Columbia River Project Water Use Plan

Lower Columbia River Fish Management Plan

Lower Columbia River Fish Population Indexing Surveys

Implementation Year 9

Reference: CLBMON-45

Final Technical Report

Study Period 2015

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CLBMON-45:
Lower Columbia River
Fish Population Indexing Survey
2015 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 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 the 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 electroshocking at night within nearshore habitats. In addition to the mark-recapture indexing sites sampled since 2001, additional sample sites were randomly selected in 2011 to 2015 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 variations in species abundance, spatial distribution, growth, length-at-age, survival, and body condition. 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. A Beverton-Holt stock-recruitment model was fit to the adult abundance ("stock") and age-1 abundance ("recruits") data. Annual estimated

percentage of egg dewatering was included as a covariate in the stock-recruitment models. Multivariate analyses were used to assess relationships between environmental variables and fish population metrics, to test for potential effects of flow regime variability.

The estimated abundance of adult Rainbow Trout increased substantially from ~25,000 in 2002 to 51,000 in 2015, and high abundances in recent years coincided with a decline in body condition and survival, suggesting density dependence. Adult Mountain Whitefish abundance declined by approximately half between 2001 (>200,000) and 2012 (~100,000) and remained at similar levels between 2012 and 2015. Walleye had lower abundance in the most recent four years than all earlier years, which corresponded with the highest observed body condition and an increase in estimated survival.

The Mountain Whitefish age-1:2 recruitment index was negatively related to estimated annual egg loss but the relationship was not statistically significant (*P*=0.3). This age-1:2 index was not calculated for Rainbow Trout because age data were not available from 2011 to 2015. 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. In the Mountain Whitefish stock-recruitment model, there was a negative effect of egg losses on recruitment but the effect was not significant (*P*=0.4). Overall, the age ratio and stock-recruitment analyses both provide limited evidence that egg dewatering in the LCR may be associated with reduced recruitment of Mountain Whitefish but that large variability in the relationships resulted in non-significant effects and suggest that factors other than dewatering are also important.

For Rainbow Trout, the parameter representing egg loss in the stock-recruitment model was statistically significant, with a predicted positive effect of egg loss on the carrying capacity for age-1 recruits. This unexpected positive relationship could be because the small percentages of egg loss (<3%) were not large enough to cause a detectable decrease in recruitment but both egg loss and recruitment were correlated with some other unmeasured factor that decreases recruitment. The interpretation was that there is no evidence of negative effects of egg losses less than 3% on recruitment of Rainbow Trout in the LCR. 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.

The multivariate analyses identified very few clear relationships in the long- or short-term variation of environmental variables, such as water temperature and discharge, and the fish population metrics. The age ratio and stock recruitment analyses are considered more robust ways to assess the effects of flow variability whereas the multivariate analyses can be considered as exploratory analyses of other covariates that could be influencing fish populations in the LCR.

Keywords: Columbia River, Hugh L. Keenleyside Dam (HLK), Density Estimation, Hierarchical Bayesian Models (HBM), Generalized Random Tessellation Stratified (GRTS) Survey

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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 (December 24 to January 21; 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 (i.e., 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 the majority of 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 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 (Golder 2002, 2003, 2004, 2005, 2006, 2007) and the current program (Golder 2008, 2009a, 2010b, Ford and Thorley 2011a, Ford and Thorley 2012, Golder and Poisson 2013a; Golder and Poisson 2014, 2015) 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 from HLK (RKm 0.0) downstream to the Kootenay River confluence (RKm 10.7). The downstream section of the Columbia River extended 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 2015, 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 sites was sampled four times (i.e., 4 sessions) between October 13 and November 5, 2015 (Table 1). Field sampling also was conducted in the late summer to fall during previous study years.

In addition to the standard indexing program described above, 20 additional sites were selected for sampling in Session 5 using a Generalized Random Tessellation Stratified (GRTS) survey (see Section 2.1.5). Session 5 was completed between November 5 and 10, 2015.

Table 1: **Annual study periods for boat electroshocking surveys conducted in the lower Columbia River, 2001 to 2015.**

Year	Start Date	End Date	Number of Sessions	Duration (in days)
2001	13 August	23 September	5	42
2002	16 September	27 October	6	42
2003	15 September	26 October	6	42
2004	13 September	30 October	7	48
2005	19 September	1 November	6	44
2006	18 September	2 November	6	46
2007	27 September	6 November	5	41
2008	22 September	3 November	5	43
2009	28 September	30 October	5	33
2010	27 September	30 October	5	34
2011	26 September	30 October	5	35
2012	24 September	25 October	5	32
2013	2 October	6 November	5	36
2014	6 October	7 November	5	33
2015	13 October	10 November	5	29

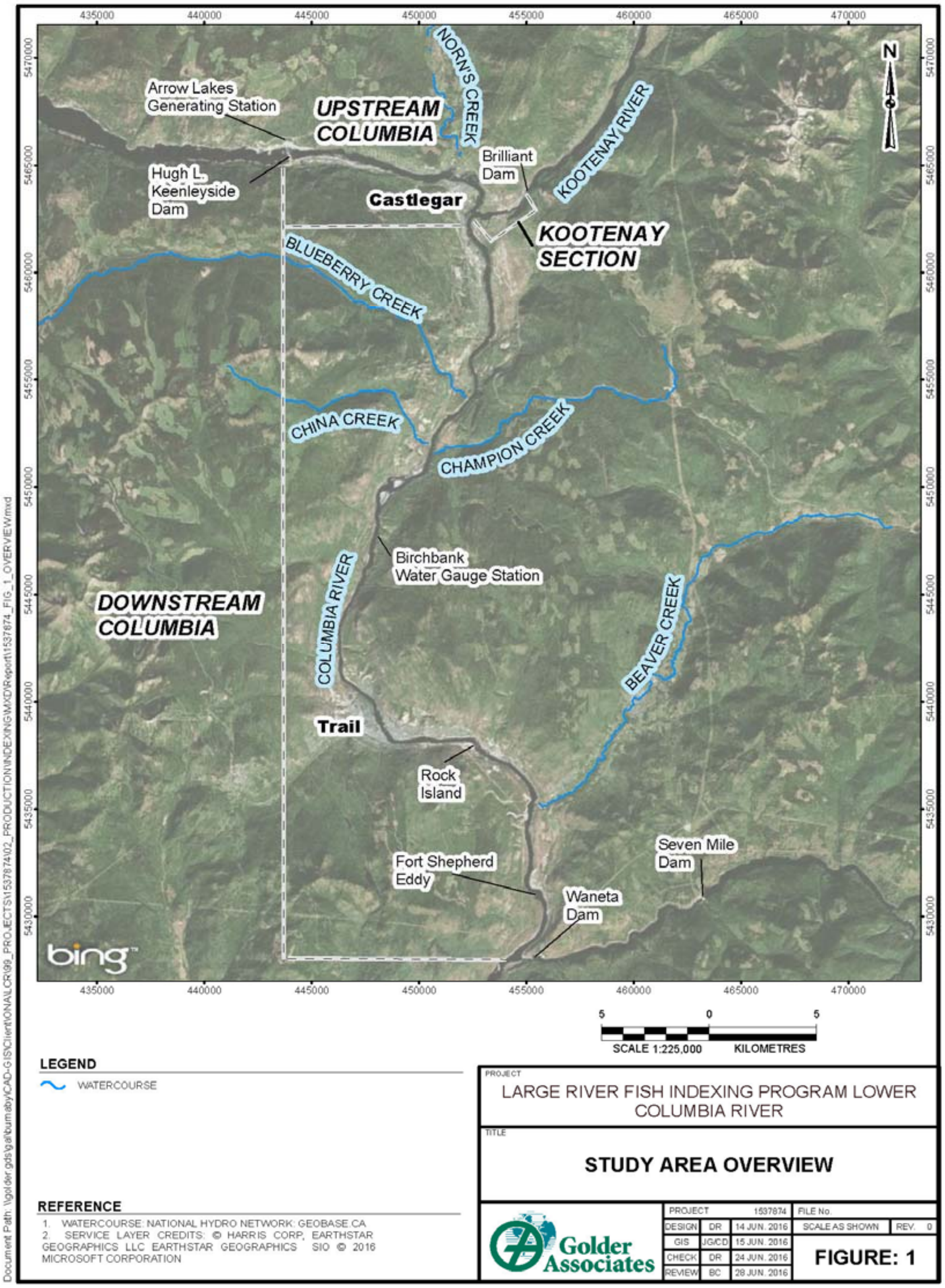

Figure 1: Overview of the lower Columbia River Fish Population Indexing study area, 2015.

2.0 METHODS

2.1 Data Collection

2.1.1 Discharge

All 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 2015 (except 2012) were obtained at hourly intervals using a Lakewood™ Universal temperature probe (accuracy ± 0.5°C) from the Water Survey of Canada gauging station at Birchbank. In 2012, 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). Hourly water temperatures for the Columbia River near Norn's Creek also were obtained from BC Hydro. 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 Airmar® 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. 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, 2015.

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 estimated duty cycle (as a percent) used during sampling
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 electroshocker 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 and Poisson 2015). 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 electroshocking was conducted at all sites along the channel margin, typically within a range of 0.5 to 4.0 m water depth. Boat electroshocking employed a Smith-Root Inc. high-output Generator Powered Pulsator (GPP 5.0) electroshocker operated out of a 160 HP outboard jet-drive riverboat manned by a three-person crew. The electroshocking 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 electroshocking unit. The two netters attempted to capture all 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 electroshocker operation) and length of shoreline sampled (in kilometres) were recorded for each sample site. Electroshocking 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 to maintain dissolved oxygen at levels above those in the river water.

Voltage was adjusted as needed to achieve an amperage output of ~1.75 A, at a frequency of 30 Hz direct current as these settings produce less electroshocking-induced injuries on Rainbow Trout (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.

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 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 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 habitat, 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 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 also were 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 2011) in the statistical program R 3.3.0 (R Team 2015), 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 concerns. 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 electroshocking survey was conducted at each GRTS survey site between November 5 and 10, 2015 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

A site form was completed at the end of each sampled site. Site habitat conditions and the number of fish observed were recorded before the start of fish processing for life history data (Table 3). The length (to the nearest 1 mm) and weight (to the nearest 1 g) of each fish was measured using a Bioscribe Electronic Fish Measuring Board (EFMB) and an A&D brand digital scale (Model GF-12K), respectively. The scale was connected directly to the EFMB using a RS232 connection and the EFMB was connected directly to the LCR Fish Indexing Database through a USB connection to a laptop computer. The length and weight of each fish was automatically recorded in the database when the measurements were taken with the EFMB's integrated stylus. Using the EFMB and associated weigh scale ensured that fish data were accurately recorded and eliminated transcription errors associated with manually typing or writing these values. All sampled fish were automatically assigned a unique identifying number by the database that provided a method of cataloguing associated ageing structures.

All index species between 120 and 160 mm FL that were in good condition following processing were marked with a Passive Integrated Transponder (PIT) tag (tag model Biomark 8.9 mm BIO9.B.01). These 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 larger fish or a No. 11 surgical scalpel for smaller fish. All fish >160 mm FL that were in good condition following processing were marked with a Plastic Infusion Process (PIP) PIT tag (12 mm x 2.25 mm, model T-IP8010 polymer shell food safe Datamars FDX-B, Hallprint Pty Ltd., Australia). These 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. All tags, tag injectors, and scalpel blades 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.

In 2015, all fish were handled using Smith-Root Fish Handling Gloves. The gloves temporarily immobilized fish by passing an electric current through the fish while it was being held. Fish recover swimming ability immediately upon release. The use of these gloves is expected to reduce handling time and reduce injuries associated with thrashing movements or being dropped, thereby reducing air exposure, injury, and physiological stress.

Table 3: List and description of variables recorded for each fish captured in the lower Columbia River, 2015.

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

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).

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 Ageing

During 2001 to 2010 study years, a subsample of Mountain Whitefish and Rainbow Trout were aged using scale samples following methods given in Ford and Thorley (2011a). In 2011 to 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 using new methods to attempt to address some of the limitations of previous scale analyses, which is described further in Section 2.2.11. All scales collected from Mountain Whitefish and Rainbow Trout from 2001 to 2015 were archived so that they could be aged in the future if needed.

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 electroshocking 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).

During the visual surveys, observers were instructed to estimate the fork lengths of observed fishes. However, given that observers often could not see the actual fork in the tail of the fish (due to the fish position or distance) observers may have been more likely to base their estimates on total length (i.e., the measurement from the tip of the caudal fin rather than the fork). Length estimates were also likely affected by magnification by water, as objects appear larger in water than in air because of the greater refractive index of water (Luria et al. 1967). Potential biases in length estimation were assessed and corrected in the length bias model (Section 2.2.4), and discussed further in Section 4.2.5.

2.1.9 Historical Data

In addition to the data collected between 2001 and 2015, 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 electroshocking and mark-recapture programs, with protocols very similar to the 2001-2015 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 2015 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 2007 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 2015 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 and is considered the companion text for the following analyses. 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); and
- permits the separation of ecological and observational processes (Kéry and Schaub 2011: 44).

HBMs were fitted to the fish indexing data using R version 3.3.0 (R Team 2015) and JAGS 4.0.1 (Plummer 2015) which interfaced with each other via jaggernaut 2.3.3 (Thorley 2013). The technical aspects of the analyses, including the general approach, model definitions in the JAGS (Just Another Gibbs Sampler; Plummer 2003) dialect of the BUGS language, and the resultant parameter estimates are provided in Appendix C. In addition, the statistical methodology, sample code, parameter estimates, and figures of results are available online (Thorley and Hogan 2016). The posterior distributions of the fixed (Kéry and Schaub 2011: 75) parameters are summarized in terms of a point estimate (mean), lower and upper 95% credible limits (2.5th and 97.5th percentiles), the standard deviation (SD), percent relative error (half the 95% credible interval as a percent of the point estimate) and significance (Kéry and Schaub 2011: 37, 42).

In general variable selection was achieved by dropping insignificant (Kéry and Schaub 2011: 37, 42) fixed (Kéry and Schaub 2011: 77–82) variables and uninformative random variables. A fixed variable was considered to be insignificant if its two-sided Bayesian p-value ≥ 0.05 (Bochkina and Richardson 2007; Lin et al. 2009) while a random variable was considered to be uninformative if its percent relative error was ≥ 80%.

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

2.2.3 Length-At-Age

The 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). 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.

Key assumptions of the length-at-age model include:

- three distinguishable age-classes for each species: age-0, age-1 and age-2 and older;
- the proportion of fish in each age-class varied randomly with year;
- the expected growth between age-classes varied with age-class;
- the expected growth between age-classes was allowed to vary randomly with age-class within year;
- the expected length increased with age-class;
- the expected length varied with year within age-class;
- body length varied as a second-order polynomial of date;
- the relationship between length and date varied randomly with age-class;
- the residual variation in length was normally distributed; and
- the standard deviation of this normal distribution varied randomly with age-class.

For age-0 fish, length-at-age was plotted by showing the estimated fork lengths by year. For age-1 fish, the change in fork length from the previous year (fall age-0 fish) to the current year was plotted. This was done to remove carry-over effects from the first year of growth (hatch to capture in the fall) because it is the inter-annual differences in growth that are of interest, rather than fork length *per se*.

Length-at-age models were used to estimate the most appropriate cut-offs between age-0, age-1 and age-2 and older individuals by year. For the purposes of estimating other population parameters by life stage, age-0 individuals were classified as fry, age-1 individuals were classified as subadult, and age-2 and older individuals were classified as adult. 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. 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.

2.2.4 Length Bias

The bias (accuracy) and error (precision) in the observers' estimates of fish length was quantified using a model with a categorical distribution that compared the length-frequency distributions of fish whose lengths were estimated by observers during the geo-referenced visual survey, to the length-frequency distribution of fish captured and measured by netters during the mark-recapture sessions. The model calculated a multiplier for each observer that minimized the difference between the estimated fish lengths from the visual surveys, and the measured lengths from the mark-recapture sessions. This multiplier, representing the observation bias, was used to correct the estimated lengths.

Key assumptions of the length bias model include:

- the proportion of fish in each length-class varied with year;
- the expected length bias varied with observer;
- the expected length error varied with observer;
- the expected length bias and error for a given observer did not vary by year; and
- the residual variation in length was normally distributed.

The observers' estimated fish lengths were corrected for the estimated bias before being classified as fry, subadult and adult based on the length-at-age cutoffs.

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 mean maximum length was constant;
- the growth coefficient (k) varied randomly with year; and
- the residual variation in growth was normally distributed.

Plots of annual growth show the estimated annual growth for a 200 mm fork length fish for Mountain Whitefish, Rainbow Trout, and Walleye. This fork length was selected to illustrate changes in fork length over time for a standard size fish.

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:

- observed site fidelity was described by a Bernoulli distribution; and
- 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 capture probability varied randomly by session within year;
- the probability of a marked fish remaining at a site was the estimated site fidelity; and
- 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 capture efficiency was the mean estimate from the capture efficiency model;
- the observer efficiency varied from the capture efficiency;
- the lineal fish density varied randomly with site, year and site within year; and
- 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. The counts of observed fish during geo-referenced visual surveys were plotted against the mean catches from the mark-recapture sessions to assess how these two metrics of abundance compared. The regression line and confidence bands on these plots represents the linear effect of the model parameter labelled “bVisitType[2]” (Appendix C), which was the multiplier based on the ratio of count to catch in the abundance model.

The annual distribution of each species was assessed using the Shannon index of evenness (E), using the following equation, where S was the number of sites and p_i was the proportion of the population belonging to the ith site.

$$E = \frac{-\sum p_i \log(p_i)}{\log(S)}$$

Evenness was used to assess inter-annual changes in spatial distribution, where a greater values of the index indicates more similar abundances among sites, and a lower value of the index indicates less even abundances among sites and a more "clumped" distribution.

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 using a multinomial likelihood. Survival was only estimated for adults because sparse recapture data for juveniles resulted in uninformative estimates.

Key assumptions of the survival model include:

- survival varied randomly with year; and
- the encounter probability varied with the total bank length sampled.

2.2.10 Body Condition

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

- 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; and
- the residual variation in weight was log-normally distributed.

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

2.2.11 Age Analysis

A subsample of Mountain Whitefish scales was analyzed to assign ages based on the number of growth annuli. Samples analyzed in 2015 included 200 Mountain Whitefish captured in 2015, 75 captured from each year from 2011 to 2014, and 35 recaptured Mountain Whitefish whose true age was known because they were initially captured at age-0 or age-1 and recaptured in a subsequent year. Samples from 2011 to 2014 were randomly selected from all age-1 and older fish, based on the estimated minimum size of age-1 fish in each year. For 2015 samples, random sample selection included 30 age-0 and 30-age-1 Mountain Whitefish based on the estimated 2014 length-at-age cutoffs, and 140 random samples from all individuals greater than the estimated maximum for age-1 fish. This was done to ensure enough older fish were included for the age bias model while still allowing the age1:2 ratio to be calculated (see below).

Scales were aged at the ONA's scale ageing laboratory in Penticton, BC. The age of Mountain Whitefish was estimated from scales by two independent agers. The scale aging process was repeated twice per ager, leading to two observations per ager per fish encounter (Hurlbert 1984). Agers did not have access to information about the scale sample, such as the fork length or capture history, when assigning ages.

Ages assigned based on scales ("scale ages") were analyzed using a state-space linear mixed model. Recaptured fish that could be aged at initial capture based on their length using the length-at-age model with a certainty ≥0.95 were assigned a known hatch year. Otherwise the hatch year was estimated by the model from the scale ages. The model used data from the 35 recaptured Mountain Whitefish of known age and 140 of the randomly sampled Mountain Whitefish captured from 2011 to 2015 that could be assigned a hatch year based on length or recapture events. Key assumptions of the scale age model include:

- the actual age was the year of capture minus the hatch year
- the scale age varied by ager;
- the scale age varied randomly with fish encounter and ager within fish encounter;
- the scale age varied linearly with age;
- the effect of age on scale age varied by ager;
- the random effects were normally distributed; and
- the residual variation in the scale ages (replicate within ager within encounter) was described by a zero-truncated normal distribution.

2.2.12 Age Ratios

This program's management questions regard the effect of variability 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. In 2015, age ratio analyses were conducted for Mountain Whitefish, which was the only species for which age data were available from 2001 to 2015.

The proportional ratio of age-1 to age-2 Mountain Whitefish (age-1:2 ratio) was calculated for each year from 2001 to 2015 using ages assigned based on scale analyses. 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. Age-1:2 ratios for fish captured in 2011 to 2015 were calculated using ages assigned as described above (Section 2.2.11). Age-1:2 ratios for fish captured from 2001 to 2010 were calculated using age data from the LCR Fish Population Indexing Database. During 2001 to 2010, scales were assigned ages following methods outlined in Mackay et al. (1990) by two to three experienced individuals. Data regarding each fish's capture history (if available) and length were made available to the scale readers, and if the readers did not agree on an age, they re-examined the scale jointly to assign a consensus age. The methods used in 2001 to 2010 were intended to use all available information to assign the most accurate age possible but differed from methods used in 2011 to 2015, when scale agers did not have information regarding fish size or capture history when analyzing scales. The purpose of the 2011 to 2015 methods is to identify and correct any scale aging biases.

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 the following year ($t+1$):

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

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 the next year (N^1_{t+1}) whereas the proportion of age-2 fish (N^2_{t+1}) is expected to be affected by egg losses two 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 log odds of the proportion of age-1 fish varied linearly with the log of the ratio of the percent egg losses; and
- the numbers of age-1 fish are extra-Binomially 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 monotonically 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.

With respect to the Mountain Whitefish and Rainbow Trout protection flows, it is important to understand if and when egg losses due to dewatering affect the number of recruits in the LCR. In stock-recruitment relationships, the spawning stock of adults is used as a proxy for reproductive potential or the number of eggs deposited (Subbey et al. 2014). Mortality of incubating eggs due to dewatering could affect density-dependent mortality of eggs or rearing juveniles, which would change the stock recruitment curve compared to in the absence of dewatering. To test for effects of dewatering on the stock recruitment relationship, the parameter β, which represents the strength of density-dependence, was allowed to vary with the proportional egg loss in the stock-recruitment model. Egg loss estimates were obtained from the Mountain Whitefish Egg Stranding Model (Golder 2013b) and from Irvine et al. (2015) for Rainbow Trout.

Key assumptions of the stock-recruitment model include:

- The prior probability for α was a uniform distribution from 0 to 5;
- The density-dependence varied with the proportional egg loss; and
- The residual variation in the number of recruits was log-normally distributed.

The carrying capacity K is given by the relationship:

$$K = \frac{\alpha}{\beta}$$

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.

2.2.14 Environmental Analyses

The second management question of CLBMON-45 is concerned with the effect of inter-annual variability in the Mountain 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. To address this question, multivariate analyses were used to examine long-term and short-term relationships between environmental and fish population time series variables.

The fish index time series were the condition (Con), growth (Grw) length-at-age (Len), survival (Sur), and Abundance (Abn) by species (MW = Mountain Whitefish, RB = Rainbow Trout, WP = Walleye) and life stage (Sub = Subadult, Ad = Adult) or age (Age0, Age1).The environmental time series included the mean discharge (DisMe) and average hourly absolute discharge difference (DisDi) in the Columbia River at Birchbank, and the average water temperature (TemMe) of the Columbia River at Norn's Creek. Mean hourly discharge difference was calculated as the mean of the absolute values of the hour to hour change. Each of the discharge and temperature variables were summarized by quarterly period (e.g., January to March, April to July, etc.). The October to December discharge and temperature time series were lagged by one year such that fish data in a given year were correlated with discharge or temperature data from the year prior to fish sampling. This was done because although November and December occur after the fall surveys were completed, habitat conditions during these months could affect the fish populations sampled in the fall of the following year.

The estimated annual proportional egg loss through dewatering (Regime) by species (MW = Mountain Whitefish, RB = Rainbow Trout) was also included as a variable. Estimated egg loss is based on models of substrate dewatering because of flow reductions during the spawning season and was obtained from Irvine et al. (2015) for Rainbow Trout and from BC Hydro's Mountain Whitefish Egg Stranding Model (Golder 2013b). The Mountain Whitefish egg loss time series was lagged by one year to account for the fact that they occur over winter and would affect fish metrics in the following year.

Other environmental time-series used in the analyses were Pacific Decadal Oscillation Index (PDO), mean annual biomass of invertebrates (EPT; Ephemeroptera, Plecoptera, Trichoptera and Dipterans) in the LCR (Olson-Russello et al. 2015), and the biomass of zooplankton (ZOO) in Arrow Lakes Reservoir (station AR8; M. Basset, Ministry of Forests, Lands, and Natural Resource Operations, pers. comm.). All time series variables were standardized by subtracting the mean and dividing by the standard deviation, prior to fitting the model.

Long-term trends common to the annual fish indexing and environmental time series were identified using dynamic factor analysis (Zuur et al. 2003) - a dimension-reduction technique especially designed for time series data. Dynamic factor analysis is a multivariate technique to reduce the number of variables and identify common trends among time series of response variables (the fish population metrics) and explanatory variables (the environmental variables). Dynamic factor analysis reduces a large number of time series to a smaller number of common trends. Weightings are calculated to interpret the relationship between the common trends and the variables. The general approach is dimension reduction similar to principal components but that accounts for temporal autocorrelation in the time series data (Zuur et al. 2003). The method is intended for relatively short, non-stationary time series (Zuur et al. 2003), which makes it suitable for the LCR data.

Key assumptions of the dynamic factor analysis model include:

- the time series were described by six underlying trends;
- the random walk processes in the trends were normally distributed; and
- the residual variation in the standardized variables was normally distributed.

A limitation of dynamic factor analysis as currently implemented in a Bayesian framework is that it is not possible to identify the individual common trends (although it is possible to identify the relationships between time series), which has been referred to as the rotation problem (Abmann et al. 2014). To visualize the relationships among fish metrics and environmental variables, non-metric multidimensional scaling (NMDS) was used to indicate the clustering of time series based on the absolute values of the dynamic factor analysis trend weightings. The more similar two time series, the closer they will tend to be on the resultant NMDS plot. Goodness of the fit of the NMDS was assessed by the stress values, which indicate how well the weightings of the variables are represented in two dimensions by the NMDS model. Stress values <20% were considered an acceptable representation, and values >20% were considered unsatisfactory (Kruskal 1964).

To assess short-term correlations between the fish population metrics and the environmental variables, the pair-wise distances between the residuals from the DFA model were calculated as 1−abs[cor(x,y)] where cor is the Pearson correlation, abs the absolute value and x and y are the two time series being compared. The short term similarities were represented visually by using NMDS to cluster the time series based on the pair-wise distances. The objective of the short-term trend analysis was to assess inter-annual associations among variables, after removing the effect of long-term trends in the variables.

3.0 RESULTS

3.1 Physical Habitat

3.1.1 Columbia River Discharge

Discharge in the LCR in 2015 was within the range of values observed during previous years of the study. Mean daily discharge in the Columbia River at the Birchbank water gauging station was very close to the average values from 2001 to 2014 through the year in 2015 (Figure 2; Appendix D, Figure D1). 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. In 2015, discharge increased during the sample period (Figure 2).

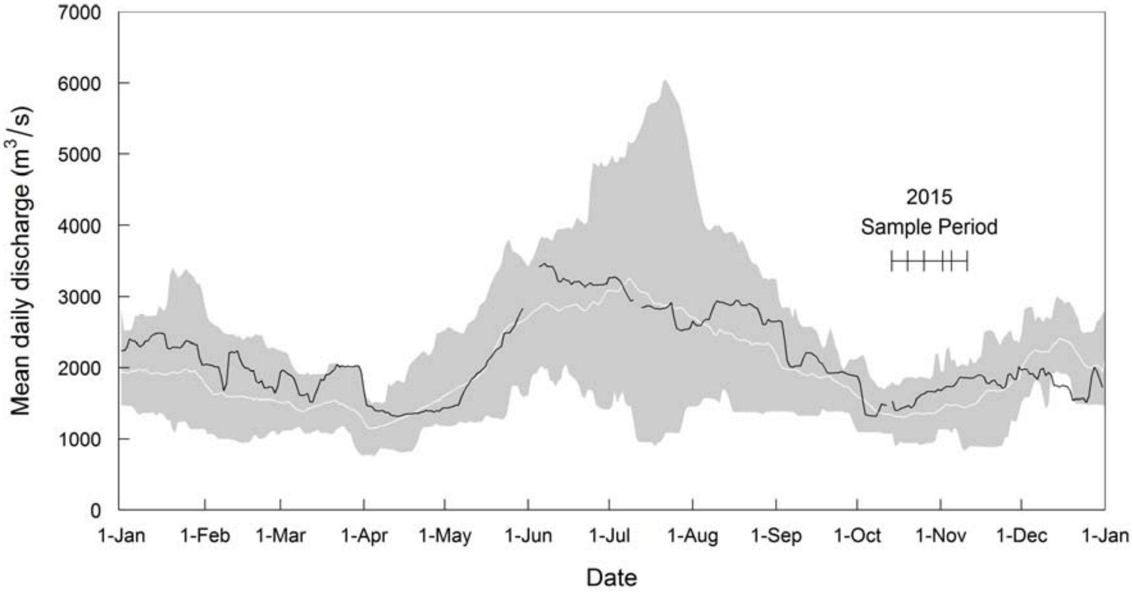

Figure 2: **Mean daily discharge (m^3/s) for the Columbia River at the Birchbank water gauging station, 2015 (black line). The shaded area represents minimum and maximum mean daily discharge values recorded at Birchbank from 2001 to 2014. The white line represents average mean daily discharge values over the same time period.**

In 2015, mean daily discharge in the Columbia River below HLK was greater than average during spring and summer, with discharge increasing approximately one month earlier in the spring than most years (Figure 3; Appendix D, Figure D2). Discharge was near average during the fall, including during the sampling period, but lower than average during December.

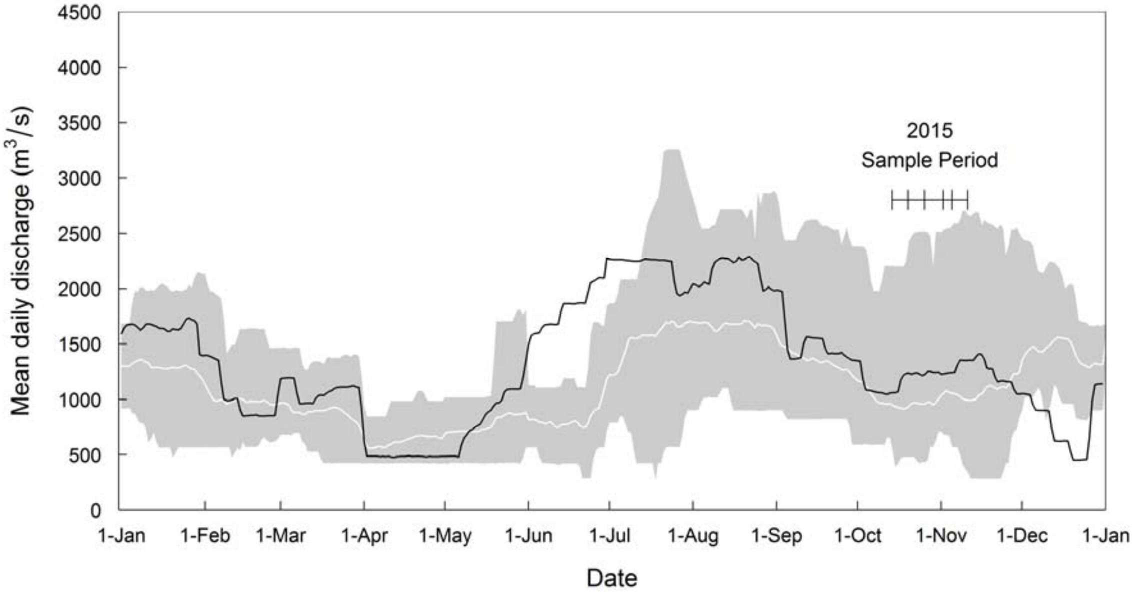

Figure 3: Mean daily discharge (m^3/s) for the Columbia River at Hugh L. Keenleyside Dam, 2015 (black line). The shaded area represents minimum and maximum mean daily discharge values recorded at the dam from 2001 to 2014. The white line represents average mean daily discharge values over the same time period.

3.1.2 Columbia River Temperature

Water temperature in the Columbia River in 2015 was similar to average values from 2011 to 2014 (Figure 4) but above average from mid-January to mid-July and below average from mid-July to October. Mean daily water temperature was approximately 2°C lower than average during September but the reason for this difference is unknown, as discharge at HLK and BRD were close to average. During the 2015 sample period, water temperatures were near average and declined throughout the sample period as in previous years (Appendix D, Figure D3). Spot temperature readings for the Columbia River taken at the time of sampling ranged between 7.6°C and 14.0°C (Appendix B, Table B3).

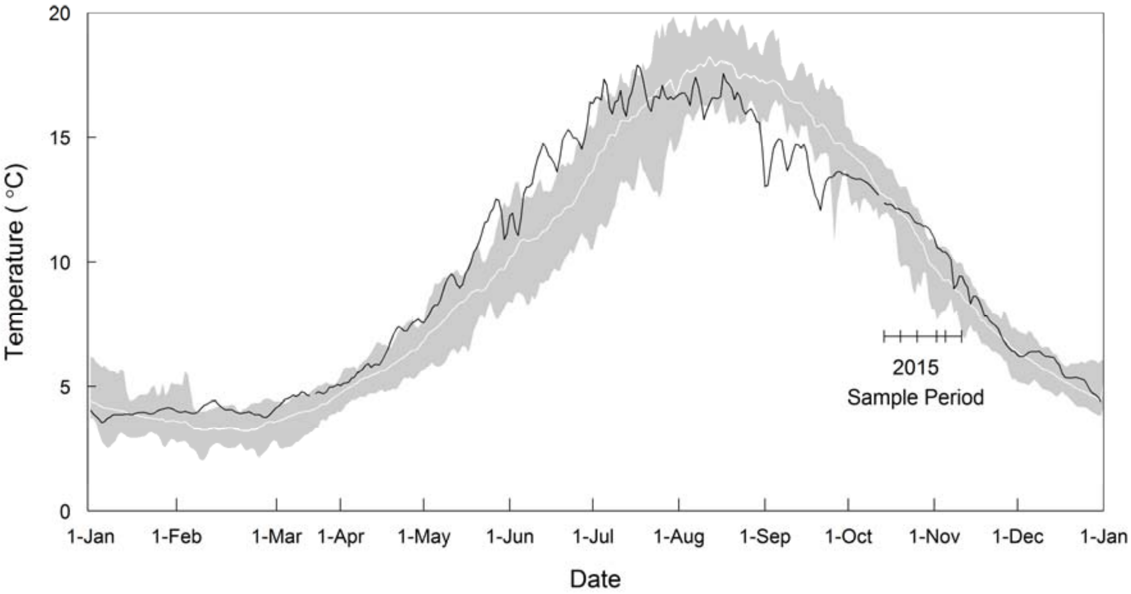

Figure 4: **Mean daily water temperature (°C) for the Columbia River at the Birchbank water gauging station, 2015 (black line). The shaded area represents the minimum and maximum mean daily water temperature values from 2001 to 2014. The white line represents the average mean daily water temperature during the same time period.**

3.1.3 Kootenay River Discharge

In 2015, mean daily discharge in the Kootenay River downstream of BRD was similar to average values from 2001 to 2014 with the exception of higher than average discharge between January and February, as well between mid-May and late November (Figure 5; Appendix D, Figure D4). Discharge levels fell below average from late November into January 2016. The spring freshet period was earlier in 2015 than average. During the sample period in October and early November, discharge was consistently higher than the average values from 2001 to 2014 but the difference was relatively small (<300 m^3/s).

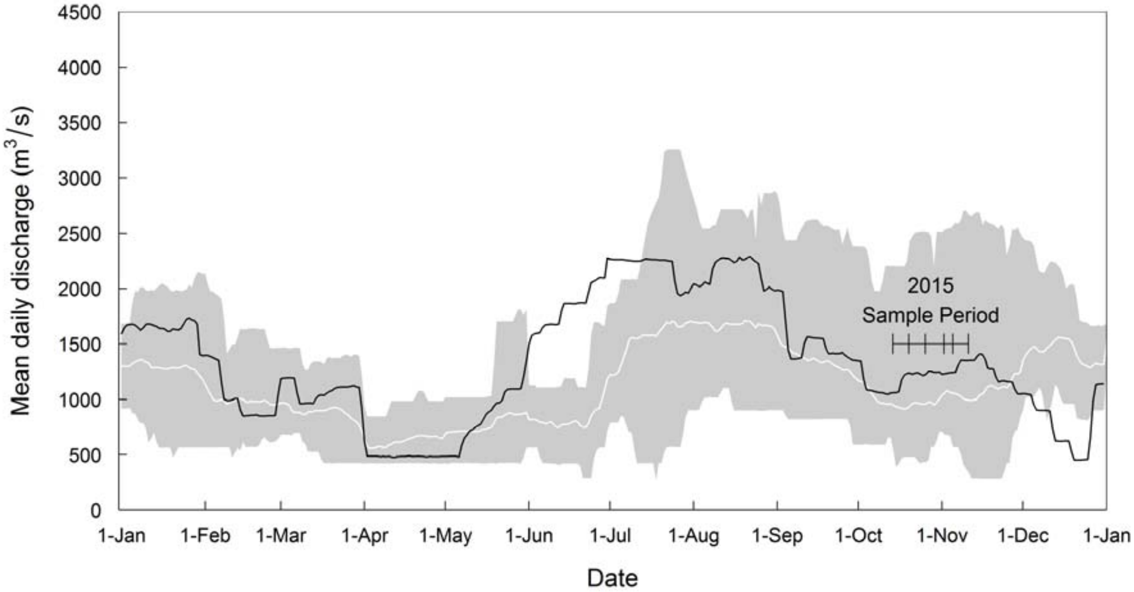

Figure 5: **Mean daily discharge (m^3/s) for the Kootenay River at BRD, 2015 (black line). The shaded area represents minimum and maximum mean daily discharge values recorded at the dam from 2001 to 2014. The white line represents average mean daily discharge values over the same time period.**

3.1.4 Kootenay River Temperature

In most previous sample years, water temperatures in the Kootenay River (downstream of BRD) generally increased from mid-February to mid-August and decreased from mid-August to mid-February (Appendix D, Figure D5). The water temperature recorded in the Kootenay River in 2015 followed this same pattern but reached peak temperature earlier in the summer and declined earlier in the fall than during previous years (Figure 6). Spot temperature readings for the Kootenay River taken at the time of sampling ranged between 10.2°C and 12.9°C (Appendix B, Table B3).

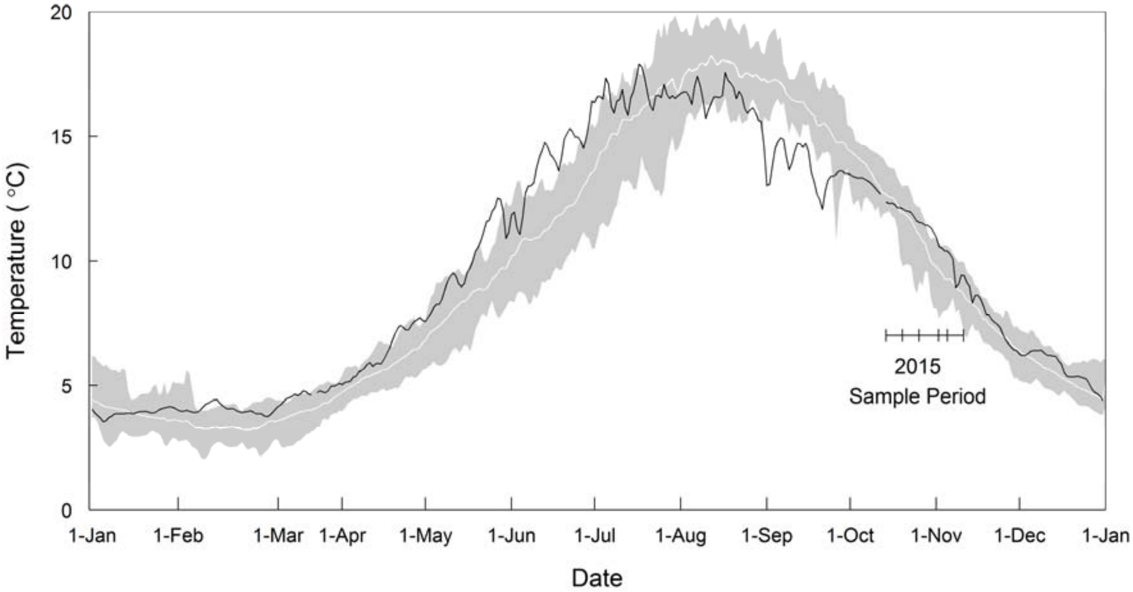

Figure 6: **Mean daily water temperature (°C) for the Kootenay River downstream of BRD, 2015 (black line).The shaded area represents minimum and maximum mean daily water temperature values recorded at the dam from 2001 to 2014. The white line represents average mean daily water temperature values over the same time period.**

3.1.5 Habitat Variables

Reach habitat descriptions for the LCR are provided by Golder (2002). Habitat data collected since 2001 indicates that a gradual increase in aquatic vegetation (dominantly Eurasian watermilfoil; *Myriophyllum spicatum*) has occurred in low water velocity areas throughout the LCR (Appendix B, Table B3). Sites with higher water velocities continue to support low levels of aquatic vegetation. 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.).

3.2 Catch

In total, 16,804 fish were recorded in the LCR in 2015 (Table 4). This total included both captured fish and observed fish that were identified to species at both the Index and GRTS sites combined.

Table 4: Number of fish caught and observed during boat electroshocking surveys and their frequency of occurrence in sampled sections of the LCR, 13 October to 5 November 2015. 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	0	0	8	<1	9	<1
Brown Trout (*Salmo trutta*)	0	0	0	0	1	<1	1	<1
Bull Trout (*Salvelinus confluentus*)	4	<1	2	<1	3	<1	9	<1
Burbot (*Lota lota*)	1	<1	0	0	5	<1	6	<1
Kokanee (*Oncorhynchus nerka*)	19	<1	2	<1	11	<1	32	<1
Lake Whitefish (*Coregonus clupeaformis*)	15	<1	0	0	64	1	79	<1
Mountain Whitefish (*Prosopium williamsoni*) adults	489	17	287	36	791	16	1567	18
Mountain Whitefish (*Prosopium wiliamsoni*) juveniles	1330	47	126	16	809	16	2265	26
Northern Pike (*Esox lucius*)	9	<1	0	0	0	0	9	<1
Rainbow Trout (*Oncorhynchus mykiss*) adults	400	14	225	28	2219	45	2844	33
Rainbow Trout (*Oncorhynchus mykiss*) juveniles	392	14	60	8	744	15	1196	14
Smallmouth Bass (*Micropterus dolomieu*)	0	0	0	0	1	<1	1	<1
Walleye (*Sanders vitreus*)	184	6	87	11	270	5	541	6
White Sturgeon (*Acipenser transmontanus*)	7	<1	3	<1	8	<1	18	<1
Yellow Perch (*Perca flavescens*)	2	<1	0	0	0	0	2	<1
Sportfish Subtotal	2853	100	792	100	4957	100	8602	100
Non-sportfish								
Carp spp. (*Cyprinus carpio*)	0	0	1	<1	0	0	1	<1
Northern Pikeminnow (*Ptychocheilus oregonensis*)	66	2	68	5	24	<1	158	2
Peamouth (*Mylocheilus caurinus*)	150	4	5	<1	1	<1	156	2
Prickly Sculpin (*Cottus asper*)	0	0	0	0	7	<1	7	<1
Redside Shiner (*Richardsonius balteatus*)	1320	36	239	19	159	5	1718	21
Sculpin spp. (*Cottidae*)	1510	42	676	54	2678	81	4864	60
Sucker spp. (*Catostomidae*)	572	16	259	21	421	13	1252	15
Tench (*Tinca tinca*)	0	0	0	0	1	<1	1	<1
Torrent Sculpin (*Cottus rhotheus*)	0	0	0	0	3	<1	3	<1
Non-Sportfish Subtotal	3618	100	1248	100	3294	100	8160	100
Total	6471	100	2040	100	8251	100	16762	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 HBMs. Although these summaries are important, they are not presented or 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 HBMs. Metrics presented in the appendices include:

- captured and observed fish count data by site and Bank Habitat Type (Appendix B, Table B4), 2015;
- catch and percent composition by species, 2001 to 2015 (Appendix E, Table E1);
- catch-rates for all sportfish (Appendix E, Table E2) and non-sportfish (Appendix E, Table E3), 2015;
- length-frequency histograms by section for Mountain Whitefish (Appendix F, Figure F1), Rainbow Trout (Appendix F, Figure F2), and Walleye (Appendix F, Figure F3), 2015;
- length-frequency histograms by year for Mountain Whitefish (Appendix F, Figure F4), Rainbow Trout (Appendix F, Figure F5), and Walleye (Appendix F, Figure F6), all years combined; and
- length-weight relationships by year for Mountain Whitefish (Appendix F, Figure F7), Rainbow Trout (Appendix F, Figure F8), and Walleye (Appendix F, Figure F9), all years combined.

3.3 Length-At-Age and Growth Rate

Outputs from the length-at-age model are presented in Table 5 and represent the most appropriate cut-offs between age-0 (fry), age-1 (subadult), and age-2 and older (adult) Mountain Whitefish and Rainbow Trout during each sample year. Length-density plots show the relative frequency of lengths by age-class (Appendix G; Figures G1 and G2). All Walleye were classified as adults by the HBMs. A comparison of von Bertalanffy growth curves for the three index species indicated that Rainbow Trout grew the fastest but reached their asymptotic length at an earlier age compared to Mountain Whitefish and Walleye (Figure 7).

Table 5: Estimated minimum and maximum fork lengths (in mm) for each life stage by year for Mountain Whitefish and Rainbow Trout in the lower Columbia River, 1990 to 1991, 2001 to 2015. Estimates were derived from the length-at-age model (Section 2.2.3).

Year	Mountain Whitefish			Rainbow Trout		
	Fry	Subadult	Adult	Fry	Subadult	Adult
1990	≤151	152-241	≥242	≤151	152-352	≥353
1991	≤136	137-230	≥231	≤131	132-339	≥340
2001	≤135	136-243	≥244	≤131	132-325	≥326
2002	≤156	157-249	≥250	≤154	154-349	≥350
2003	≤156	157-251	≥252	≤160	161-344	≥345
2004	≤153	154-242	≥243	≤144	145-336	≥337
2005	≤163	164-246	≥247	≤164	165-350	≥351
2006	≤166	167-268	≥269	≤168	169-367	≥368
2007	≤168	169-272	≥273	≤165	166-376	≥377
2008	≤164	165-262	≥263	≤146	147-342	≥343
2009	≤162	163-256	≥257	≤147	148-342	≥343
2010	≤169	170-264	≥265	≤144	145-340	≥341
2011	≤159	160-264	≥265	≤154	155-346	≥347
2012	≤155	156-268	≥269	≤154	155-347	≥348
2013	≤176	177-282	≥283	≤169	170-359	≥360
2014	≤169	170-278	≥279	≤158	159-342	≥343
2015	≤159	160-263	≥264	≤172	173-340	≥341

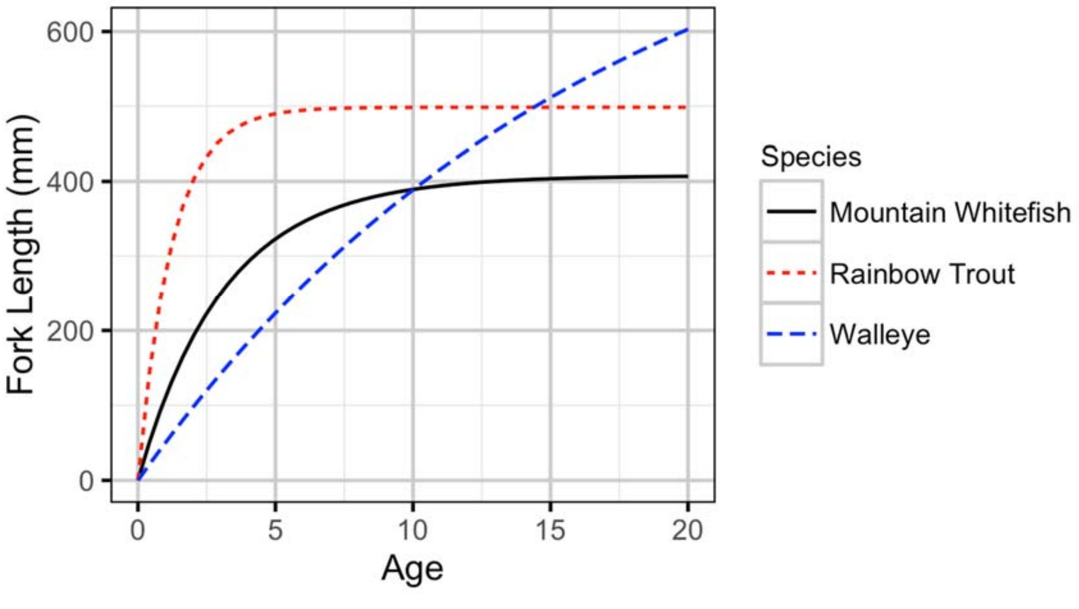

Figure 7: Growth curve showing length-at-age by species as predicted by the von Bertalanffy model for the lower Columbia River, 2001-2015.

