Columbia River Project Water Use Plan

Revelstoke Flow Management Plan

Middle Columbia River Fish Population Indexing Program

Implementation Year 10

Reference: CLBMON-16

Technical Report

Study Period 2016

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CLBMON-16:
Middle Columbia River
Fish Population Indexing Survey
2016 Report

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Executive Summary

A year-round 142 m³/s minimum flow release from Revelstoke Dam (REV) was implemented in December 2010 as part of BC Hydro's Water Use Plan for the Columbia River. The implementation of the minimum flow coincided with the commissioning of an additional generation unit at Revelstoke Dam (REV5) that increased the maximum generation discharge capacity of the dam from 1,700 m³/s to 2,124 m³/s. The combined effects of these changes in dam operations are referred to as a flow regime change. The key environmental objective of the minimum flow release is to increase the abundance and diversity of fish populations in the middle Columbia River (MCR). The MCR Fish Population Indexing Program addresses four key management questions:

- Is there a change in abundance of adult fish using the MCR that corresponds with the implementation of a year-round minimum flow?
- Is there a change in growth rate of adults of the most common fish species using the MCR that corresponds with the implementation of a year-round minimum flow?
- Is there a change in body condition (measured as a function of relative weight to length) of adult fish using the MCR that corresponds with the implementation of a year-round minimum flow?
- Is there a change in spatial distribution of adult fish using the MCR that corresponds with the implementation of a year-round minimum flow?

Another objective of the program, although not specifically identified as a key management hypothesis, is to investigate and document changes in species richness or species diversity in the MCR in response to the minimum flow release. Data were collected for the MCR Fish Population Indexing Program during four years (2007 to 2010) prior to and six years after (2011 to 2016) the minimum flow release. In addition, data were collected from 2001 to 2006 as part of BC Hydro's Large River Fish Indexing Program, a similar program designed to monitor fish populations in the MCR.

The study area encompassed the 12 km portion of the Columbia River between Revelstoke Dam and the Illecillewaet River confluence. Fish were sampled by boat electroshocking at night within nearshore habitats. All captured fish were measured for fork length and weighed. Select species were implanted with a Passive Integrated Transponder (PIT) tag for individual identification. Between 2001 and 2016, each site was sampled three to five times per year in consecutive weeks as part of the mark-recapture study. Temporal and spatial variations in species richness, species evenness, abundance, spatial distribution, growth, and body condition were estimated using hierarchical Bayesian models (HBMs).

There was an increase in species richness and evenness between 2001 and 2008 which was attributed to substantial increases in the abundance of several less common species. The density and/or probability of occupancy of Burbot (*Lota lota*), Lake Whitefish (*Coregonus clupeaformis*), Northern Pikeminnow (*Ptychocheilus oregonensis*), Rainbow Trout (*Oncorhynchus mykiss*), Redside Shiner (*Richardsonius balteatus*) and sculpin species (*Cottidae* spp.) all increased, while densities of more common species such as Bull Trout (*Salvelinus confluentus*) and Mountain Whitefish (*Prosopium williamsoni*) remained relatively stable during this time period.

A second change in the fish community occurred following the flow regime change beginning in 2011, with declining richness and occupancy of less common species such as Burbot, Northern Pikeminnow, Rainbow Trout, and sculpin species. At the same time, species evenness increased between 2011 and 2015, which was attributed primarily to increasing abundance of suckers.

Estimates of body condition or growth of several fish species in the MCR declined in the first five years following the flow regime change. Body condition estimates for Bull Trout and Largescale Sucker both declined after the flow regime change. Estimates of the growth rate of Bull Trout also declined in the years after the flow regime change. The low body condition of Bull Trout coincided with declines in the abundance of Kokanee, which are an important prey for Bull Trout. Similar declines in condition and growth of Bull Trout and Largescale Sucker, as well as a reduction in Kokanee abundance in Arrow Lakes Reservoir, suggest a broad-scale decline in growing conditions in the MCR. The decline in adult Largescale Sucker condition between 2010 and 2015 coincided with a large increase in density estimates of sucker species, which suggests competition for resources and density-dependent growth. Similarly, body condition estimates of suckers increased in 2016, which coincided with a decrease in Sucker abundance and density.

There was an upstream shift in the distribution of some species in the years following the flow regime change. The upstream shift was observed in some years for both juvenile and adult Bull Trout and Mountain Whitefish. However, overlapping credible intervals suggested that these changes may not be statistically significant. It could be that greater discharges from Revelstoke Dam after the flow regime change make habitats further upstream in the study area more suitable for some species, although it is unclear whether greater discharges in recent years were caused by climatic variability, the new flow regime, or both.

Recommendations for future years of study include: 1) continuing mark-recapture sampling during the fall to gather data comparable to years prior to the flow regime change; 2) conducting scale analysis involving circuli measurements to assess growth of fish before and after the flow regime change; and 3) developing specific hypotheses to test relationships between fish population metrics and physical habitat and productivity variables from other monitoring programs in the MCR.

Keywords: Inventory, Columbia River, Revelstoke Dam, Abundance Estimation, Hierarchical Bayesian Analysis

Table E1: Status of management questions and hypotheses after Year 10 of the Middle Columbia River Fish Population Indexing Survey (CLBMON-16).

Objective	Management Questions	Management Hypotheses	Year 10 (2016) Status
Systematically collect fish population data prior to and following the implementation of the 142 m^3/s minimum flows and REV5 to quantitatively assess the changes in abundance, growth, diversity and distribution of fishes in the middle Columbia River.	Is there a change in the abundance of adult life stages of fish using the MCR that corresponds with the implementation of a year-round minimum flow?	**Ho_1:** The implementation of a 142 m^3/s minimum flow release from Revelstoke Dam will not significantly affect the abundance and diversity of adult fish present in the MCR during index surveys.	Density estimates of sucker species increased substantially after the flow regime change. Abundance estimates of Bull Trout declined after the flow regime change but the difference was small and not statistically significant. Mountain Whitefish abundance estimates were similar before and after the flow regime change. There were decreases in the probability of occupancy of several less common species, including Burbot, Northern Pikeminnow, Rainbow Trout, and sculpin, that coincided with the timing of the new flow regime. It is unknown whether the flow regime change caused these changes or only happened at the same time because of unknown factors not measured during the monitoring program. Hypothesis cannot be rejected.
	Is there a change in growth rate of adult life stages of the most common fish species using the MCR that corresponds with the implementation of a year-round minimum flow?	**Ho_2:** The implementation of a 142 m^3/s minimum flow release from Revelstoke Dam will not significantly affect the mean growth rate of adult fish present in the MCR during index surveys.	Growth rate estimates for Bull Trout declined after the flow regime change, which was likely related to concurrent decreases in Kokanee abundance. Mountain Whitefish and Rainbow Trout growth estimates did not indicate any change related to the flow regime but sample sizes were very small for Rainbow Trout. Growth of all other species could not be estimated because of small numbers of recaptured fish. Hypothesis cannot be rejected.
	Is there a change in body condition (measured as a function of relative length to weight) of adult life stages of fish using the MCR that corresponds with the implementation of a year-round minimum flow?	**Ho_3:** The implementation of a 142 m^3/s minimum flow release from Revelstoke Dam will not significantly affect the body condition of adult fish present in the MCR during index surveys.	Estimates of body condition of Bull Trout and Largescale Sucker decreased after the flow regime change. The decrease in Bull Trout condition coincided with a decrease in the abundance of Kokanee, which are an important prey item. The decrease in Largescale Sucker condition coincided with a three-fold increase in the density of sucker species, suggesting competition for resources. It is not possible to conclude whether the flow regime contributed to the changes in body condition. Hypothesis cannot be rejected.
	Is there a change in spatial distribution of adult life stages of fish using the MCR that corresponds with the implementation of a year-round minimum flow?	Ho_4: The implementation of a 142 m^3/s minimum flow release from Revelstoke Dam will not significantly alter the distribution of fish present in the MCR during index surveys.	There was an upstream shift in the distribution of some species in years following the flow regime change. The upstream shift was observed in some years for both adult and juvenile Bull Trout and Mountain Whitefish. Previous reports from this study also suggested an upstream shift of Rainbow Trout and Northern Pikeminnow. However, overlapping credible intervals suggested that these changes may not be statistically significant. Hypothesis cannot be rejected.

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1.0 INTRODUCTION

Since the establishment of the Columbia River Treaty (CRT) between the United States and Canada in the 1960s and the subsequent construction of numerous hydroelectric dams and water storage facilities, management groups have aimed to mitigate the impacts of those facilities on the local and regional ecosystems through long-term monitoring projects. In 2007, BC Hydro implemented a Water Use Plan (WUP; BC Hydro 2007) for the Canadian portion of the Columbia River. As part of the WUP, the Columbia River Water Use Plan Consultative Committee (WUP CC) recommended the establishment of a year-round 142 m^3/s minimum flow release from Revelstoke Dam (REV; BC Hydro 2005). The key environmental objective of the minimum flow release is to increase the abundance and diversity of fish populations in the middle Columbia River (MCR). Implementation of the minimum flow release coincided with the commissioning of a new and additional fifth generating unit (REV5) at REV on 20 December 2010. The addition of REV5 also increased the maximum generation discharge capacity of the REV from 1,700 m^3/s to 2,124 m^3/s. The combined effects of the minimum flow release and the increased maximum discharge capacity from REV are collectively referred to as the flow regime change.

The MCR includes the ~48 km long section of the Columbia River from the outlet of REV downstream to Beaton Flats. Due to data gaps regarding the status of aquatic communities in the MCR and uncertainty about the environmental benefits of a minimum flow release on the MCR ecosystem, the WUP CC recommended the development and implementation of the Revelstoke Flow Management Plan (RFMP). These projects are designed to measure the productivity of the MCR ecosystem in relation to the minimum flow release, each of which contribute to the overall understanding of the system:

- CLBMON-15a: MCR Physical Habitat Monitoring;
- CLBMON-15b: MCR Ecological Productivity Monitoring;
- CLBMON-16: MCR Fish Population Indexing Surveys;
- CLBMON-17: MCR Juvenile Fish Habitat Use Assessment;
- CLBMON-18: MCR Adult Fish Habitat Use Assessment; and
- CLBMON-53: MCR Juvenile Fish Stranding Assessment.

Under the RFMP, four years of adult fish monitoring were conducted prior to the implementation of the minimum flow release (2007-2010). Between 2001 and 2006, adult fish populations were monitored in the MCR under the Large River Fish Indexing Program (Golder 2002, 2003, 2004a, 2005a, 2006, 2007). Together, with four years of data collected after the RFMP was implemented (Golder 2008, 2009, 2010, Ford and Thorley 2011a), these data provide 10 years of baseline information that will be used to understand the effect of the minimum flow release on adult fish in the MCR (Table 1). Currently, nine years of monitoring are planned after the implementation of the minimum flow release (i.e., 2011-2019). The current year study (2016) describes the sixth year of monitoring after an additional (i.e., fifth) generating unit was added to REV (REV5), and after the minimum flow release was established.

Table 1: Summary of study years for adult fish population monitoring in the middle Columbia River and associated BC Hydro programs.

Study Year	Associated BC Hydro Programs	Flow Regime	Seasons Sampled
2001	LRFIP[a]	Before Minimum Flow and REV5	Fall
2002	LRFIP[a]	Before Minimum Flow and REV5	Fall
2003	LRFIP[a]	Before Minimum Flow and REV5	Fall
2004	LRFIP[a]	Before Minimum Flow and REV5	Fall
2005	LRFIP[a]	Before Minimum Flow and REV5	Fall
2006	LRFIP[a]	Before Minimum Flow and REV5	Fall
2007	RFMP[b]	Before Minimum Flow and REV5	Fall
2008	RFMP[b] and WUP[c]	Before Minimum Flow and REV5	Fall
2009	RFMP[b] and WUP[c]	Before Minimum Flow and REV5	Fall
2010	RFMP[b] and WUP[c]	Before Minimum Flow and REV5	Fall
2011	RFMP[b] and WUP[c]	After Minimum Flow and REV5	Spring and Fall
2012	RFMP[b] and WUP[c]	After Minimum Flow and REV5	Spring and Fall
2013	RFMP[b] and WUP[c]	After Minimum Flow and REV5	Spring
2014	RFMP[b] and WUP[c]	After Minimum Flow and REV5	Fall
2015	RFMP[b] and WUP[c]	After Minimum Flow and REV5	Spring and Fall
2016	RFMP[b] and WUP[c]	After Minimum Flow and REV5	Spring (visual survey only) and Fall

a. LRFIP = Large River Fish Indexing Program
b. RFMP = Revelstoke Flow Management Plan
c. WUP = Water Use Plan

1.1 Study Objectives

The primary objective of the MCR Fish Population Indexing Survey (CLBMON-16) is to systematically collect fish population data prior to and following the flow regime change to monitor changes in abundance, growth, diversity and distribution of fish in the MCR.

Specific secondary objectives are to:

- Build on earlier investigations to further refine the sampling strategy, sampling methodology and analytical procedures required to establish a long-term monitoring program for fish populations in the MCR;
- Identify gaps in understanding, data and current knowledge about fish populations; and
- Provide recommendations for future monitoring.

The key management questions and hypotheses described in Sections 1.2 and 1.3, respectively, are from BC Hydro (2010a) and are specifically related to the effects of the minimum flow release. However, the addition of REV5 to REV and the resultant higher downstream flows due to increased generating capacity may have an equal or greater effect on fish population metrics downstream than the minimum flow release. Due to the inability to separate the effects of these two flow changes, the following questions and hypotheses are more generally related to the overall flow regime change, taking into account both REV5 and the minimum flow release.

1.2 Key Management Questions

Key management questions to be addressed by this monitoring program are:

- Is there a change in abundance of adult life stages of fish using the MCR that corresponds with the implementation of a year round minimum flow?
- Is there a change in growth rate of adult life stages of the most common fish species using the MCR that corresponds with the implementation of a year round minimum flow?
- Is there a change in body condition (measured as a function of relative weight to length) of adult life stages of fish using the MCR that corresponds with the implementation of a year round minimum flow?
- Is there a change in spatial distribution of adult life stages of fish using the MCR that corresponds with the implementation of a year round minimum flow?

1.3 Management Hypotheses

The specific hypotheses to be tested under CLBMON-16 are related to the abundance, growth, body condition and distribution of fish observed:

Ho_1: The implementation of a 142 m^3/s minimum flow release from REV will not significantly affect the abundance and diversity of adult fish present in the MCR during index surveys.

Ho_2: The implementation of a 142 m^3/s minimum flow release from REV will not significantly affect the mean growth rate of adult fish present in the MCR during index surveys.

Ho_3: The implementation of a 142 m^3/s minimum flow release from REV will not significantly affect the body condition of adult fish present in the MCR during the index surveys.

Ho_4: The implementation of a 142 m^3/s minimum flow release from REV will not significantly alter the distribution of fish present in the MCR during index surveys.

1.4 Background

Revelstoke Dam is located on the Columbia River approximately 8 km upstream from the Trans-Canada Highway Bridge, which crosses the Columbia River in the City of Revelstoke (Figure 1). The dam was constructed with the primary objective of power generation, and uses the combined storage capacity of Revelstoke Reservoir (impounded by REV) and Kinbasket Reservoir (impounded by Mica Dam). REV is not one of the CRT dams (i.e., Mica, Hugh L. Keenleyside, Duncan, and Libby dams); however, the operation of Revelstoke Dam is affected by treaty and operational considerations upstream (i.e., Mica Dam) and downstream (i.e., Hugh L. Keenleyside [HLK]). REV is the second largest power plant operating within BC Hydro's hydroelectric grid, and provides 21% of BC Hydro's total systems capacity (https://www.bchydro.com/energy-in-bc/our_system/generation/our_facilities/columbia.html).

Typically, REV is operated as a daily peaking plant, where flow releases are high through daylight hours when energy demands are higher (BC Hydro 1999). Overnight, when energy demands are typically lower, water releases are reduced, but must be maintained above 142 m^3/s (i.e., the minimum flow release). For operational reasons, the minimum flow of 142 m^3/s is not typically reached and the lowest flows are between 142 and 160 m^3/s (BC Hydro, personal communication). Periods of minimum flow release can occur at any time, but are more common at night during the spring (March to May) and fall (September to November) when electricity demands are low. Prior to the flow regime change, flows from REV ranged from 0 to 1,700 m^3/s. With REV5, the maximum discharge through REV is 2,124 m^3/s, an increase of 424 m^3/s. With both REV5 and the minimum flow release, discharge through REV can range from 142 to 2,124 m^3/s.

The availability and quality of aquatic habitat in the MCR is affected by flow releases from REV and by the operation of HLK downstream, controlling water level elevations in Arrow Lakes Reservoir (ALR). The length of flowing river in the MCR changes depending on water level elevations in ALR. When ALR is at full pool (EL 440 m), backwatering influences the MCR up to the base of REV. High pool levels in ALR usually occur from early July to late November. In late November, ALR is managed for downstream power production and flood control for the following spring freshet period. Reservoir elevations vary over time and depend on annual climatic conditions, CRT obligations, and operational needs. At ALR's minimum reservoir elevation (EL 420 m), approximately 48 km of the MCR is riverine. As such, the effects of the minimum flow release are expected to be greater when reservoir levels are low (i.e. during the winter and spring), and less when reservoir levels are high (i.e., during the summer and fall).

1.5 Study Area

CLBMON-16 encompasses the 11.7 km portion of the Columbia River from REV downstream to the Illecillewaet River confluence (Figure 1). The study area is differentiated into two separate reaches. Reach 4 extends from REV (RKm 238.0 as measured from the Canada-US border) to the confluence with the Jordan River (Rkm 231.8). Reach 3 extends from the Jordan River downstream to the Illecillewaet River confluence (Rkm 226.3).

Reach 2 (the Illecillewaet River confluence to the Akolkolex River confluence [RKm 206.0]) was sampled as part of CLBMON-16 in 2007, 2008, and 2009. This reach has not been sampled since 2009, as it was deemed unlikely to be influenced by the minimum flow release. Sampling in Reach 2 was removed from the Terms of Reference in 2010. Reach 1 (the Akolkolex River confluence downstream to Beaton Flats [RKM 190.0]) was not sampled as part of CLBMON-16 during any study year and also was removed from the Terms of Reference in 2010 (BC Hydro 2010a).

In 2016, the sample sites covered the entire shoreline of Reaches 3 and 4 (similar to monitoring in 2007 to 2015). Between 2001 and 2006 (i.e., prior to the WUP), sampling was limited to Reach 4 and the Big Eddy portion of Reach 3 (Figure 1); the portion of Reach 3 downstream of Big Eddy was not sampled during these years. Each site was a section of river between 519 and 2,270 m in length along either the left or right bank.

The locations of the eight sites sampled in Reach 4 and the seven sites sampled in Reach 3 in 2016 are illustrated in Appendix A, Figures A1 and A2. Site descriptions and UTM locations for all sites are listed in Appendix A, Table A1. In 2016, each site was sampled three times (i.e., three sessions) in fall (11 to 27 October) for the mark-recapture survey (Table 2). In addition to mark-recapture surveys, visual enumeration boat electroshocking surveys were conducted in the MCR for the third consecutive year in both spring and fall. These visual surveys are described in Section 2.1.5. The timing of the 2016 fall surveys corresponded to fall sample sessions that were conducted between 2001 and 2015.

Table 2: Annual study periods for mark-recapture boat electroshocking surveys conducted in the middle Columbia River, 2001 to 2016.

Year	Season	Start Date	End Date	Number of Sessions	Duration (in days)
2001	Fall	12 September	11 October	5	30
2002	Fall	22 October	14 November	4	24
2003	Fall	15 October	30 October	4	16
2004	Fall	13 October	24 October	4	12
2005	Fall	5 October	25 October	4	21
2006	Fall	2 October	24 October	4	23
2007	Fall	27 September	24 October	5	28
2008	Fall	23 September	4 November	5	43
2009	Fall	28 September	30 October	5	33
2010	Fall	4 October	29 October	4	26
2011	Spring	30 May	24 June	4	26
2011	Fall	3 October	27 October	4	25
2012	Spring	28 May	22 June	4	26
2012	Fall	2 October	25 October	4	24
2013	Spring	27 May	20 June	4	26
2014	Fall	16 October	30 October	3	15
2015	Spring	2 June	12 June	2	11
2015	Fall	13 October	29 October	3	17
2016	Fall	11 October	27 October	3	17

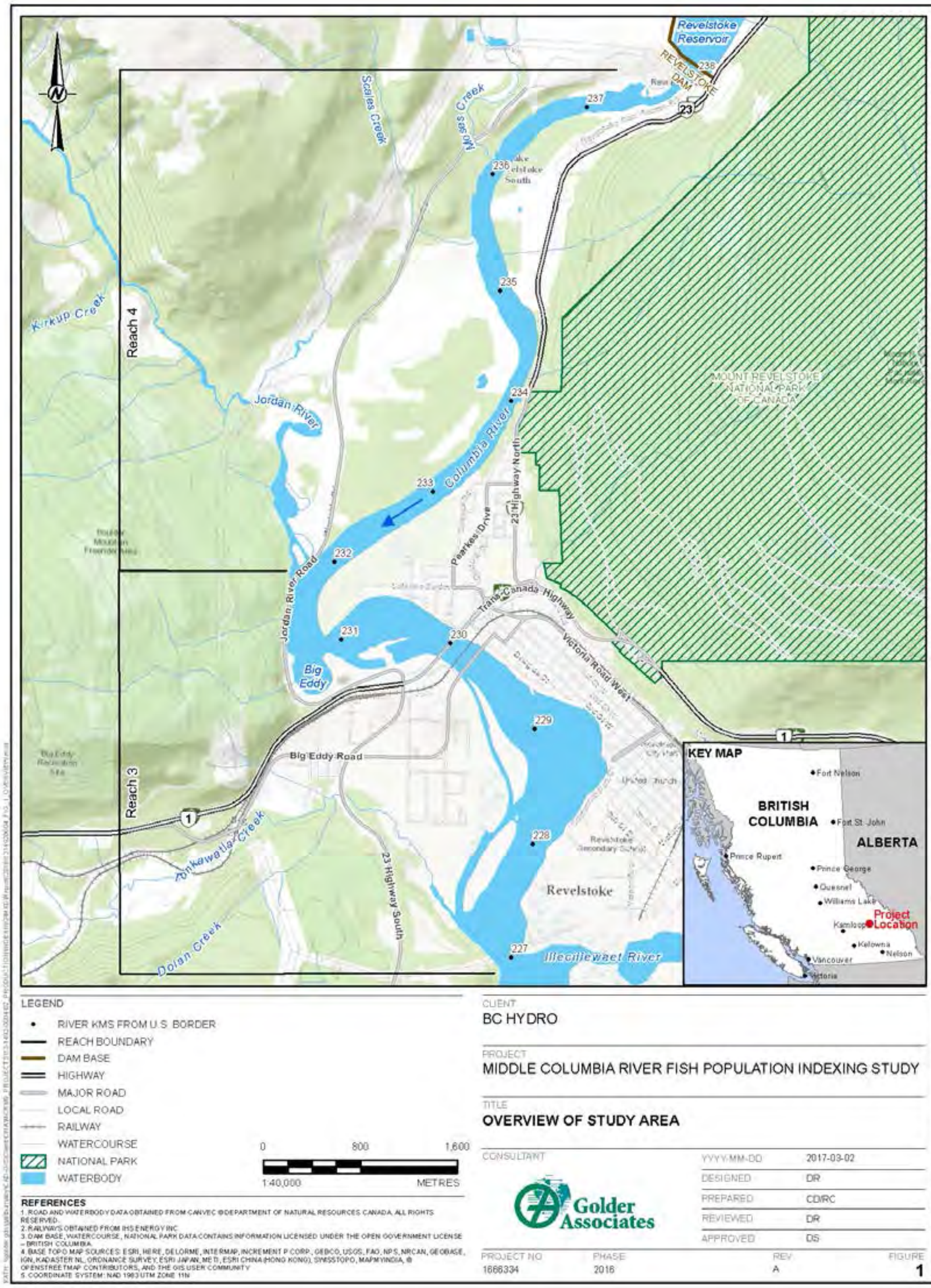

Figure 1: Overview of the middle Columbia River study area, 2016.

2.0 METHODS

2.1 Data Collection

2.1.1 Discharge

Hourly average discharge data for the mainstem Columbia River (discharge through REV) from 2001 to 2016 were obtained from BC Hydro's Columbia-Kootenay River Temperature and Discharge Database. Discharges throughout this report are presented as cubic metres per second (m^3/s).

2.1.2 Water Elevation

Hourly water level elevation data for the mainstem Columbia River near Nakusp (RKm 132.2) from 2001 to 2016 were obtained from BC Hydro's Columbia-Kootenay River Temperature and Discharge Database. Water elevations throughout this report are presented as metres above sea level (masl).

2.1.3 Water Temperature

Water temperature data recorded at 10-minute intervals from 2007 to 2016 were obtained from BC Hydro's MCR Physical Habitat Monitoring Program (CLBMON-15a). Data from 2007 to 2013 and 2015 to 2016 were from Station 2 and data from 2014 were from Station 2AS because data from Station 2 were not available. The two stations are at the same general location approximately 4 km downstream of REV (RKm 234.0) but Station 2 is installed in a stand-pipe on the shore whereas Station 2AS is attached to an anchor on the substrate. The two stations are thought to be within 0.2°C (ONA and LGL Ltd., personal communication, 22 March 2015). Temperature data throughout this report are presented as daily mean values.

Spot measurements of water temperatures were obtained at all sample sites at the time of sampling using a hull-mounted Airmar® digital thermometer (accuracy ± 0.2°C).

2.1.4 Habitat Conditions

Several habitat variables were qualitatively assessed at all sample sites (Table 3). Variables selected were limited to those for which information had been obtained during previous study years and were intended to detect changes in site conditions among years that could have affected sampling effectiveness.

The type and amount of instream cover for fish was visually estimated at all sites. 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). Mean and maximum depths were estimated by the boat operator based on the boat's sonar depth display.

Each site was categorized into various habitat types using the Bank Habitat Types Classification System (Appendix B, Table B1; R.L. & L. 1994, 1995). Bank type length within each site was calculated using ArcView® GIS software (Appendix B, Table B2). Netters estimated the number of fish by species and by bank habitat type. Bank habitat types less than approximately 100 m in length were combined with adjacent bank habitat types to facilitate the netters' ability to remember fish counts. In all study years, most netters were experienced in boat electroshocking. Less experienced netters always worked with a more experienced netter to ensure proper training and increase consistency in netting and observation efficiency among years.

Table 3: List and description of habitat variables recorded at each sample site in the middle Columbia River, 2016.

Variable	Description
Date	The date the site was sampled
Time	The time the site was sampled
Estimated Flow Category	A categorical ranking of Revelstoke Dam discharge (high; low; transitional) based on crew observations of channel fullness
Air Temperature	Air temperature at the time of sampling (to the nearest 1°C)
Water Temperature	Water temperature at the time of sampling (to the nearest 1°C)
Water Conductivity	Water conductivity measured near the mid-point of the site after 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 electrical current 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 duration of electroshocker operation (to the nearest 1 second)
Mean Depth	The mean water column depth recorded during sampling (to the nearest 0.1 m)
Maximum Depth	The maximum water column depth recorded during sampling (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 1.0 m visibility) based on visual estimates
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) based on visual estimates
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 sample
Sample Comments	Any additional comments regarding the sample

2.1.5 Geo-referenced Visual Enumeration Survey

From 2014 to 2016, a geo-referenced visual enumeration survey was conducted as complementary technique to the mark-recapture surveys for monitoring fish abundance in the MCR. In 2016, the geo-referenced visual enumeration survey was conducted in the spring (14-15 June) and fall (5-6 October) at each of the mark-recapture index sites. The survey consisted of a boat electroshocking pass using the same methods as the mark-recapture survey (Section 2.1.6), except that fish were only counted and not captured with nets. Two observers were positioned in the same location as they would have been for netting, where they identified, enumerated, and estimated the length of observed fish. Two other individuals recorded all the observation data dictated by the observers, and recorded the geographical location of each observation using a hand-held GPS (Global Positioning System) unit. Species counted during the surveys were the same as those captured and tagged during the mark-recapture surveys (i.e., all fish species except for Kokanee [*Oncorhynchus nerka*], Redside Shiner [*Richardsonius balteatus*], and sculpin species [*Cottidae*]).

The rationale behind these geo-referenced visual enumeration surveys was to avoid potential missed observations of fish that may occur when netters turn to put captured fish in the livewell during mark-recapture surveys. Geo-referenced visual enumeration surveys allow for continuous direct counts of observed fish that are likely more accurate than counts of fish made by netters during mark-recapture surveys. In addition, the visual surveys provide fine-scale distribution data, which could be used to understand mesohabitat use by fish in the MCR and better address management questions regarding spatial distribution.

During the visual surveys, observers were instructed to estimate the fork lengths of observed fish. 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 of 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 (Sections 2.2.9 and 3.6.10)

2.1.6 Fish Capture

In 2016, fish were captured during the fall (11-27 October) sampling session using methods similar to previous years of the project (Golder 2002, 2003, 2004a, 2005a, 2006, 2007, 2008, 2009, 2010; Ford and Thorley 2011a, 2012, Golder and Poisson 2013; ONA, Golder, and Poisson 2014; Golder, Poisson, and ONA 2015, 2016a).

Boat electroshocking was conducted in Reaches 3 and 4 of the study area to capture fish within nearshore habitats along the channel margins. Boat electroshocking employed a Smith-Root Inc. high-output Generator Powered Pulsator (GPP 5.0) electroshocker operated out of a 150 HP outboard jet-drive riverboat by a three-person crew. The electroshocking procedure consisted of maneuvering 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 fish stunned by the electrical field. Captured fish were immediately sorted by the Bank Habitat Type (Appendix B, Table B1) according to where they were captured and placed into separate partitions in an onboard live-well. Fish that could be 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.

Kokanee, Redside Shiner, and sculpin species were excluded from the mark-recapture component of the program. The abundance of Kokanee in the study area is highly variable and determined by recruitment processes outside of the study area and entrainment rates through REV. The distribution of Redside Shiner is generally limited to Big Eddy (rkm 231) and the Centennial Park Boat Launch areas of Reach 3 (rkm 228, Figure 1). The small patches and high variability limited recapture success; thus limiting the effectiveness of a mark-recapture program for this species. Sculpin species are relatively common throughout the study area; however, they are difficult to capture during boat electroshocking operations and are more amenable to other shallow water sampling techniques. Sculpin species and Redside Shiner also were studied as part of BC Hydro's Middle Columbia River Juvenile Habitat Use Program (CLBMON-17; Triton 2014). For the above reasons, up to 50 Kokanee, 50 Redside Shiner, and 50 sculpin species were captured and processed for life history data; subsequently, these species were enumerated by the netters and recorded as "observed".

Boat electroshocking sites varied between 519 m and 2,270 m in length. If, due to logistical reasons, a site could not be fully sampled (e.g., public too close to shore, water too shallow, other research activities in the area, etc.) the difference in distance between what was sampled and the established site length was estimated and subtracted from the site length in subsequent analyses.

Voltage was adjusted as needed to achieve an amperage output of ~1.9 A (based on boat electroshocker's current meter) at a frequency of 30 Hz direct current. These settings have been shown to result in lower electroshocking-induced injury rates for Rainbow Trout (*Oncorhynchus mykiss*) than when using greater frequencies (60 or 120 Hz) and amperages (1.5 to 3.3. A; Golder 2004b, 2005b). Although electrical output was variable (i.e., depending on water conductivity, water depth, and water temperature), field crews attempted to maintain similar electrical output levels for all sites over all sessions. In addition to using electroshocker settings proven to reduce injury rates, field crews took additional measures to reduce the likelihood of impacting fish stocks. These measures included:

- turning off the electricity when large schools of fish were observed;
- using an array curtain instead of the boat hull as the cathode to reduce distortion in the electrical field;
- turning off the electricity when larger fish or vulnerable fish species are observed (e.g., White Sturgeon [*Acipenser transmontanus*]);
- netting fish as quickly as possible to limit the amount of time they are in the electrical field;
- netting fish prior to them entering tetanus because fish captured prior to tetanus, i.e., in taxis, are less likely to experience spinal hemorrhaging (Golder 2004b, 2005b); and
- preventing fish from entering the electrical field after they have been removed (i.e., crew members would not net a second fish if they already have a fish in their net).

To reduce the possibility of capturing the same fish multiple times in one session, when possible, fish were released upstream after processing, approximately halfway through the site in which they were captured.

2.1.7 Safety Communications

The operation of REV as a daily peaking plant can result in rapid and unpredictable changes in dam discharges. Real-time dam discharge rate changes were monitored by field crews via text messages automatically sent from the BC Hydro flow operations monitoring computer to the field crew's cell phone. These messages were sent when dam discharge either increased or decreased by 200 m^3/s. This real-time discharge information was essential for logistical planning and allowed the crew to maximize sampling effort during the period when discharge was sufficient to allow effective sampling. To prevent the boat and crew from being stranded in shallow water during periods of low flow, sampling efforts were typically limited to Reach 3 upon notification of a flow reduction to a level below 200 m^3/s.

2.1.8 Fish Processing

A site form was completed at the end of each sampled site. Site habitat conditions and observed fish were recorded before processing captured fish. Life history and other data collected for captured fish are shown in Table 4. Fish were measured to the nearest 1 mm for fork length (FL) or total length (TL) depending on the species and weighed to the nearest 1 g using an A&D Weighing™ digital scale (Model SK-5001WP; accuracy ±1 g). Life history data were entered directly into the Middle Columbia River Fish Indexing Database using a laptop computer. All sampled fish were automatically assigned a unique identifying number by the database that provided a method of cataloguing associated ageing structures.

All fish (with the exception of Kokanee, Redside Shiner, and sculpin species as detailed in Section 2.1.6) that were 120 mm or larger in FL and were in good condition were marked with a Passive Integrated Transponder (PIT) tag (Food Safe, 12 mm x 2.25 mm, model T-IP8010, ISO, FDX-B, Datamars). Fish between 120 and 170 mm FL had a tag implanted into the abdominal cavity just off the mid-line and anterior to the pelvic girdle using a single shot applicator (model MK7, Biomark Inc., Boise, Idaho, USA) or a No. 11 surgical scalpel (depending on the size of the fish). Fish ≥170 mm FL had tags implanted with a Hallprint-brand single shot 12 mm polymer PIT tag applicator gun into the dorsal musculature on the left side below the dorsal fin near the pterygiophores. All tags and tag injectors were immersed in an antiseptic (Super Germiphene™) and rinsed with distilled water prior to insertion. Tags were checked to ensure they were inserted securely and the tag number was recorded in the Middle Columbia River Fish Indexing Database.

