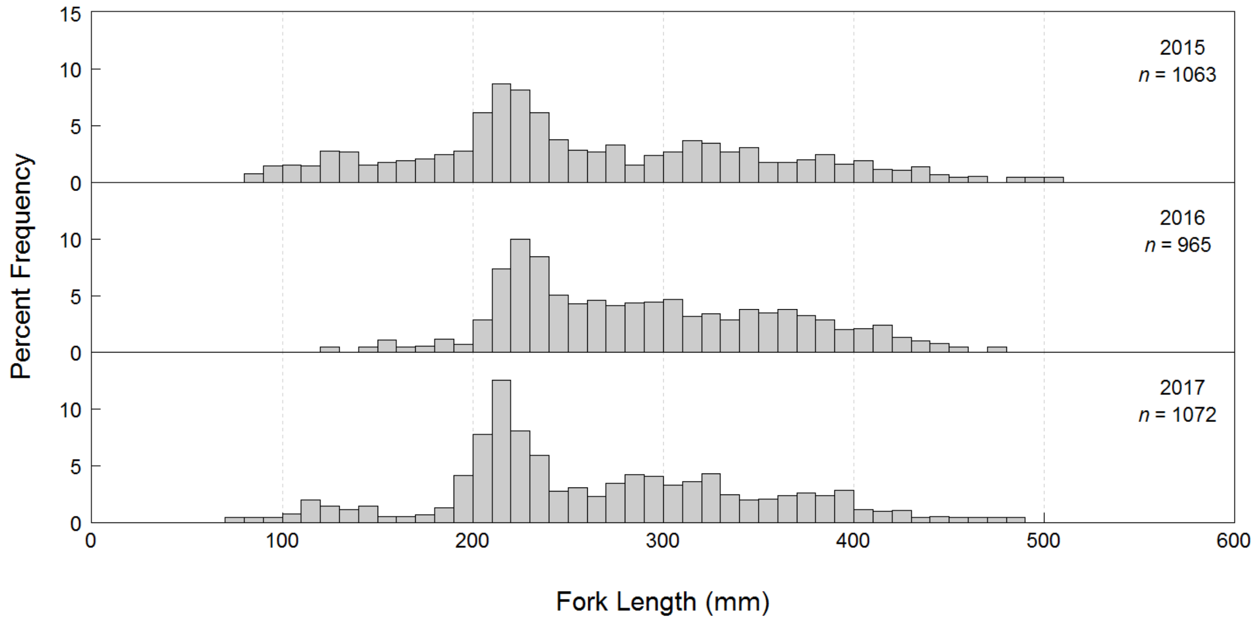

Figure F4. Concluded.

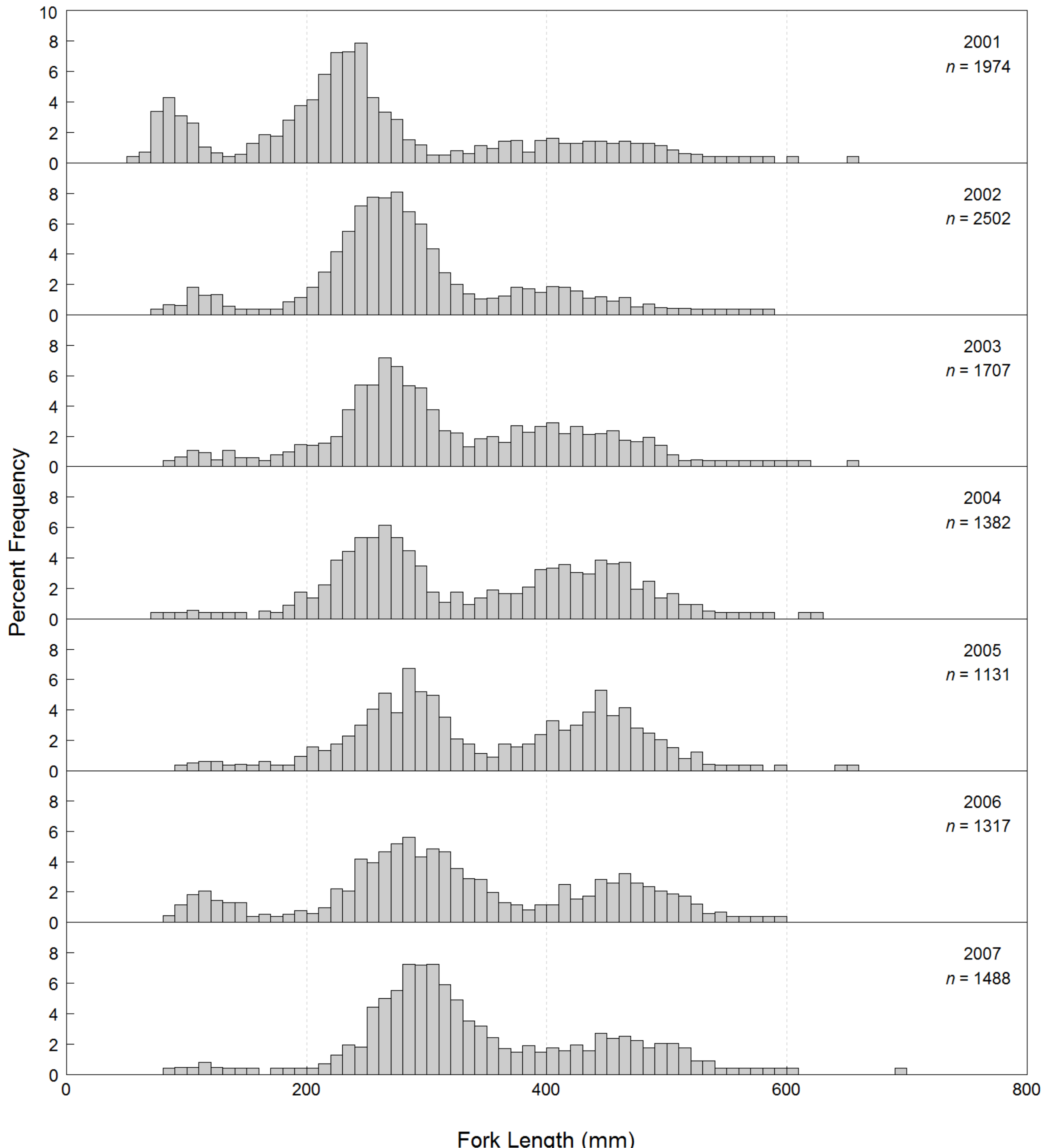

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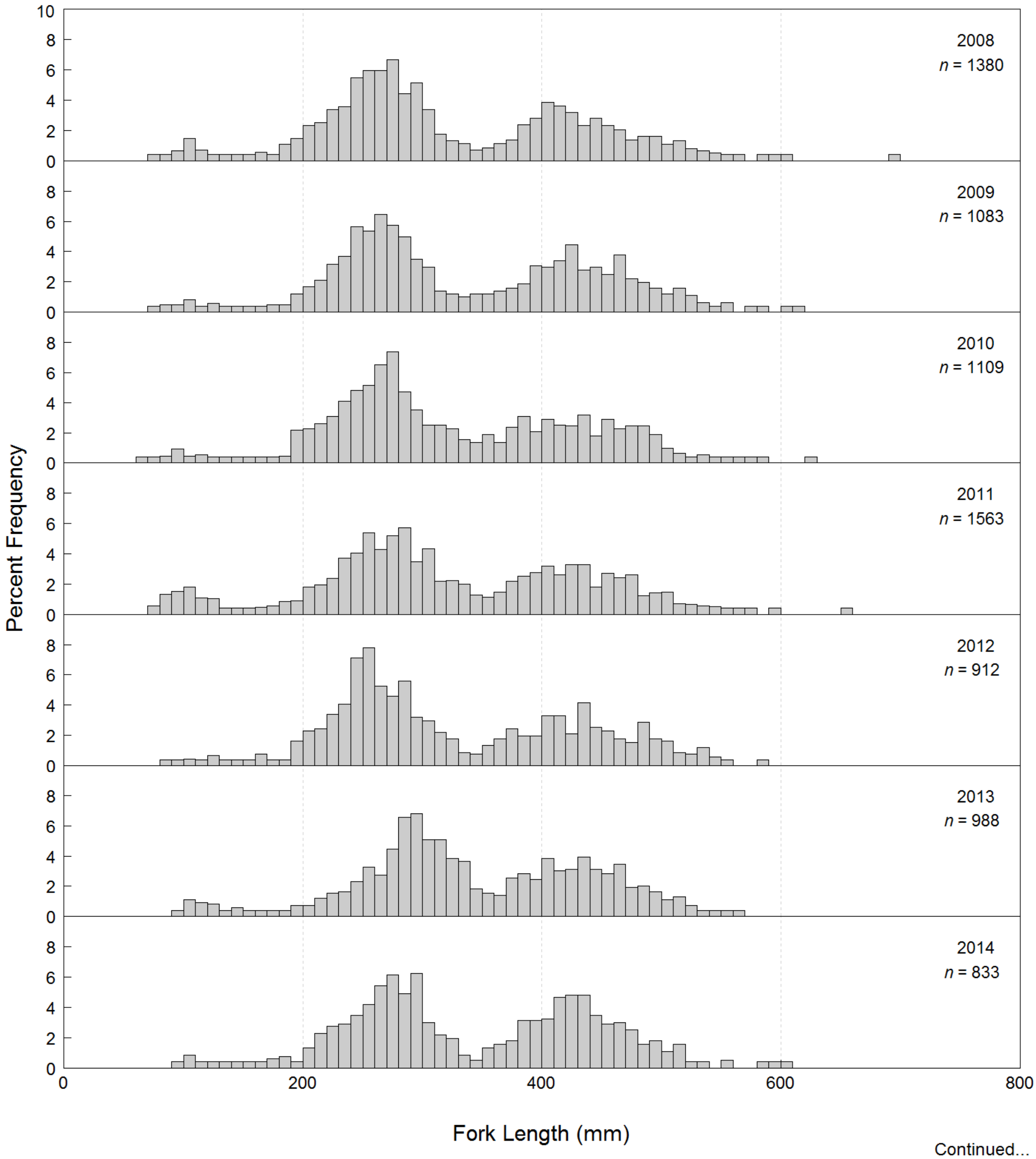
Figure F5. Length-frequency distributions by year for Rainbow Trout captured by boat electroshocking in sampled sections of the lower Columbia River, 2001 to 2017.



Continued...

Figure F5. Continued.