3.3.1 Mountain Whitefish

Mountain Whitefish fry had the smallest mean fork lengths in 1991 and 2001. The mean fork length of Mountain Whitefish fry fluctuated between 116 and 135 mm between 2002 and 2015 (Figure 8; left panel). The growth of subadult (age-1) Mountain Whitefish, measured as the change in length-at-age compared to fry the previous year, generally increased between 2002 and 2010 (Figure 8; right panel). The mean growth of subadult Mountain Whitefish was greater in 2013 than all previous years but declined to near-average values in 2014 and 2015. The length of adult Mountain Whitefish (i.e., age-2 and older) is not presented because this group consisted of multiple age-classes.

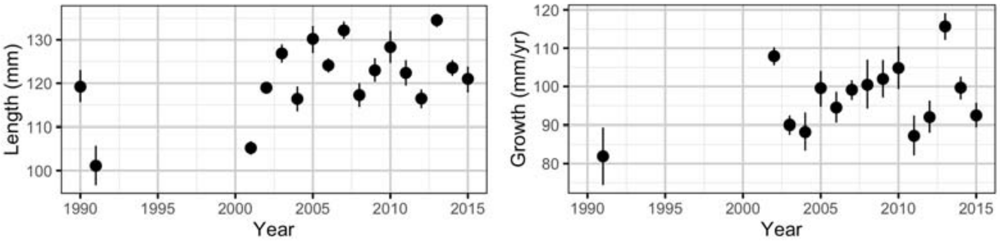

Figure 8: Length-at-age of fry (left) and fry to subadult growth (right) for Mountain Whitefish in the lower Columbia River, 1990 to 1991 and 2001 to 2015. Values are means with 95% CRIs.

Analysis of annual growth of recaptured individuals indicated an increase in average annual growth between 2003 and 2009, and variable annual growth between 2010 and 2015, although credible intervals overlapped between most estimates (Figure 9). The average annual growth was lowest during 2012 and greatest in 2014 and 2015.

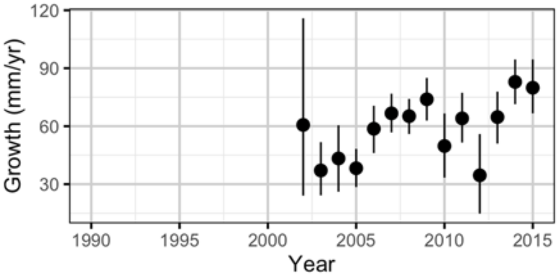

Figure 9: Expected inter-annual growth (mean with 95% CRIs) for a 200 mm fork length Mountain Whitefish based on recaptured individuals in the lower Columbia River, 2001 to 2015.

3.3.2 Rainbow Trout

The length-at-age models indicated a gradual decrease in the average fork length of Rainbow Trout fry between 2005 and 2010 (Figure 10; left panel) and an increase from 2010 to 2015. Mean length-at-age of fry was ~20 mm greater in 2015 than preceding years. Rainbow Trout fry were significantly smaller in 2001 when compared to all other study years. This result is consistent with small size of Mountain Whitefish fry in 2001 (Figure 8). The inter-annual growth of subadult (age-1) Rainbow Trout, measured as the change in length-at-age compared to fry the previous year, fluctuated from 135 to

173 mm from 2001 to 2007 then steadily increased from 2008 to 2013 (Figure 10; right panel). Mean growth of age-1 Rainbow Trout in 2015 was in the middle of the range of previous year's estimates. Length-at-age was not assessed in detail for adult Rainbow Trout (i.e., age-2 and older) because this group consisted of multiple age-classes.

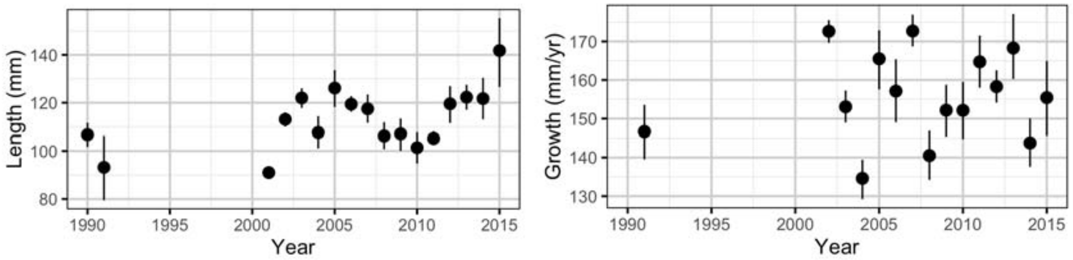

Figure 10: **Length-at-age of fry (left) and fry to subadult growth (right) for Rainbow Trout in the lower Columbia River, 1990 to 1991 and 2001 to 2015.Values are means with 95% CRIs.**

Analysis of annual growth of recaptured individuals indicated slower growth from 2002 to 2004 when compared to later study years (Figure 11). Estimates of mean growth generally declined from 2006 to 2015. Overall, annual growth of Rainbow Trout was variable and changed up to 25% during a one year period.

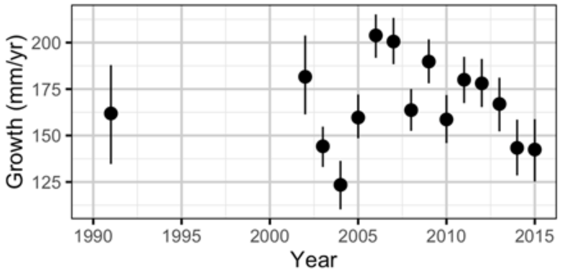

Figure 11: **Expected inter-annual growth (mean with 95% CRIs) for a 200 mm fork length Rainbow Trout based on recaptured individuals in the lower Columbia River, 2001 to 2015.**

3.3.3 Walleye

Analysis of annual growth of recaptured Walleye indicated variable growth rates for this species; however, credible intervals overlapped for many of the estimates (Figure 12). Annual growth increased from 2001 to 2006, followed by several years of lower growth from 2009 to 2011. Mean growth was greatest in 2013 but decreased to near-average values in 2014 and 2015 (Figure 12).

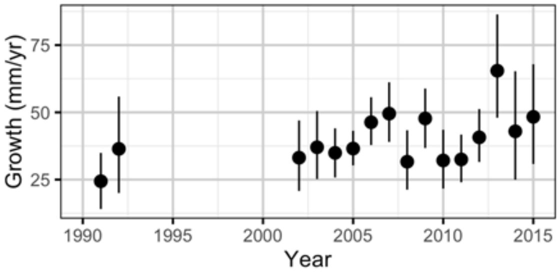

Figure 12: **Expected inter-annual growth (mean with 95% CRIs) for a 200 mm fork length Walleye based on recaptured individuals in the lower Columbia River, 2001 to 2015.**

3.3.4 Length Bias

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 observers in 2013, 2014 and 2015 underestimated fork lengths for all three index species (Figure 13). The bias was similar between observers for Mountain Whitefish with underestimates of 9-14% (Figure 14). Underestimates of Rainbow Trout lengths varied between 14 and 24%. Bias in estimated Walleye fork lengths ranged between 7 and 20%. Estimates of observer bias were used to correct estimated fork lengths before classifying fish into age-classes for abundance analyses.

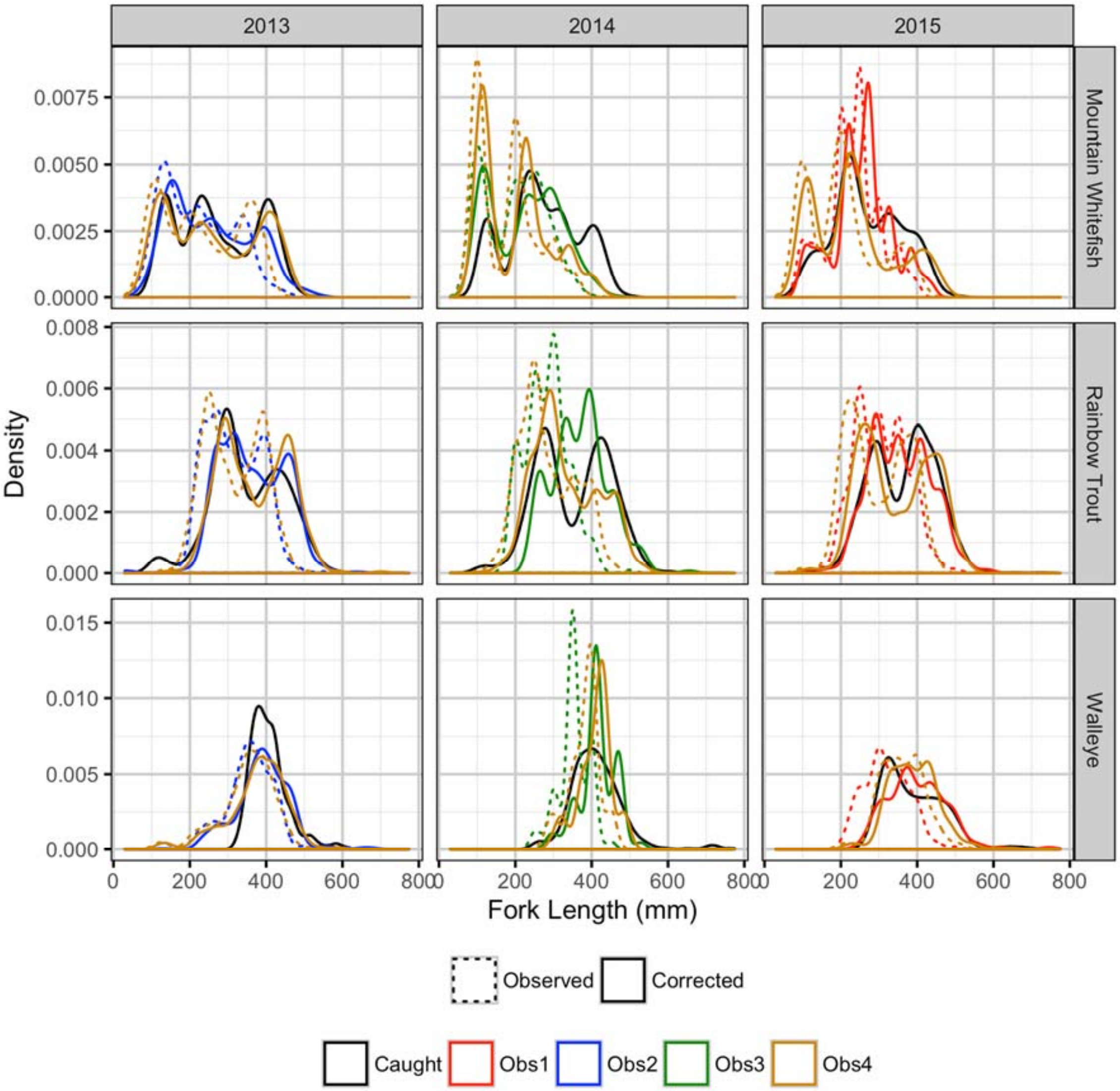

Figure 13: Fork length-density plots for measured and estimated fork lengths of fish caught or observed in the lower Columbia River, 2013-2015. The black line shows fish that were caught. Observed data are shown by coloured dashed lines and corrected data are shown by coloured solid lines.

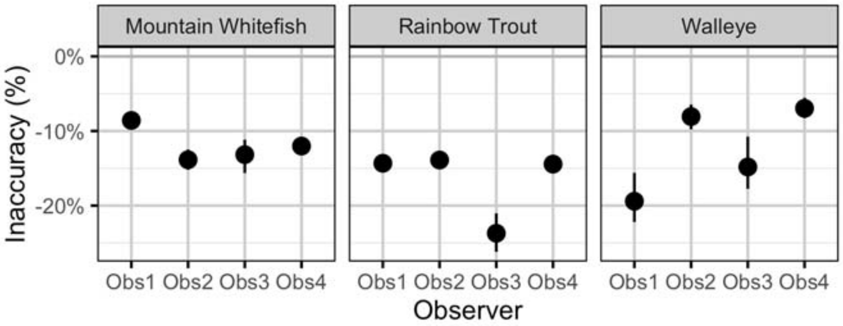

Figure 14: Bias in observer estimated fork lengths of index species based on length bias model of captured (mark-recapture surveys) and estimated (geo-referenced visual surveys) length-frequency distributions from the lower Columbia River, 2015.

3.4 Spatial Distribution and Abundance

3.4.1 Site Fidelity

Site fidelity was high (>75%) for Rainbow Trout and Walleye smaller than 200 mm fork length but decreased with increasing length for both species (Figure 15). However, the effect of length on site fidelity was only statistically significant for Rainbow Trout (*P*<0.001) and not for Walleye (*P* = 0.5). Site fidelity was approximately 50% for Mountain Whitefish and did not vary significantly by length (*P* = 0.5).

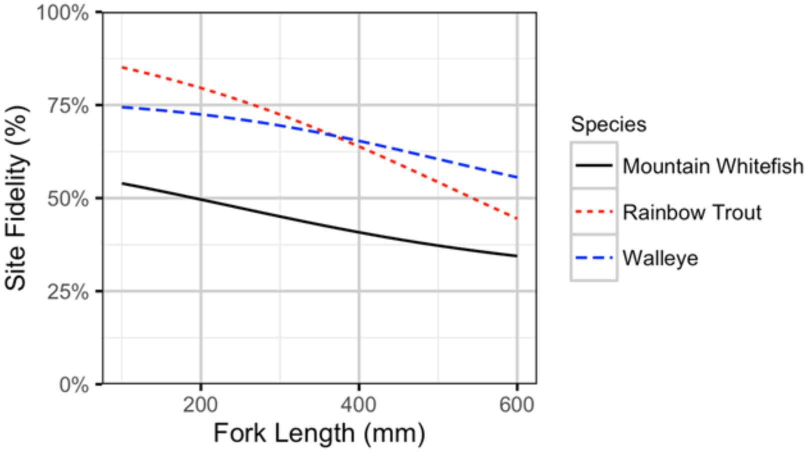

Figure 15: Site fidelity, defined as the expected probability that a fish is recaptured at the same site where it was marked, by species and fork length in the lower Columbia River, 2001 to 2015.

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 but not all 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).

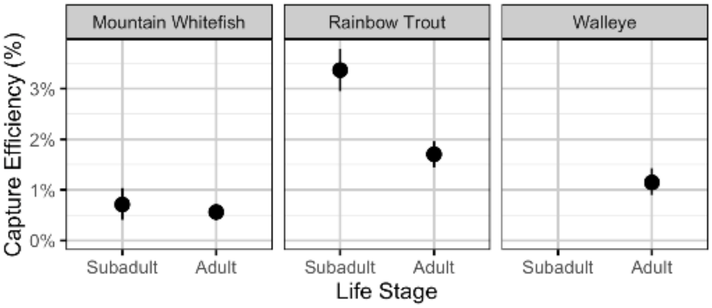

Figure 16: Capture efficiency (mean with 95% CRIs) by species from mark-recapture data from the lower Columbia River, 2001-2015.

3.4.3 Mountain Whitefish

The estimated abundance of subadult Mountain Whitefish in index sites in the LCR decreased from ~125 000 in 2001 to <20 000 in 2005. Subadult abundance increased in 2006-2007 and 2010-2015 but remained much lower than the abundance estimated for the early 2000s. Estimates suggested a steady decline in abundance of adult Mountain Whitefish between 2001 (>200 000) and 2012 (~100,000) and similar abundance with overlapping confidence intervals between 2010 and 2015.

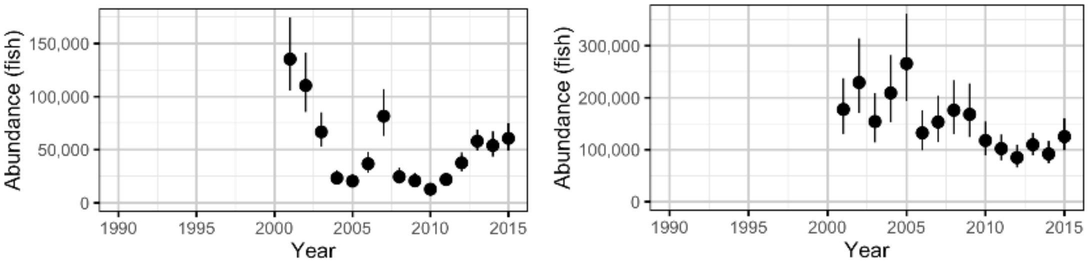

Figure 17: Abundance (means with 95% CRIs) of subadult (left) and adult (right) Mountain Whitefish at index sample sites in the lower Columbia River, 2001-2015.

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). In comparison, subadult Mountain Whitefish densities were low in the Kootenay River and in the Columbia River downstream of the Kootenay River confluence, river sections which typically have higher water velocities.

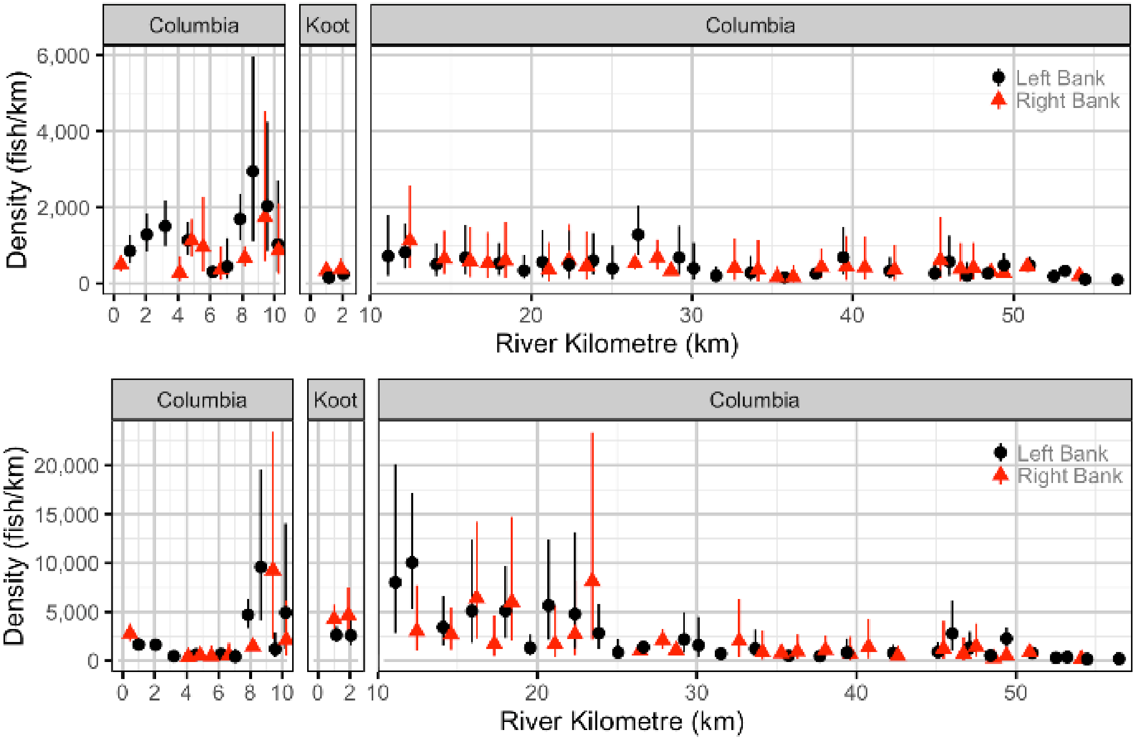

Figure 18: **Density (means with 95% CRIs) of subadult (top) and adult (bottom) Mountain Whitefish by river kilometre in the lower Columbia River, 2001-2015.**

Adult Mountain Whitefish site-level density estimates (Figure 18) had larger credible intervals than estimates generated for subadult Mountain Whitefish. However, 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). Shannon's index of evenness did not suggest any inter-annual differences in distribution of abundance among sites for subadult or adult Mountain Whitefish (Figure G8, Appendix G).

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 2015 (Figure 19). Adult Rainbow Trout abundance increased from ~25,000 in 2002 to the maximum of ~51,000 in 2015.

Rainbow Trout site-level density estimates had large credible intervals (Figure 20), particularly at sites that were only sampled between 2012 and 2015. Despite the uncertainty, 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. Shannon's index of evenness did not suggest any inter-annual differences in distribution of abundance among sites for subadult or adult Rainbow Trout (Figure G9, Appendix G).

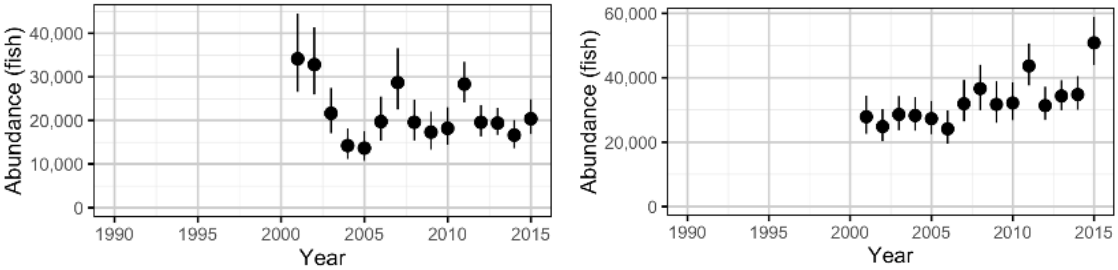

Figure 19: Abundance (means with 95% CRIs) of subadult (left) and adult (right) Rainbow Trout at index sample sites in the lower Columbia River, 2001-2015.

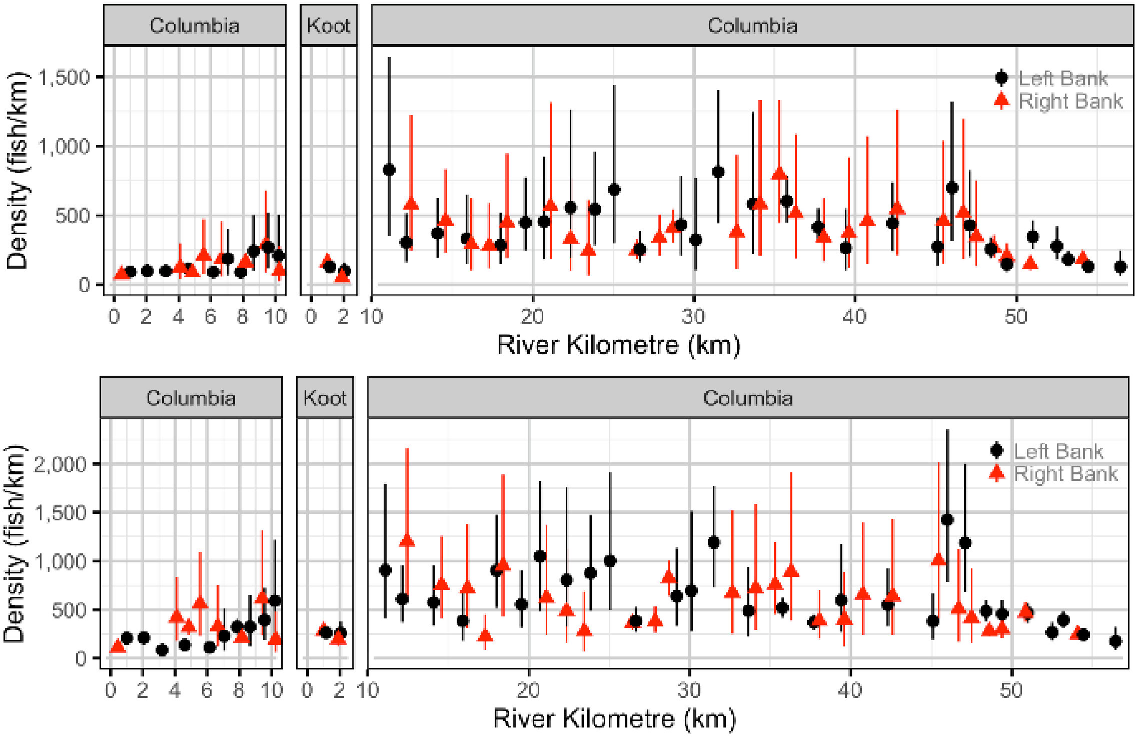

Figure 20: **Density (means with 95% CRIs) of subadult (top) and adult (bottom) Rainbow Trout by river kilometre in the lower Columbia River, 2001-2015.**

3.4.5 Walleye

Since 2001, Walleye abundance has fluctuated with peaks in 2004 and 2011. Walleye abundance estimates were lower from 2011 to 2015 than during previous years from 2001 to 2010 (Figure 21). Density estimates for Walleye were greatest in the Kootenay River, at the three sites closest to HLK, 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 synoptic sites sampled during the GRTS survey (not sampled prior to 2012) was comparable to the density at index sites. Shannon's index of evenness did not suggest any inter-annual differences in distribution of abundance among sites for Walleye (Figure G10, Appendix G).

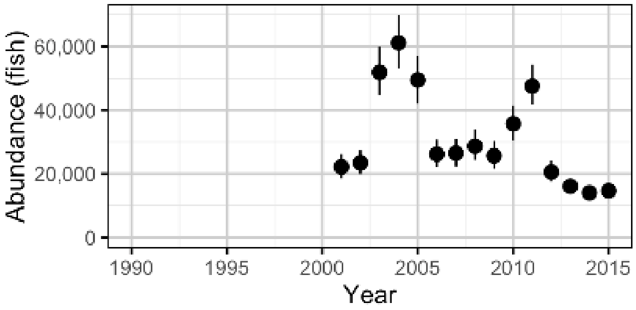

Figure 21: **Abundance (means with 95% CRIs) of adult Walleye at index sample sites in the lower Columbia River, 2001-2015.**

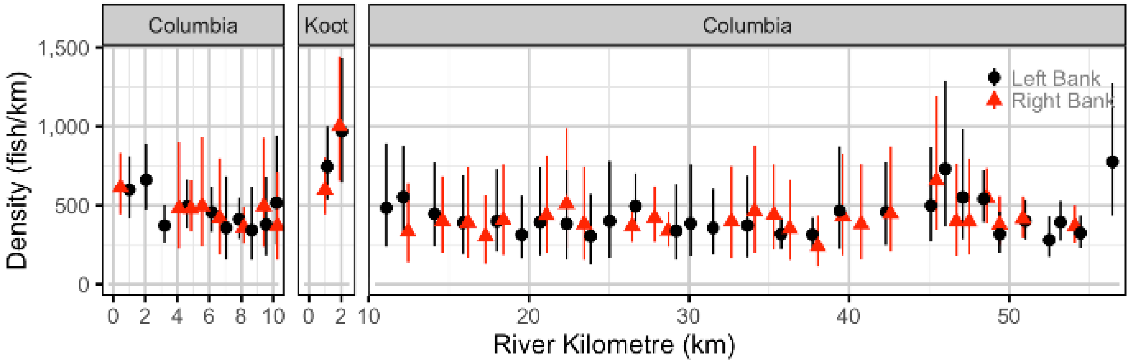

Figure 22: **Density (means with 95% CRIs) of adult Walleye by river kilometre in the lower Columbia River, 2001-2015.**

3.4.6 Geo-referenced Visual Enumeration Surveys

The results show a positive relationship between counts of fish during the visual surveys and mean catches during mark-recapture surveys at the same sites (Figure 23). The count:catch ratio was generally greater in 2013 and 2015 and lower in 2014 for adult Mountain Whitefish, Rainbow Trout, and Walleye but similar between years for subadult Mountain Whitefish. There appeared to be more variability, indicating a less consistent relationship between count and catch, at higher abundances for Walleye, especially in 2013.

Figure 23 shows the mean catches from all four mark-recapture sessions versus the counts from the visual surveys. Exploratory analyses also included comparing catches from the first mark-recapture session to visual survey counts in case potential changes in capture efficiency or avoidance behaviour by fish affected the relationship in subsequent weeks of electrofishing. The results indicated a very similar relationship (data not shown) regardless of whether the mean catch of all sessions, or only first session data were used. Therefore, the mean of all mark-recapture sessions was presented to better utilize the complete data-set. The plots in Figure 23 are not intended to provide predictive models but represent preliminary exploration of relationships between the two methods.

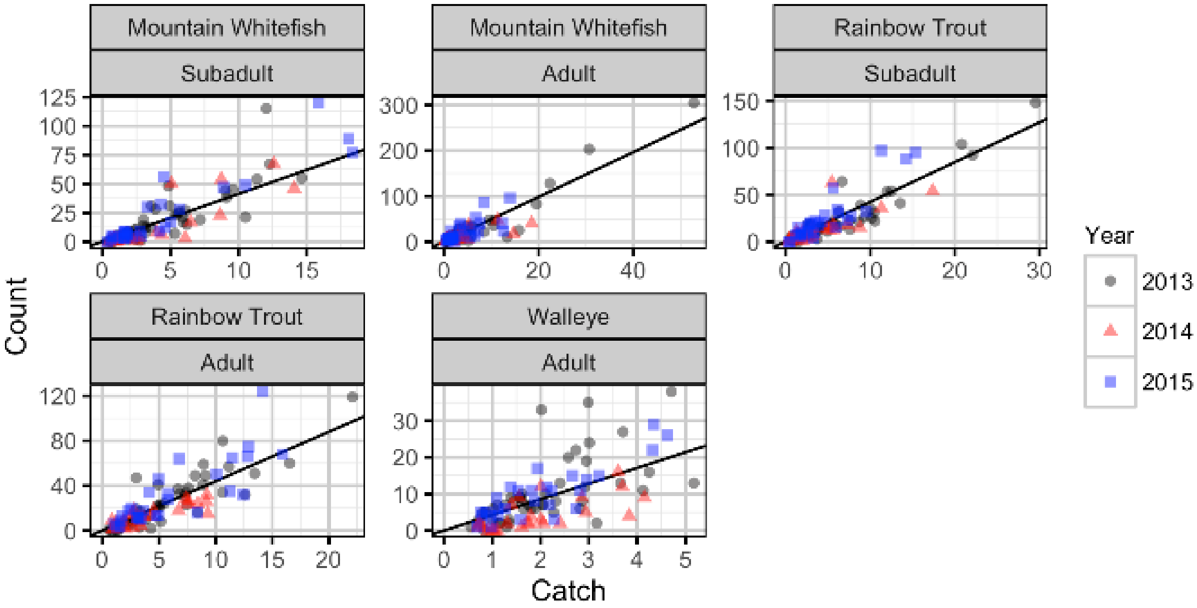

Figure 23: **Comparison of counts of observed fish during visual surveys to catch during mark-recapture surveys in the lower Columbia River. Points are the mean number of captured fish during four mark-recapture sessions versus the counts during the geo-referenced visual surveys in 2013, 2014 and 2015. The solid line is the parameter in the abundance model that represents the count:catch efficiency and the dotted lines are its 95% CRIs (Section 2.2.8).**

The visual surveys also 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 compared 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 24% to 90%. Adult survival generally increased between 2001 and 2008, and decreased from 2011 to 2015, although there were substantial year-to-year variations and large uncertainty in the estimates (Figure 24). Survival estimates for Mountain Whitefish were less precise than corresponding estimates for Rainbow Trout (see Section 3.5.2). The inter-annual capture efficiency, on which the survival estimate was based, was approximately 1-2% (Figure G11, Appendix G).

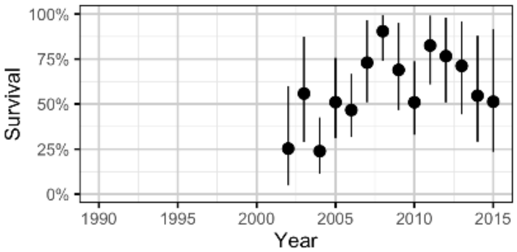

Figure 24: **Survival estimates (mean with 95% CRIs) for adult Mountain Whitefish in the lower Columbia River, 2001-2015.**

3.5.2 Rainbow Trout

Survival estimates of Rainbow Trout increased gradually from 29% in 2003 to 55% in 2011, but sharply declined to 31-38% in 2012 to 2015 (Figure 25). The inter-annual capture efficiency was 4% (Figure G12, Appendix G).

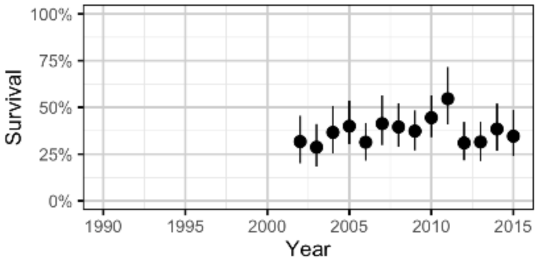

Figure 25: **Survival estimates (mean with 95% CRIs) for adult Rainbow Trout in the lower Columbia River, 2001-2015.**

3.5.3 Walleye

Survival estimates for Walleye were lower in 2013 and 2014 (35-38%) than earlier years but increased 53% in 2015 (Figure 26). However, credibility intervals overlapped for all years. The inter-annual capture efficiency was ~2% (Figure G13, Appendix G).

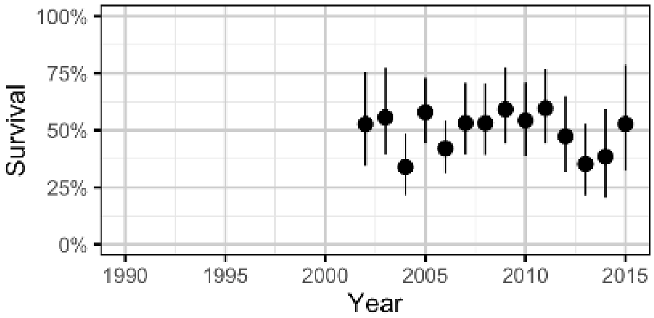

Figure 26: **Survival estimates (mean with 95% CRIs) for adult Walleye in the lower Columbia River, 2001-2015.**

3.6 Body Condition

3.6.1 Mountain Whitefish

The body condition of subadult Mountain Whitefish varied little (~2%) from 2008 to 2015 (Figure 27; left panel). Adult Mountain Whitefish body condition increased from 2003 to 2006, then decreased from 2006 to 2008, and was stable from 2009 to 2015 (Figure 27; right panel). Adult body condition was much lower in the 1990s than between 2001 and 2015, with effect sizes of 6-14% lower than a typical year.

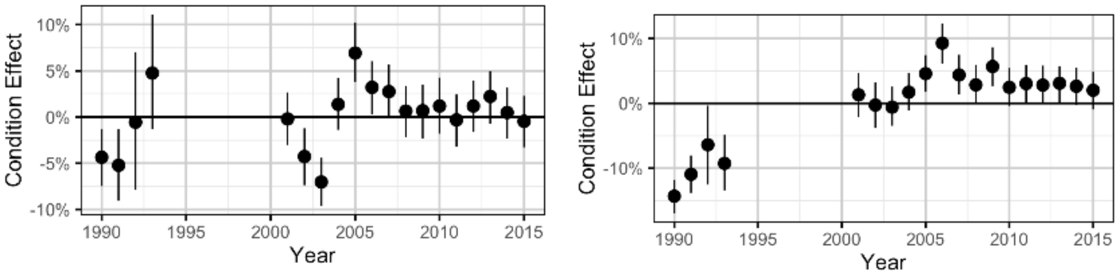

Figure 27: **Body condition effect size estimates (mean with 95% CRIs) for subadult (left panel) and adult (right panel) Mountain Whitefish in the lower Columbia River, 1990 to 1993 and 2001 to 2015.**

3.6.2 Rainbow Trout

The body condition of subadult and adult Rainbow Trout was substantially higher in 2002 and 2006 compared to other study years (Figure 28). For subadults, body condition estimates increased from 2003 to 2006, decreased from 2006 to 2011, and were similar from 2012 to 2015. Credible intervals for most estimates overlapped, indicating that inter-annual differences were not statistically significant. The body condition of adult Rainbow Trout was similar in most study years, except for the higher values observed in 1993, 2002, and 2006. Adult body condition declined in recent years of the study from 2013 to 2015, which coincided with increasing abundance estimates (Section 3.4.4).

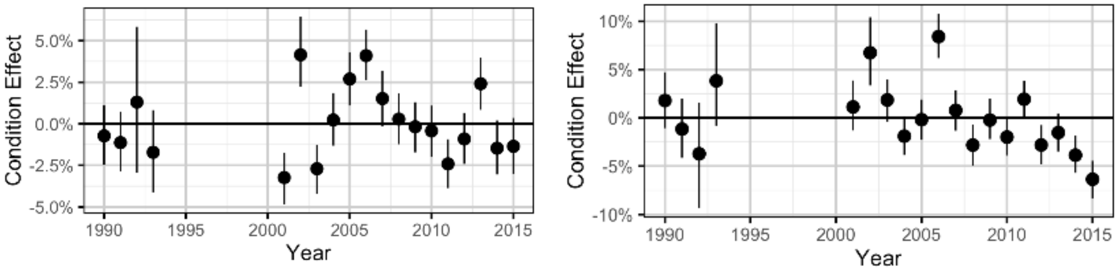

Figure 28: **Body condition effect size estimates (mean with 95% CRIs) for subadult (left panel) and adult (right panel) Rainbow Trout in the lower Columbia River, 1990 to 1993 and 2001 to 2015.**

3.6.3 Walleye

Walleye body condition fluctuated with no consistent trend since the early 1990s (Figure 29). However, body condition estimates in 2012 to 2015 were greater than most previous years. Overall, the results suggest fluctuating body condition of Walleye since 2001 but greater body condition in the last four years than earlier years of the monitoring program.

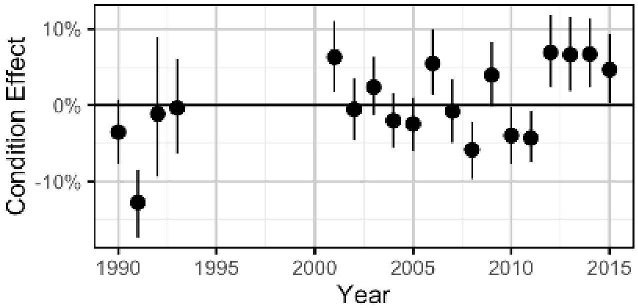

Figure 29: **Body condition effect size estimates (median with 95% CRIs) by year (left panel) and date (right panel) for Walleye in the lower Columbia River, 1990 to 1993 and 2001 to 2015.**

3.7 Age Model

Based on the scale age model, both scale agers on average identified age-1 fish of "known" age (age determined by lengths) as age-2 (Figure 30). There was also a large amount of variability in assigned ages within each known age class. For example, ager1 recorded known age-1 fish as 1 – 4 years; similarly ager2 recorded known age-1 fish as 0 – 4 years. Although assigned ages were on average overestimated by one year, the bias was relatively consistent. Therefore, assigned ages for fish captured from 2011 to 2015 were corrected by subtracting one year before using the age data in the age ratio analysis (Section 3.8). Age data previously analyzed for age-0, 1 and 2 Mountain Whitefish from 2001 to 2010 were considered acceptably reliable, based on agreement between length-frequencies, scale analysis, and recapture histories analyzed in previous study years; therefore, ages from 2001 to 2010 were not corrected before the age ratio analysis.

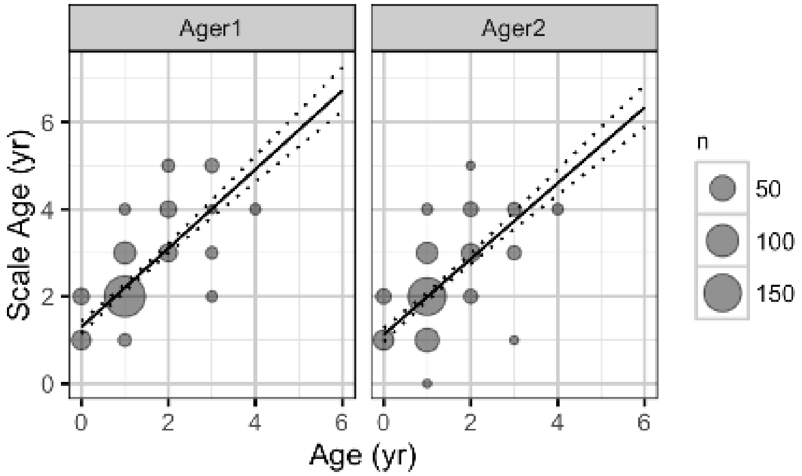

Figure 30: **Estimated scale age of Mountain Whitefish comparing known age (x-axis) estimated by length to ager (y-axis) estimates (with 95% CRIs).**

3.8 Age Ratios

The proportion of age-1 Mountain Whitefish, which was used as an indicator of annual recruitment strength, ranged from a minimum of 34% for the 2006 spawning year to a maximum of 80% in 2010 (Figure 31). The estimated proportion of egg mortality due to dewatering was greatest in 2008 (30%) and 2012 (36%) based on the egg loss model (Figure 32). Trends in the logged ratio of egg loss (Figure 33), which represents the dewatering effects on age-1 fish one year prior and on age-2 fish two years prior, were similar to those for the annual egg loss estimates (Figure 32), with the greatest estimated losses in 2002, 2008, and 2012. There was a negative relationship between the age-1 recruitment index and estimated egg losses (Figure 34) but the relationship was not statistically significant (*P*=0.3). Although this relationship was not significant, the effect size of egg loss on recruitment is shown in Figure 35.

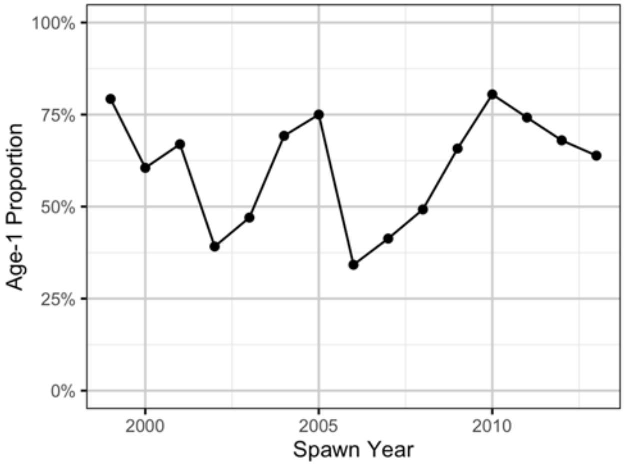

Figure 31: **Proportion of age-1 to age-2 Mountain Whitefish in boat electroshocking catch in the lower Columbia River by spawning year, 1999 to 2014.**

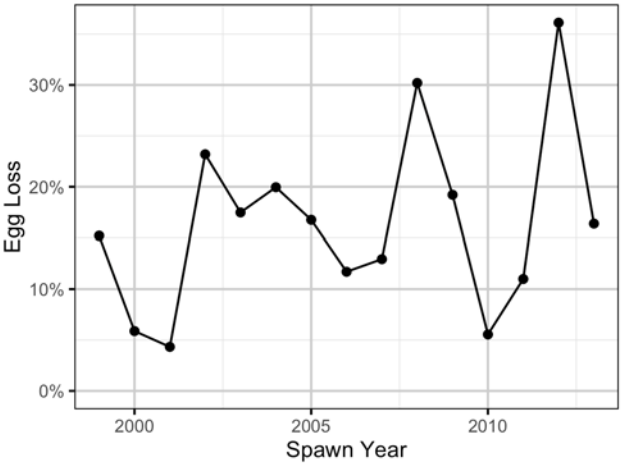

Figure 32: Estimated proportion of Mountain Whitefish egg loss due to dewatering in the lower Columbia River by spawning year, 1999 to 2013, based on the egg loss model.

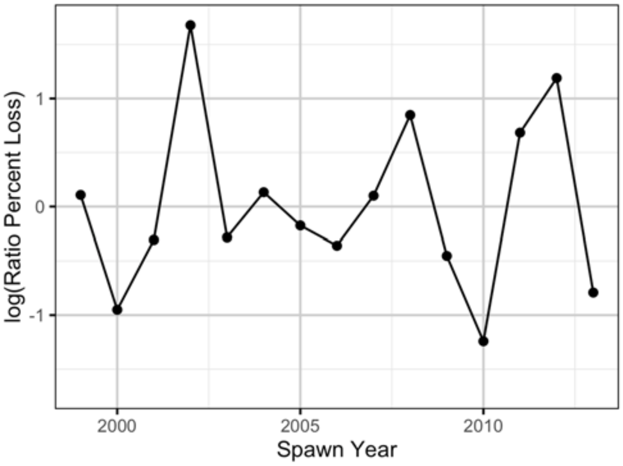

Figure 33: Ratio of percentage egg loss for Mountain Whitefish in the lower Columbia River by spawning year, 1999 to 2013.

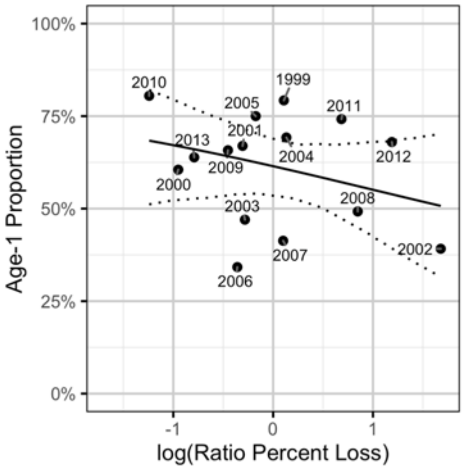

Figure 34: **Relationship between the proportion of age-1 to age-2 Mountain Whitefish and the estimated proportion of Mountain Whitefish egg loss due to dewatering. Year labels represent the spawning year. The predicted relationship is indicated by the solid black line and dotted line represents the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

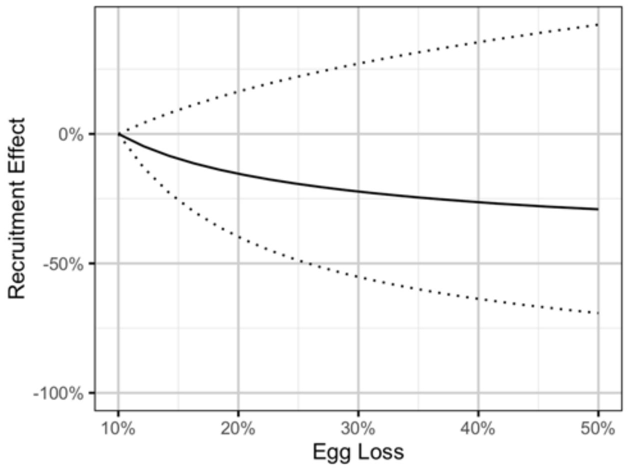

Figure 35: **Predicted percent change in age-1 Mountain Whitefish abundance by egg loss in the spawn year relative to 10% egg loss in the spawn year (with 95% CRIs).**

3.9 Stock-Recruitment Relationship

3.9.1 Mountain Whitefish

The Beverton-Holt stock-recruitment curve had poor fit with Mountain Whitefish data for the LCR (Figure 36). The stock-recruitment relationship did not suggest any 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. However, 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 predicted carrying capacity decreased with increasing proportion of egg loss (Figure 37) but the effect of egg loss was not significant in the model (*P*=0.4).

The largest estimated egg loss occurred for the 2012 spawning year (36%) but the number of recruits was greater than the average recruitment predicted by the stock-recruitment curve (Figure 36). On the other hand, the years with the next greatest estimated egg loss, which were 2002 (23%) and 2008 (30%), had low numbers of recruits despite large stock sizes, which supports a potential negative effect of egg dewatering on recruitment. Years with low levels of estimated egg loss (e.g. 2001, 2010, 2011) tended to result in greater numbers of age-1 fish than average values predicted by the curve. Therefore, the data suggest a negative effect of egg loss on recruitment of Mountain Whitefish, but with significant variability in the relationship, and some outlier years, such as 2012, where significant (36%) egg losses did not appear to affect recruitment.

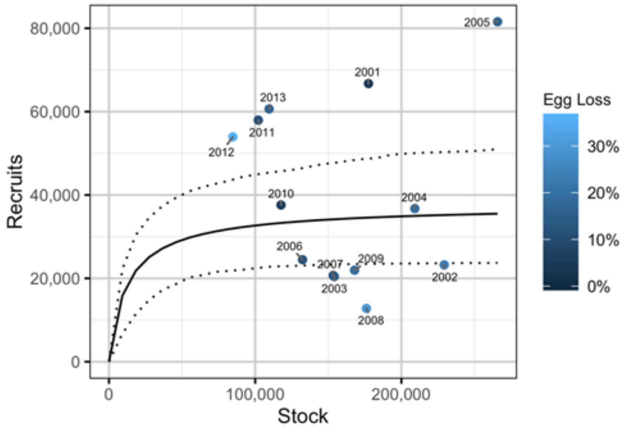

Figure 36: Predicted stock-recruitment relationship between age-2+ spawners ("Stock") and subsequent age-1 Mountain Whitefish ("Recruits") by spawn year (with 95% CRIs). Estimated proportion of egg loss due to dewatering for each spawning year is shown by blue shading of points.

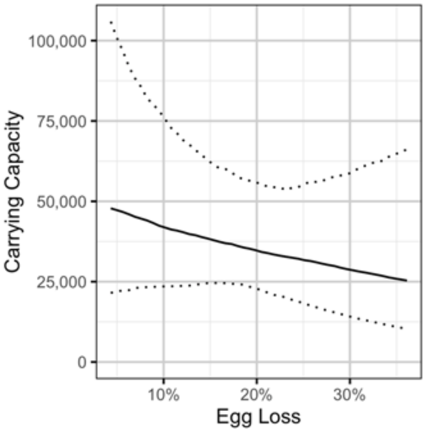

Figure 37: Predicted carrying capacity of age-1 Mountain Whitefish recruits by percentage egg loss (with 95% CRIs).

3.9.2 Rainbow Trout

The Beverton-Holt stock-recruitment curve fitted poorly the Rainbow Trout data for the LCR (Figure 38). The stock-recruitment relationship 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 lower part of the stock recruitment curve (<20,000 adults) where a decrease in recruitment but an increase 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 predicted carrying capacity for age-1 recruits increased with increasing egg loss (Figure 39) and the effect of egg loss on density-dependence was significant in the stock-recruitment model (*P*=0.04). This trend was opposite of what was expected, as increasing egg losses should decrease the number of recruits. However, the observed egg losses were relatively small, with estimates of less than 3% in all years. Possible reasons for the positive effect of egg loss on recruitment are discussed in Section 4.8.