Table 4: List and description of variables recorded for each fish captured in the middle Columbia River, 2016.

Variable	Description
Species	The species of fish recorded
Size Class	A general size class for observed fish (YOY for age-0 fish, Immature for fish <250 mm FL, Adult for fish >250 mm FL)
Length	The fork length (FL) or total length (TL) of the fish to the nearest 1 mm
Weight	The wet weight of the fish to the nearest 1 g
Sex and Maturity	The sex and maturity of a fish (determine 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
Tag Scar	The presence of a scar from a previous tag application
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 regarding the fish

Scale samples were collected from Kokanee, Lake Whitefish, Mountain Whitefish, Northern Pikeminnow (*Ptychocheilus oregonensis*), Peamouth (*Mylocheilus caurinus*), Rainbow Trout, and Redside Shiner in accordance with the methods outlined in Mackay et al. (1990). All scales were stored in appropriately labelled coin envelopes and air-dried before long-term storage. Scale samples were not aged during the current study year but were catalogued for potential future study.

Overall, sampling methods were very similar between 2001 and 2016, with major changes to the study identified in Table 5. Minor changes to the study design between 2001 and 2016 that do not confound the interpretation of study results, such as small modifications to electroshocker settings or minor revisions to site delineations, are not presented.

Table 5: Key changes in sampling methods for the middle Columbia River fish population indexing study (CLBMON-16), 2001 to 2016.

Methodology Change	Years	Description
Number of sampling sessions (fall season)	2014-2016	Three sampling sessions
	2002-2006, 2010-2012	Four sampling sessions
	2001, 2007-2009	Five sampling sessions
Sampling locations	2001-2007	Reach 4 and the Big Eddy portion of Reach 3 were sampled
	2007-2009	Reaches 2, 3 and 4 were sampled
	2009-2016	Reaches 3 and 4 were sampled
Fish tag type	2001-2004	T-bar anchor tags exclusively
	2005	T-bar anchor tags and PIT tags
	2006-2016	PIT tags exclusively
Species captured and tagged	2001	Bull Trout, Largescale Sucker (*Catostomus macrocheilus*), Mountain Whitefish, Rainbow Trout
	2002-2009	Bull Trout, Mountain Whitefish, Rainbow Trout
	2010-2016	All species except Kokanee, Redside Shiner, and sculpin species
Electroshocking specifications and settings	2001-2004	Frequency was 60 Hz; boat hull used as the cathode
	2005-2016	Frequency was 30 Hz; array curtain was used as the cathode
Seasons sampled	2001-2010, 2014	Fall only
	2011-2012, 2015-2016	Spring and Fall
	2013	Spring only
Geo-referenced visual enumeration survey	2014-2016	Trial of new method consisting of visual counts during boat electroshocking without netting fish

2.2 Data Analyses

2.2.1 Data Compilation and Validation

Data were entered directly into the Middle Columbia River Fish Indexing Database using Microsoft® Access 2010 software. The database has several integrated features to ensure 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.

2.2.2 Life Stage Assignment

Bull Trout, Rainbow Trout, Mountain Whitefish, and Largescale Sucker were assigned a life stage (i.e., fry, juvenile, or adult) based on the fork length (FL) values provided in Table 6. These values were based on length-frequency distributions and professional judgment. Fry were excluded from all Hierarchical Bayesian Models (HBMs) except for the estimations of occupancy and count density; these two analyses included observational data for which it was not always possible to reliably distinguish fry.

Table 6: Fork length (in mm) based life stage classifications used in hierarchical Bayesian analyses for fish captured in the middle Columbia River, 2001 to 2016.

Species	Fry	Juvenile	Adult
Bull Trout	<120	120 to 399	≥400
Largescale Sucker	<120	120 to 349	≥350
Mountain Whitefish	<120 (i.e., age-0)	120 to 174 (i.e., age-1)	≥175 (i.e., age-2 and older)
Rainbow Trout	<120	120 to 249	≥250

2.2.3 Hierarchical Bayesian Analysis

The temporal and spatial variation in species richness and evenness, abundance, growth, and body condition were analyzed using hierarchical Bayesian models using data from 2001 to 2016. The book 'Bayesian Population Analysis using WinBUGS: A hierarchical perspective' by Kery and Schaub (2011) provides an excellent reference for hierarchical Bayesian methods and is considered the companion text for the following analyses. A Bayesian approach was chosen over a frequentist approach to fitting models for the MCR data for several reasons. Firstly, a Bayesian approach allows more realistic, system-specific models to be fitted (Kuparinen et al. 2012). Secondly, a Bayesian approach allows derived values, such as species richness, to be readily calculated with credible intervals (Kery and Schaub 2011 p.41). A Bayesian approach also readily handles missing values which are common in ecological studies such as the MCR and provides directly interpretable parameter estimates whose reliability does not depend on the sample size, which is important when recapture rates are low. The only disadvantage is the additional computational time required to fit models using a Bayesian as compared to a frequentist approach.

Hierarchical Bayesian models were fitted to the fish indexing data for the MCR using R version 3.2.2 (R Core Team 2016) and JAGS 4.1.0 (Plummer 2015) which interfaced with each other via the jmbr package for R (Thorley 2017). For additional information on hierarchical Bayesian modelling in the BUGS (Bayesian analysis Using Gibbs Sampling) language, of which JAGS uses a dialect, the reader is referred to Kery and Schaub (2011) pages 41-44. The technical aspects of the analyses, including the general approach and model definitions in the JAGS (Just Another Gibbs Sampler; Plummer 2003) dialect of the BUGS language, are provided in Appendix F. The resultant parameter estimates are tabulated in Appendix G. In addition, the model definitions, parameter estimates and source code are all available online at http://www.poissonconsulting.ca/f/577548349 (Thorley and Campos 2017).

The results were displayed graphically by plotting the modeled relationship between a particular variable (e.g., year) and the estimated mean values of the response variable. Uncertainty in the estimates is indicated by 95% credible intervals (CRIs), which are the Bayesian equivalent of 95% confidence intervals. If the model assumptions are correct, then there is 95% probability that the actual underlying values lie between the upper and lower bounds. An estimate is statistically significant if its 95% CRIs do not include 0. If two values have non-overlapping CRIs, then the difference between them is by definition statistically significant.

However, it is important to realize that estimates can have overlapping CRIs but the difference between them can still be statistically significantly different. For example, the estimates of the annual count density depend on the differences between years as well as the density in a typical year. As uncertainty in the density in a typical year affects all the estimates, it can cause the CRIs to overlap even if the differences between years are significantly different. If it is important to establish the statistical significance of a difference or trend where the CRIs overlap, then this can be determined from the posterior probability distributions.

Also, it is important to realize that statistical significance does not indicate biological importance. For example, a difference may be statistically significant but so small as to be of no consequence for the population. Conversely, the uncertainty in a difference may include 0 rendering the difference statistically insignificant while also admitting the possibility of a large and potentially impactful effect. For further information on the limitations of statistical significance, see Greenland et al. (2016).

In the plots, the mean values of the response variable with 95% CRIs are shown while the remaining variables were held constant. Unless stated otherwise, continuous and discrete fixed variables were held constant at their mean and first level values, respectively, while random variables were held constant at their typical values (i.e., the expected values of the underlying hyperdistributions; Kery and Schaub 2011, p.77-82). Where informative, the influence of particular variables was expressed in terms of the effect size (i.e., the percent change in the response variable) with 95% CRIs (Bradford et al. 2005).

2.2.4 Occupancy and Species Richness

Occupancy, which is the probability that a particular species was present at a site, was estimated from the temporal replication of detection data (Kery and Schaub 2011, p.414-418), i.e., each site was surveyed multiple times within a season. A species was considered to have been detected if one or more individuals of the species were caught or counted. The model estimated the probability that a species was present at a given (or typical) site in a given (or typical) year as opposed to the probability that a species was present in the entire study area. Occupancy was estimated for species which had sufficient variation in their frequency of encounter to provide information on changes through time and included the following six species: Burbot (*Lota lota*), Lake Whitefish, Northern Pikeminnow, Rainbow Trout, Redside Shiner, and sculpin species.

Key assumptions of the occupancy model included:

- occupancy (the probability of presence) was described by a generalized linear mixed model with a logit link;
- occupancy varied with season;
- occupancy varied randomly with site;
- the effect of year on occupancy was autoregressive with a lag of one year and varied with flow regime;
- sites were closed (i.e., the species is present or absent at a site for all sessions within a particular season of a year), which was assessed through estimates of site fidelity (Section 2.2.6); and
- observed presence was described by a Bernoulli distribution, given occupancy.

Species richness was estimated by summing the estimated occupancies for all species that had estimates of occupancy. In contrast to the traditional calculation of species richness that simply counts the number of species observed, this method excluded species that were very infrequently encountered, or nearly always encountered as they provide no information on inter-annual variation in species presence due to dam operations and in the case of very rarely encountered species add additional uncertainty. Mountain Whitefish, Bull Trout, and sucker species were not included because they were nearly always encountered. Very rarely encountered species, such as Cutthroat Trout and White Sturgeon, were not included in estimates of richness based on the assumption that these species were always present at some unknown low density, and whether or not they were detected in a given year was due to chance, and not reflective of true presence or absence in the study area.

The traditional measure of species richness calculated as the number of species observed is based on the unrealistic assumptions that detection probability of each species is 100% and that detection probability does not change over time (Boulinier et al. 1998; Gotelli and Colwell 2001). Therefore, the number of species may not be a reliable indicator of richness over time, because it may fluctuate due to changes in detection probability or chance encounters with rare species. The method used in this study takes into account varying detection probabilities over time. Although the method used in this study resulted in lower estimates of richness (compared to the number of species), results were a robust index of richness that could be compared against flow regime changes. As species introductions or extirpations likely did not occur in the study area during the monitoring period, this method provides a more reliable method of evaluating changes in species richness in the fish community in the study area. Similar methods of using estimates of species occupancy to calculate species richness have previously been used to model richness of plant communities (Gelfand et al. 2005) and birds (Kery and Royle 2008). The estimates of species richness in this study should not be interpreted as the total number of species present in the study area, but can be considered an indicator of changes in the number of species at typical sites in the study area over time.

2.2.5 Count Density, Species Diversity, and Evenness

Counts of each species were obtained by summing all fish captured or observed at a particular site and sampling session. Count data were analyzed using an overdispersed Poisson model (Kery and Schaub 2011, p.55-56). Unlike Kery and Schaub (2011), who used a log-normal distribution to account for the extra-Poisson variation, the current model used a gamma distribution with identical shape and scale parameters because it has a mean of 1 and therefore no overall effect on the expected count. The model did not distinguish between abundance and observer efficiency (i.e., it estimated the count, which is the product of the two). As such, it was necessary to assume that variations in observer efficiency were negligible in order to interpret estimates as relative abundance. The model estimated the number of fish expected to be captured or observed at each site per river kilometre based on the sampling data, the influence of other variables in the model, and the prior distributions of model parameters. These estimates were used as an indicator of relative density and are referred to in this report as count density, in fish counted per kilometre (count/km).

Key assumptions of the count model included:

- count density (count/km) was described by an autoregressive generalized linear mixed model with a logarithm link;
- count density varied with season;
- count density varied randomly with site, year, and the interaction between site and year;
- the effect of year on count density was autoregressive with a lag of one year (i.e., density in each year was affected by the density in the previous year), and varied with flow regime (period); and
- observed counts were described by a Poisson-gamma distribution, given the mean count.

The Shannon index of species diversity (H) was calculated using the following formula (Shannon and Weaver 1949; Krebs 1999):

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

Where S is the number of species and p_i is the proportion of the total number of individuals belonging to the i^{th} species, which is often referred to as the proportional abundance. Shannon's Index of evenness (E) was calculated using the formula (Pielou 1966):

$$E = H/\ln(S)$$

Shannon's diversity depends on the total number of species, as well as the evenness in the proportional abundances. By dividing Shannon's diversity by the natural logarithm of the number of species, evenness is a measure of how evenly fish are distributed among species. In this study, count densities from the count model for Rainbow Trout, suckers, Burbot and Northern Pikeminnow were combined with the equivalent count estimates for Bull Trout and Adult Mountain Whitefish from the abundance model to calculate the proportional abundances and Shannon's Index of evenness.

In the MCR, the total number of species present in the study area likely does not vary from year to year, although uncommon species may or may not be detected in a given site or year. For the hierarchical Bayesian model for count data, the estimated count density of uncommon species was low but was never zero, even if it was not detected in a certain year or site. This likely provides a more realistic representation of fish populations in the study area compared to an analysis that assumes densities of zero at sites or years where a species was not observed. However, this approach also means that the number of species, S, was the same for all years and sites when calculating Shannon's diversity. Therefore, the estimates of diversity among sites and years primarily reflect evenness, as the number of species is constant. Because S is constant, the denominator in the equation for evenness becomes a scaling constant that results in values between 0 and 1. Thus, for the purposes of comparing trends over time in the MCR, evenness and diversity are equivalent. For this reason, only evenness is presented in this report.

As species introductions or extirpations likely did not occur in the study area during the monitoring period, the methods used to calculate richness and evenness provide a more reliable and robust method of evaluating changes in diversity and relative abundances over time or among sites. Taken together, richness and evenness can be used to assess changes in species diversity that could be related to the effects of the flow regime change.

2.2.6 Site Fidelity

Site fidelity was the estimated probability of a recaptured fish being caught at the same site at which it was previously encountered. These estimates were used to evaluate the extent to which sites are closed within a sampling season (i.e., whether fish remained at the same site between sessions). A logistic analysis of covariance (Kery 2010) was used to estimate the probability that intra-annual recaptures were caught at the same site as previously encountered (site fidelity) for the fall and spring seasons, depending on fork length.

Key assumptions of the site fidelity model included:

- site fidelity varied with season, fork length, and the interaction between season and length; and
- observed site fidelity was described by a Bernoulli distribution.

2.2.7 Abundance

Abundance was estimated using the catch data from mark-recapture survey and the observer count data from geo-referenced visual surveys using an overdispersed Poisson model. The model used estimates of capture efficiency from the within year recaptures 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 at each site including counted observed fish, captured fish, and fish that were present but not observed or captured. The annual abundance estimates represent the total number of fish in all indexing sites combined. To maximize the number of recaptures the model grouped all the sites into a supersite for the purposes of estimating the number of marked fish but analyzed the total captures at the site level. The model was a Bayesian equivalent to an autoregressive generalized linear mixed model with a logit link for capture efficiency and a natural logarithm link for abundance.

Key assumptions of the abundance model included:

- density (fish/km) varied with season;
- density varied randomly with site and the interaction between site and year;
- density varied with river kilometre (distribution);
- the relationship between density and river kilometre (distribution) varied with flow regime and season;
- the relationship between density and river kilometre (distribution) varied randomly with year;
- the effect of year on lineal density (fish/km) was autoregressive with a lag of one year;
- the change in the annual density (rate of population growth) varied by discharge regime;
- the change in the annual density (rate of population growth) varied randomly by year;
- efficiency (the probability of capture) varied by season and method (captured or observed);
- efficiency varied randomly by session within season within year;
- marked and unmarked fish had the same probability of capture;
- observed fish were encountered at a different rate than captured fish;
- there was no tag loss, mortality, or misidentification of fish;
- there was no migration into or out of the study area (supersite) among sessions;
- the number of fish captured was described by a Poisson-gamma distribution; and
- the overdispersion varied by encounter type (captured or observed).

Adult Largescale Sucker and adult Rainbow Trout were analyzed using a reduced model because the full model did not converge, likely because of the shorter time-series (2010-2017) and/or small sample sizes for these species. The reduced model had: 1) no effect of river kilometre on density; 2) no difference in the error or efficiency between encounter types (captured or observed); and 3) no autoregressive component, i.e., with the density varying randomly by year as a random effect. The reduced model did not include an effect of the flow regime so before/after changes were assessed graphically by comparing trends in the estimates across years.

2.2.8 Geo-referenced Visual Enumeration Survey

The visual surveys provided data regarding the within-site distribution of fish in the MCR. Data from the visual surveys were used to create maps showing the observed densities of the most abundant fish species (Bull Trout, Mountain Whitefish, and sucker species). This type of map can be used to identify important fish habitats, and in future years to assess changes in fish distribution and habitat usage.

The number of fish observed during visual surveys was compared to the number captured during mark-recapture surveys at each site and is referred to as the percent relative efficiency. A relative efficiency of 0% indicates that the same numbers of fish were counted as captured. The relative error of the two methods was compared based on their overdispersion, which is the amount of variability in the counts that is greater than expected by the modeled distribution. The overdispersion in the counts from visual surveys was compared to the overdispersion in the number of fish captured during mark-recapture surveys, which is referred to as the relative error, and was used to variability in these metrics.

2.2.9 Length Bias Model

The bias (accuracy) and error (precisions) in each observer's length estimates during the geo-referenced visual surveys were quantified using a model with a categorical distribution that compared the proportions of fish in different length-classes for each observer to the equivalent proportions for the fish measured during mark-recapture surveys. The observed fish lengths were corrected for the estimated length biases.

Key assumptions of the observer length correction model include:

- the expected length bias varied by observer;
- the expected length error varied by observer; and
- the residual variation in length was independently and identically normally distributed.

2.2.10 Growth

Annual growth was estimated from inter-annual recaptured fish using the Fabens (1965) method for estimating the von Bertalanffy (1938) growth curve. There were enough inter-annual recapture data to estimate growth using this method for Bull Trout, Mountain Whitefish, and Rainbow Trout. Growth was based on the change in length between fall seasons.

Key assumptions of the growth model included:

- the asymptotic size was constant;
- the growth coefficient varied with flow regime (period);
- the growth coefficient varied randomly with year; and
- observed growth (change in length) was normally distributed.

Plots of annual growth show the mean estimate of the growth coefficient, k, which represents the rate at which fish approach the asymptotic size. When reviewing the data and model results for Mountain Whitefish, it was observed that the majority of individuals appeared to stop growing at approximately 275 mm in FL, which suggested an asymptotic size of approximately 300 mm. However, numerous larger individuals between 300 and 425 mm showed considerable growth (5-25 mm per year) between recaptures, which caused issues with model fit and biased values of the growth coefficient. The reason for the differences in body size at which growth attenuated could have been that there were two sub-populations of Mountain Whitefish in the study area, which is discussed further in Section 4.4.2. To address this problem, the growth model for Mountain Whitefish did not include fish with fork lengths >275 mm. The growth analysis of fish ≤275 mm showed the same trends as the analysis that included all Mountain Whitefish (not shown), but had more realistic values of the growth coefficient. The analysis presented is a better way to assess the inter-annual differences in growth of Mountain Whitefish in the MCR but does not reflect growth of large (>275 mm), adult fish.

2.2.11 Body Condition

Condition (weight conditional on length) was estimated via an analysis of length-weight relations (He et al. 2008). The model was based on the allometric relationship, $W=\alpha L^{\beta}$, where W is the weight (mass), α is the coefficient, β is the exponent and L is the length.

Key assumptions of the condition model included:

- the intercept of the log-transformed allometric relationship was described by a linear mixed model;
- the intercept of the log-transformed allometric relationship varied with flow regime and season;
- the intercept of the log-transformed allometric relationship varied randomly with year, site and the interaction between year and site;
- the slope of the log-transformed allometric relationship was described by a linear mixed model;
- the slope of the log-transformed allometric relationship varied with flow regime and season;
- the slope of the log-transformed allometric relationship varied randomly with year; and
- the residual variation in weight for the log-transformed allometric relationship was independently and identically normally distributed.

The effect of flow regime was not included in the body condition model for Largescale Sucker because there was only one year of data prior to the flow regime change.

3.0 RESULTS

3.1 Discharge

In 2016, mean daily discharge in the MCR was similar to the average from 2001 to 2015 for most of the year, except during mid-February to March and late October and November when discharge was lower than average (Appendix C, Figure C1). During the georeferenced visual survey conducted in the spring of 2016, discharge was near-average (Figure 2). Discharge was lower than average during the majority of the fall sampling period.

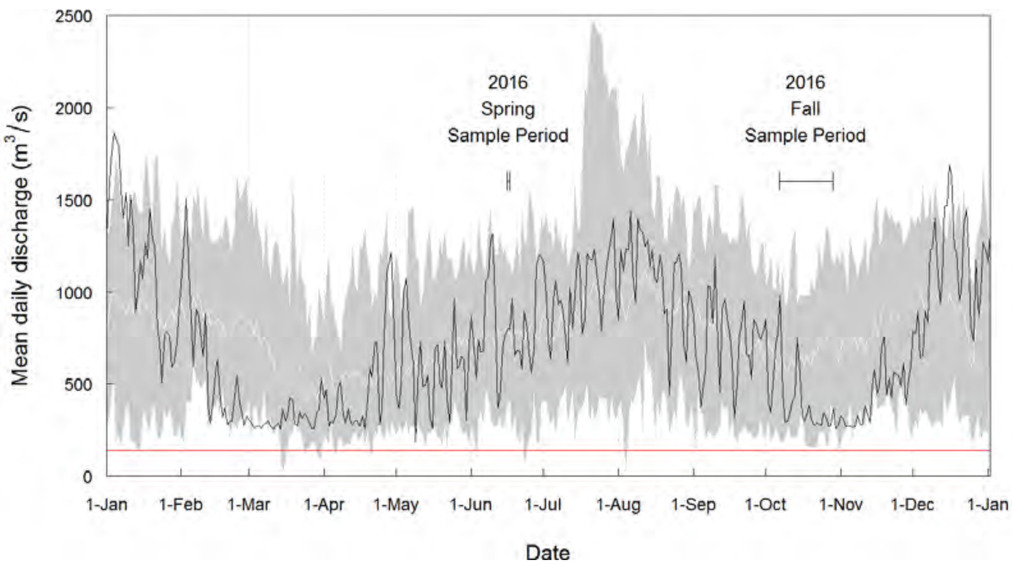

Figure 2: Mean daily discharge (m^3/s) for the Columbia River at Revelstoke Dam, 2016. The shaded area represents minimum and maximum mean daily discharge values recorded at the dam from 2001 to 2015. The white line represents average mean daily discharge values over that same time period. The red line represents the minimum flow release of 142 m^3/s.

Similar to previous study years, discharge in 2016 exhibited large hourly fluctuations, a reflection of the primary use of the facility for daily peaking operations. Daily peak discharge was greater during the first week of sampling, ranging from ~900 to 1,400 m^3/s, than during the second and third weeks, when peak daily discharges were typically 500 to 600 m^3/s (Appendix C, Figure C2). Daily minimum discharges were similar in all three weeks of sampling during the fall with typical nightly lows between 200 and 300 m^3/s. Since the implementation of the minimum flow release, discharge from REV rarely declines to 142 m^3/s due to operational considerations (BC Hydro, personal communication). In years since the flow regime change, the lowest discharges recorded during any day over the year have typically been between 140 and 160 m^3/s.

3.2 Water Elevation

In 2016, mean daily water elevation in ALR was below the long-term average for a large part of the year including January to March and July to November (Appendix C, Figure C3). ALR elevation during the visual survey in June (~437 m) was approximately 2 m greater than average for that period (~435 m). ALR elevation during the fall sampling in October 2016 (~427 m) was approximately 5 m lower than the average (~432 m) and near the long-term minimum (~426 m). Historically, water elevations in ALR were lower than average from 2001 to 2006 and 2015, greater than average from 2007 to 2012, and near the long-term average in 2013 and 2014 (Appendix C, Figure C3).

3.3 Water Temperature

Water temperature data in 2016 are only available from January to mid-May because the temperature loggers for CLBMON15A have not been downloaded since then. During that period, mean daily water temperature was 1 to 3 °C higher than average and was higher than any previous year since 2007 during February to mid-May (Figure 3; Appendix C, Figure C4). Water temperature data are not available for the MCR prior to 2007. Spot temperature readings taken at the time of sampling ranged between 5.7 and 8.2°C during the spring study period and between 8.7 and 10.6°C during the fall study period.

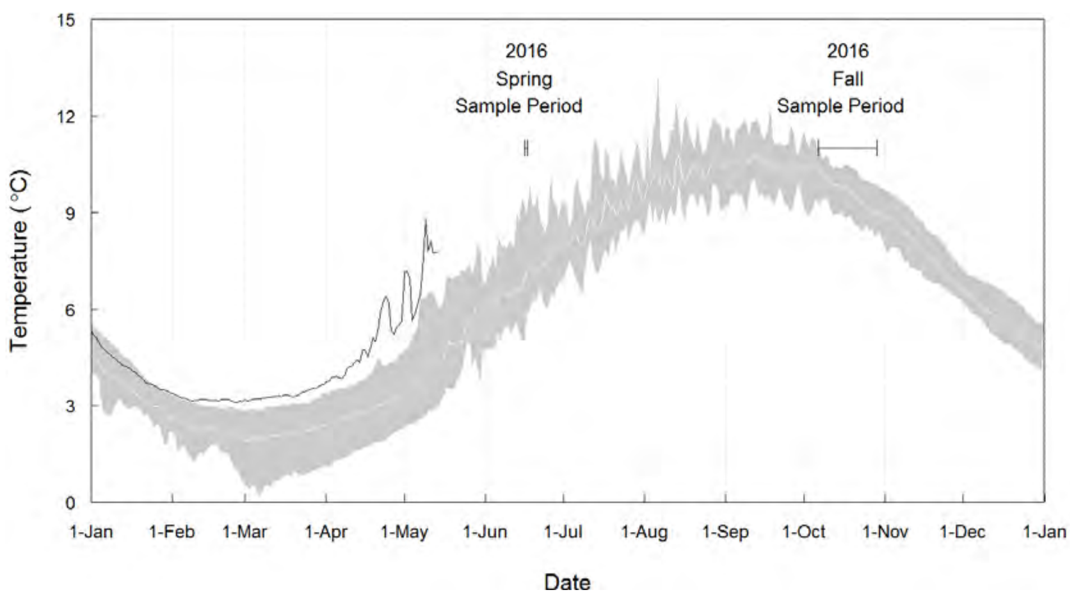

Figure 3: Mean daily water temperature in the middle Columbia River study area, 2016 (black line). The shaded area represents minimum and maximum mean daily water temperature values recorded by BC Hydro's Physical Habitat Monitoring Program (CLBMON-15a) from 2007 to 2015.

3.4 Catch

In total, 6030 fish, comprising 11 species, were captured or observed and recorded in the MCR during the fall sampling period (Appendix D, Table D1). The number of fish caught and observed by species during fall study periods from 2001 to 2016 are shown in Appendix D, Table D1. Various metrics were used to provide background information on fish populations, and to help set initial parameter value estimates. Although these general summaries are important, they are not discussed in specific detail in this report. The location in the appendices of life history and catch metrics are shown in Table 7.

Table 7: Fish life history and catch summary information presented in appendices.

Metric	Appendix Location
captured and observed species count data by site and bank habitat type in 2016	Appendix B, Table B4
catch-per-unit-effort for all sportfish and non-sportfish in 2016	Appendix D, Tables D2-D3
inter-site movement summaries for Bull Trout, Largescale Sucker, Mountain Whitefish, and Rainbow Trout, for all years combined	Appendix D, Figures D1- D4
catch and recapture summaries by species in 2016	Appendix D, Table D4
length-frequency histograms by species for all years between 2001 to 2016 when sufficient data were available	Appendix E, Figures E1- E9
length-weight relationships by species for all years between 2001 and 2016 when sufficient data were available	Appendix E, Figures E10-E19

All data collected as part of the program between 2001 and 2016 are included in the Middle Columbia River Fish Indexing Database (database provided to BC Hydro).

For all plots in this report, sites are ordered left to right by increasing distance from REV based on the upstream boundary of each site; red symbols denote sites located on the right bank (as viewed facing downstream); black symbols denote sites located on the left bank. For year-based figures, black symbols denote fall sample periods; red symbols denote spring sample periods.

3.5 Species Richness and Diversity

Annual estimates of species richness were used to detect changes in species presence at a typical site and do not indicate the total number of species present (Figure 4). Species richness increased from <0.5 species in a typical site in 2001 to ~2.5 species per site in 2008, which was attributed to increasing occupancy of several species, including Burbot, Lake Whitefish, Northern Pikeminnow, Rainbow Trout, Redside Shiner, and sculpin species (Appendix H, Figures H1-H6). Species richness peaked in 2008 to 2011 (~2.5 species per site), except with lower richness in 2009. After the flow regime change, estimates of species richness declined from 2011 to 2014, and changed little in 2015 and 2016. Species richness was lower in the spring than in the fall (2011, 2012 and 2015), which was associated with lower probability of occupancy by Burbot, Lake Whitefish, Northern Pikeminnow, and Redside Shiner.

Site estimates of species richness over river distance (right panel; Figure 4) represent changes in the number of species estimated to be present at each site in a typical year. Species richness was noticeably lower at Site 232.6-R (immediately upstream of the Jordan River confluence) when compared to nearby sites. Downstream of Big Eddy (RKm 231.2), species richness was lower along the right bank than along the left bank. Overall, species richness was greater in Reach 3 than in Reach 4.

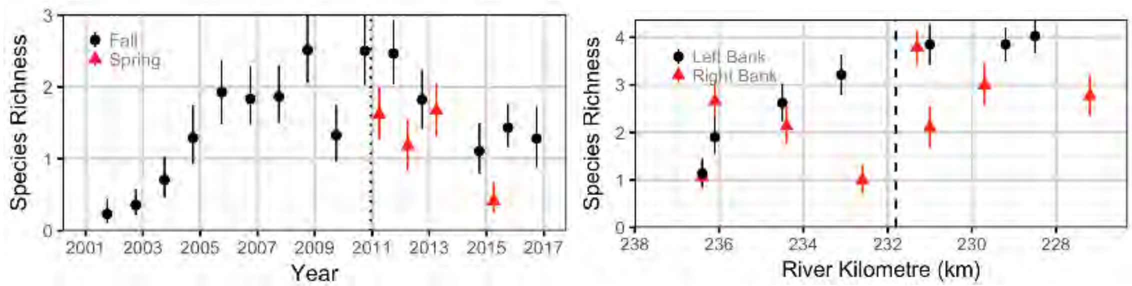

Figure 4: Species richness estimates (with 95% credible intervals) by year and season (left panel) and site (right panel) for the middle Columbia River study area, 2001 to 2016. The dotted line (left panel) represents the implementation of the minimum flow release and REV5 operations. The dashed line (right panel) represents the divide between Reaches 3 and 4 at the Jordan River confluence.

Species evenness increased from 18% in 2002 to 25% in 2004 and fluctuated between 22% and 27% between 2005 and 2010 (Figure 5). After the flow regime change, evenness increased from 22% in 2011 to 29% in 2015. Spring estimates of evenness were greater than fall estimates from 2011 to 2013 and 2015. In Reach 3, species evenness increased with proximity to Arrow Lakes Reservoir (decreasing river kilometre). Site 233.1-L (along the Revelstoke Golf Course) had particularly high evenness relative to adjacent sites (Figure 5). This pattern of greater evenness at Site 233.1-L was likely due to lower Mountain Whitefish densities in this site when compared to neighbouring sites (see Section 3.6.4).

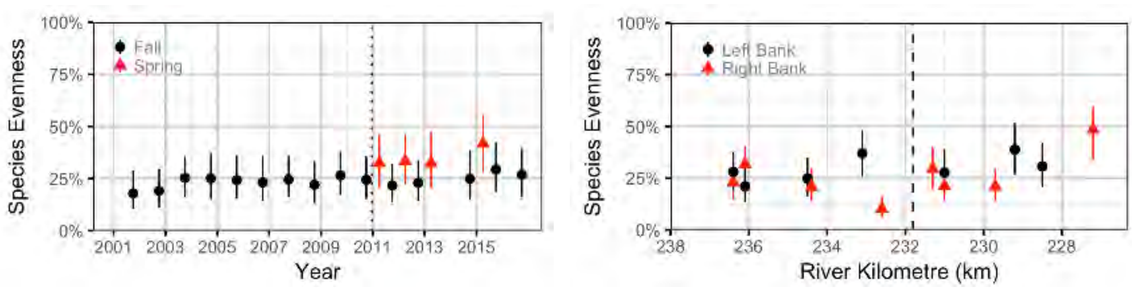

Figure 5: Species evenness estimates (with 95% credible intervals) by year and season (left panel) and site (right panel) for the middle Columbia River study area, 2001 to 2016. The dotted line (left panel) represents the implementation of the minimum flow release and REV5 operations. The dashed line (right panel) represents the divide between Reaches 3 and 4 at the Jordan River confluence.

3.6 Spatial Distribution and Abundance

Two different indicators of abundance were used for fish species in the MCR:

1) count density estimates from a HBM using count data (i.e., the number of fish caught and observed per river kilometre) as an indicator of relative lineal density; and,

2) abundance estimates from a HBM of mark-recapture data as indicator of overall abundance in the study area.

Estimates of abundance were only possible for Bull Trout, Largescale Sucker, Mountain Whitefish, and Rainbow Trout due to low recapture rates of other species. Count density was estimated for Burbot, Northern Pikeminnow, Rainbow Trout, and sucker species. Both count density and abundance were estimated for Rainbow Trout because abundance estimates were only possible for years since 2007 due to low sample sizes; therefore, count density estimates were also produced for Rainbow Trout to assess trends across the entire monitoring period (2001-2016). Extremely low and/or variable count data for Brook Trout, Cutthroat Trout, Kokanee, Lake Whitefish, Peamouth, Pygmy Whitefish (*Prosopium coulteri*), Redside Shiner, White Sturgeon, and Yellow Perch resulted in unreliable estimates of density for these species; consequently these estimates are not reported.

To assess changes in the spatial distribution of fish in the MCR, river kilometre and the interaction between river kilometre and flow regime were included as predictor variables in the mark-recapture abundance models. Plots of the effect of the river kilometre by year, referred to as 'Distribution' on the y-axis, were used to assess inter-annual differences in the distribution of fish. The effect of river kilometre represents the slope adjustor for the year-specific effect of distribution on density, where positive values indicate a positive relationship between density and river kilometre, and negative values indicate a negative relationship. Therefore, an increase in the effect of river kilometre can be interpreted as an upstream shift in distribution and a decrease in the effect indicates a more downstream distribution. The effect of the flow regime on the distribution of fish in the MCR was assessed by the interaction between river kilometre and flow regime, where statistical significance would indicate a difference in the effect of river kilometre on fish density between flow regimes.