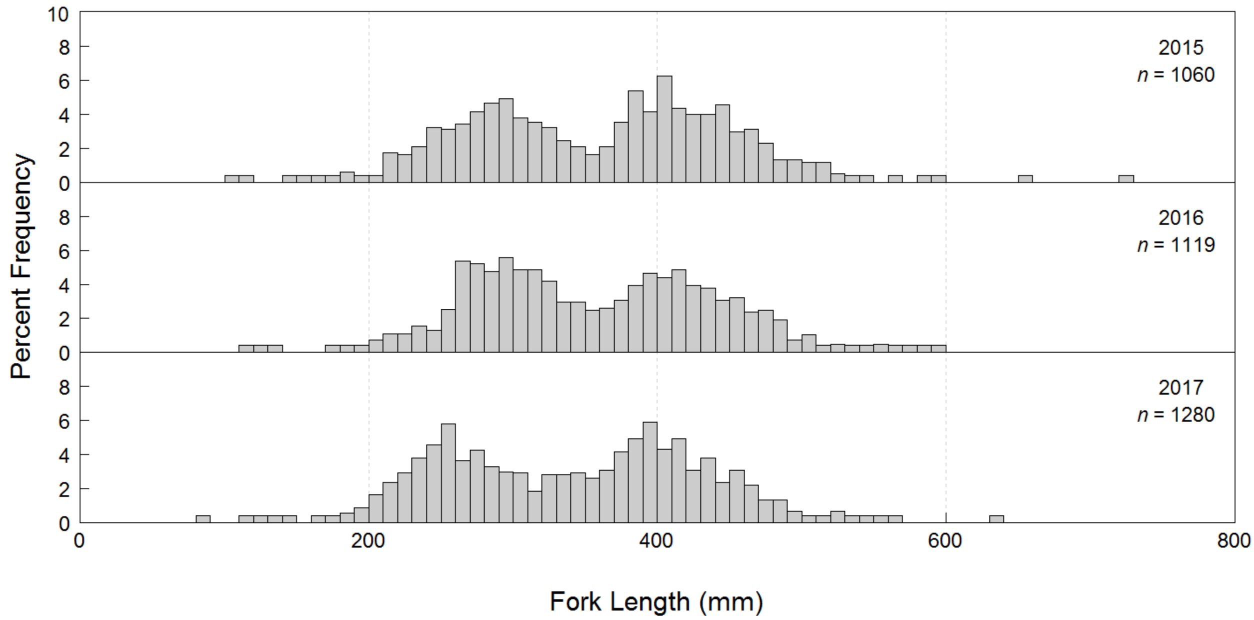


Figure F5. Concluded.

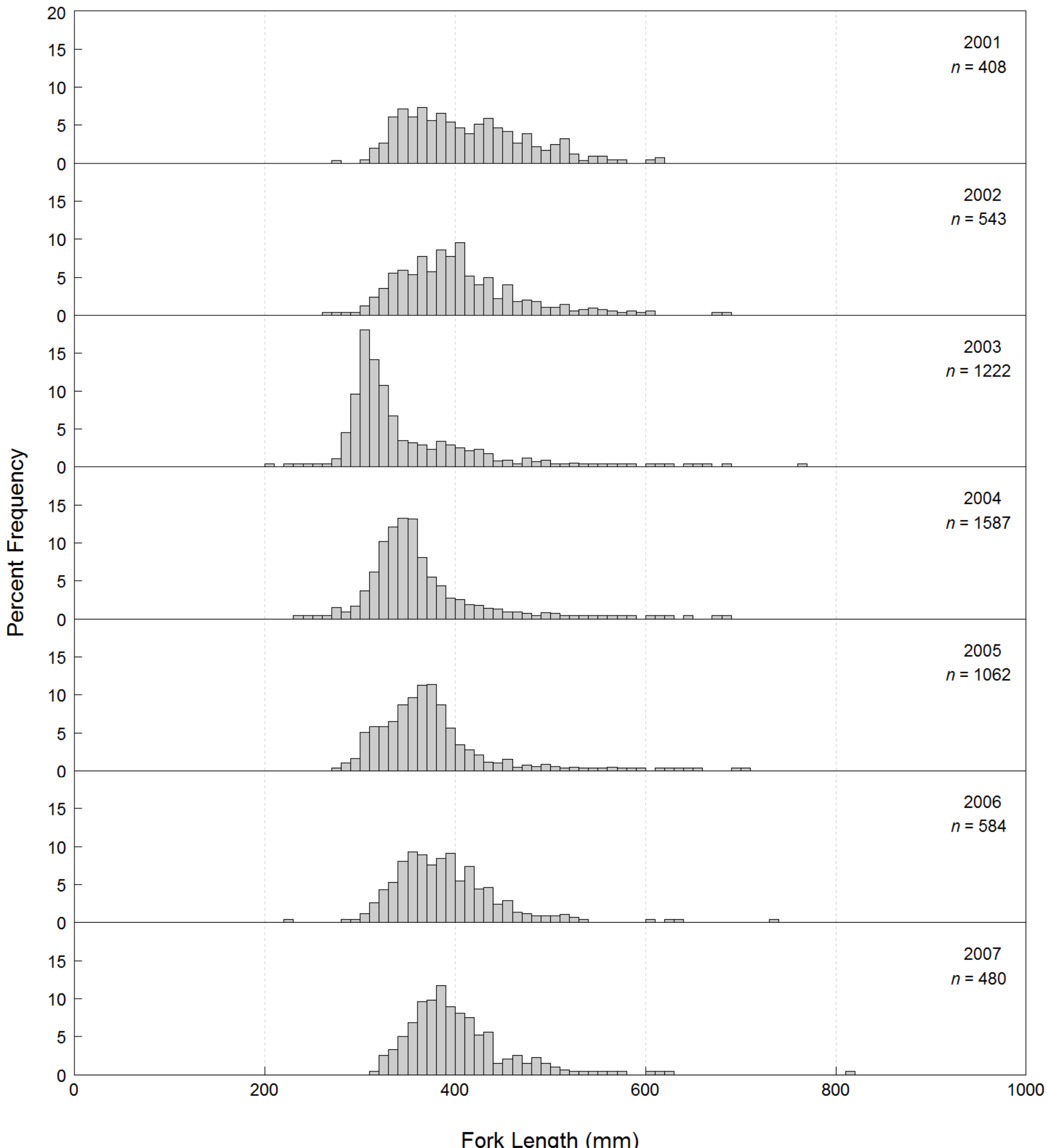


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Figure F6. Length-frequency distributions by year for Walleye captured by boat electroshocking in sampled sections of the lower Columbia River, 2001 to 2017.

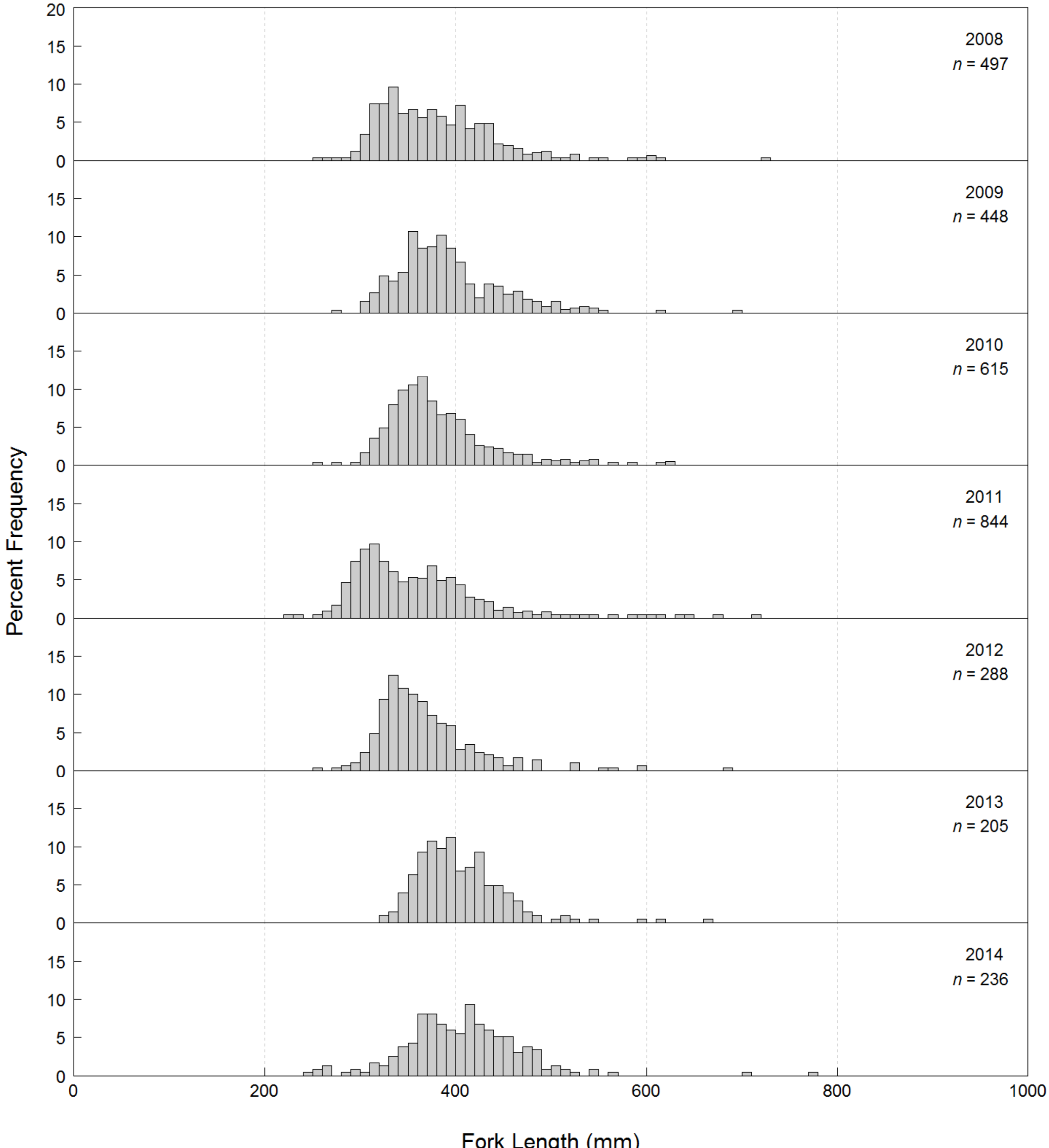

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Figure F6. Continued.