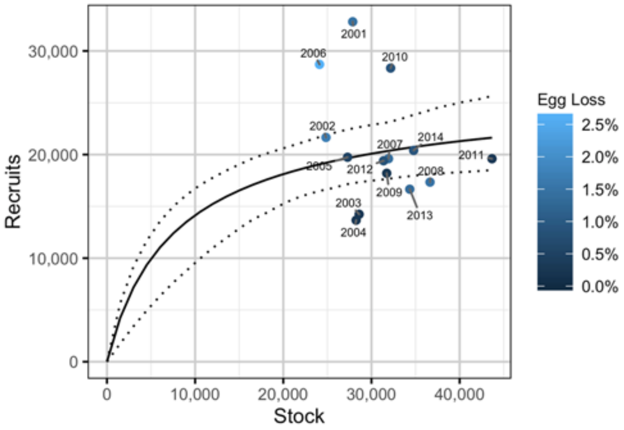

Figure 38: **Predicted stock-recruitment relationship between age-2+ spawners (“Stock”) and subsequent age-1 Rainbow Trout (“Recruits”) by spawn year (with 95% CRIs). Estimated proportion of egg loss due to dewatering for each spawning year is shown by blue shading of points.**

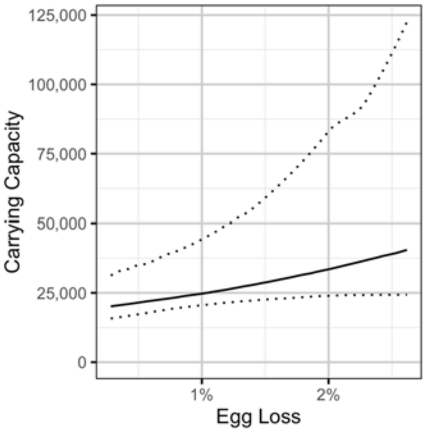

Figure 39: **Predicted carrying capacity of age-1 Rainbow Trout recruits by percentage egg loss (with 95% CRIs).**

3.10 Environmental Analyses

3.10.1 Long-Term Trends

Multivariate analyses were used to assess relationships between the environmental and fish population variables (Table 6). Dynamic factor analysis reduced the 17 environmental time series and 20 fish indexing time series to six common trends. Figure 40 shows the standardized values of the environmental and fish indexing time series along with the predicted values and credible intervals produced by the dynamic factor analysis. NMDS was used to graphically assess variables that had the most similar trends over time, as indicated by proximity on the NMDS plot. Mean discharge of the Columbia River (January to March [“DisMeJanMar”], April to June [“DisMeAprJun”] and July to September [“DisMeJulSep”]) was related to the annual biomass of invertebrates (“EPT”; Figure 41), with decreases in 2009 and 2010 (Figure 40).

Hourly discharge variability in the fall (October – December) was correlated with the abundance of adult Walleye. Similar to the 2014 NMDS, the estimated annual proportion of Mountain Whitefish egg loss (“RegimeMW”) was most closely related to the length of age-0 Mountain Whitefish in 2015. The estimated proportion of Rainbow Trout egg loss (“RegimeRB”) was most closely related to the length of both age-1 Rainbow Trout and Mountain Whitefish, as well to the growth of Rainbow Trout. The high stress value (26.8%) of the NMDS suggested poor representation of the fish and environmental variables in two dimensional space, which likely contributed to the weak correlations among variables.

Table 6: Definitions of abbreviated names used in analysis of environmental and fish variables.

Abbreviation	Definition	Abbreviation	Definition
AbnAdMW	Abundance of Adult Mountain Whitefish	GrwMW	Growth of Mountain Whitefish
AbnAdRB	Abundance of Adult Rainbow Trout	GrwRB	Growth of Rainbow Trout
AbnAdWP	Abundance of Adult Walleye	GrwWP	Growth of Walleye
AbnSubMW	Abundance of Subadult Mountain Whitefish	LenAge0MW	Length of Age-0 Mountain Whitefish
AbnSubRB	Abundance of Subadult Rainbow Trout	LenAge0RB	Length of Age-0 Rainbow Trout
ConAdMW	Condition of Adult Mountain Whitefish	LenAge1MW	Change in Length For Age-0 to Age-1 Mountain Whitefish
ConAdRB	Condition of Adult Rainbow Trout	LenAge1RB	Change in Length For Age-0 to Age-1 Rainbow Trout
ConAdWP	Condition of Adult Walleye	PDO	Pacific Decadal Oscillation Index
ConSubMW	Condition of Subadult Mountain Whitefish	RegimeMW	Estimated Proportional Annual Egg Loss, Mountain Whitefish
ConSubRB	Condition of Subadult Rainbow Trout	RegimeRB	Estimated Proportional Annual Egg Loss, Rainbow Trout
DisDiAprJun	Mean of Hourly Discharge Difference, April to June	SurAdMW	Survival of Adult Mountain Whitefish
DisDiJanMar	Mean of Hourly Discharge Difference, January to March	SurAdRB	Survival of Adult Rainbow Trout
DisDiJulSep	Mean of Hourly Discharge Difference, July to September	SurAdWP	Survival of Adult Walleye
DisDiOctDec	Mean of Hourly Discharge Difference, October to December	TemMeAprJun	Mean Water Temperature, April to June
DisMeAprJun	Mean Discharge, April to June	TemMeJanMar	Mean Water Temperature, January to March
DisMeJanMar	Mean Discharge, January to March	TemMeJulSep	Mean Water Temperature, July to September
DisMeJulSep	Mean Discharge, July to September	TemMeOctDec	Mean Water Temperature, October to December
DisMeOctDec	Mean Discharge, October to December	Zoo	Biomass of Zooplankton in Arrow Lakes Reservoir
EPT	Annual Biomass of Invertebrates (Ephemeroptera, Plecoptera, Trichoptera and Dipterans)		

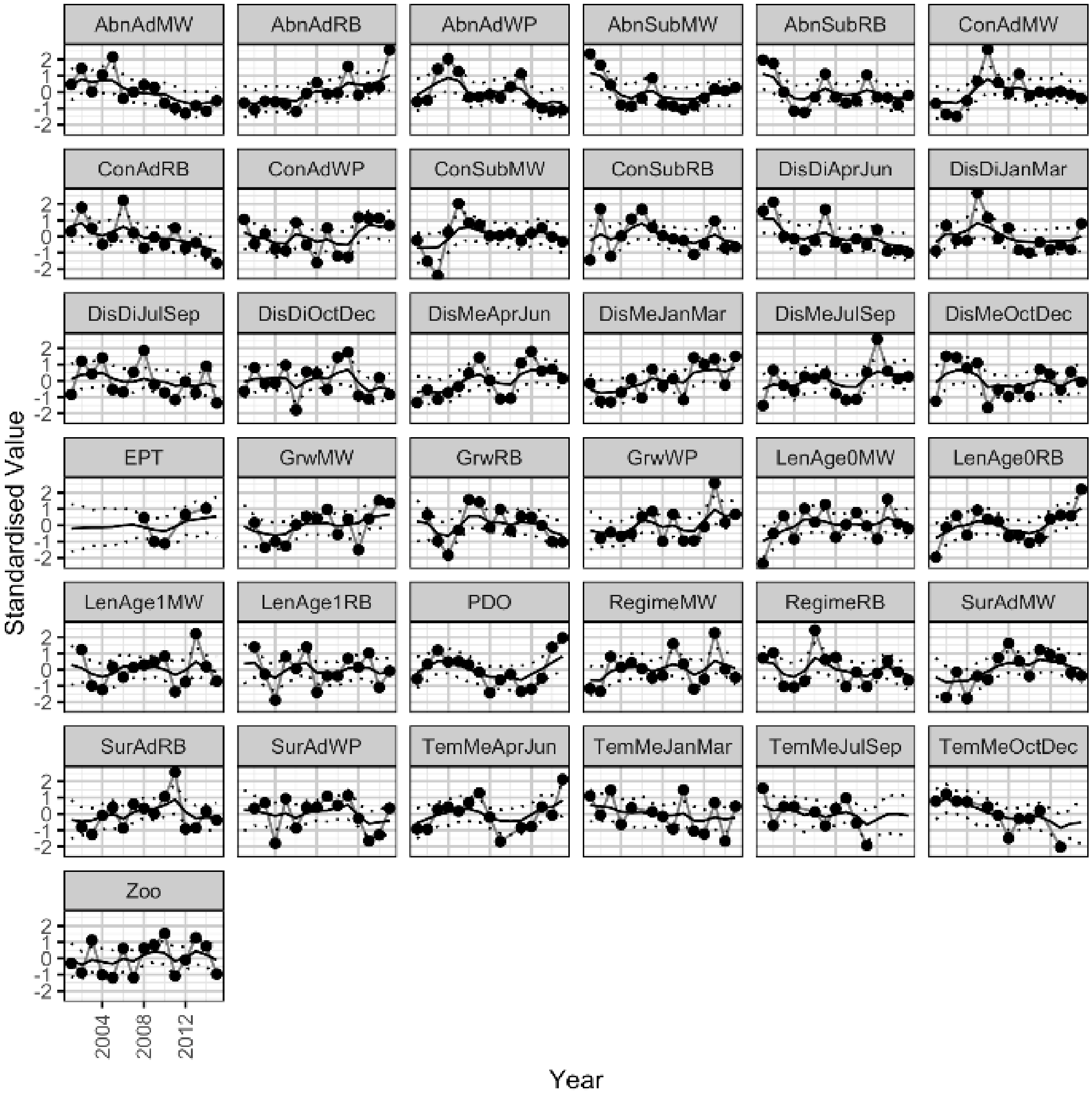

Figure 40: **Environmental and fish index time series in the lower Columbia River, 2001-2015. Black points are standardized values of the variables and the thicker black line represents predicted values (with 95% CRIs as dotted lines) from the dynamic factor analysis.**

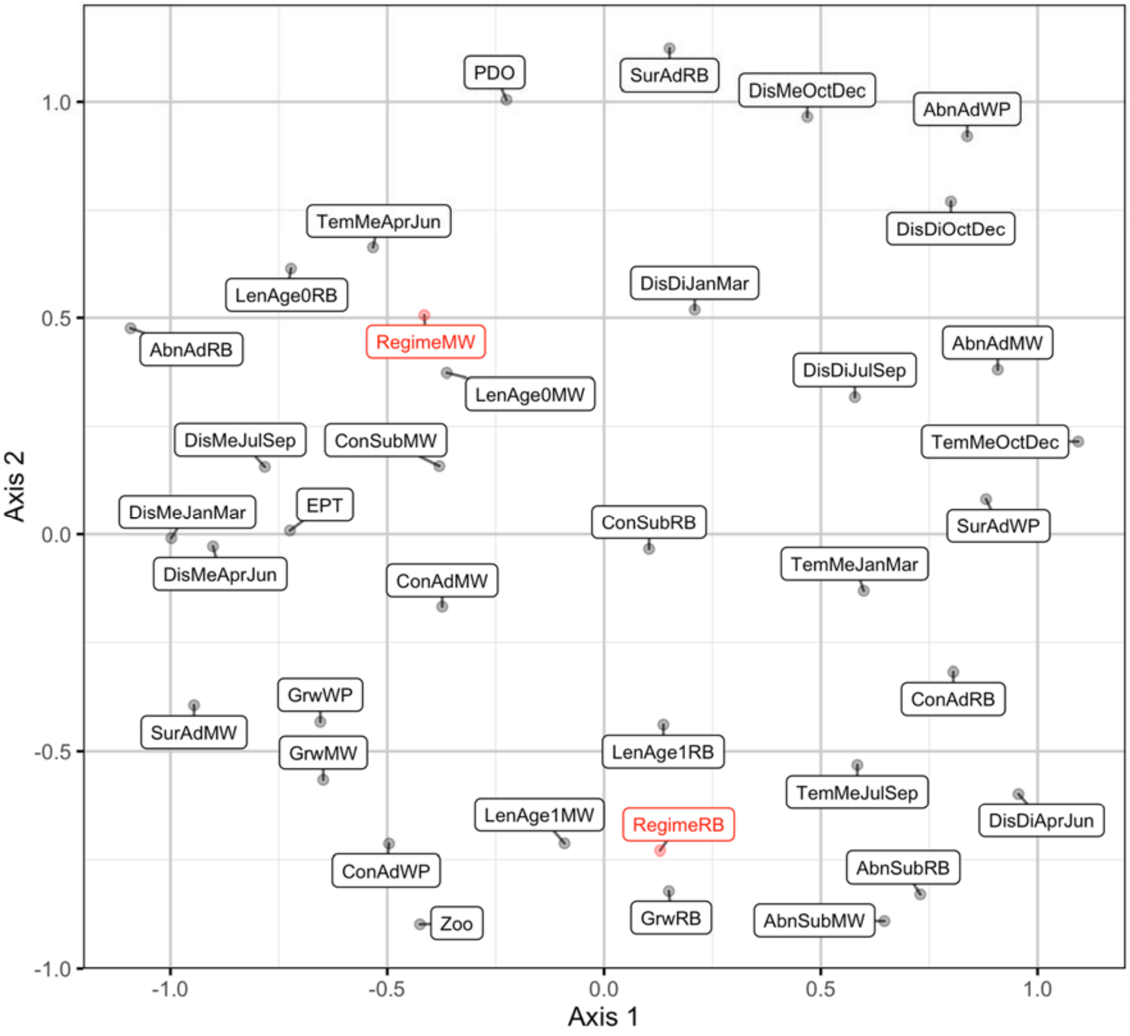

Figure 41: **Non-metric multidimensional plot showing clustering of standardized variables by trend weightings from the dynamic factor analysis used to assess common long-term trends in the environmental and fish variables (stress = 26.8).**

3.10.2 Short-Term Trends

Correlations between the residuals of the dynamic factor analysis model were calculated to assess short-term inter-annual associations among variables, after removing the effect of long-term trends. The analysis did not suggest a large number of short-term associations, as indicated by relatively spread-out points on the NMDS plot (Appendix G, Figure G14). Although there were no large groupings of variables, there were some environmental variables with residual variability that was similar to that of fish metrics. For example, the hourly discharge variability in fall (October – December) was correlated with the condition of adult Walleye and the survival of adult Rainbow Trout. The hourly discharge difference in winter (January – March) had similar short term variation as the abundance of Mountain Whitefish and the condition of subadult Mountain Whitefish. Overall, the analysis did not suggest any strong short-term associations in the data.

3.11 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). Catch of Northern Pike declined in 2014 and 2015. In 2014 and 2015, a Northern Pike gill netting suppression program was conducted by

Mountain Water Research for the Ministry of Forests Land and Natural Resources Operations (MFLNRO) and Teck Metals Ltd. (Baxter 2016). A total of 249 Northern Pike were removed during the gill netting program in 2014 (n=133) and 2015 (n=116).

During the LCR Fish Indexing Program in 2015, all Northern Pike were captured in the Columbia River upstream of the Kootenay River confluence. As requested by the MFLNRO (J. Burrows, pers. comm.), all captured Northern Pike were euthanized.

Table 7: 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

Other aquatic invasive species captured or observed within the LCR in 2015 include nine Brook Trout (*Salvelinus fontinalis*), two Yellow Perch (*Perca flavescens*), one Tench (*Tinca tinca*), one Brown Trout (*Salmo trutta*), and one Smallmouth Bass (*Micropterus dolomieu*).

In 2015, six Burbot were recorded in the LCR, which was the lowest number captured since 2001 (minimum = 3; maximum = 247; Appendix E, Table E1). Seventeen White Sturgeon (5 adults and 12 immatures) were recorded (all observed; none captured) during the 2015 survey. Observational information for these fish is provided in Attachment A.

4.0 DISCUSSION

The results of the monitoring program from 2001 to 2015 and how they related to the management questions are discussed in the following sections. 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

4.1.1 Mountain Whitefish

Length-at-age models for fry and subadult Mountain Whitefish suggested increased growth between 2001 and 2007. Growth of Mountain Whitefish based on the model using inter-year recaptures also increased between 2003 and 2007. This period of increasing length-at-age and growth corresponded with declining abundance of subadult Mountain Whitefish, suggesting an inverse relationship between abundance and growth. Density-dependent growth suggests there may be competition for food, habitat or other resources when the abundance of subadult Mountain Whitefish is high in the LCR. Body condition (a short-term proxy for growth) was also greater in 2005 when abundance was low.

In the NMDS of long-term trends (Figure 41), the percent Mountain Whitefish egg loss was positively correlated with the length of age-0 Mountain Whitefish. If the similar trends in egg dewatering and fry length were not simply due to chance, it could have been that the discharge reductions during the egg incubation, emergence or early rearing period could have a positive effect on subsequent growth and size-at-age.

Among watersheds in Idaho, USA, Meyer et al. (2009) found that Mountain Whitefish growth was positively correlated with mean annual water temperature. In the LCR analysis, water temperature was not correlated with long or short-term variation in Mountain Whitefish size or growth. Overall, water temperature was relatively similar among years (Appendix D, Figure D3), which suggested that inter-annual variation in discharge and dam operations did not result in very large variation in water temperature in the LCR, which could explain the failure to detect strong relationships with fish populations.

4.1.2 Rainbow Trout

Rainbow Trout had substantial inter-annual variability in growth that ranged from 123 to 203 mm between 2001 and 2015 for a 200 mm individual (Figure 7). Length-at-age of fry, subadult growth based on length-at-age, and growth based on inter-annual recapture did not show similar inter-annual trends. Fry length-at-age was greater in 2015 than any previous study year. Reasons for the increase in fry length are unknown. In comparison, Mountain Whitefish were not larger than normal in 2015. Trends in length-at-age for fry and subadult Rainbow Trout may differ due to differences in habitat or food preferences in these life stages.

Length-at-age and growth of Rainbow Trout were correlated with the estimated proportion of Rainbow Trout egg loss (Figure 41). Egg dewatering cannot plausibly have direct effects on length of age-1 Rainbow Trout. However, the results suggest that changes in the size of adult Rainbow Trout were correlated with discharge reductions that dewater eggs in the spring and summer.

4.1.3 Walleye

Annual growth of Walleye increased from 2002 to 2007, peaked in 2013, and was near average in 2014 and 2015. Growth in 2013 (based on change in length from fall 2012 to fall 2013) was greater than all other years and followed a year with low abundance in 2012. This suggests a density-dependent relationship with greater growth of Walleye when abundance is low. However, there was not a consistent relationship between density and growth in other years of the study.

Overall, a lack of age data and limited number of inter-year recaptures hinder growth analyses for Walleye. 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

Abundance of subadult Mountain Whitefish decreased markedly 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 an approximately 85% 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.

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, young of the year 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 38% of the fish prey fish identified (Baxter 2016). 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 concerns the effects of variation in flow regime on Mountain Whitefish abundance. The estimated proportion of Mountain Whitefish egg loss, which reflects annual variability in discharge reductions, was not associated with the abundance of subadult (age-1) or adult (age-2 and older) Mountain Whitefish, based on the multivariate analysis. The abundance of Mountain Whitefish fry would be expected to be related to the proportion of egg loss from the previous year but 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.

The environmental variable most closely associated with the abundance of adult Mountain Whitefish was mean water temperature during the fall. Mountain Whitefish spawn in the late fall and winter and the onset of spawning is linked to water temperature (Golder 2014). Therefore, the association between water temperature and abundance could be related to Mountain Whitefish moving into the study area for spawning purposes. A better understanding of Mountain Whitefish migrations in the study area would be necessary to discern whether the correlation with water temperature reflects changes in abundances or fish movements in the study area.

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 doubled from ~25,000 in 2002 to ~51,000 in 2015. In comparison, estimates of spawner abundance based on visual observations and an area-under-the-curve model increased nearly ten-fold from ~1600 spawners in 1999 to ~13,000 in 2014 (Irvine et al. 2015). 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 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).

In many years, capture efficiency of subadult Rainbow Trout decreased during each successive sample session (Appendix G, Figure G5). This result is disconcerting, as it 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 also was 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 2010 to 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 (WDFW Unpublished Data), 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.

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, electroshocking 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 electroshocking surveys every year since 2010. Attempts to suppress the growing Northern Pike population through a targeted gill-netting program in 2014 and

2015 appear to be reasonably successful with 249 individuals removed, which was estimated to represent 30-40% of the population (Baxter 2016). The number of Northern Pike caught and observed by boat electrofishing during this program decreased from 135 in 2013 to 25 in 2014 and nine in 2015, which also suggests that suppression efforts decreased population size in the study area.

Northern Pike likely originated from established populations in the Pend d'Oreille River. Very high water levels in 2012 resulted in many areas with flooded terrestrial vegetation in the upper LCR, which may have provided suitable spawning habitat for Northern Pike and further facilitated an increase in their local abundance. This highly efficient piscivore has the potential to alter the populations of index species and other fishes in the LCR.

The introduction of a non-native species is a large factor contributing to the decline of salmonids in a portion of the Columbia River in the USA (Sanderson et al. 2009). As control or eradication are most effective close to the time of introduction, when abundance and spatial distribution are low (Myers et al. 2000), additional information regarding Northern Pike in the LCR is urgently needed if resource managers wish to control or prevent further invasion by this species. Such studies are beyond the scope of CLBMON-45, but would provide valuable information to help interpret trends and answer management questions regarding index species.

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 or 2015, 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).

4.2.5 Georeferenced Visual Enumeration Surveys

Visual surveys were conducted for the third consecutive year in 2015. In all three years, counts of observed fish from visual surveys generally corresponded well with mean catches from mark-recapture surveys (Figure 23). There were some differences among years, with a greater count:catch ratio in 2013 and 2015 than in 2014, and greater variability in the relationship for Walleye in 2013 than in other years. These differences may be attributed to differences in sampling conditions or observers that affected observation or capture efficiency. Advantages of the visual surveys compared to mark-recaptures surveys include reduced handling of fish, less sampling time per site that could allow more sites to be sampled, and the addition of finer-scale distribution data.

When estimating the lengths of fish during visual surveys, there were several potential sources of error or bias. Length estimates may have been affected by magnification by water, as objects appear larger in water than in air because of the greater refractive index of water (Luria et al. 1967). The depth of fish in the water column is also expected to have an impact on perceived length. Despite these factors, the results suggest that the observers were reasonably accurate in their estimates of fish length (Figure 14). The length bias model suggested that, on average, observers underestimated fish lengths by ~10-20%, depending on species (Figure 14). The length bias model provided a useful method to assess and quantify biases in length estimation and adjust fish lengths before use in other analyses.

4.3 Spatial Distribution

4.3.1 Mountain Whitefish

Subadult Mountain Whitefish densities were greatest in the 10-km reach between HLK and the Kootenay River confluence. This result 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 2015 (Attachment A). Most recently, Northern Pike have been captured in increasing numbers 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 2016). 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 this age-class were highest near Norn's Creek Fan, in the downstream portions of the Kootenay River, upstream of Sullivan Creek, and near the City of Trail Airport. Norn's Creek Fan, the Kootenay River, and the City of Trail Airport area are known Mountain Whitefish spawning locations (Golder 2012), whereas the site located upstream of Sullivan Creek is close to a known spawning area (i.e., Lower Cobble Island), which may indicate that Mountain Whitefish use these areas for holding purposes prior to spawning.

The results did not suggest any large temporal changes in the spatial distributions of subadult and adult Mountain Whitefish between 2001 and 2015. Shannon's index of evenness, which represents the similarity of abundance among sites, did not differ among years during the study period.

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. 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). Shannon's index of evenness did not indicate any changes in the relative abundance among sites, which suggests similar spatial distribution across index sites during the study period.

The densities of subadult and adult Rainbow Trout at synoptic sites (i.e., sites that were not systematically sampled prior to 2011) were generally similar to indexing sites, except at synoptic 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 synoptic 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. 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 Sculpin species and Redside Shiner densities 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 through 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.

Shannon’s index of evenness did not indicate any changes in the relative abundance among sites, which suggests no 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 (24-90%). 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 Whiteifsh in Idaho (Meyer et al. 2009).

Currently, each of the management hypotheses is tested using separate HBMs, 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 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 2015, possibly because Mountain Whitefish were moving into and out of the study area in the fall study period for spawning migrations (Golder and Poisson 2013b). 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 29 to 55% across all study years. For adult Rainbow Trout, both survival and abundance increased gradually between 2001 and 2011. However, survival decreased to 30-35% during 2012 to 2015. 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. 2015), which may reflect density-dependent survival and intra-specific competition for resources.

4.4.3 Walleye

Walleye survival increased from 2006 to 2011, was lower in 2013 to 2014 (35-38%), and increased to 53% in 2015, which was near the long-term average. Walleye abundance, however, has remained low after decreasing in 2011. 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), interpretation of annual survival could be confounded by fish movements. Multivariate analyses suggested that the survival of Walleye was associated with the long-term trend in mean temperature during both fall (October – December) and winter (January - March).

4.5 Body Condition

4.5.1 Mountain Whitefish

The body condition of subadult Mountain Whitefish fluctuated between 1990 and 2015 with no consistent trend over this time period though it has been less variable since 2006. Similarly, body condition of adult Mountain Whitefish was variable between 1990 and 2010 but has been fairly consistent through to 2015. The changes in body condition of adult Mountain Whitefish varied from -14% to 9% (compared to a typical year) between 1990 and 2015 (Figure 27). 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 23% variation (-14 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 (~-10% effect size) in the early 1990s compared to between 2001 and 2015 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 2015 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. Larval Trichoptera and larval Diptera are major food sources for Mountain Whitefish in the LCR (Golder 2009a). The decrease in estimated biomass of invertebrates (EPT and Dipterans) measured in the LCR in 2009 and 2010 (Figure 41) was not associated with any decrease in body condition of Mountain Whitefish. The results do not suggest a correlation between estimated invertebrate biomass and Mountain Whitefish body condition as this was based on a relatively small time-series for invertebrates (five years of data).

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

Although there was no sustained temporal trend in body condition for Rainbow Trout, body condition was greater in 2002 and 2006 for both subadult and adult Rainbow Trout compared to other study years. Both water temperature and discharge in the Columbia River were near historical averages in 2002 and 2006, and body condition was not correlated with either of these variables. Thus, the results do not suggest that variations in flow regime explain the inter-annual differences in Rainbow Trout body condition.

The decrease 7% in body condition between 2011 and 2015 coincided with high and increasing abundance of Rainbow Trout. This may indicate an increase in intra-specific competition for food that caused the decrease in body condition. The recent high abundance and low body condition also coincided with a decrease in adult survival estimates, which suggests that low body condition may lead to lower survival of Rainbow Trout in the LCR. 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 in the study area fluctuated between 1990 and 2015 and the only variable following a similar trend in the multivariate analysis was the biomass of zooplankton in the LCR. Body condition was greater in 2012 to 2015 than in most previous years and coincided with very low abundance, suggesting density-dependent growth that could be due to intraspecific competition for food and cover, similar to that reported for this species by other researchers (Hartman and Margraf 1992; Porath and Peters 1997; Forney 2011).

4.6 Scale Age

Scales of Mountain Whitefish and Rainbow Trout were aged during previous years of this program from 2001 to 2010. These previous analyses suggested that age-0 and age-1 fish could be accurately aged using scales but that these age-classes could also reliably be distinguished based on length-at-age cutoffs alone. Ageing accuracy declined for age-3 and older individuals, likely because as body growth slows after reaching maturity, annuli near the outer edge of the scale become difficult to discern.

There were two main objectives of ageing analyses conducted in the 2015 study year: 1) assign ages to recaptured fish of known age to model the difference between assigned and true age; and 2) use age data from 2001 to 2015 to calculate age-1:2 ratios as an annual index of recruitment in the LCR (Section 4.7). Age analyses were conducted only for Mountain Whitefish in 2015. Similar analyses would also be informative for Rainbow Trout but ageing for this species is not included in the current scope of work.

The scale age model showed that agers in 2015 were, on average, overestimating ages by one year. As the bias was relatively consistent across age-classes and agers, the data were corrected by subtracting one year prior to using ages in the age ratio analysis. Overestimation of ages was not expected as others have reported that scale-based estimates typically underestimate ages of adult whitefish in the LCR (Golder 2008) and elsewhere (Barnes and Power 1984; Skurdal et al. 1985). The consistent overestimation, even for juvenile Mountain Whitefish, suggests that agers may have been consistently counting a false annuli or some other feature that previous agers (2001-2010) did not, and that this feature does not represent a yearly growth ring. This bias can be corrected in future years of the study, either through correcting the bias in the model (similar to the correction in the 2015 analysis) or by training of agers regarding which annuli to count, and which should be considered false annuli.

As the 2011-2015 ages were corrected for bias, these age data were considered suitable for the analysis of age-1:2 ratios (below). The age data from 2001 to 2015 could also be used in a catch curve analysis of survival, to corroborate the mark-recapture survival estimates, which currently have large uncertainty. Catch curve analyses are planned for the next year of the study, after ageing techniques and the bias correction model have been refined.

4.7 Age Ratios

The proportional ratio of age-1:2 Mountain Whitefish was used as in indicator of recruitment to assess annual variation and the effects of egg dewatering. The age-1:2 ratio ranged from 34% to 80% between the 1999 and 2013 spawning years, which suggests substantial inter-annual variation in recruitment during the monitoring period. The age-1:2 ratio recruitment index was negatively related to the estimated annual egg loss but the relationship was not statistically significant because of the large variability in the relationship between these two variables (Figure 34). The variability in the recruitment-egg loss relationship was likely because there are many of other factors, such as population dynamics, environmental conditions, and ecological interactions, that also influence survival and recruitment, in addition to egg dewatering. Nonetheless, this analysis provides some limited evidence that observed water level fluctuations that are predicted to dewater eggs were associated with reduced recruitment of Mountain Whitefish in the LCR between 2001 and 2015.

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 2010 whereas scales were collected and but not analyzed for Rainbow Trout from 2011 to 2015.

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 2015 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.

The stock-recruitment model included a parameter to test the effects of egg loss due to dewatering. For Mountain Whitefish, there was a non-significant negative relationship between predicted egg loss and the carrying capacity. Years with high egg loss tended to have lower recruitment than the average value predicted based on stock size. However, there were exceptions to this trend, especially in 2012, which had the greatest predicted egg loss (36%) and the lowest estimated adult abundance, but greater than average recruitment of age-1 fish. Our interpretation is that there is some limited evidence of a negative effect of egg dewatering on recruitment of Mountain Whitefish but because of the large observed variability, factors other than egg loss and spawning stock size like have a large influence on recruitment.

For Rainbow Trout in the LCR, the parameter representing egg loss in the model was statistically significant, with a predicted positive effect of egg loss on the carrying capacity for age-1 recruits. This unexpected positive relationship could be because the small percentages of egg loss (<3%) were not large enough to cause a detectable decrease in recruitment but both egg loss and recruitment were correlated with some other unmeasured factor that decreases recruitment. For instance, greater predicted egg loss may be correlated with lower initial water levels during spring, which may have some unknown negative effect on survival and recruitment. The spatial distribution of spawning also varies with river level (Irvine et al. 2015) which could affect recruitment, for instance, if there is greater competition for spawning or rearing areas in years with low water and therefore fewer dewatering events. Based on the available data, there is no evidence of negative effects of egg losses less than 3% 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). For the LCR, it is unknown how or if different environmental variables may influence survival and recruitment. In general, environmental variables such as water temperature and discharge were not correlated with subadult or adult abundance based on the multivariate analysis (Section 3.10). It is possible to include environmental covariates, in addition to estimated egg dewatering, in the stock-recruitment model to attempt to account for variation in recruitment that is not accounted for by spawning stock size. However, this approach would only be recommended to test specific hypotheses regarding variables thought to influence recruitment and not as an exploratory assessment of all possible environmental effects on recruitment.

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 2015, and high abundances in recent years coincided with a decline in body condition and survival, suggesting density dependence. Data for Walleye also suggested density-dependence with a decrease in abundance and increase in body condition in the most recent years (2012 to 2015).

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, the age-1:2 recruitment index and the stock–recruitment relationship both suggested a negative effect of egg losses on recruitment but the effects were not statistically significant. Large variability in Mountain Whitefish recruitment for a particular level of egg loss or spawner abundance suggested weak predictive ability and 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 3% 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.

There were no strong correlations between fish population metrics and environmental variables. The age ratio and stock recruitment analyses are considered more robust ways to assess the effects of flow variability whereas the DFA can be considered as an exploratory analysis of other covariates that could be influencing fish populations in the LCR. The large number of plausible covariates that could potentially impact fish abundance and condition, given the relatively short time series, can easily lead to spurious correlations, and this type of exploratory analysis is only useful as a screening tool to develop more specific hypotheses that are supported by additional evidence or the literature.

5.0 RECOMMENDATIONS

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

- Refine scale ageing protocols and modelling to ensure that the age data are comparable across all years, accurately reflect age distribution of the populations, and allow sources of variability to be quantified.
- Calculate the age-1:2 recruitment index for Rainbow Trout to assess inter-annual variation and the effects of egg dewatering. Currently, age data are only available for Rainbow Trout captured from 2001 to 2010.
- Conduct scale ageing for Rainbow Trout from scales collected in 2011 to 2015, and during future years of the study, to allow scale age bias modelling and calculation of age-1:2 recruitment index for all study years.
- 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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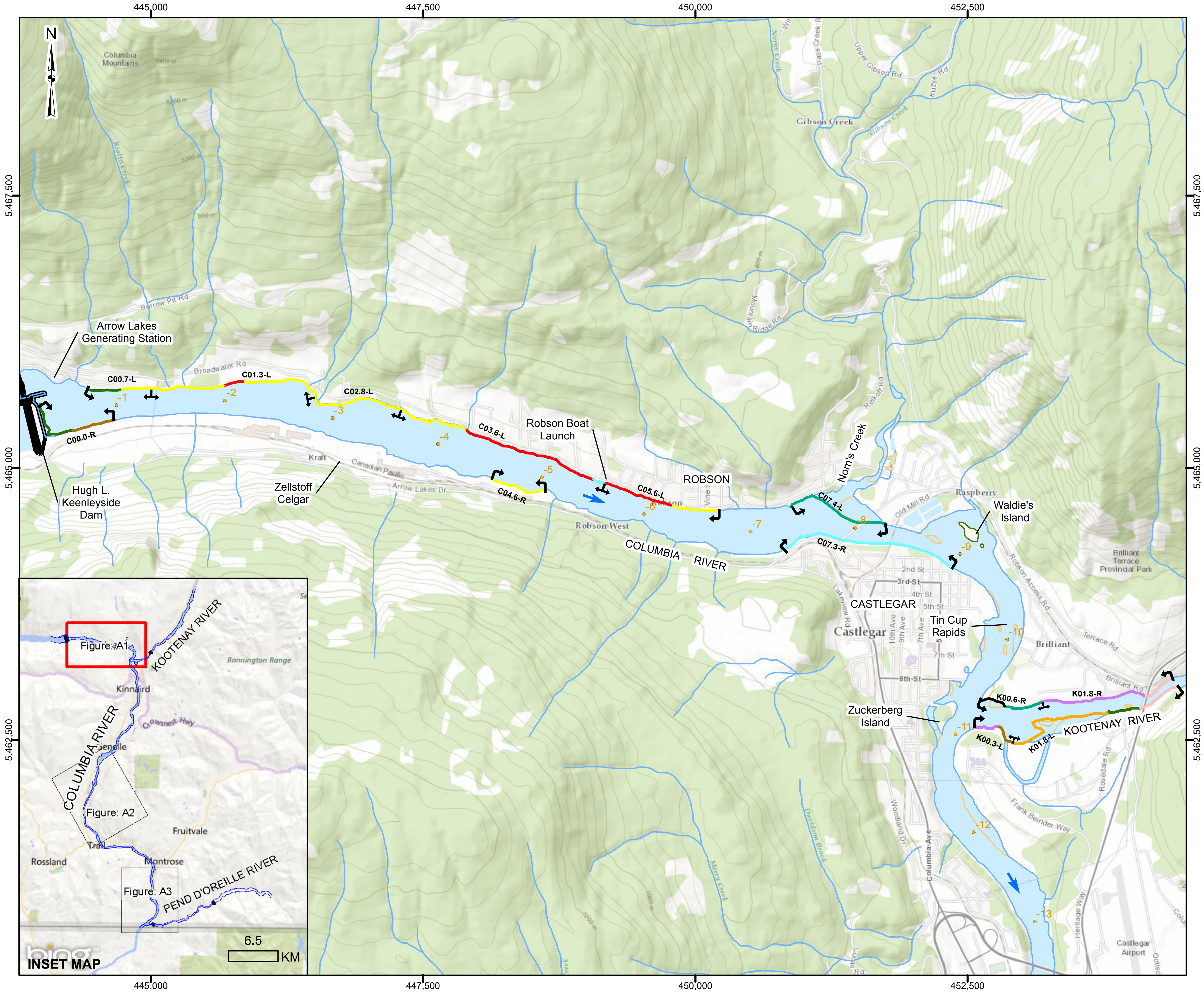
Appendix A - Maps



LEGEND

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

BANK HABITAT TYPE

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

REFERENCE

SERVICE LAYER CREDITS: SOURCES: ESRI, HERE, DELORME, TOMTOM, 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
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SCALE 1:35,000

PROJECT

LARGE RIVER FISH INDEXING PROGRAM
LOWER COLUMBIA RIVER

TITLE

UPPER SECTION OF STUDY AREA
2015 SAMPLE SITE LOCATIONS

Golder Associates

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GIS	JG/CD	15 JUN. 2016		
CHECK	DR	24 JUN. 2016		
REVIEW	BC	28 JUN. 2016		

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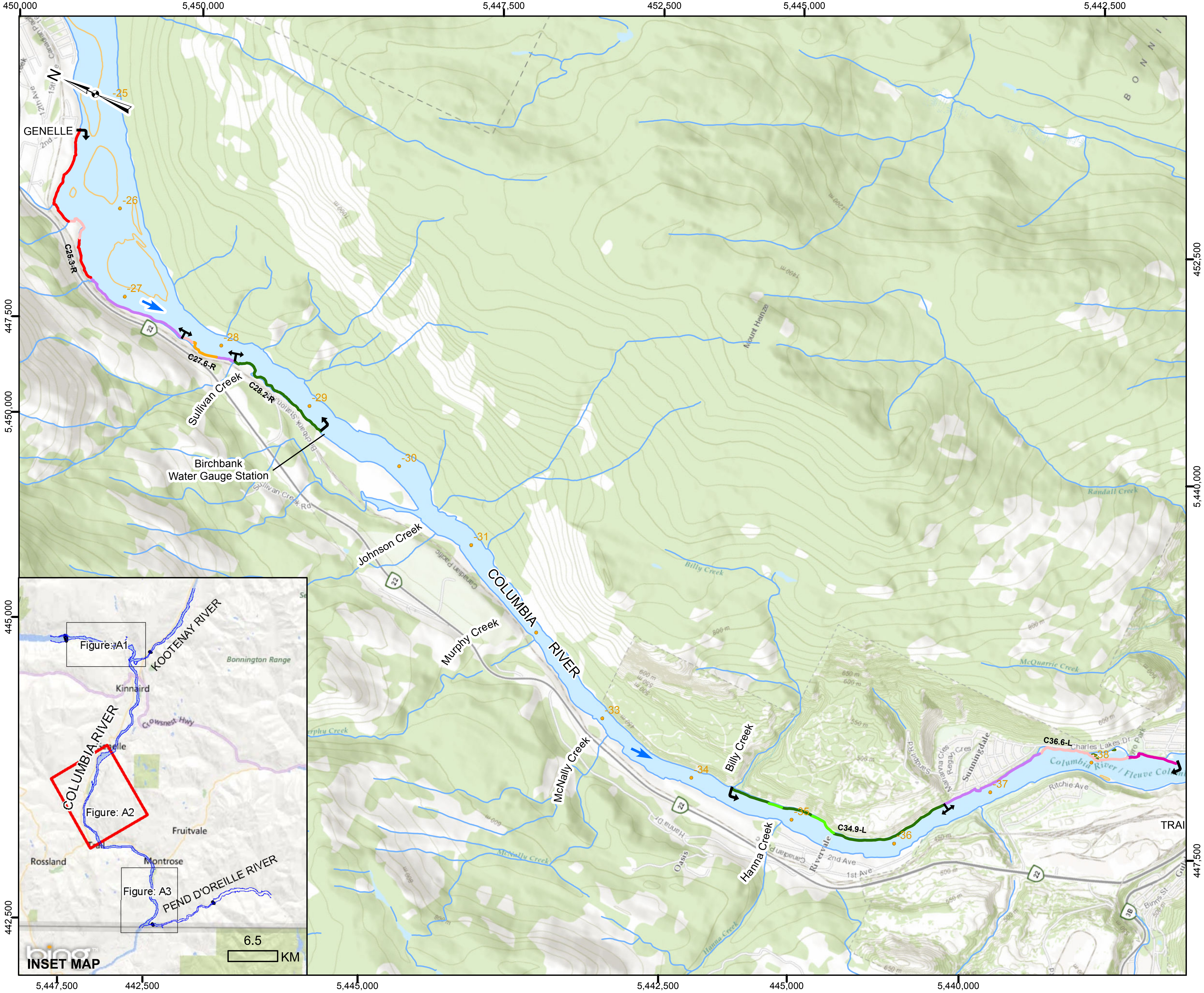

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LEGEND

- ● 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
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- A3 - ARMOURED SMALL/LARGE BOULDER
- A4 - ARMOURED LARGE BOULDER
- A5 - BEDROCK BANKS
- A6 - MAN-MADE RIP-RAP
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- D1 - DEPOSITIONAL SAND/SILT
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- D3 - DEPOSITIONAL LARGE COBBLE
- EDDY - EDDY

REFERENCE

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PROJECT

LARGE RIVER FISH INDEXING PROGRAM
LOWER COLUMBIA RIVER

TITLE

MIDDLE SECTION OF STUDY AREA 2015 SAMPLE SITE LOCATIONS

Golder Associates

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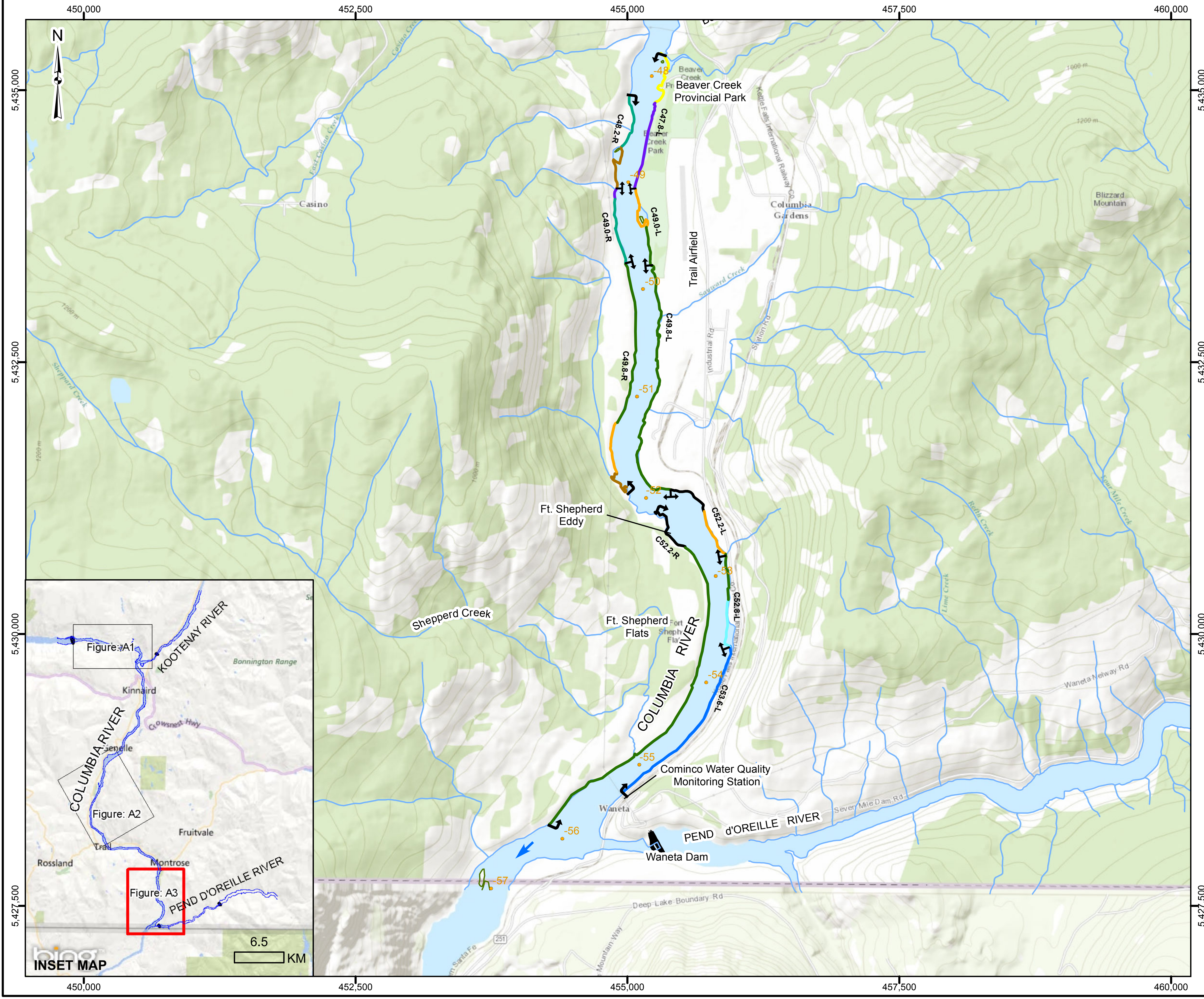

LEGEND

●	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

REFERENCE

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PROJECT
LARGE RIVER FISH INDEXING PROGRAM
LOWER COLUMBIA RIVER

TITLE
LOWER SECTION OF STUDY AREA 2015 SAMPLE SITE LOCATIONS

Golder Associates

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Table A1 Locations and distances from Hugh L. Keenleyside Dam of boat electroshocking sites in the lower Columbia River, 2015.

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

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

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

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

Table A2 Locations of selected sites and available sites included in the Generalized Random Tessellation Stratified (GRTS) survey, 2015.

Site Designation	Location (km)[a]	Bank[b]	Upstream UTM Coordinates			Downstream UTM Coordinates			Sites Selected in 2015
			Zone	Easting	Northing	Zone	Easting	Northing	
Columbia River Upstream									
C01.0-R	1.0	RDB	11U	444717	5465448	11U	447236	5465125	
C03.6-R	3.6	RDB	11U	447236	5465125	11U	448125	5464914	
C05.1-R	5.1	RDB	11U	448612	5464808	11U	449518	5464513	
C06.0-R	6.0	RDB	11U	449518	5464513	11U	450804	5464243	
C06.7-L	6.7	LDB	11U	450223	5464603	11U	450876	5464645	
C08.4-L	8.4	LDB	11U	451833	5464445	11U	452304	5464244	X
C08.6-L	8.6	LDB	11U	452132	5464468	11U	452720	5464206	
C08.9-R	8.9	RDB	11U	452375	5464074	11U	452797	5463486	
C09.0-L	9.0	LDB	11U	452286	5462718	11U	452286	5462718	
C09.2-L	9.2	LDB	11U	452720	5464206	11U	452987	5463481	
C09.8-L	9.8	LDB	11U	452926	5463604	11U	452620	5462860	
C09.8-R	9.8	RDB	11U	452761	5463608	11U	452416	5462880	
Columbia River Downstream									
C10.7-R	10.7	LDB	11U	452416	5462880	11U	452217	5462050	
C10.8-R	10.8	RDB	11U	452154	5462718	11U	452154	5462718	
C10.9-L	10.9	LDB	11U	452584	5462607	11U	453290	5460373	X
C11.5-R	11.5	RDB	11U	452217	5462050	11U	453103	5460426	
C13.4-L	13.4	LDB	11U	453290	5460373	11U	453321	5459007	X
C13.4-R	13.4	RDB	11U	453103	5460426	11U	453221	5458057	X
C14.8-L	14.8	LDB	11U	453321	5459007	11U	453210	5456890	
C15.8-R	15.8	RDB	11U	453221	5458057	11U	453234	5457317	X
C16.6-R	16.6	RDB	11U	453234	5457317	11U	452358	5456216	
C17.0-L	17.0	LDB	11U	453210	5456890	11U	452622	5455322	X
C18.0-R	18.0	RDB	11U	452358	5456216	11U	452351	5455401	
C18.8-R	18.8	RDB	11U	452351	5455401	11U	452122	5454012	
C19.0-L	19.0	LDB	11U	452622	5455322	11U	452444	5454183	X
C20.1-L	20.1	LDB	11U	452444	5454182	11U	451645	5453285	X
C20.4-R	20.4	RDB	11U	452122	5454012	11U	451093	5453191	
C21.3-L	21.3	LDB	11U	451645	5453285	11U	450603	5451637	
C21.8-R	21.8	RDB	11U	451093	5453191	11U	450495	5452148	
C22.9-R	22.9	RDB	11U	450495	5452148	11U	450188	5451058	
C23.4-L	23.4	LDB	11U	450603	5451637	11U	450368	5450764	X
C24.0-R	24.0	RDB	11U	450188	5451058	11U	449356	5450418	
C24.3-L	24.3	LDB	11U	450368	5450764	11U	449178	5449989	X
C25.3-L	25.3	MID	11U	448978	5450229	11U	448978	5450229	X
C26.2-L	26.2	MID	11U	448938	5449626	11U	448938	5449626	X
C27.5-L	27.5	LDB	11U	448193	5449036	11U	448064	5447758	
C28.8-L	28.8	LDB	11U	448064	5447758	11U	447820	5446998	
C29.2-R	29.2	RDB	11U	447715	5447420	11U	447397	5446252	
C29.6-L	29.6	LDB	11U	447820	5446998	11U	447491	5446079	
C30.5-R	30.5	RDB	11U	447397	5446252	11U	446817	5444824	
C30.6-L	30.6	LDB	11U	447491	5446079	11U	446746	5444432	X
C32.0-R	32.0	RDB	11U	446817	5444824	11U	446256	5443655	
C32.4-L	32.4	LDB	11U	446746	5444432	11U	446353	5442572	
C33.3-R	33.3	RDB	11U	446256	5443655	11U	446260	5442116	
C34.9-R	34.9	RDB	11U	446260	5442116	11U	446294	5441253	X
C35.7-R	35.7	RDB	11U	446294	5441253	11U	447152	5440472	
C36.9-R	36.9	RDB	11U	447152	5440472	11U	448305	5438607	
C38.8-L	38.8	LDB	11U	448340	5439017	11U	449001	5438233	X
C39.2-R	39.2	RDB	11U	448305	5438607	11U	448995	5438083	
C40.0-L	40.0	LDB	11U	449001	5438233	11U	450090	5438405	
C40.0-R	40.0	RDB	11U	448995	5438083	11U	450459	5438222	
C41.1-L	41.1	LDB	11U	450090	5438405	11U	452466	5438365	X
C41.5-R	41.5	RDB	11U	450459	5438222	11U	452579	5438015	
C43.5-L	43.5	LDB	11U	452466	5438365	11U	453245	5437597	
C43.7-R	43.7	RDB	11U	452579	5438015	11U	453275	5437384	
C44.6-L	44.6	LDB	11U	453245	5437597	11U	454179	5437228	X
C44.7-R	44.7	RDB	11U	453275	5437384	11U	454560	5436673	
C45.6-L	45.6	LDB	11U	454179	5437228	11U	454855	5436623	X
C46.2-R	46.2	RDB	11U	454560	5436673	11U	455141	5435856	
C46.4-L	46.4	LDB	11U	454855	5436623	11U	455319	5435321	X
C47.2-R	47.2	RDB	11U	455141	5435856	11U	455017	5434942	
C56.0-L	56.0	LDB	11U	454774	5428024	11U	453949	5427733	X

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

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

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 electroshocking sites within the lower Columbia River, 2015.