In 2016, models of count density and abundance included an autoregressive effect of year on abundance to account for temporal autocorrelation. The estimates of the autoregressive effect of year on abundance represent the rate of population growth and are shown in Appendix H (Figures H7-H14). Positive rates of population growth indicate increasing abundance and negative rates of population growth indicate decreasing abundance.

Capture efficiencies for Bull Trout, Largescale Sucker, Mountain Whitefish and Rainbow Trout are reported together in Section 3.6.8. Site fidelity, which is the estimated probability of a recaptured fish being caught at the same site it was previously encountered in, is presented in Section 3.6.9.

3.6.1 Bull Trout

Juvenile Bull Trout abundance estimates increased from 2001 to 2006 and have remained relatively stable since 2007 (Figure 6). There were sites of relatively high and low abundance of juveniles in Reaches 3 and 4 with no obvious trend between abundance and river kilometre (right panel; Figure 6). The abundance of juvenile Bull Trout did not differ significantly by season ($P = 0.5$). The rate of population growth of juvenile Bull Trout did not differ by flow regime ($P = 0.2$; Appendix H, Figure H12).

Abundance estimates for adult Bull Trout increased from 1,100 in 2001 to 2,100 in 2009, followed by a decrease to ~1,500 in 2016 (Figure 7). Credible intervals for adult Bull Trout abundance estimates overlapped in all years of the study. Mean estimates of abundance of adult Bull Trout were greater in fall (~1,500-1,700 adults) than in spring (~1,100-1,400) in years when sampling was conducted in both seasons but the difference was not significant (*P* = 0.5). Bull Trout abundance in a typical year was greatest immediately downstream of REV (between RKm 236 and 237) and downstream of the Jordan River confluence (between RKm 231 and 232). The rate of population growth for adult Bull Trout did not differ between flow regimes (*P* = 0.3; Appendix H, Figure H11).

The distribution of juvenile Bull Trout by river kilometre was similar in all years of the study. An exception was a downstream shift in distribution in 2001 and 2006; however credible intervals overlapped in all years (left panel; Figure 8). The distribution of juvenile Bull Trout was similar in all sampling seasons (left panel; Figure 8). However, adult Bull Trout were distributed further upstream in the spring than in the fall, as indicated by larger positive values of the distribution coefficient (right panel; Figure 8), and a significant interaction between river kilometre (distribution) and season (*P* < 0.001). The interaction between river kilometre (distribution) and flow regime was not significant for juvenile (*P* = 0.7) or adult (*P* = 0.3) Bull Trout, indicating that the spatial distribution did not differ by flow regime.

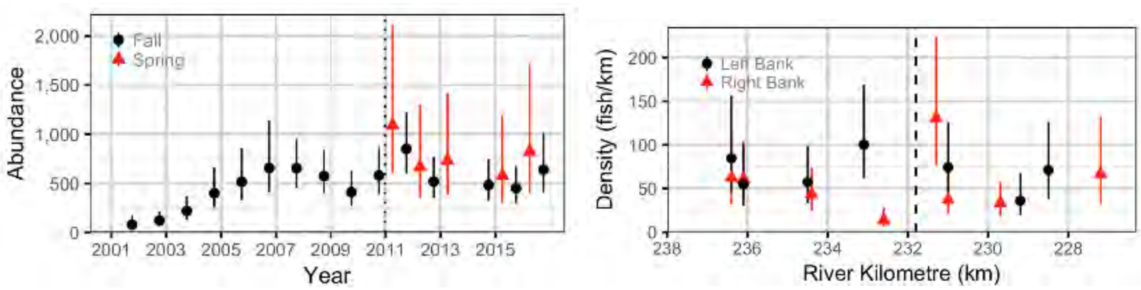

Figure 6: Abundance estimates (with 95% credible intervals) by year and season (left panel) and site (right panel) for juvenile Bull Trout in the middle Columbia River study area, 2001 to 2016. The dotted line (left panel) represents the implementation of the minimum flow release and REV5 operations. The dashed line (right panel) represents the divide between Reaches 3 and 4 at the Jordan River confluence.

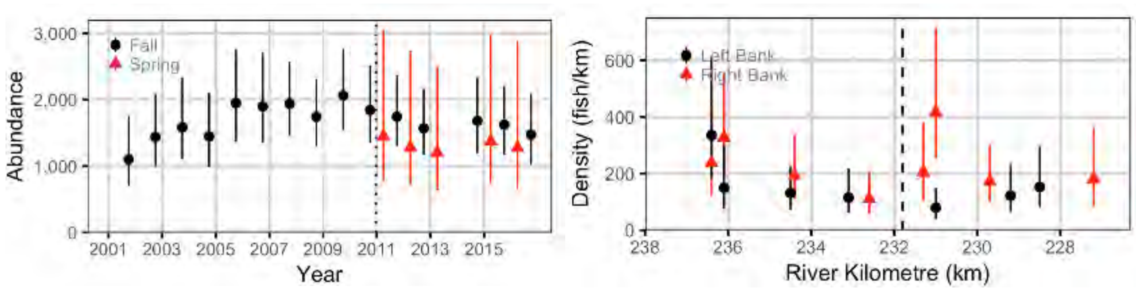

Figure 7: Abundance estimates (with 95% credible intervals) by year and season (left panel) and site (right panel) for adult Bull Trout in the middle Columbia River study area, 2001 to 2016. The dotted line (left panel) represents the implementation of the minimum flow release and REV5 operations. The dashed line (right panel) represents the divide between Reaches 3 and 4 at the Jordan River confluence.

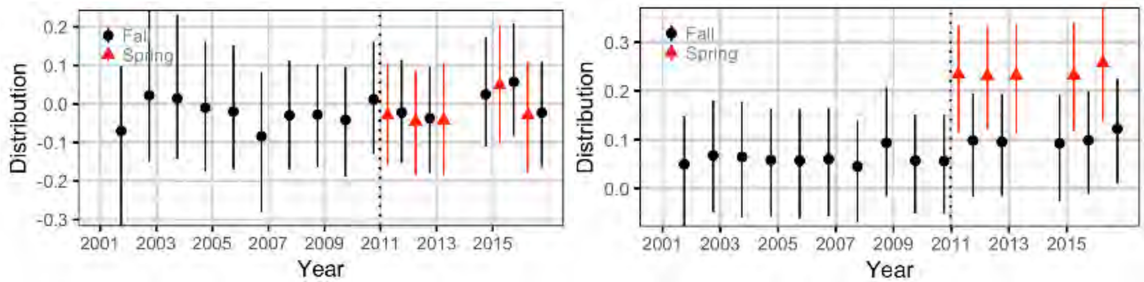

Figure 8: Effect of year on the distribution (with 95% credible intervals) of juvenile (left panel) and adult (right panel) Bull Trout densities by year in the middle Columbia River study area, 2001 to 2016. Positive values indicate an upstream shift in distribution and negative values indicate a downstream shift. The dotted line represents the implementation of the minimum flow release and REV5 operations.

3.6.2 Burbot

Overall, count densities for Burbot (<1.0 fish/km) were low compared to count densities of most other species caught during all study years. Both adult and juvenile life stages of Burbot were captured and observed during the monitoring period although the majority of individuals (95%) were adults. Count density estimates of Burbot were higher in 2008 and 2011 than in other study years and decreased in years after 2011 (Figure 9). Count density of Burbot was very low in 2014 to 2016. Count density varied significantly by season (P = 0.02) with higher densities in the fall than in the spring. Burbot density was greatest near the Revelstoke Golf Course (233.1-L), downstream of Big Eddy (231.0-L), and near the Centennial Park Boat Launch (228.5-L). The rate of population growth in Burbot density did not vary significantly with flow regime (P = 0.1; Appendix H, Figure H8).

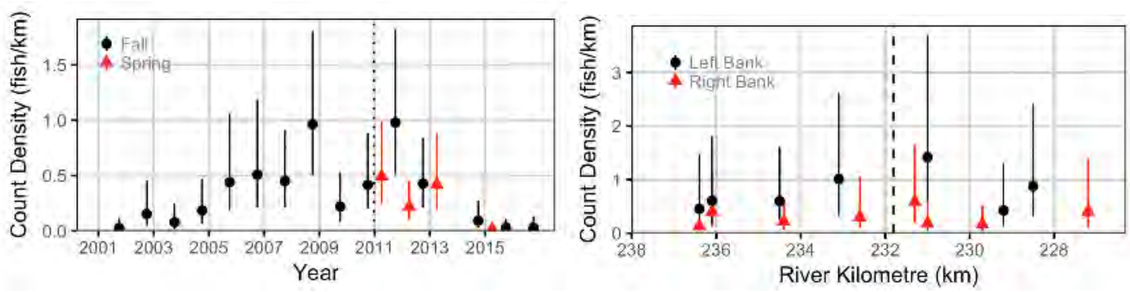

Figure 9: Count density estimates (with 95% credible intervals) by year and season (left panel) and site (right panel) for Burbot in the middle Columbia River study area, 2001 to 2016. The dotted line (left panel) represents the implementation of the minimum flow release and REV5 operations. The dashed line (right panel) represents the divide between Reaches 3 and 4 at the Jordan River confluence.

3.6.3 Kokanee

The model estimating Kokanee count density did not converge because of extremely variable counts for this species across sites, years, and seasons. Similarly, the probability of occupancy was not estimated for Kokanee because the highly variable counts did not provide reliable information about Kokanee abundance in the study area. This monitoring program is not intended and not effective for enumerating Kokanee, as discussed further in Section 4.3.3.

3.6.4 Mountain Whitefish

The estimated abundance of juvenile Mountain Whitefish was greatest in 2010 (~15,000) and 2011 (~20,000) and lower in all other years (~6,000-10,000; Figure 10). Juvenile Mountain Whitefish abundance did not differ between spring and fall seasons ($P = 0.5$). The estimated abundance of adult Mountain Whitefish in the fall fluctuated between 2001 and 2016 with no consistent long-term trend (Figure 11). Adult abundance estimates were greater in 2016 than most previous years but credible intervals overlapped for all estimates. Abundance of adults in the spring was lower than in the fall ($P < 0.001$). The rate of population growth did not differ significantly between flow regimes for juvenile ($P = 0.6$) or adult ($P = 0.7$) Mountain Whitefish (Appendix H, Figures H13-H14).

The estimated abundance of Mountain Whitefish was greatest along the right bank upstream of the Jordan River confluence (rkm 232) to the Tonkawatla Creek confluence (rkm 237) and lower along the left bank from the upstream end of the Revelstoke Golf Club to the Centennial Park Boat Launch for both juveniles and adults (right panels; Figures 10 and 11). The estimated effect of distribution (river kilometre) on density varied among years but did not indicate any sustained changes in distribution (Figure 12). The results suggested that Mountain Whitefish were distributed further downstream in spring than in fall, as indicated by lower values of the distribution effect estimate, for both juveniles and adults (Figure 12). The significant interaction between river kilometre and season also supported seasonal differences in distribution for juvenile ($P = 0.008$) and adult ($P = 0.001$) Mountain Whitefish. The interaction between river kilometre (distribution) and flow regime was not significant for juvenile ($P = 0.4$) or adult ($P = 0.3$) Mountain Whitefish, indicating that the effect of river kilometre on abundance did not differ by flow regime.

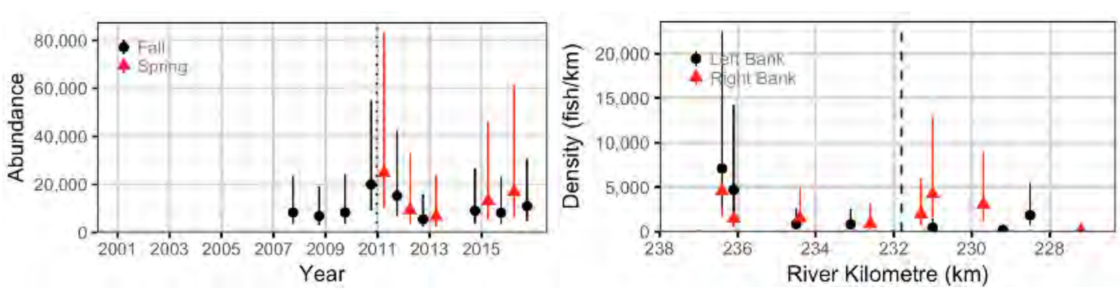

Figure 10: Abundance estimates (with 95% credible intervals) by year and season (left panel) and site (right panel) for juvenile Mountain Whitefish in the middle Columbia River study area, 2007 to 2016. The dotted line (left panel) represents the implementation of the minimum flow release and REV5 operations. The dashed line (right panel) represents the divide between Reaches 3 and 4 at the Jordan River confluence.

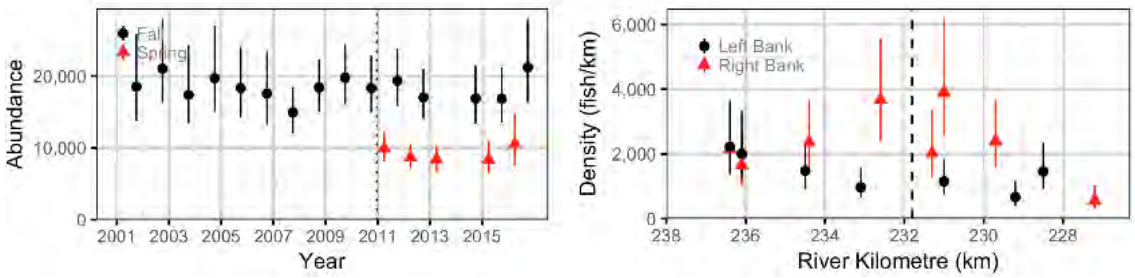

Figure 11: Abundance estimates (with 95% credible intervals) by year and season (left panel) and site (right panel) for adult Mountain Whitefish in the middle Columbia River study area, 2001 to 2016. The dotted line (left panel) represents the implementation of the minimum flow release and REV5 operations. The dashed line (right panel) represents the divide between Reaches 3 and 4 at the Jordan River confluence.

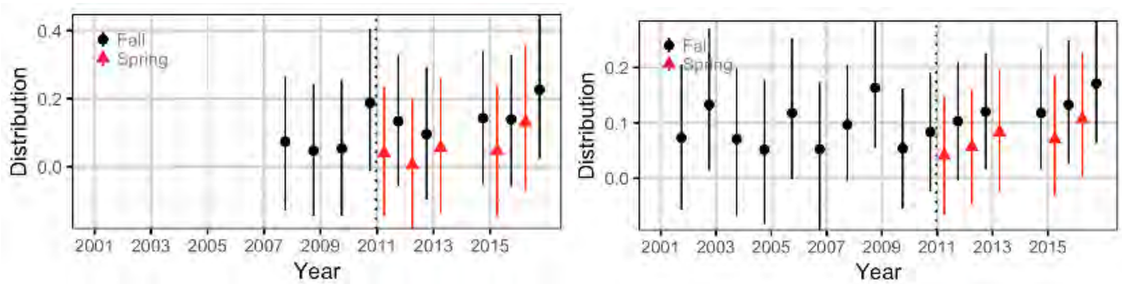

Figure 12: Effect year on the distribution (with 95% credible intervals) of juvenile (left panel) and adult (right panel) Mountain Whitefish densities by year in the middle Columbia River study area, 2001 to 2016. Positive values indicate an upstream shift in distribution and negative values indicate a downstream shift. The dotted line represents the implementation of the minimum flow release and REV5 operations.

3.6.5 Rainbow Trout

Rainbow Trout count density estimates (all life stages) increased from 0.1 fish/km in 2001 to 1.7 fish/km in 2008 (Figure 13). Count density of Rainbow Trout decreased from 1.8 fish/km in 2011 to <0.7 fish/km between 2014 and 2016. Abundance estimates for adult Rainbow Trout fluctuated between 49 and 99 fish/km with no long-term trend and overlapping credible intervals for all estimates (Figure 14). Estimates of abundance (P = 0.8) and count density (P = 0.7) did not differ among seasons. The rate of population growth based on change in count density of Rainbow Trout was not significantly different among flow regimes (P = 0.2; Appendix H, Figure H7).

Estimates of Rainbow Trout density were greater in Reach 3 than in Reach 4 and were greatest at sites on the left bank that had predominantly rip-rap substrate (Appendix A, Figure A2). River kilometre was not included as a variable in the abundance model for Rainbow Trout because of small sample sizes so the effect of the flow regime on the distribution of Rainbow Trout was not statistically tested by the model.

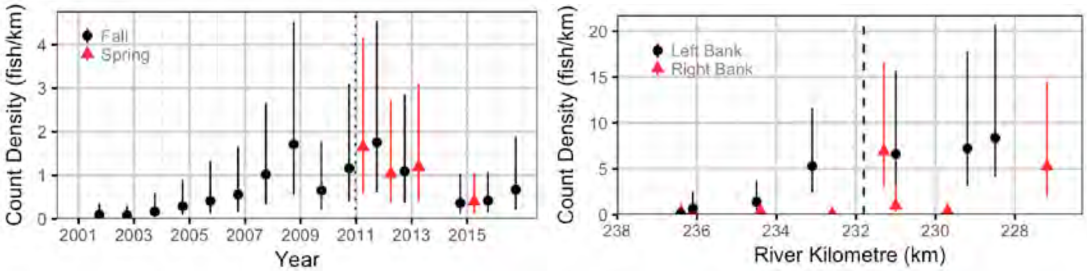

Figure 13: Count density estimates (with 95% credible intervals) by year and season (left panel) and site (right panel) for Rainbow Trout (all life stages) in the middle Columbia River study area, 2001 to 2016. The dotted line (left panel) represents the implementation of the minimum flow release and REV5 operations. The dashed line (right panel) represents the divide between Reaches 3 and 4 at the Jordan River confluence.

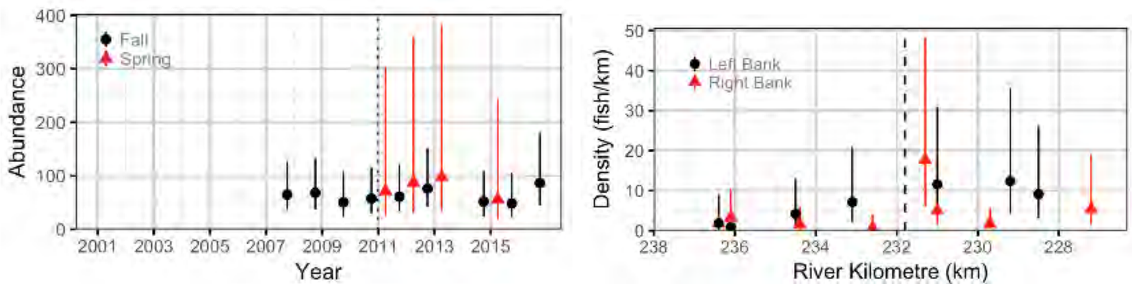

Figure 14: Abundance estimates (with 95% credible intervals) by year and season (left panel) and site (right panel) for adult Rainbow Trout in the middle Columbia River study area, 2007 to 2016. The dotted line (left panel) represents the implementation of the minimum flow release and REV5 operations. The dashed line (right panel) represents the divide between Reaches 3 and 4 at the Jordan River confluence.

3.6.6. Sucker Species

In 2001 and from 2010 to 2016, sucker species that were captured were identified to the species level; sucker species were not identified to the species level during other study years. During years when sucker species were recorded, Largescale Sucker accounted for approximately 97% of the sucker species catch and the remaining 3% were Longnose Sucker (*Catostomus catostomus*) during the fall sample periods. During the spring sample periods (2011 to 2013 and 2015), 68% of the Sucker catch was Largescale Sucker and 32% was Longnose Sucker.

Sucker species count densities increased from 2008 to 2015 and decreased in 2016. Estimated densities increased three-fold from 2008 to 2015 with most of the increase occurring between 2013 and 2015 (Figure 15). Abundance estimates of Largescale Sucker also suggested a decrease in abundance in 2016 (Figure 16). Density of sucker species and abundance of Largescale Sucker did not vary by season (P = 0.3 and P > 0.9). The rate of population growth based on count density of sucker species was not significantly different between flow regimes (P = 0.7; Appendix H, Figure H10).

Sucker species densities were generally lowest immediately downstream of REV and highest in Reach 3 (Figure 15). There was no statistical test of the effect of the flow regime on the distribution of suckers because river kilometre was not included in the count density or abundance models.

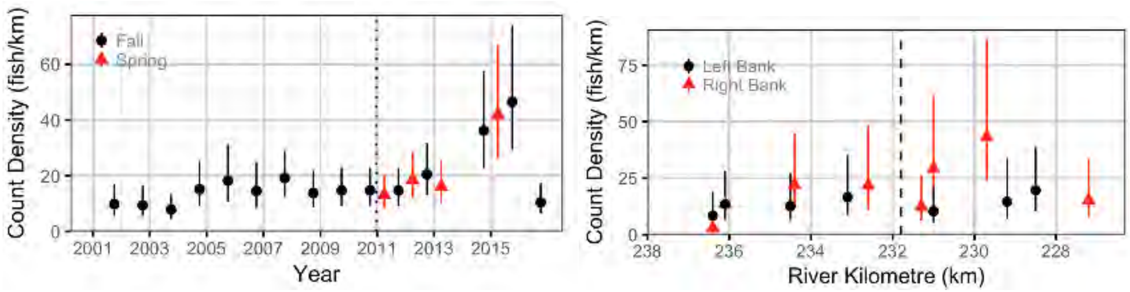

Figure 15: Count density estimates (with 95% credible intervals) by year and season (left panel) and site (right panel) for sucker species in the middle Columbia River study area, 2001 to 2016. The dotted line (left panel) represents the implementation of the minimum flow release and REV5 operations. The dashed line (right panel) represents the divide between Reaches 3 and 4 at the Jordan River confluence.

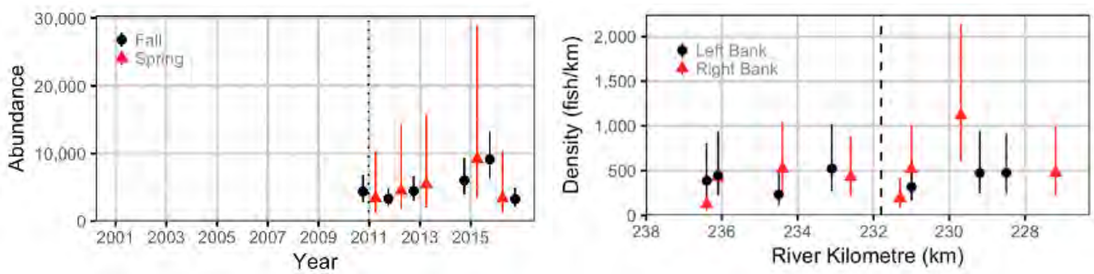

Figure 16: Abundance estimates (with 95% credible intervals) by year and season (left panel) and site (right panel) for Largescale Sucker in the middle Columbia River study area, 2010 to 2016. The dotted line (left panel) represents the implementation of the minimum flow release and REV5 operations. The dashed line (right panel) represents the divide between Reaches 3 and 4 at the Jordan River confluence.

3.6.7 Northern Pikeminnow

Density estimates for Northern Pikeminnow in the MCR increased from <0.1 fish/km in 2001 to ~1 fish/km in 2010 and ranged from 0.3 to 0.5 fish/km between 2011 and 2016 (Figure 17). Season was a significant predictor of Northern Pikeminnow density ($P < 0.001$), with fall densities approximately 7 times greater than spring densities. The annual rate of population growth for Northern Pikeminnow density did not differ significantly between flow regimes ($P = 0.2$; Appendix H, Figure H9).

Estimates of Northern Pikeminnow density were greater in Reach 3 than in Reach 4, and increased with decreasing river kilometre, which represents increasing proximity to Arrow Lakes Reservoir (Figure 17).

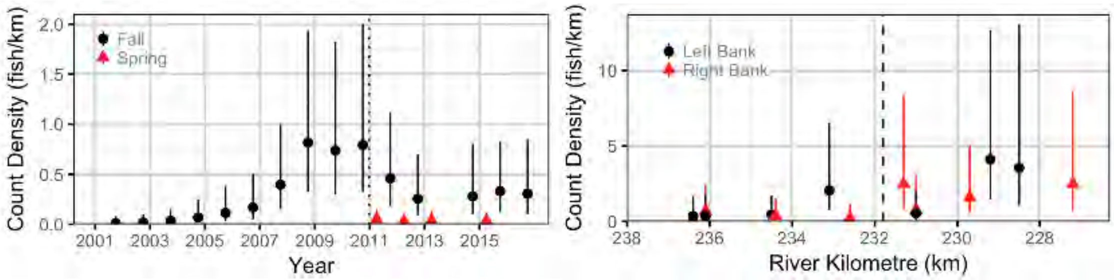

Figure 17: Count density estimates (with 95% credible intervals) by year and season (left panel) and site (right panel) for Northern Pikeminnow in the middle Columbia River study area, from 2001 to 2016. The dotted line (left panel) represents the implementation of the minimum flow release and REV5 operations. The dashed line (right panel) represents the divide between Reaches 3 and 4 at the Jordan River confluence.

3.6.8 Capture Efficiencies

Capture efficiency was calculated as part of the abundance model using mark-recapture data. Mean estimates of capture efficiency for Bull Trout were consistent over time, ranging from 2.3 to 6.0% across all sessions and years for juveniles and 1.7 to 3.5% for adults (Appendix H, Figures H15-H16).

Capture efficiency of Largescale Sucker ranged from 5 to 6% during the three mark-recapture sessions in 2016, which was greater than capture efficiency in previous years during the fall, which ranged from 1 to 5% (Appendix H, Figure H17). Capture efficiency of Largescale Sucker was lower during the spring than fall, with values typically less than 2%. Capture efficiency was low for juvenile Mountain Whitefish (<1%), but stable across sampling sessions and years (Appendix H, Figure H18). For adult Mountain Whitefish (age-2 and older), capture efficiency was similar across years and sessions but greater in the spring (~3-6%) than in the fall (~1-3%; Appendix H, Figure H19). This may indicate that adult Mountain Whitefish were more likely to leave the study area after marking during the fall than they were during the spring.

Capture efficiency of Rainbow Trout ranged from 5 to 9% in the fall and 3 to 6% in the spring (Appendix H, Figure H20). Although there were small differences in capture efficiency among species and life stages, there were no long-term trends in capture efficiency over time or sessions. Inter-session variations in capture efficiency did not appear to co-vary substantially among species. This indicates that field crews maintained similar capture efficiency within and among sample sessions.

The abundance model used data for captured fish during the mark-recapture surveys and counted fish during the geo-referenced visual surveys. Capture efficiency was calculated based on the marked and recaptured fish. The relative efficiency was calculated as the percent difference between counted and captured fish, relative to the number of captured fish. Relative efficiency of close to 100% for adult Bull Trout suggested that twice as many fish of this species were observed and counted than were captured by netters (Appendix H, Figure H21). The relative efficiency for adult Mountain Whitefish was 64%.

For juveniles, the relative efficiency of counted to captured was 44% for Mountain Whitefish and close to 0% for Bull Trout, indicating that similar numbers were counted and captured. The relative error, which is a measure of the variability (overdispersion) in the number of fish counted versus captured, was ~150% for Mountain Whitefish and ~100% for adult Bull Trout, which indicates greater variability in the georeferenced counts than in the catches during mark-recapture (Appendix H, Figure H22).

3.6.9 Site Fidelity

Site fidelity was defined as the probability that a fish recaptured within the same season in a particular year was encountered at the same site as the previous capture. Site fidelity was used to evaluate the extent to which sites are closed within a sampling season (Appendix H, Figures H23 to H26). Site fidelity of Bull Trout was greater in fall than in spring, and declined with increasing body size (fork length) from ~70% for a 200 mm fish to ~25% for a 600 mm fish during the fall season (Appendix H, Figure H23). Site fidelity of Largescale Sucker increased with increasing body size from ~25% for a 300 mm fish to ~70% for a 500 mm fish during the fall season (Appendix H, Figure H24). For Mountain Whitefish, site fidelity did not vary by body length during the fall, with site fidelity estimates of ~50% (Appendix H, Figure H25). During spring sampling, Mountain Whitefish site fidelity increased between body sizes of 150 to 350 mm and was close to 100% for fish larger than 350 mm. Site fidelity of Rainbow Trout decreased with increasing body size from ~75% for a 200 mm fish to ~50% for a 350 mm fish during the fall season (Appendix H, Figure H26). Credible intervals for site fidelity estimates were large (often >50% range), especially for spring sampling and species with fewer recaptures such as Rainbow Trout, indicating high uncertainty in the probability of being recaptured at the same site for a given season and body size.

3.6.10 Observer Length Bias

The length bias model used the length-frequency distribution of captured fish to estimate the bias in the estimated lengths of fish counted in the geo-referenced visual survey. The results suggested that most observers underestimated lengths (Figure 18). The bias depended on species with underestimates up to 24% for Mountain Whitefish, 25% for sucker species, and up to 17% for Bull Trout (Figure 19). Estimates of observer bias were used to correct estimated fork lengths of fish observed during the visual survey.

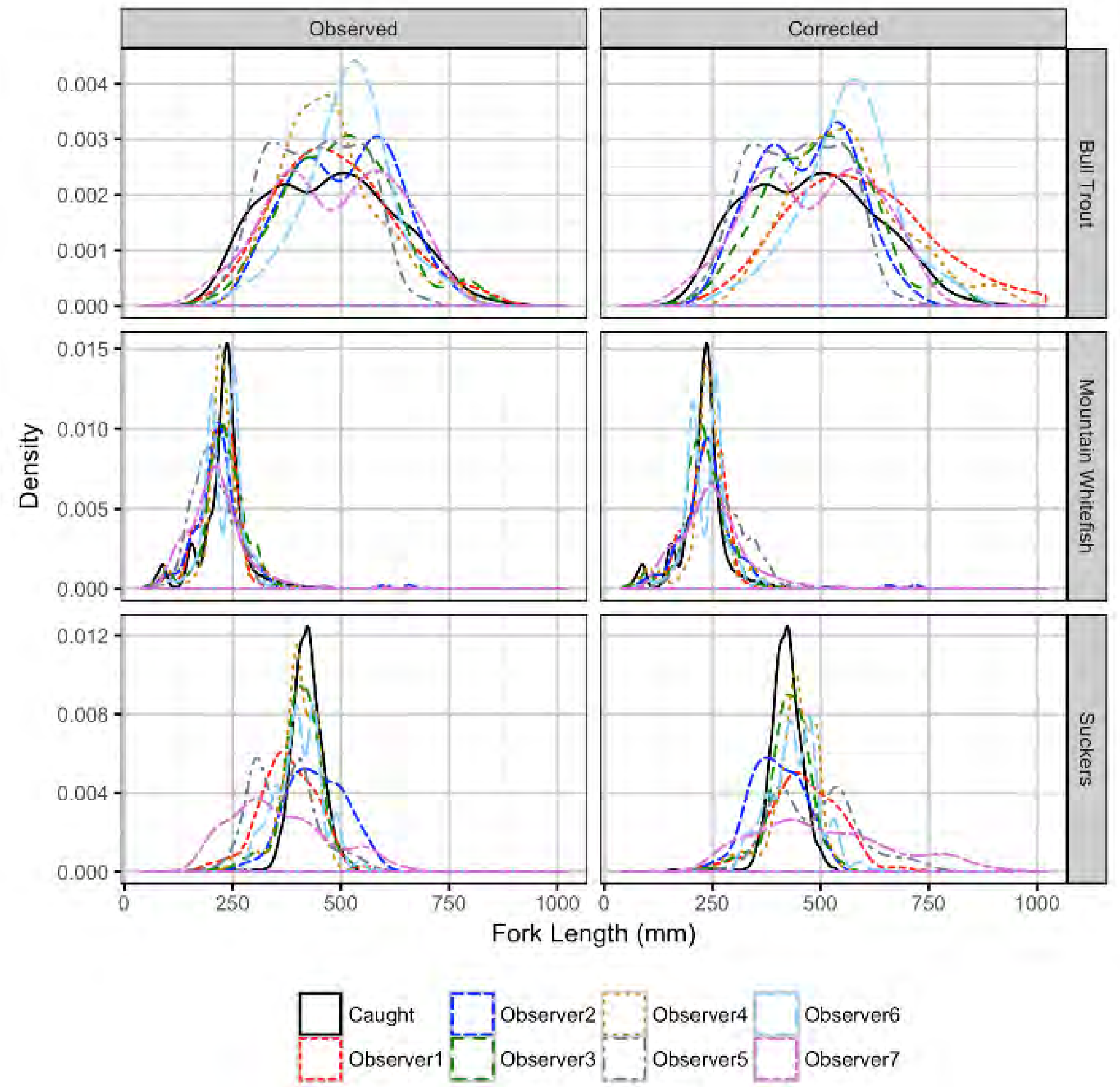

Figure 18: Fork length-density plots for measured and estimated fork lengths of fish caught or observed in the middle Columbia River study area, 2014-2016.

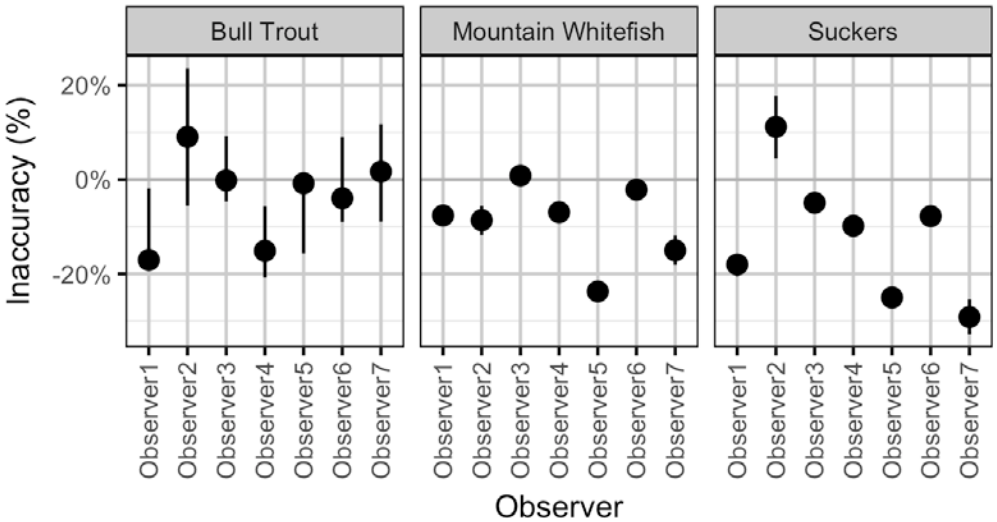

Figure 19: Inaccuracy (bias) in observer estimated fork lengths of fish based on length bias model of captured (mark-recapture surveys) and estimated (geo-referenced visual surveys) length-frequency distributions from the middle Columbia River study area, 2014-2016.