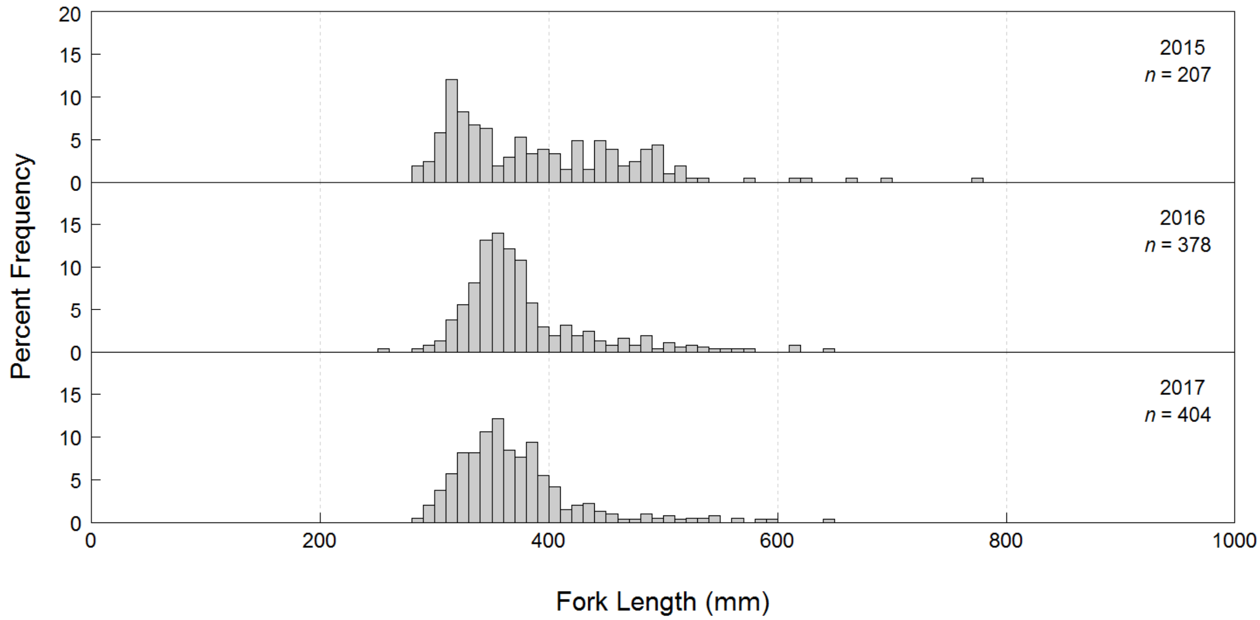

Figure F6. Concluded.

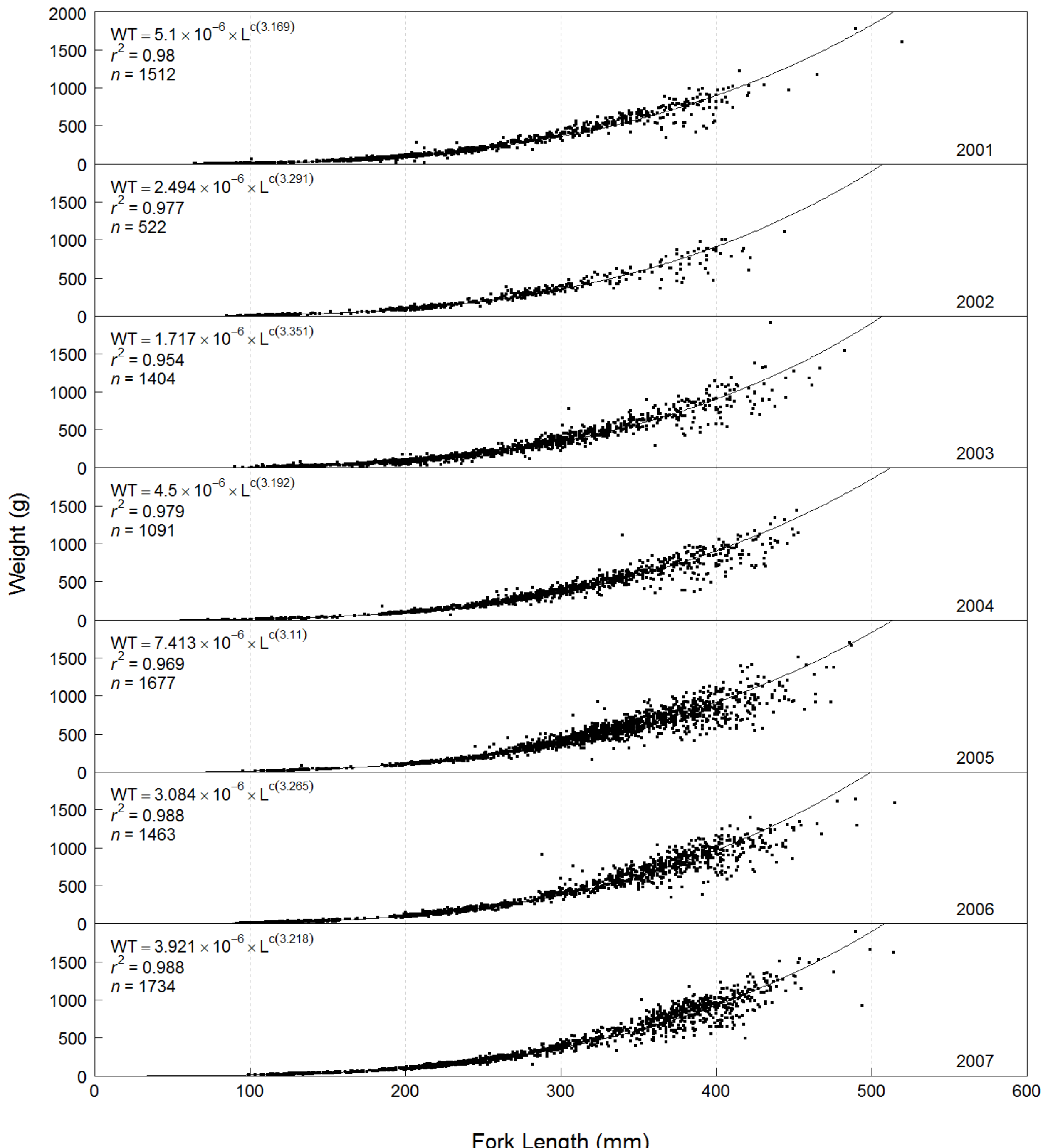

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Figure F7. Length-weight regressions for Mountain Whitefish captured by boat electroshocking in the lower Columbia River, 2001 to 2017.

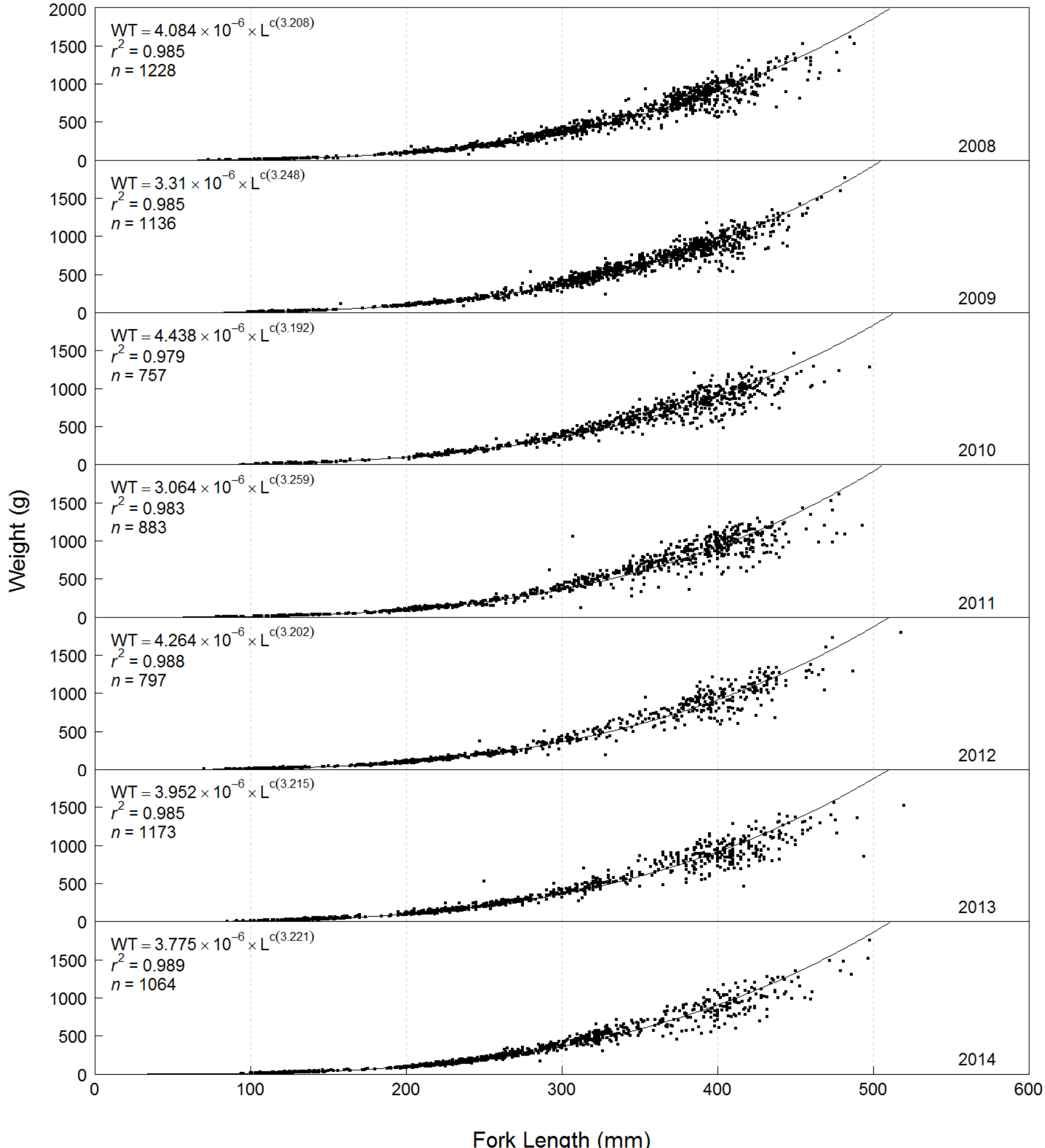

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Figure F7. Continued.