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 sites in the Middle Columbia River, 13 October to 10 November 2015.

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	4	12.60	170	Clear	High	High	High	60	0	0	0	0	10	30
Kootenay	K01.8-R	2	6	12.50	170	Clear	High	High	High	0	0	0	0	0	70	30
Kootenay	K01.8-R	3	9	11.30	140	Mostly cloudy	High	High	High	20	0	0	0	0	65	15
Kootenay	K01.8-R	4	4	10.20	170	Partly cloudy	High	High	High	0	0	0	0	0	65	35
Kootenay	K01.8-L	1	4	12.50	170	Clear	High	High	High	10	0	0	0	0	60	30
Kootenay	K01.8-L	2	5	11.80	170	Clear	High	High	High	25	0	0	0	0	60	15
Kootenay	K01.8-L	3	6	11.30	140	Mostly cloudy	High	High	High	15	0	0	0	0	70	15
Kootenay	K01.8-L	4	4	10.30	170	Partly cloudy	High	High	High	10	0	0	0	0	50	40
Kootenay	K00.6-R	1	4	12.80	170	Clear	High	High	High	20	0	0	30	0	50	0
Kootenay	K00.6-R	2	5	11.80	170	Clear	High	High	High	0	0	0	15	0	80	5
Kootenay	K00.6-R	3	8	11.30	140	Partly cloudy	High	High	High	0	0	0	40	0	60	0
Kootenay	K00.6-R	4	5	10.50	170	Partly cloudy	High	High	High	0	0	0	35	0	50	15
Kootenay	K00.3-L	1	4	12.90	170	Clear	High	High	High	20	0	0	0	0	15	65
Kootenay	K00.3-L	2	5	12.30	170	Clear	High	High	High	20	0	0	0	0	50	30
Kootenay	K00.3-L	3	9	11.30	140	Partly cloudy	High	High	High	60	0	0	0	0	10	30
Kootenay	K00.3-L	4	2	10.50	170	Mostly cloudy	High	High	High	20	0	0	0	0	30	50
Lower	C56.0-L	5	4	9.70	150	Mostly cloudy	High	High	High	30	0	0	0	0	0	70
Lower	C53.6-L	1	8	11.50	140	Clear	High	High	High	10	0	0	0	0	10	80
Lower	C53.6-L	2	5	11.00	150	Clear	High	High	High	40	0	0	0	0	0	60
Lower	C53.6-L	3	6	10.50	140	Partly cloudy	High	High	High	40	0	0	0	0	0	60
Lower	C53.6-L	4	4	9.70	150	Partly cloudy	High	High	High	40	0	0	0	0	10	50
Lower	C52.8-L	1	8	11.50	140	Clear	High	High	High	10	0	10	0	0	30	50
Lower	C52.8-L	2	5	10.60	150	Clear	High	High	High	25	0	0	0	0	50	25
Lower	C52.8-L	3	6	10.50	140	Partly cloudy	High	High	High	30	0	0	0	0	30	40
Lower	C52.8-L	4	3	9.40	150	Clear	High	High	High	30	0	0	0	0	40	30
Lower	C52.2-R	1	8	11.60	150	Clear	High	High	High	10	0	0	0	0	70	20
Lower	C52.2-R	2	4	10.60	140	Clear	High	High	High	10	0	0	0	0	0	90
Lower	C52.2-R	3	6	10.50	140	Partly cloudy	High	High	High	10	0	0	0	0	40	50
Lower	C52.2-R	4	2	9.40	150	Mostly cloudy	High	High	High	0	0	0	0	0	60	40
Lower	C52.2-L	1	9	11.50	140	Clear	High	High	High	20	0	0	0	0	10	70
Lower	C52.2-L	2	5	10.70	150	Clear	High	High	High	0	0	0	0	0	0	100
Lower	C52.2-L	3	6	10.50	140	Partly cloudy	High	High	High	15	0	0	1	0	0	84
Lower	C52.2-L	4	3	9.40	150	Partly cloudy	High	High	High	20	0	0	0	0	20	60
Lower	C49.8-R	1	9	11.50	150	Clear	High	High	High	15	0	0	0	0	75	10
Lower	C49.8-R	2	5	11.00	140	Clear	High	High	High	15	0	0	1	0	60	24
Lower	C49.8-R	3	8	10.50	140	Mostly cloudy	High	High	High	20	0	0	2	0	70	8
Lower	C49.8-R	4	1	9.00	150	Clear	High	High	High	0	0	0	1	0	74	25
Lower	C49.8-L	1	9	11.50	150	Clear	High	High	High	15	0	5	0	0	70	10
Lower	C49.8-L	2	9	10.90	150	Clear	High	High	High	10	0	0	0	0	60	30
Lower	C49.8-L	3	6	10.50	140	Partly cloudy	High	High	High	20	0	0	0	0	70	10

Continued...

[a] See Appendix B, Figures B1 to B3 for sample site locations.

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

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

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

Table B3 Continued.

Section	Site[a]	Session	Air Temperature (°C)	Water Temperature (°C)	Conductivity (µS)	Cloud Cover[b]	Water Surface Visibility	Instream Velocity[c]	Water Clarity[d]	Cover Types (%)						
										Substrate Interstices	Woody Debris	Turbulence	Aquatic Vegetation	Terrestrial Vegetation	Shallow Water	Deep Water
Lower	C49.8-L	4	4	9.40	150	Partly cloudy	High	High	High	0	0	0	2	0	80	18
Lower	C49.0-R	1	11	11.60	150	Clear	High	High	High	20	0	0	0	0	60	20
Lower	C49.0-R	2	5	11.30	140	Clear	High	High	High	10	0	0	0	0	70	20
Lower	C49.0-R	3	9	10.50	140	Partly cloudy	High	High	High	10	0	0	0	0	30	60
Lower	C49.0-R	4	2	9.00	150	Clear	High	High	High	10	0	0	0	0	40	50
Lower	C49.0-L	1	10	11.60	150	Clear	High	High	High	10	0	0	0	0	80	10
Lower	C49.0-L	2	11	11.30	150	Clear	High	High	High	0	0	0	0	0	90	10
Lower	C49.0-L	3	7	10.50	140	Partly cloudy	High	High	High	10	0	0	0	0	80	10
Lower	C49.0-L	4	6	9.00	150	Mostly cloudy	High	High	High	0	0	0	0	0	80	20
Lower	C48.2-R	1	12	11.70	150	Clear	High	High	High	10	0	0	5	0	80	5
Lower	C48.2-R	2	8	11.30	140	Clear	High	High	High	0	0	0	10	0	80	10
Lower	C48.2-R	3	11	10.50	140	Partly cloudy	High	High	High	0	0	0	0	0	90	10
Lower	C48.2-R	4	2	9.40	150	Clear	High	High	High	0	0	0	2	0	70	28
Lower	C47.8-L	1	12	11.60	150	Clear	High	High	High	10	0	0	5	0	80	5
Lower	C47.8-L	2	11	11.30	140	Clear	High	High	High	10	0	0	15	0	60	15
Lower	C47.8-L	3	9	10.50	140	Partly cloudy	High	High	High	20	0	0	10	0	60	10
Lower	C47.8-L	4	7	10.20	150	Mostly cloudy	High	High	High	30	0	0	10	0	50	10
Lower	C46.4-L	5	1	8.20	150	Clear	High	High	High	20	0	0	0	0	60	20
Lower	C45.6-L	5	1	8.20	150	Clear	High	High	High	30	0	0	0	0	60	10
Lower	C44.6-L	5	1	8.60	150	Clear	High	High	High	20	0	0	0	0	60	20
Lower	C41.1-L	5	1	8.20	150	Clear	High	High	High	30	0	0	0	0	50	20
Middle	C38.8-L	5	1	8.20	150	Clear	High	High	High	40	0	0	0	0	20	40
Middle	C36.6-L	1	6	11.20	160	Clear	High	High	High	10	0	0	2	0	0	88
Middle	C36.6-L	2	5	11.30	140	Clear	High	High	High	15	0	0	2	0	23	60
Middle	C36.6-L	3	8	10.50	140	Mostly cloudy	High	High	High	0	0	0	5	0	0	95
Middle	C36.6-L	4	-1	9.40	150	Clear	High	High	High	10	0	0	5	0	25	60
Middle	C34.9-R	5	1	8.20	150	Clear	High	High	High	40	0	0	0	0	0	60
Middle	C34.9-L	1	9	11.30	150	Clear	High	High	High	30	0	0	0	0	0	70
Middle	C34.9-L	2	5	11.30	140	Clear	High	High	High	20	0	0	0	0	0	80
Middle	C34.9-L	3	8	10.50	140	Mostly cloudy	High	High	High	30	0	0	0	0	10	60
Middle	C34.9-L	4	-1	9.40	150	Clear	High	High	High	25	0	0	0	0	25	50
Middle	C30.6-L	5	4	8.50	150	Clear	High	High	High	25	0	0	0	0	25	50
Middle	C28.2-R	1	10	11.30	150	Clear	High	High	High	20	0	0	0	0	70	10
Middle	C28.2-R	2	9	11.30	140	Clear	High	High	High	0	0	0	0	0	80	20
Middle	C28.2-R	3	9	10.50	140	Mostly cloudy	High	High	High	10	0	0	0	0	80	10
Middle	C28.2-R	4	4	9.40	150	Clear	High	High	High	10	0	0	0	0	80	10
Middle	C27.6-R	1	10	11.30	150	Clear	High	High	High	40	0	0	0	0	0	60
Middle	C27.6-R	2	9	11.30	140	Clear	High	High	High	20	0	0	0	0	20	60
Middle	C27.6-R	3	9	10.50	140	Mostly cloudy	High	High	High	10	0	0	0	0	50	40
Middle	C27.6-R	4	4	9.40	150	Clear	High	High	High	20	0	0	0	0	50	30

Continued...

[a] See Appendix B, Figures B1 to B3 for sample site locations.

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

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

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

Table B3 Continued.

Section	Site[a]	Session	Air Temperature (°C)	Water Temperature (°C)	Conductivity (µS)	Cloud Cover[b]	Water Surface Visibility	Instream Velocity[c]	Water Clarity[d]	Cover Types (%)						
										Substrate Interstices	Woody Debris	Turbulence	Aquatic Vegetation	Terrestrial Vegetation	Shallow Water	Deep Water
Middle	C26.2-L	5	3.00	7.80	160	Clear	High	High	High	0	0	0	0	0	70	30
Middle	C25.3-R	1	11.00	11.30	150	Clear	High	High	High	30	0	0	0	0	0	70
Middle	C25.3-R	2	10.00	11.30	140	Clear	High	High	High	20	0	0	0	0	0	80
Middle	C25.3-R	3	8.00	11.60	150	Mostly cloudy	Medium	High	High	10	0	0	0	0	0	90
Middle	C25.3-R	4	8.00	9.40	150	Clear	High	High	High	0	0	0	0	0	20	80
Middle	C25.3-L	5	4.00	7.60	150	Mostly cloudy	High	High	High	0	0	0	0	0	80	20
Middle	C24.3-L	5	4.00	7.60	150	Mostly cloudy	High	High	High	10	0	0	0	0	30	60
Middle	C23.4-L	5	4.00	7.60	150	Partly cloudy	High	High	High	0	0	0	0	0	80	20
Middle	C20.1-L	5	5.00	7.60	150	Mostly cloudy	High	High	High	15	0	0	0	0	70	15
Upper	C19.0-L	5	5.00	7.60	150	Mostly cloudy	High	High	High	30	0	0	0	0	10	60
Upper	C17.0-L	5	6.00	7.60	160	Mostly cloudy	High	High	High	15	0	0	1	0	29	55
Upper	C15.8-R	5	4.00	8.00	150	Mostly cloudy	Medium	High	High	25	0	0	0	0	35	40
Upper	C13.4-R	5	5.00	8.20	150	Mostly cloudy	Medium	High	High	20	0	0	0	0	40	40
Upper	C13.4-L	5	6.00	8.90	160	Mostly cloudy	Medium	High	High	20	0	0	0	0	60	20
Upper	C10.9-L	5	6.00	9.30	160	Mostly cloudy	Medium	High	High	0	0	0	0	0	70	30
Upper	C08.4-L	5	7.00	8.60	140	Mostly cloudy	Medium	High	High	20	0	0	0	0	50	30
Upper	C07.4-L	1	5.00	10.90	140	Clear	High	Low	High	10	0	0	30	0	60	0
Upper	C07.4-L	2	10.00	10.90	140	Clear	High	Medium	High	0	0	0	20	0	60	20
Upper	C07.4-L	3	11.00	10.50	140	Mostly cloudy	High	High	High	0	0	0	20	0	60	20
Upper	C07.4-L	4	8.00	9.30	130	Partly cloudy	High	Low	High	0	0	0	35	0	35	30
Upper	C07.3-R	1	5.00	10.90	140	Clear	High	Low	High	45	0	10	0	0	0	45
Upper	C07.3-R	2	10.90	14.00	140	Clear	High	Medium	High	30	0	0	0	0	0	70
Upper	C07.3-R	3	10.00	10.50	140	Partly cloudy	High	High	High	50	0	0	0	0	10	40
Upper	C07.3-R	4	6.00	9.70	130	Partly cloudy	High	High	High	30	0	0	0	0	0	70
Upper	C05.6-L	1	5.00	10.90	140	Clear	High	Low	High	10	2	0	88	0	0	0
Upper	C05.6-L	2	7.00	10.90	140	Partly cloudy	High	Low	High	0	5	0	5	0	70	20
Upper	C05.6-L	3	8.00	10.50	140	Mostly cloudy	High	Low	High	0	10	0	15	0	50	25
Upper	C05.6-L	4	5.00	9.30	140	Partly cloudy	High	Low	High	0	5	0	20	0	40	35
Upper	C04.6-R	1	5.00	10.90	140	Clear	High	Low	High	0	0	0	100	0	0	0
Upper	C04.6-R	2	9.00	10.90	140	Partly cloudy	Medium	Low	High	0	0	0	95	0	0	5
Upper	C04.6-R	3	7.00	10.50	140	Mostly cloudy	High	Low	High	0	0	0	95	0	5	0
Upper	C04.6-R	4	5.00	9.30	140	Mostly cloudy	High	Low	High	0	0	0	90	0	10	0
Upper	C03.6-L	1	9.00	10.90	140	Clear	High	Low	High	5	0	0	85	0	5	5
Upper	C03.6-L	2	9.00	10.90	140	Partly cloudy	Medium	Low	High	0	0	0	20	0	70	10
Upper	C03.6-L	3	8.00	10.50	140	Mostly cloudy	High	Low	High	0	0	0	40	0	40	20
Upper	C03.6-L	4	7.00	9.30	140	Mostly cloudy	High	Low	High	10	0	0	30	0	40	20
Upper	C02.8-L	1	6.00	10.90	140	Clear	High	Low	High	0	0	0	70	0	30	0
Upper	C02.8-L	2	10.00	10.90	140	Partly cloudy	Medium	Low	High	0	0	0	75	0	20	5
Upper	C02.8-L	3	7.00	10.50	140	Partly cloudy	High	Low	High	0	0	0	80	0	20	0
Upper	C02.8-L	4	7.00	9.30	140	Mostly cloudy	High	Low	High	0	0	0	70	0	30	0

Continued...

[a] See Appendix B, Figures B1 to B3 for sample site locations.

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

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

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

Table B3 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	7	10.50	140	Clear	High	Low	High	10	0	0	70	0	20	0
Upper	C01.3-L	2	9	10.90	140	Mostly cloudy	High	Low	High	20	0	0	15	0	50	15
Upper	C01.3-L	3	7	10.50	140	Partly cloudy	High	Low	High	0	0	0	15	0	80	5
Upper	C01.3-L	4	7	9.30	140	Mostly cloudy	High	Low	High	10	0	0	20	0	60	10
Upper	C00.7-L	1	7	10.90	140	Clear	High	Low	High	30	0	0	0	0	60	10
Upper	C00.7-L	2	10	10.90	140	Mostly cloudy	High	Low	High	15	0	0	0	0	70	15
Upper	C00.7-L	3	7	10.50	140	Clear	Medium	Low	High	15	0	0	0	0	75	10
Upper	C00.7-L	4	8	9.30	140	Mostly cloudy	High	Low	High	25	0	0	0	0	70	5
Upper	C00.0-R	1	8	10.50	140	Clear	High	Low	High	70	1	0	0	0	20	9
Upper	C00.0-R	2	10	10.90	140	Mostly cloudy	High	Low	High	10	0	0	5	0	70	15
Upper	C00.0-R	3	8	10.10	140	Clear	Medium	Low	High	10	0	0	0	0	70	20
Upper	C00.0-R	4	10	9.30	140	Mostly cloudy	High	Low	High	10	0	0	0	0	60	30

[a] See Appendix B, Figures B1 to B3 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 the Middle Columbia River, 13 October to 10 November 2015.

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	Kokanee															**0**
	C00.0-R	Mountain Whitefish															**0**
	C00.0-R	Northern Pikeminnow		9													**9**
	C00.0-R	Peamouth		32											14		**46**
	C00.0-R	Rainbow Trout															**0**
	C00.0-R	Redside Shiner		621											183		**804**
	C00.0-R	Sculpin spp.		47											100		**147**
	C00.0-R	Sucker spp.															**0**
	C00.0-R	Walleye		13													**13**
	C00.0-R	White Sturgeon													2		**2**
	Site C00.0-R Total		**0**	**722**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**299**	**0**	**1021**
	C00.7-L	Bull Trout															**0**
	C00.7-L	Mountain Whitefish		41													**41**
	C00.7-L	Northern Pikeminnow															**0**
	C00.7-L	Peamouth		12													**12**
	C00.7-L	Rainbow Trout		13													**13**
	C00.7-L	Redside Shiner									15						**15**
	C00.7-L	Sculpin spp.									23						**23**
	C00.7-L	Sucker spp.															**0**
	C00.7-L	Walleye															**0**
	C00.7-L	White Sturgeon		1													**1**
	Site C00.7-L Total		**0**	**67**	**0**	**0**	**0**	**0**	**0**	**0**	**38**	**0**	**0**	**0**	**0**	**0**	**105**
	C01.3-L	Bull Trout															**0**
	C01.3-L	Mountain Whitefish									223						**223**
	C01.3-L	Northern Pike									1						**1**
	C01.3-L	Northern Pikeminnow															**0**
	C01.3-L	Peamouth									21						**21**
	C01.3-L	Rainbow Trout									66						**66**
	C01.3-L	Redside Shiner									196						**196**
	C01.3-L	Sculpin spp.									135						**135**
	C01.3-L	Sucker spp.									126						**126**
	C01.3-L	Walleye									33						**33**
	Site C01.3-L Total		**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**801**	**0**	**0**	**0**	**0**	**0**	**801**
	C02.8-L	Mountain Whitefish									132						**132**
	C02.8-L	Northern Pikeminnow									1						**1**
	C02.8-L	Peamouth									8						**8**
	C02.8-L	Rainbow Trout									13						**13**
	C02.8-L	Sculpin spp.									12						**12**
	C02.8-L	Sucker spp.									63						**63**
	C02.8-L	Walleye									4						**4**
	Site C02.8-L Total		**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**233**	**0**	**0**	**0**	**0**	**0**	**233**
	C03.6-L	Kokanee															**0**
	C03.6-L	Mountain Whitefish									109						**109**
	C03.6-L	Northern Pikeminnow															**0**
	C03.6-L	Peamouth				5											**5**
	C03.6-L	Rainbow Trout	48								65						**113**
	C03.6-L	Redside Shiner															**0**
	C03.6-L	Sculpin spp.															**0**
	C03.6-L	Sucker spp.									40						**40**
	C03.6-L	Walleye									10						**10**
	C03.6-L	White Sturgeon	1														**1**
	Site C03.6-L Total		**49**	**0**	**0**	**5**	**0**	**0**	**0**	**0**	**224**	**0**	**0**	**0**	**0**	**0**	**278**
	C04.6-R	Mountain Whitefish									50						**50**
	C04.6-R	Northern Pike									5						**5**
	C04.6-R	Rainbow Trout									38						**38**
	C04.6-R	Redside Shiner									1						**1**
	C04.6-R	Sculpin spp.									12						**12**
	C04.6-R	Sucker spp.									30						**30**
	C04.6-R	Walleye									2						**2**
	C04.6-R	Yellow Perch									1						**1**
	Site C04.6-R Total		**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**139**	**0**	**0**	**0**	**0**	**0**	**139**
	C05.6-L	Burbot															**0**
	C05.6-L	Kokanee															**0**
	C05.6-L	Mountain Whitefish															**0**
	C05.6-L	Northern Pikeminnow	5														**5**
	C05.6-L	Peamouth															**0**
	C05.6-L	Rainbow Trout	37														**37**
	C05.6-L	Redside Shiner	48														**48**
	C05.6-L	Sculpin spp.	540								120						**660**
	C05.6-L	Sucker spp.															**0**
	C05.6-L	Walleye	5														**5**
	Site C05.6-L Total		**635**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**120**	**0**	**0**	**0**	**0**	**0**	**755**
	C07.3-R	Brook Trout															**0**
	C07.3-R	Bull Trout				1											**1**
	C07.3-R	Lake Whitefish				3											**3**
	C07.3-R	Mountain Whitefish				100											**100**
	C07.3-R	Northern Pikeminnow				2											**2**
	C07.3-R	Peamouth				1											**1**
	C07.3-R	Rainbow Trout				54											**54**
	C07.3-R	Sculpin spp.				330											**330**
	C07.3-R	Sucker spp.				20											**20**
	C07.3-R	Walleye				6											**6**
	Site C07.3-R Total		**0**	**0**	**0**	**517**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**517**
	C07.4-L	Kokanee												1			**1**
	C07.4-L	Lake Whitefish												7			**7**
	C07.4-L	Mountain Whitefish												175			**175**
	C07.4-L	Northern Pikeminnow												2			**2**
	C07.4-L	Peamouth												2			**2**
	C07.4-L	Rainbow Trout												83			**83**
	C07.4-L	Redside Shiner												2			**2**
	C07.4-L	Sculpin spp.												32			**32**
	C07.4-L	Sucker spp.												128			**128**
	C07.4-L	Walleye												4			**4**
	C07.4-L	White Sturgeon												3			**3**
	Site C07.4-L Total		**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**439**	**0**	**0**	**439**
Upstream Columbia River Total			**684**	**789**	**0**	**522**	**0**	**0**	**0**	**0**	**1555**	**0**	**0**	**439**	**299**	**0**	**4288**

[a] See Appendix A, Figures A1 and A2 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	
Kootenay	K00.3-L	Bull Trout													1		**1**
	K00.3-L	Mountain Whitefish															**0**
	K00.3-L	Rainbow Trout															**0**
	K00.3-L	Sculpin spp.															**0**
	K00.3-L	Sucker spp.															**0**
	K00.3-L	Walleye								4							**4**
	Site K00.3-L Total		**0**	**0**	**0**	**0**	**0**	**0**	**0**	**4**	**0**	**0**	**0**	**0**	**1**	**0**	**5**
	K00.6-R	Bull Trout															**0**
	K00.6-R	Mountain Whitefish															**0**
	K00.6-R	Peamouth														2	**2**
	K00.6-R	Rainbow Trout															**0**
	K00.6-R	Sculpin spp.												65		5	**70**
	K00.6-R	Sucker spp.															**0**
	K00.6-R	Walleye														14	**14**
	Site K00.6-R Total		**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**65**	**0**	**21**	**86**
	K01.8-L	Carp spp.															**0**
	K01.8-L	Kokanee										1					**1**
	K01.8-L	Mountain Whitefish		34								51					**85**
	K01.8-L	Northern Pikeminnow										9					**9**
	K01.8-L	Peamouth										3					**3**
	K01.8-L	Rainbow Trout										45					**45**
	K01.8-L	Redside Shiner					26										**26**
	K01.8-L	Sculpin spp.		31								253					**284**
	K01.8-L	Sucker spp.															**0**
	K01.8-L	Walleye															**0**
	K01.8-L	White Sturgeon										1					**1**
	Site K01.8-L Total		**0**	**65**	**0**	**0**	**26**	**0**	**0**	**0**	**0**	**363**	**0**	**0**	**0**	**0**	**454**
	K01.8-R	Kokanee					1										**1**
	K01.8-R	Mountain Whitefish															**0**
	K01.8-R	Northern Pikeminnow															**0**
	K01.8-R	Rainbow Trout															**0**
	K01.8-R	Redside Shiner															**0**
	K01.8-R	Sculpin spp.								307							**307**
	K01.8-R	Sucker spp.								85							**85**
	K01.8-R	Walleye															**0**
	K01.8-R	White Sturgeon								2							**2**
	Site K01.8-R Total		**0**	**0**	**0**	**0**	**1**	**0**	**0**	**394**	**0**	**0**	**0**	**0**	**0**	**0**	**395**
Kootenay Total			**0**	**65**	**0**	**0**	**27**	**0**	**0**	**398**	**0**	**363**	**0**	**65**	**1**	**21**	**940**
Downstream Columbia River	C25.3-R	White Sturgeon	2														**2**
	C25.3-R	Walleye	4							4							**8**
	C25.3-R	Lake Whitefish	4														**4**
	C25.3-R	Redside Shiner	31														**31**
	C25.3-R	Rainbow Trout	53							68							**121**
	C25.3-R	Northern Pikeminnow					1										**1**
	C25.3-R	Mountain Whitefish								26							**26**
	C25.3-R	Sculpin spp.															**0**
	C25.3-R	Sucker spp.															**0**
	Site C25.3-R Total		**94**	**0**	**0**	**0**	**1**	**0**	**0**	**98**	**0**	**0**	**0**	**0**	**0**	**0**	**193**
	C27.6-R	Mountain Whitefish															**0**
	C27.6-R	Rainbow Trout															**0**
	C27.6-R	Sculpin spp.					1										**1**
	C27.6-R	Sucker spp.								1		1					**2**
	C27.6-R	Walleye					1										**1**
	Site C27.6-R Total		**0**	**0**	**0**	**0**	**2**	**0**	**0**	**1**	**0**	**1**	**0**	**0**	**0**	**0**	**4**
	C28.2-R	Mountain Whitefish		39													**39**
	C28.2-R	Rainbow Trout		92													**92**
	C28.2-R	Sculpin spp.		70													**70**
	C28.2-R	Sucker spp.		9													**9**
	C28.2-R	Walleye		6													**6**
	Site C28.2-R Total		**0**	**216**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**216**
	C34.9-L	Mountain Whitefish															**0**
	C34.9-L	Northern Pikeminnow		1													**1**
	C34.9-L	Rainbow Trout		145	40												**185**
	C34.9-L	Redside Shiner		7	1												**8**
	C34.9-L	Sculpin spp.		35													**35**
	C34.9-L	Sucker spp.			4												**4**
	C34.9-L	Walleye		13													**13**
	C34.9-L	White Sturgeon		1													**1**
	Site C34.9-L Total		**0**	**202**	**45**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**247**
	C36.6-L	Lake Whitefish											5				**5**
	C36.6-L	Mountain Whitefish															**0**
	C36.6-L	Rainbow Trout					64			107							**171**
	C36.6-L	Redside Shiner					10										**10**
	C36.6-L	Sculpin spp.															**0**
	C36.6-L	Sucker spp.															**0**
	C36.6-L	Walleye															**0**
	Site C36.6-L Total		**0**	**0**	**0**	**0**	**74**	**0**	**0**	**107**	**0**	**0**	**5**	**0**	**0**	**0**	**186**
	C47.8-L	Brook Trout									1						**1**
	C47.8-L	Burbot							1								**1**
	C47.8-L	Kokanee															**0**
	C47.8-L	Lake Whitefish															**0**
	C47.8-L	Mountain Whitefish							10								**10**
	C47.8-L	Northern Pikeminnow									1						**1**
	C47.8-L	Prickly Sculpin															**0**
	C47.8-L	Rainbow Trout							53								**53**
	C47.8-L	Redside Shiner									20						**20**
	C47.8-L	Sculpin spp.									70						**70**
	C47.8-L	Sucker spp.									62						**62**
	C47.8-L	Torrent Sculpin															**0**
	C47.8-L	Walleye									9						**9**
	Site C47.8-L Total		**0**	**0**	**0**	**0**	**0**	**0**	**64**	**0**	**163**	**0**	**0**	**0**	**0**	**0**	**227**
	C48.2-R	Mountain Whitefish															**0**
	C48.2-R	Rainbow Trout															**0**
	C48.2-R	Redside Shiner		2													**2**
	C48.2-R	Sculpin spp.													28		**28**
	C48.2-R	Sucker spp.															**0**
	C48.2-R	Walleye													3		**3**
	Site C48.2-R Total		**0**	**2**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**31**	**0**	**33**

[a] See Appendix A, Figures A1 and A2 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] A1	A2	A3	A4	A5	A6	A1+A2	A2+A3	D1	D2	D3	D1+D2	BW	Eddy	Total
	C49.0-L	Burbot		1													**1**
	C49.0-L	Lake Whitefish															**0**
	C49.0-L	Mountain Whitefish		40													**40**
	C49.0-L	Rainbow Trout		42													**42**
	C49.0-L	Redside Shiner		3													**3**
	C49.0-L	Sculpin spp.															**0**
	C49.0-L	Sucker spp.															**0**
	C49.0-L	Walleye		4													**4**
	C49.0-L	White Sturgeon		1													**1**
	Site C49.0-L Total		**0**	**91**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**91**
	C49.0-R	Lake Whitefish			1												**1**
	C49.0-R	Mountain Whitefish															**0**
	C49.0-R	Rainbow Trout															**0**
	C49.0-R	Sculpin spp.															**0**
	C49.0-R	Sucker spp.															**0**
	C49.0-R	Walleye												2			**2**
	Site C49.0-R Total		**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**2**	**0**	**0**	**3**
	C49.8-L	Bull Trout															**0**
	C49.8-L	Burbot		2													**2**
	C49.8-L	Lake Whitefish		10													**10**
	C49.8-L	Mountain Whitefish		72													**72**
	C49.8-L	Rainbow Trout		135													**135**
	C49.8-L	Redside Shiner		3													**3**
	C49.8-L	Sculpin spp.		645													**645**
	C49.8-L	Sucker spp.		35													**35**
	C49.8-L	Walleye		5													**5**
	Site C49.8-L Total		**0**	**907**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**907**
	C49.8-R	Burbot					1										**1**
	C49.8-R	Lake Whitefish															**0**
	C49.8-R	Mountain Whitefish		53													**53**
	C49.8-R	Peamouth										1					**1**
	C49.8-R	Rainbow Trout		59													**59**
	C49.8-R	Sculpin spp.															**0**
	C49.8-R	Sucker spp.													51		**51**
	C49.8-R	Walleye															**0**
	Site C49.8-R Total		**0**	**112**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**51**	**0**	**165**
	C52.2-L	Brook Trout															**0**
	C52.2-L	Lake Whitefish										1				1	**2**
	C52.2-L	Mountain Whitefish															**0**
	C52.2-L	Rainbow Trout														42	**42**
	C52.2-L	Sculpin spp.														13	**13**
	C52.2-L	Sucker spp.														6	**6**
	C52.2-L	Walleye														4	**4**
	Site C52.2-L Total		**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**66**	**67**
	C52.2-R	Brook Trout														1	**1**
	C52.2-R	Lake Whitefish		16													**16**
	C52.2-R	Mountain Whitefish		46													**46**
	C52.2-R	Northern Pikeminnow		1													**1**
	C52.2-R	Rainbow Trout		68												40	**108**
	C52.2-R	Sculpin spp.															**0**
	C52.2-R	Smallmouth Bass															**0**
	C52.2-R	Sucker spp.															**0**
	C52.2-R	Walleye		8													**8**
	Site C52.2-R Total		**0**	**139**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**41**	**180**
	C52.8-L	Brown Trout															**0**
	C52.8-L	Lake Whitefish															**0**
	C52.8-L	Mountain Whitefish				11											**11**
	C52.8-L	Rainbow Trout				26											**26**
	C52.8-L	Sculpin spp.		1		15											**16**
	C52.8-L	Sucker spp.				1											**1**
	C52.8-L	Walleye				1											**1**
	Site C52.8-L Total		**0**	**1**	**0**	**54**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**55**
	C53.6-L	Bull Trout															**0**
	C53.6-L	Lake Whitefish						6									**6**
	C53.6-L	Mountain Whitefish															**0**
	C53.6-L	Rainbow Trout															**0**
	C53.6-L	Sculpin spp.															**0**
	C53.6-L	Sucker spp.						2									**2**
	C53.6-L	Walleye															**0**
	Site C53.6-L Total		**0**	**0**	**0**	**0**	**0**	**8**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**8**
Downstream Columbia River Total			**94**	**1670**	**46**	**54**	**78**	**8**	**64**	**206**	**163**	**3**	**5**	**2**	**82**	**107**	**2582**
Grand Total			**778**	**2524**	**46**	**576**	**105**	**8**	**64**	**604**	**1718**	**366**	**5**	**506**	**382**	**128**	**7810**

[a] See Appendix A, Figures A1 and A2 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 2015

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 queried from a BC Hydro database maintained by Poisson Consulting. The Rainbow Trout egg dewatering estimates were provided by Irvine et al (Irvine, Baxter, and Thorley 2015) and the Mountain Whitefish egg stranding estimates by BC Hydro.

The data were prepared for analysis using R version 3.3.0 (R Core Team 2015).

Data Analysis

Hierarchical Bayesian models were fitted to the data using R version 3.3.0 (R Core Team 2015) and JAGS 4.0.1 (Plummer 2015) which interfaced with each other via jaggernaut 2.3.3 (J. L. Thorley 2013). For additional information on hierarchical Bayesian modelling in the BUGS language, of which JAGS uses a dialect, the reader is referred to Kery and Schaub (2011, 41–44).

Unless indicated otherwise, the models used prior distributions that were *vague* in the sense that they did not affect the posterior distributions (Kery and Schaub 2011, 36). The posterior distributions were estimated from a minimum of 1,000 Markov Chain Monte Carlo (MCMC) samples thinned from the second halves of three chains (Kery and Schaub 2011, 38–40). Model convergence was confirmed by ensuring that Rhat (Kery and Schaub 2011, 40) was less than 1.1 for each of the parameters in the model (Kery and Schaub 2011, 61). Where relevant, model adequacy was confirmed by examination of residual plots.

The posterior distributions of the *fixed* (Kery and Schaub 2011, 75) parameters are summarised in terms of a *point* estimate (mean), *lower* and *upper* 95% credible limits (2.5th and 97.5th percentiles), the standard deviation (*SD*), percent relative *error* (half the 95% credible interval as a percent of the point estimate) and *significance* (Kery and Schaub 2011, 37, 42).

Variable selection was achieved by dropping fixed (Kery and Schaub 2011, 77–82) variables with two-sided p-values ≥ 0.05 (Kery and Schaub 2011, 37, 42) and random variables with percent relative errors $\geq 80\%$. The Deviance Information Criterion (DIC) was not used because it is of questionable validity when applied to hierarchical models (Kery and Schaub 2011, 469).

The results are displayed graphically by plotting the modeled relationships between particular variables and the response with 95% credible intervals (CRIs) 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). Where informative the influence of particular variables is expressed in terms of the *effect size* (i.e., percent change in the response variable) with 95% CRIs (Bradford, Korman, and Higgins 2005).

Model Code

The JAGS model code, which uses a series of naming conventions, is presented below.

Condition

Variable/Parameter	Description
`bCorrelation`	Correlation coefficient between `bWeightYear` and `bWeightLengthYear`
`bWeight`	Intercept of `eLogWeight`
`bWeightDayte`	Linear effect of dayte on `eLogWeight`
`bWeightLength`	Linear effect of length on `eLogWeight`
`bWeightLengthDayte`	Effect of dayte on effect of length on `eLogWeight`
`bWeightLengthYear[i]`	Effect of `i`th year on effect of length on `eLogWeight`
`bWeightYear[i]`	Effect of `i`th year on `eLogWeight`
`Dayte[i]`	Day of year `i`th fish was captured
`eLogWeight[i]`	Expected `log(Weight)` of `i`th fish
`Length[i]`	`log(Length)` of `i`th fish
`sWeight`	SD of residual variation in `log(Weight)`
`sWeightLengthYear`	SD of effect of year on effect of length on `eLogWeight`
`sWeightYear`	SD of effect of year on `eLogWeight`
`Weight[i]`	Observed weight of `i`th fish
`Year[i]`	Year `i`th fish was captured

Condition - Model1

```
model {

  bWeight ~ dnorm(5, 5^-2)
  bWeightLength ~ dnorm(3, 2^-2)

  bWeightDayte ~ dnorm(0, 2^-2)
  bWeightLengthDayte ~ dnorm(0, 2^-2)

  sWeightYear ~ dunif(0, 1)
  sWeightLengthYear ~ dunif(0, 1)
  for (i in 1:nYear) {
    bWeightYear[i] ~ dnorm(0, sWeightYear^-2)
    bWeightLengthYear[i] ~ dnorm(0, sWeightLengthYear^-2)
  }

  sWeight ~ dunif(0, 1)
  for(i in 1:length(Length)) {
    eLogWeight[i] <-    bWeight
                      + bWeightDayte * Dayte[i]
                      + bWeightYear[Year[i]]
                      + ( bWeightLength
                        + bWeightLengthDayte * Dayte[i]
                        + bWeightLengthYear[Year[i]]
                        ) * Length[i]

    Weight[i] ~ dlnorm(eLogWeight[i], sWeight^-2)
  }
}
```

Growth

Variable/Parameter	Description
`bK`	Intercept of `log(eK)`
`bKYear[i]`	Random effect of `i`th year on `log(eK)`
`bLinf`	Mean maximum length
`eGrowth[i]`	Expected growth between release and recapture of `i`th recapture
`eK[i]`	Expected von Bertalanffy growth coefficient in `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`	SD of residual variation in `Growth`
`sKYear`	SD of effect of year on `log(eK)`
`Year[i]`	Release year of `i`th recapture
`Years[i]`	Years between release and recapture of `i`th recapture

Growth - Model1

```
model {

  bK ~ dnorm (0, 5^-2)
  sKYear ~ dunif (0, 5)
  for (i in 1:nYear) {
    bKYear[i] ~ dnorm(0, sKYear^-2)
    log(eK[i]) <- bK + bKYear[i]
  }

  bLinf ~ dunif(100, 1000)
  sGrowth ~ dunif(0, 100)

  for (i in 1:length(Year)) {
    eGrowth[i] <- (bLinf - LengthAtRelease[i]) * (1 - exp(-sum(eK[Year[i]:(Year[i] +
Years[i] - 1)])))

    Growth[i] ~ dnorm(eGrowth[i], sGrowth^-2)
  }
}
```

Length-At-Age

Variable/Parameter	Description
`Age[ii]`	Observed age-class of `ii`th fish
`bAge[ii]`	Effect of `ii`th age-class on `logit(pAgeYear)`
`bAgeYear[ii, jj]`	Effect of `ii`th age-class within `jj`th year on `logit(pAgeYear)`
`bDayte[ii]`	Effect of `ii`th age-class on linear effect of dayte on `eLength`
`bDayte2[ii]`	Effect of `ii`th age-class on quadratic effect of dayte on `eLength`
`bGrowthAge[ii]`	Growth of fish to `ii`th age-class
`bGrowthAgeYear[ii, jj]`	Growth of fish to `ii`th age-class within `jj`th year
`bLengthAgeYear[ii, jj]`	Effect of `ii`th age-class within `jj`th year on `eLength`
`eGrowthAgeYear[ii, jj]`	Total growth of fish to `ii`th age-class in `jj`th year
`eLength[ii]`	Expected length of `ii`th fish
`Length[ii]`	Observed length of `ii`th fish
`pAgeYear[ii, jj]`	Proportion of fish in `ii`th age-class within `jj`th year
`sAgeYear`	SD of effect of age-class within year on `bAgeYear`
`sGrowthAgeYear[ii]`	SD of effect of age-class within year on fish growth
`sLengthAge[ii]`	SD of residual variation in `eLength` of fish in `ii`th age-class
`Year[ii]`	Year in which `ii`th fish was caught

Length-At-Age - Model1

```
model{

  for(ii in 1:nAge){
    bGrowthAge[ii] ~ dunif(10, 100)
    sGrowthAgeYear[ii] ~ dunif(0, 25)
    for(jj in 1:nYear) {
      bGrowthAgeYear[ii, jj] ~ dnorm(0, sGrowthAgeYear[ii]^-2)
      eGrowthAgeYear[ii, jj] <- bGrowthAge[ii] + bGrowthAgeYear[ii, jj]
    }
  }

  bLengthAgeYear[1, 1] <- eGrowthAgeYear[1, 1]
  for(ii in 2:nAge){
    bLengthAgeYear[ii, 1] <- bLengthAgeYear[ii-1, 1] - bGrowthAgeYear[ii-1, 1] +
eGrowthAgeYear[ii, 1]
  }

  for(jj in 2:nYear){
    bLengthAgeYear[1, jj] <- eGrowthAgeYear[1, jj]
    for(ii in 2:nAge){
      bLengthAgeYear[ii, jj] <- bLengthAgeYear[ii-1, jj-1] + eGrowthAgeYear[ii, jj]
    }
  }

  for(ii in 1:nAge)  {
    bDayte[ii] ~ dnorm(0, 10)
    bDayte2[ii] ~ dnorm(0, 10)
  }

  sAgeYear ~ dunif(0, 5)
  for(ii in 1:(nAge - 1)){
    bAge[ii] ~ dnorm(0, 2^-2)
    for(jj in 1:nYear){
      bAgeYear[ii, jj] ~ dnorm(0, sAgeYear^-2)
    }
  }

  for(jj in 1:nYear){
    logit(pAgeYear[1, jj]) <- bAge[1] + bAgeYear[1, jj]
    for(ii in 2:(nAge - 1)){
      pAgeYear[ii, jj] <- (1 - sum(pAgeYear[1:(ii - 1), jj])) * ilogit(bAge[ii] +
bAgeYear[ii, jj])
    }
    pAgeYear[nAge, jj] <- (1 - sum(pAgeYear[1:(nAge - 1), jj]))
  }

    for(ii in 1:nAge){
    sLengthAge[ii] ~ dunif(0, 50)
  }

    for(ii in 1:length(Length)){
    Age[ii] ~ dcat(pAgeYear[1:nAge, Year[ii]])
    eLength[ii] <-  bLengthAgeYear[Age[ii], Year[ii]]
                  + bDayte[Age[ii]] * Dayte[ii]
                  + bDayte2[Age[ii]] * Dayte[ii]^2
```

```
    Length[ii] ~ dnorm(eLength[ii], sLengthAge[Age[ii]]^-2)
  }
}
```

Observer Length Correction

Variable/Parameter	Description
`bLength[i]`	Relative inaccuracy of `i`th observer
`ClassLength[i]`	Mean length of fish belonging to `i`th class
`dClass[i]`	Prior value for the proportion of fish in the `i`th class
`eClass[i]`	Expected class of `i`th fish
`eLength[i]`	Expected length of `i`th fish
`eSLength[i]`	Expected SD of residual variation in length of `i`th fish
`Length[i]`	Observed fork length of `i`th fish
`Observer[i]`	Observer of `i`th fish where the first observer used a length board
`pClass[i]`	Proportion of fish in the `i`th class
`sLength[i]`	Relative imprecision of `i`th observer
`Year[i]`	Year `i`th fish was observed

Observer Length Correction - Model1

```
model{

  for(j in 1:nYear){
    for(i in 1:nClass) {
      dClass[i, j] <- 1
    }
    pClass[1:nClass, j] ~ ddirch(dClass[, j])
  }

  bLength[1] <- 1
  sLength[1] <- 1

  for(i in 2:nObserver) {
    bLength[i] ~ dunif(0.5, 2)
    sLength[i] ~ dunif(2, 10)
  }

  for(i in 1:length(Length)){
    eClass[i] ~ dcat(pClass[, Year[i]])
    eLength[i] <- bLength[Observer[i]] * ClassLength[eClass[i]]
    eSLength[i] <- sLength[Observer[i]] * ClassSD
    Length[i] ~ dnorm(eLength[i], eSLength[i]^-2)
  }
}
```

Survival

Variable/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`	SD of `bSurvivalYear`

Survival - Model1

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

  bSurvival ~ dnorm(0, 5^-2)

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

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

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

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

Site Fidelity

Variable/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

Site Fidelity - Model1

```
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])
  }
}
```

Capture Efficiency

Variable/Parameter	Description

`bEfficiency`	Intercept for `logit(eEfficiency)`
`bEfficiencySessionYear`	Effect of `Session` within `Year` 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
`sEfficiencySessionYear`	SD of effect of `Session` within `Year` on `logit(eEfficiency)`
`Session[i]`	Session of `i`th visit
`Tagged[i]`	Number of marked fish tagged prior to `i`th visit
`Year[i]`	Year of `i`th visit

Capture Efficiency - Model1

```
model {

  bEfficiency ~ dnorm(0, 5^-2)

  sEfficiencySessionYear ~ dunif(0, 2)
  for (i in 1:nSession) {
    for (j in 1:nYear) {
      bEfficiencySessionYear[i, j] ~ dnorm(0, sEfficiencySessionYear^-2)
    }
  }

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

    logit(eEfficiency[i]) <- bEfficiency + bEfficiencySessionYear[Session[i],
Year[i]]

    eFidelity[i] ~ dnorm(Fidelity[i], FidelitySD[i]^-2) T(0, 1)
    Recaptures[i] ~ dbin(eEfficiency[i] * eFidelity[i], Tagged[i])
  }
}
```

Abundance

Variable/Parameter	Description
`bDensity`	Intercept for `log(eDensity)`
`bDensitySite`	Effect of `Site` on `log(eDensity)`
`bDensitySiteYear`	Effect of `Site` within `Year` on `log(eDensity)`
`bDensityYear`	Effect of `Year` on `log(eDensity)`
`bVisitType`	Effect of `VisitType` on `Efficiency`
`eDensity[i]`	Expected density during `i`th visit
`eDispersion`	Overdispersion of `Fish`
`Efficiency[i]`	Survey efficiency during `i`th visit
`Fish[i]`	Observed count during `i`th visit
`ProportionSampled[i]`	Proportion of site surveyed during `i`th visit
`sDensitySite`	SD of effect of `Site` on `log(eDensity)`
`sDensitySiteYear`	SD of effect of `Site` within `Year` on `log(eDensity)`
`sDensityYear`	SD of effect of `Year` on `log(eDensity)`
`sDispersion`	SD of overdispersion term
`Site[i]`	Site of `i`th visit
`SiteLength[i]`	Length of site during `i`th visit
`VisitType[i]`	Survey type (catch versus count) during `i`th visit
`Year[i]`	Year of `i`th visit