3.7 Growth Rate

Growth rate based on recaptured fish was estimated using von Bertalanffy curves for Bull Trout, Mountain Whitefish, and Rainbow Trout. Limited mark-recapture data prevented detailed growth-related analysis for all other species.

3.7.1 Bull Trout

Based on the HBM of annual growth of recaptured individuals, the estimated growth rate of Bull Trout decreased between 2010 and 2016 (Figure 20). Values of the growth coefficient (k) after the flow regime change (2011-2016) were within the range observed during the previous flow regime (2001-2010). There was no significant difference in the estimated growth coefficient before and after the flow regime change (*P* > 0.9).

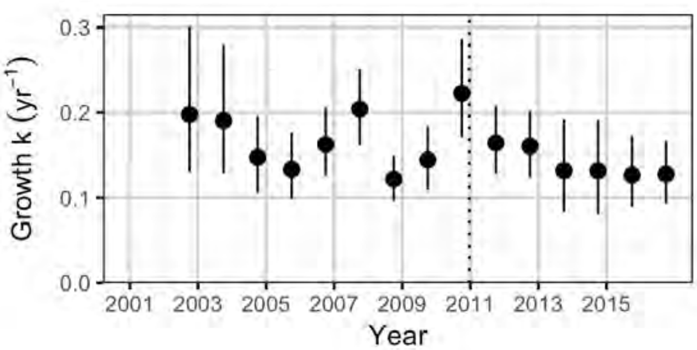

Figure 20: Annual estimates of the von Bertalanffy growth coefficient (with 95% credible intervals) by year for Bull Trout in the middle Columbia River study area, 2001 to 2016. The dotted line represents the implementation of the minimum flow release and REV5 operations.

3.7.2 Mountain Whitefish

Estimates of the annual growth coefficient of recaptured Mountain Whitefish increased from 0.21 in 2004 to 0.46 in 2010, except for the low estimate (0.21) in 2009 (Figure 21). Growth coefficient estimates fluctuated between 0.21 and 0.35 from 2011 and 2016 after the flow regime change. There was no significant difference in the estimated growth coefficient before and after the flow regime change ($P > 0.9$).

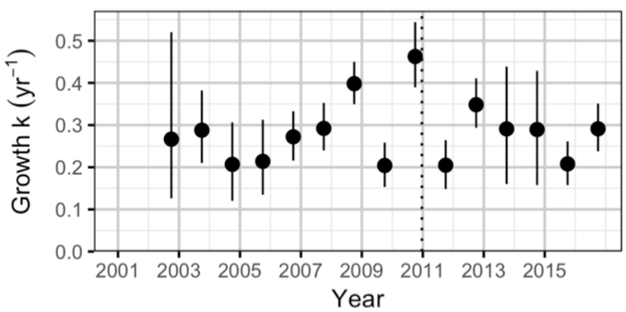

Figure 21: Annual estimates of the von Bertalanffy growth coefficient (with 95% credible intervals) by year for Mountain Whitefish ≤275 mm in fork length in the middle Columbia River study area, 2001 to 2016. The dotted line represents the implementation of the minimum flow release and REV5 operations.

3.7.3 Rainbow Trout

From 2006 to 2012 the estimated growth of recaptured Rainbow Trout was similar with mean annual growth coefficients of approximately 0.15 to 0.2. No estimate was possible between 2014 and 2016 because there were too few inter-year recaptures (zero in 2014, one in 2015, and five in 2016). There was no significant difference in the estimated growth before and after the flow regime change ($P > 0.9$).

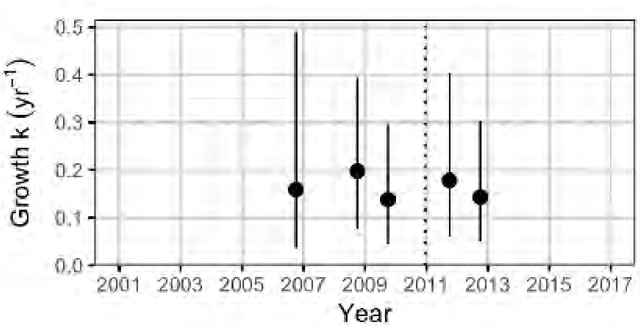

Figure 22: Annual estimates of the von Bertalanffy growth coefficient (with 95% credible intervals) by year for Rainbow Trout in the middle Columbia River study area, 2006 to 2016. The dotted line represents the implementation of the minimum flow release and REV5 operations.

3.8 Body Condition

Variation in body condition is presented in terms of the percent difference in body weight for a given length relative to the expected body weight in a typical year or at a typical site for each species. Body condition estimates were not available for 2001 because fish were not weighed during that study year.

3.8.1 Bull Trout

In previous study years, modelling results indicated that a Bull Trout marked with a T-bar anchor tag during a previous study year tended to be in significantly better condition than its unmarked equivalent, while a Bull Trout marked with a PIT tag was not (Ford and Thorley 2011a, 2012). In the analysis presented in this report, only previously untagged fish were included in models of body condition to avoid potential tagging effects.

Trends in estimates of the body condition of Bull Trout in the MCR were similar for juveniles and adults (Figures 23 and 24). Body condition estimates were greatest in 2003 and 2004 and decreased after the flow regime change, with an effect size of 15% lower than a typical year for juveniles and 11% lower for adults in 2016. The slope of the weight-length relationship did not differ by flow regime (*P* = 0.4) but the intercept did differ by flow regime (*P* < 0.001), indicating significantly lower body condition for Bull Trout after the flow regime change than before. There was no effect of season on the slope (*P* = 0.6) or intercept (*P* = 0.9) of the weight-length relationships, suggesting no significant difference in Bull Trout body condition between spring and fall.

For both juvenile and adult Bull Trout, there was little variation in condition among sample sites (Figures 23 and 24, respectively).

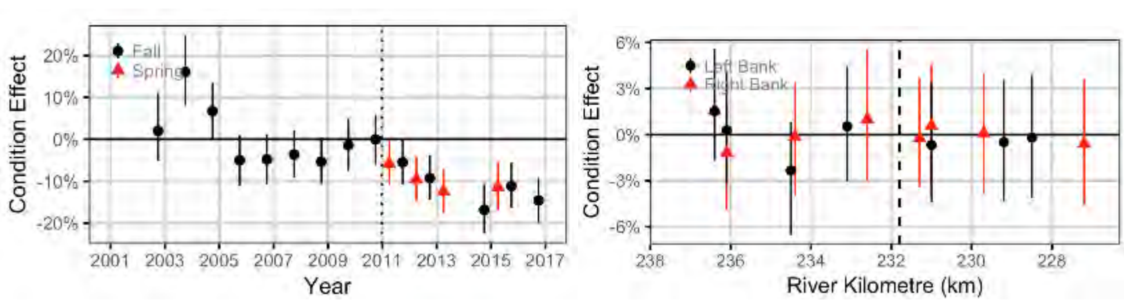

Figure 23: Body condition effect size estimates (with 95% credible intervals) by year and season (left panel) and site (right panel) for a 300 mm FL juvenile Bull Trout in the middle Columbia River study area, 2002 to 2016. The dotted line (left panel) represents the implementation of the minimum flow release and REV5 operations. The dashed line (right panel) represents the divide between Reaches 3 and 4 at the Jordan River confluence.

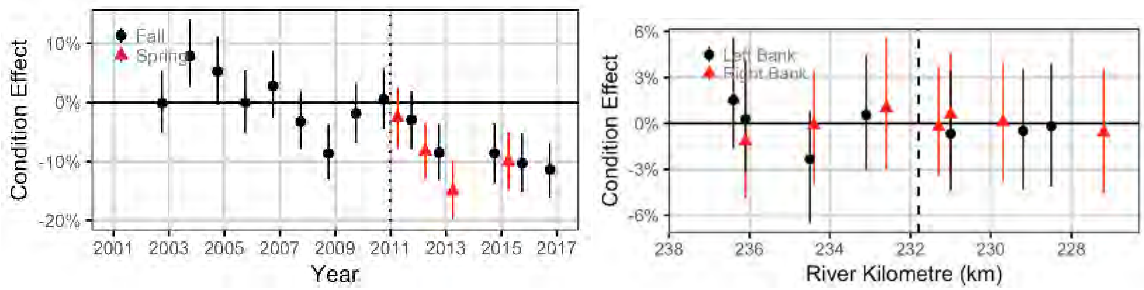

Figure 24: Body condition effect size estimates (with 95% credible intervals) by year and season (left panel) and site (right panel) for a 500 mm FL adult Bull Trout in the middle Columbia River study area, 2002 to 2016. The dotted line (left panel) represents the implementation of the minimum flow release and REV5 operations. The dashed line (right panel) represents the divide between Reaches 3 and 4 at the Jordan River confluence.

3.8.3 Largescale Sucker

Estimates of the body condition of juvenile Largescale Sucker varied little among years between 2010 and 2015 but decreased slightly in 2016 (Figure 25). Body condition of juvenile Largescale Sucker was similar among sites in the study area (Figure 25). The estimated body condition of adult Largescale Sucker declined in years following the flow regime change in 2010. In 2016, the estimate of body condition increased slightly but remained lower than average, with an effect size of -3% (Figure 26). Adult body condition was similar among sites within the study area. The effect of flow regime on the weight-length relationship of Largescale Sucker was not statistically tested because there was only one study season prior to the flow regime change. The slope and intercept of the weight-length relationship differed by season (both $P < 0.001$), with greater values in spring than fall.

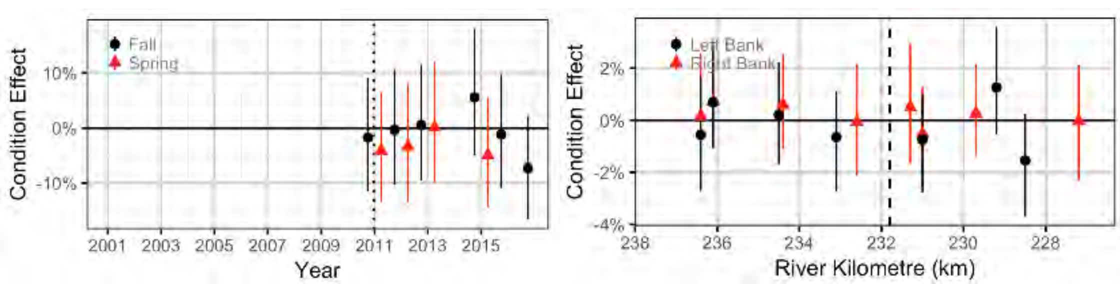

Figure 25: Body condition effect size estimates (with 95% credible intervals) by year and season (left panel) and site (right panel) for a 300 mm FL juvenile Largescale Sucker in the middle Columbia River study area, 2010 to 2016. The dotted line (left panel) represents the implementation of the minimum flow release and REV5 operations. The dashed line (right panel) represents the divide between Reaches 3 and 4 at the Jordan River confluence.

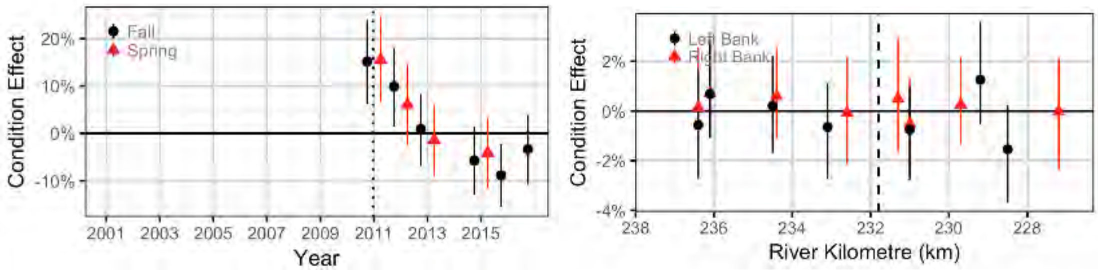

Figure 26: Body condition effect size estimates (with 95% credible intervals) by year and season (left panel) and site (right panel) for a 500 mm FL adult Largescale Sucker in the middle Columbia River study area, 2010 to 2016. The dotted line (left panel) represents the implementation of the minimum flow release and REV5 operations. The dashed line (right panel) represents the divide between Reaches 3 and 4 at the Jordan River confluence.

3.8.2 Mountain Whitefish

In previous years of the study, Mountain Whitefish marked with T-bar anchor tags had significantly lower body condition than unmarked fish, whereas there was no difference between PIT-tagged fish and unmarked fish (Ford and Thorley 2011a, 2012). Analyses in this report only included previously untagged fish to avoid potential effects of tagging on body condition.

Body condition estimates of juvenile Mountain Whitefish showed a decline from a 6% effect size in 2003 to -5% in 2011 (Figure 27). Body condition estimates of juveniles ranged from -5% to 3% between 2012 and 2016 (fall seasons). Body condition estimates of adult Mountain Whitefish declined from 2006 to 2009, and fluctuated between -3% and -5% thereafter, indicating lower than average body condition since 2009 (Figure 28).

Flow regime did not have an effect on the slope of the length-weight relationship ($P = 0.3$) but did have an effect on the intercept ($P = 0.005$). This suggests that Mountain Whitefish body condition was significantly greater before the flow regime change than after. There was a difference in the slope ($P < 0.001$) and intercept ($P < 0.001$) of the length-weight relationship by season. Adult Mountain Whitefish had significantly greater body condition in the fall than in the spring. For all study years combined, adult Mountain Whitefish body condition estimates were lower in Reach 4 and higher in Reach 3 (Figure 28).

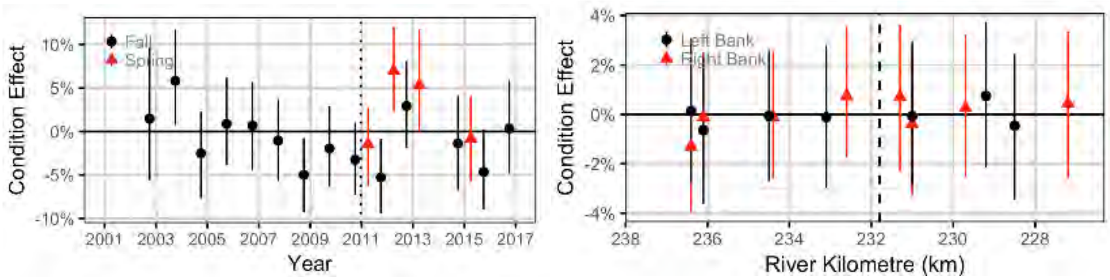

Figure 27: Body condition effect size estimates (with 95% credible intervals) by year and season (left panel) and site (right panel) for a 100 mm FL juvenile Mountain Whitefish in the middle Columbia River study area, 2002 to 2016. The dotted line (left panel) represents the implementation of the minimum flow release and REV5 operations. The dashed line (right panel) represents the divide between Reaches 3 and 4 at the Jordan River confluence.

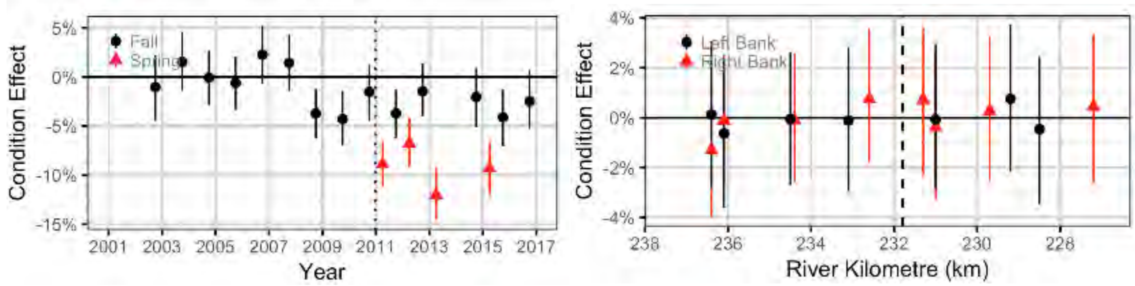

Figure 28: Body condition effect size estimates (with 95% credible intervals) by year and season (left panel) and site (right panel) for a 250 mm FL adult Mountain Whitefish in the middle Columbia River study area, 2002 to 2016. The dotted line (left panel) represents the implementation of the minimum flow release and REV5 operations. The dashed line (right panel) represents the divide between Reaches 3 and 4 at the Jordan River confluence.

3.8.3 Rainbow Trout

Body condition of juvenile Rainbow Trout varied little among study years and credible intervals overlapped for all estimates (Figures 29 and 30). For adult Rainbow Trout, estimates of body condition in the fall decreased from 2% in 2010 to -5% in 2014, followed by near average condition (0% effect size) in 2015 and lower condition (-4%) in 2016 (Figure 30). Estimates of body condition could not be calculated for Rainbow Trout prior to 2003 because weights were not recorded in 2001 and Rainbow Trout were not encountered in 2002. Body condition could not be estimated for Rainbow Trout at Site 232.6-R because this species has never been captured at that site.

There was no difference between the slope (P = 0.5) or intercept (P = 0.6) of Rainbow Trout weight-length relationships before and after the flow regime change, suggesting no effect of the flow regime on Rainbow Trout body condition. The slope of the weight-length relationship did not differ by season (P = 0.9) but the intercept did differ by season (P < 0.001), indicating a significantly lower body condition in the spring than the fall.

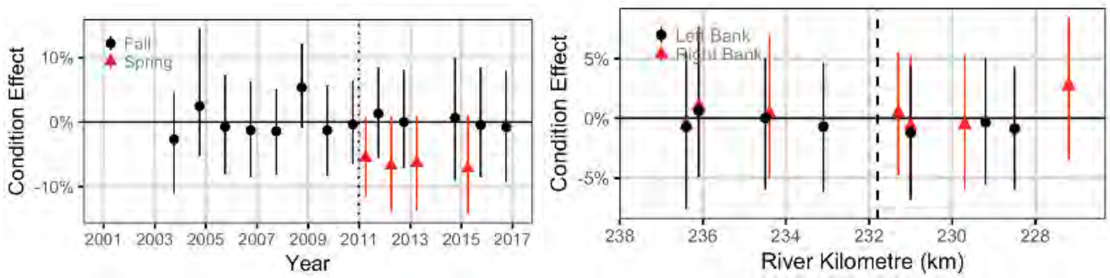

Figure 29: Body condition effect size estimates (with 95% credible intervals) by year and season (left panel) and site (right panel) for a 150 mm FL juvenile Rainbow Trout in the middle Columbia River study area, 2003 to 2016. The dotted line (left panel) represents the implementation of the minimum flow release and REV5 operations. The dashed line (right panel) represents the divide between Reaches 3 and 4 at the Jordan River confluence.

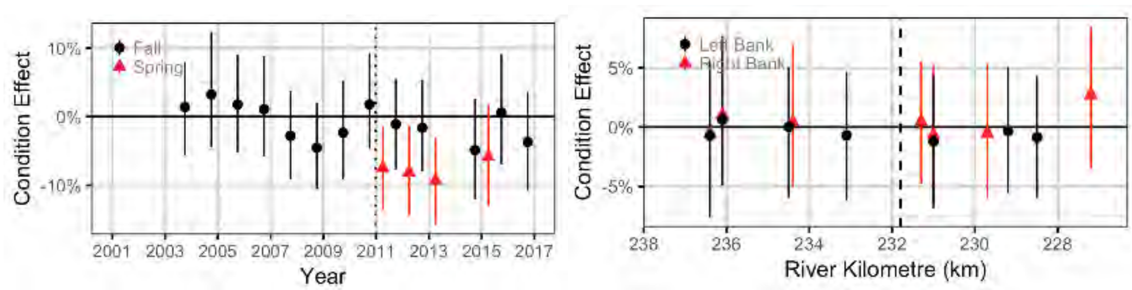

Figure 30: Body condition effect size estimates (with 95% credible intervals) by year and season (left panel) and site (right panel) for a 300 mm FL adult Rainbow Trout in the middle Columbia River study area, 2003 to 2016. The dotted line (left panel) represents the implementation of the minimum flow release and REV5 operations. The dashed line (right panel) represents the divide between Reaches 3 and 4 at the Jordan River confluence.

3.8.4 Other Species

Length and weight data were recorded for all species encountered between 2010 and 2016. In addition to Bull Trout, Largescale Sucker, Mountain Whitefish, and Rainbow Trout, body condition also was analyzed for Lake Whitefish, Northern Pikeminnow, Prickly Sculpin, and Redside Shiner. Wide credible intervals precluded any meaningful interpretation of the results for these species.

4.0 DISCUSSION

The primary objective of CLBMON-16 is to answer four key management questions:

- Is there a change in the abundance of adult life stages of fish using the MCR that corresponds with the implementation of a year-round minimum flow?
- Is there a change in growth rate of adult life stages of the most common fish species using the MCR that corresponds with the implementation of a year-round minimum flow?
- Is there a change in body condition (measured as a function of relative weight to length) of adult life stages of fish using the MCR that corresponds with the implementation of a year-round minimum flow?
- Is there a change in spatial distribution of adult life stages of fish using the MCR that corresponds with the implementation of a year-round minimum flow?

Another objective of the program, although not specifically identified as a key management question, is to investigate and document changes in species richness or species diversity in the MCR in response to the minimum flow release.

As discussed previously, the increased generation capacity of REV5 has an equal or greater potential to result in changes to fish population metrics downstream from REV as the implementation of a year-round minimum flow release. Due to the inability to separate the effects of these two flow changes, the following discussions are restricted to the effects of the overall flow regime change. The expected effects of the new flow regime on physical habitat in the MCR include increased permanently wetted area, increased frequency of high discharge, and greater river levels and velocities downstream of the dam (BC Hydro 2010b). Key environmental objectives of the minimum flow component of the new flow regime include increased benthic productivity, increased recruitment of juvenile fish, and increased abundance, condition, and growth of adult fish (BC Hydro 2010a).

4.1 Discharge, Temperature, and Revelstoke Dam Operations

In 2016, discharge in the MCR was near average (years 2001-2015) for some of the year but below average during late winter (mid-February through March) and fall (late October and November). Reservoir elevation in ALR was also lower than average during most of the year. Water temperature was only available from January to May but was much greater than normal during this period, with daily mean temperatures 1 to 3°C higher than average. The low discharge and reservoir elevation and corresponding warm water temperature were likely more related to local weather and inter-annual variation than to operations at REV, as 2016 was characterized by a lower than average snowpack and a warm spring with an earlier than normal run-off (BC MFLNRO 2016). Both natural inter-annual variability and the flow regime change have the potential to influence fish populations in the MCR.

Variation in discharge before and after the flow regime change was not analyzed in detail within this study. However, discharges were presented (Section 3.1 and Appendix C) to provide context when interpreting trends in fish populations in the MCR. The effects of the flow regime change on water levels and other habitat variables are assessed as part of BC Hydro's MCR Physical Habitat Monitoring Project (CLBMON-15a). A key finding of that study based on modelling results in years past was a predicted 32% increase in permanently wetted riverbed area during times of low reservoir elevation and no backwatering effect from ALR (Golder 2013). An increase in the permanently wetted riverbed area would be expected to increase the benthic productivity in the study area, which could result in benefits to the fish community (Perrin et al. 2004). In addition, the results suggested greater diel variation in water levels at some sites after the flow regime change (Golder 2013). Greater diel variation is plausible because the range of possible discharges at REV changed from 0-1,700 m^3/s to 142-2,124 m^3/s with the flow regime change. There also were possible differences in diel temperature variations, with greater daily temperature ranges expected before the flow regime change than after, although modelled differences were small (<1°C) and may or may not be biologically significant (Golder 2013). The changes in hydrology after the new flow regime have the potential to affect fish populations through direct effects such as habitat suitability and bioenergetics, or through "bottom-up" effects related to changes in primary production and food availability. In future years of the monitoring programs, the changes in hydrology measured by CLBMON-15Aa will be compared to time-series of primary productivity measured as part of the MCR Ecological Productivity Monitoring Project (CLBMON-15b) and fish population data collected during this program.

4.2 Species Richness and Diversity

Estimates of species richness increased from <0.5 species in a typical site in 2001 to ~2.5 species per site in 2008. The increase in richness from 2001 to 2008 was related to increases in the probability of occupancy of several species, including Burbot, Lake Whitefish, Northern Pikeminnow, Rainbow Trout, Redside Shiner, and sculpin species. During years when species richness increased, electroshocking protocols (Section 2.1.6) and capture efficiencies of tagged species (Section 3.6.8) were similar. Therefore, the observed increases in the probability of occupancy likely reflect real changes in abundance and not sampling biases, such as increased netting efficiency over time.

The increase in evenness from 2001 to 2004 (18 to 25%) resulted from the less common species becoming relatively more common during that time period. Density estimates showed increasing trends for Burbot, Northern Pikeminnow, and Rainbow Trout, whereas densities of more common species, such as Bull Trout and Mountain Whitefish remained relatively stable. Species richness was lower in the spring than in the fall, which was related to lower probability of occupancy of Burbot, Northern Pikeminnow, Lake Whitefish, and Redside Shiner. Species evenness was higher in spring than fall, likely because of lower densities of the most common species, Mountain Whitefish and Bull Trout.

After 2010, species richness decreased but species evenness increased from 22 to 29%. The decline in richness was related to decreasing probability of occupancy for most taxa, including Burbot, Northern Pikeminnow, Rainbow Trout, and sculpin species. The concurrent increase in estimates of evenness from 2011 to 2015 was related to decrease in Mountain Whitefish, which was the most abundant species, and an increase in sucker species, which were relatively less common. These changes in species richness and evenness coincided with the implementation of the new flow regime, as they began in the first year or two after the change; however, the observational design of the study does not allow assessment of whether the change in flow regime was the cause of these changes.

Overall, species richness generally increased with distance downstream from the dam. Higher species richness downstream is likely a reflection of this portion of the study area serving as a transition zone between the flowing section of the Columbia River and ALR. If this transition zone provides diverse habitat types, including more riverine and lacustrine areas, then it could explain the higher richness compared to other reaches. For most of the study area, species richness was higher on the left bank than the right bank. The left bank has more armoured substrate types (85%) than the right bank (57%; Appendix B, Table B2), which has a greater proportion of depositional substrate types.

Species evenness was significantly higher in Site 233.1-L (along the left bank in Reach 4 along the Revelstoke Golf Course) than in neighbouring sites, in part due to lower Mountain Whitefish densities in this site relative to other sites. During the fall season, Mountain Whitefish generally prefer areas with shallow water depths and cobble/boulder substrate (Golder 2012). Site 233.1-L is characterized by steep banks, deep water, and large (i.e., rip-rap) substrate.

In summary, increasing trends from 2001 to 2008 in richness, evenness, and the probability of occupancy for several less common species suggest a substantial change in the fish community during this time period. Species richness declined sharply in 2009 but increased in 2010, whereas species evenness has stayed relatively consistent between 2005 and 2010. A second major change in the fish community occurred beginning in 2012, with declining richness and occupancy of most less common species, but increasing evenness, which may have been related to increasing abundance of suckers (2011 to 2015).

4.3 Management Question #1 – Abundance

4.3.1 Bull Trout

Trends in the estimated abundance of juvenile and adult Bull Trout did not suggest any changes related to flow regime. Juvenile Bull Trout abundance declined in the first five years after the flow regime change (2011-2015), but estimates were within the range observed during the five years prior to the flow regime change. Adult Bull Trout abundance declined in the first two years after the flow regime change but the decline began two years before the change.

Adult Bull Trout abundance was greater in the fall than in the spring in the study area. Prior to the spring 2011 survey, it was assumed that Bull Trout were most abundant in the study area during the fall season due to feeding activity on spawning Kokanee. Bull Trout abundance during other portions of the year was assumed to be lower. This assumption was based on relatively low Bull Trout catch-rates during the 2001 survey (which was conducted several weeks earlier than other surveys), declining Bull Trout catch-rates over the duration of most study periods, and angler tag return data from ALR. However, large numbers of adults also were caught in the study area in the spring, and juvenile abundance was similar in spring and fall, suggesting that many juvenile and adults likely reside in the MCR study area year-round.

Site fidelity of Bull Trout was approximately 15-20% greater in the fall than in the spring, depending on body size, with larger fish more likely to be recaptured at different sites than smaller fish (Appendix H, Figure H23). The lower site fidelity of large adult Bull Trout during the fall could reflect pre-spawning movements or larger home ranges compared to smaller fish. The distribution of adult Bull Trout was further upstream in the spring than in the fall (Figure 8) but it is not clear whether this trend may be related to seasonal changes in prey distribution, pre-spawning movements, or other factors.

4.3.2 Burbot

Estimated count densities of Burbot increased from 2001 to 2008, decreased in 2009, and increased in 2010 and 2011. Densities decreased from 2012 to 2015 and remained low in 2016. There were large inter-annual fluctuations, such as low density in 2009 and 2010, that make it more difficult to interpret these time trends relative to the effect of the flow regime. Based on catch-rates recorded during BC Hydro's Arrow Reservoir Burbot Life History and Habitat Use Study (CLBMON-31; LGL 2009), Burbot are relatively common in upper Arrow Lake (i.e., Reaches 1 and 2) when compared to Reaches 3 and 4. During the 2008 and 2011 field seasons when Burbot densities were greatest, ALR levels were higher than during any other study years (Appendix C, Figure C3), with the reservoir backing up into Reach 4 for most of the field season during both years. Higher water elevation levels during the 2008 and 2011 field seasons may help explain higher Burbot count densities observed during those study years.

Densities of Burbot were very low in the last three years of sampling, with very few Burbot caught or observed in the fall of 2014 (n = 3), 2015 (n = 0), or 2016 (n = 3; Appendix D, Table D1). Burbot are uncommon in the study area and are difficult to net and observe because they typically remain on the substrate near cover after being subjected to the electric field. It is possible that these low densities were related to new and less experienced netters on the field crew in 2014 to 2016. Alternatively, estimates of Burbot densities may have been low simply because of fewer chance encounters of this uncommon species, or because of real declines of their abundance within the study area.

4.3.3. Kokanee

Density and probability of occupancy of Kokanee were not estimated because the extremely variable counts of this species resulted in modelling difficulties and unreliable estimates. Sockeye salmon, including the land-locked Kokanee form, often have large inter-annual variation and cyclical patterns of low and high abundance (Quinn 2005), which may partly explain the variability in site occupancy and density. Kokanee migrate into the MCR during the fall season to spawn in adjoining tributaries, but this species generally rears and feeds in large lakes (e.g., ALR; Scott and Crossman 1973). Because the study area is primarily used as a migratory corridor during the fall, it is unlikely that abundance of this species in the MCR will be influenced by the flow regime change. Other dam-related factors, such as entrainment rates through REV, could potentially have a larger impact on the abundance of Kokanee in the MCR. Boat electroshocking in the MCR is not intended nor is it effective for enumerating Kokanee populations in the MCR and ALR. Kokanee abundance is more effectively assessed through spawning ground enumeration and hydro-acoustic surveys in the reservoir, both of which are already being conducted. Hydro-acoustic data indicate low abundance of Kokanee in upper Arrow Lakes Reservoir in all years since 2012 (Basset et al. 2016). Low abundance of Kokanee in Upper Arrow Lakes Reservoir was attributed to poor growth and survival of juvenile Kokanee, which was related to declines in edible phytoplankton and zooplankton, and possibly a large disease-related die-off of the 2010 cohort (Bassett et al. 2016).

4.3.4 Mountain Whitefish

Abundance estimates of both juvenile and adult Mountain Whitefish did not suggest any significant change after the new flow regime. There were relatively higher densities of juvenile Mountain Whitefish in 2010 (before flow regime change) and 2011 (after flow regime change) compared to other study years, which were likely the result of large numbers of age-0 fish in 2009 and 2010 (Appendix E, Figure E2). These two cohorts represent spawning that occurred during the winters of 2008/2009 and 2009/2010, time periods that were characterized by water temperatures and river discharges comparable to other study years, but higher than average water elevation during winter in ALR, especially in 2008/2009 (Appendix C, Figure C3). Estimates of adult Mountain Whitefish abundance were greater in 2016 than most previous years but did not suggest any change related to the flow regime.

Mountain Whitefish abundance could potentially be affected by the new flow regime if food availability or habitat suitability changed in a way that affected recruitment or survival. A previous study in the MCR found that the activity of adult Mountain Whitefish, based on telemetry data, was not correlated with within-hour changes in discharge but was correlated with discharge magnitude (Taylor and Lewis 2011). This suggests that the greater possible discharge magnitude of the new flow regime may affect swimming activity of Mountain Whitefish but it is unknown if this has implications for their survival or abundance. The flow regime change could also potentially affect Mountain Whitefish populations through effects on spawning in the mainstem. Evidence of Mountain Whitefish spawning in the MCR is limited to reports by field crews of adult Mountain Whitefish in spawning condition (i.e., gravid or ripe individuals) during most study years, although spawning locations are unknown.

Adult Mountain Whitefish abundance was greater in the fall than in the spring. As Mountain Whitefish spawn in the late fall and winter (McPhail 2007), the greater abundance in the fall could indicate adults moving upstream from ALR to potential spawning areas either in the MCR or its tributaries. The abundance of juveniles was slightly greater in spring than in fall but the difference was not statistically significant.

Recapture rates of adult Mountain Whitefish were higher in the spring (~3-6%) than in the fall (~1-3%; Appendix H, Figure H19). Reasons for the large increase in capture efficiency in the spring are unknown but could be related to greater likelihood of adult Mountain Whitefish leaving the study area in the fall, as estimates of site fidelity indicated greater movement among sites in the fall than in the spring (Appendix H, Figure H25). This degree of seasonal difference in capture efficiency was not noted for any other species or life stages, which indicates that the increase was not due to a sampling bias (e.g., equipment error, selective netting by the field crew, differences in water conductivity, etc.) but more likely related to seasonal changes in behaviour of adult Mountain Whitefish. Mountain Whitefish spawn between November and February in the lower Columbia River (LCR) downstream of HLK (Golder 2012), so some adult fish may migrate out of the MCR during the fall and into tributaries for spawning. However, capture efficiency did not decline in subsequent sessions of the fall season in most years, which would be expected if the number of Mountain Whitefish leaving the study area increased during the fall sampling season. Without mark-recapture data, seasonal differences in sampling efficiency would not have been detected and abundance would have been overestimated.