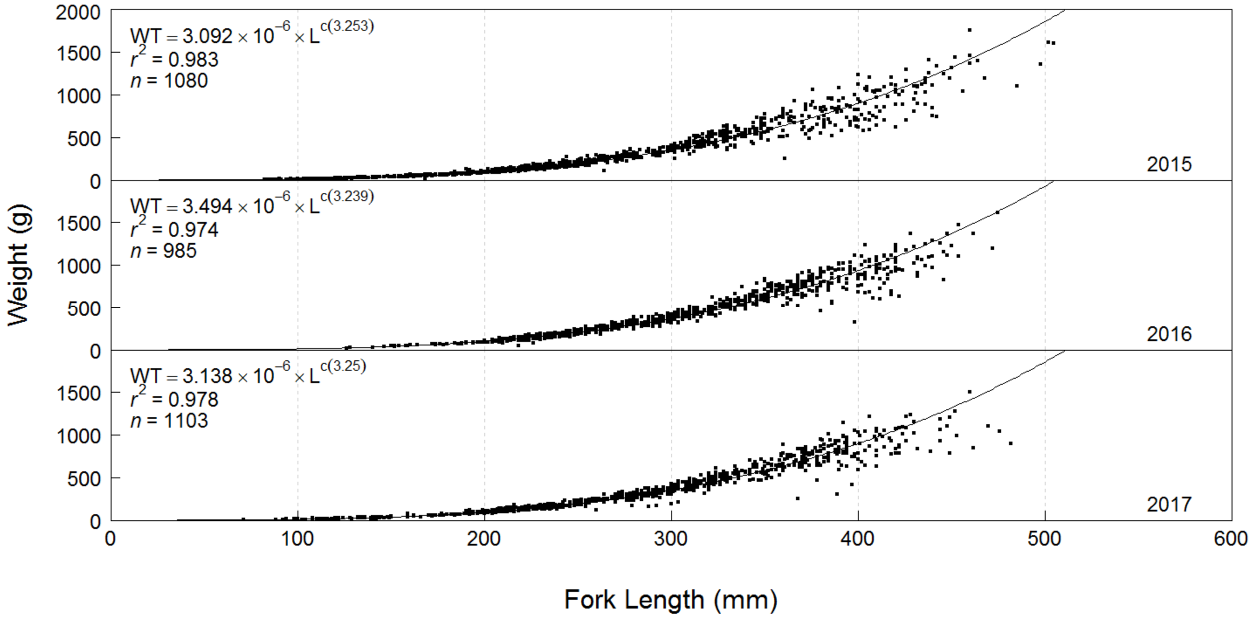

Figure F7. Concluded.

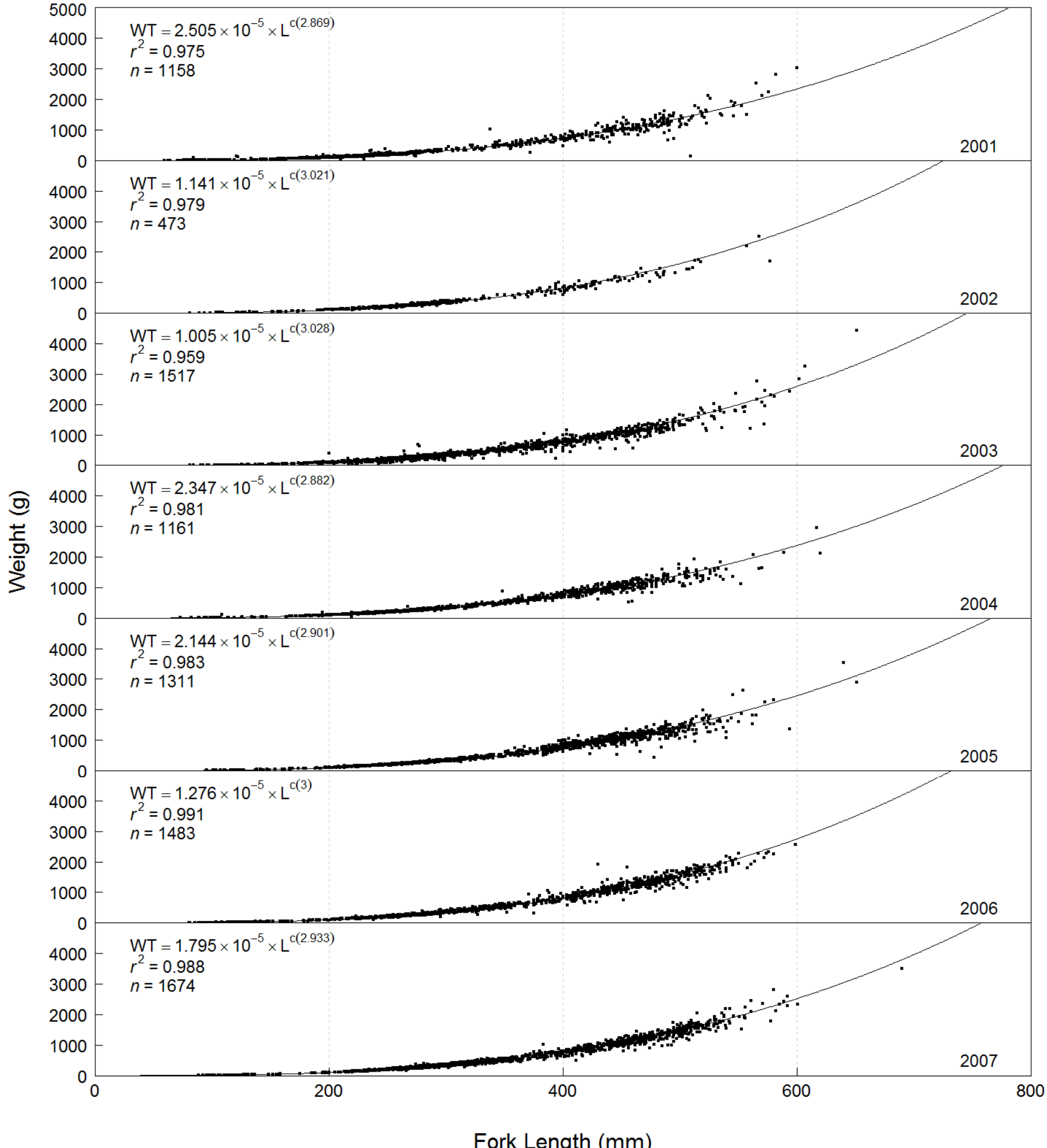

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Figure F8. Length-weight regressions for Rainbow Trout captured by boat electroshocking in the lower Columbia River, 2001 to 2017.

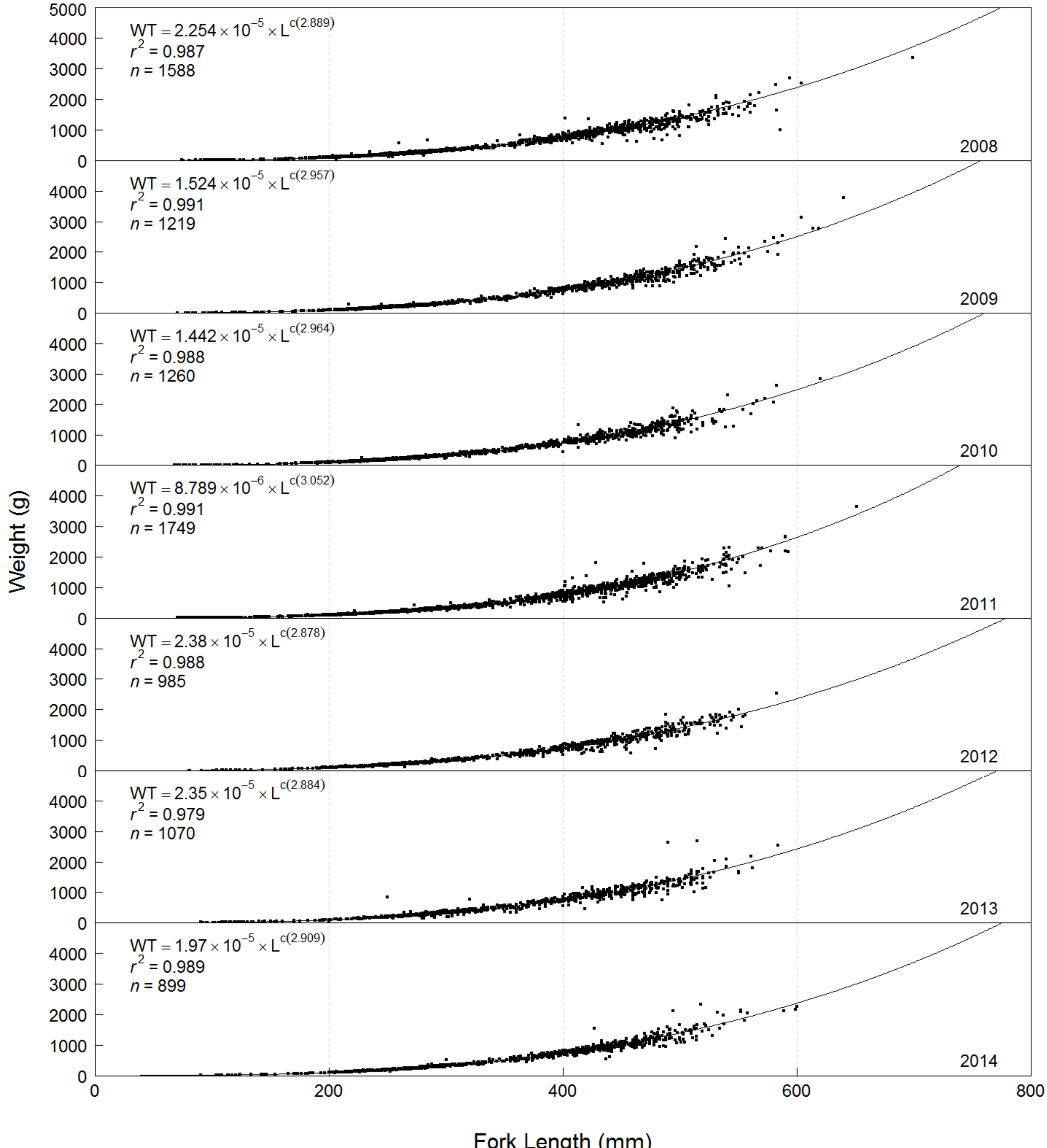

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Figure F8. Continued.

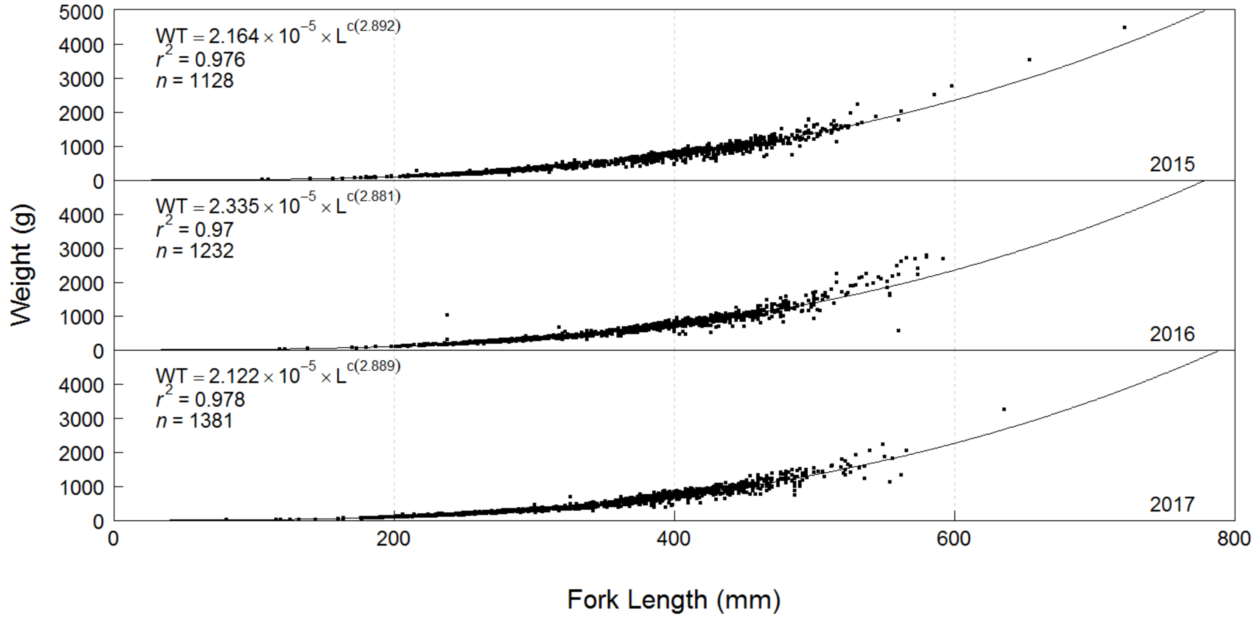

Figure F8. Concluded.