Abundance - Model1

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

  bVisitType[1] <- 1
  for (i in 2:nVisitType) {
    bVisitType[i] ~ dunif(0, 10)
  }

  sDensityYear ~ dunif(0, 2)
  for (i in 1:nYear) {
    bDensityYear[i] ~ dnorm(0, sDensityYear^-2)
  }

  sDensitySite ~ dunif(0, 2)
  sDensitySiteYear ~ dunif(0, 2)
  for (i in 1:nSite) {
    bDensitySite[i] ~ dnorm(0, sDensitySite^-2)
    for (j in 1:nYear) {
      bDensitySiteYear[i, j] ~ dnorm(0, sDensitySiteYear^-2)
    }
  }

  sDispersion ~ dunif(0, 5)
  for (i in 1:length(Fish)) {
    log(eDensity[i]) <- bDensity + bDensitySite[Site[i]] + bDensityYear[Year[i]] +
bDensitySiteYear[Site[i],Year[i]]

    eDispersion[i] ~ dgamma(1 / sDispersion^2, 1 / sDispersion^2)
    Fish[i] ~ dpois(eDensity[i] * SiteLength[i] * ProportionSampled[i] *
Efficiency[i] * bVisitType[VisitType[i]] * eDispersion[i])
  }
}
```

Long-Term Trends

Variable/Parameter	Description
`bDistance[i,j]`	Euclidean distance between ith and jth `Variable`
`bTrendYear[t,y]`	Expected value for tth trend in yth `Year`
`eValue[v,y,t]`	Expected standardised value for vth `Variable` in yth `Year` considering tth trends
`sTrend`	SD in trend random walks
`sValue`	SD for residual variation in `Value`
`Value[i]`	Standardised value for ith data point
`Variable[i]`	Variable for ith data point
`Year[i]`	Year of ith data point
`Z[v,y]`	Expected weighting for vth `Variable` in yth `Year`

Long-Term Trends - Model1

```
model{

  sTrend ~ dunif(0, 1)
  for (t in 1:nTrend) {
    bTrendYear[t,1] ~ dunif(-1,1)
    for(y in 2:nYear){
      bTrendYear[t,y] ~ dnorm(bTrendYear[t,y-1], sTrend^-2)
    }
  }
```

```
  for(v in 1:nVariable){
    for(t in 1:nTrend) {
      Z[v,t] ~ dunif(-1,1)
    }
    for(y in 1:nYear){
      eValue[v,y,1] <- Z[v,1] * bTrendYear[1,y]
      for(t in 2:nTrend) {
        eValue[v,y,t] <- eValue[v,y,t-1] + Z[v,t] * bTrendYear[t,y]
      }
    }
  }

  sValue ~ dunif(0, 1)
  for(i in 1:length(Value)) {
    Value[i] ~ dnorm(eValue[Variable[i], Year[i], nTrend], sValue^-2)
  }

  for(i in 1:nVariable) {
    for(j in 1:nVariable) {
      bDistance[i,j] <- sqrt(sum((Z[i,]-Z[j,])^2))
    }
  }
}
```

Scale Age

Variable/Parameter	Description
`Ager[i]`	`i`th ager
`bIntercept`	Intercept of `eScaleAge`
`bInterceptAger[i]`	Effect of `Ager[i]` on the intercept of `eScaleAge`
`bInterceptEncounterID[i]`	Random effect of `EncounterID[i]` on the intercept of `eScaleAge`
`bInterceptEncounterIDAger[i,j]`	Random effect of the interaction of `EncounterID[i]` and `Ager[j]` on the intercept of `eScaleAge`
`BirthYear[i]`	BirthYear of the `i`th fish
`bSlope`	Intercept on the slope of the effect of `eAge` on `eScaleAge`
`bSlopeAger[i]`	Effect of `Ager[i]` on the slope of the effect of `eAge` on `eScaleAge`
`dYear[i]`	`i`th parameter of the Dirichlet distribution on `pYear`
`eAge[i]`	Expected true age of the fish on the `i`th scale age observation
`EncounterID[i]`	ID of the `i`th encounter
`eScaleAge[i]`	Expected scale age on the `i`th scale age observation
`FishID[i]`	Fish ID of the `i`th scale age
`pYear[i]`	Probability that a fish is born in the `i`th year, starting with 1993
`ScaleAge[i]`	`i`th scale age observation
`sInterceptEncounterID`	SD of `bInterceptEncounterID`
`sInterceptEncounterIDAger`	SD of `bInterceptEncounterIDAger`
`sSD[i]`	SD of the `i`th ager due to pseudo-replication
`Year[i]`	Encounter year of the `i`th scale age observation

Scale Age - Model1

```
model {
  for(i in 1:nBirthYear) {
    dYear[i] <- 1
  }
  pYear ~ ddirch(dYear[])
  for(i in 1:nFishID){
```

```
    BirthYear[i] ~ dcat(pYear)
  }
  mBirthYear <- BirthYear
  bIntercept <- 0
  bSlope <- 1
  for(i in 1:nAger) {
    sSD[i] ~ dunif(0, 5)
  }
  for(i in 1:nAger) {
    bInterceptAger[i] ~ dnorm(0, 2^-2)
    bSlopeAger[i] ~ dnorm(0, 2^-2)
  }
  sInterceptEncounterID ~ dunif(0, 2)
  sInterceptEncounterIDAger ~ dunif(0, 2)
  for(i in 1:nEncounterID) {
    bInterceptEncounterID[i] ~ dnorm(0, sInterceptEncounterID^-2)
    for(j in 1:nAger) {
      bInterceptEncounterIDAger[i,j] ~ dnorm(0, sInterceptEncounterIDAger^-2)
    }
  }
  for(i in 1:length(ScaleAge)){
    eAge[i] <- Year[i] - BirthYear[FishID[i]]
    eScaleAge[i] <- bIntercept + bInterceptAger[Ager[i]] + (bSlope +
bSlopeAger[Ager[i]]) * eAge[i] + bInterceptEncounterID[EncounterID[i]] +
bInterceptEncounterIDAger[EncounterID[i], Ager[i]]
    ScaleAge[i] ~ dnorm(eScaleAge[i], sSD[Ager[i]]^-2) T(0,)
  }
}
```

Age-Ratios

Variable/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
`Year[i]`	The spawn year of the Age-1 fish in the `i`th year

Age-Ratios - Model1

```
model{

  bProbAge1 ~ dnorm(0, 1000^-2)
  bProbAge1Loss ~ dnorm(0, 1000^-2)

  sDispersion ~ dunif(0, 1000)
  for(i in 1:length(LossLogRatio)){
    eDispersion[i] ~ dnorm(0, sDispersion^-2)
    logit(eProbAge1[i]) <- bProbAge1 + bProbAge1Loss * LossLogRatio[i] +
eDispersion[i]
    Age1[i] ~ dbin(eProbAge1[i], Age1and2[i])
  }
}
```

Stock-Recruitment

Variable/Parameter	Description
`bAlpha`	`eRecruits` per `Stock` at low `Stock` density
`bBeta`	Intercept for `log(eBeta)`
`bBetaEggLoss`	Effect of `EggLoss` on `bBeta`
`eBeta`	Effect of density-dependence
`EggLoss[i]`	Calculated proportional egg loss for `i`th spawn year
`eRecruits[i]`	Expected value of `Recruits`
`Recruits[i]`	Number of Age-1 recruits from `i`th spawn year
`sRecruits`	SD of residual variation in `Recruits`
`Stock[i]`	Number of Age-2+ spawners in `i`th spawn year

Stock-Recruitment - Model1

```
model {

  bAlpha ~ dunif(0, 5)
  bBeta ~ dunif(0, 1)
  bBetaEggLoss ~ dnorm(0, 2^-2)