4.3.5 Rainbow Trout

Count density estimates for Rainbow Trout gradually increased from 2001 to 2008 and decreased in 2012 to 2015. On the other hand, abundance estimates were relatively consistently for all years when mark-recapture data were available (2007-2016). Low catches of this species resulted in high uncertainty in density and abundance estimates. Although there was a decrease in count density during fall following the flow regime change, the abundance estimates do not support an effect of the flow regime on the Rainbow Trout abundance in the MCR.

The abundance of Rainbow Trout by site increased with proximity to ALR, with the greatest abundance in sites in the transition zone between ALR and the MCR. The upstream extent of the transition zone, which depends on the ALR elevation, may therefore influence the distribution of Rainbow Trout in the study area. River kilometre was not included in the count density or abundance models for Rainbow Trout in 2016 because small sample sizes did not allow estimating the full models that included the effects of varying distribution. However, previous years of the study reported an upstream shift in the distribution of Rainbow Trout starting in 2008 and continuing after the flow regime change, which may have been related to changes in reservoir elevations (Golder, Poisson, and ONA 2016a).

Rainbow Trout in the LCR typically spawn between early March and late June when water temperatures are between 4 and 14°C (Thorley and Baxter 2012). In the MCR, spring surveys in 2011-2015 were conducted in June when water temperatures were between 5 and 9°C. If Rainbow Trout in the MCR spawn under conditions similar to those in the LCR, the spring surveys would have occurred during their expected spawning season. Water temperatures in the MCR are rarely higher than approximately 11°C (Appendix C, Figure C4). During the spring 2011 survey, three Rainbow Trout (4% of the total Rainbow Trout catch) were in spawning condition (all three were males). None of the Rainbow Trout caught during the spring surveys in 2012, 2013, or 2015 were releasing gametes or in obvious spawning condition. Spawning redds were not observed by the field crew during any of the spring surveys. This suggests that the MCR is not a major spawning area for this species; therefore, annual variations in Rainbow Trout densities are not likely related to the spawning success of this species in the MCR. The bulk of Rainbow Trout spawning probably occurs in tributaries because high ALR water elevations during the late spring and early summer would flood most potential spawning habitat downstream of the Illecillewaet River confluence. A Rainbow Trout spawning assessment would be required to determine the extent of mainstem spawning for this species.

4.3.6 Sucker Species

Count density of sucker species increased nearly three-fold from 2008 to 2015, from 14 to 45 fish per kilometre during this period, but decreased to 10 fish per kilometre in 2016 (Figure 15). Although the increase in sucker species density started in 2009 before the flow regime change, the most dramatic increase occurred following the flow regime change. Abundance estimates of Largescale Sucker also increased from 2010 to 2015 and decreased sharply in 2016. One of the predicted and desired effects of the minimum flow was to increase permanently wetted area and primary productivity, including algae (Perrin et al. 2004). As sucker species feed primarily on periphyton and aquatic invertebrates (Dauble 1986), sucker species are expected to respond to changes in productivity caused by flow regime sooner than fishes at higher trophic levels.

Conversely, the long-lived nature of these species (at least age-15; Scott and Crossman 1973) and the number of years it takes for these fish to reach sexual maturity (age-5; Nelson and Paetz 1992) could result in a time-lag before changes in habitat conditions affect abundance of mature adult suckers originating from the MCR. Therefore, the observed increases in Sucker species density may be explained by increased usage of the MCR by fish originating from ALR, increased production of Sucker species within the MCR, or both.

Of the sucker species captured in the spring sessions, a large percentage (26 to 42% in 2011 to 2013) were identified as spawners, through the release of eggs or milt or the presence of tubercles (both species combined). These observations suggest that the MCR could be a major spawning area for these species. During surveys, sucker species were routinely observed in suitable spawning habitats (shallow riffles over small gravel substrate) at Sites 232.6-R, 231.0-R, and 229.7-L. If suckers spawn in these areas, there is the potential for eggs to become stranded during nightly flow reductions or for fry to become stranded prior to emergence (approximately four weeks after spawning; Scott and Crossman 1973) when BC Hydro drafts ALR (which can occur at any time after early July).

4.3.7 Northern Pikeminnow

The estimated density of Northern Pikeminnow in the MCR increased from 2007 to 2010 but drastically decreased from 2011 to 2013 and remained low in 2014 to 2016. The decrease in the density of Northern Pikeminnow in 2011 coincided with the implementation of the flow regime change. However, reasons for the decrease in estimated density of Northern Pikeminnow are unknown.

Northern Pikeminnow density was approximately 7 times greater in the fall than in spring of 2011 to 2016, which suggests that this species uses habitat in the MCR in the fall but may migrate out of the study area sometime before the spring. Northern Pikeminnow spawn in the spring, typically at locations in streams with water velocity less than 0.4 m/s but occasionally in lakes (McPhail 2007). Little is known about spawning behaviour of Northern Pikeminnow in the MCR, so it is unclear if the very low densities observed in the spring are due to spawning migration out of the area or other factors.

4.3.8 Sculpin Species

The probability of occupancy of sculpin species at a typical site increased from 3% in 2001 to >80% in 2006 to 2008, decreased to 55% in 2009 and increased in 2010 and 2011. Occupancy in the fall declined following the flow regime change from 83% in 2011 to 21-39% in 2014 to 2016. As sampling protocols were relatively consistent from 2001 to 2008, these results suggest a substantial change in sculpin species abundance during this period. Reasons for the increase in sculpin abundance (2001-2008) are unknown. Typically during boat electroshocking surveys, the electrical field is not strong enough to attract sculpin species to the water surface. This means that most sculpin species observed in the MCR are usually at depths greater than 1.0 m. Observations or captures made at these depths are influenced by water surface visibility, water clarity, netter efficiency, and water velocity. A preliminary review of habitat data recorded at the time of sampling (Appendix B, Table B3) did not indicate poorer observational conditions during any particular study year.

Occupancy estimates for sculpin species declined starting after 2011 but it is not known if this was caused by the flow regime change. The large increase in occupancy between 2001 and 2008 occurred during the same general flow regime at Revelstoke Dam. As most of the decrease in occupancy occurred in 2014 and 2015, which were years with new and less experienced netters on the field crew, and sculpin are difficult to observe and capture because of their small size and behaviour, it is possible that the decrease could be in part related to the changes in field crew. Given their small body size and the associated inefficiency of the selected sampling method at capturing sculpin species, it is unlikely that the program, in its current form, will generate reliable estimates to answer the management questions for these species. Sculpin species were routinely captured as part of BC Hydro's MCR Juvenile Fish Habitat Use Program (CLBMON-17; Triton 2014). If necessary, it may be more practical to answer specific management questions regarding these species using data collected under that program.

4.4 Management Question #2 – Growth Rate

Growth rate was examined using a HBM based on individual growth rates of inter-year recaptured fish. Limited mark-recapture data excluded this analysis for all species except Bull Trout, Mountain Whitefish and Rainbow Trout.

Information on annual growth rates for species other than Bull Trout, Mountain Whitefish and Rainbow Trout may become available in future study years as more life history and mark-recapture data are collected. However, given the limited dataset that exists for species other than Bull Trout, Mountain Whitefish and Rainbow Trout prior to the implementation of the flow regime change (i.e., prior to 2010), it is unlikely that the HBMs will be able to link any changes in annual growth of these species to changes in the flow regime.

4.4.1 Bull Trout

The estimated growth rate coefficient of Bull Trout declined in years following the flow regime change, although growth rates following the change were within the range previously observed. The difference in growth rate before and after the flow regime change was not statistically significant. The decreasing trend in the growth coefficient of Bull Trout following the flow regime change was associated with a similar trend in their body condition, and declines in condition of other fish species including Mountain Whitefish and Largescale Sucker. Kokanee in upper Arrow Lakes Reservoir, which are an important prey for Bull Trout in the study area, declined in abundance during most of the years (2012-2016) when Bull Trout growth and condition were decreasing, and this change in prey availability could have been related to the decline in Bull Trout growth rates. The similar declines in several species suggest a possible broad-scale change in growing conditions in the study area.

4.4.2 Mountain Whitefish

Estimates of the von Bertalanffy growth coefficient suggest increasing growth from 2004 to 2008 and inter-annual fluctuations evident thereafter, including lower growth rates in 2009, 2011 and 2015. Length-at-age analyses in previous years of this study reported a substantial decline in the length-at-age of age-1 Mountain Whitefish in 2011 and 2012 (Golder and Poisson 2013), which supports the low growth estimates observed in 2011.

Length-at-age was not modelled in this report because of ageing error and/or insufficient sample sizes for most species and life stages (other than age-0 and age-1 Mountain Whitefish).

The von Bertalanffy model for Mountain Whitefish only used fish ≤275 mm in fork length because the data suggested there were two groups of fish that stop growing at different sizes. The majority of recaptured fish had slow or no growth beginning at approximately 275 mm in size but a smaller number of fish had considerable growth (5-25 mm per year) when recaptured at sizes between 300 and 400 mm in fork length. There are many possible reasons for the two groups of Mountain Whitefish with different growth trajectories including: 1) populations from different habitats, such as river residents versus adfluvial fish from ALR; 2) sex differences in the asymptotic size; and 3) a dietary shift that allows larger fish to continue growing. Omitting fish >275 mm provided better estimates of the growth coefficient to assess changes over time but does not reflect continued growth of large fish (>275 mm) in the study area.

Changes in river discharge related to the new flow regime could affect the growth of Mountain Whitefish in several ways. The increased permanently wetted area is expected to result in greater primary productivity, which could result in increases in secondary productivity including invertebrates that would increase food availability for Mountain Whitefish. In the Skeena River, another large 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). The flow regime could also affect the growth of Mountain Whitefish if changes in the magnitude or variability in discharge affect foraging efficiency, energetic costs of swimming, or habitat suitability. A telemetry study in the MCR found that swimming activity of Mountain Whitefish was positively correlated with discharge magnitude (Taylor et al. 2012), which could mean greater energetic costs of swimming for Mountain Whitefish if discharges are higher under the new flow regime.

4.4.3 Rainbow Trout

Rainbow Trout growth rate coefficients had wide credibility intervals but the mean values varied little before and after the change in flow regime. Growth was only estimated for 2007 to 2012 because sample sizes of inter-year recapture Rainbow Trout were too low in other years. The results do not suggest any change in the growth of Rainbow Trout associated with the flow regime change but there is relatively large uncertainty with this conclusion because of few years of data before and after the flow regime change and small sample sizes each year.

4.5 Management Question #3 – Body Condition

Body condition was analyzed using a HBM for Lake Whitefish, Largescale Sucker, Northern Pikeminnow, Prickly Sculpin, and Redside Shiner (in addition to Bull Trout, Mountain Whitefish, and Rainbow Trout; see below); however, limited data for these species resulted in wide credible intervals surrounding all estimates. Temporal or spatial trends in body condition were not observed for any of the above species. Length and weight data were only collected for these species from 2010 to 2016, and due to the small sample sizes, credible intervals surrounding body condition estimates were wide. Given the limited dataset that exists for most species prior to the flow regime change (i.e., 1 year of data), it is unlikely that the HBM will be able to link any observed changes in body condition for these species to flow regime changes.

4.5.1 Bull Trout

Estimates of adult Bull Trout body condition decreased in the mid-2000s, increased slightly in 2009 and 2010, and decreased again from 2011 to 2016. The recent decline in Bull Trout body condition estimates (2011-2016) was observed for both juvenile (-15%) and adult (-11%) life stages. Previous analysis for this study suggested a correlation between the trends in Bull Trout body condition and the abundance of Kokanee in Arrow Lakes Reservoir, both of which declined to very low levels in 2012 to 2016 (Golder, Poisson, and ONA 2016a). Kokanee are known to be one of the primary prey items of Bull Trout in the fall in the MCR and elsewhere (McPhail and Baxter 1996). Other investigators have suggested that region-wide climatic variability could be influencing Kokanee abundance (Bassett et al. 2016) because Kokanee stocks have also declined since 2010 in Kinbasket Reservoir (Sebastian and Weir 2013) and Kootenay Lake (Andrusak and Andrusak 2015). In the MCR, the similar trends among species in body condition (Bull Trout and Largescale Sucker) and growth (Bull Trout and Mountain Whitefish), all of which declined at some point since 2011, also support the idea of a broad-scale change in growing conditions in the study area.

Bull Trout body condition decreased to the lowest levels observed in the study following the flow regime change and the flow regime change had a statistically significant effect on Bull Trout body condition in the HBM. However, because of the observational study design it is not possible to determine whether the low body condition was caused by the flow regime, or simply coincided with the change but was caused by other environmental changes and large-scale climatic variability.

There was very little variation in Bull Trout body condition between sample sites. This suggests that: 1) all sample sites were homogenous in terms of habitat quality; or 2) individual fish did not remain associated with any particular site for a long enough time prior to capture for the habitat quality of that site to affect their body condition. Based on variability of habitat measurements taken during the field season (e.g., available cover, water velocities, water depths, etc.) the former scenario is unlikely to be true. The latter scenario is more likely to influence body condition since REV operations dewater large portions of the channel margin on a nightly basis, which forces fish to seek refuge in different areas. This diurnal movement, coupled with annual migratory patterns for this species, support a hypothesis that some fish do not remain in a particular site long enough for that association to have a measurable impact on body condition.

4.5.2 Largescale Sucker

Estimates of the body condition of adult Largescale Sucker decreased 20% from 2010 to 2015. This coincided with a large increase in the estimated density of sucker species (Largescale and Longnose Sucker) from 2010 to 2015, which suggests competition for resources and density-dependent growth. In 2016, the estimated abundance and density of suckers decreased sharply, and body condition increased, possibly due to reduced intra-species competition. It is unknown whether the sharp decline in 2016 following the period of rapid population growth (2011-2015) was related to the change in flow regime, natural demographic processes, or other factors. The observed decrease in body condition was the opposite of predicted effects of the new flow regime, which was expected to result in a greater area of permanently wetted substrate that would translate in greater algal productivity, and increases in the body condition of organisms like Sucker that consume algae.

It may be that declining adult Sucker condition from 2011 to 2015 is partly explained by changing age structure of the population, rather than a decline in weight-at-length for a given age group. The von Bertalanffy growth curve could not be calculated for Largescale Sucker but in general this species is known to mature at ~400 mm in body length and 5-9 years of age, after which there is very little annual growth in body length (Dauble 1986). Therefore, mature fish might continue to increase in weight but not increase substantially in length after a certain age. If so, then the increase in Sucker density and concomitant decrease in body condition could be explained by an increase in abundance of newly recruited adult Sucker and decrease in the proportion of older Sucker. The body condition model predicts condition for a specific length (500 mm for Largescale Sucker) and therefore inter-year comparisons are not affected by differences in length distribution among years. However, if older fish are heavier at a particular length compared to younger fish, then a change in age structure (younger distribution) could have contributed to the observed decline in body condition.

4.5.3 Mountain Whitefish

The body condition of adult Mountain Whitefish was significantly lower after the flow regime change than before. However, the period of low body condition of adult Mountain Whitefish started in 2008, a few years before the flow regime change. The fact that body condition decreased before 2010 means that the new flow regime was not the cause of initial decrease in body condition in 2008, although we cannot rule out the possibility that the new flow regime had some effect, either positive or negative, on body condition after 2010. For instance, if the flow regime change had a positive effect on body condition, it could have prevented body condition from decreasing further. Or if the flow change had a negative effect on body condition, it may have prevented body condition from recovering after the initial decrease in 2008. We cannot rule out these possibilities but the most parsimonious interpretation is that the flow change did not have any significant effect on Mountain Whitefish body condition because estimates were relatively stable between 2008 and 2016. Although the cause of low body condition of Mountain Whitefish in years after the flow regime change is unknown, it coincided with lower than average condition of other species including Bull Trout and Largescale Sucker.

The flow regime change, which included an increase in the minimum and maximum flows, could potentially result in increases in both mean and the variation in discharge, depending on natural environmental variability (e.g., snowpack) in a particular year. A previous study in the MCR found that the activity of adult Mountain Whitefish, based on telemetry data, was not correlated with within-hour changes in discharge but was correlated with discharge magnitude (Taylor and Lewis 2011). Therefore, increased discharge in the MCR could result in greater energetic costs for Mountain Whitefish, which could lead to lower body condition.

The body condition of Mountain Whitefish was higher in Reach 3 than in Reach 4. This result may be due to additional nutrients flowing into the MCR from the Jordan River (i.e., the divide line between the two reaches) resulting in higher productivity downstream of the confluence. As recommended in the CLBMON 15b study by Schleppe et al. (2011), monitoring the benthos upstream and downstream of the confluence would provide valuable insights into this result. Mountain Whitefish body condition was highest within Site 231.3-R (Big Eddy). This site is located immediately downstream of the Jordan River confluence. Due to the topography of the area, most of the water flowing out of the Jordan River circulates through Big Eddy before flowing downstream.

Significantly greater body condition of Mountain Whitefish in the fall compared to the spring may reflect greater food availability during summer than in winter or be a result of lower body condition following winter spawning for adult Mountain Whitefish. Abundance and biomass of benthic invertebrates was greater in the fall than in the spring season in the MCR (Schleppe and Larratt 2015).

4.5.4 Rainbow Trout

Estimates of body condition of adult Rainbow Trout decreased in the first four years after the flow regime change, with a decrease of 7% between 2010 and 2014. Body condition of Rainbow Trout was slightly above average in 2015 but decreased again in 2016 when the effect size was -4%. The results did not support a significant effect of the flow regime on Rainbow Trout condition. However, the decline in condition in the first few years after the new flow regime was similar to that observed for other species including Bull Trout and Largescale Sucker, which suggests that similar changes in habitat conditions could have played a role in the decreases. As was observed for Mountain Whitefish, body condition of Rainbow Trout was much lower in the spring than in the fall, likely because of less food availability in winter than in summer.

Body condition of Rainbow Trout was greatest at the site further downstream and closest to ALR (227.2-R). Boat electroshocking surveys were conducted in Reach 2 in 2008 and 2009. During those surveys, 42 Rainbow Trout were measured for length and weight. Although based on relatively few data points, a preliminary review of these data did not indicate higher body conditions in Reach 2 when compared to Rainbow Trout recorded in Reach 3. Boat electroshocking surveys have never been conducted in the Illecillewaet River under the current program. However, a study of juvenile fish habitat use in the MCR (CLBMON-17) found that juvenile Rainbow Trout caught in tributaries had greater body condition than those caught in the mainstem MCR (Triton 2012).

4.6 Management Question #4 – Spatial Distribution

The effect of the flow regime change on the spatial distribution of fish in the MCR was evaluated by testing whether the linear relationship between abundance and river kilometre varied by flow regime. In the abundance models, if the interaction between river kilometre (distribution) and flow regime was significant, the interpretation was that the flow regime had a significant effect on the spatial distribution of fish in the MCR. However, this effect of flow regime on distribution could only be included in the models for Bull Trout and Mountain Whitefish abundance. Abundance and count density models of all other species did not include the effect of flow regime on distribution because of smaller sample sizes and difficulties fitting the full model that included river kilometre.

Previous years of this study reported a possible upstream shift in distribution after the flow regime in several species but that was most prominent for Rainbow Trout and sucker species (Golder, Poisson, and ONA 2016a). In the current analysis, there was a small upstream shift in the distribution of adult Bull Trout and juvenile Mountain Whitefish but the difference was not statistically significant. If there was a real upstream shift in distribution of some species after the flow regime, then it could be because the year-round minimum flow and greater permanently wetted area made habitat in the upstream riverine portion of the MCR more attractive for these species.

The spatial distribution of fishes in the MCR, including seasonal and temporal trends, is discussed for each species in the following sections. The fine-scale distribution of Bull Trout, Mountain Whitefish, and Sucker species as recorded during the georeferenced visual survey in 2016 is provided on maps in Appendix I.

4.6.1 Bull Trout

Bull Trout densities in Reach 4 were highest near the Moses Creek Spawning Channel (RKm 236.4) and tended to decrease with increasing distance downstream from REV. Similarly, in Reach 3, Bull Trout densities were highest near the Jordan River confluence (RKm 231.6) and tended to decrease with distance downstream from the confluence. Both Moses Creek and the Jordan River are known spawning areas for Kokanee. The pattern of decreasing Bull Trout densities with increased distance downstream of both tributaries suggests that Bull Trout may be aggregating to feed on pre-spawning Kokanee entering these systems or on spent Kokanee exiting these systems. However, densities of Bull Trout also were high at these locations during the spring, which suggests that availability of Kokanee spawners as prey is not the only factor leading to high Bull Trout densities near the tributaries.

The distribution of Bull Trout was, on average, further upstream in the spring than in the fall for adults but not seasonally different for juveniles. Seasonal shifts in the movement and distribution of large–bodied, migratory species like Bull Trout are expected but the reasons for the small upstream shift in the spring in the MCR are not known.

4.6.2 Burbot

Density of Burbot was greatest at Site 231.0-L, which is along the left bank between the Revelstoke Golf Course and the Rock Groyne. This site contains rip-rap substrate, steep banks, and high water velocities. Higher catch-rates of Burbot were recorded in similar habitats downstream of HLK as part of BC Hydro's LCR Fish Population Indexing Program (CLBMON-45; Ford and Thorley 2011b).

4.6.3 Kokanee

Spatial distribution was assessed using catch data (Appendix D, Table D2) because densities were not estimated using HBMs due to extremely variable data that prevented models from converging. Kokanee catches were higher at sites that included confluences of major tributaries or were immediately downstream of tributaries (i.e., Moses Creek, Scales Creek, Jordan River). Schools of Kokanee were also often observed near the Trans-Canada highway Bridge. Kokanee are in the study area primarily during the fall season for spawning; for that reason, densities are higher near tributaries (either spawning at the creek mouths or migrating into the creeks to spawn). Based on field observations, distribution was patchy, with large numbers of fish observed in small areas, reflecting schooling behavior of pre-spawning Kokanee.

4.6.4 Mountain Whitefish

Adult Mountain Whitefish were most common from Site 232.6-R (upstream of the Jordan River confluence) to Big Eddy Bridge (Site 227.2-R). Habitat in this portion of the study area is dominated by shallow water depths, high water velocities, and small substrate (i.e., gravel and cobble) and may serve as a holding area for this species prior to spawning. Mountain Whitefish spawning has not been documented in the MCR; however, field crews have noted both gravid and ripe Mountain Whitefish during surveys.

Mountain Whitefish densities were noticeably lower on the left bank (i.e., between the Revelstoke Golf Course and the Rock Groyne). Habitat in this area is typified by high water velocities, high water depths, and rip-rap or large substrate banks. Site 227.2-R (Salmon Rocks) has similar habitat characteristics and also had low adult Mountain Whitefish densities. Habitat preferences inferred from these observations generally agree with studies from other areas in western Canada, as Mountain Whitefish are typically found in areas with moderate to high flows, large gravels or cobbles, and shallow depths (Ford et al. 1995, McPhail 2007, Golder 2012).

Juvenile Mountain Whitefish were most common in the upstream portion of Reach 4 (i.e., opposite the Moses Creek Spawning Channel) and in the upstream portion of Reach 3 (i.e., between Big Eddy and Big Eddy Bridge). Spatial distributions of juvenile and adult Mountain Whitefish were quite similar, which suggested similar habitat preferences for these age groups. Ford et al. (1995) reported that diets of age-1 and age-2 Mountain Whitefish were similar but differed from age-3, 4 and 5 fish, which could help explain similar habitat preferences between juvenile and adult fish in this study.

There were no change in the distribution of adult Mountain Whitefish after the new flow regime. The distribution of juvenile Mountain Whitefish was slightly more upstream after the flow regime change than before but the difference was not significant. The model suggested a more downstream distribution of Mountain Whitefish in the spring than the fall for both juveniles and adults but this seasonal difference was small.

4.6.5 Rainbow Trout

Between 2001 and 2016, Rainbow Trout densities were highest in Big Eddy, adjacent to the rip-rapped left bank of Reach 3, and at Salmon Rocks (Site 227.2-R). Rainbow Trout densities were low throughout Reach 4 and along the right bank of Reach 3, with the exception of Big Eddy and Salmon Rocks.

In the fall of 2009, BC Hydro stabilized the bank of the Columbia River by adding large boulders and rip-rap to an approximately 1.4 km section of the bank along the Revelstoke Golf Course (Site 233.1-L; Appendix A, Figure A2). Effectiveness monitoring was conducted to assess whether there was loss of fish habitat caused by the bank stabilization (Masse Environmental Consultants Ltd. 2015). The analysis used fish data collected from this program (CLBMON-16) and suggested an increase in Rainbow Trout density after the bank stabilization but the difference was not significant. Catch-per-unit-effort of juvenile and small-bodied fishes, captured as part of the juvenile fish monitoring program (CLBMON-17; Triton 2014), suggested a decrease in salmonid species at this site, which was hypothesized to be related to the greater water velocities after the bank stabilization (Masse Environmental Consultants Ltd. 2015). Overall, the data do not suggest a significant or lasting change in the density or habitat use of Rainbow Trout or other species at this site that was related to the bank stabilization.

4.6.6 Sucker Species

For all sucker species combined, density generally increased with increased distance downstream of the dam. Sucker species prefer lower water velocity areas (except during their spawning season). In general, water velocities in the MCR are lower in Reach 3 than in Reach 4. Reach 3 also contains more backwater habitat areas (e.g., upstream of the Tonkawatla Creek confluence, behind the islands upstream of the Centennial Park Boat Launch, upstream of the Illecillewaet River confluence, and immediately downstream of the Rock Groyne; Appendix A, Figure A2) that are suitable for rearing and feeding. Because of their preference for low velocity habitats, the extent of backwatering from ALR is expected to have an effect on the distribution of sucker species, as well as changes in discharge related to the flow regime.

4.6.7 Northern Pikeminnow

Northern Pikeminnow densities were higher in Reach 3 than in Reach 4 and density increased with proximity to ALR. Credible intervals overlapped for all estimates, but densities for this species were generally higher in sites that contained backwater habitat areas or had lower water velocities, such as Site 228.5-L (upstream of the Illecillewaet River confluence), Site 231.3-L (Big Eddy), Site 227.2-R (Salmon Rocks), and Site 229.2-L (between the Rock Groyne and the Centennial Park Boat Launch). This distribution reflects this species preference for low velocity habitats (Scott and Crossman 1973). Northern Pikeminnow were more abundant in the MCR during the fall than during the spring. Given the large size of the Northern Pikeminnow present during the fall season, it is possible that these fish were in the study area to feed on spawning Kokanee, as was reported in Pend d'Oreille Lake, Washington (Clarke et al. 2005).

4.6.8 Sculpin Species

Catches of sculpin species were highest in Big Eddy and along the rip-rap on the left bank of Reach 3. Of the sculpin species captured since 2010, 93% were Prickly Sculpin (n = 289) and 7% were Slimy Sculpin (*Cottus cognatus*) (n = 23). Sculpin were observed and captured in both Reach 3 and 4, but 66% of fish recorded since 2010 were in Reach 3. Greater catch in Reach 3 than 4, even though these reaches are close to the length (Appendix B, Table B2), could be because sculpin are more common, or because the slower water or other habitat differences make capturing sculpin more efficient in Reach 3 than in Reach 4.

4.7 Summary

Information regarding the abundance, spatial distribution, body condition, growth, and diversity of fish species in the MCR was collected for 10 years prior to the flow regime change and for 6 years since the flow regime change. These data were analyzed using hierarchical Bayesian methods as a robust and defensible way to assess trends over time and space, and the effects of the flow regime change on fish populations. Several fish population variables changed in years following the flow regime but because of the observational design of the study, it is difficult to determine whether the change in flow regime caused these changes or merely coincided with them.

There was an increase in species richness and evenness between 2001 and 2008 that was attributed to significant increases in the occupancy and/or density of several less common species. The probability of occupancy of Burbot, Lake Whitefish, Northern Pikeminnow, Rainbow Trout, Redside Shiner, and sculpin species all increased between 2001 and 2005-2008, depending on the species. The abundance of more common species, such as Bull Trout and Mountain Whitefish remained relatively stable during this time period. Although the results suggest a substantial change in the fish community between 2001 and 2008, reasons for the change are unknown. A second change in the fish community occurred following the flow regime change beginning in 2011, with declining species richness and occupancy of less common species, such as

Burbot, Northern Pikeminnow, Rainbow Trout, and sculpin species. At the same time, species evenness increased in the few years after the flow regime change, which was attributed to relatively low estimates of density of the most common species, Mountain Whitefish, and increasing abundance of suckers.

There was some evidence to suggest that body condition or growth of fish in the MCR may have declined in the first five years following the flow regime change (2011-2015). Body condition estimates for Bull Trout and Largescale Sucker both declined after the flow regime change. Estimates of the growth rate of Bull Trout also declined in the years after the flow regime change. The low body condition of Bull Trout was correlated with declines in the abundance of Kokanee, which are an important prey for Bull Trout. The decrease in body condition of Largescale Sucker was associated with a rapid increase in abundance estimates of this species, which suggests density-dependence and intra-species competition. The similar declines in condition and growth of Bull Trout and Largescale Sucker as well as Kokanee abundance in Arrow Lakes Reservoir suggest a broad-scale decline in growing conditions that affected fish across various trophic levels, including primary consumers, insectivores, and piscivores. In 2016, this trend reversed for Largescale Sucker, with a large decrease in abundance, and a corresponding increase in body condition.

This program's management hypotheses relate to changes in fish populations before and after the change in flow regime. However, effects of the flow regime are confounded with inter-annual variation in weather that also affects variables such as discharge, water temperature, and reservoir levels. Therefore, it is important to understand relationships between environmental variables like discharge and fish population metrics. In some previous years of the study, relationships between fish and environmental variables were assessed through time-series correlation analysis (Golder, Poisson, and ONA 2016a). This exploratory approach was useful for identifying possible correlations but one limitation was the large number of possible relationships, which increased the chance of detecting spurious relationships. A better approach would be to develop specific hypotheses regarding the most likely pathways through which the flow regime could affect lower trophic levels and fish populations. We recommend that BC Hydro and investigators working on different monitoring programs in the MCR including physical habitat (CLBMON-15a), ecological productivity (CLBMON-15b), and fish population indexing (CLBMON-16) work together to develop the specific hypotheses and identify the best descriptive statistics to use as explanatory variables. These hypotheses and the models developed to test them will be used to better understand relationships between fish populations and environmental variables, which will improve understanding of how the flow regime may have affected fish populations in the MCR.

5.0 RECOMMENDATIONS

In consideration of the results of this study and the overall objectives of CLBMON-16, fish population indexing surveys should continue in future years, with the modifications recommended below.

- Sampling during the fall season is necessary in order to gather data comparable to years prior to the flow regime change and adequately address the management questions. It is recommended that a minimum of three mark-recapture sessions be conducted each year so that uncertainty in capture efficiency can be estimated and sufficient numbers of fish are captured to address management questions.
- A recent exploratory analysis conducted for this monitoring program suggested that measurements of growth rings (circuli) on fish scales could be used to assess growth and possibly to assign ages of Mountain Whitefish in the MCR (Golder, Poisson, and ONA 2016b). Scale analysis involving circuli measurements is recommended to assess growth of fish before and after the flow regime change. This analysis is not included the current scope of work but is recommended as a complementary method to assess management hypotheses if surplus budget is available.
- Specific hypotheses should be developed regarding how the flow regime change is most likely to affect fish populations. It is recommended that BC Hydro and investigators from all related monitoring programs in the MCR provide input on the hypotheses and the predictor variables used to test them. Future years of this monitoring program will develop models to test these hypotheses to improve understanding of how the flow regime affects fish populations in the MCR.