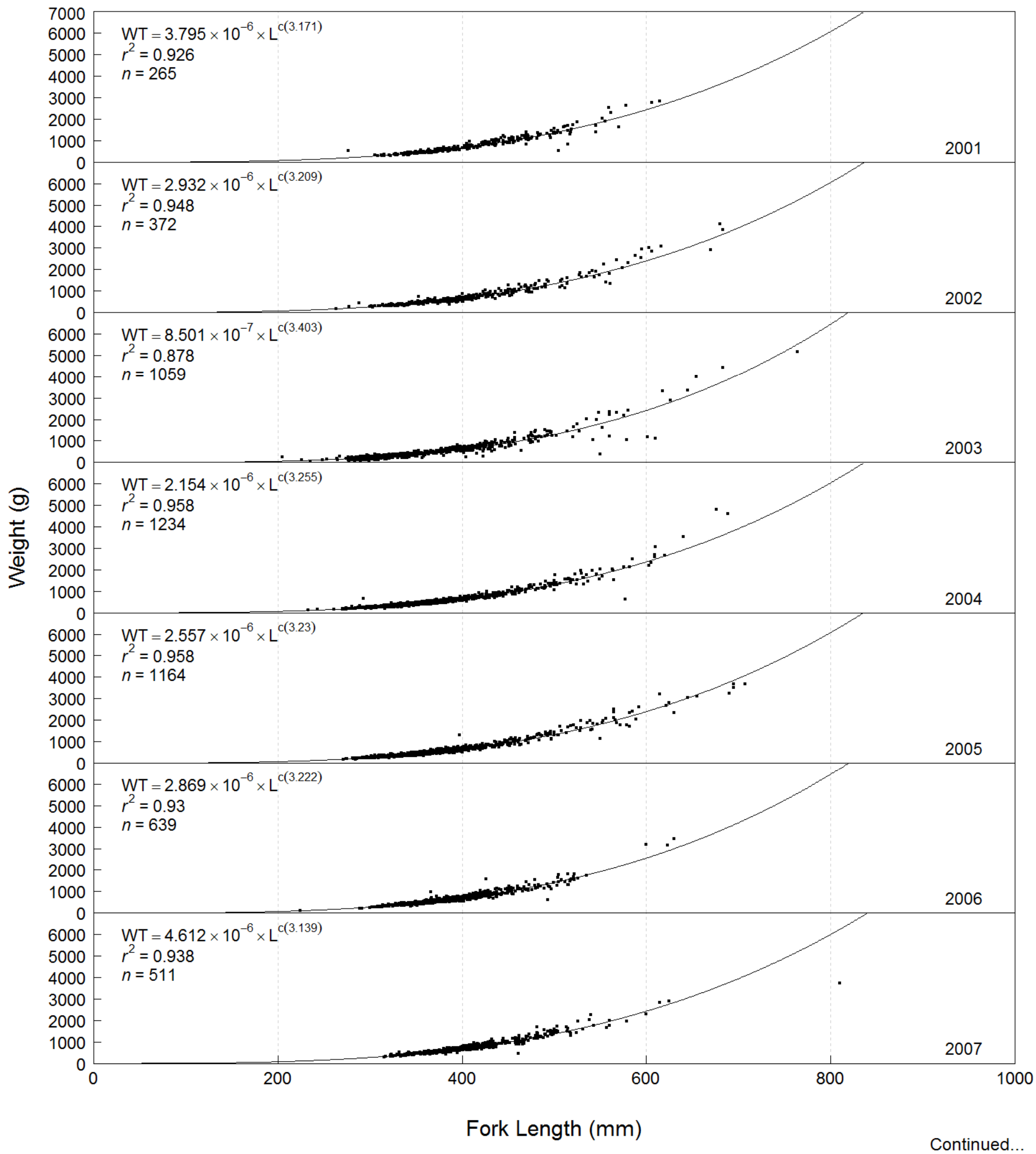

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Figure F9. Length-weight regressions for Walleye captured by boat electroshocking in the lower Columbia River, 2001 to 2017.

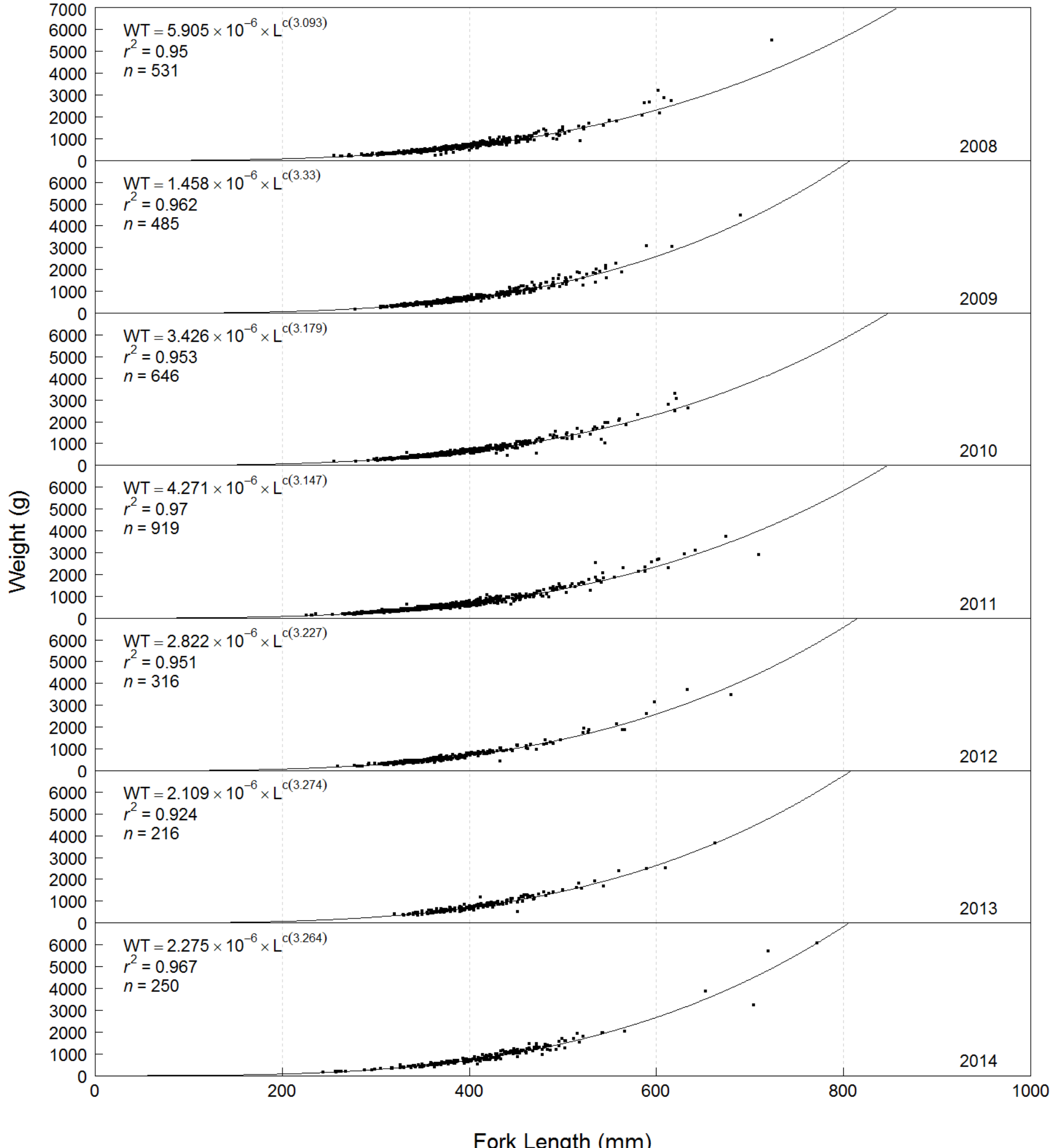

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Figure F9. Continued.

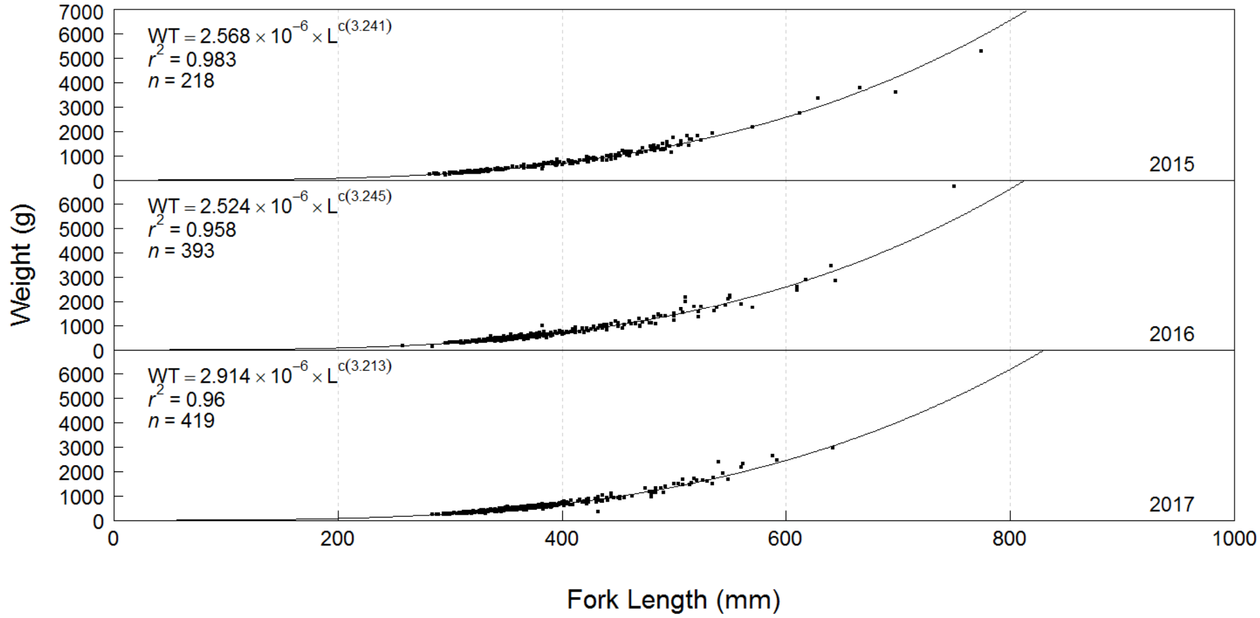

Figure F9. Concluded.