  sRecruits ~ dunif(0, 5)
  for(i in 1:length(Stock)){
    log(eBeta[i]) <- log(bBeta) + bBetaEggLoss * EggLoss[i]
    eRecruits[i] <- (bAlpha * Stock[i]) / (1 + eBeta[i] * Stock[i])
    Recruits[i] ~ dlnorm(log(eRecruits[i]), sRecruits^-2)
  }
}
```

Results

Model Parameters

The posterior distributions for the *fixed* (Kery and Schaub 2011 p. 75) parameters in each model are summarised below.

Condition - Mountain Whitefish

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bWeight	5.424370	5.406310	5.445060	0.009990	0	0.0010
bWeightDayte	-0.015066	-0.019090	-0.010863	0.002134	27	0.0010
bWeightLength	3.160900	3.107500	3.218900	0.029300	2	0.0010
bWeightLengthDayte	-0.005500	-0.016540	0.005660	0.005790	200	0.3474
sWeight	0.154752	0.152997	0.156710	0.000956	1	0.0010
sWeightLengthYear	0.111160	0.075100	0.168110	0.023690	42	0.0010
sWeightYear	0.045810	0.032460	0.066240	0.008920	37	0.0010

Convergence	Iterations
1.02	10000

Condition - Rainbow Trout

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bWeight	5.952320	5.942210	5.963430	0.005420	0	0.001
bWeightDayte	-0.003453	-0.006563	-0.000413	0.001526	89	0.028
bWeightLength	2.929740	2.899100	2.957610	0.014300	1	0.001
bWeightLengthDayte	0.044650	0.035310	0.053560	0.004710	20	0.001
sWeight	0.111289	0.109906	0.112719	0.000742	1	0.001
sWeightLengthYear	0.058340	0.037510	0.087850	0.013370	43	0.001

sWeightYear	0.024720	0.017140	0.035690	0.004750	38	0.001

Convergence	Iterations
1.04	10000

Condition - Walleye

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bWeight	6.287860	6.265450	6.306010	0.009850	0	0.0010
bWeightDayte	0.018084	0.014997	0.021211	0.001611	17	0.0010
bWeightLength	3.220100	3.171200	3.273900	0.025500	2	0.0010
bWeightLengthDayte	-0.014000	-0.032850	0.005420	0.009550	140	0.1358
sWeight	0.098755	0.097282	0.100400	0.000796	2	0.0010
sWeightLengthYear	0.099390	0.064490	0.148790	0.022730	42	0.0010
sWeightYear	0.040760	0.029420	0.059710	0.008060	37	0.0010

Convergence	Iterations
1.04	10000

Growth - Mountain Whitefish

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bK	-1.1810	-1.5232	-0.9085	0.1523	26	7e-04
bLinf	407.9200	401.9800	414.2400	3.1400	2	7e-04
sGrowth	12.7340	11.4840	14.1220	0.6500	10	7e-04
sKYear	0.4573	0.2529	0.8177	0.1500	62	7e-04

Convergence	Iterations
1.06	4000

Growth - Rainbow Trout

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bK	-0.2041	-0.3243	-0.0812	0.0646	60	0.0014
bLinf	498.5600	493.6400	504.1000	2.6700	1	0.0007
sGrowth	29.7660	28.3510	31.1880	0.7130	5	0.0007
sKYear	0.2434	0.1636	0.3808	0.0539	45	0.0007

Convergence	Iterations
1.02	1000

Growth - Walleye

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bK	-2.8036	-3.1421	-2.4763	0.1744	12	7e-04
bLinf	867.3000	729.4000	988.3000	68.3000	15	7e-04
sGrowth	18.8670	17.3310	20.5080	0.8170	8	7e-04
sKYear	0.3275	0.1794	0.5432	0.0958	56	7e-04

Convergence	Iterations
1.04	2000

Length-At-Age - Mountain Whitefish

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bAge[1]	-1.9931	-2.3632	-1.6512	0.1848	18	0.0010
bAge[2]	-0.8471	-1.2793	-0.4283	0.2229	50	0.0010
bDayte[1]	3.0928	2.6095	3.6037	0.2564	16	0.0010
bDayte[2]	2.4010	1.8910	2.9330	0.2650	22	0.0010
bDayte[3]	1.4300	0.8740	1.9820	0.2830	39	0.0010
bDayte2[1]	-0.6846	-1.1276	-0.2755	0.2109	62	0.0010
bDayte2[2]	-0.0914	-0.4785	0.3162	0.2026	440	0.6867
bDayte2[3]	1.2020	0.6710	1.7260	0.2740	44	0.0010
bGrowthAge[1]	99.0810	97.3210	99.9780	0.7770	1	0.0010
bGrowthAge[2]	96.7060	93.0080	99.6640	1.8550	3	0.0010
bGrowthAge[3]	98.9240	96.2030	99.9730	1.0180	2	0.0010

sAgeYear	0.8713	0.6665	1.1408	0.1204	27	0.0010
sGrowthAgeYear[1]	22.2950	17.6960	24.8810	1.9610	16	0.0010
sGrowthAgeYear[2]	9.6290	6.4100	14.4900	2.1170	42	0.0010
sGrowthAgeYear[3]	23.7380	21.0460	24.9500	1.0710	8	0.0010
sLengthAge[1]	14.4989	14.1175	14.8843	0.2021	3	0.0010
sLengthAge[2]	21.9360	21.1250	22.7830	0.4180	4	0.0010
sLengthAge[3]	45.4510	44.6890	46.2240	0.3870	2	0.0010

Convergence	Iterations
1.05	10000

Length-At-Age - Rainbow Trout

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bAge[1]	-3.1540	-3.4546	-2.8313	0.1585	10	0.0010
bAge[2]	0.4468	0.2107	0.7704	0.1430	63	0.0040
bDayte[1]	0.8170	0.2620	1.3920	0.2970	69	0.0040
bDayte[2]	3.0350	2.5060	3.5450	0.2670	17	0.0010
bDayte[3]	0.2790	-0.3330	0.9060	0.3060	220	0.3593
bDayte2[1]	0.0490	-0.4900	0.5710	0.2750	1100	0.8743
bDayte2[2]	0.7356	0.2526	1.2048	0.2362	65	0.0020
bDayte2[3]	0.3450	-0.1760	0.8840	0.2730	150	0.2016
bGrowthAge[1]	99.0050	96.3850	99.9690	0.9630	2	0.0010
bGrowthAge[2]	99.4760	97.8960	99.9810	0.5340	1	0.0010
bGrowthAge[3]	99.5270	98.2050	99.9880	0.4580	1	0.0010
sAgeYear	0.6505	0.4979	0.8472	0.0918	27	0.0010
sGrowthAgeYear[1]	19.4600	14.0400	24.5200	2.8200	27	0.0010
sGrowthAgeYear[2]	24.6960	23.9450	24.9920	0.2780	2	0.0010
sGrowthAgeYear[3]	24.8295	24.3591	24.9956	0.1677	1	0.0010
sLengthAge[1]	18.1640	17.2610	19.1650	0.4840	5	0.0010
sLengthAge[2]	38.1550	37.4970	38.7840	0.3340	2	0.0010
sLengthAge[3]	49.9275	49.7136	49.9984	0.0727	0	0.0010

Convergence	Iterations
1.03	10000

Observer Length Correction - Mountain Whitefish

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bLength[1]	1.00000	1.00000	1.00000	0.00000	0	0.001
bLength[2]	0.91427	0.90470	0.92417	0.00500	1	0.001
bLength[3]	0.86202	0.85032	0.87484	0.00629	1	0.001
bLength[4]	0.86742	0.83560	0.89047	0.01323	3	0.001
bLength[5]	0.88006	0.87199	0.88733	0.00391	1	0.001
sLength[1]	1.00000	1.00000	1.00000	0.00000	0	0.001
sLength[2]	2.02053	2.00062	2.07767	0.02047	2	0.001
sLength[3]	3.69060	3.27810	4.13140	0.22320	12	0.001
sLength[4]	2.02970	2.00070	2.11350	0.03080	3	0.001
sLength[5]	2.00622	2.00017	2.02330	0.00629	1	0.001

Convergence	Iterations
1.02	10000

Observer Length Correction - Rainbow Trout

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bLength[1]	1.00000	1.00000	1.00000	0.00000	0	0.001
bLength[2]	0.85658	0.84843	0.86427	0.00416	1	0.001
bLength[3]	0.86109	0.85000	0.87311	0.00585	1	0.001
bLength[4]	0.76364	0.73892	0.78866	0.01271	3	0.001
bLength[5]	0.85534	0.84924	0.86174	0.00316	1	0.001
sLength[1]	1.00000	1.00000	1.00000	0.00000	0	0.001

sLength[2]	2.02375	2.00076	2.08957	0.02432	2	0.001
sLength[3]	2.57100	2.02700	3.28500	0.34200	24	0.001
sLength[4]	4.40400	3.12200	5.88400	0.68600	31	0.001
sLength[5]	2.01610	2.00031	2.05944	0.01643	1	0.001

Convergence	Iterations
1.04	10000

Observer Length Correction - Walleye

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bLength[1]	1.00000	1.00000	1.00000	0.00000	0	0.001
bLength[2]	0.80463	0.77794	0.84193	0.01706	4	0.001
bLength[3]	0.91895	0.90352	0.93395	0.00799	2	0.001
bLength[4]	0.85273	0.82315	0.89489	0.01820	4	0.001
bLength[5]	0.93104	0.91736	0.94542	0.00737	2	0.001
sLength[1]	1.00000	1.00000	1.00000	0.00000	0	0.001
sLength[2]	3.50600	2.02100	5.90800	1.26400	55	0.001
sLength[3]	2.54500	2.01300	4.38400	0.59300	47	0.001
sLength[4]	2.80700	2.01400	4.94200	0.83200	52	0.001
sLength[5]	2.12420	2.00230	2.52730	0.16570	12	0.001

Convergence	Iterations
1.06	10000

Survival - Mountain Whitefish

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bEfficiency	-4.7426	-4.9714	-4.4943	0.1237	5	0.0010
bEfficiencySampledLength	0.3685	0.1123	0.6191	0.1331	69	0.0080
bSurvival	0.5120	-0.2480	1.5780	0.4420	180	0.1897
sSurvivalYear	1.4220	0.6820	2.7070	0.5310	71	0.0010

Convergence	Iterations
1.04	10000

Survival - Rainbow Trout

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bEfficiency	-3.1917	-3.3926	-2.9925	0.1052	6	0.0010
bEfficiencySampledLength	0.0171	-0.1717	0.1904	0.0930	1100	0.8503
bSurvival	-0.5470	-0.8470	-0.2489	0.1566	55	0.0020
sSurvivalYear	0.4188	0.1971	0.7474	0.1497	66	0.0010

Convergence	Iterations
1.01	10000

Survival - Walleye

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bEfficiency	-4.0380	-4.2540	-3.8131	0.1118	5	0.0010
bEfficiencySampledLength	0.0716	-0.1053	0.2718	0.0967	260	0.4611
bSurvival	-0.0143	-0.3643	0.3912	0.1935	2600	0.9022
sSurvivalYear	0.5614	0.2347	1.1094	0.2152	78	0.0010

Convergence	Iterations
1.02	10000

Site Fidelity - Mountain Whitefish

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bFidelity	-0.1591	-0.5215	0.2092	0.1864	230	0.3960
bLength	-0.1244	-0.5324	0.2515	0.1979	320	0.5294

Convergence	Iterations
1	1000

Site Fidelity - Rainbow Trout

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bFidelity	0.8356	0.6709	1.0041	0.0857	20	7e-04
bLength	-0.3489	-0.5189	-0.1903	0.0826	47	7e-04

Convergence	Iterations
1.01	1000

Site Fidelity - Walleye

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bFidelity	0.7068	0.4225	1.0060	0.1510	41	0.0007
bLength	-0.0974	-0.3909	0.1949	0.1497	300	0.5134

Convergence	Iterations
1.01	1000

Capture Efficiency - Mountain Whitefish - Subadult

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bEfficiency	-4.9651	-5.4962	-4.5578	0.2399	9	0.001
sEfficiencySessionYear	0.4570	0.0130	1.1490	0.3170	120	0.001

Convergence	Iterations
1.02	20000

Capture Efficiency - Mountain Whitefish - Adult

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bEfficiency	-5.1857	-5.5147	-4.9082	0.1536	6	0.001
sEfficiencySessionYear	0.2660	0.0373	0.6738	0.1681	120	0.001

Convergence	Iterations
1.06	10000

Capture Efficiency - Rainbow Trout - Subadult

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bEfficiency	-3.3595	-3.4944	-3.2360	0.0668	4	0.001
sEfficiencySessionYear	0.3888	0.2688	0.5243	0.0644	33	0.001

Convergence	Iterations
1.01	10000

Capture Efficiency - Rainbow Trout - Adult

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bEfficiency	-4.0582	-4.2215	-3.9124	0.0799	4	0.001
sEfficiencySessionYear	0.2203	0.0197	0.4396	0.1116	95	0.001

Convergence	Iterations
1.02	10000

Capture Efficiency - Walleye - Adult

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bEfficiency	-4.4631	-4.6975	-4.2344	0.1190	5	0.001
sEfficiencySessionYear	0.6125	0.4107	0.8769	0.1208	38	0.001

Convergence	Iterations
1.03	10000

Abundance - Mountain Whitefish - Subadult

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bDensity	5.36470	5.00840	5.6595	0.17420	6	0.001
bVisitType[1]	1.00000	1.00000	1.0000	0.00000	0	0.001
bVisitType[2]	4.13100	3.54900	4.8370	0.33600	16	0.001
sDensitySite	0.81530	0.65470	1.0286	0.09420	23	0.001

sDensitySiteYear	0.46200	0.40170	0.5302	0.03210	14	0.001
sDensityYear	0.73410	0.50900	1.0830	0.15290	39	0.001
sDispersion	0.50023	0.45882	0.5413	0.02111	8	0.001

Convergence	Iterations
1.08	10000

Abundance - Mountain Whitefish - Adult

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bDensity	6.46330	6.04450	6.72500	0.16700	5	0.001
bVisitType[1]	1.00000	1.00000	1.00000	0.00000	0	0.001
bVisitType[2]	4.91600	4.17200	5.76700	0.41500	16	0.001
sDensitySite	1.12670	0.91200	1.36630	0.11590	20	0.001
sDensitySiteYear	0.41310	0.36010	0.47010	0.02850	13	0.001
sDensityYear	0.39250	0.25270	0.63750	0.09320	49	0.001
sDispersion	0.53922	0.50833	0.57488	0.01679	6	0.001

Convergence	Iterations
1.05	20000

Abundance - Rainbow Trout - Subadult

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bDensity	4.82630	4.55990	5.08550	0.13110	5	0.001
bVisitType[1]	1.00000	1.00000	1.00000	0.00000	0	0.001
bVisitType[2]	4.23200	3.75200	4.80700	0.27000	12	0.001
sDensitySite	0.75020	0.61290	0.92000	0.07860	20	0.001
sDensitySiteYear	0.40880	0.35920	0.45950	0.02580	12	0.001
sDensityYear	0.32360	0.20810	0.51060	0.08050	47	0.001
sDispersion	0.40328	0.37313	0.43576	0.01563	8	0.001

Convergence	Iterations
1.03	40000

Abundance - Rainbow Trout - Adult

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bDensity	5.32330	5.07870	5.55360	0.11960	4	0.001
bVisitType[1]	1.00000	1.00000	1.00000	0.00000	0	0.001
bVisitType[2]	4.40500	3.88800	4.99000	0.27800	13	0.001
sDensitySite	0.68580	0.56070	0.82960	0.06980	20	0.001
sDensitySiteYear	0.25922	0.20764	0.30729	0.02545	19	0.001
sDensityYear	0.23530	0.14900	0.37430	0.05660	48	0.001
sDispersion	0.40359	0.36958	0.43821	0.01703	9	0.001

Convergence	Iterations
1.06	10000

Abundance - Walleye - Adult

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bDensity	5.33400	5.03470	5.59550	0.14040	5	0.001
bVisitType[1]	1.00000	1.00000	1.00000	0.00000	0	0.001
bVisitType[2]	4.27900	3.64600	4.88500	0.31700	14	0.001
sDensitySite	0.37980	0.28170	0.50120	0.05560	29	0.001
sDensitySiteYear	0.23607	0.18586	0.28434	0.02567	21	0.001
sDensityYear	0.51690	0.34770	0.75250	0.10730	39	0.001
sDispersion	0.46160	0.43091	0.49239	0.01635	7	0.001

Convergence	Iterations
1.05	20000

Long-Term Trends

Parameter	Estimate	Lower	Upper	SD	Error	Significance
sTrend	0.3606	0.2094	0.5101	0.0807	42	0.001
sValue	0.7822	0.6862	0.8867	0.0516	13	0.001

Convergence	Iterations
1.05	10000

Scale Age

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bInterceptAger[1]	1.23550	1.08000	1.37660	0.07470	12	0.0007
bInterceptAger[2]	1.19080	1.04130	1.34400	0.08270	13	0.0007
bSlope	1.00000	1.00000	1.00000	0.00000	0	0.0007
bSlopeAger[1]	-0.03490	-0.15240	0.08590	0.05920	340	0.5107
bSlopeAger[2]	-0.21150	-0.33800	-0.08870	0.06510	59	0.0014
sInterceptEncounterID	0.34470	0.27330	0.41360	0.03520	20	0.0007
sInterceptEncounterIDAger	0.24160	0.16030	0.32200	0.03980	33	0.0007
sSD[1]	0.34405	0.30868	0.38529	0.02033	11	0.0007
sSD[2]	0.48260	0.43624	0.53493	0.02551	10	0.0007

Convergence	Iterations
1.01	4000

Age-Ratios

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bProbAge1	0.4794	0.1157	0.8280	0.1809	74	0.0075
bProbAge1Loss	-0.0100	-0.5230	0.6330	0.2760	5800	0.9237
sDispersion	0.7515	0.4992	1.1949	0.1841	46	0.0010

Convergence	Iterations
1.04	5000

Stock-Recruitment - Mountain Whitefish

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bAlpha	3.3610000	1.012000	4.9340000	1.113000	58	0.0010
bBeta	0.0000883	0.000023	0.0001634	0.000038	80	0.0010
bBetaEggLoss	0.1087000	-0.381900	0.5391000	0.237100	420	0.6048
sRecruits	0.7331000	0.481700	1.1401000	0.169900	45	0.0010

Convergence	Iterations
1	10000

Stock-Recruitment - Rainbow Trout

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bAlpha	3.6010000	1.6540000	4.9370000	0.9570000	46	0.001
bBeta	0.0001461	0.0000474	0.0002273	0.0000497	62	0.001
bBetaEggLoss	-0.2113000	-0.4298000	-0.0131000	0.1047000	99	0.038
sRecruits	0.2503000	0.1634000	0.3946000	0.0602000	46	0.001

Convergence	Iterations
1	10000

Appendix D – Discharge, Temperature, and Elevation Data

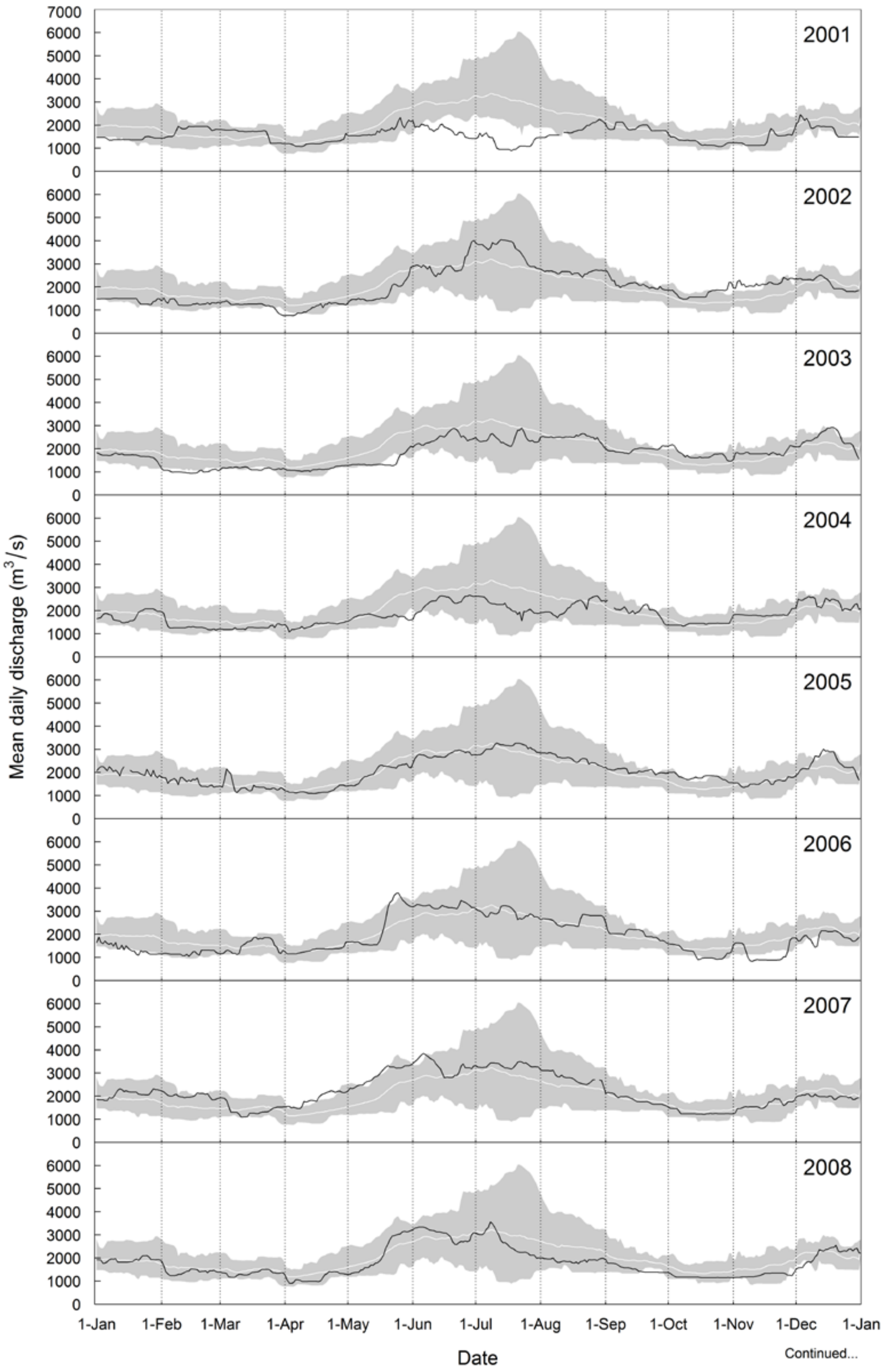

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Figure D1. Mean daily discharge (m³/s) for the Columbia River at the Birchbank water gauging station (black line), 2001 to 2015. The shaded area represents minimum and maximum mean daily discharge recorded at Birchbank during other study years between 2001 and 2015. The white line represents average mean daily discharge over the same time period.

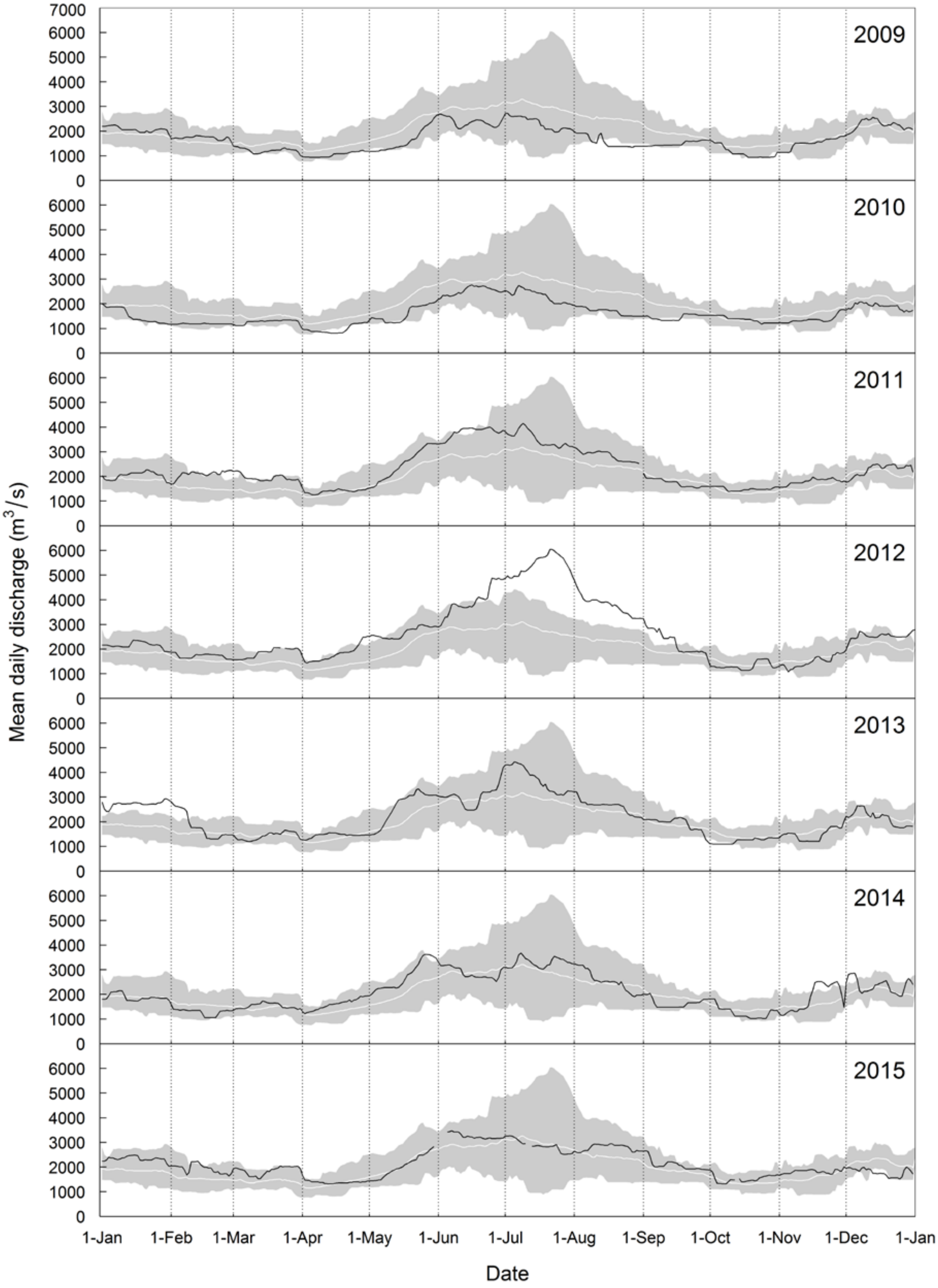

Figure D1. Concluded.

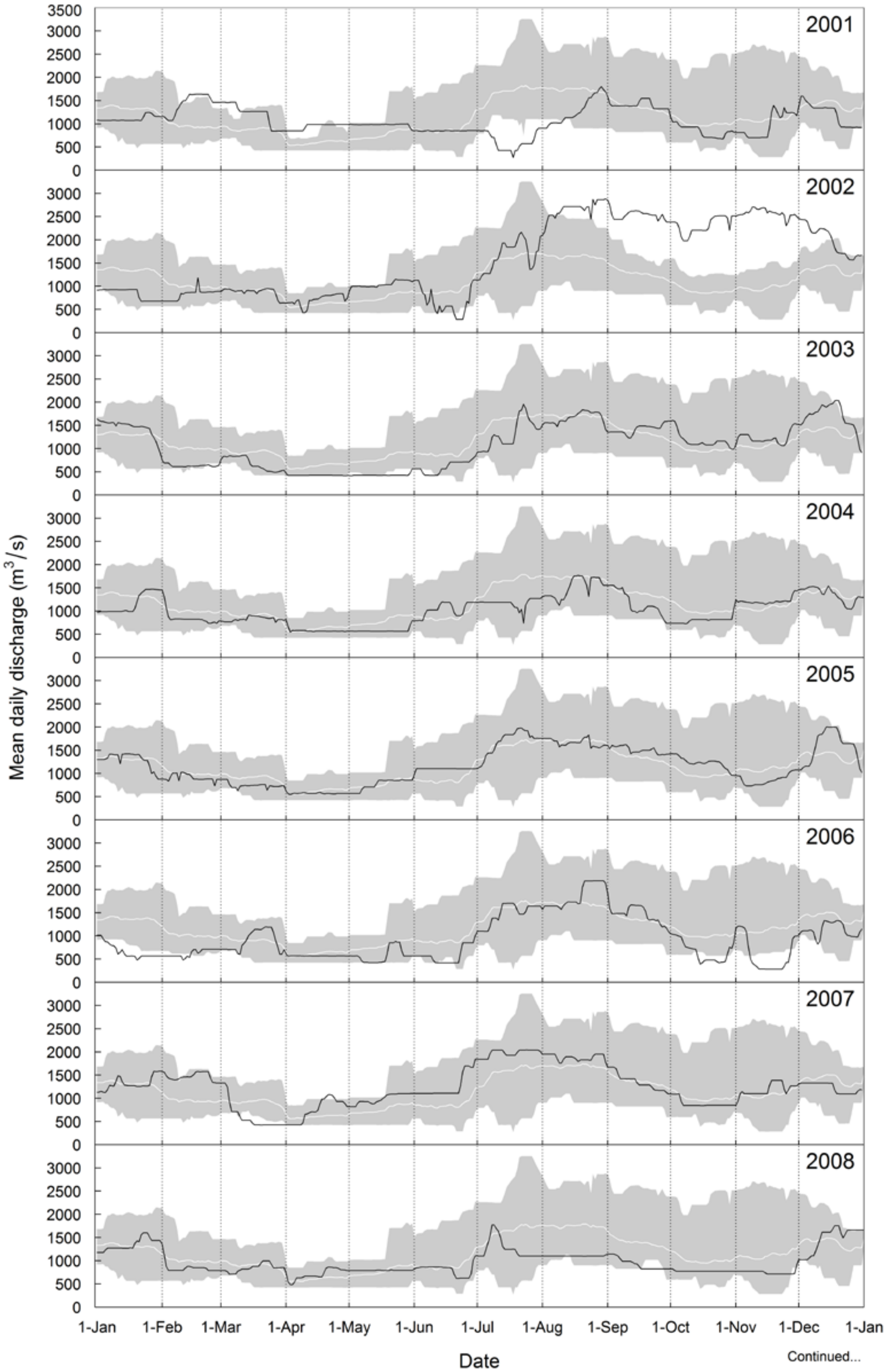

Figure D2. Mean daily discharge (m³/s) for the Columbia River at Hugh L. Keenleyside Dam (HLK), 2001 to 2015 (black line). The shaded area represents minimum and maximum mean daily discharge recorded at HLK during other study years between 2001 and 2015. The white line represents average mean daily discharge over the same time period.

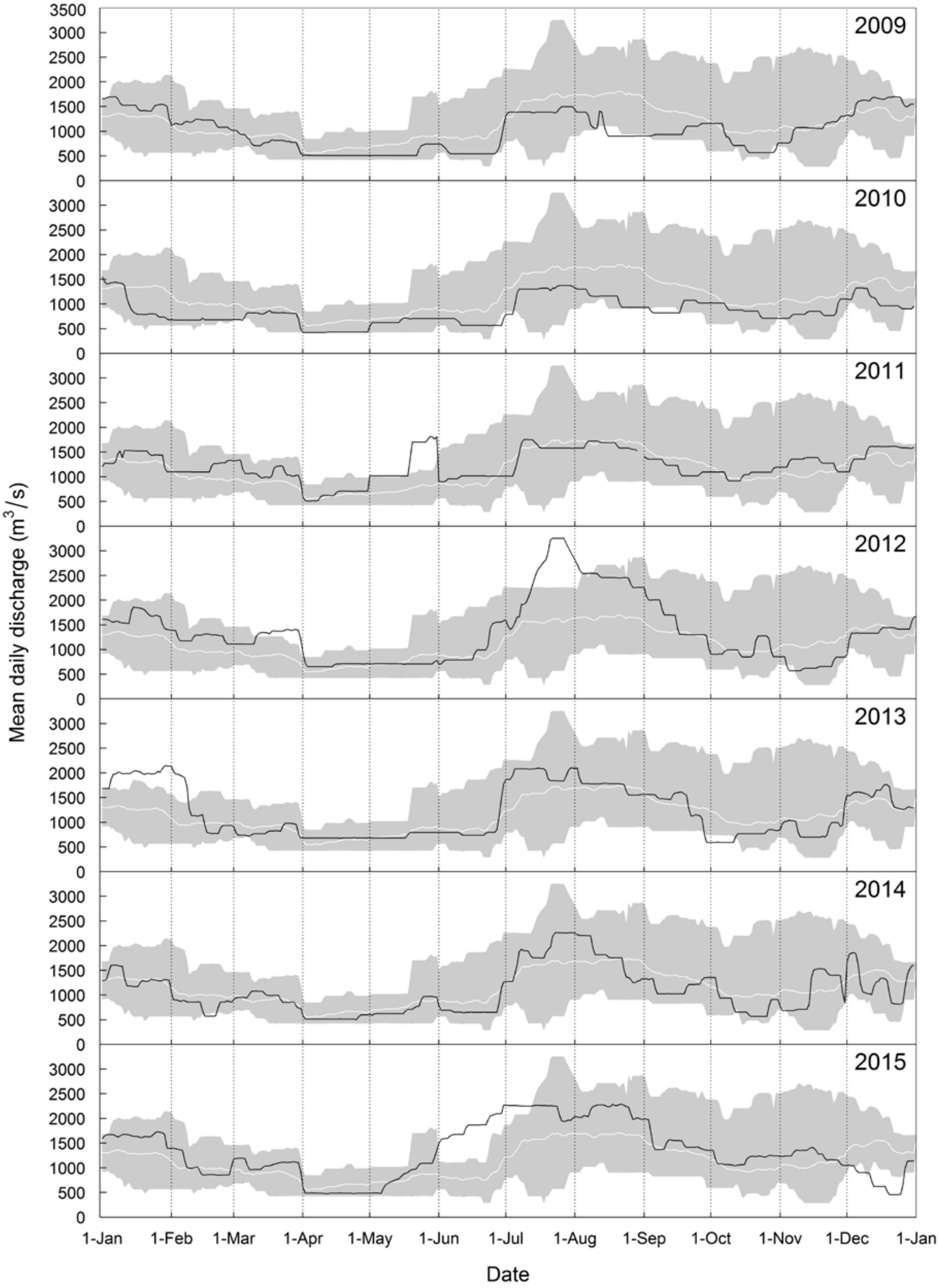

Figure D2. Concluded.

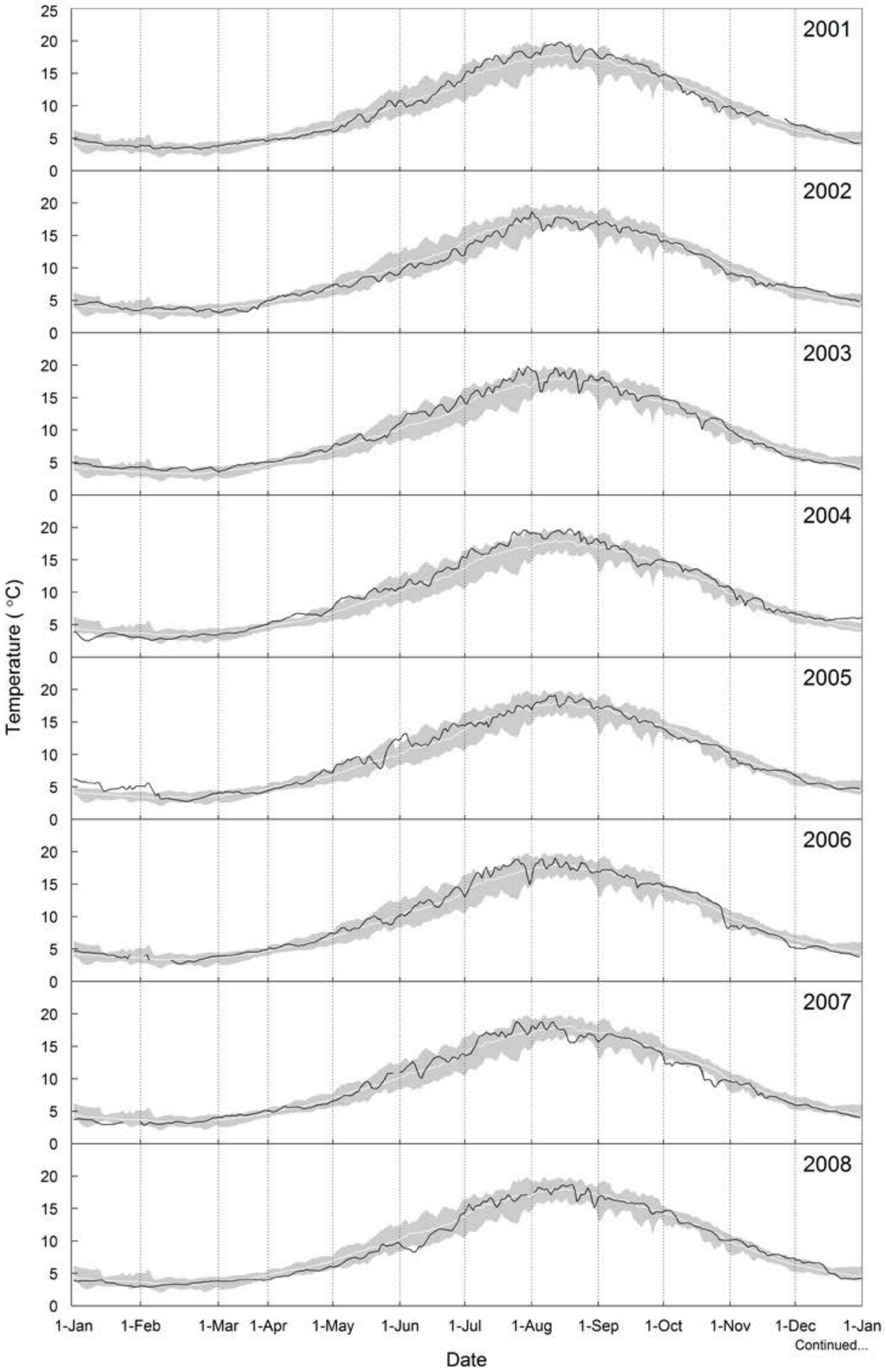

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Figure D3. Mean daily water temperatures (°C) for the Columbia River (black line), 2001 to 2015. Data from all years except 2012 were recorded at the Birchbank water gauging station. Data from 2012 were recorded near Fort Shepherd. The shaded area represents minimum and maximum mean daily water temperatures during other study years between 2001 and 2015. The white line represents average mean daily water temperature over the same time period.

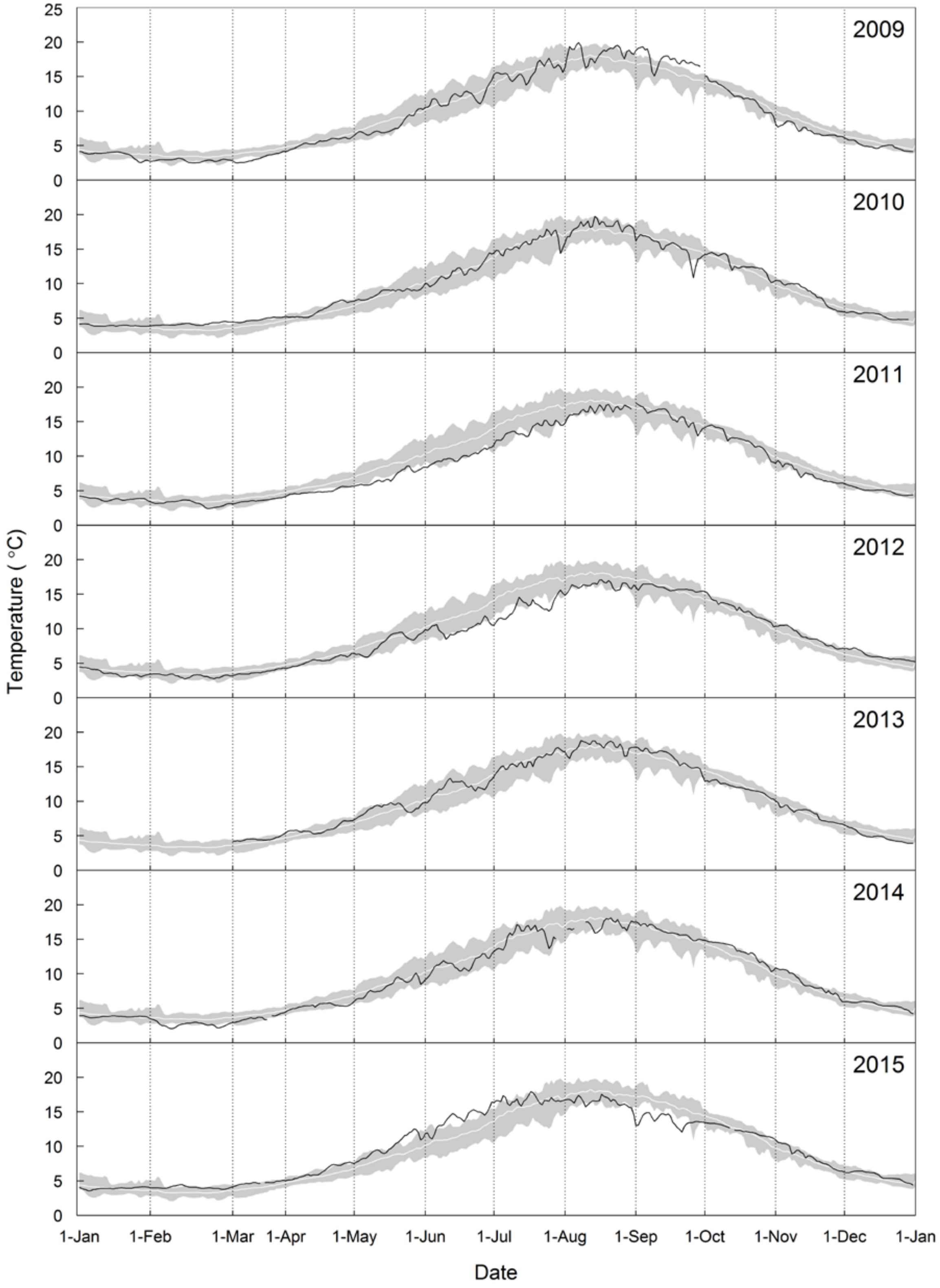

Figure D3. Concluded.

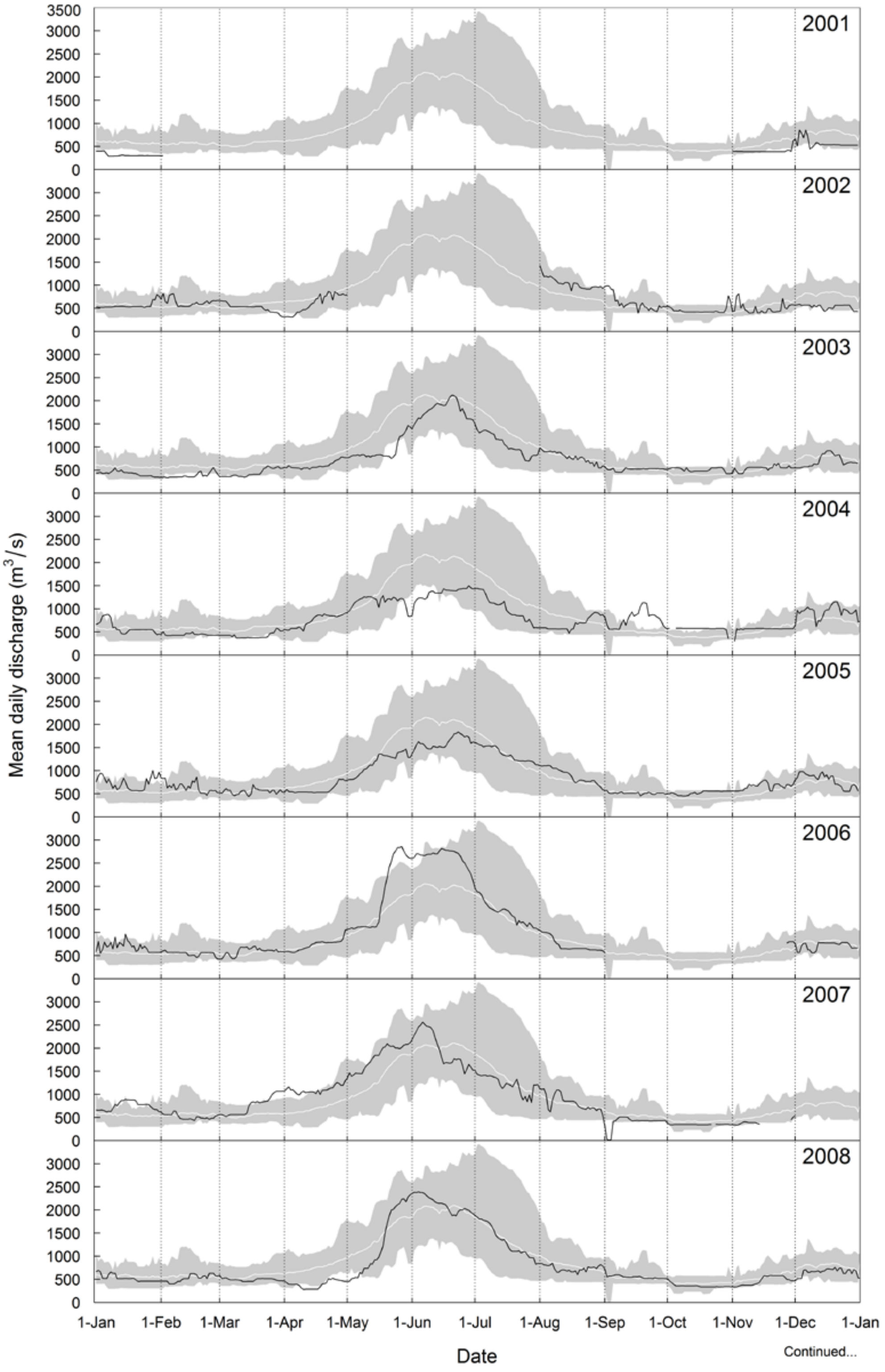

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Figure D4. Mean daily discharge (m³/s) for the Kootenay River at Brilliant Dam (BRD), 2001 to 2015 (black line). The shaded area represents minimum and maximum mean daily discharge recorded at BRD during other study years between 2001 and 2015. The white line represents average mean daily discharge over the same time period.

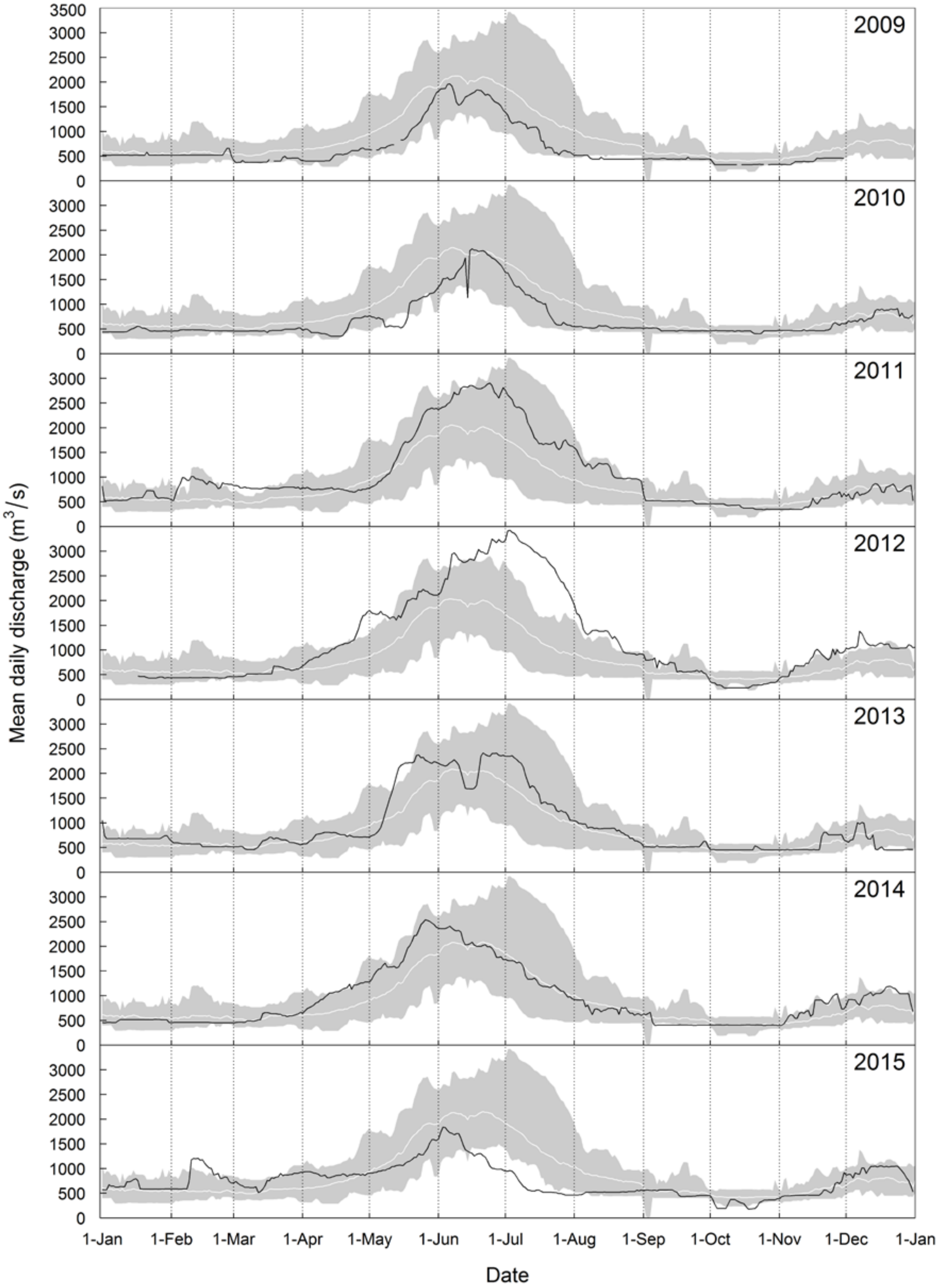

Figure D4. Concluded.

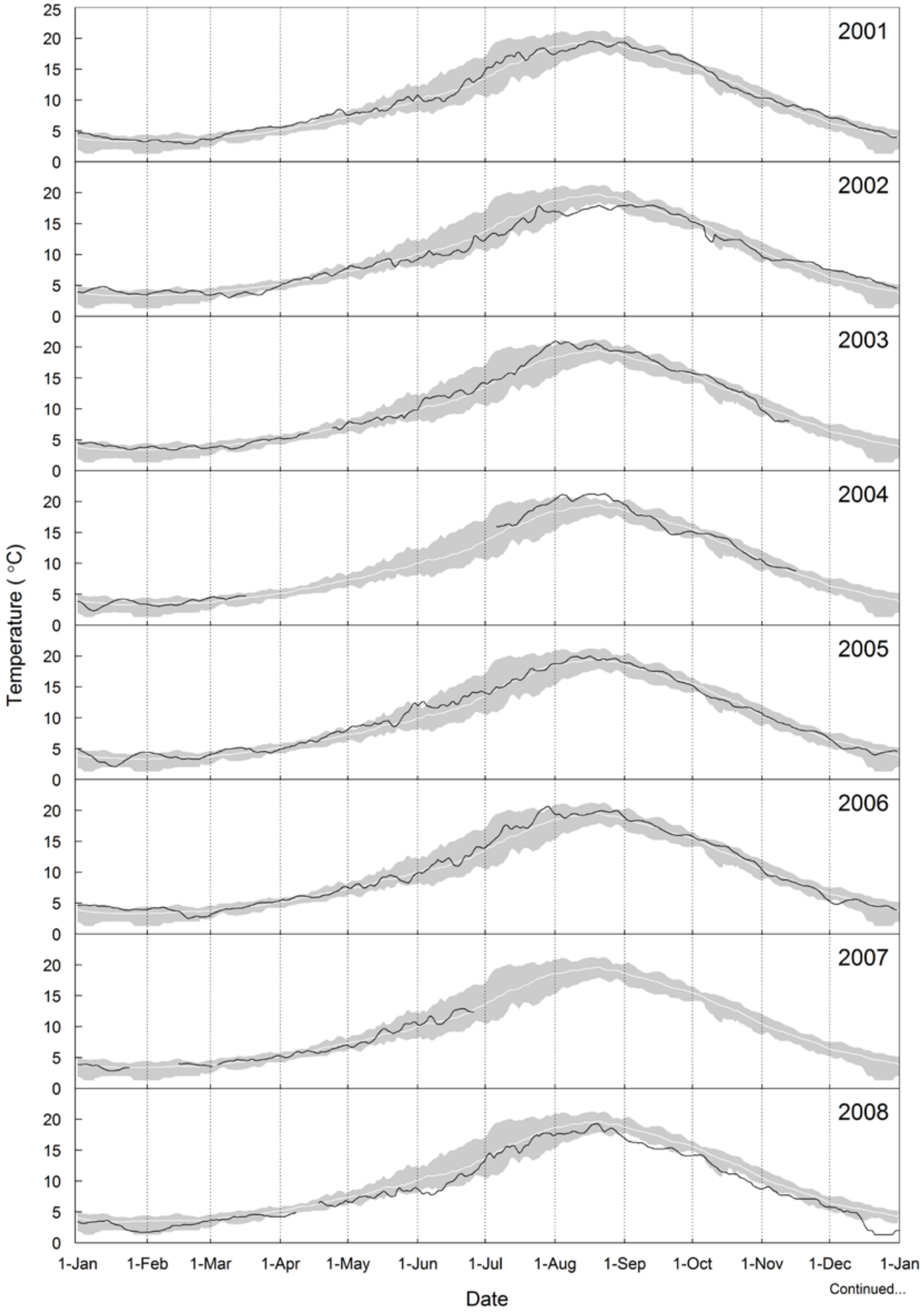

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Figure D5. Mean daily water temperatures (°C) for the Kootenay River at Brilliant Dam (BRD), 2001 to 2015 (black line). The shaded area represents minimum and maximum mean daily water temperatures recorded at BRD during other study years between 2001 and 2015. The white line represents average mean daily water temperature over the same time period.

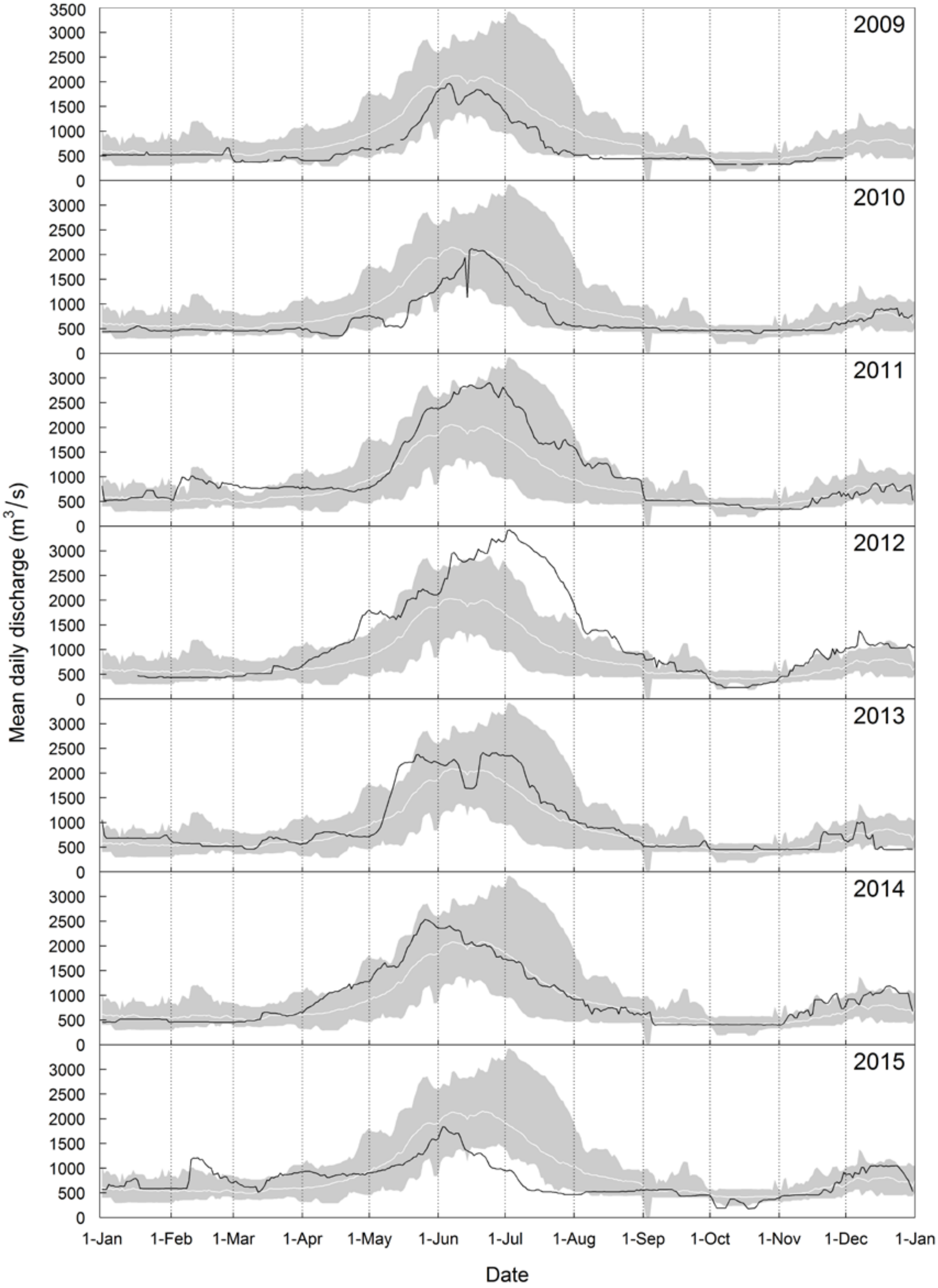


Figure D5. Concluded.

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 2015. 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		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]	%[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	146	<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	42	<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	160	<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	1338	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	11 082	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	2389	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	90 067	42	11
Northern Pike																			7	<1	9	<1	11	<1	125	1	25	<1	9	<1	186	<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	82 803	39	10
Smallmouth Bass					4	<1	3	<1	4	<1	53	<1	16	<1	1	<1			1	<1	8	<1					9	<1	1	<1	100	<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	23 584	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	170	<1	
Yellow Perch					1	<1	4	<1	1	<1	24	<1	1	<1					12	<1	2	<1			1	<1			2	<1	48	<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	212 164	100	25
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	12 250	2	2
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	1464	<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	112 990	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	373 443	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	96 143	16	12
Tench											1	<1	5	<1	1	<1			2	<1					2	<1	1	<1			12	<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	596 372	100	74
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		808 536		

[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, 13 October to 10 November 2015.

Section	Session	Site	Date	Time Sampled (s)	Length Sampled (km)	Number Caught (CPUE = no. fish/km/hr)																											
						Brook Trout		Brown Trout		Bull Trout		Burbot		Kokanee		Lake Whitefish		Mountain Whitefish		Northern Pike		Rainbow Trout		Smallmouth Bass		Walleye		White Sturgeon		Yellow Perch		All Species	
						No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE
Columbia River U/S	1	C00.0-R	13-Oct-15	858	0.94									1	4.46			35	156.23			22	98.2			9	40.17	1	4.46			68	303.53
		C00.7-L	13-Oct-15	670	0.59													53	482.67			7	63.75			1	9.11					61	555.53
		C01.3-L	14-Oct-15	1808	1.6					1	1.24							163	202.85	1	1.24	33	41.07			6	7.47					204	253.87
		C02.8-L	14-Oct-15	880	0.88													37	172			5	23.24									42	195.25
		C03.6-L	14-Oct-15	1977	2.09									2	1.74			61	53.15			47	40.95			4	3.49	1	0.87			115	100.2
		C04.6-R	14-Oct-15	603	0.52													23	264.06	1	11.48	22	252.58			3	34.44			1	11.48	50	574.05
		C05.6-L	14-Oct-15	1136	1.1							1	2.88	2	5.76			36	103.71			22	63.38			4	11.52					65	187.26
		C07.3-R	14-Oct-15	1003	1.7											3	6.33	36	76.01			37	78.12			5	10.56					81	171.02
		C07.4-L	14-Oct-15	914	1													59	232.39			17	66.96					2	7.88			78	307.22