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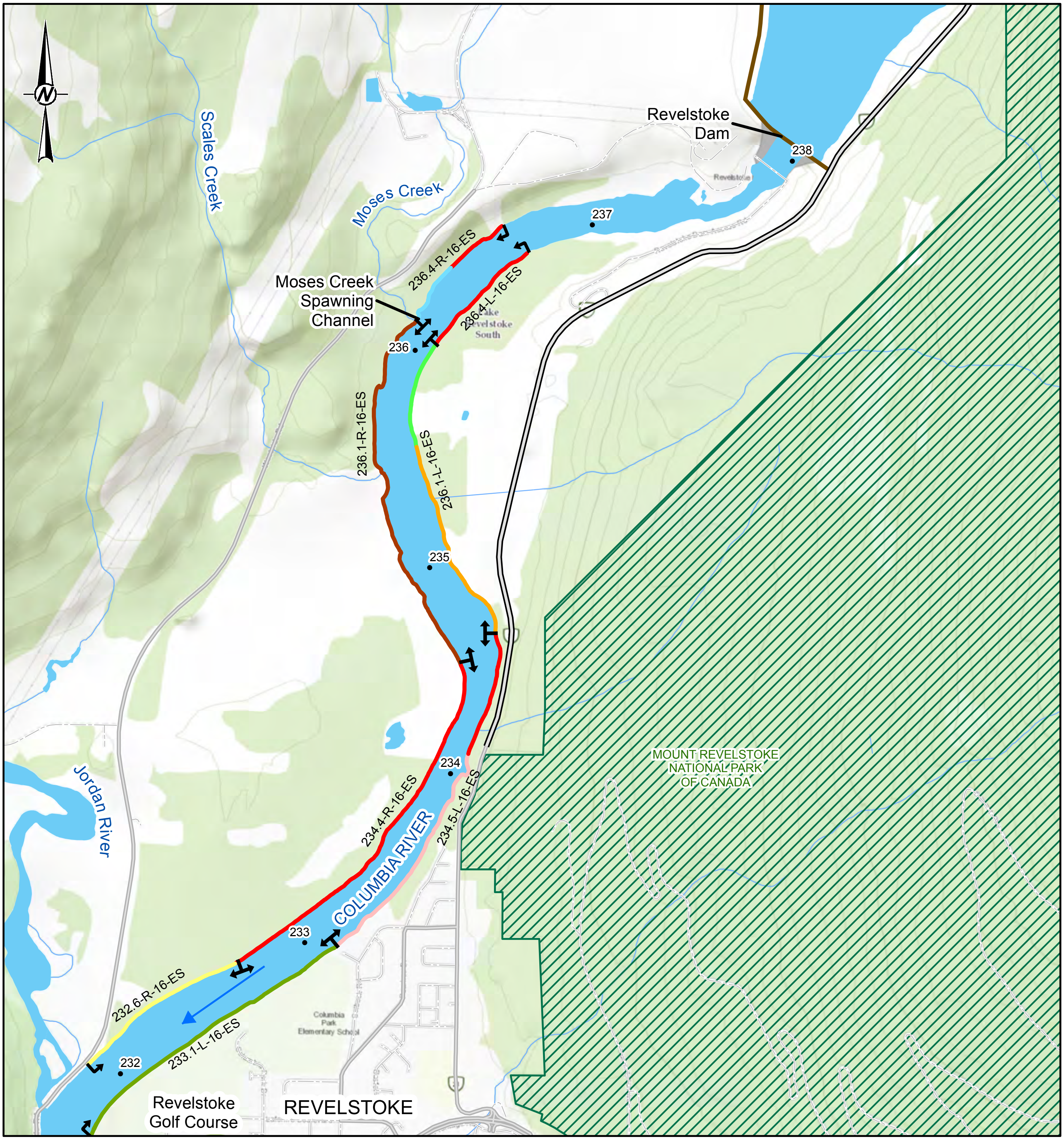
Appendix A - Maps



LEGEND

- RIVER KMS FROM U.S. BORDER
- DIRECTION OF FLOW
- HIGHWAY
- MAJOR ROAD
- LOCAL ROAD
- WATERCOURSE
- DAM BASE
- NATIONAL PARK
- WATERBODY

BANK HABITAT TYPE

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

0 400 800

1:25,000 METRES

REFERENCES

1. ROAD AND WATERBODY DATA OBTAINED FROM CANVEC © DEPARTMENT OF NATURAL RESOURCES CANADA. ALL RIGHTS RESERVED.
2. RAILWAYS OBTAINED FROM IHS ENERGY INC.
3. DAM BASE, WATERCOURSE, NATIONAL PARK DATA CONTAINS INFORMATION LICENSED UNDER THE OPEN GOVERNMENT LICENSE – BRITISH COLUMBIA.
4. BASE TOPO MAP SOURCES: ESRI, HERE, DELORME, INTERMAP, INCREMENT P CORP., GEBCO, USGS, FAO, NPS, NRCAN, GEOBASE, IGN, KADASTER NL, ORDNANCE SURVEY, ESRI JAPAN, METI, ESRI CHINA (HONG KONG), SWISSTOPO, MAPMYINDIA, © OPENSTREETMAP CONTRIBUTORS, AND THE GIS USER COMMUNITY
5. COORDINATE SYSTEM: NAD 1983 UTM ZONE 11N

CLIENT
BC HYDRO

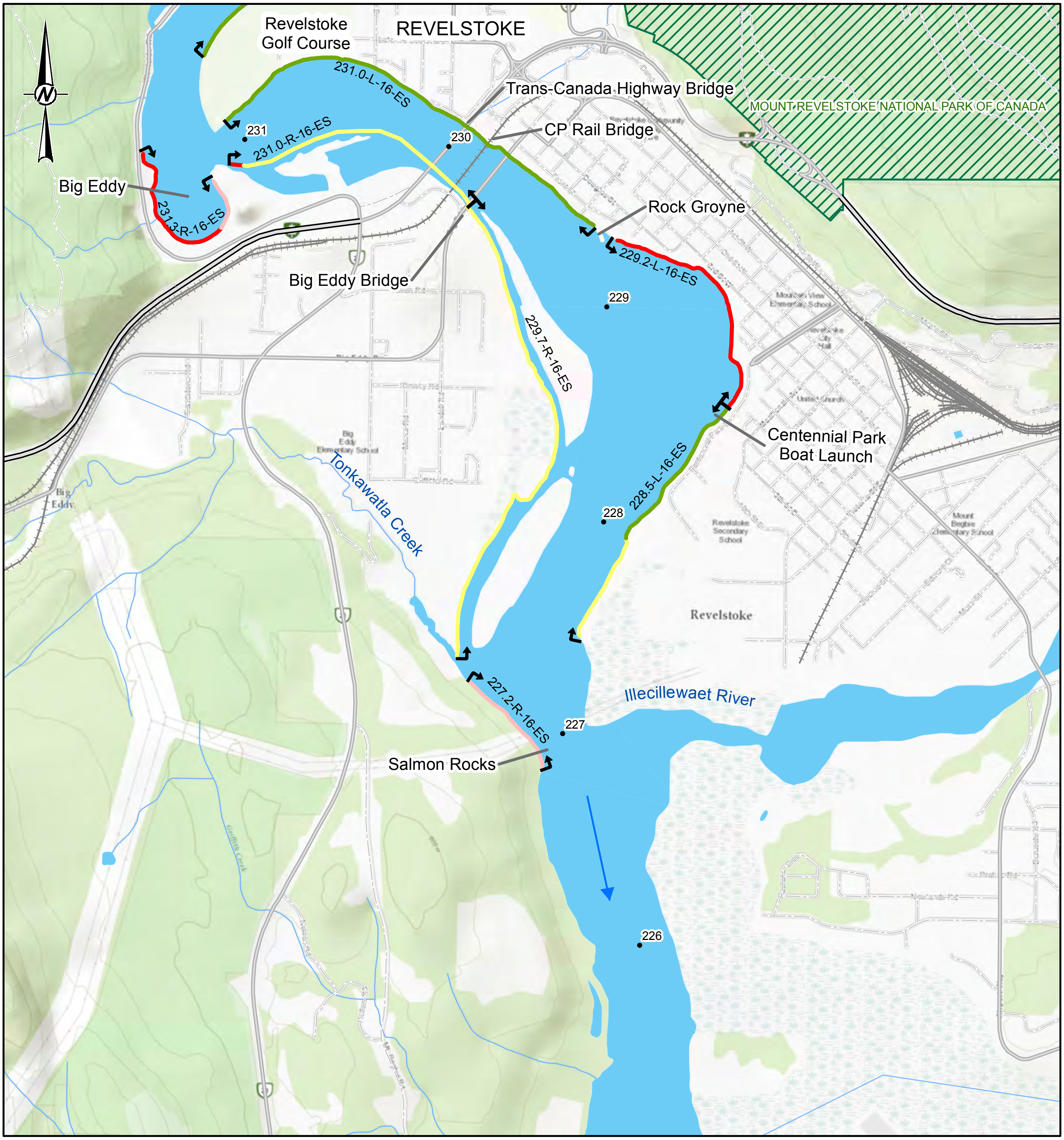
PROJECT
MIDDLE COLUMBIA RIVER FISH POPULATION INDEXING STUDY

TITLE
BANK HABITAT TYPE AND SAMPLE LOCATIONS - REACH 4

CONSULTANT
Golder Associates

YYYY-MM-DD	2017-03-01
DESIGNED	DR
PREPARED	CD/RC
REVIEWED	DR
APPROVED	DS

PROJECT NO.	PHASE	REV.	FIGURE
1666334	2016	A	A1



LEGEND

- RIVER KMS FROM U.S. BORDER
- DIRECTION OF FLOW
- HIGHWAY
- MAJOR ROAD
- LOCAL ROAD
- RAILWAY
- WATERCOURSE
- WATERBODY
- NATIONAL PARK

BANK HABITAT TYPE

- A1- ARMOURED COBBLE/GRAVEL
- A5- BEDROCK BANKS
- A6- MAN-MADE RIP-RAP
- D1- DEPOSITIONAL SAND/SILT

Citations

0 400 800

1:25,000 METRES

REFERENCES

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5. COORDINATE SYSTEM: NAD 1983 UTM ZONE 11N

CLIENT
BC HYDRO

PROJECT
MIDDLE COLUMBIA RIVER FISH POPULATION INDEXING STUDY

TITLE
BANK HABITAT TYPE AND SAMPLE LOCATIONS - REACH 3

CONSULTANT
Golder Associates

YYYY-MM-DD	2017-03-01
DESIGNED	DR
PREPARED	CD/RC
REVIEWED	DR
APPROVED	DS

PROJECT NO.	PHASE	REV.	FIGURE
1666334	2016	A	A2

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IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI A

25mm

Table A1 Locations and distances from Revelstoke Dam of boat electroshocking sites in the middle Columbia River, 2016.

Site Designation[a]	Location (km)[b]	Bank[c]	UTM Coordinates		
			Zone	Easting	Northing
Reach 4					
236.4-R-16-ES U/S	236.4	Right	11U	415126	5655641
236.4-R-16-ES D/S	236.1	Right	11U	414721	5655227
236.4-L-16-ES U/S	236.4	Left	11U	415228	5655538
236.4-L-16-ES D/S	236.1	Left	11U	414821	5655127
236.1-L-16-ES U/S	236.1	Left	11U	414821	5655127
236.1-L-16-ES D/S	234.5	Left	11U	415048	5653833
236.1-R-16-ES U/S	236.1	Right	11U	414721	5655227
236.1-R-16-ES D/S	234.4	Right	11U	414936	5653705
234.4-R-16-ES U/S	234.4	Right	11U	414936	5653705
234.4-R-16-ES D/S	232.6	Right	11U	413944	5652387
234.5-L-16-ES U/S	234.5	Left	11U	415048	5653833
234.5-L-16-ES D/S	233.1	Left	11U	414048	5652251
233.1-L-16-ES U/S	233.1	Left	11U	414380	5652467
233.1-L-16-ES D/S	231.6	Left	11U	413294	5651640
232.6-R-16-ES U/S	232.6	Right	11U	413944	5652387
232.6-R-16-ES D/S	231.9	Right	11U	413292	5651941
Reach 3					
231.3-R-16-ES U/S	231.3	Right	11U	413030	5651196
231.3-R-16-ES D/S	231.2	Right	11U	413333	5651079
231.0-L-16-ES U/S	231.0	Left	11U	413408	5651353
231.0-L-16-ES D/S	229.3	Left	11U	415023	5650860
231.0-R-16-ES U/S	231.0	Right	11U	413418	5651133
231.0-R-16-ES D/S	229.7	Right	11U	414486	5651009
229.7-R-16-ES U/S	229.7	Right	11U	414486	5651009
229.7-R-16-ES D/S	227.3	Right	11U	414436	5648973
229.2-L-16-ES U/S	229.2	Left	11U	415089	5650679
229.2-L-16-ES D/S	228.5	Left	11U	415608	5650080
228.5-L-16-ES U/S	228.5	Left	11U	415608	5650080
228.5-L-16-ES D/S	227.4	Left	11U	414942	5649059
227.2-R-16-ES U/S	227.2	Right	11U	414474	5648871
227.2-R-16-ES D/S	226.9	Right	11U	414804	5648490

[a] U/S = Upstream limit of site; D/S = Downstream limit of site.
[b] River kilometres measured upstream from the Canada-U.S. border.
[c] Bank location as viewed facing downstream.

Appendix B – Habitat Summary Information

Table B1 Descriptions of categories used in the Middle 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 Lengths of bank habitat types within boat electroshocking sites in the middle Columbia River, 2016.

Reach	Site[a]	Length (m) of Bank Habitat Type[b]								Total Length (m)
		A1	A3	A4	A5	A6	A1+A2	D1	D2	
4	236.4-R-16-ES	296		298						**594**
	236.4-L-16-ES	581								**581**
	236.1-L-16-ES		482						928	**1410**
	236.1-R-16-ES						1733			**1733**
	234.4-R-16-ES	1736								**1736**
	234.5-L-16-ES	559			1095					**1654**
	233.1-L-16-ES					1408				**1408**
	232.6-R-16-ES							796		**796**
Reach 4 Total		**3172**	**482**	**298**	**1095**	**1408**	**1733**	**796**	**928**	**9911**
3	231.3-R-16-ES	665			231					**896**
	231.0-L-16-ES					1964				**1964**
	231.0-R-16-ES	55						1138		**1193**
	229.7-R-16-ES							2270		**2270**
	229.2-L-16-ES	1101								**1101**
	228.5-L-16-ES					742		489		**1231**
	227.2-R-16-ES				519					**519**
Reach 3 Total		**1820**	**0**	**0**	**751**	**2706**	**0**	**3897**	**0**	**9173**
Grand Total		**4992**	**482**	**298**	**1845**	**4114**	**1733**	**4693**	**928**	**19 085**

[a] See Appendix A, Figures A1 and A2 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, 11 October to 27 October 2016.

Reach	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	Terrestrial Vegetation	Shallow Water	Deep Water
4	236.4-R-16-ES	75	5	10.60	140	Clear	High	High	High	85	0	5	0	0	10
4	236.4-R-16-ES	76	8	9.80	150	Overcast	High	Medium	High	80	0	5	0	15	0
4	236.4-R-16-ES	77	5	9.60	140	Overcast	Medium	High	High	80	0	5	0	10	5
4	236.4-L-16-ES	75	5	10.60	140	Clear	High	Medium	High	100	0	0	0	0	0
4	236.4-L-16-ES	76	7	9.80	150	Overcast	High	Medium	High	70	0	5	0	25	0
4	236.4-L-16-ES	77	5	9.70	140	Overcast	Medium	High	High	70	0	5	0	20	5
4	236.1-R-16-ES	75	5	10.40	150	Clear	High	Medium	High	89	1	0	0	0	10
4	236.1-R-16-ES	76	10	9.80	150	Overcast	High	Low	High	70	0	0	0	20	10
4	236.1-R-16-ES	77	2	9.60	140	Overcast	Medium	Low	High	80	0	0	0	15	5
4	236.1-L-16-ES	75	7	10.40	150	Clear	High	Medium	High	100	0	0	0	0	0
4	236.1-L-16-ES	76	5	9.90	150	Overcast	High	Medium	High	70	0	0	0	20	10
4	236.1-L-16-ES	77	5	9.70	140	Overcast	Medium	High	High	100	0	0	0	0	0
4	234.5-L-16-ES	75	0	10.40	150	Clear	High	Low	High	85	0	5	0	0	10
4	234.5-L-16-ES	76	5	9.80	150	Overcast	High	Medium	High	60	0	5	0	25	10
4	234.5-L-16-ES	77	8	9.70		Overcast	High	Low	High	45	0	5	0	30	20
4	234.4-R-16-ES	75	0	10.30	150	Clear	High	High	High	90	10	0	0	0	0
4	234.4-R-16-ES	76	5	9.80	150	Overcast	High	Low	High	80	0	0	0	20	0
4	234.4-R-16-ES	77	5	9.60	140	Overcast	Low	Medium	High	100	0	0	0	0	0
4	233.1-L-16-ES	75	7	10.20	150	Overcast	Medium	High	High	80	10	5	0	0	5
4	233.1-L-16-ES	76	5	9.80	150	Overcast	High	Medium	High	70	0	0	0	20	10
4	233.1-L-16-ES	77	5	9.70	140	Overcast	High	Medium	High	80	5	5	0	0	10
4	232.6-R-16-ES	75	0	10.20	150	Overcast	High	High	High	100	0	0	0	0	0
4	232.6-R-16-ES	76	5	9.70	150	Overcast	Low	Low	High	90	0	0	0	10	0
4	232.6-R-16-ES	77	5	9.60	150	Overcast	High	Medium	High	100	0	0	0	0	0

[a] See Appendix A, Figures A1 and A2 for sample site locations.

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

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

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

Continued...

Table B3 Concluded.

Reach	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	Terrestrial Vegetation	Shallow Water	Deep Water	Other Cover
3	231.3-R-16-ES	75	0	10.00	150	Overcast	High	Low	High	10	10	5	0	55	20	0
3	231.3-R-16-ES	76	0	9.40	150	Overcast	High	Low	High	20	10	0	0	40	25	5
3	231.3-R-16-ES	77	5	9.30	150	Overcast	Medium	Low	High	10	10	0	0	40	40	0
3	231.0-R-16-ES	75	0	10.00	150	Overcast	High	Low	High	50	20	5	0	20	5	0
3	231.0-R-16-ES	76	5	9.20	150	Overcast	High	Low	High	70	5	5	0	10	10	0
3	231.0-R-16-ES	77	8	9.30	140	Overcast	Medium	Low	High	35	5	10	0	40	10	0
3	231.0-L-16-ES	75	5	10.00	150	Overcast	Medium	High	High	50	5	5	0	20	20	0
3	231.0-L-16-ES	76	0	9.50	150	Overcast	High	High	High	50	5	5	0	10	30	0
3	231.0-L-16-ES	77	5	9.30	140	Overcast	Medium	Medium	High	70	0	5	0	10	15	0
3	229.7-R-16-ES	75	0	10.00	170	Overcast	High	Low	High	80	10	0	0	5	5	0
3	229.7-R-16-ES	76	5	9.20	150	Overcast	Medium	Low	High	50	5	0	0	45	0	0
3	229.7-R-16-ES	77	8	9.20	140	Overcast	High	Low	High	60	10	0	0	15	15	0
3	229.2-L-16-ES	75	0	9.90	150	Overcast	Medium	Low	High	15	5	0	0	30	50	0
3	229.2-L-16-ES	76	0	9.50	150	Overcast	High	Low	High	10	5	0	0	60	25	0
3	229.2-L-16-ES	77	5	9.20	140	Overcast	Medium	Low	High	0	5	0	0	50	45	0
3	228.5-L-16-ES	75	0	9.80	150	Overcast	Low	Medium	High	20	5	0	0	30	25	20
3	228.5-L-16-ES	76	0	9.20	150		High	High	High	30	0	0	0	20	50	0
3	228.5-L-16-ES	77	5	9.20	140	Overcast	Low	Low	High	50	0	0	0	20	20	10
3	227.2-R-16-ES	75	0	9.90	170	Overcast	High	High	High	10	5	5	0	20	60	0
3	227.2-R-16-ES	76	5	9.10	150	Overcast	High	Low	High	30	0	0	0	0	70	0
3	227.2-R-16-ES	77	5	8.70	140	Overcast	Low	Low	High	30	0	0	0	0	70	0

[a] See Appendix A, Figures A1 and A2 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, 11 October to 27 October 2016.

Reach	Site[a]	Species	Size Class	Bank Habitat Type[a]								Total
				A1	A3	A4	A5	A6	A1+A2	D1	D2	
4	232.6-R-16-ES	Bull Trout	Adult									**0**
	232.6-R-16-ES	Lake Whitefish	Adult							1		**1**
	232.6-R-16-ES	Largescale Sucker	Adult									**0**
	232.6-R-16-ES	Mountain Whitefish	Adult									**0**
	232.6-R-16-ES	Mountain Whitefish	Immature									**0**
	232.6-R-16-ES	Mountain Whitefish	YOY									**0**
	232.6-R-16-ES	Sucker Spp.	Adult							5		**5**
	232.6-R-16-ES	Sucker Spp.	Immature							2		**2**
	Site 232.6-R-16-ES Total			**0**	**0**	**0**	**0**	**0**	**0**	**8**	**0**	**8**
	233.1-L-16-ES	Bull Trout	Adult									**0**
	233.1-L-16-ES	Burbot	Adult					1				**1**
	233.1-L-16-ES	Largescale Sucker	Adult									**0**
	233.1-L-16-ES	Largescale Sucker	YOY									**0**
	233.1-L-16-ES	Longnose Sucker	Immature									**0**
	233.1-L-16-ES	Mountain Whitefish	Adult									**0**
	233.1-L-16-ES	Mountain Whitefish	Immature									**0**
	233.1-L-16-ES	Mountain Whitefish	YOY									**0**
	233.1-L-16-ES	Prickly Sculpin	All									**0**
	233.1-L-16-ES	Rainbow Trout	Adult									**0**
	233.1-L-16-ES	Rainbow Trout	Immature									**0**
	233.1-L-16-ES	Sculpin Spp.	All					12				**12**
	233.1-L-16-ES	Slimy Sculpin	All									**0**
	233.1-L-16-ES	Sucker Spp.	Adult					20				**20**
	Site 233.1-L-16-ES Total			**0**	**0**	**0**	**0**	**33**	**0**	**0**	**0**	**33**
	234.4-R-16-ES	Bull Trout	Adult									**0**
	234.4-R-16-ES	Bull Trout	Immature									**0**
	234.4-R-16-ES	Kokanee	All									**0**
	234.4-R-16-ES	Lake Whitefish	Adult									**0**
	234.4-R-16-ES	Largescale Sucker	Adult									**0**
	234.4-R-16-ES	Mountain Whitefish	Adult									**0**
	234.4-R-16-ES	Mountain Whitefish	All									**0**
	234.4-R-16-ES	Mountain Whitefish	Immature									**0**
	234.4-R-16-ES	Mountain Whitefish	YOY									**0**
	234.4-R-16-ES	Sculpin Spp.	All	14								**14**
	234.4-R-16-ES	Sucker Spp.	Adult	65								**65**
	234.4-R-16-ES	Sucker Spp.	Immature	1								**1**
	Site 234.4-R-16-ES Total			**80**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**80**
	234.5-L-16-ES	Bull Trout	Adult									**0**
	234.5-L-16-ES	Bull Trout	Immature									**0**
	234.5-L-16-ES	Largescale Sucker	Adult									**0**
	234.5-L-16-ES	Largescale Sucker	Immature									**0**
	234.5-L-16-ES	Longnose Sucker	Immature									**0**
	234.5-L-16-ES	Mountain Whitefish	Adult									**0**
	234.5-L-16-ES	Mountain Whitefish	Immature									**0**
	234.5-L-16-ES	Mountain Whitefish	YOY									**0**
	234.5-L-16-ES	Prickly Sculpin	All									**0**
	234.5-L-16-ES	Rainbow Trout	Adult									**0**
	234.5-L-16-ES	Sucker Spp.	Adult	2			16					**18**
	234.5-L-16-ES	Sucker Spp.	Immature				1					**1**
	Site 234.5-L-16-ES Total			**2**	**0**	**0**	**17**	**0**	**0**	**0**	**0**	**19**

[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.

Reach	Site[a]	Species	Size Class	Bank Habitat Type[a]								Total
				A1	A3	A4	A5	A6	A1+A2	D1	D2	
	236.1-L-16-ES	Bull Trout	Adult									**0**
	236.1-L-16-ES	Lake Whitefish	Adult									**0**
	236.1-L-16-ES	Largescale Sucker	Adult									**0**
	236.1-L-16-ES	Longnose Sucker	Adult									**0**
	236.1-L-16-ES	Mountain Whitefish	Adult									**0**
	236.1-L-16-ES	Mountain Whitefish	Immature									**0**
	236.1-L-16-ES	Mountain Whitefish	YOY									**0**
	236.1-L-16-ES	Northern Pikeminnow	Adult									**0**
	236.1-L-16-ES	Sucker Spp.	Adult		1					7	4	**12**
	Site 236.1-L-16-ES Total			**0**	**1**	**0**	**0**	**0**	**0**	**7**	**4**	**12**
	236.1-R-16-ES	Bull Trout	Adult									**0**
	236.1-R-16-ES	Kokanee	Adult						3			**3**
	236.1-R-16-ES	Kokanee	All									**0**
	236.1-R-16-ES	Lake Whitefish	Adult									**0**
	236.1-R-16-ES	Largescale Sucker	Adult									**0**
	236.1-R-16-ES	Largescale Sucker	Immature									**0**
	236.1-R-16-ES	Longnose Sucker	Immature									**0**
	236.1-R-16-ES	Mountain Whitefish	Adult									**0**
	236.1-R-16-ES	Mountain Whitefish	Immature									**0**
	236.1-R-16-ES	Mountain Whitefish	YOY									**0**
	236.1-R-16-ES	Northern Pikeminnow	Adult									**0**
	236.1-R-16-ES	Rainbow Trout	Adult									**0**
	236.1-R-16-ES	Sculpin Spp.	All						6			**6**
	236.1-R-16-ES	Sucker Spp.	Adult						32			**32**
	236.1-R-16-ES	Sucker Spp.	Immature						1			**1**
	Site 236.1-R-16-ES Total			**0**	**0**	**0**	**0**	**0**	**42**	**0**	**0**	**42**
	236.4-L-16-ES	Bull Trout	Adult									**0**
	236.4-L-16-ES	Largescale Sucker	Adult									**0**
	236.4-L-16-ES	Mountain Whitefish	Adult									**0**
	236.4-L-16-ES	Mountain Whitefish	Immature									**0**
	236.4-L-16-ES	Mountain Whitefish	YOY									**0**
	236.4-L-16-ES	Northern Pikeminnow	Adult									**0**
	236.4-L-16-ES	Rainbow Trout	Adult									**0**
	236.4-L-16-ES	Sculpin Spp.	All	1								**1**
	236.4-L-16-ES	Sucker Spp.	Adult	7								**7**
	Site 236.4-L-16-ES Total			**8**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**8**
	236.4-R-16-ES	Bull Trout	Adult									**0**
	236.4-R-16-ES	Kokanee	Adult			1						**1**
	236.4-R-16-ES	Kokanee	All									**0**
	236.4-R-16-ES	Largescale Sucker	Adult									**0**
	236.4-R-16-ES	Mountain Whitefish	Adult									**0**
	236.4-R-16-ES	Mountain Whitefish	Immature									**0**
	236.4-R-16-ES	Mountain Whitefish	YOY									**0**
	236.4-R-16-ES	Prickly Sculpin	All									**0**
	236.4-R-16-ES	Sculpin Spp.	All	3			1					**4**
	236.4-R-16-ES	Sucker Spp.	Adult			1						**1**
	236.4-R-16-ES	Sucker Spp.	Immature	2								**2**
	Site 236.4-R-16-ES Total			**5**	**0**	**2**	**1**	**0**	**0**	**0**	**0**	**8**
Reach 4 Total				**95**	**1**	**2**	**18**	**33**	**42**	**15**	**4**	**210**

[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.

Reach	Site[a]	Species	Size Class	Bank Habitat Type[a]								Total
				A1	A3	A4	A5	A6	A1+A2	D1	D2	
3	227.2-R-16-ES	Sucker Spp.	Adult				7					**7**
	227.2-R-16-ES	Mountain Whitefish	Immature				9					**9**
	227.2-R-16-ES	Sculpin Spp.	All				17					**17**
	227.2-R-16-ES	Bull Trout	Adult									**0**
	227.2-R-16-ES	Bull Trout	Immature									**0**
	227.2-R-16-ES	Largescale Sucker	Adult									**0**
	227.2-R-16-ES	Mountain Whitefish	Adult									**0**
	227.2-R-16-ES	Prickly Sculpin	All									**0**
	227.2-R-16-ES	Rainbow Trout	Adult									**0**
	227.2-R-16-ES	Rainbow Trout	Immature									**0**
	227.2-R-16-ES	Rainbow Trout	YOY									**0**
	Site 227.2-R-16-ES Total			**0**	**0**	**0**	**33**	**0**	**0**	**0**	**0**	**33**
	228.5-L-16-ES	Bull Trout	Adult									**0**
	228.5-L-16-ES	Bull Trout	Immature									**0**
	228.5-L-16-ES	Largescale Sucker	Adult									**0**
	228.5-L-16-ES	Mountain Whitefish	Adult									**0**
	228.5-L-16-ES	Mountain Whitefish	Immature					10		15		**25**
	228.5-L-16-ES	Mountain Whitefish	YOY									**0**
	228.5-L-16-ES	Prickly Sculpin	All									**0**
	228.5-L-16-ES	Rainbow Trout	Adult									**0**
	228.5-L-16-ES	Rainbow Trout	Immature									**0**
	228.5-L-16-ES	Redside Shiner	All									**0**
	228.5-L-16-ES	Sculpin Spp.	All					2		4		**6**
	228.5-L-16-ES	Sucker Spp.	Adult					3		7		**10**
	Site 228.5-L-16-ES Total			**0**	**0**	**0**	**0**	**15**	**0**	**26**	**0**	**41**
	229.2-L-16-ES	Bull Trout	Adult									**0**
	229.2-L-16-ES	Bull Trout	Immature									**0**
	229.2-L-16-ES	Largescale Sucker	Adult									**0**
	229.2-L-16-ES	Largescale Sucker	Immature									**0**
	229.2-L-16-ES	Largescale Sucker	YOY									**0**
	229.2-L-16-ES	Mountain Whitefish	Adult									**0**
	229.2-L-16-ES	Mountain Whitefish	Immature	36								**36**
	229.2-L-16-ES	Mountain Whitefish	YOY	7								**7**
	229.2-L-16-ES	Northern Pikeminnow	Adult									**0**
	229.2-L-16-ES	Prickly Sculpin	All									**0**
	229.2-L-16-ES	Rainbow Trout	Adult									**0**
	229.2-L-16-ES	Rainbow Trout	Immature									**0**
	229.2-L-16-ES	Redside Shiner	All									**0**
	229.2-L-16-ES	Sculpin Spp.	All	13								**13**
	229.2-L-16-ES	Sucker Spp.	Adult	35								**35**
	Site 229.2-L-16-ES Total			**91**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**91**

[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.

Reach	Site[a]	Species	Size Class	Bank Habitat Type[a]								Total
				A1	A3	A4	A5	A6	A1+A2	D1	D2	
	229.7-R-16-ES	Bull Trout	Adult									**0**
	229.7-R-16-ES	Bull Trout	Immature							1		**1**
	229.7-R-16-ES	Kokanee	Adult							1		**1**
	229.7-R-16-ES	Kokanee	All									**0**
	229.7-R-16-ES	Lake Whitefish	Adult									**0**
	229.7-R-16-ES	Largescale Sucker	Adult									**0**
	229.7-R-16-ES	Longnose Sucker	Adult									**0**
	229.7-R-16-ES	Longnose Sucker	Immature									**0**
	229.7-R-16-ES	Mountain Whitefish	Adult									**0**
	229.7-R-16-ES	Mountain Whitefish	Immature									**0**
	229.7-R-16-ES	Mountain Whitefish	YOY									**0**
	229.7-R-16-ES	Rainbow Trout	Adult									**0**
	229.7-R-16-ES	Redside Shiner	All									**0**
	229.7-R-16-ES	Sucker Spp.	Adult							50		**50**
	Site 229.7-R-16-ES Total			**0**	**0**	**0**	**0**	**0**	**0**	**52**	**0**	**52**
	231.0-L-16-ES	Brook Trout	Adult									**0**
	231.0-L-16-ES	Brook Trout	Immature									**0**
	231.0-L-16-ES	Bull Trout	Adult									**0**
	231.0-L-16-ES	Bull Trout	Immature									**0**
	231.0-L-16-ES	Burbot	Adult									**0**
	231.0-L-16-ES	Kokanee	All									**0**
	231.0-L-16-ES	Lake Whitefish	Adult									**0**
	231.0-L-16-ES	Largescale Sucker	Adult									**0**
	231.0-L-16-ES	Largescale Sucker	Immature									**0**
	231.0-L-16-ES	Longnose Sucker	Immature									**0**
	231.0-L-16-ES	Mountain Whitefish	Adult									**0**
	231.0-L-16-ES	Mountain Whitefish	Immature									**0**
	231.0-L-16-ES	Mountain Whitefish	YOY					8				**8**
	231.0-L-16-ES	Northern Pikeminnow	Adult									**0**
	231.0-L-16-ES	Prickly Sculpin	All									**0**
	231.0-L-16-ES	Rainbow Trout	Adult									**0**
	231.0-L-16-ES	Rainbow Trout	Immature									**0**
	231.0-L-16-ES	Sculpin Spp.	All					12				**12**
	231.0-L-16-ES	Sucker Spp.	Adult					6				**6**
	Site 231.0-L-16-ES Total			**0**	**0**	**0**	**0**	**26**	**0**	**0**	**0**	**26**
	231.0-R-16-ES	Bull Trout	Adult									**0**
	231.0-R-16-ES	Bull Trout	Immature									**0**
	231.0-R-16-ES	Largescale Sucker	Adult									**0**
	231.0-R-16-ES	Mountain Whitefish	Adult									**0**
	231.0-R-16-ES	Mountain Whitefish	Immature									**0**
	231.0-R-16-ES	Mountain Whitefish	YOY									**0**
	231.0-R-16-ES	Northern Pikeminnow	Adult									**0**
	231.0-R-16-ES	Rainbow Trout	Adult	2								**2**
	231.0-R-16-ES	Redside Shiner	All									**0**
	231.0-R-16-ES	Sculpin Spp.	All	2								**2**
	231.0-R-16-ES	Sucker Spp.	Adult							22		**22**
	Site 231.0-R-16-ES Total			**4**	**0**	**0**	**0**	**0**	**0**	**22**	**0**	**26**

[a] See Appendix A, Figures A1 and A2 for sample site locations.