Appendix G – Additional Results

Appendix G: Additional Figures

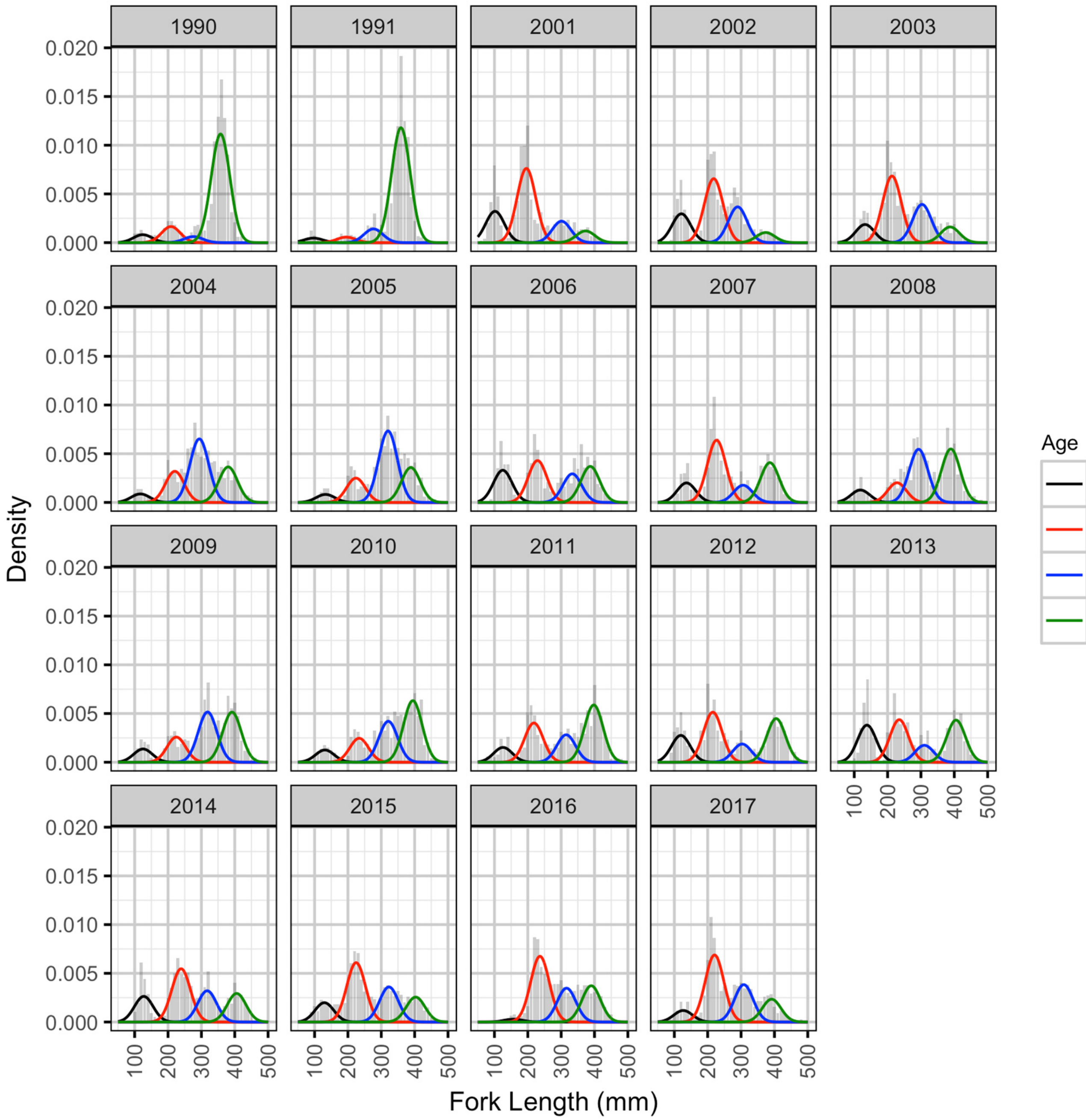

Figure G1: Predicted length-density plot for Mountain Whitefish by life stage and year.

Appendix G: Additional Figures

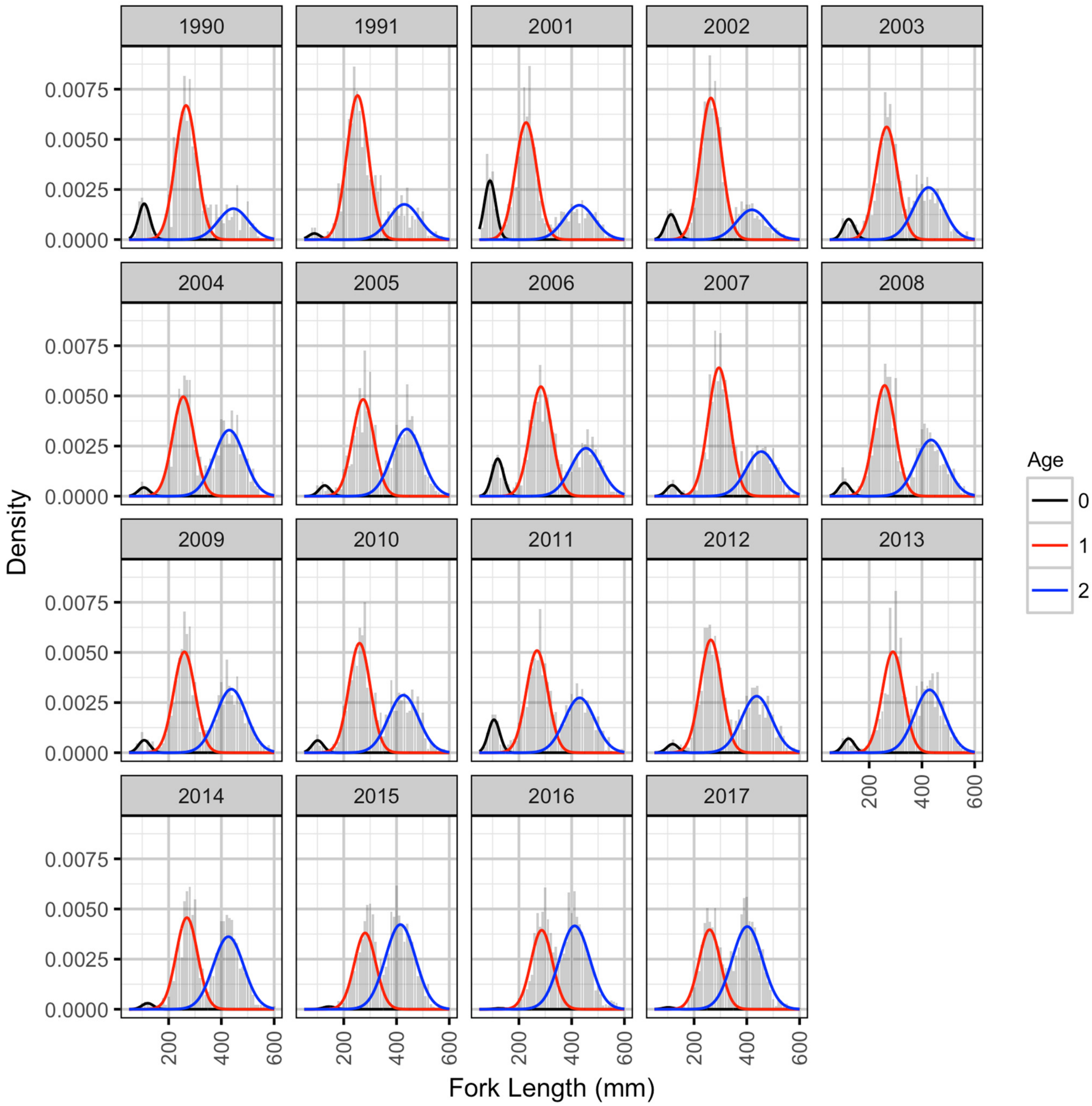

Figure G2: Predicted length-density plot for Rainbow Trout by life stage and year.

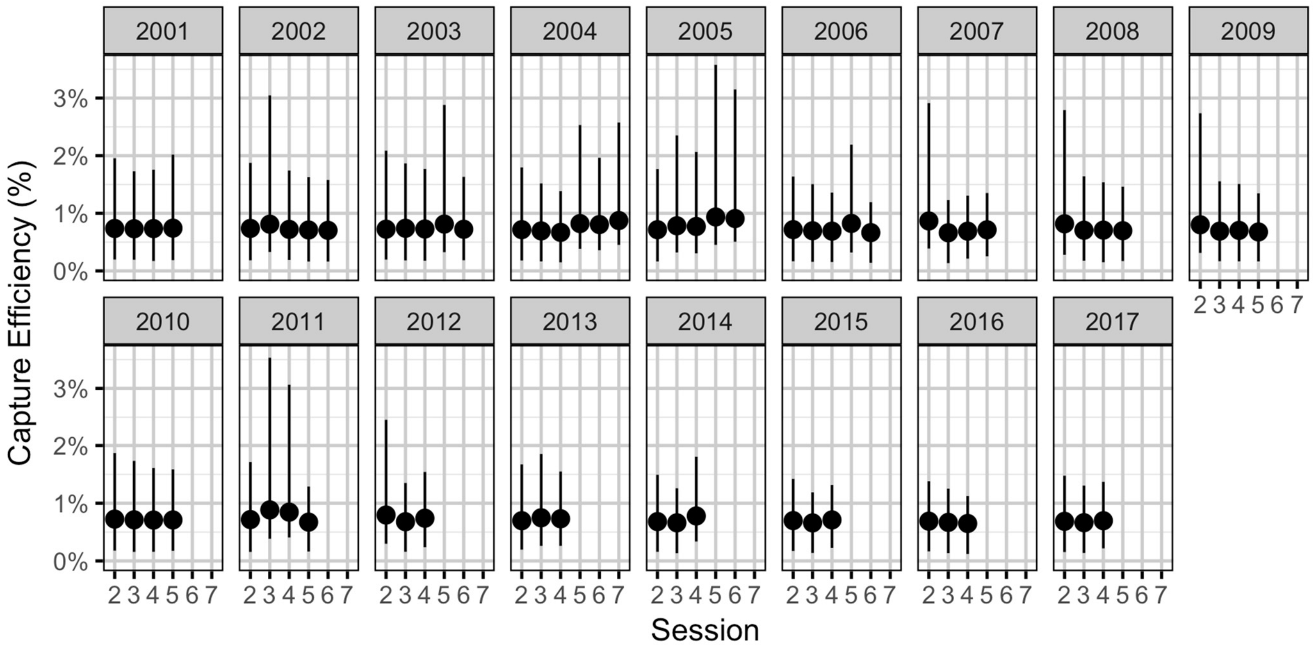

Figure G3: *Capture efficiency (mean with 95% credible intervals) of subadult Mountain Whitefish by year and sample session in the lower Columbia River, 2001–2017.*