	Session Summary			**1094**	**10.4**	**0**	**0**	**0**	**0**	**1**	**0.32**	**1**	**0.32**	**5**	**1.58**	**3**	**0.95**	**503**	**159.15**	**2**	**0.63**	**212**	**67.08**	**0**	**0**	**32**	**10.13**	**4**	**1.27**	**1**	**0.32**	**764**	**241.74**
	2	C00.0-R	19-Oct-15	820	0.865									1	5.08			23	116.73			18	91.36			14	71.06	1	5.08			57	289.3
		C00.7-L	19-Oct-15	696	0.59					1	8.77							10	87.67			6	52.6			7	61.37					24	210.4
		C01.3-L	19-Oct-15	1611	1.59													90	126.49	2	2.81	30	42.16			18	25.3					140	196.76
		C02.8-L	19-Oct-15	1034	0.88													59	233.43			7	27.69			2	7.91					68	269.03
		C03.6-L	20-Oct-15	2140	2.09									3	2.41			54	43.46			57	45.88			8	6.44					122	98.2
		C04.6-R	20-Oct-15	526	0.52													19	250.07	2	26.32	9	118.46									30	394.85
		C05.6-L	20-Oct-15	1076	1.1									1	3.04			25	76.04			23	69.96			4	12.17					53	161.2
		C07.3-R	20-Oct-15	941	1.65													48	111.29			23	53.33									71	164.62
		C07.4-L	20-Oct-15	860	1											3	12.56	68	284.65			29	121.4			3	12.56	1	4.19			104	435.35
	Session Summary			**1078**	**10.3**	**0**	**0**	**0**	**0**	**1**	**0.32**	**0**	**0**	**5**	**1.62**	**3**	**0.97**	**396**	**128.39**	**4**	**1.3**	**202**	**65.49**	**0**	**0**	**56**	**18.16**	**2**	**0.65**	**0**	**0**	**669**	**216.91**
	3	C00.0-R	25-Oct-15	1023	0.94													31	116.05			9	33.69			8	29.95					48	179.7
		C00.7-L	25-Oct-15	798	0.59													24	183.51			2	15.29					1	7.65			27	206.45
		C01.3-L	25-Oct-15	1623	1.6					1	1.39							52	72.09	1	1.39	11	15.25			9	12.48					74	102.59
		C02.8-L	25-Oct-15	905	0.88													69	311.9			5	22.6			1	4.52					75	339.03
		C03.6-L	26-Oct-15	2051	2.09									2	1.68			88	73.9			21	17.64			4	3.36					115	96.58
		C04.6-R	26-Oct-15	533	0.52													19	246.79			3	38.97			1	12.99					23	298.74
		C05.6-L	26-Oct-15	1112	1.1									3	8.83			11	32.37			20	58.86			3	8.83					37	108.89
		C07.3-R	27-Oct-15	809	1.69													56	147.45			17	44.76			5	13.17					78	205.38
		C07.4-L	26-Oct-15	933	1													101	389.71			37	142.77			4	15.43					142	547.91
	Session Summary			**1087**	**10.4**	**0**	**0**	**0**	**0**	**1**	**0.32**	**0**	**0**	**5**	**1.59**	**0**	**0**	**451**	**143.62**	**1**	**0.32**	**125**	**39.81**	**0**	**0**	**35**	**11.15**	**1**	**0.32**	**0**	**0**	**619**	**197.12**
	4	C00.0-R	01-Nov-15	999	0.94													21	80.51			23	88.17			2	7.67					46	176.35
		C00.7-L	01-Nov-15	605	0.59													18	181.54			12	121.03			3	30.26					33	332.82
		C01.3-L	01-Nov-15	1785	1.6													89	112.18			43	54.2			29	36.55					161	202.94
		C02.8-L	01-Nov-15	925	0.88													29	128.26			12	53.07			4	17.69					45	199.02
		C03.6-L	02-Nov-15	2187	2.04									3	2.42			95	76.66			52	41.96			14	11.3					164	132.33
		C04.6-R	02-Nov-15	798	0.52													26	225.56	2	17.35	17	147.48							1	8.68	46	399.07
		C05.6-L	02-Nov-15	1152	1.1													26	73.86			17	48.3			6	17.05					49	139.2
		C07.3-R	02-Nov-15	990	1.7	1	2.14			1	2.14							35	74.87			33	70.59			3	6.42					73	156.15
		C07.4-L	02-Nov-15	859	1									1	4.19	4	16.76	61	255.65			42	176.02			1	4.19					109	456.81
	Session Summary			**1144**	**10.4**	**1**	**0.3**	**0**	**0**	**1**	**0.3**	**0**	**0**	**4**	**1.21**	**4**	**1.21**	**400**	**121.03**	**2**	**0.61**	**251**	**75.95**	**0**	**0**	**62**	**18.76**	**0**	**0**	**1**	**0.3**	**726**	**219.67**
	5	C08.4-L	07-Nov-15	385	0.5											5	93.51	72	1346.49			14	261.82									91	1701.82
	Session Summary			**385**	**0.5**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**5**	**93.51**	**72**	**1346.49**	**0**	**0**	**14**	**261.82**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**91**	**1701.82**
Section Total All Samples				**40025**	**41.985**	**1**		**0**		**4**		**1**		**19**		**15**		**1822**		**9**		**804**		**0**		**185**		**7**		**2**		**2869**	
Section Average All Samples				**1082**	**1.13**	**0**	**0.08**	**0**	**0**	**0**	**0.32**	**0**	**0.08**	**1**	**1.51**	**0**	**1.19**	**49**	**144.39**	**0**	**0.71**	**22**	**63.71**	**0**	**0**	**5**	**14.66**	**0**	**0.55**	**0**	**0.16**	**78**	**227.36**
Section Standard Error of Mean						**0.03**	**0.06**	**0**	**0**	**0.05**	**0.25**	**0.03**	**0.08**	**0.16**	**0.35**	**0.2**	**2.57**	**5.21**	**36.04**	**0.1**	**0.88**	**2.34**	**9.66**	**0**	**0**	**0.97**	**2.72**	**0.08**	**0.35**	**0.04**	**0.38**	**7.14**	**44.76**

Table E2 Continued.

Section	Session	Site	Date	Time Sampled (s)	Length Sampled (km)	Number Caught (CPUE = no. fish/km/hr)																											
						Brook Trout		Brown Trout		Bull Trout		Burbot		Kokanee		Lake Whitefish		Mountain Whitefish		Northern Pike		Rainbow Trout		Smallmouth Bass		Walleye		White Sturgeon		Yellow Perch		All Species	
						No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE
Kootenay River	1	K00.3-L	15-Oct-15	214	0.44													4	***152.93***			4	***152.93***									8	***305.86***
		K00.6-R	15-Oct-15	556	0.6					1	***10.79***							16	***172.66***			4	***43.17***			7	***75.54***					28	***302.16***
		K01.8-L	15-Oct-15	1628	1.87									1	***1.18***			32	***37.84***			21	***24.83***			7	***8.28***					61	***72.13***
		K01.8-R	15-Oct-15	1072	1.3									1	***2.58***			40	***103.33***			11	***28.42***			8	***20.67***					60	***154.99***
	Session Summary			**868**	**4.2**	**0**	***0***	**0**	***0***	**1**	***0.99***	**0**	***0***	**2**	***1.97***	**0**	***0***	**92**	***90.85***	**0**	***0***	**40**	***39.5***	**0**	***0***	**22**	***21.72***	**0**	***0***	**0**	***0***	**157**	***155.04***
	2	K00.3-L	21-Oct-15	223	0.44																	2	***73.38***			2	***73.38***					4	***146.76***
		K00.6-R	21-Oct-15	618	0.6													11	***106.8***			12	***116.5***			5	***48.54***					28	***271.84***
		K01.8-L	20-Oct-15	1684	1.87													33	***37.73***			18	***20.58***			8	***9.15***					59	***67.45***
		K01.8-R	20-Oct-15	1244	1.3													26	***57.88***			9	***20.03***			3	***6.68***					38	***84.59***
	Session Summary			**942**	**4.2**	**0**	***0***	**0**	***0***	**0**	***0***	**0**	***0***	**0**	***0***	**0**	***0***	**70**	***63.69***	**0**	***0***	**41**	***37.31***	**0**	***0***	**18**	***16.38***	**0**	***0***	**0**	***0***	**129**	***117.38***
	3	K00.3-L	27-Oct-15	232	0.44					1	***35.27***							9	***317.4***			6	***211.6***			3	***105.8***					19	***670.06***
		K00.6-R	27-Oct-15	462	0.6													11	***142.86***			7	***90.91***			3	***38.96***					21	***272.73***
		K01.8-L	28-Oct-15	1628	1.87													46	***54.4***			47	***55.58***			14	***16.56***	1	***1.18***			108	***127.71***
		K01.8-R	27-Oct-15	1211	1.3													34	***77.75***			48	***109.76***			9	***20.58***					91	***208.09***
	Session Summary			**883**	**4.2**	**0**	***0***	**0**	***0***	**1**	***0.97***	**0**	***0***	**0**	***0***	**0**	***0***	**100**	***97.07***	**0**	***0***	**108**	***104.84***	**0**	***0***	**29**	***28.15***	**1**	***0.97***	**0**	***0***	**239**	***232***
	4	K00.3-L	03-Nov-15	216	0.44													18	***681.82***			2	***75.76***			3	***113.64***					23	***871.21***
		K00.6-R	03-Nov-15	549	0.6													43	***469.95***			12	***131.15***			7	***76.5***					62	***677.6***
		K01.8-L	02-Nov-15	1619	1.87													45	***53.51***			47	***55.89***			5	***5.95***					97	***115.34***
		K01.8-R	02-Nov-15	1218	1.3													45	***102.31***			36	***81.85***			3	***6.82***	2	***4.55***			86	***195.53***
	Session Summary			**900**	**4.2**	**0**	***0***	**0**	***0***	**0**	***0***	**0**	***0***	**0**	***0***	**0**	***0***	**151**	***143.81***	**0**	***0***	**97**	***92.38***	**0**	***0***	**18**	***17.14***	**2**	***1.9***	**0**	***0***	**268**	***255.24***
Section Total All Samples				**14374**	**16.84**	**0**		**0**		**2**		**0**		**2**		**0**		**413**		**0**		**286**		**0**		**87**		**3**		**0**		**793**	
Section Average All Samples				**898**	**1.05**	**0**	***0***	**0**	***0***	**0**	***0.48***	**0**	***0***	**0**	***0.48***	**0**	***0***	**26**	***98.32***	**0**	***0***	**18**	***68.08***	**0**	***0***	**5**	***20.71***	**0**	***0.71***	**0**	***0***	**50**	***188.78***
Section Standard Error of Mean						**0**	***0***	**0**	***0***	**0.09**	***2.26***	**0**	***0***	**0.09**	***0.17***	**0**	***0***	**3.99**	***45.56***	**0**	***0***	**4.23**	***13.39***	**0**	***0***	**0.86**	***9.52***	**0.14**	***0.29***	**0**	***0***	**8.3**	***60.67***

Table E2 Continued.

Section	Session	Site	Date	Time Sampled (s)	Length Sampled (km)	Number Caught (CPUE = no. fish/km/hr)																											
						Brook Trout		Brown Trout		Bull Trout		Burbot		Kokanee		Lake Whitefish		Mountain Whitefish		Northern Pike		Rainbow Trout		Smallmouth Bass		Walleye		White Sturgeon		Yellow Perch		All Species	
						No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE
Columbia River D/S	1	C25.3-R	15-Oct-15	1258	2.71													29	***30.62***			36	***38.02***			3	***3.17***	1	***1.06***			69	***72.86***
		C27.6-R	15-Oct-15	336	0.61													4	***70.26***			10	***175.64***			1	***17.56***					15	***263.47***
		C28.2-R	15-Oct-15	762	1.13													17	***71.08***			41	***171.42***			2	***8.36***					60	***250.85***
		C34.9-L	16-Oct-15	1803	2.14													8	***7.46***			87	***81.17***			3	***2.8***	1	***0.93***			99	***92.37***
		C36.6-L	16-Oct-15	1448	2.39											2	***2.08***	13	***13.52***			84	***87.38***			8	***8.32***					107	***111.31***
		C47.8-L	17-Oct-15	1218	1.44	1	***2.05***									3	***6.16***	7	***14.37***			42	***86.21***			6	***12.32***					59	***121.1***
		C48.2-R	16-Oct-15	610	1.01													5	***29.22***			16	***93.49***			1	***5.84***					22	***128.55***
		C49.0-L	17-Oct-15	493	0.93							1	***7.85***			3	***23.56***	27	***212***			23	***180.59***			1	***7.85***	1	***7.85***			56	***439.7***
		C49.0-R	16-Oct-15	638	0.72																	14	***109.72***			1	***7.84***					15	***117.55***
		C49.8-L	17-Oct-15	1557	2.45							1	***0.94***			4	***3.77***	22	***20.76***			62	***58.51***			4	***3.77***					93	***87.77***
		C49.8-R	16-Oct-15	1150	2.39													32	***41.91***			55	***72.04***			7	***9.17***					94	***123.12***
		C52.2-L	18-Oct-15	860	0.89	1	***4.7***											12	***56.44***			17	***79.96***									30	***141.1***
		C52.2-R	17-Oct-15	1867	3.79											8	***4.07***	24	***12.21***			43	***21.88***	1	***0.51***	10	***5.09***					86	***43.75***
		C52.8-L	18-Oct-15	411	0.89													7	***68.89***			8	***78.73***			1	***9.84***					16	***157.47***
		C53.6-L	18-Oct-15	922	1.72											6	***13.62***	3	***6.81***			14	***31.78***			3	***6.81***					26	***59.02***
	Session Summary			**1022**	**25.2**	**2**	***0.28***	**0**	***0***	**0**	***0***	**2**	***0.28***	**0**	***0***	**26**	***3.63***	**210**	***29.35***	**0**	***0***	**552**	***77.16***	**1**	***0.14***	**51**	***7.13***	**3**	***0.42***	**0**	***0***	**847**	***118.4***
	2	C25.3-R	21-Oct-15	1357	2.72											1	***0.98***	10	***9.75***			45	***43.89***									56	***54.62***
		C27.6-R	21-Oct-15	341	0.61													4	***69.23***			14	***242.3***			1	***17.31***					19	***328.83***
		C28.2-R	21-Oct-15	734	1.13													12	***52.08***			27	***117.19***			3	***13.02***					42	***182.3***
		C34.9-L	21-Oct-15	1810	2.14													4	***3.72***			53	***49.26***			6	***5.58***					63	***58.55***
		C36.6-L	22-Oct-15	1470	2.39											2	***2.05***	7	***7.17***			68	***69.68***			2	***2.05***					79	***80.95***
		C47.8-L	22-Oct-15	1236	1.44	2	***4.05***					1	***2.02***	1	***2.02***	1	***2.02***	3	***6.07***			32	***64.72***			7	***14.16***					47	***95.06***
		C48.2-R	22-Oct-15	834	1.01													16	***68.38***			13	***55.56***			4	***17.1***					33	***141.04***
		C49.0-L	23-Oct-15	482	0.93													13	***104.4***			21	***168.65***									34	***273.06***
		C49.0-R	22-Oct-15	480	0.72													2	***20.83***			18	***187.5***			4	***41.67***					24	***250***
		C49.8-L	23-Oct-15	1514	2.45					1	***0.97***	1	***0.97***			2	***1.94***	22	***21.35***			56	***54.35***			2	***1.94***					84	***81.52***
		C49.8-R	22-Oct-15	1129	2.39											1	***1.33***	38	***50.7***			21	***28.02***			4	***5.34***					64	***85.39***
		C52.2-L	23-Oct-15	761	0.89													2	***10.63***			13	***69.1***									15	***79.73***
		C52.2-R	23-Oct-15	1921	3.79											6	***2.97***	19	***9.39***			38	***18.79***			6	***2.97***					69	***34.12***
		C52.8-L	23-Oct-15	606	0.89											1	***6.67***	8	***53.4***			15	***100.12***			1	***6.67***					25	***166.87***
		C53.6-L	23-Oct-15	984	1.72													7	***14.89***			24	***51.05***			9	***19.14***					40	***85.08***
	Session Summary			**1044**	**25.2**	**2**	***0.27***	**0**	***0***	**1**	***0.14***	**2**	***0.27***	**1**	***0.14***	**14**	***1.92***	**167**	***22.85***	**0**	***0***	**458**	***62.67***	**0**	***0***	**49**	***6.7***	**0**	***0***	**0**	***0***	**694**	***94.96***
	3	C25.3-R	28-Oct-15	1451	2.73											3	***2.73***	12	***10.91***			55	***49.98***			7	***6.36***	1	***0.91***			78	***70.89***
		C27.6-R	28-Oct-15	365	0.61													6	***97.01***			14	***226.36***									20	***323.38***
		C28.2-R	28-Oct-15	790	1.13													14	***56.46***			47	***189.54***			3	***12.1***					64	***258.09***
		C34.9-L	29-Oct-15	1714	2.14													20	***19.63***			52	***51.04***			8	***7.85***					80	***78.52***
		C36.6-L	29-Oct-15	1294	2.39											1	***1.16***	12	***13.97***			68	***79.16***			2	***2.33***					83	***96.62***
		C47.8-L	30-Oct-15	1160	1.44	2	***4.31***									2	***4.31***	12	***25.86***			55	***118.53***			10	***21.55***					81	***174.57***
		C48.2-R	29-Oct-15	810	1.01													7	***30.8***			21	***92.41***			4	***17.6***					32	***140.81***
		C49.0-L	30-Oct-15	946	0.93													18	***73.65***			12	***49.1***			2	***8.18***					32	***130.94***
		C49.0-R	29-Oct-15	500	0.72											1	***10***	1	***10***			8	***80***			1	***10***					11	***110***
		C49.8-L	30-Oct-15	1362	2.425											4	***4.36***	32	***34.88***			35	***38.15***			4	***4.36***					75	***81.75***
		C49.8-R	29-Oct-15	1192	2.39							1	***1.26***			1	***1.26***	23	***29.06***			37	***46.76***			7	***8.85***					69	***87.19***
		C52.2-L	30-Oct-15	822	0.89											2	***9.84***	5	***24.6***			21	***103.34***			6	***29.53***					34	***167.31***
		C52.2-R	30-Oct-15	1897	3.79													11	***5.51***			35	***17.53***			6	***3***					52	***26.04***
		C52.8-L	30-Oct-15	991	0.89											2		7				15				2						26	
		C53.6-L	31-Oct-15	896	1.72					1	***2.34***							6	***14.02***			13	***30.37***			3	***7.01***					23	***53.73***
	Session Summary			**1079**	**25.2**	**2**	***0.26***	**0**	***0***	**1**	***0.13***	**1**	***0.13***	**0**	***0***	**16**	***2.12***	**186**	***24.63***	**0**	***0***	**488**	***64.61***	**0**	***0***	**65**	***8.61***	**1**	***0.13***	**0**	***0***	**760**	***100.62***

Table E2 Concluded.

Section	Session	Site	Date	Time Sampled (s)	Length Sampled (km)	Number Caught (CPUE = no. fish/km/hr)																											
						Brook Trout		Brown Trout		Bull Trout		Burbot		Kokanee		Lake Whitefish		Mountain Whitefish		Northern Pike		Rainbow Trout		Smallmouth Bass		Walleye		White Sturgeon		Yellow Perch		All Species	
						No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE
Columbia River D/S	4	C25.3-R	03-Nov-15	1361	2.73													22	21.32			42	40.69			4	3.88					68	65.89
		C27.6-R	03-Nov-15	349	0.61													8	135.28			30	507.3			1	16.91					39	659.5
		C28.2-R	03-Nov-15	711	1.13													28	125.46			49	219.56									77	345.02
		C34.9-L	03-Nov-15	1743	2.14													23	22.2			74	71.42			4	3.86					101	97.48
		C36.6-L	04-Nov-15	1169	2.39													14	18.04			55	70.87			5	6.44					74	95.35
		C47.8-L	04-Nov-15	1260	1.44	1	1.98									2	3.97	5	9.92			52	103.17			5	9.92					65	128.97
		C48.2-R	05-Nov-15	772	1.01													17	78.49			14	64.64			3	13.85					34	156.98
		C49.0-L	04-Nov-15	521	0.93											1	7.43	37	274.91			28	208.04			5	37.15					71	527.52
		C49.0-R	05-Nov-15	550	0.72													7	63.64			10	90.91			3	27.27					20	181.82
		C49.8-L	04-Nov-15	1519	2.45													37	35.79			78	75.45			4	3.87					119	115.11
		C49.8-R	05-Nov-15	1207	2.39													36	44.93			23	28.7			3	3.74					62	77.37
		C52.2-L	04-Nov-15	748	0.89													4	21.63			15	81.12			1	5.41					20	108.15
		C52.2-R	05-Nov-15	1904	3.79	1	0.5									2	1	31	15.47			44	21.95			5	2.49					83	41.41
		C52.8-L	04-Nov-15	510	0.89			1	7.93									4	31.73			8	63.45			1	7.93					14	111.04
		C53.6-L	04-Nov-15	912	1.72													7	16.06			14	32.13			1	2.29					22	50.49
	Session Summary			**1016**	**25.2**	**2**	**0.28**	**1**	**0.14**	**0**	**0**	**0**	**0**	**0**	**0**	**5**	**0.7**	**280**	**39.37**	**0**	**0**	**536**	**75.37**	**0**	**0**	**45**	**6.33**	**0**	**0**	**0**	**0**	**869**	**122.19**
	5	C10.9-L	07-Nov-15	1980	2.18													193	160.97			34	28.36									227	189.32
		C13.4-L	07-Nov-15	1181	1.39											3	6.58	37	81.14			45	98.68			4	8.77					89	195.18
		C13.4-R	08-Nov-15	2056	2.52													61	42.38			77	53.5			3	2.08	1	0.69			142	98.67
		C15.8-R	08-Nov-15	763	0.82									10	57.54			50	287.7			24	138.09			3	17.26					87	500.59
		C17.0-L	08-Nov-15	1921	1.91													63	61.81			67	65.74			6	5.89	3	2.94			139	136.38
		C19.0-L	08-Nov-15	921	1.28													24	73.29			43	131.31			2	6.11					69	210.71
		C20.1-L	08-Nov-15	888	1.27													60	191.53			59	188.34			3	9.58					122	389.44
		C23.4-L	08-Nov-15	683	0.93													52	294.71			63	357.06			2	11.34					117	663.11
		C24.3-L	08-Nov-15	837	1.29													24	80.02			64	213.39			3	10					91	303.41
		C25.3-L	09-Nov-15	906	1.78													37	82.6			30	66.97			14	31.25					81	180.82
		C26.2-L	09-Nov-15	622	1.25													43	199.1			10	46.3									53	245.4
		C30.6-L	09-Nov-15	1318	1.84					1	1.48							21	31.17			91	135.09			2	2.97					115	170.71
		C34.9-R	09-Nov-15	831	0.89													2	9.74			63	306.66									65	316.39
		C38.8-L	09-Nov-15	650	1.3													27	115.03			26	110.77									53	225.8
		C41.1-L	09-Nov-15	1671	2.41													26	23.24			78	69.73			10	8.94					114	101.91
		C44.6-L	10-Nov-15	702	1.01													10	50.77			25	126.94			6	30.46					41	208.17
		C45.6-L	10-Nov-15	680	0.9													19	111.76			71	417.65			3	17.65					93	547.06
		C46.4-L	10-Nov-15	947	1.58													12	28.87			89	214.13									101	243.01
		C56.0-L	05-Nov-15	777	0.94													2	9.86			11	54.22									13	64.08
	Session Summary			**1070**	**27.5**	**0**	**0**	**0**	**0**	**1**	**0.12**	**0**	**0**	**10**	**1.22**	**3**	**0.37**	**763**	**93.35**	**0**	**0**	**970**	**118.67**	**0**	**0**	**61**	**7.46**	**4**	**0.49**	**0**	**0**	**1812**	**221.69**
Section Total All Samples				**82752**	**128.355**	**8**		**1**		**3**		**5**		**11**		**64**		**1606**		**0**		**3004**		**1**		**271**		**8**		**0**		**4982**	
Section Average All Samples				**1047**	**1.62**	**0**	**0.21**	**0**	**0.03**	**0**	**0.08**	**0**	**0.13**	**0**	**0.29**	**1**	**1.71**	**20**	**43.02**	**0**	**0**	**38**	**80.47**	**0**	**0.03**	**3**	**7.26**	**0**	**0.21**	**0**	**0**	**63**	**133.46**
Section Standard Error of Mean						**0.04**	**0.1**	**0.01**	**0.1**	**0.02**	**0.04**	**0.03**	**0.1**	**0.13**	**0.73**	**0.18**	**0.42**	**2.78**	**7.29**	**0**	**0**	**2.63**	**10.07**	**0.01**	**0.01**	**0.33**	**1**	**0.05**	**0.11**	**0**	**0**	**4.27**	**15.54**
All Sections Total All Samples				**137151**	**187.18**	**9**	**0**	**1**	**0**	**9**	**0**	**6**	**0**	**32**	**0**	**79**	**0.01**	**3841**	**0.54**	**9**	**0**	**4094**	**0.57**	**1**	**0**	**543**	**0.08**	**18**	**0**	**2**	**0**	**8644**	**1.21**
All Sections Average All Samples						**0**	**0.17**	**0**	**0.02**	**0**	**0.17**	**0**	**0.11**	**0**	**0.59**	**1**	**1.46**	**29**	**71.1**	**0**	**0.17**	**31**	**75.78**	**0**	**0.02**	**4**	**10.05**	**0**	**0.33**	**0**	**0.04**	**65**	**160**
All Sections Standard Error of Mean						**0.03**	**0.06**	**0.01**	**0.06**	**0.02**	**0.29**	**0.02**	**0.07**	**0.09**	**0.45**	**0.12**	**0.76**	**2.51**	**13.36**	**0.03**	**0.25**	**1.92**	**6.89**	**0.01**	**0**	**0.35**	**1.7**	**0.04**	**0.12**	**0.01**	**0.11**	**3.46**	**17.77**