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

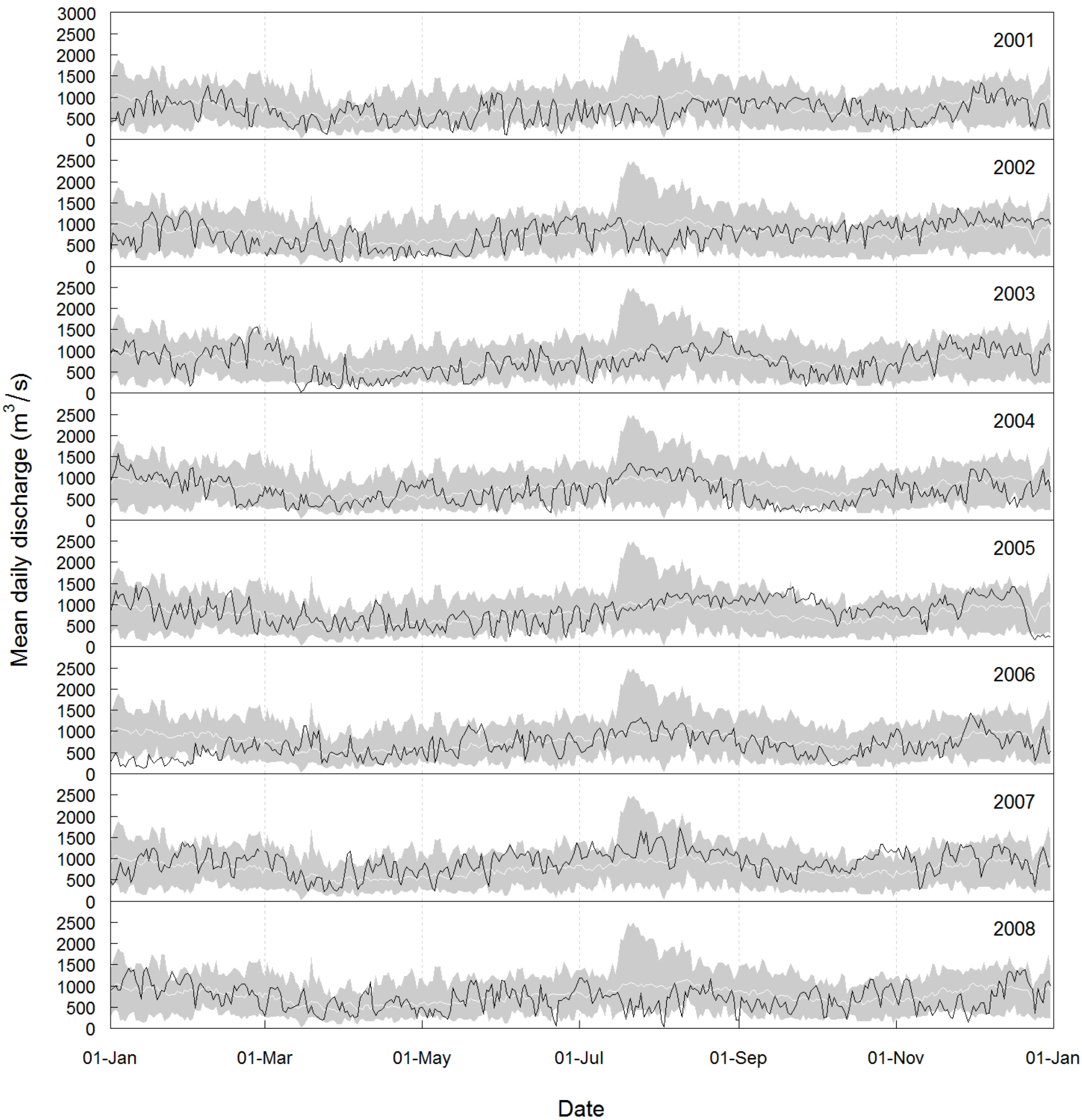
Table B4 Concluded.

Reach	Site[a]	Species	Size Class	Bank Habitat Type[a]								Total
				A1	A3	A4	A5	A6	A1+A2	D1	D2	
	231.3-R-16-ES	Bull Trout	Adult									**0**
	231.3-R-16-ES	Bull Trout	Immature									**0**
	231.3-R-16-ES	Kokanee	All									**0**
	231.3-R-16-ES	Lake Whitefish	Adult									**0**
	231.3-R-16-ES	Largescale Sucker	Adult									**0**
	231.3-R-16-ES	Mountain Whitefish	Adult									**0**
	231.3-R-16-ES	Mountain Whitefish	Immature									**0**
	231.3-R-16-ES	Mountain Whitefish	YOY									**0**
	231.3-R-16-ES	Northern Pikeminnow	Immature									**0**
	231.3-R-16-ES	Prickly Sculpin	All									**0**
	231.3-R-16-ES	Rainbow Trout	Adult									**0**
	231.3-R-16-ES	Rainbow Trout	Immature									**0**
	231.3-R-16-ES	Redside Shiner	All									**0**
	231.3-R-16-ES	Sculpin Spp.	All	13			1					**14**
	231.3-R-16-ES	Sucker Spp.	Adult	5								**5**
	Site 231.3-R-16-ES Total			**18**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**19**
Reach 3 Total				**113**	**0**	**0**	**34**	**41**	**0**	**100**	**0**	**288**
Grand Total				**208**	**1**	**2**	**52**	**74**	**42**	**115**	**4**	**498**

[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 – Discharge Temperature and Elevation Data



Continued...

Figure C1 Mean daily discharge (m³/s) for the Columbia River at Revelstoke Dam, 2001 to 2016. The shaded area represents minimum and maximum mean daily discharge values recorded at Revelstoke Dam during other study years (between 2001 and 2016). The white line represents average mean daily discharge values over the same time period.

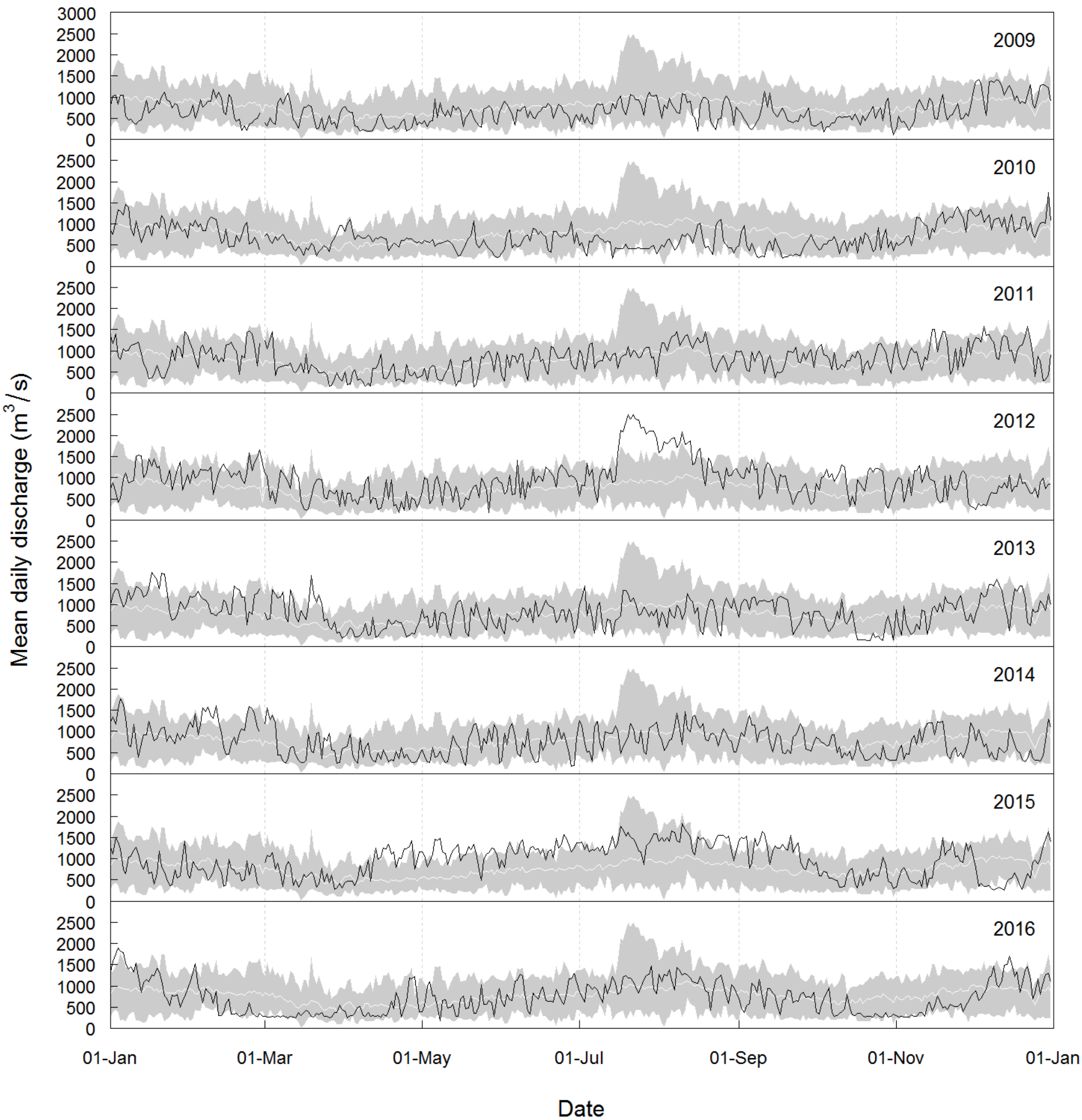


Figure C1 Concluded.

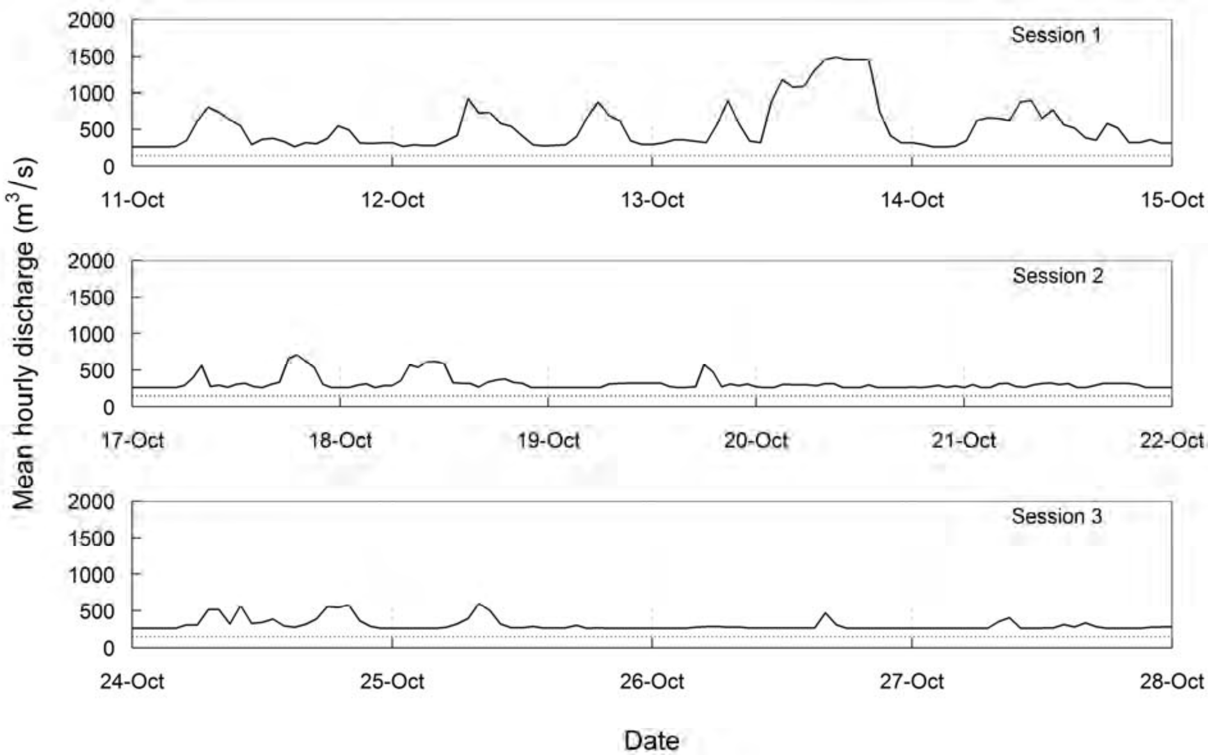
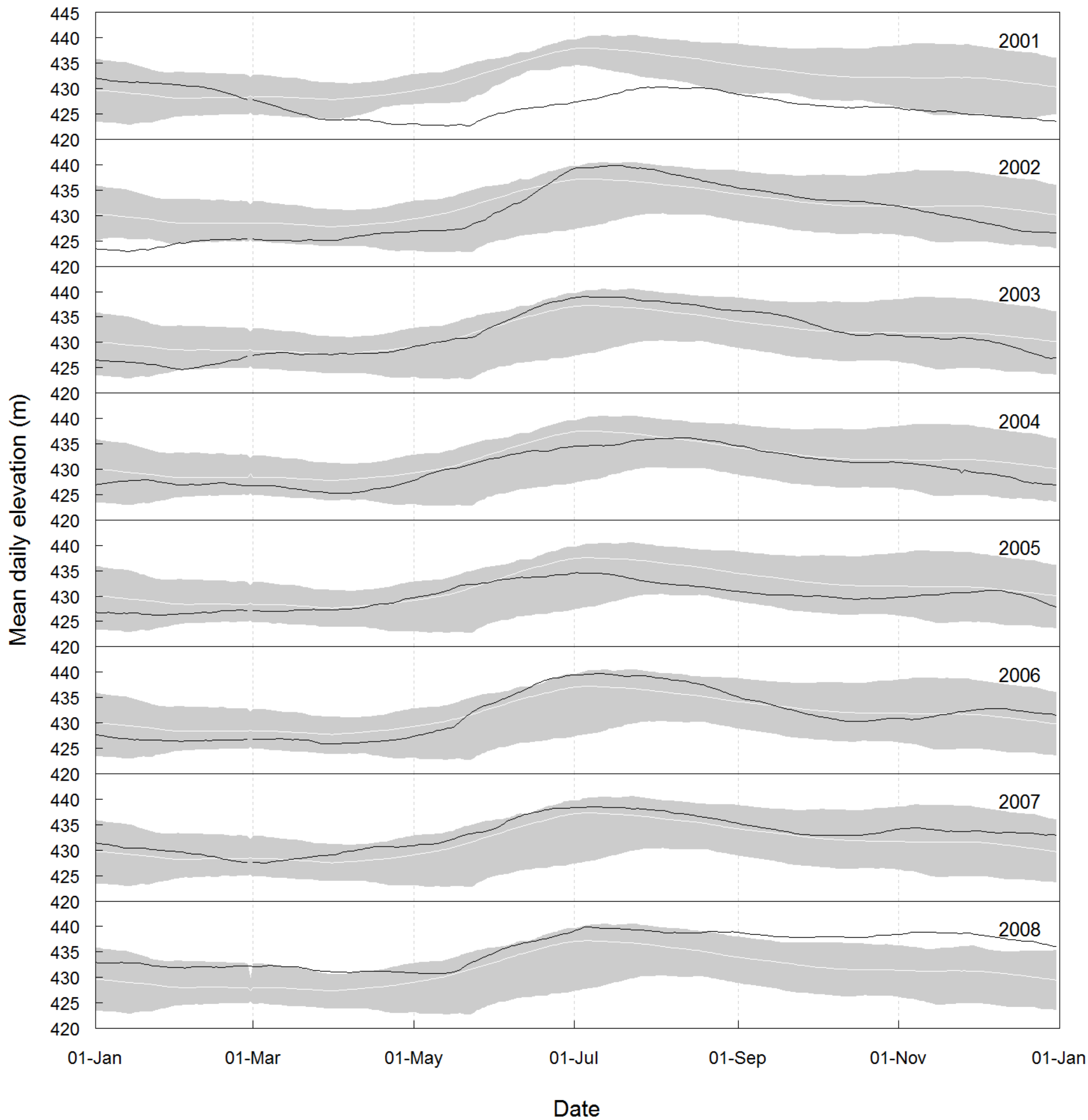


Figure C2 Mean hourly discharge (m³/s) for the Columbia River at Revelstoke Dam by sample session, October 11 to 28, 2016. The dotted line denotes the 142 m³/s minimum flow release.



Continued...

Figure C3 Mean daily water level elevation (in metres above sea level) for the Columbia River at Nakusp (Arrow Lakes Reservoir), 2001 to 2016. The shaded area represents minimum and maximum mean daily water elevations recorded at Nakusp during other study years (between 2001 and 2016). The white line represents average mean daily water elevation over the same time period.

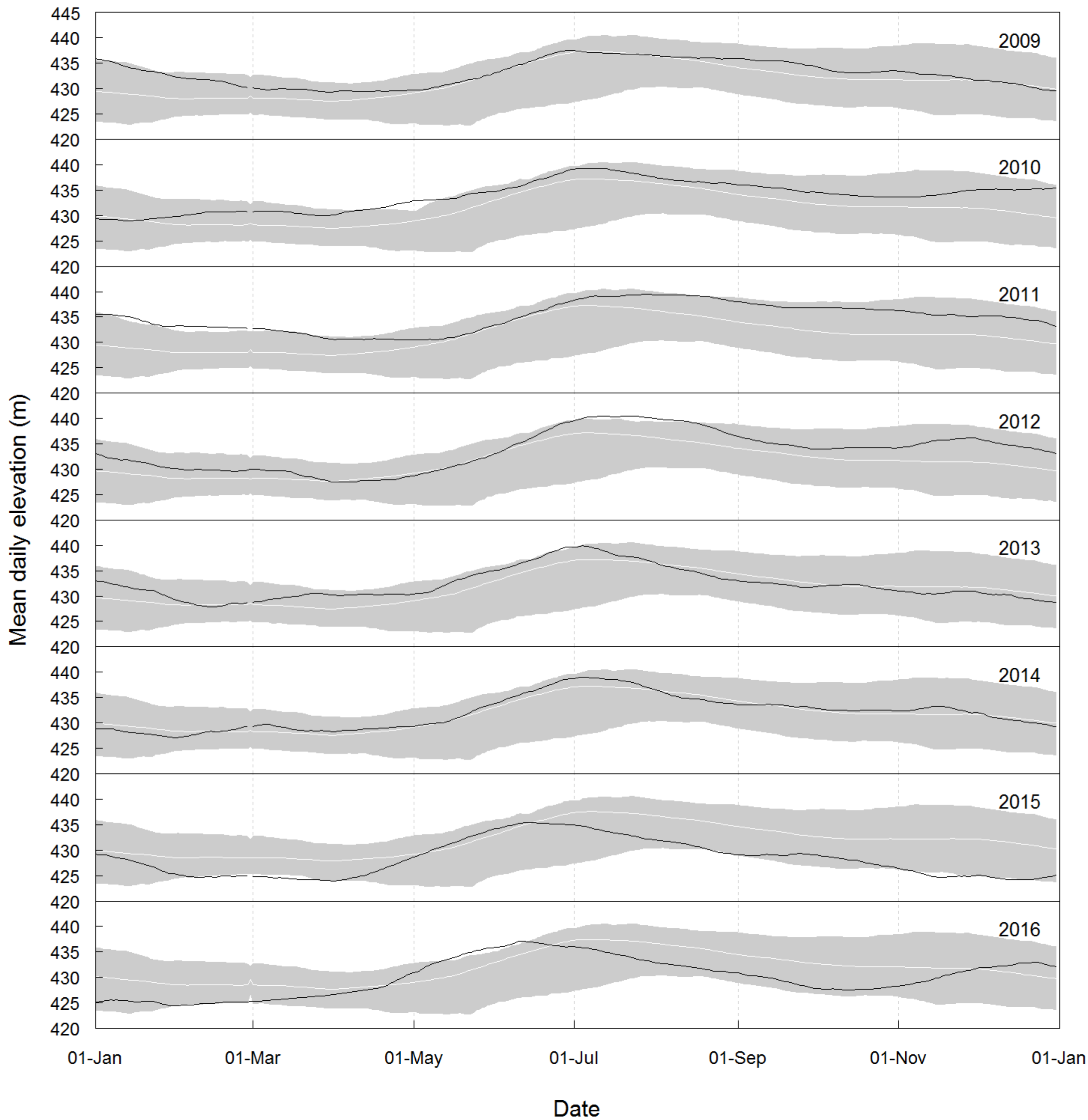
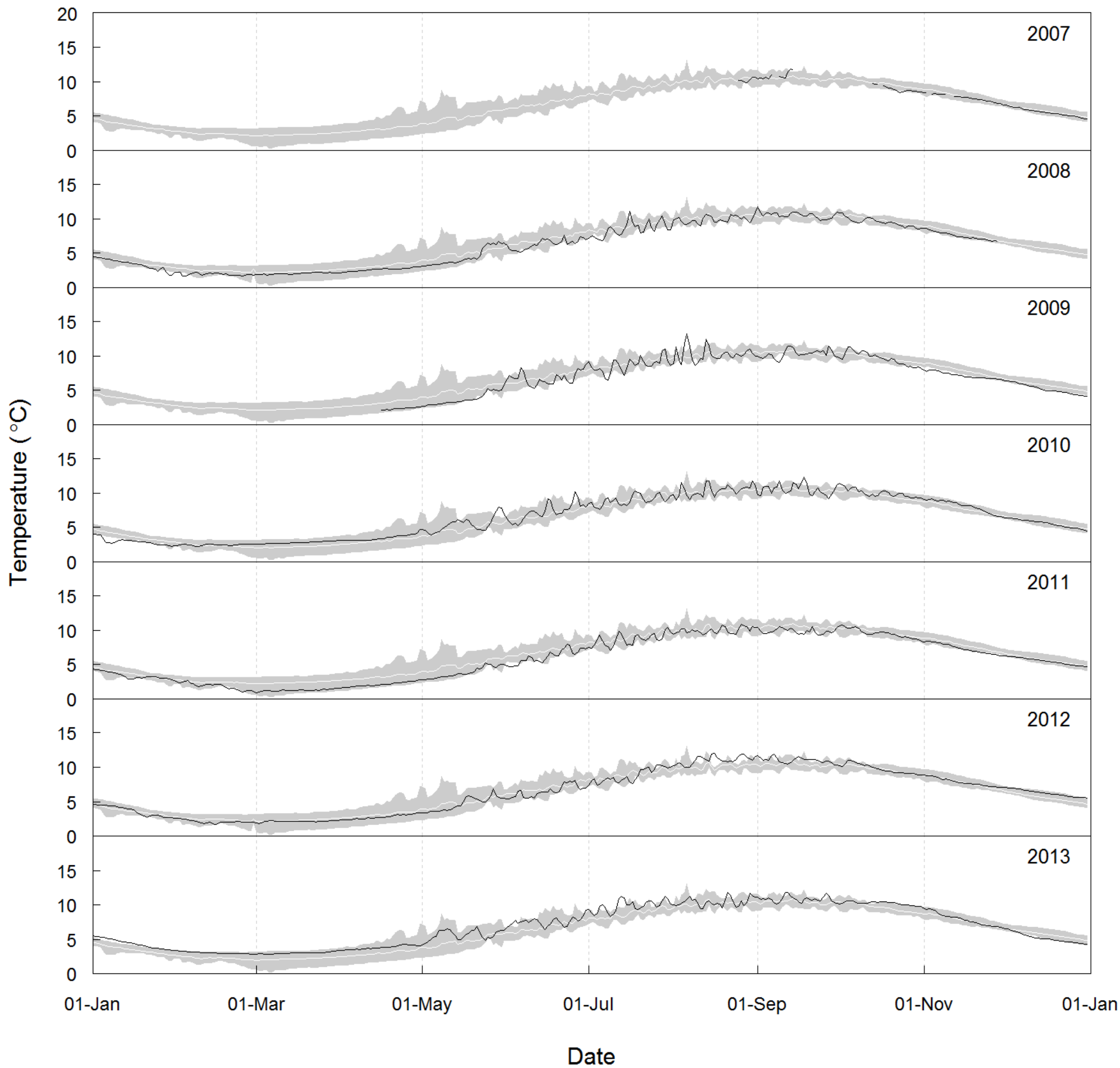


Figure C3 Concluded.



Continued...

Figure C4 Mean daily water temperature (°C) for the Columbia River at Revelstoke Dam, 2007 to 2016. The shaded area represents minimum and maximum mean daily water temperatures recorded at Revelstoke Dam during other study years (between 2007 and 2016). The white line represents average mean daily water temperature over the same time period. Temperature data for 2007-2013 and 2015-2016 are from Station 2 of the Middle Columbia River Physical Habitat Monitoring Program (CLBMON-15a). Data for 2014 are from Station 2AS because data from Station 2 were not available.

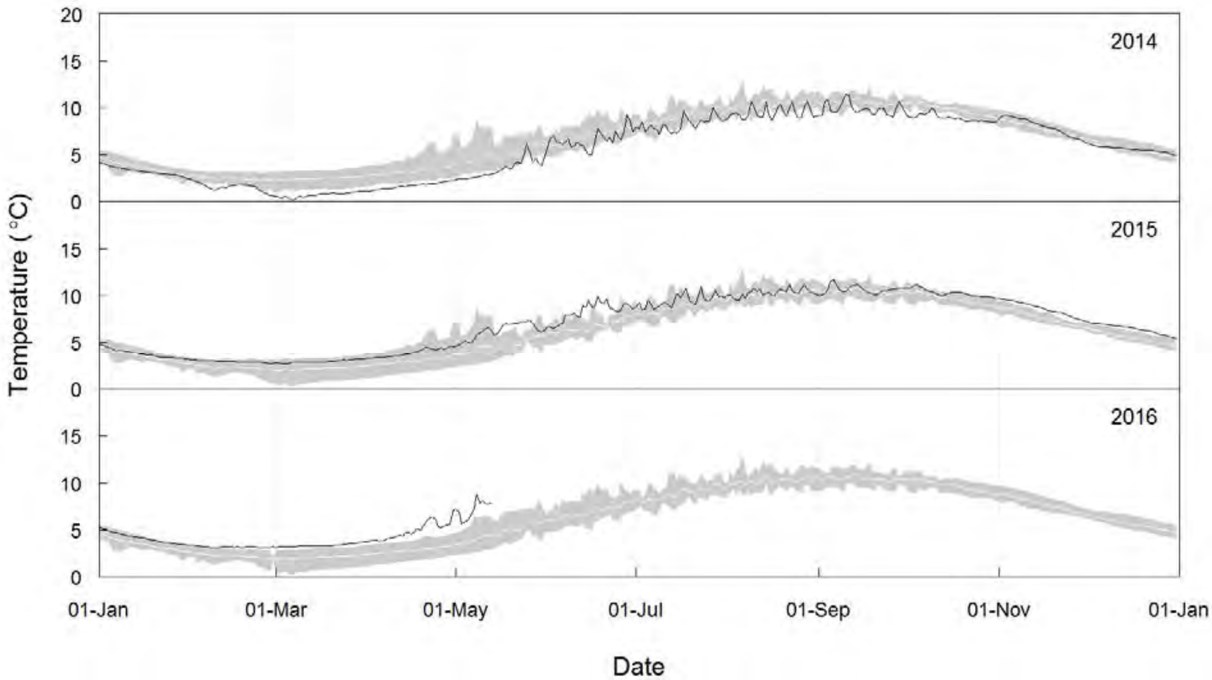


Figure C4 Concluded.

Appendix D – Catch and Effort

Table D1 Number of fish caught and observed during boat electroshocking surveys conducted during the fall season and their frequency of occurrence in sampled sections of the Middle Columbia River, 2001 to 2016.

	2001[a]		2002[a]		2003[a]		2004[a]		2005[a]		2006[a]		2007[a]		2008[a]		2009[a]		2010[a]		2011[a]		2012[a]		2014[a]		2015[a]		2016[a]	
Species	*n*[b]	%[c]	*n*[b]	%[c]	*n*[b]	%[c]	*n*[b]	%[c]	*n*[b]	%[c]	*n*[b]	%[c]	*n*[b]	%[c]	*n*[b]	%[c]	n[b,d]	%[c]	*n*[b]	%[c]	*n*[b]	%[c]	*n*[b]	%[c]	*n*[b]	%[c]	*n*[b]	%[c]	*n*[b]	%[c]
Sportfish																														
Brook Trout					1	<1	1	<1					1	<1					1	<1	3	<1							2	<1
Bull Trout	385	2	355	7	416	12	349	9	440	7	358	4	882	3	784	7	598	3	532	2	659	4	498	9	442	6	481	10	337	7
Burbot			7	<1	1	<1	6	<1	14	<1	14	<1	32	<1	63	1	9	<1	22	<1	61	<1	27	<1	3	<1			2	<1
Cutthroat Trout													1	<1					1	<1										
Kokanee	7654	46	48	1	263	8	107	3	1861	30	5874	62	20 602	70	1892	16	17 295	75	18 304	68	8173	53	86	1	2999	43	13	<1	18	<1
Lake Whitefish	16	<1	34	1	53	2	63	2	275	4	60	1	12	<1	42	<1	17	<1	983	4	230	1	92	2	29	<1	464	9	22	<1
Mountain Whitefish	8593	52	4428	91	2706	79	3368	86	3509	57	3133	33	7861	27	8743	73	4973	22	6720	25	6014	39	5059	87	3529	50	4079	81	4571	91
Pygmy Whitefish			1	<1													10	<1												
Rainbow Trout	7	<1			5	<1	14	<1	11	<1	15	<1	157	1	320	3	103	<1	111	<1	217	1	70	1	15	<1	24	<1	47	1
White Sturgeon	1	<1															1	<1												
Yellow Perch							8	<1	2	<1	3	<1	9	<1	134	1	1	<1	104	<1	2	<1	2	<1						
Sportfish subtotal	16 656	100	4873	100	3445	100	3916	100	6112	100	9457	100	29 557	100	11 978	100	23 007	100	26 778	100	15 359	100	5834	100	7017	100	5061	100	4999	100
Non-sportfish																														
Northern Pikeminnow	12	1			1	<1	2	<1	3	<1	2	<1	35	1	124	1	202	8	52	2	39	1	17	1	10	1	16	1	15	1
Peamouth	3	<1									1	<1	1	<1	6	<1	13	1			1	<1								
Redside Shiner			11	6	1	<1	239	26	246	29	97	8	553	18	3901	38	736	29	976	33	237	8	286	9	1	<1	61	3	52	5
Sculpin spp.[e]	3	<1	7	4	4	2	268	30	179	21	849	67	1387	45	5086	50	709	27	772	26	1807	59	1010	32	107	6	146	6	132	13
Sucker spp.[e]	1189	99	170	90	206	97	393	44	426	50	318	25	1088	36	1043	10	919	36	1168	39	974	32	1835	58	1705	94	2165	91	832	81
Non-sportfish subtotal	1207	100	188	100	212	100	902	100	854	100	1267	100	3064	100	10 160	100	2579	100	2968	100	3058	100	3148	100	1823	100	2388	100	1031	100
All species	17 863		5061		3657		4818		6966		10 724		32 621		22 138		25 586		29 746		18 417		8982		8840		7449		6030	

[a] From 2001 to 2006, the study area included all of Reach 4 and the Big Eddy section of Reach; from 2007 to 2016 the study area included all of Reaches 4 and 3.
[b] Includes fish observed and identified to species.
[c] Percent composition of sportfish or non-sportfish catch.
[d] Excludes fish recorded during the last session; data were not comparable due to lost observational datasheets.
[e] Species combined for table or not identified to species.

Table D2 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) during the fall season in the Middle Columbia River, 11 October to 27 October 2016.