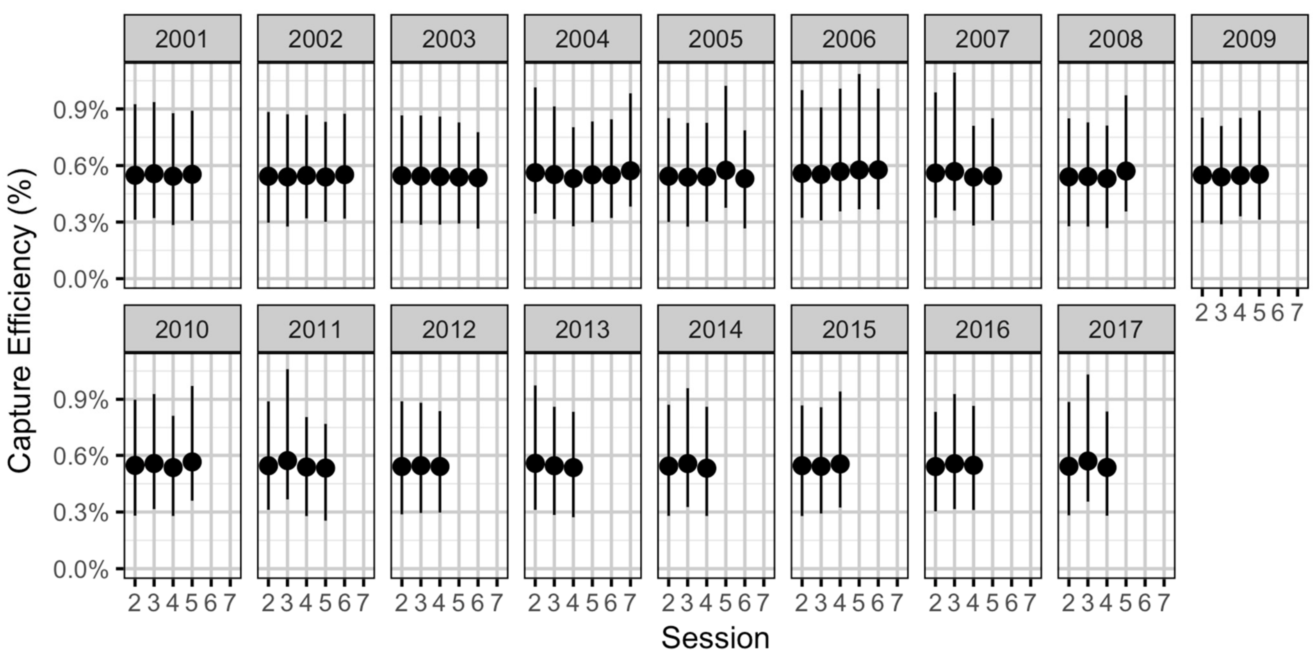

Figure G4: *Capture efficiency (mean with 95% credible intervals) of adult Mountain Whitefish by year and sample session in the lower Columbia River, 2001–2017.*

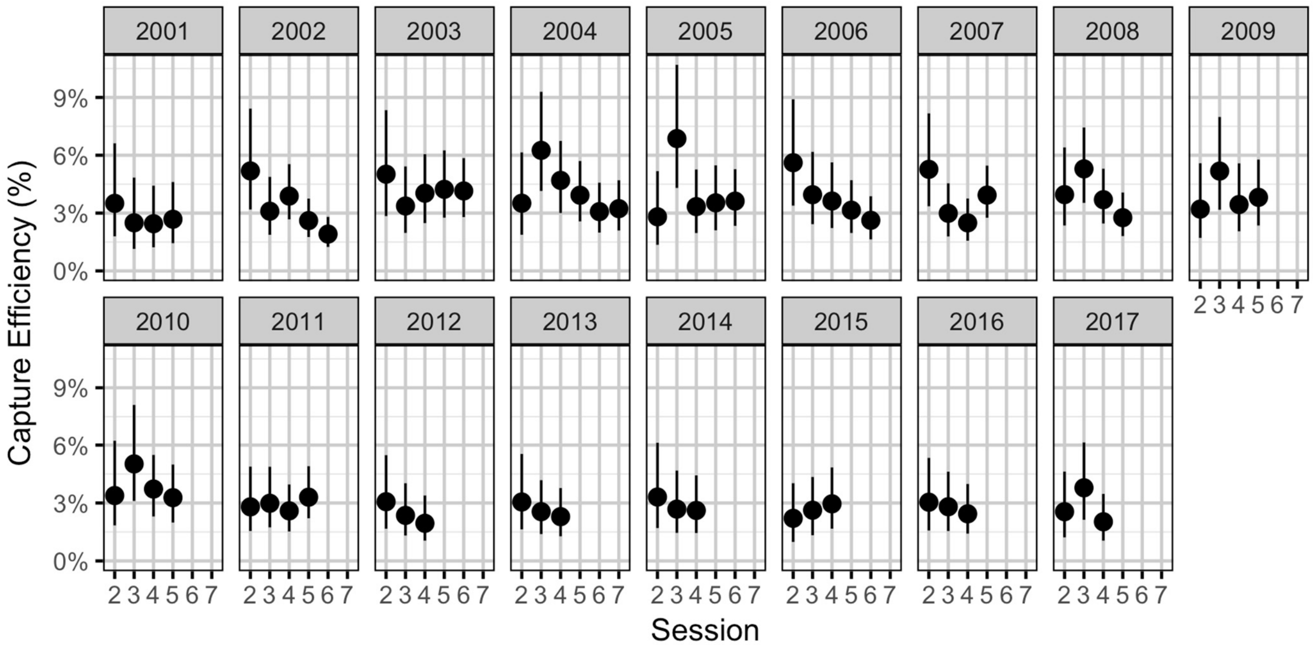

Figure G5: Capture efficiency (mean with 95% credible intervals) of subadult Rainbow Trout by year and sample session in the lower Columbia River, 2001–2017.

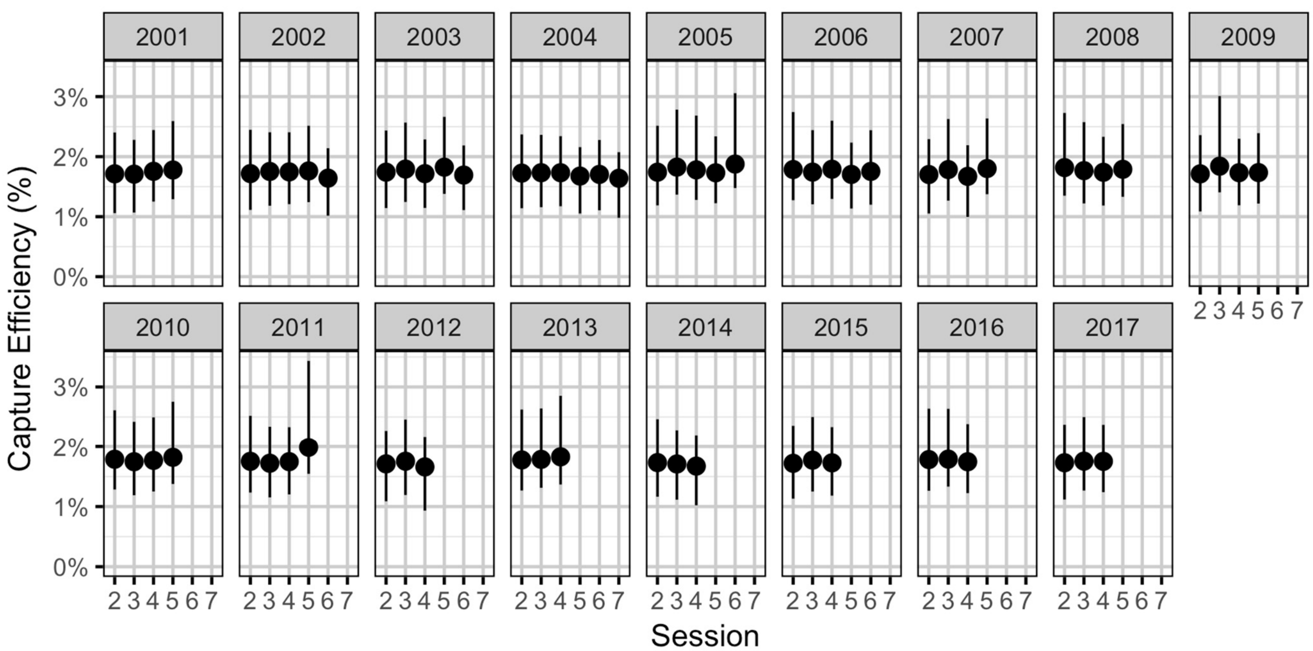

Figure G6: Capture efficiency (mean with 95% credible intervals) of adult Rainbow Trout by year and sample session in the lower Columbia River, 2001–2017.