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, 13 October to 10 November 2015.

Section	Session	Site	Date	Time Sampled (s)	Length Sampled (km)	Number Caught (CPUE = no. fish/km/hr)															
						Carp spp.		Northern Pikeminnow		Peamouth		Redside Shiner		Sculpin spp.		Sucker spp.		Tench		All Species	
						No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE
Columbia River U/S	1	C00.0-R	13-Oct-15	858	0.94			2	***8.93***	2	***8.93***	415	***1852.4***			5	***22.32***			424	***1892.58***
		C00.7-L	13-Oct-15	670	0.59			5	***45.54***	14	***127.5***			3	***27.32***	1	***9.11***			23	***209.46***
		C01.3-L	14-Oct-15	1808	1.6			2	***2.49***	8	***9.96***	100	***124.45***	67	***83.38***	80	***99.56***			257	***319.83***
		C02.8-L	14-Oct-15	880	0.88					1	***4.65***					25	***116.22***			26	***120.87***
		C03.6-L	14-Oct-15	1977	2.09			9	***7.84***	1	***0.87***	9	***7.84***	4	***3.49***	13	***11.33***			36	***31.37***
		C04.6-R	14-Oct-15	603	0.52							1	***11.48***			12	***137.77***			13	***149.25***
		C05.6-L	14-Oct-15	1136	1.1			3	***8.64***			77	***221.83***	110	***316.9***	31	***89.31***			221	***636.68***
		C07.3-R	14-Oct-15	1003	1.7			2	***4.22***							7	***14.78***			9	***19***
		C07.4-L	14-Oct-15	914	1											22	***86.65***			22	***86.65***
	Session Summary			**1094**	**10.4**	**0**	*0*	**23**	*7.28*	**26**	*8.23*	**602**	*190.48*	**184**	*58.22*	**196**	*62.02*	**0**	*0*	**1031**	*326.22*
	2	C00.0-R	19-Oct-15	820	0.865			4	***20.3***	5	***25.38***	183	***928.8***	70	***355.28***	12	***60.91***			274	***1390.67***
		C00.7-L	19-Oct-15	696	0.59			4	***35.07***	10	***87.67***	3	***26.3***							17	***149.04***
		C01.3-L	19-Oct-15	1611	1.59			12	***16.87***	10	***14.05***	45	***63.24***	17	***23.89***	21	***29.51***			105	***147.57***
		C02.8-L	19-Oct-15	1034	0.88					2	***7.91***					18	***71.22***			20	***79.13***
		C03.6-L	20-Oct-15	2140	2.09			2	***1.61***			6	***4.83***	17	***13.68***	16	***12.88***			41	***33***
		C04.6-R	20-Oct-15	526	0.52									2	***26.32***	7	***92.13***			9	***118.46***
		C05.6-L	20-Oct-15	1076	1.1			2	***6.08***			3	***9.12***	40	***121.66***	15	***45.62***			60	***182.49***
		C07.3-R	20-Oct-15	941	1.65									20	***46.37***	1	***2.32***			21	***48.69***
		C07.4-L	20-Oct-15	860	1									5	***20.93***	36	***150.7***			41	***171.63***
	Session Summary			**1078**	**10.3**	**0**	*0*	**24**	*7.78*	**27**	*8.75*	**240**	*77.81*	**171**	*55.44*	**126**	*40.85*	**0**	*0*	**588**	*190.64*
	3	C00.0-R	25-Oct-15	1023	0.94					21	***78.62***	80	***299.49***	20	***74.87***	3	***11.23***			124	***464.22***
		C00.7-L	25-Oct-15	798	0.59			7	***53.52***			25	***191.16***	15	***114.69***	6	***45.88***			53	***405.25***
		C01.3-L	25-Oct-15	1623	1.6			1	***1.39***			17	***23.57***			12	***16.64***			30	***41.59***
		C02.8-L	25-Oct-15	905	0.88											15	***67.81***			15	***67.81***
		C03.6-L	26-Oct-15	2051	2.09									2	***1.68***	23	***19.32***			25	***21***
		C04.6-R	26-Oct-15	533	0.52											4	***51.96***			4	***51.96***
		C05.6-L	26-Oct-15	1112	1.1					5	***14.72***	75	***220.73***	430	***1265.53***	17	***50.03***			527	***1551.01***
		C07.3-R	27-Oct-15	809	1.69					1	***2.63***			255	***671.44***	8	***21.06***			264	***695.14***
		C07.4-L	26-Oct-15	933	1			2	***7.72***					15	***57.88***	35	***135.05***			52	***200.64***
	Session Summary			**1087**	**10.4**	**0**	*0*	**10**	*3.18*	**27**	*8.6*	**197**	*62.73*	**737**	*234.7*	**123**	*39.17*	**0**	*0*	**1094**	*348.38*
	4	C00.0-R	01-Nov-15	999	0.94			4	***15.33***	18	***69.01***	126	***483.04***	57	***218.52***	9	***34.5***			214	***820.39***
		C00.7-L	01-Nov-15	605	0.59			1	***10.09***	18	***181.54***	5	***50.43***	16	***161.37***	1	***10.09***			41	***413.5***
		C01.3-L	01-Nov-15	1785	1.6					8	***10.08***	34	***42.86***	55	***69.33***	20	***25.21***			117	***147.48***
		C02.8-L	01-Nov-15	925	0.88			1	***4.42***	5	***22.11***			12	***53.07***	5	***22.11***			23	***101.72***
		C03.6-L	02-Nov-15	2187	2.04			3	***2.42***	14	***11.3***	1	***0.81***	115	***92.79***	23	***18.56***			156	***125.88***
		C04.6-R	02-Nov-15	798	0.52									10	***86.76***	7	***60.73***			17	***147.48***
		C05.6-L	02-Nov-15	1152	1.1					5	***14.2***	113	***321.02***	80	***227.27***	23	***65.34***			221	***627.84***
		C07.3-R	02-Nov-15	990	1.7									55	***117.65***	4	***8.56***			59	***126.2***
		C07.4-L	02-Nov-15	859	1					2	***8.38***	2	***8.38***	12	***50.29***	35	***146.68***			51	***213.74***
	Session Summary			**1144**	**10.4**	**0**	*0*	**9**	*2.72*	**70**	*21.18*	**281**	*85.03*	**412**	*124.66*	**127**	*38.43*	**0**	*0*	**899**	*272.02*
	5	C08.4-L	07-Nov-15	385	0.5									6	***112.21***					6	***112.21***
	Session Summary			**385**	**0.5**	**0**	*0*	**0**	*0*	**0**	*0*	**0**	*0*	**6**	*112.21*	**0**	*0*	**0**	*0*	**6**	*112.21*
Section Total All Samples				**40025**	**41.985**	**0**		**66**		**150**		**1320**		**1510**		**572**		**0**		**3618**	
Section Average All Samples				**1082**	**1.13**	**0**	*0*	**2**	*5.23*	**4**	*11.89*	**36**	*104.61*	**41**	*119.66*	**15**	*45.33*	**0**	*0*	**98**	*286.71*
Section Standard Error of Mean						**0**	*0*	**0.45**	*2.09*	**0.99**	*6.54*	**12.84**	*56.38*	**13.5**	*38.55*	**2.47**	*7.34*	**0**	*0*	**20.32**	*72.35*

Table E3 Continued.

Section	Session	Site	Date	Time Sampled (s)	Length Sampled (km)	Number Caught (CPUE = no. fish/km/hr)															
						Carp spp.		Northern Pikeminnow		Peamouth		Redside Shiner		Sculpin spp.		Sucker spp.		Tench		All Species	
						No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE
Kootenay River	1	K00.3-L	15-Oct-15	214	0.44											2	***76.47***			2	***76.47***
		K00.6-R	15-Oct-15	556	0.6					1	***10.79***					12	***129.5***			13	***140.29***
		K01.8-L	15-Oct-15	1628	1.87	1	***1.18***	1	***1.18***					205	***242.42***					207	***244.78***
		K01.8-R	15-Oct-15	1072	1.3							2	***5.17***							2	***5.17***
	Session Summary			**868**	**4.2**	**1**	***0.99***	**1**	***0.99***	**1**	***0.99***	**2**	***1.97***	**205**	***202.44***	**14**	***13.82***	**0**	***0***	**224**	***221.2***
	2	K00.3-L	21-Oct-15	223	0.44									2	***73.38***	2	***73.38***			4	***146.76***
		K00.6-R	21-Oct-15	618	0.6									70	***679.61***	34	***330.1***			104	***1009.71***
		K01.8-L	20-Oct-15	1684	1.87			2	***2.29***			20	***22.86***	30	***34.3***	28	***32.01***			80	***91.46***
		K01.8-R	20-Oct-15	1244	1.3							5	***11.13***	78	***173.63***	5	***11.13***			88	***195.89***
	Session Summary			**942**	**4.2**	**0**	***0***	**2**	***1.82***	**0**	***0***	**25**	***22.75***	**180**	***163.79***	**69**	***62.78***	**0**	***0***	**276**	***251.14***
	3	K00.3-L	27-Oct-15	232	0.44									3	***105.8***	16	***564.26***			19	***670.06***
		K01.8-L	28-Oct-15	1628	1.87			11	***13.01***					39	***46.12***	19	***22.47***			69	***81.59***
		K01.8-R	27-Oct-15	1211	1.3			51	***116.62***			200	***457.35***	200	***457.35***	58	***132.63***			509	***1163.95***
	Session Summary			**1024**	**3.6**	**0**	***0***	**62**	***60.55***	**0**	***0***	**200**	***195.31***	**242**	***236.33***	**93**	***90.82***	**0**	***0***	**597**	***583.01***
	4	K00.3-L	03-Nov-15	216	0.44											14	***530.3***			14	***530.3***
		K00.6-R	03-Nov-15	549	0.6					1	***10.93***					17	***185.79***			18	***196.72***
		K01.8-L	02-Nov-15	1619	1.87			1	***1.19***	3	***3.57***	12	***14.27***	17	***20.21***	30	***35.67***			63	***74.91***
		K01.8-R	02-Nov-15	1218	1.3			2	***4.55***					32	***72.75***	22	***50.02***			56	***127.32***
	Session Summary			**900**	**4.2**	**0**	***0***	**3**	***2.86***	**4**	***3.81***	**12**	***11.43***	**49**	***46.67***	**83**	***79.05***	**0**	***0***	**151**	***143.81***
Section Total All Samples				**13912**	**16.24**	**1**		**68**		**5**		**239**		**676**		**259**		**0**		**1248**	
Section Average All Samples				**927**	**1.08**	**0**	***0.24***	**5**	***16.26***	**0**	***1.2***	**16**	***57.15***	**45**	***161.65***	**17**	***61.94***	**0**	***0***	**83**	***298.44***
Section Standard Error of Mean						**0.07**	***0.08***	**3.4**	***7.72***	**0.21**	***0.99***	**13.23**	***30.29***	**17.77**	***50.87***	**4.08**	***47.76***	**0**	***0***	**33.52**	***93.04***

Table E3 Concluded.

Section	Session	Site	Date	Time Sampled (s)	Length Sampled (km)	Number Caught (CPUE = no. fish/km/hr)															
						Carp spp.		Northern Pikeminnow		Peamouth		Redside Shiner		Sculpin spp.		Sucker spp.		Tench		All Species	
						No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE
Columbia River D/S	1	C25.3-R	15-Oct-15	1258	2.71											3	3.17			3	3.17
		C27.6-R	15-Oct-15	336	0.61											2	35.13			2	35.13
		C28.2-R	15-Oct-15	762	1.13											1	4.18			1	4.18
		C36.6-L	16-Oct-15	1448	2.39									6	6.24	5	5.2			11	11.44
		C47.8-L	17-Oct-15	1218	1.44									8	16.42	15	30.79			23	47.21
		C49.0-L	17-Oct-15	493	0.93											3	23.56			3	23.56
		C49.0-R	16-Oct-15	638	0.72									2	15.67	8	62.7			10	78.37
		C49.8-L	17-Oct-15	1557	2.45									50	47.19					50	47.19
		C49.8-R	16-Oct-15	1150	2.39									30	39.29	8	10.48			38	49.77
		C52.2-R	17-Oct-15	1867	3.79			1	0.51							6	3.05			7	3.56
	Session Summary			**1073**	**18.6**	**0**	0	**1**	0.18	**0**	0	**0**	0	**96**	17.32	**51**	9.2	**0**	0	**148**	26.7
	2	C25.3-R	21-Oct-15	1357	2.72									1	0.98	2	1.95			3	2.93
		C27.6-R	21-Oct-15	341	0.61									1	17.31					1	17.31
		C28.2-R	21-Oct-15	734	1.13									5	21.7	2	8.68			7	30.38
		C34.9-L	21-Oct-15	1810	2.14			1	0.93					3	2.79	2	1.86			6	5.58
		C36.6-L	22-Oct-15	1470	2.39							10	10.25	90	92.22	27	27.67			127	130.13
		C47.8-L	22-Oct-15	1236	1.44									280	566.34	47	95.06			327	661.41
		C48.2-R	22-Oct-15	834	1.01									12	51.29	20	85.48			32	136.76
		C49.0-L	23-Oct-15	482	0.93									84	674.61	8	64.25			92	738.86
		C49.0-R	22-Oct-15	480	0.72									8	83.33					8	83.33
		C49.8-L	23-Oct-15	1514	2.45									275	266.9	18	17.47			293	284.37
		C49.8-R	22-Oct-15	1129	2.39									5	6.67	31	41.36			36	48.03
		C52.2-L	23-Oct-15	761	0.89									8	42.52	1	5.32			9	47.84
		C52.2-R	23-Oct-15	1921	3.79											1	0.49			1	0.49
		C52.8-L	23-Oct-15	606	0.89									16	106.8	1	6.67			17	113.47
		C53.6-L	23-Oct-15	984	1.72									50	106.35	2	4.25			52	110.61
	Session Summary			**1044**	**25.2**	**0**	0	**1**	0.14	**0**	0	**10**	1.37	**838**	114.67	**162**	22.17	**0**	0	**1011**	138.34
	3	C25.3-R	28-Oct-15	1451	2.73			1	0.91			15	13.63	5	4.54					21	19.08
		C28.2-R	28-Oct-15	790	1.13									5	20.16	4	16.13			9	36.29
		C34.9-L	29-Oct-15	1714	2.14									3	2.94	2	1.96			5	4.91
		C36.6-L	29-Oct-15	1294	2.39									10	11.64	15	17.46			25	29.1
		C47.8-L	30-Oct-15	1160	1.44							10	21.55	40	86.21	25	53.88			75	161.64
		C48.2-R	29-Oct-15	810	1.01							2	8.8	13	57.21	18	79.21			33	145.21
		C49.0-L	30-Oct-15	946	0.93									8	32.74	13	53.2			21	85.93
		C49.0-R	29-Oct-15	500	0.72									36	360					36	360
		C49.8-L	30-Oct-15	1362	2.425									250	272.49	2	2.18			252	274.67
		C49.8-R	29-Oct-15	1192	2.39									130	164.28	12	15.16			142	179.44
		C52.2-L	30-Oct-15	822	0.89									5	24.6	2	9.84			7	34.45
		C52.2-R	30-Oct-15	1897	3.79									3	1.5	2	1			5	2.5
		C53.6-L	31-Oct-15	896	1.72									100	233.6					100	233.6
	Session Summary			**1141**	**23.7**	**0**	0	**1**	0.13	**0**	0	**27**	3.59	**608**	80.94	**95**	12.65	**0**	0	**731**	97.32
	4	C25.3-R	03-Nov-15	1361	2.73							16	15.5	3	2.91	5	4.84			24	23.25
		C28.2-R	03-Nov-15	711	1.13									60	268.85	2	8.96			62	277.81
		C34.9-L	03-Nov-15	1743	2.14							8	7.72	30	28.95	1	0.97			39	37.64
		C36.6-L	04-Nov-15	1169	2.39									50	64.43					50	64.43
		C47.8-L	04-Nov-15	1260	1.44			1	1.98			10	19.84	72	142.86	10	19.84			93	184.52
		C48.2-R	05-Nov-15	772	1.01									10	46.17	1	4.62			11	50.79
		C49.0-L	04-Nov-15	521	0.93							3	22.29	60	445.79	7	52.01			70	520.09
		C49.0-R	05-Nov-15	550	0.72											1	9.09			1	9.09
		C49.8-L	04-Nov-15	1519	2.45							3	2.9	70	67.71	15	14.51			88	85.13
		C49.8-R	05-Nov-15	1207	2.39					1	1.25			10	12.48					11	13.73
		C52.2-L	04-Nov-15	748	0.89											3	16.22			3	16.22
		C52.2-R	05-Nov-15	1904	3.79									50	24.94	4	2			54	26.94
		C53.6-L	04-Nov-15	912	1.72									32	73.44					32	73.44
	Session Summary			**1106**	**23.7**	**0**	0	**1**	0.14	**1**	0.14	**40**	5.49	**447**	61.39	**49**	6.73	**0**	0	**538**	73.89
	5	C10.9-L	07-Nov-15	1980	2.18									50	41.7	3	2.5			53	44.2
		C13.4-L	07-Nov-15	1181	1.39			4	8.77					6	13.16	7	15.35			17	37.28
		C13.4-R	08-Nov-15	2056	2.52							10	6.95	170	118.12	3	2.08			183	127.15
		C15.8-R	08-Nov-15	763	0.82									32	184.13	1	5.75			33	189.88
		C17.0-L	08-Nov-15	1921	1.91			3	2.94			2	1.96			5	4.91			10	9.81
		C19.0-L	08-Nov-15	921	1.28			10	30.54			20	61.07	19	58.02	6	18.32			55	167.96
		C20.1-L	08-Nov-15	888	1.27			1	3.19					15	47.88	6	19.15			22	70.23
		C23.4-L	08-Nov-15	683	0.93											4	22.67			4	22.67
		C25.3-L	09-Nov-15	906	1.78			1	2.23			10	22.32			16	35.72			27	60.27
		C26.2-L	09-Nov-15	622	1.25									10	46.3					10	46.3
		C30.6-L	09-Nov-15	1318	1.84			1	1.48			20	29.69	35	51.96	4	5.94			60	89.07
		C34.9-R	09-Nov-15	831	0.89									12	58.41	3	14.6			15	73.01
		C38.8-L	09-Nov-15	650	1.3									40	170.41					40	170.41
		C44.6-L	10-Nov-15	702	1.01									20	101.55	5	25.39			25	126.94
		C45.6-L	10-Nov-15	680	0.9									115	676.47					115	676.47
		C46.4-L	10-Nov-15	947	1.58									75	180.45					75	180.45
		C56.0-L	05-Nov-15	777	0.94							20	98.58	100	492.89	1	4.93	1	4.93	122	601.33
	Session Summary			**1049**	**23.8**	**0**	0	**20**	2.88	**0**	0	**82**	11.82	**699**	100.79	**64**	9.23	**1**	0.14	**866**	124.87
Section Total All Samples				**73423**	**115.005**	**0**		**24**		**1**		**159**		**2688**		**421**		**1**		**3294**	
Section Average All Samples				**1080**	**1.69**	**0**	0	**0**	0.7	**0**	0.03	**2**	4.61	**40**	77.91	**6**	12.2	**0**	0.03	**48**	95.47
Section Standard Error of Mean						**0**	0	**0.16**	0.47	**0.01**	0.02	**0.65**	1.83	**7.44**	19.01	**1.04**	2.69	**0.01**	0.07	**7.94**	20.34
All Sections Total All Samples				**127360**	**173.23**	1	0	158	0.03	156	0.03	1718	0.28	4874	0.8	1252	0.2	1	0	8160	1.33
All Sections Average All Samples						0	0.02	1	3.09	1	3.05	14	33.64	41	95.44	10	24.52	0	0.02	68	159.78
All Sections Standard Error of Mean						0.01	0.01	0.46	1.21	0.35	2.15	4.47	18.39	6.27	17.12	1.17	7.44	0.01	0.04	8.92	28.84

Appendix F – Life History

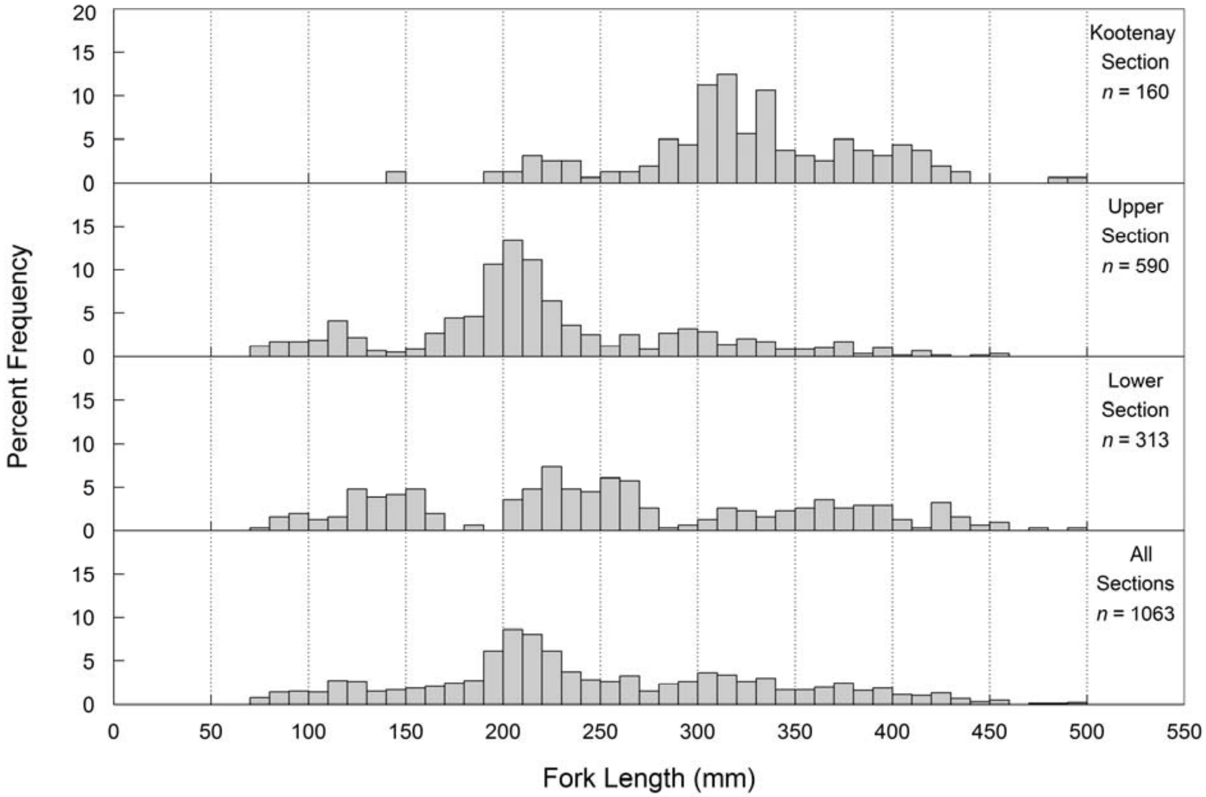


Figure F1. Length-frequency distributions by site for Mountain Whitefish captured by boat electroshocking in sampled sections of the lower Columbia River, October 13 to November 05, 2015.

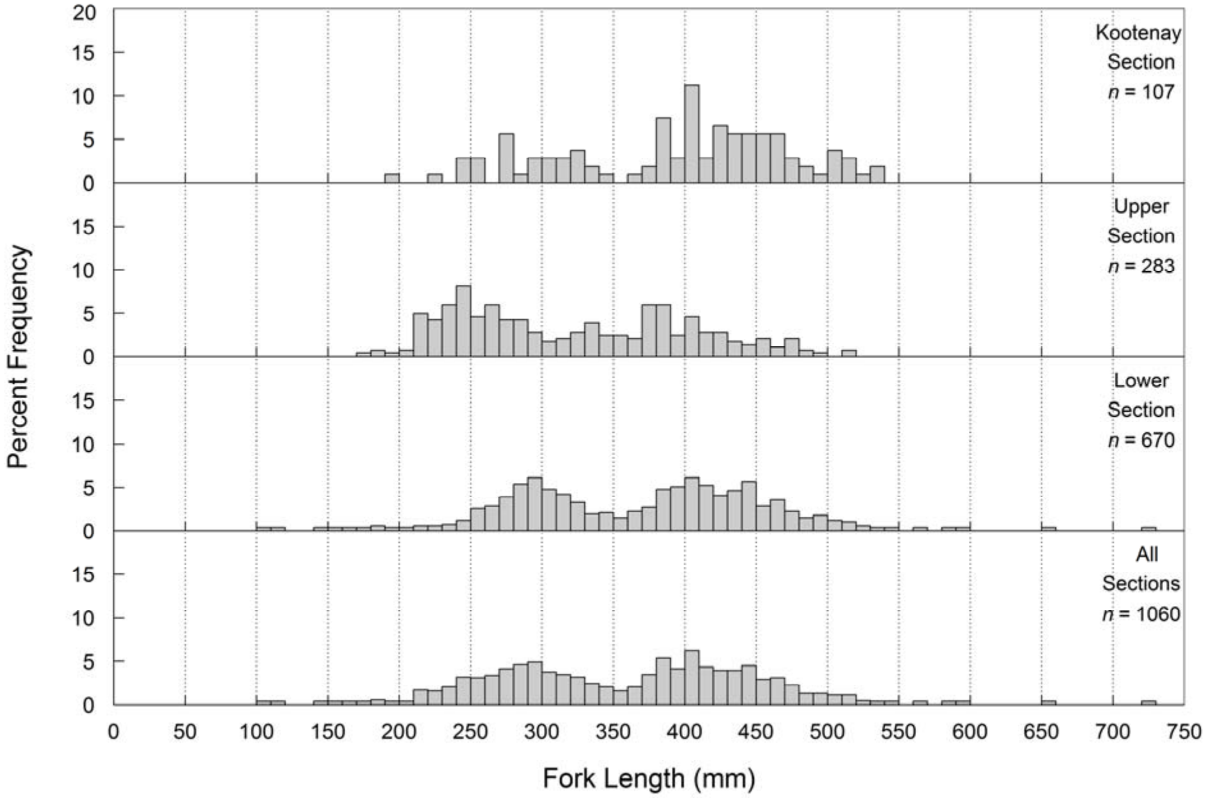


Figure F2. Length-frequency distributions by site for Rainbow Trout captured by boat electroshocking in sampled sections of the lower Columbia River, October 13 to November 05, 2015.

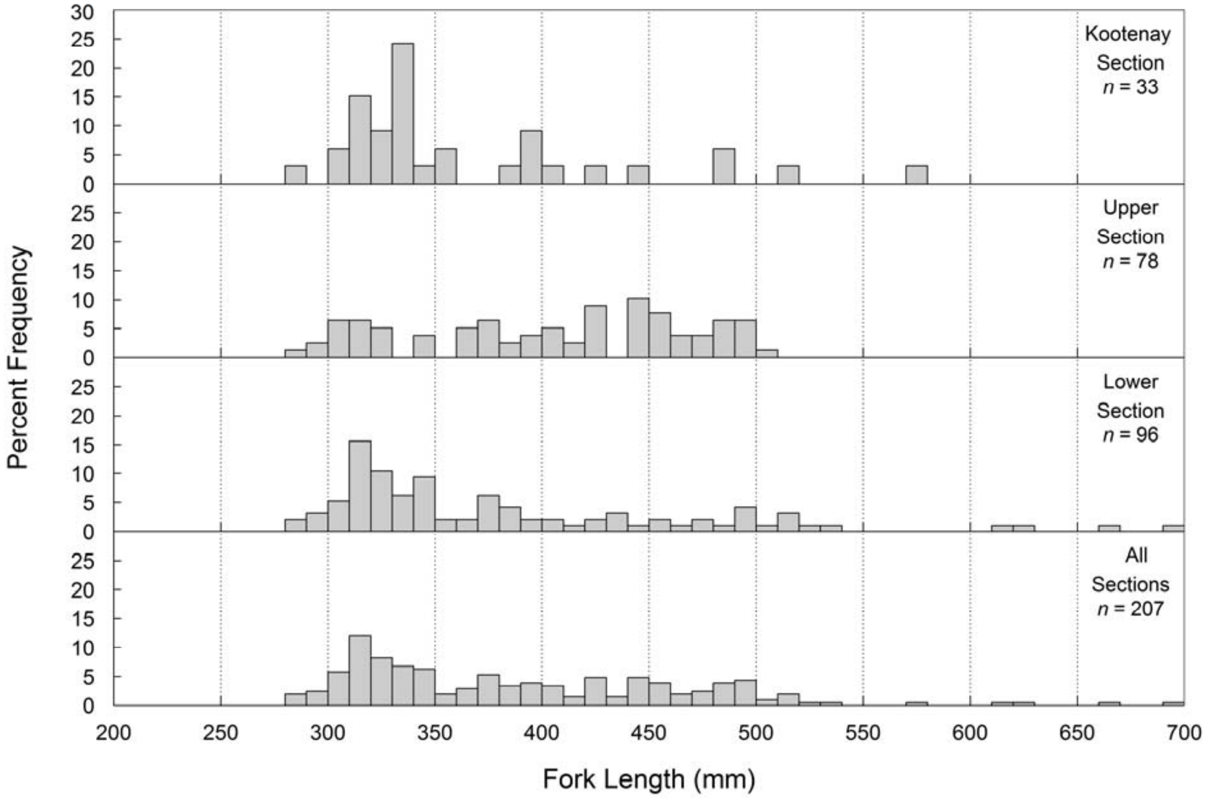
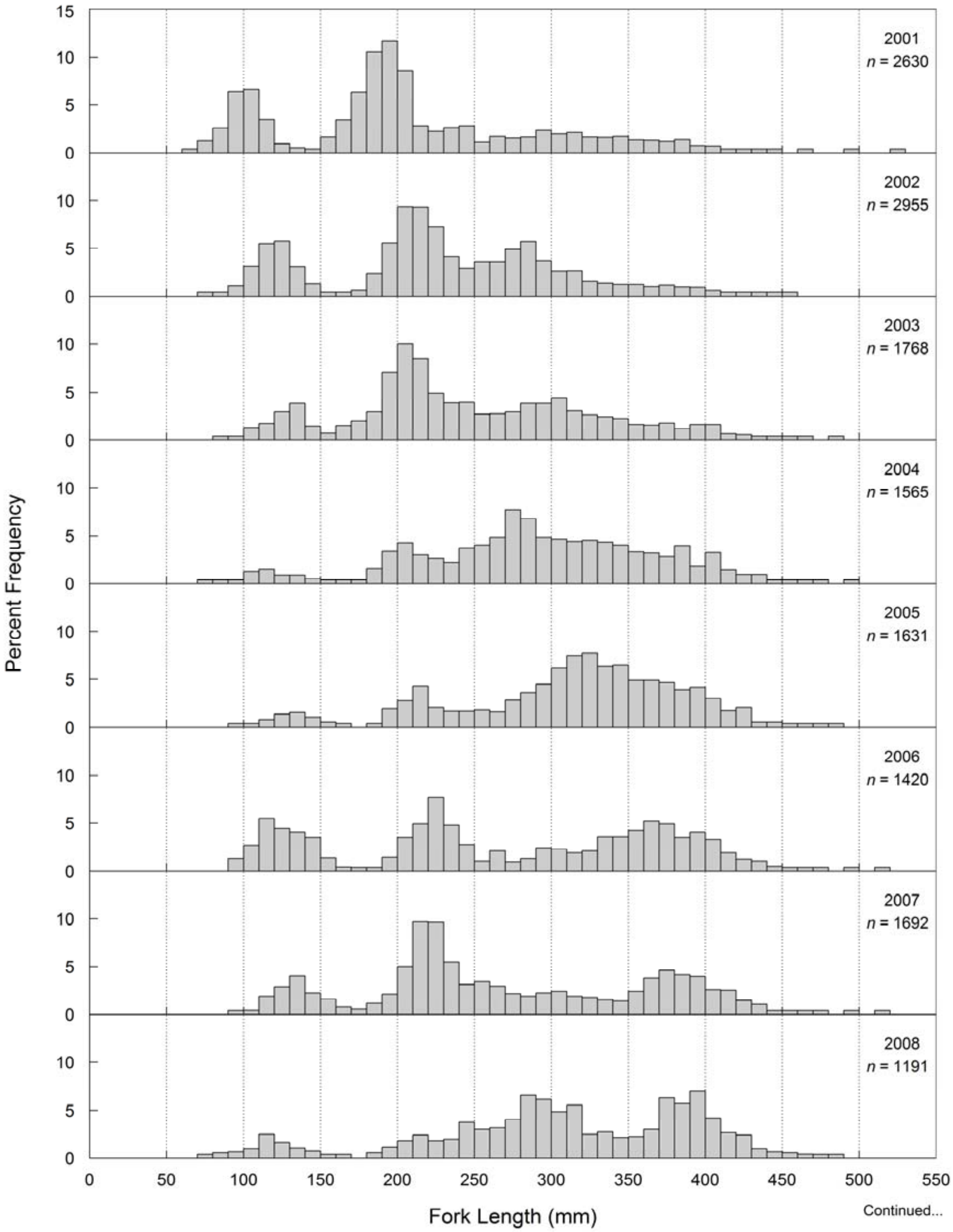


Figure F3. Length-frequency distributions by site for Walleye captured by boat electroshocking in sampled sections of the lower Columbia River, October 13 to November 05, 2015.



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 2015.

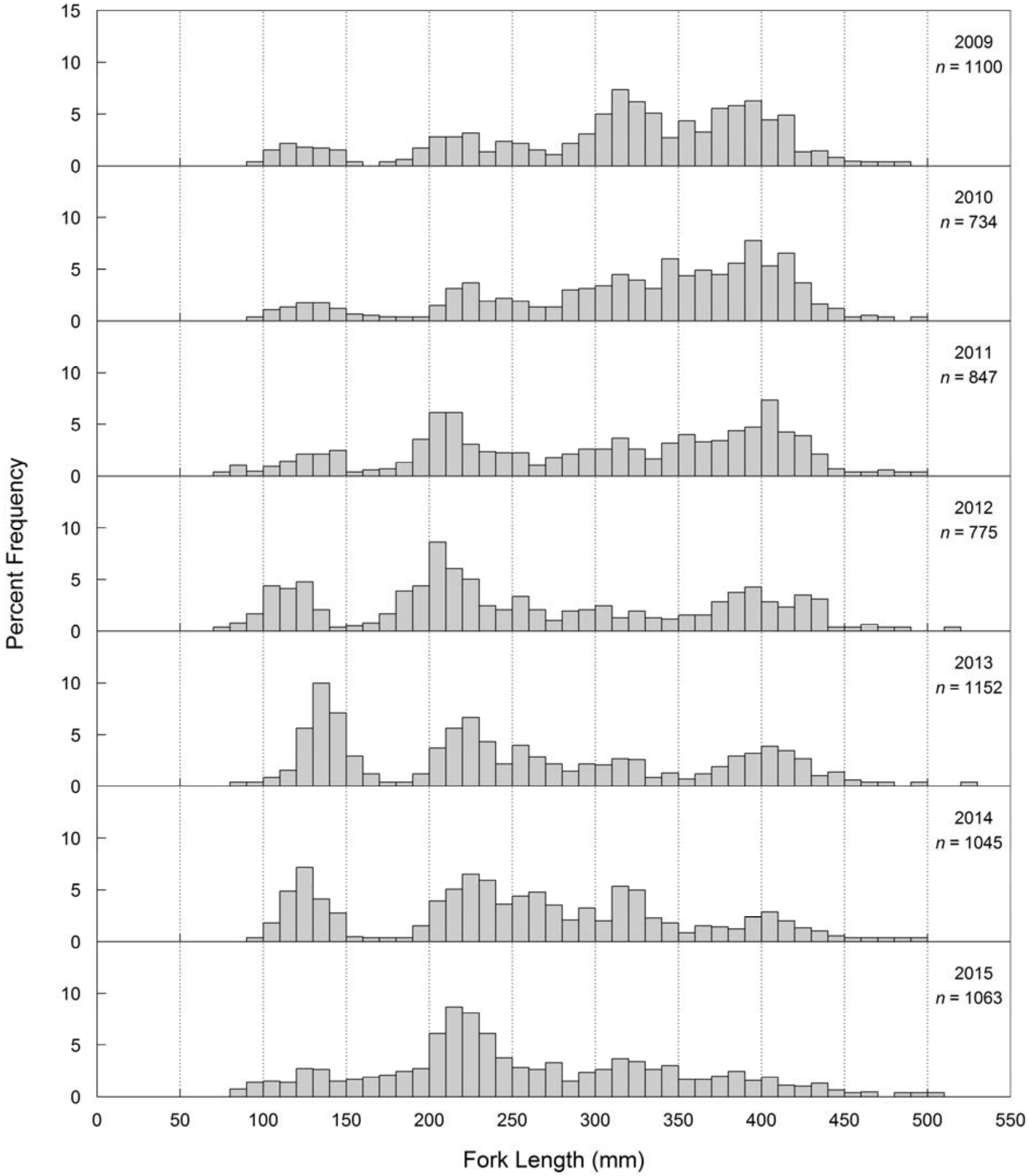


Figure F4. Concluded.

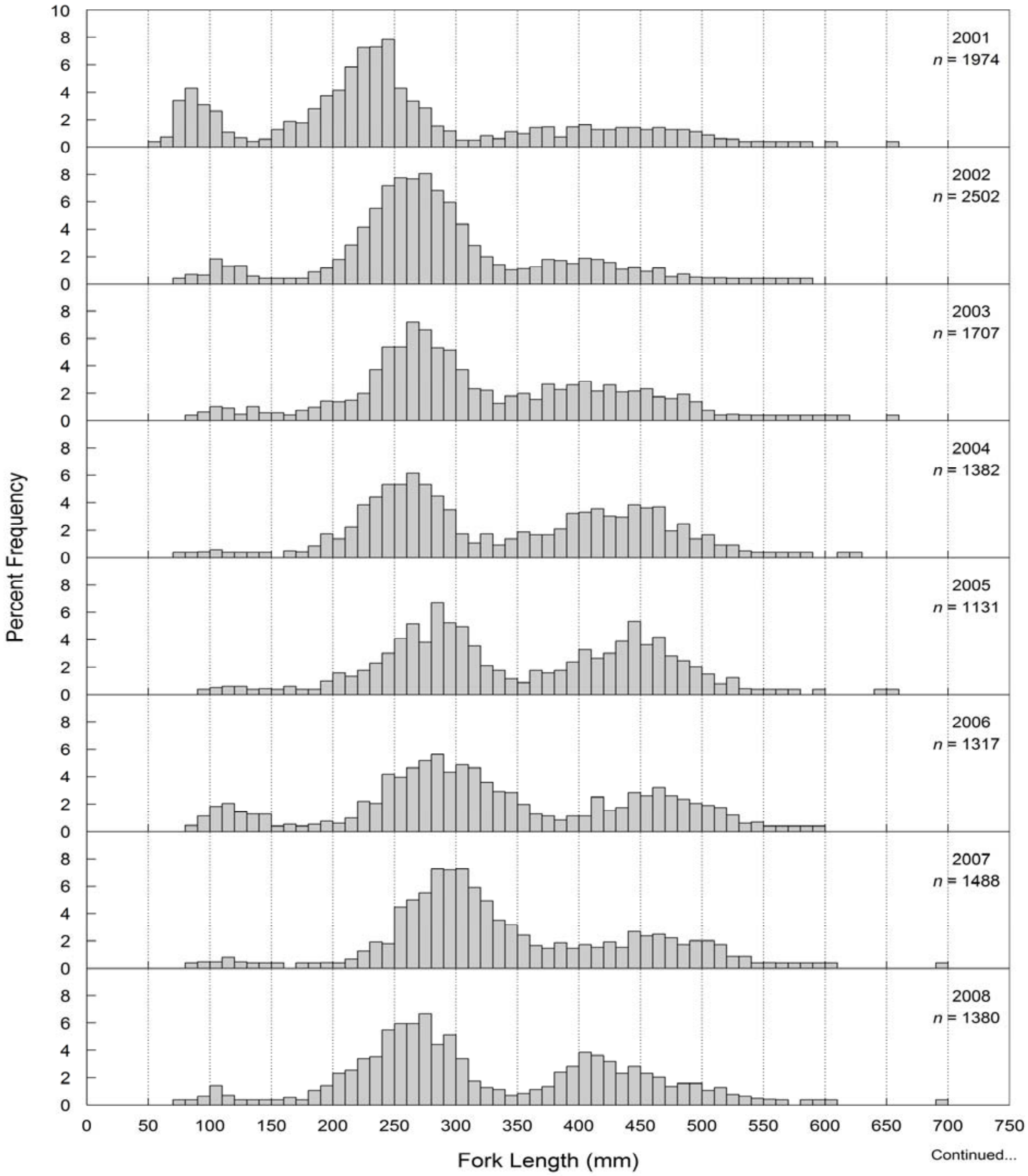


Figure F5. Length-frequency distributions by year for Rainbow Trout captured by boat electroshocking in sampled sections of the lower Columbia River, 2001 to 2015.

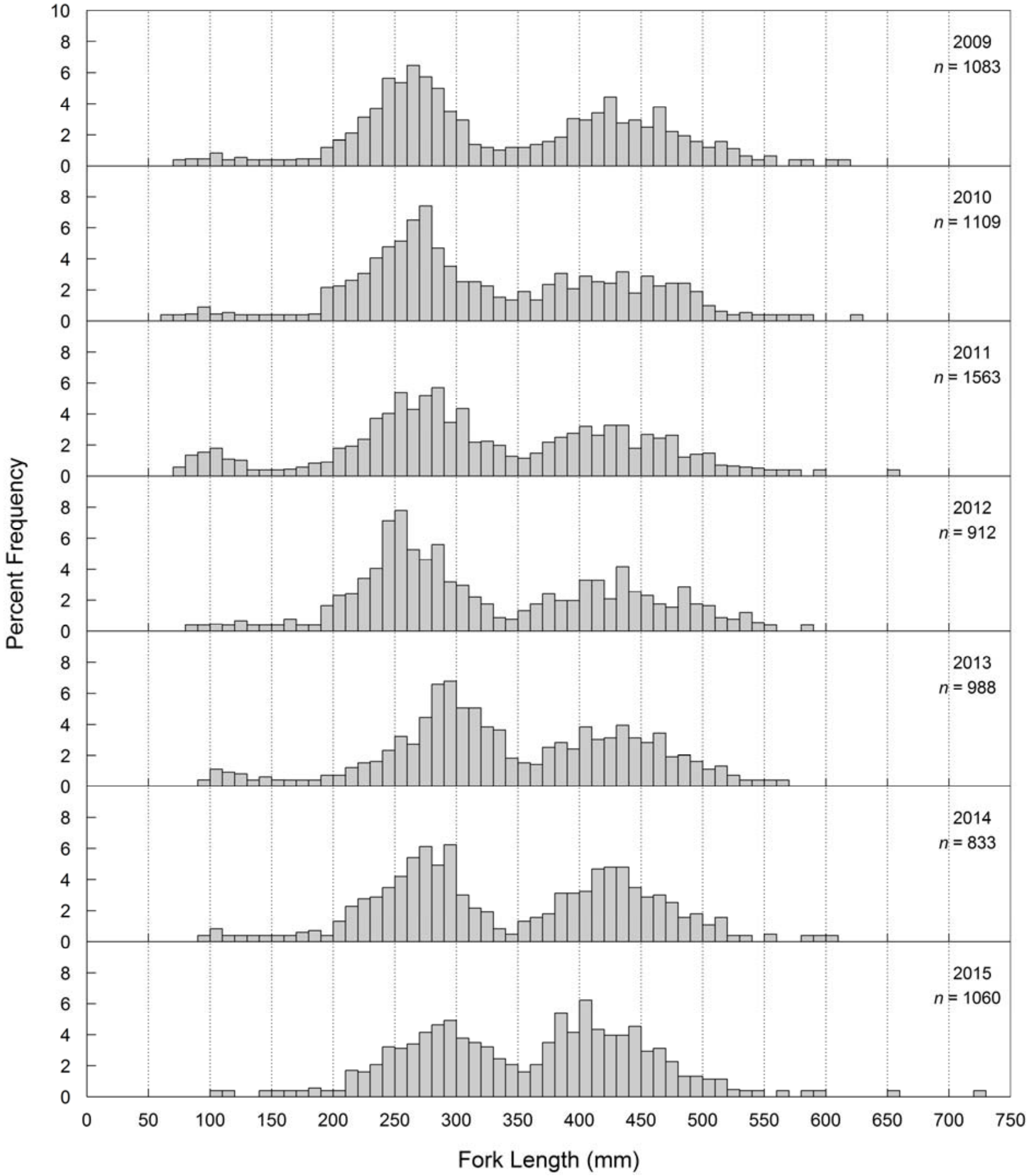
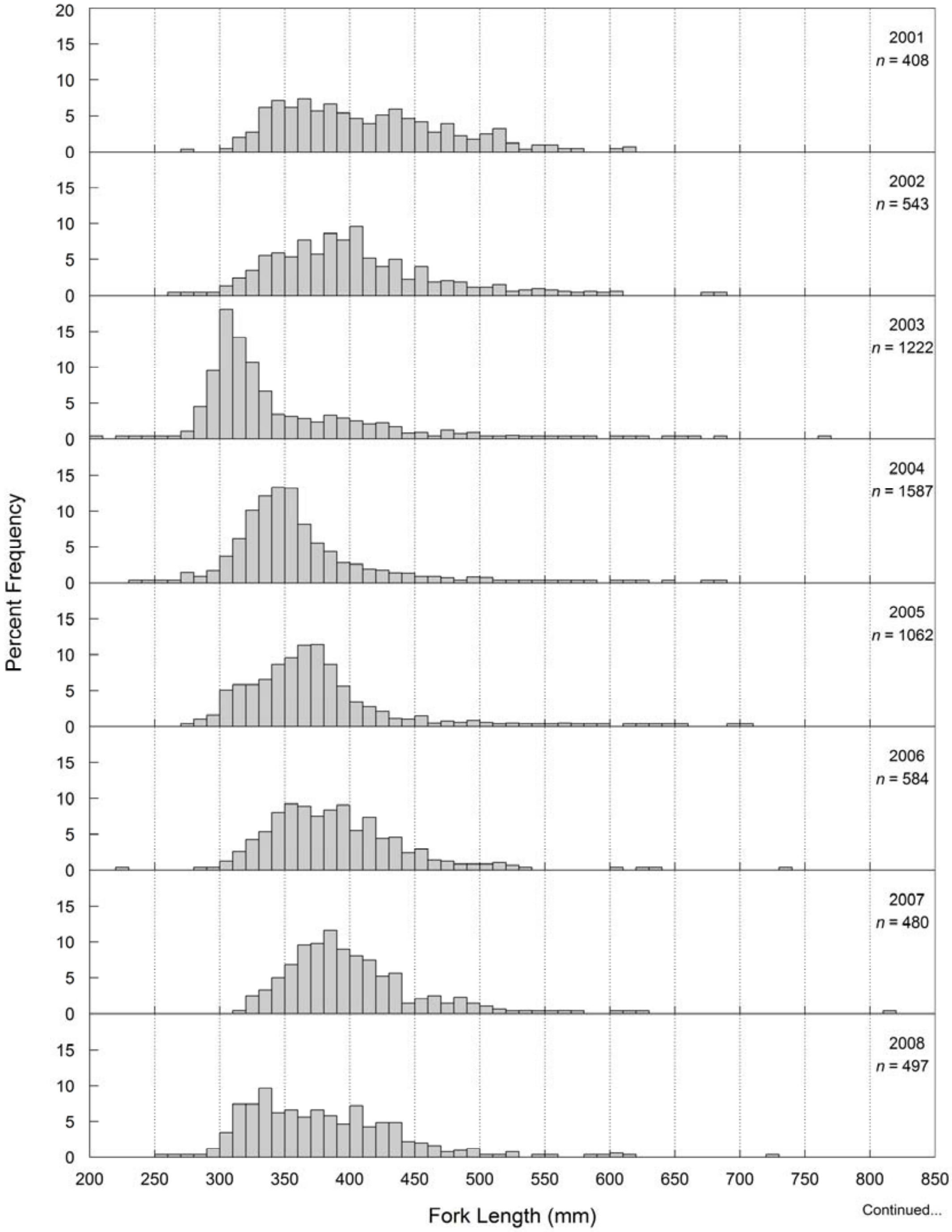


Figure F5. Concluded.



Continued...

Figure F6. Length-frequency distributions by year for Walleye captured by boat electroshocking in sampled sections of the lower Columbia River, 2001 to 2015.

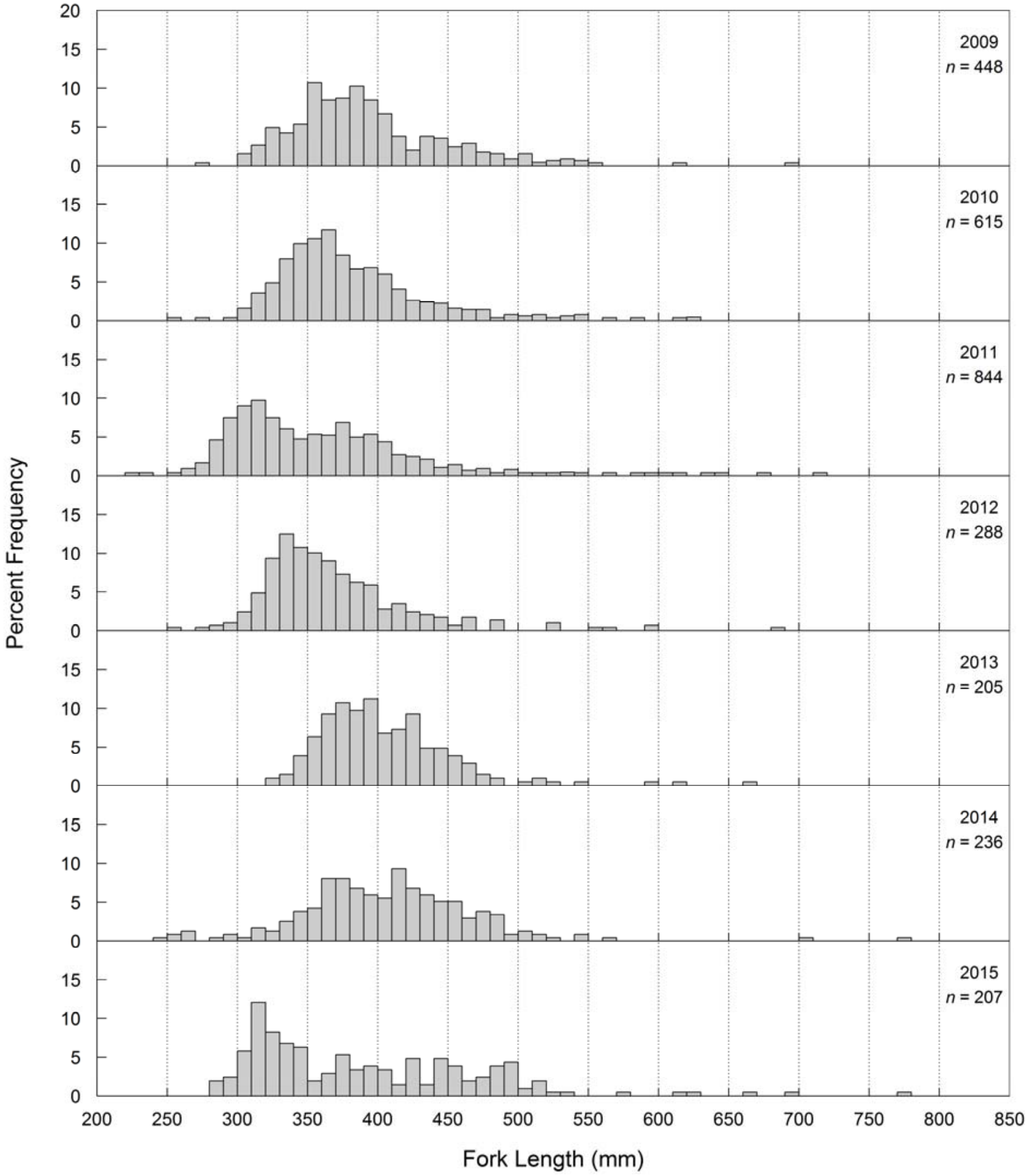
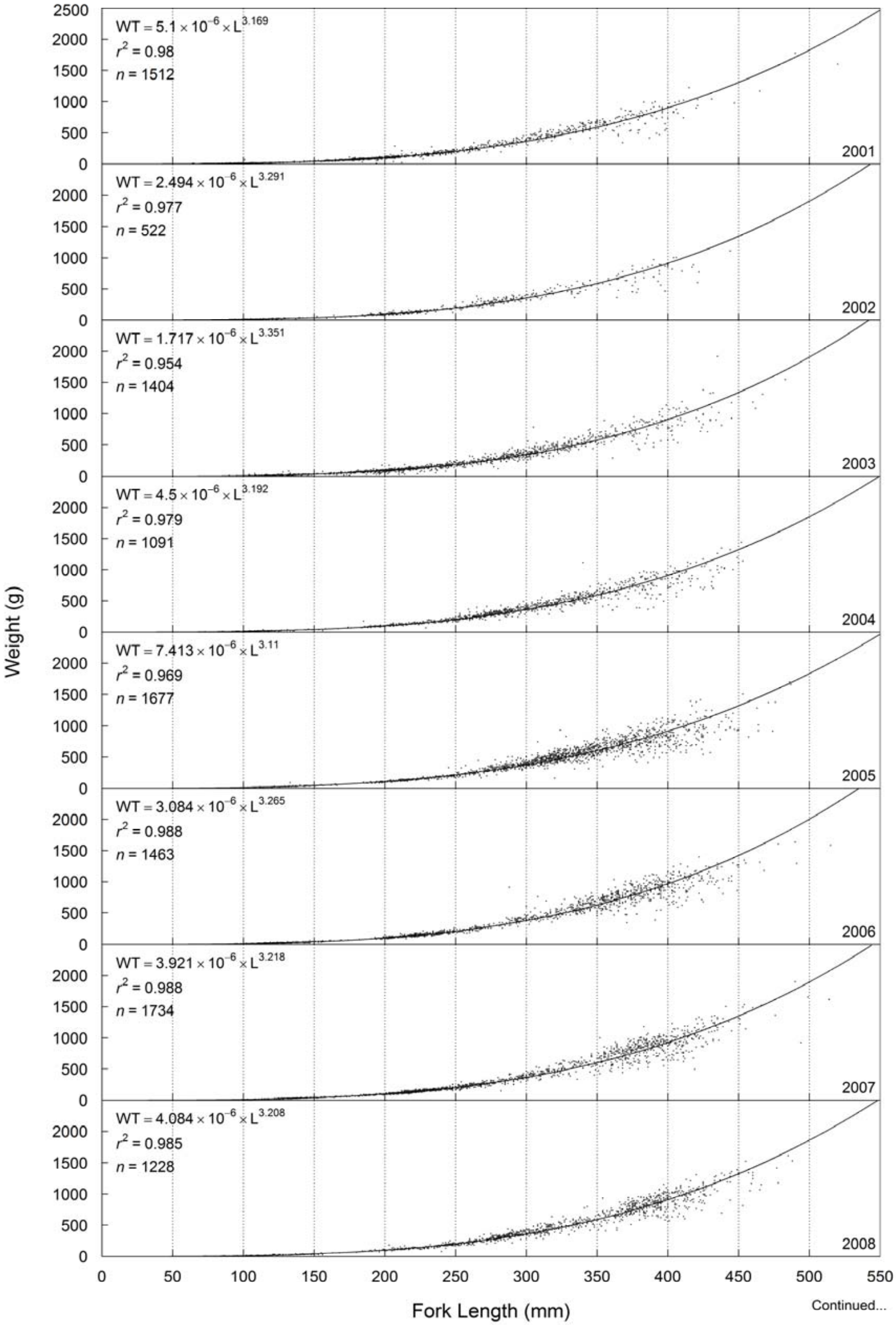


Figure F6. Concluded.



Continued...

Figure F7. Length-weight regressions for Mountain Whitefish captured by boat electroshocking in the lower Columbia River, 2001 to 2015.

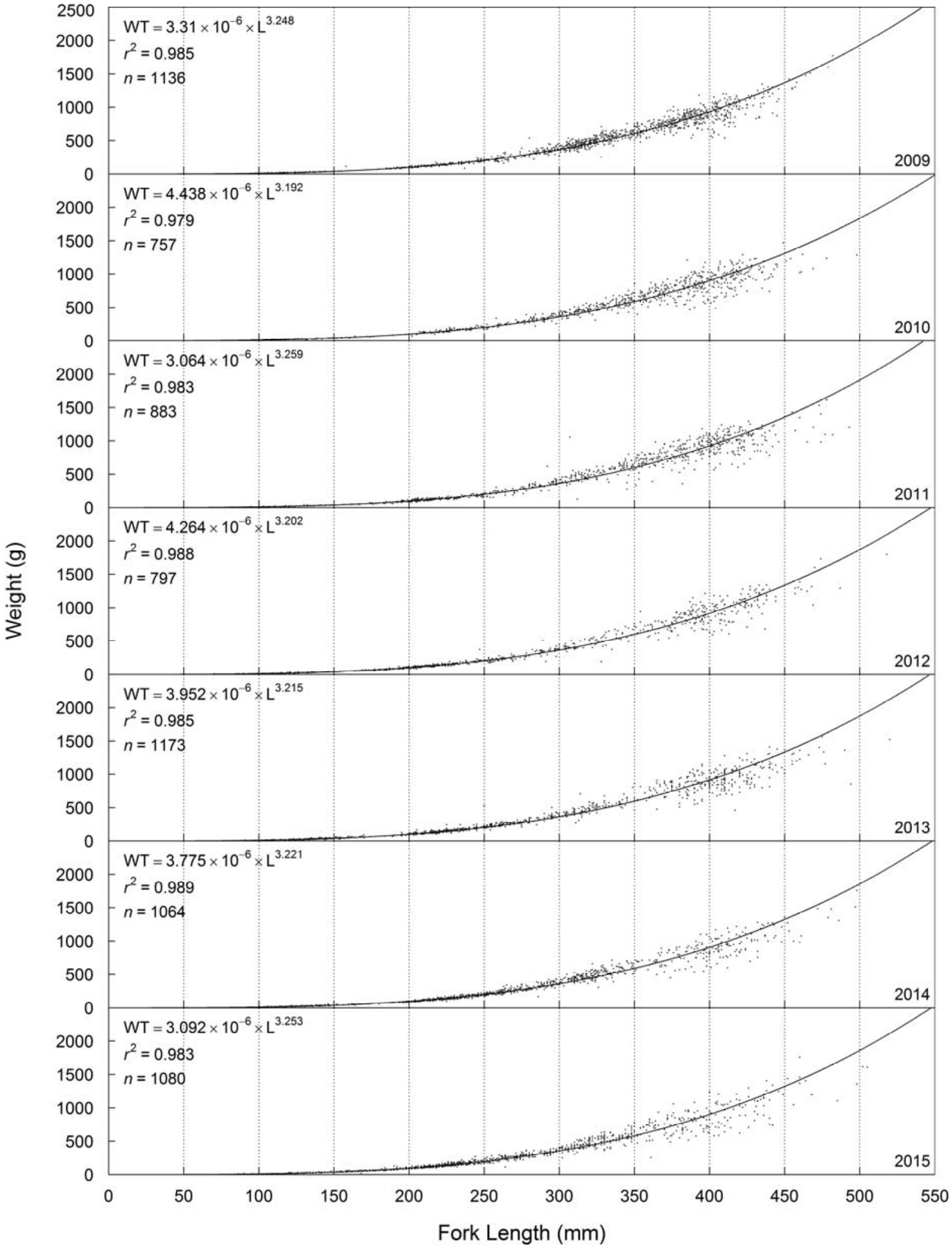
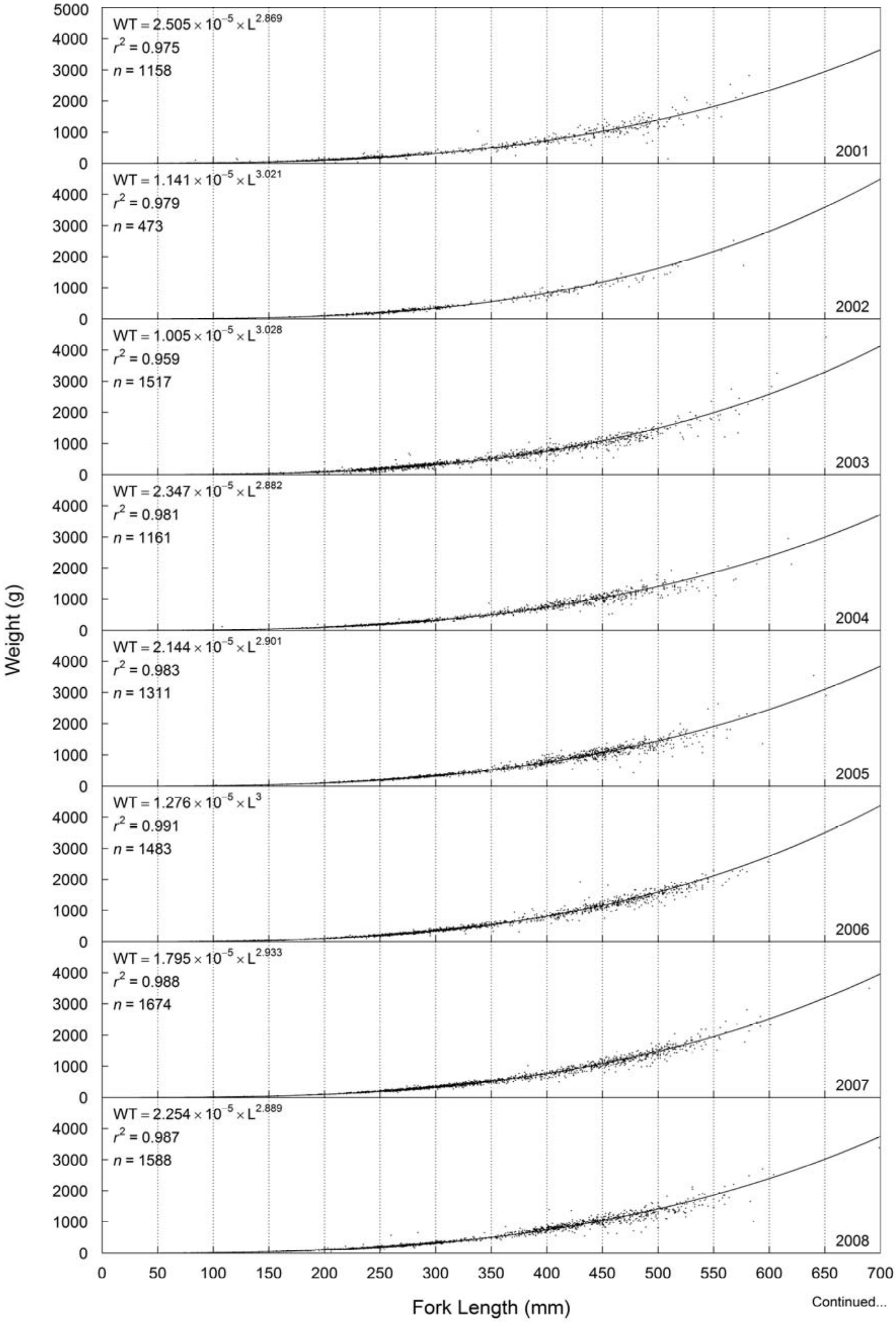


Figure F7. Concluded.



Continued...

Figure F8. Length-weight regressions for Rainbow Trout captured by boat electroshocking in the lower Columbia River, 2001 to 2015.

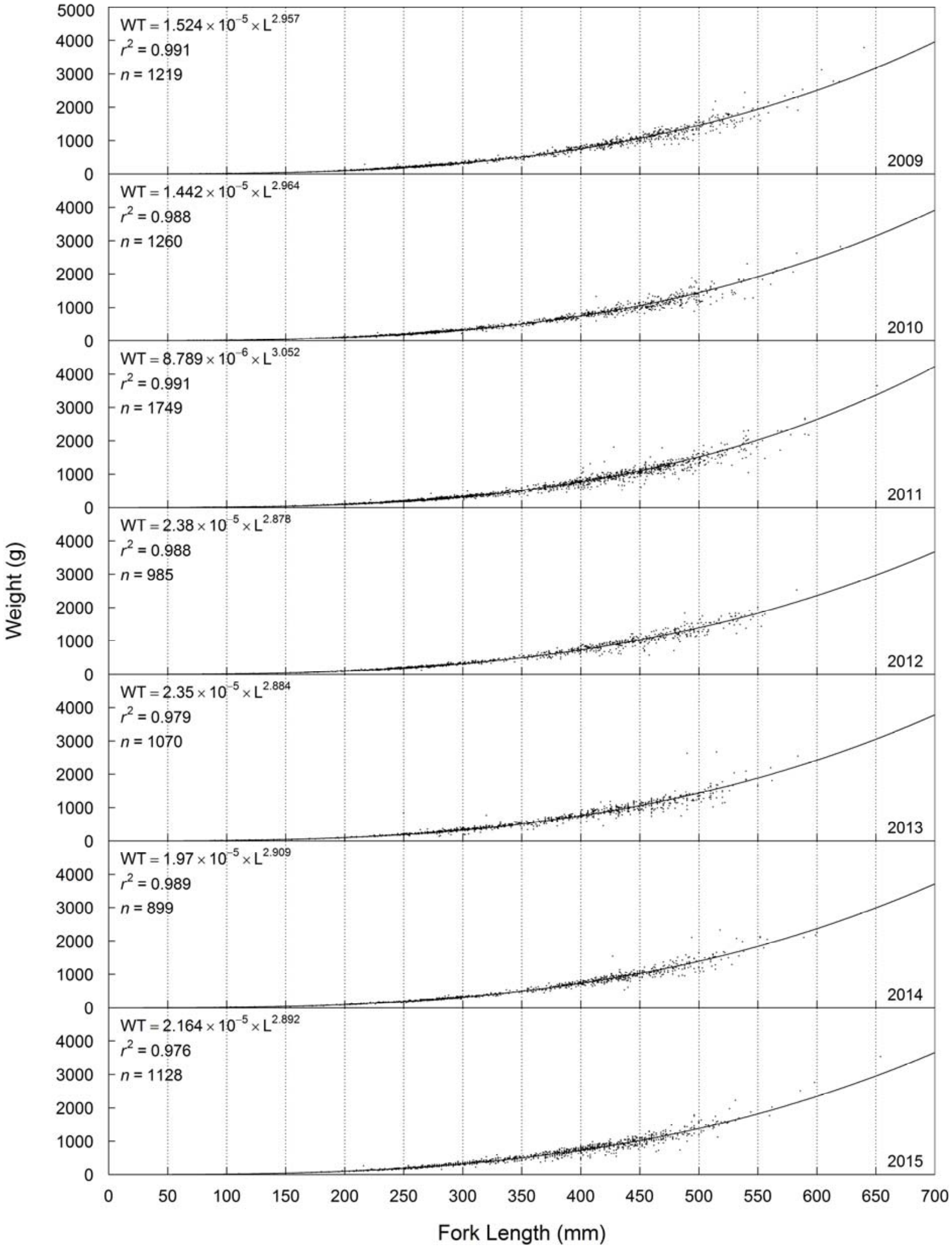
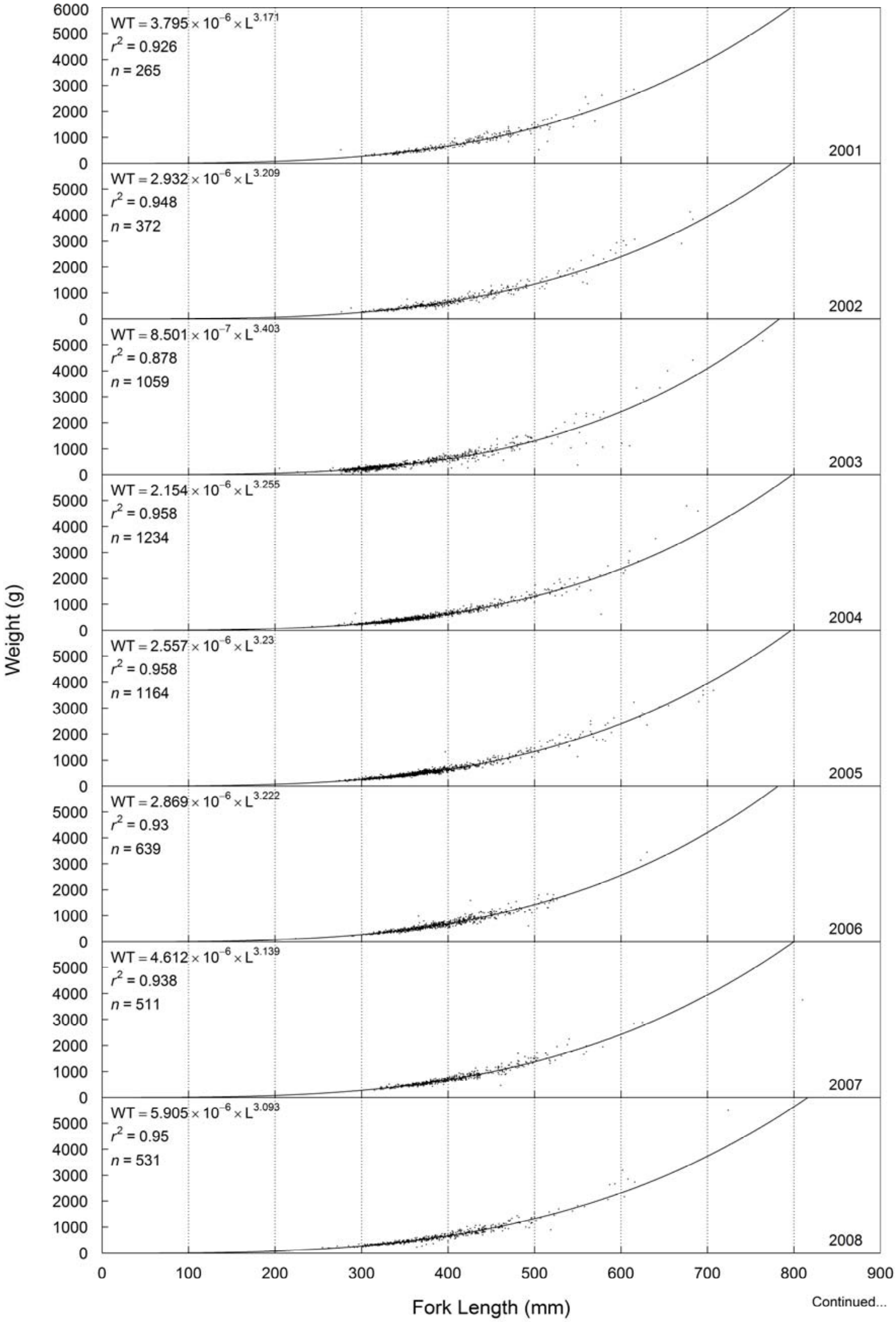


Figure F8. Concluded.



Continued...

Figure F9. Length-weight regressions for Walleye captured by boat electroshocking in the lower Columbia River, 2001 to 2015.

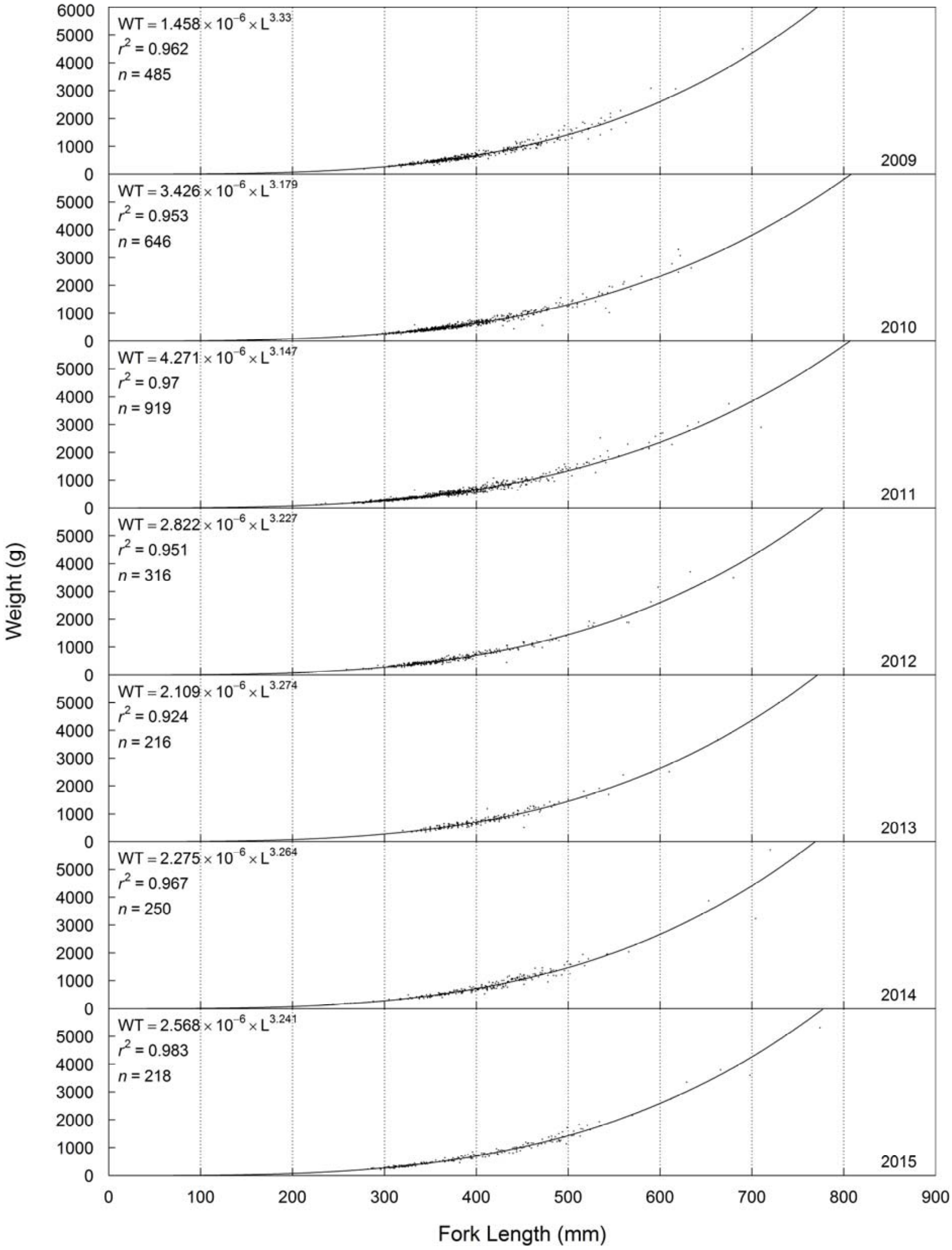


Figure F9. Concluded.

Appendix G – Additional Results

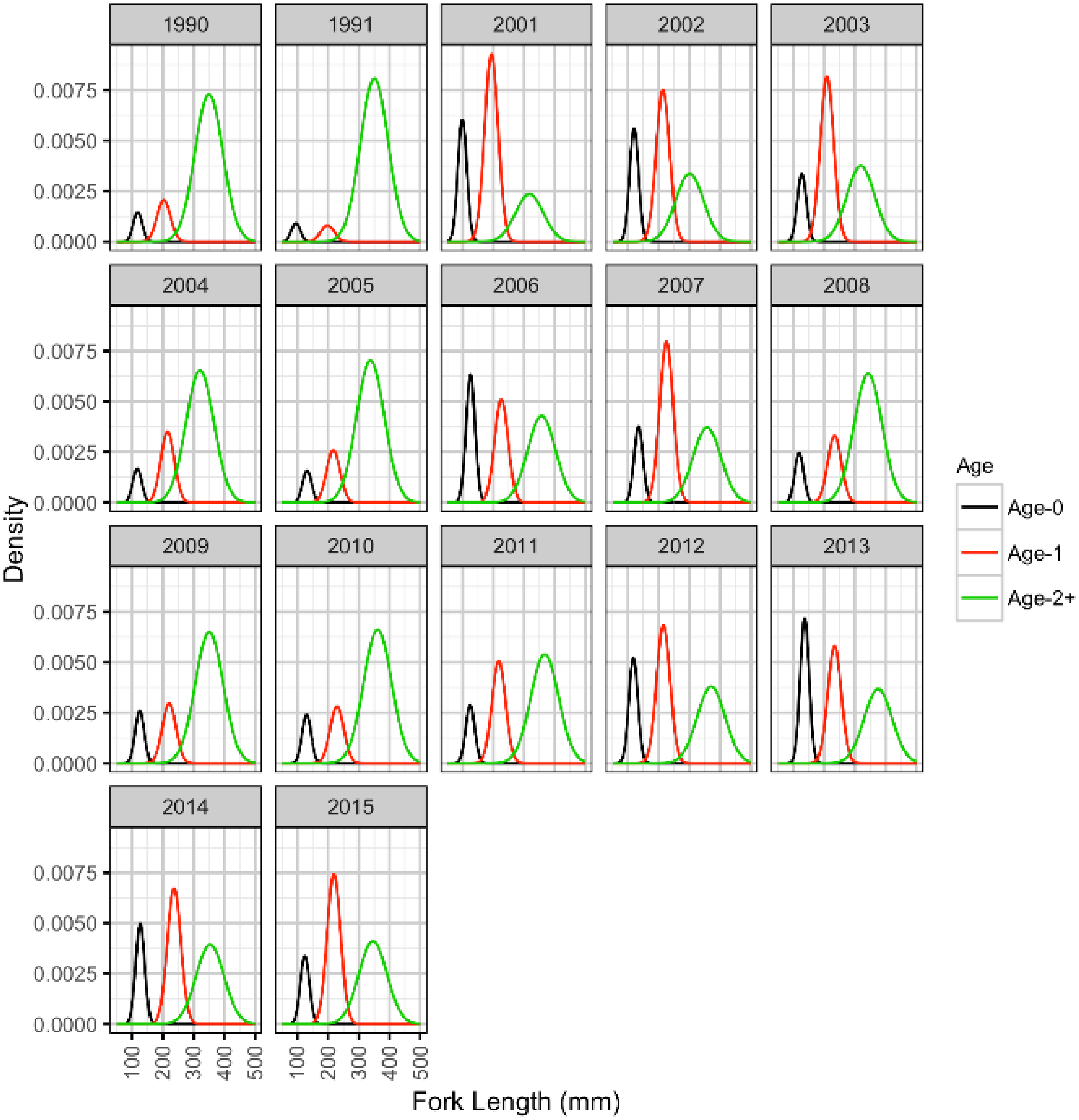


Figure G1: Predicted length-density plot for Mountain Whitefish by life-stage and year.

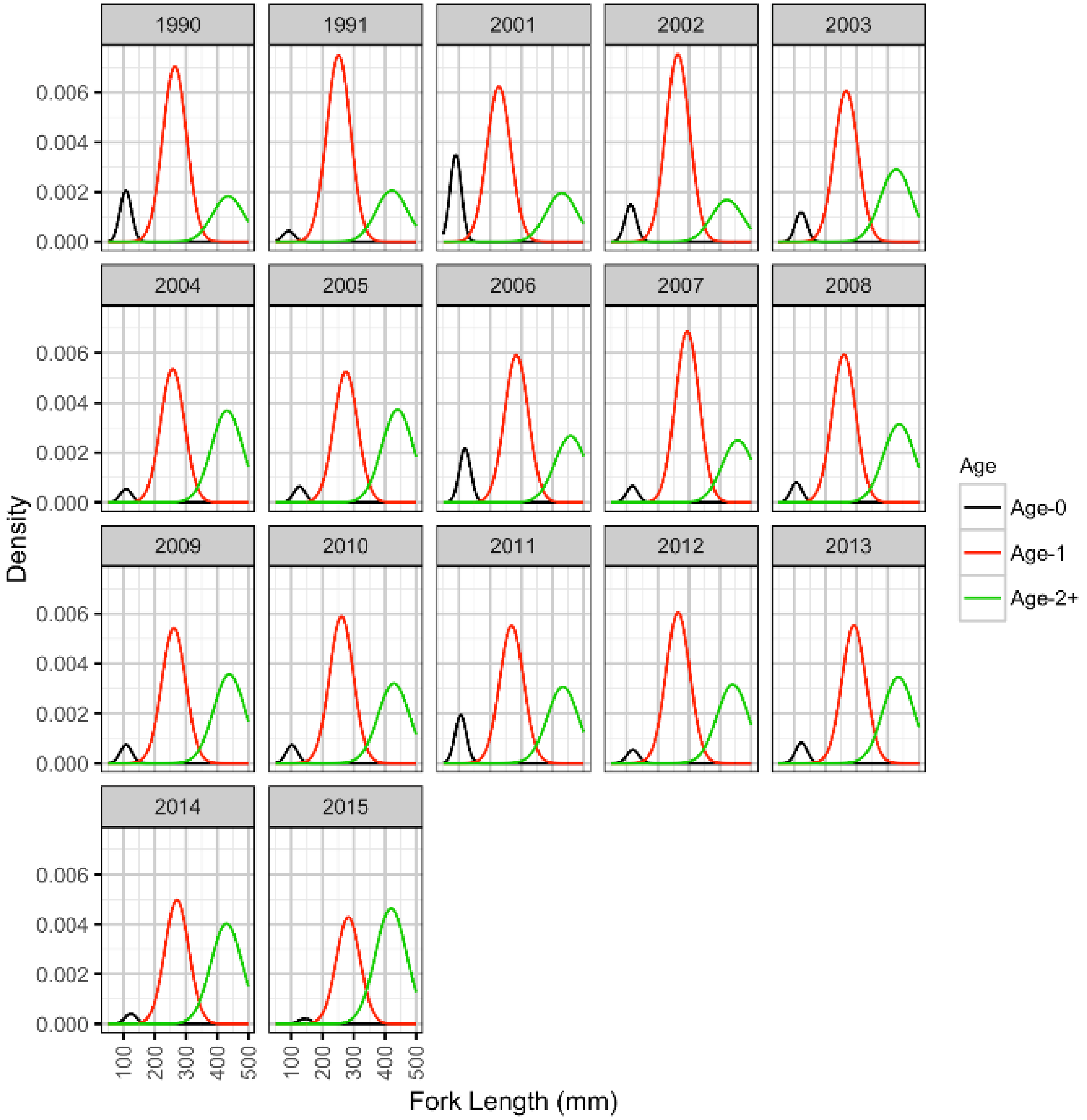


Figure G2: Predicted length-density plot for Rainbow Trout by life-stage and year.

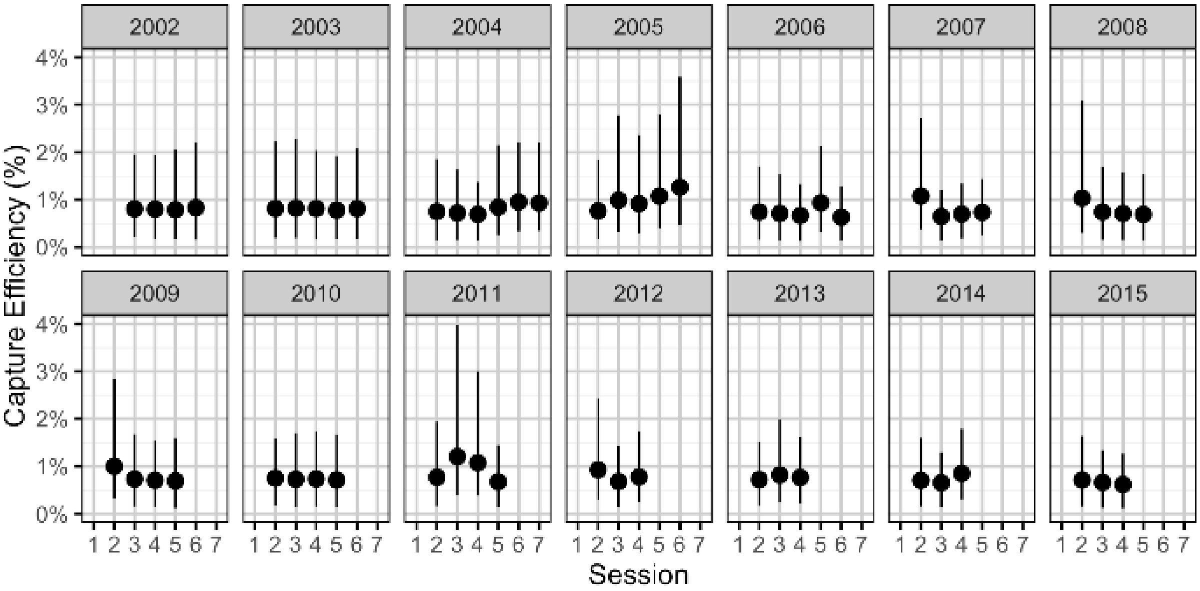


Figure G3: Capture efficiency (mean with 95% credible intervals) of subadult Mountain Whitefish by year and sample session in the lower Columbia River, 2001-2015.

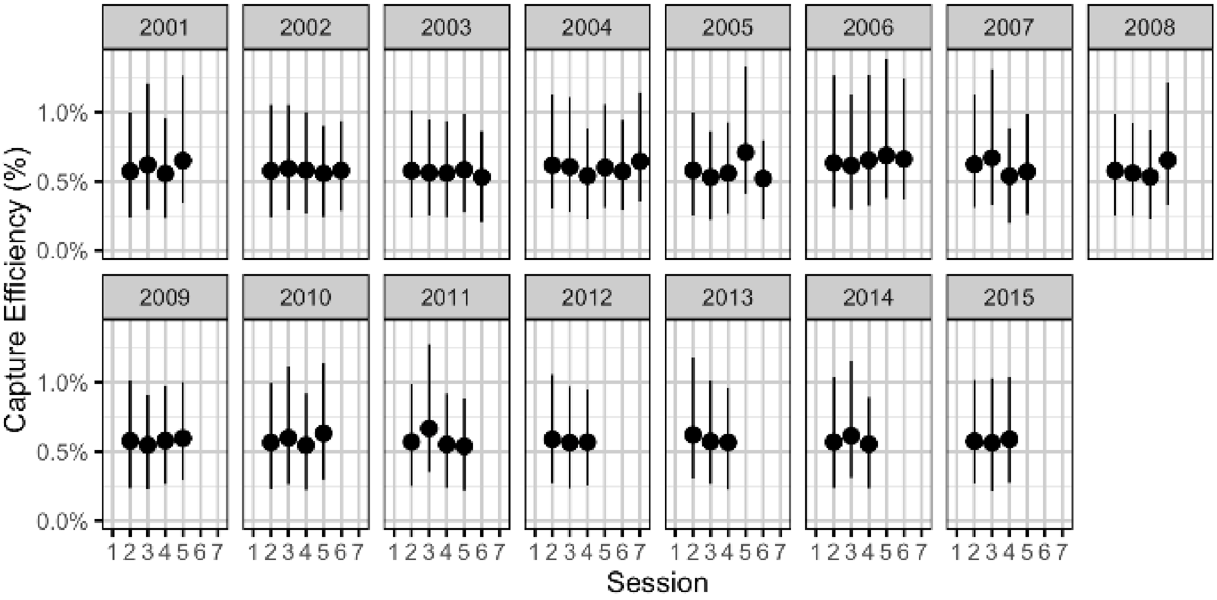


Figure G4: Capture efficiency (mean with 95% credible intervals) of adult Mountain Whitefish by year and sample session in the lower Columbia River, 2001-2015.

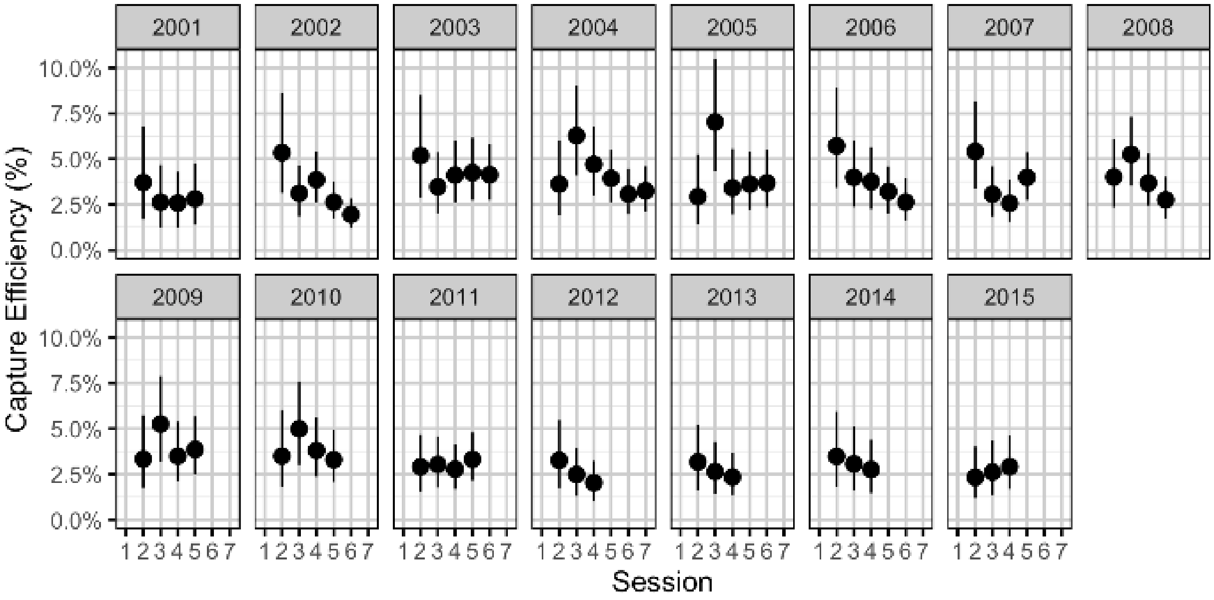


Figure G5: Capture efficiency (mean with 95% credible intervals) of subadult Rainbow Trout by year and sample session in the lower Columbia River, 2001-2015.

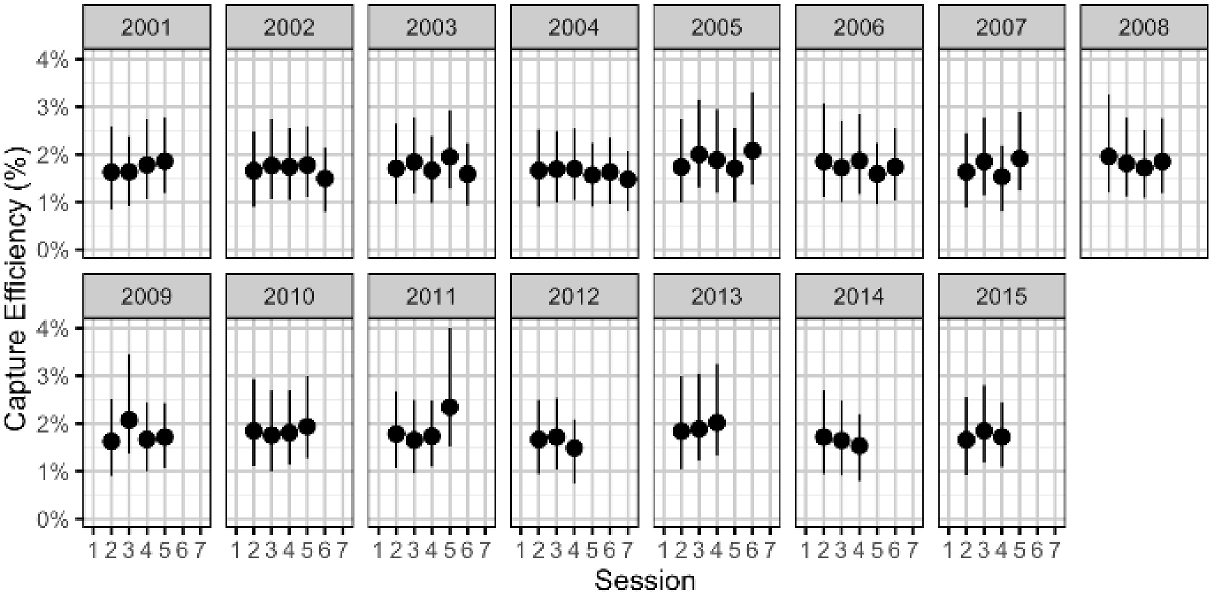


Figure G6: Capture efficiency (mean with 95% credible intervals) of adult Rainbow Trout by year and sample session in the lower Columbia River, 2001-2015.

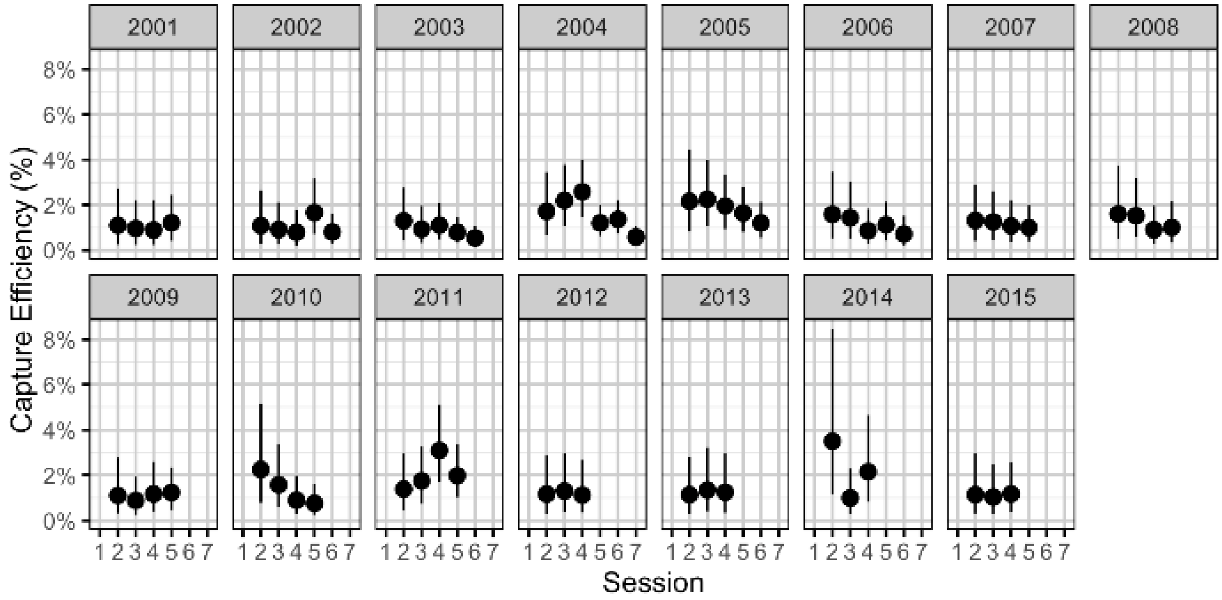


Figure G7: Capture efficiency (mean with 95% credible intervals) of adult Walleye by year and sample session in the lower Columbia River, 2001-2015.

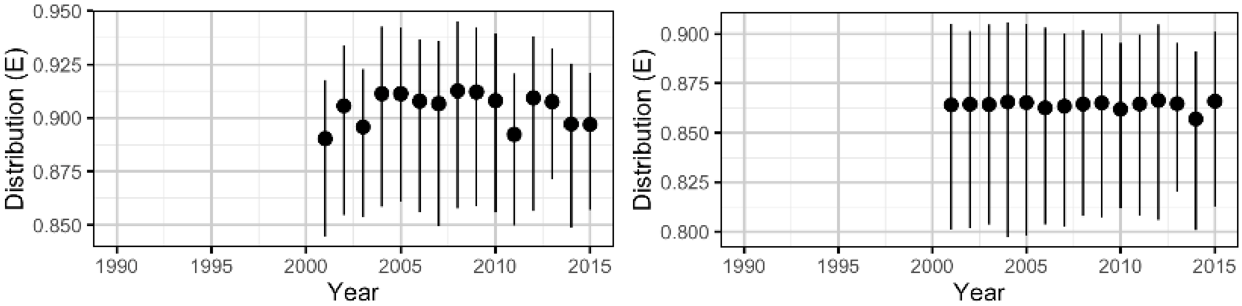


Figure G8: Predicted evenness of spatial distribution for sub-adult (left) and adult (right) Mountain Whitefish by year (with 95% CRIs).

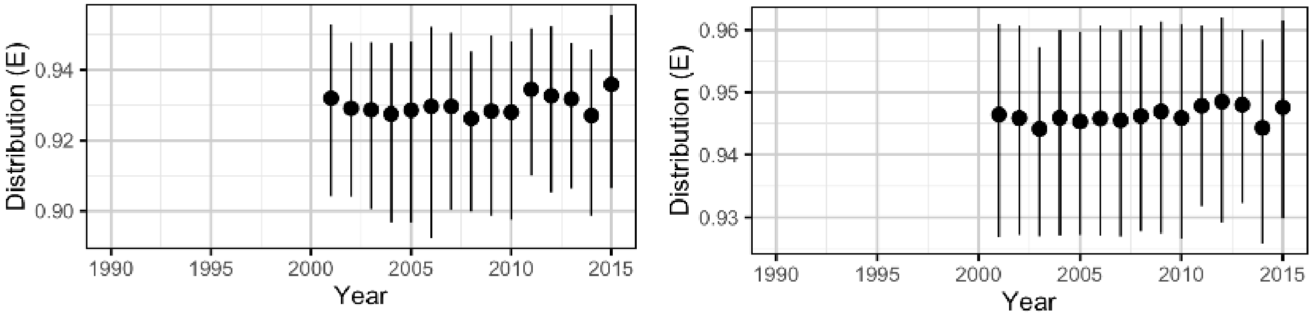


Figure G9: Predicted evenness of spatial distribution for sub-adult (left) and adult (right) Rainbow Trout by year (with 95% CRIs).

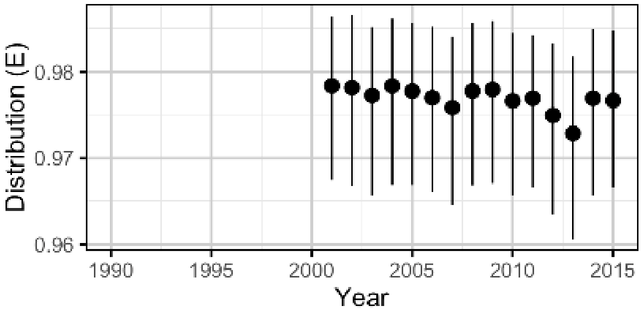


Figure G10: Predicted evenness of spatial distribution for adult Walleye by year (with 95% CRIs).

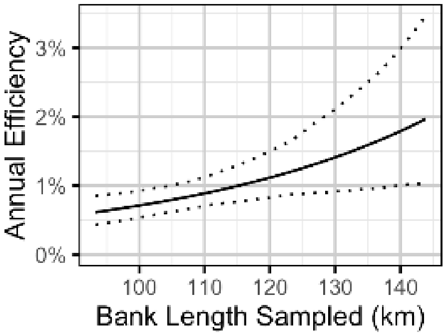


Figure G11: Predicted annual efficiency of capture for adult Mountain Whitefish by amount of bank length sampled (km).

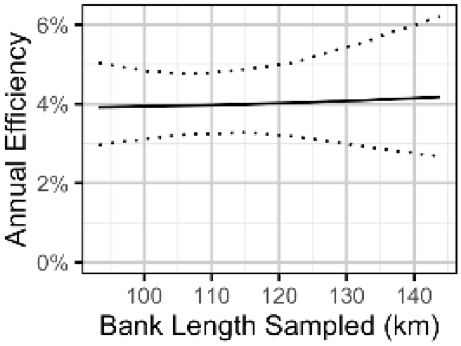


Figure G12: Predicted annual efficiency of capture for adult Rainbow Trout by amount of bank length sampled (km).

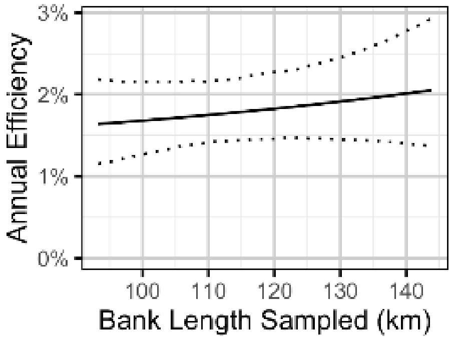


Figure G13: Predicted annual efficiency of capture for Walleye by amount of bank length sampled (km).

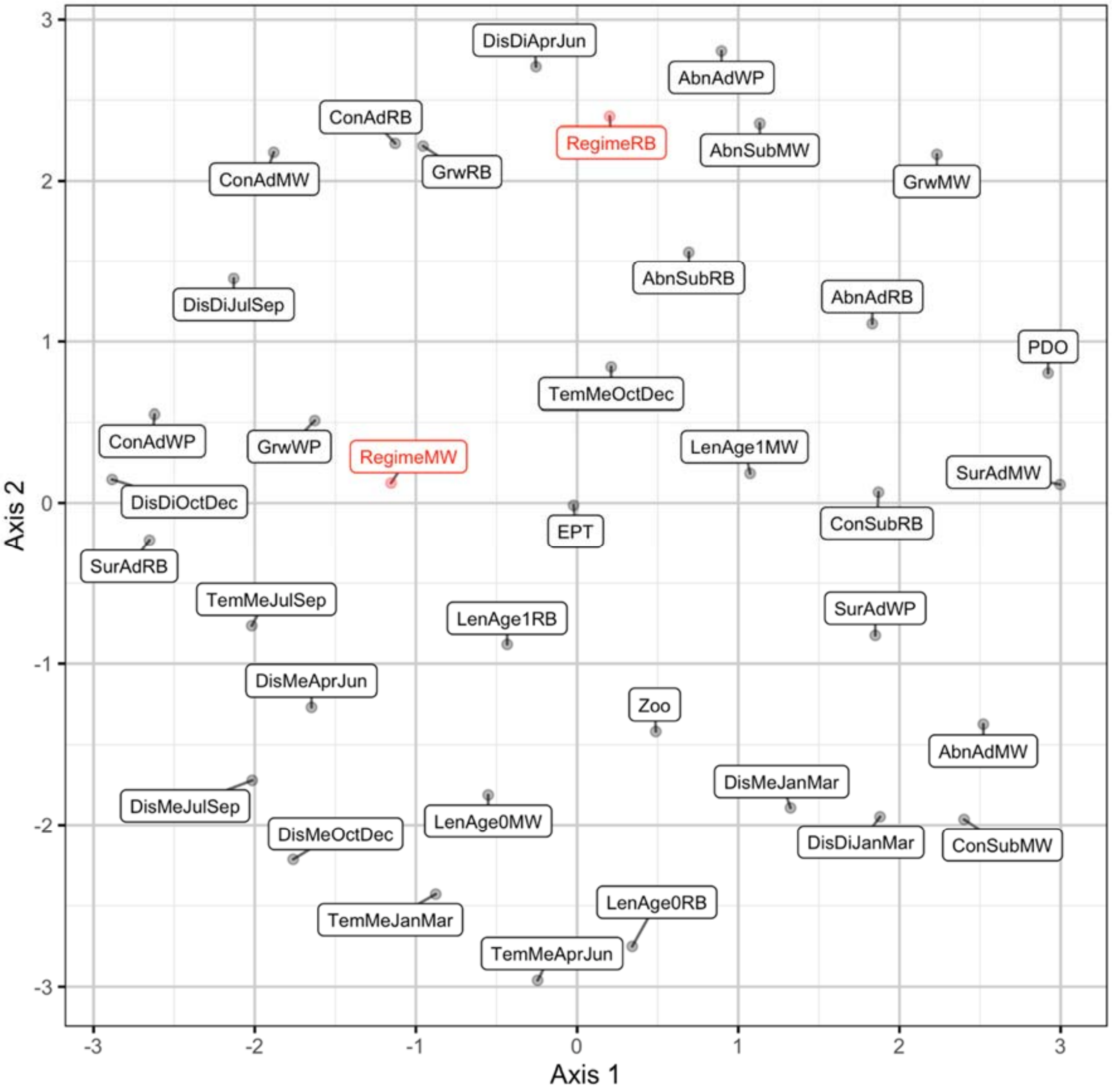


Figure G14: Non-metric multidimensional scaling plot showing clustering of variables by absolute correlations of short-term variation in environmental and fish variables (stress = 35.3). Short-term trends represent the variation in the variables after the effects of long-term trends from the dynamic factor analysis were removed from the time series.

Appendix H – Spatial Distribution Maps

This monitoring report has been completed as part of BC Hydro’s Water License Requirements. Copies are on file at BC Hydro. In order to protect sensitive information regarding the distribution of fish populations in the study area, a copy of this appendix is not available for viewing through this website. For further information concerning this study or the report, please contact Water License Requirements through the “Contact Us” button located at the top of this webpage.