Appendix G: Additional Figures

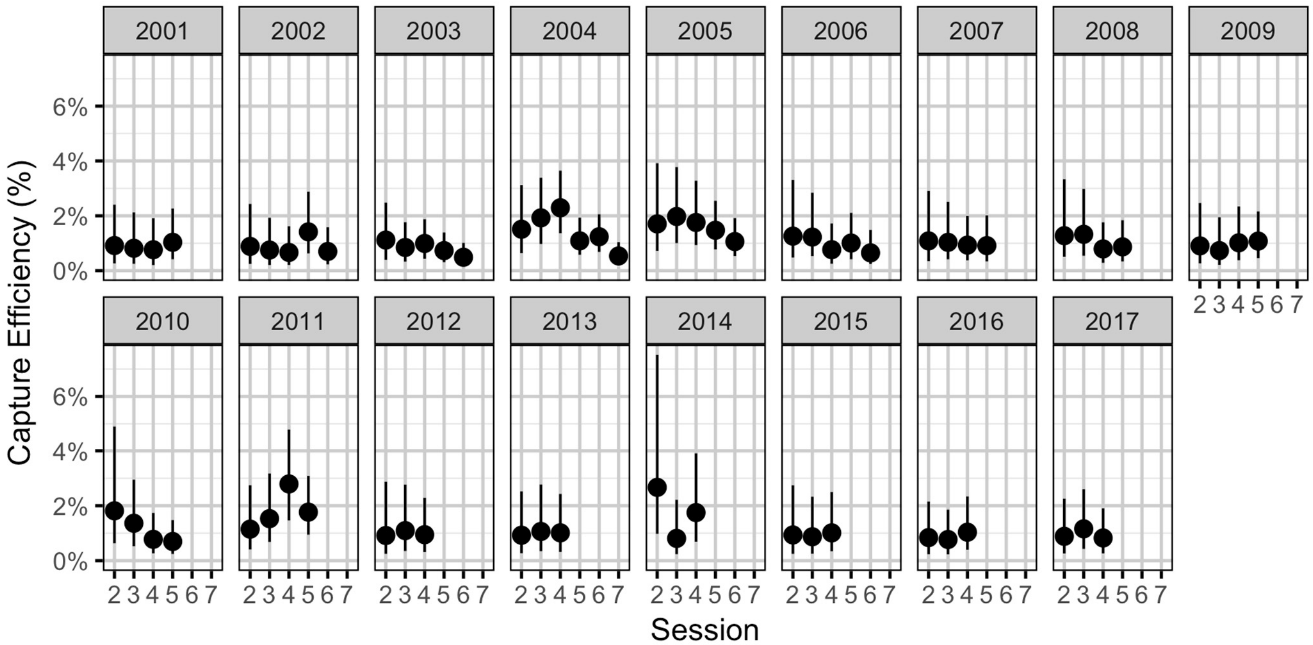

Figure G7: *Capture efficiency (mean with 95% credible intervals) of adult Walleye by year and sample session in the lower Columbia River, 2001–2017.*

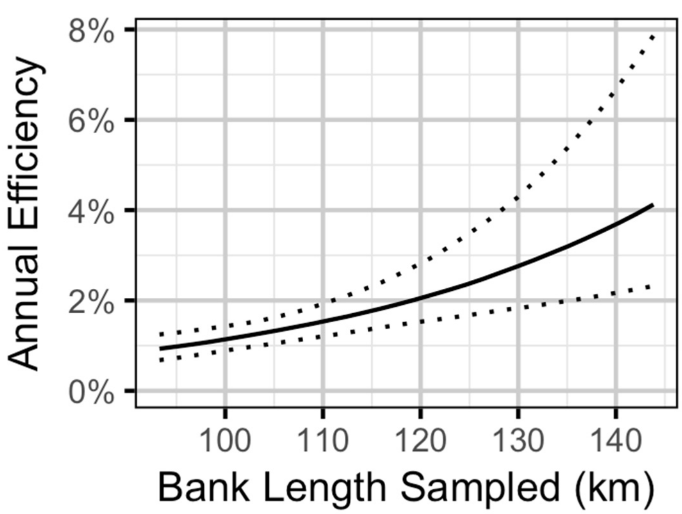

Figure G8: Predicted annual efficiency of capture for adult Mountain Whitefish by amount of bank length sampled (km).

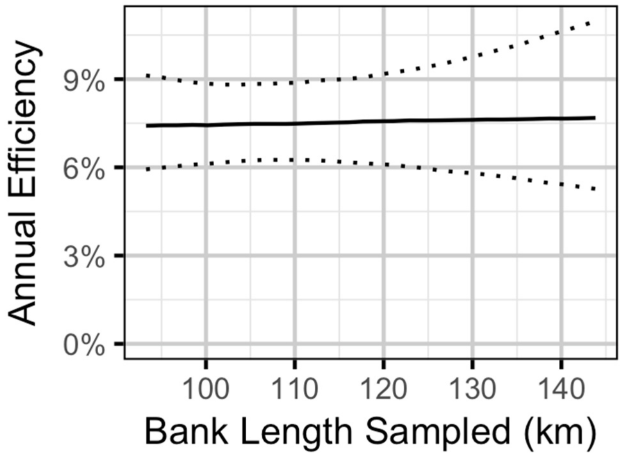

Figure G9: Predicted annual efficiency of capture for adult Rainbow Trout by amount of bank length sampled (km).

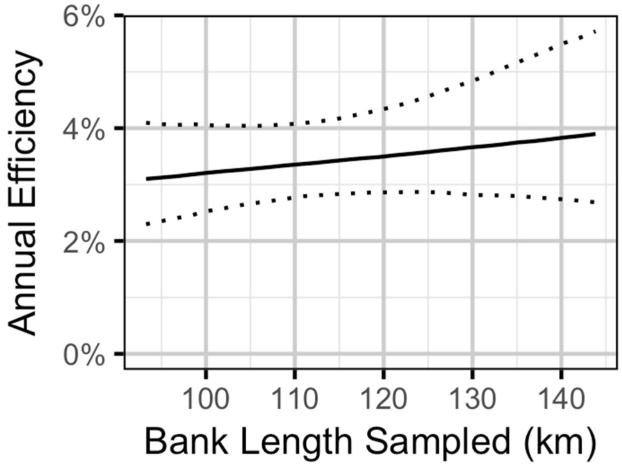

Figure G10: Predicted annual efficiency of capture for Walleye by amount of bank length sampled (km).

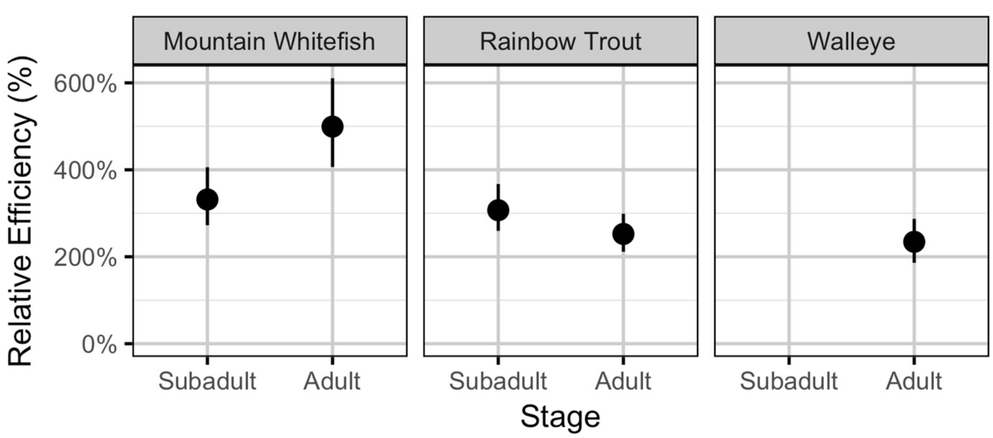

Figure G11: Predicted relative efficiency of capture vs counting for each species by life stage.

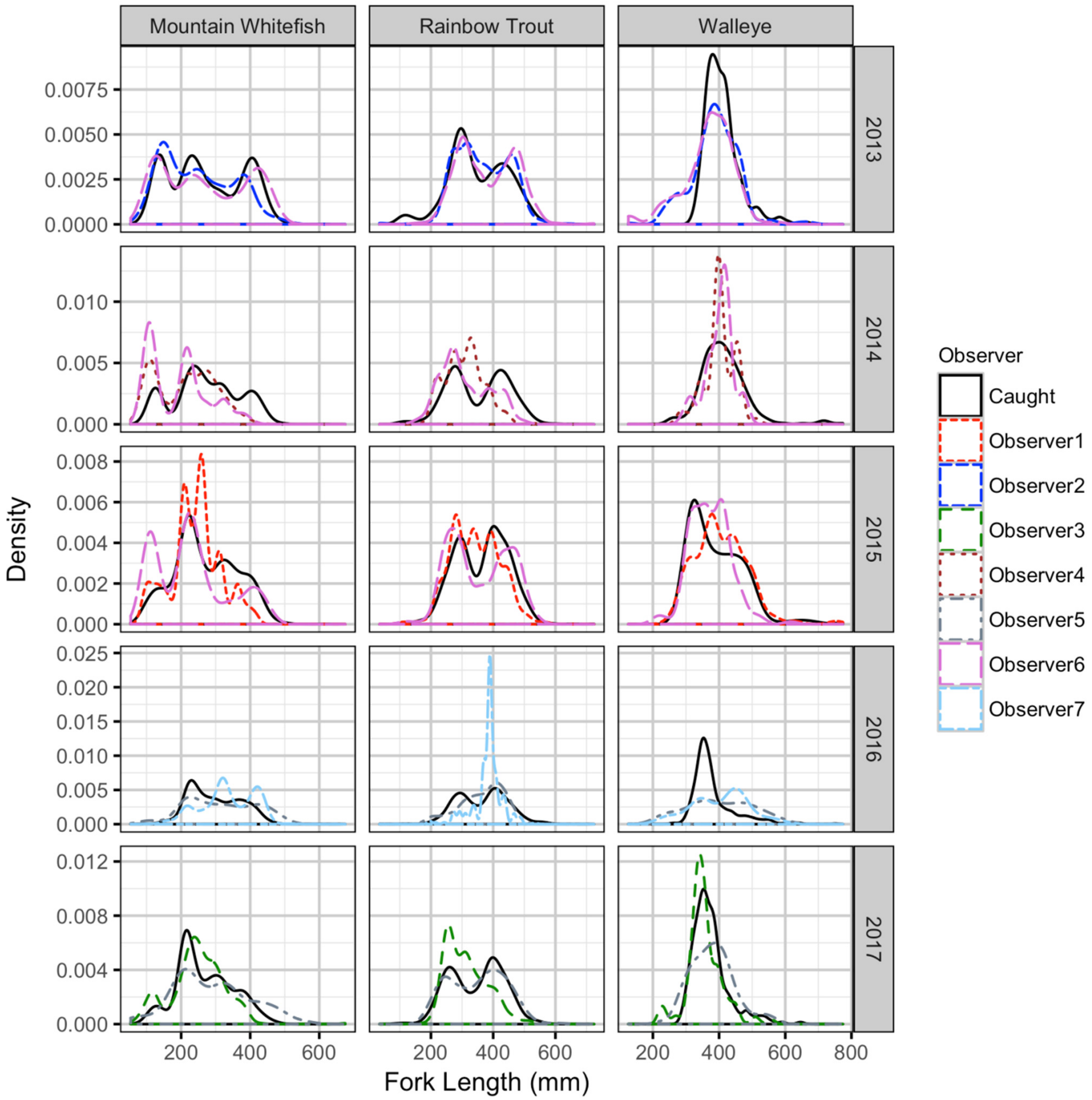

Figure G12: Corrected fork length-density plots for measured and estimated fork lengths of fish caught or observed in the lower Columbia River, 2013–2017. The black line shows fish that were caught. Observed data are shown by coloured dashed lines.

Appendix H – Spatial Distribution Maps