					Time	Length	Number Caught (CPUE = no. fish/km/h)															
Reach	Section	Session	Site	Date	Sampled	Sampled	Brook Trout		Bull Trout		Burbot		Kokanee		Lake Whitefish		Mountain Whitefish		Rainbow Trout		All Species	
					(s)	(km)	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE
4	Upper	1	0232.6-R	13-Oct-16	437	0.80			2	20.7							40	413.97			42	434.67
			0233.1-L	14-Oct-16	814	1.41			15	47.12							57	179.04	1	3.14	73	229.3
			0234.4-R	13-Oct-16	1299	1.74			18	28.74			1	1.6			141	225.09			160	255.43
			0234.5-L	12-Oct-16	1642	1.65			12	15.91							123	163.04			135	178.95
			0236.1-L	12-Oct-16	779	1.41			4	13.11							72	235.98			76	249.09
			0236.1-R	12-Oct-16	1477	1.73			20	28.13			6	8.44			124	174.4			150	210.97
			0236.4-L	11-Oct-16	420	0.58			2	29.51							66	973.69			68	1003.2
			0236.4-R	11-Oct-16	344	0.59			4	70.47			4	70.47			54	951.37			62	1092.32
		Session Summary			**902**	**9.90**	**0**	**0**	**77**	**31.04**	**0**	**0**	**11**	**4.43**	**0**	**0**	**677**	**272.93**	**1**	**0.4**	**766**	**308.81**
		2	0232.6-R	18-Oct-16	640	0.80			2	14.13							54	381.6			56	395.73
			0233.1-L	19-Oct-16	935	1.31			10	29.44	1	2.94					115	338.52			126	370.9
			0234.4-R	18-Oct-16	1400	1.74			8	11.85					2	2.96	233	345.13			243	359.94
			0234.5-L	19-Oct-16	1633	1.65			7	9.33							258	343.87	1	1.33	266	354.54
			0236.1-L	17-Oct-16	936	1.41			12	32.73					2	5.46	112	305.51			126	343.7
			0236.1-R	18-Oct-16	1507	1.73			13	17.92					6	8.27	171	235.71	2	2.76	192	264.66
			0236.4-L	17-Oct-16	413	0.58			4	60.01							42	630.12	1	15	47	705.14
			0236.4-R	17-Oct-16	386	0.59			7	109.91							50	785.05			57	894.96
		Session Summary			**981**	**9.80**	**0**	**0**	**63**	**23.59**	**1**	**0.37**	**0**	**0**	**10**	**3.74**	**1035**	**387.57**	**4**	**1.5**	**1113**	**416.78**
		3	0232.6-R	26-Oct-16	561	0.80			2	16.12					1	8.06	52	419.21			55	443.39
			0233.1-L	26-Oct-16	1071	1.41			2	4.77							89	212.47	2	4.77	93	222.02
			0234.4-R	25-Oct-16	1447	1.74			10	14.33							285	408.44			295	422.77
			0234.5-L	25-Oct-16	1812	1.65			12	14.41							335	402.4	1	1.2	348	418.01
			0236.1-L	24-Oct-16	756	1.41			8	27.02					5	16.89	87	293.82			100	337.72
			0236.1-R	24-Oct-16	1627	1.73			12	15.32							282	360.05			294	375.37
			0236.4-L	24-Oct-16	346	0.58			5	89.54							58	1038.67			63	1128.21
			0236.4-R	24-Oct-16	330	0.59			3	55.1							30	550.96			33	606.06
		Session Summary			**994**	**9.90**	**0**	**0**	**54**	**19.75**	**0**	**0**	**0**	**0**	**6**	**2.19**	**1218**	**445.58**	**3**	**1.1**	**1281**	**468.63**
	Section Total All Samples				**23012**	**29.64**	**0**		**194**		**1**		**11**		**16**		**2930**		**8**		**3160**	
	Section Average All Samples				**959**	**1.23**	**0**	**0**	**8**	**24.57**	**0**	**0.13**	**0**	**1.39**	**1**	**2.03**	**122**	**371.14**	**0**	**1.01**	**132**	**400.27**
	Section Standard Error of Mean						**0**	**0**	**1.09**	**5.47**	**0.04**	**0.12**	**0.29**	**2.94**	**0.33**	**0.84**	**18.48**	**52.97**	**0.13**	**0.65**	**19.03**	**58.01**
3	Eddy	1	0231.3-R	13-Oct-16	1099	0.90			15	54.84			1	3.66	1	3.66	81	296.13	3	10.97	101	369.25
		Session Summary			**1099**	**0.90**	**0**	**0**	**15**	**54.6**	**0**	**0**	**1**	**3.64**	**1**	**3.64**	**81**	**294.81**	**3**	**10.92**	**101**	**367.61**
		2	0231.3-R	19-Oct-16	1256	0.90			8	25.59			2	6.4			32	102.37	4	12.8	46	147.15
		Session Summary			**1256**	**0.90**	**0**	**0**	**8**	**25.48**	**0**	**0**	**2**	**6.37**	**0**	**0**	**32**	**101.91**	**4**	**12.74**	**46**	**146.5**
		3	0231.3-R	26-Oct-16	1057	0.90			2	7.6			1	3.8			49	186.26	3	11.4	55	209.07
		Session Summary			**1057**	**0.90**	**0**	**0**	**2**	**7.57**	**0**	**0**	**1**	**3.78**	**0**	**0**	**49**	**185.43**	**3**	**11.35**	**55**	**208.14**
	Section Total All Samples				**3412**	**2.69**	**0**		**25**		**0**		**4**		**1**		**162**		**10**		**202**	
	Section Average All Samples				**1137**	**0.90**	**0**	**0**	**8**	**29.45**	**0**	**0**	**1**	**4.71**	**0**	**1.18**	**54**	**190.82**	**3**	**11.78**	**67**	**237.94**
	Section Standard Error of Mean						**0**	**0**	**3.76**	**13.77**	**0**	**0**	**0.33**	**0.89**	**0.33**	**1.22**	**14.36**	**56.1**	**0.33**	**0.55**	**17.03**	**66.17**
3	Middle	1	0227.2-R	13-Oct-16	535	0.52			9	116.69							1	12.97			10	129.65
			0228.5-L	14-Oct-16	1287	1.23			10	22.72							24	54.54	2	4.54	36	81.8
			0229.2-L	14-Oct-16	1141	1.10			5	14.33							29	83.11	1	2.87	35	100.3
			0229.7-R	13-Oct-16	1704	2.27			19	17.68			2	1.86			115	107.03	1	0.93	137	127.51
			0231.0-L	14-Oct-16	1263	1.96	1	1.45	9	13.06					1	1.45	46	66.76	2	2.9	59	85.63
			0231.0-R	14-Oct-16	1239	1.19			10	24.36							204	496.85	2	4.87	216	526.07
		Session Summary			**1195**	**8.30**	**1**	**0.36**	**62**	**22.5**	**0**	**0**	**2**	**0.73**	**1**	**0.36**	**419**	**152.08**	**8**	**2.9**	**493**	**178.94**
		2	0227.2-R	21-Oct-16	653	0.52			4	42.49							12	127.47	3	31.87	19	201.83
			0228.5-L	21-Oct-16	1099	1.23											14	37.25	3	7.98	17	45.24
			0229.2-L	20-Oct-16	1191	1.10			3	8.24							11	30.2			14	38.44
			0229.7-R	20-Oct-16	1429	1.71			9	13.26							270	397.78			279	411.03
			0231.0-L	20-Oct-16	1394	1.96			6	7.89	1	1.31					58	76.27	4	5.26	69	90.73
			0231.0-R	20-Oct-16	1428	1.19			7	14.79							229	483.92			236	498.71
		Session Summary			**1199**	**7.70**	**0**	**0**	**29**	**11.31**	**1**	**0.39**	**0**	**0**	**0**	**0**	**594**	**231.62**	**10**	**3.9**	**634**	**247.22**
		3	0227.2-R	27-Oct-16	581	0.52			3	35.82							3	35.82	3	35.82	9	107.45
			0228.5-L	27-Oct-16	1102	1.23			1	2.65							10	26.54	3	7.96	14	37.15
			0229.2-L	26-Oct-16	1177	1.10			3	8.33							18	50	1	2.78	22	61.12
			0229.7-R	27-Oct-16	1075	1.10			4	12.18					4	12.18	162	493.19			170	517.55
			0231.0-L	26-Oct-16	1406	1.96	1	1.3	10	13.04			1	1.3			43	56.06	4	5.21	59	76.92
			0231.0-R	26-Oct-16	1224	1.19			6	14.79							230	567.03			236	581.83
		Session Summary			**1094**	**7.10**	**1**	**0.46**	**27**	**12.51**	**0**	**0**	**1**	**0.46**	**4**	**1.85**	**466**	**215.98**	**11**	**5.1**	**510**	**236.37**
	Section Total All Samples				**20928**	**23.10**	**2**		**118**		**1**		**3**		**5**		**1479**		**29**		**1637**	
	Section Average All Samples				**1163**	**1.28**	**0**	**0.27**	**7**	**15.81**	**0**	**0.13**	**0**	**0.4**	**0**	**0.67**	**82**	**198.15**	**2**	**3.89**	**91**	**219.32**
	Section Standard Error of Mean						**0.08**	**0.1**	**1.05**	**6.14**	**0.06**	**0.07**	**0.12**	**0.12**	**0.23**	**0.68**	**21.95**	**47.56**	**0.34**	**2.45**	**22.19**	**46.61**
All Sections Total All Samples					**47352**	**55.43**	2	0	337	0.46	2	0	18	0.02	22	0.03	4571	6.27	47	0.06	4999	6.86
All Sections Average All Samples							0	0.12	7	20.8	0	0.12	0	1.11	0	1.36	102	282.14	1	2.9	111	308.55
All Sections Standard Error of Mean							0.03	0.04	0.75	3.92	0.03	0.07	0.17	1.57	0.2	0.52	13.5	38.73	0.2	1.13	13.77	40.85

Table D3 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) during the fall season in the Middle Columbia River, 11 October to 27 October 2016.

Reach	Section	Session	Site	Date	Time Sampled (s)	Length Sampled (km)	Number Caught (CPUE = no. fish/km/h)									
							Northern Pikeminnow		Redside Shiner		Sculpin spp.		Sucker spp.		All Species	
							No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE
4	Upper	1	0232.6-R	13-Oct-16	437	0.80							3	31.05	3	31.05
			0233.1-L	14-Oct-16	814	1.41					11	34.55	17	53.4	28	87.95
			0234.4-R	13-Oct-16	1299	1.74							51	81.42	51	81.42
			0234.5-L	12-Oct-16	1642	1.65							12	15.91	12	15.91
			0236.1-L	12-Oct-16	779	1.41	1	3.28					9	29.5	10	32.78
			0236.1-R	12-Oct-16	1477	1.73	1	1.41					25	35.16	26	36.57
			0236.4-L	11-Oct-16	420	0.58	1	14.75			1	14.75	7	103.27	9	132.78
			0236.4-R	11-Oct-16	344	0.59							7	123.33	7	123.33
		Session Summary			**902**	**9.90**	**3**	***1.21***	**0**	***0***	**12**	***4.84***	**131**	***52.81***	**146**	***58.86***
		2	0232.6-R	18-Oct-16	640	0.80							3	21.2	3	21.2
			0233.1-L	19-Oct-16	935	1.31					6	17.66	30	88.31	36	105.97
			0234.4-R	18-Oct-16	1400	1.74					14	20.74	49	72.58	63	93.32
			0234.5-L	19-Oct-16	1633	1.65							11	14.66	11	14.66
			0236.1-L	17-Oct-16	936	1.41							10	27.28	10	27.28
			0236.1-R	18-Oct-16	1507	1.73					6	8.27	30	41.35	36	49.62
			0236.4-L	17-Oct-16	413	0.58							7	105.02	7	105.02
			0236.4-R	17-Oct-16	386	0.59					3	47.1	3	47.1	6	94.21
		Session Summary			**981**	**9.80**	**0**	***0***	**0**	***0***	**29**	***10.86***	**143**	***53.55***	**172**	***64.41***
		3	0232.6-R	26-Oct-16	561	0.80							2	16.12	2	16.12
			0233.1-L	26-Oct-16	1071	1.41					1	2.39	29	69.23	30	71.62
			0234.4-R	25-Oct-16	1447	1.74							54	77.39	54	77.39
			0234.5-L	25-Oct-16	1812	1.65					1	1.2	20	24.02	21	25.22
			0236.1-L	24-Oct-16	756	1.41							16	54.04	16	54.04
			0236.1-R	24-Oct-16	1627	1.73							42	53.62	42	53.62
			0236.4-L	24-Oct-16	346	0.58							10	179.08	10	179.08
			0236.4-R	24-Oct-16	330	0.59					2	36.73	1	18.37	3	55.1
		Session Summary			**994**	**9.90**	**0**	***0***	**0**	***0***	**4**	***1.46***	**174**	***63.65***	**178**	***65.12***
	Section Total All Samples				**23012**	**29.64**	**3**		**0**		**45**		**448**		**496**	
	Section Average All Samples				**959**	**1.23**	**0**	***0.38***	**0**	***0***	**2**	***5.7***	**19**	***56.75***	**21**	***62.83***
	Section Standard Error of Mean						**0.07**	***0.62***	**0**	***0***	**0.76**	***2.82***	**3.37**	***8.33***	**3.68**	***8.8***
3	Eddy	1	0231.3-R	13-Oct-16	1099	0.90			2	7.31			6	21.94	8	29.25
		Session Summary			**1099**	**0.90**	**0**	***0***	**2**	***7.28***	**0**	***0***	**6**	***21.84***	**8**	***29.12***
		2	0231.3-R	19-Oct-16	1256	0.90	1	3.2	1	3.2	16	51.18	2	6.4	20	63.98
		Session Summary			**1256**	**0.90**	**1**	***3.18***	**1**	***3.18***	**16**	***50.96***	**2**	***6.37***	**20**	***63.69***
		3	0231.3-R	26-Oct-16	1057	0.90			9	34.21			1	3.8	10	38.01
		Session Summary			**1057**	**0.90**	**0**	***0***	**9**	***34.06***	**0**	***0***	**1**	***3.78***	**10**	***37.84***
	Section Total All Samples				**3412**	**2.69**	**1**		**12**		**16**		**9**		**38**	
	Section Average All Samples				**1137**	**0.90**	**0**	***1.18***	**4**	***14.13***	**5**	***18.85***	**3**	***10.6***	**13**	***44.76***
	Section Standard Error of Mean						**0.33**	***1.07***	**2.52**	***9.72***	**5.33**	***17.06***	**1.53**	***5.66***	**3.71**	***10.43***
3	Middle	1	0227.2-R	13-Oct-16	535	0.52					1	12.97	5	64.83	6	77.79
			0228.5-L	14-Oct-16	1287	1.23			2	4.54	4	9.09	10	22.72	16	36.36
			0229.2-L	14-Oct-16	1141	1.10	3	8.6	13	37.25	10	28.66	33	94.57	59	169.08
			0229.7-R	13-Oct-16	1704	2.27			1	0.93			51	47.47	52	48.4
			0231.0-L	14-Oct-16	1263	1.96	1	1.45					15	21.77	16	23.22
			0231.0-R	14-Oct-16	1239	1.19	1	2.44					33	80.37	34	82.81
		Session Summary			**1195**	**8.30**	**5**	***1.81***	**16**	***5.81***	**15**	***5.44***	**147**	***53.35***	**183**	***66.42***
		2	0227.2-R	21-Oct-16	653	0.52					17	180.58	8	84.98	25	265.56
			0228.5-L	21-Oct-16	1099	1.23			2	5.32	2	5.32	4	10.64	8	21.29
			0229.2-L	20-Oct-16	1191	1.10	2	5.49			2	5.49	52	142.76	56	153.74
			0229.7-R	20-Oct-16	1429	1.71							54	79.56	54	79.56
			0231.0-L	20-Oct-16	1394	1.96	1	1.31			1	1.31	11	14.46	13	17.09
			0231.0-R	20-Oct-16	1428	1.19			20	42.26	2	4.23	7	14.79	29	61.28
		Session Summary			**1199**	**7.70**	**3**	***1.17***	**22**	***8.58***	**24**	***9.36***	**136**	***53.03***	**185**	***72.14***
		3	0227.2-R	27-Oct-16	581	0.52					3	35.82	5	59.69	8	95.51
			0228.5-L	27-Oct-16	1102	1.23			1	2.65	5	13.27	7	18.58	13	34.5
			0229.2-L	26-Oct-16	1177	1.10	3	8.33	1	2.78	7	19.45	41	113.9	52	144.46
			0229.7-R	27-Oct-16	1075	1.10							28	85.24	28	85.24
			0231.0-L	26-Oct-16	1406	1.96					17	22.16	4	5.21	21	27.38
			0231.0-R	26-Oct-16	1224	1.19							7	17.26	7	17.26
		Session Summary			**1094**	**7.10**	**3**	***1.39***	**2**	***0.93***	**32**	***14.83***	**92**	***42.64***	**129**	***59.79***
	Section Total All Samples				**20928**	**23.10**	**11**		**40**		**71**		**375**		**497**	
	Section Average All Samples				**1163**	**1.28**	**1**	***1.47***	**2**	***5.36***	**4**	***9.51***	**21**	***50.24***	**28**	***66.59***
	Section Standard Error of Mean						**0.24**	***0.68***	**1.27**	***2.99***	**1.29**	***9.86***	**4.35**	***9.66***	**4.48**	***15.65***
All Sections Total All Samples					**47352**	**55.43**	***15***	***0.02***	***52***	***0.07***	***132***	***0.18***	***832***	***1.14***	***1031***	***1.41***
All Sections Average All Samples							***0***	***0.93***	***1***	***3.21***	***3***	***8.15***	***18***	***51.35***	***23***	***63.64***
All Sections Standard Error of Mean							***0.11***	***0.43***	***0.55***	***1.43***	***0.73***	***4.34***	***2.55***	***6.07***	***2.71***	***7.87***

Table D4 Summary of the number (N) of fish captured and recaptured in sampled sections of the Middle Columbia River during the fall season, 11 October to 27 October 2016.

Species	Size-class	Session	N Captured	N Marked	N Recaptured (within year)	N Recaptured (between years)
Burbot	All	1	0	0	-	0
		2	1	1	0	0
		3	0	0	0	0
Burbot Total			1	1	0	0
Bull Trout	All	1	81	72	-	9
		2	69	52	3	14
		3	51	40	5	6
Bull Trout Total			201	164	8	29
Lake Whitefish	All	1	2	2	-	0
		2	6	6	0	0
		3	8	8	0	0
Lake Whitefish Total			16	16	0	0
Mountain Whitefish	All	1	481	404	-	77
		2	638	506	29	103
		3	640	506	46	88
Mountain Whitefish Total			1759	1416	75	268
Northern Pikeminnow	All	1	8	7	-	1
		2	4	3	0	1
		3	3	1	1	1
Northern Pikeminnow Total			15	11	1	3
Rainbow Trout	All	1	8	8	-	0
		2	15	12	1	2
		3	15	11	4	0
Rainbow Trout Total			38	31	5	2
Sucker spp.	All	1	173	144	-	29
		2	194	141	14	39
		3	163	110	33	20
Sucker spp. Total			530	395	47	88

Appendix E – Life History

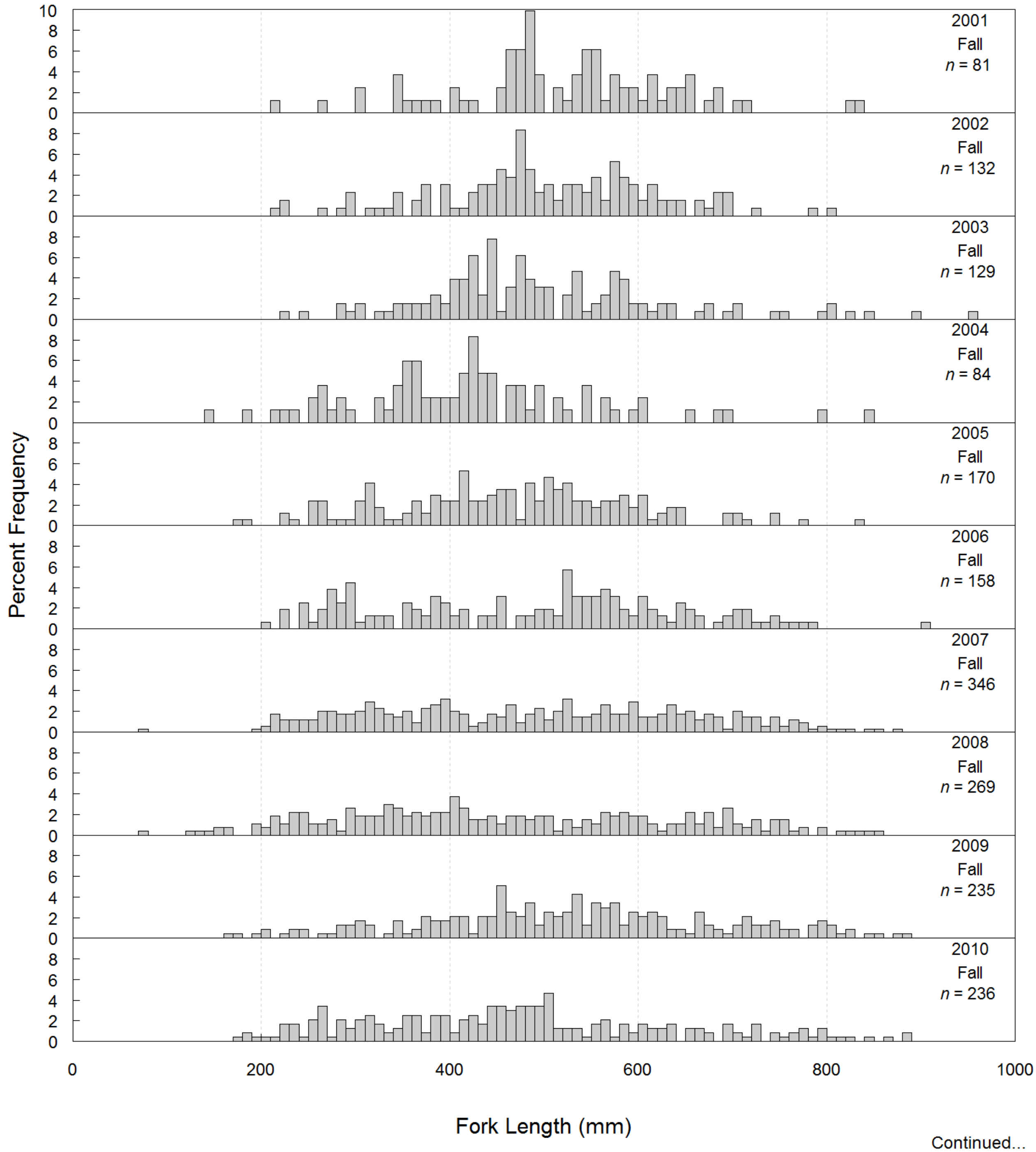


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Figure E1 Length-frequency distributions for Bull Trout captured by boat electroshocking in Reaches 3 and 4 of the Middle Columbia River, 2001 to 2016. Bull Trout that were initially marked during an earlier year of the program were excluded from the analysis due to potential tagging effects on growth. Boat electroshocking surveys were not conducted downstream of Big Eddy for all years prior to 2007.

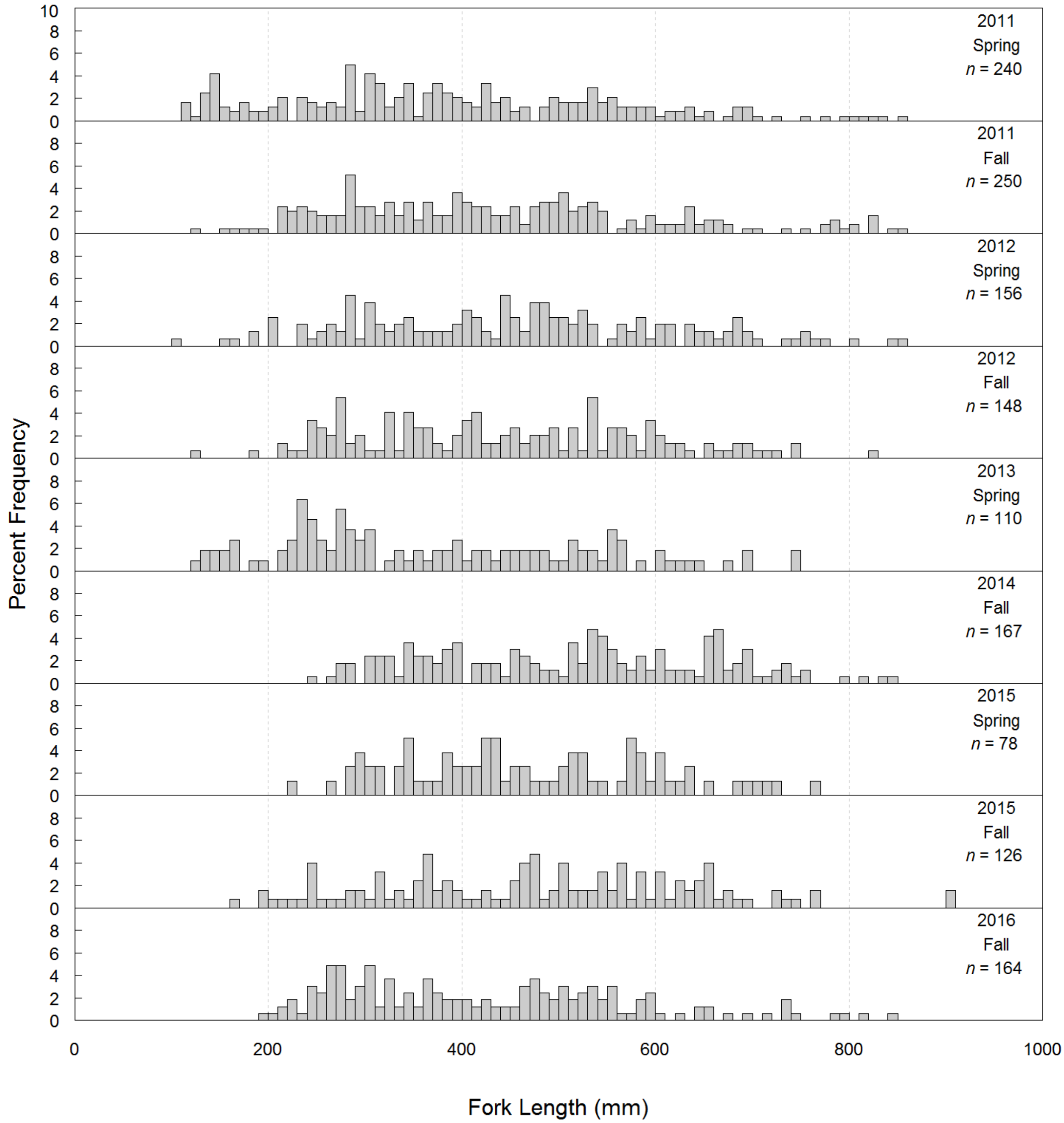

Figure E1 Concluded.

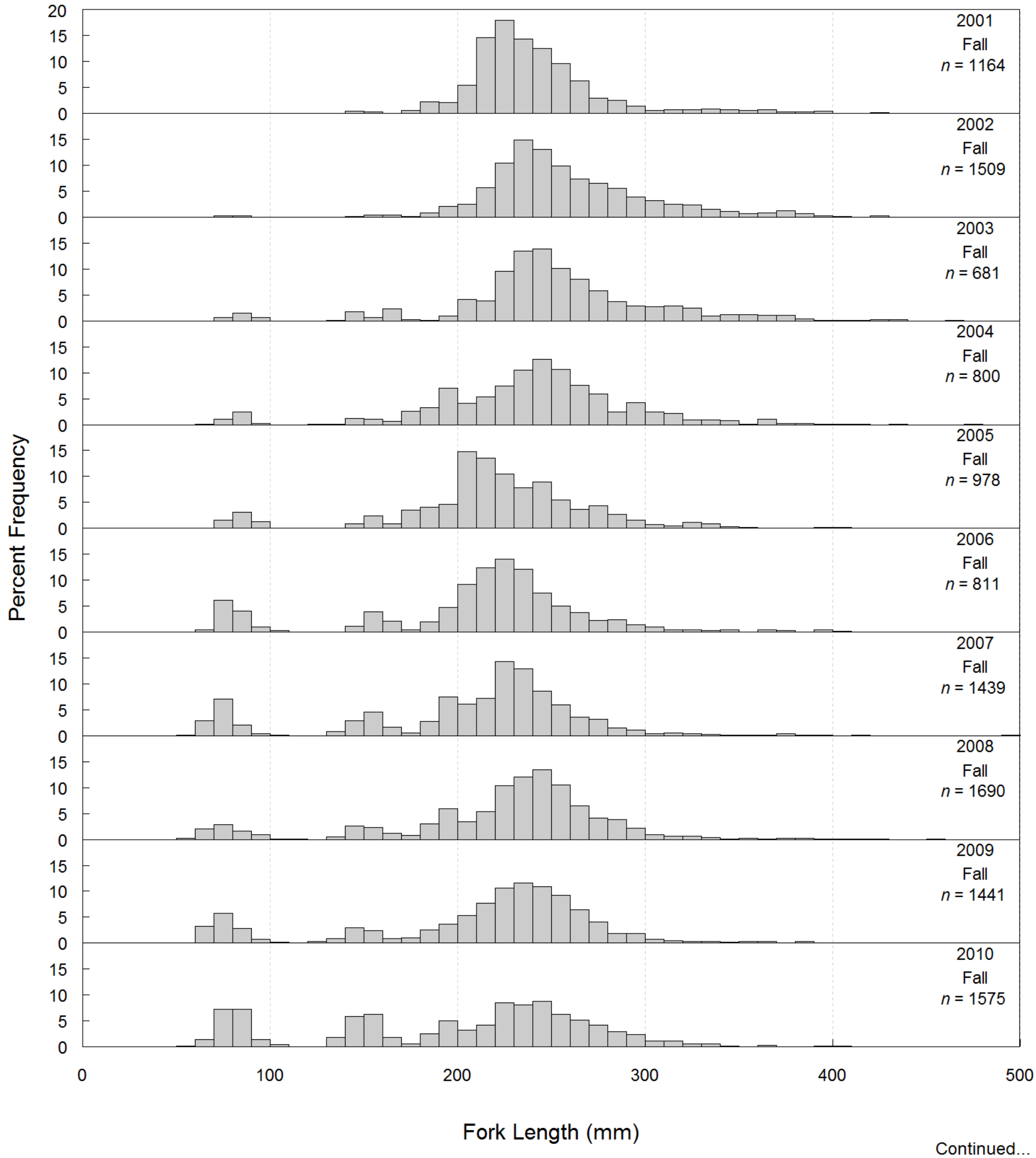

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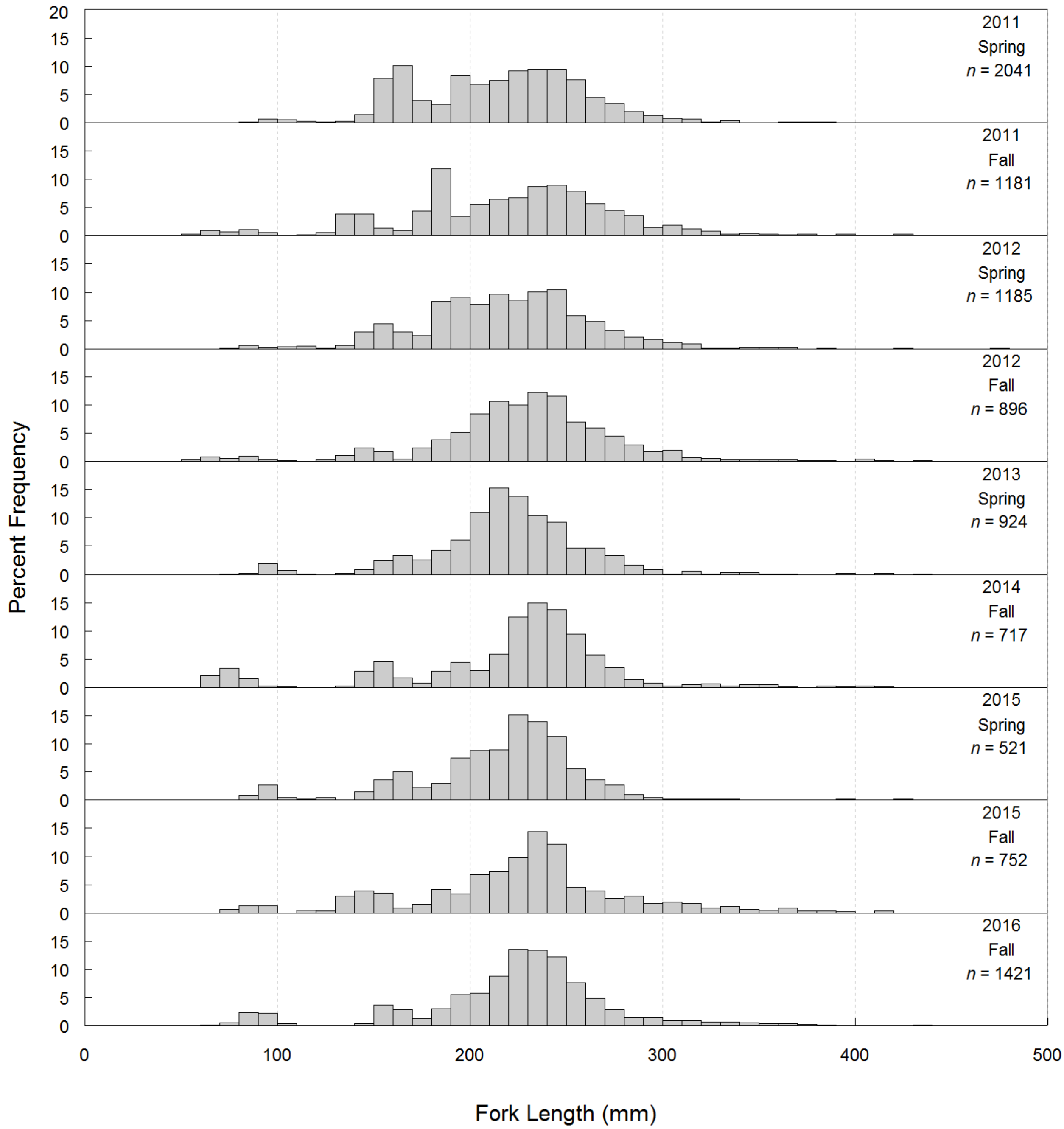
Figure E2 Length-frequency distributions for Mountain Whitefish captured by boat electroshocking in Reaches 3 and 4 of the Middle Columbia River, 2001 to 2016. Mountain Whitefish that were initially marked during an earlier year of the program were excluded from the analysis due to potential tagging effects on growth. Boat electroshocking surveys were not conducted downstream of Big Eddy for all years prior to 2007.



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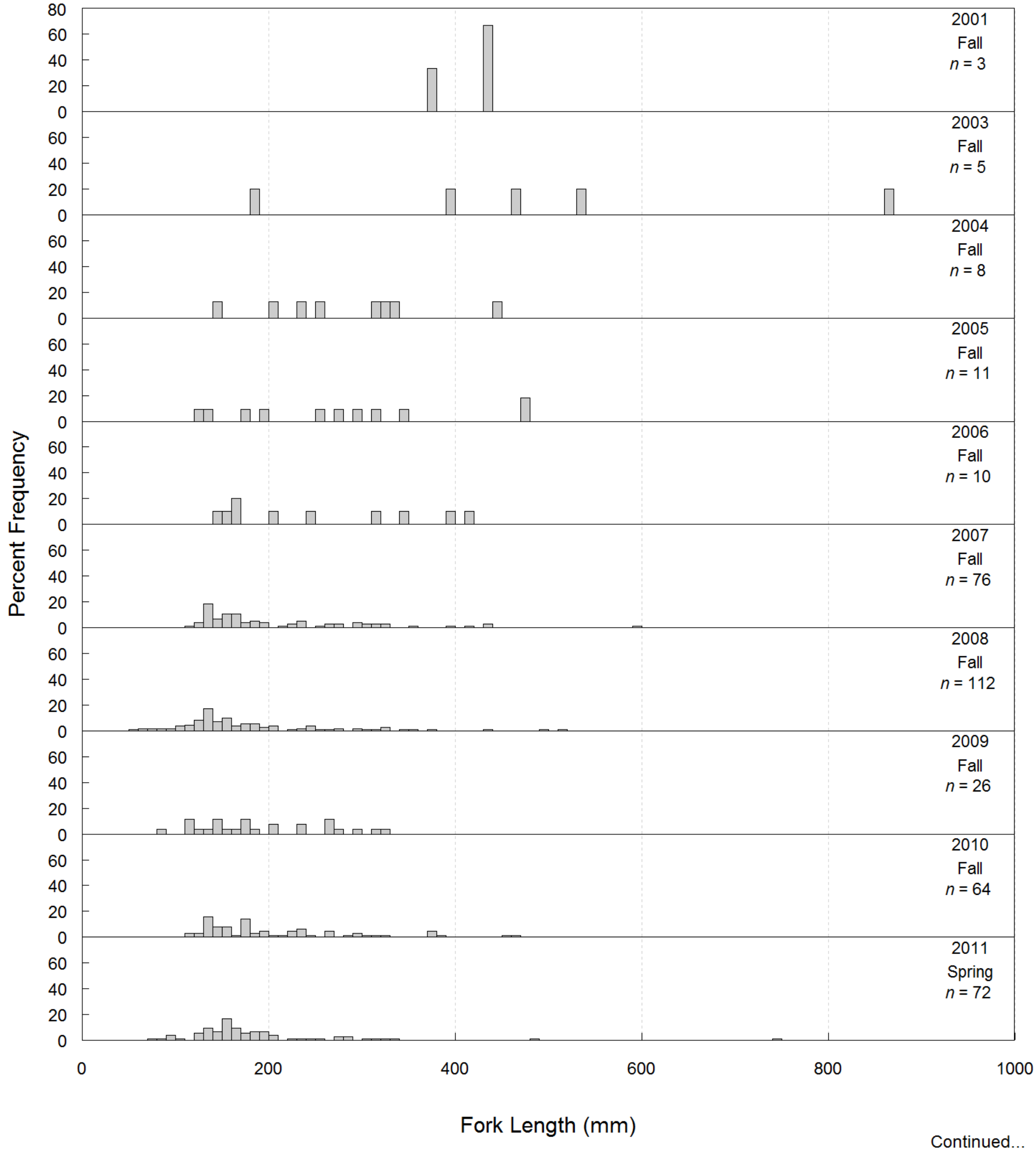

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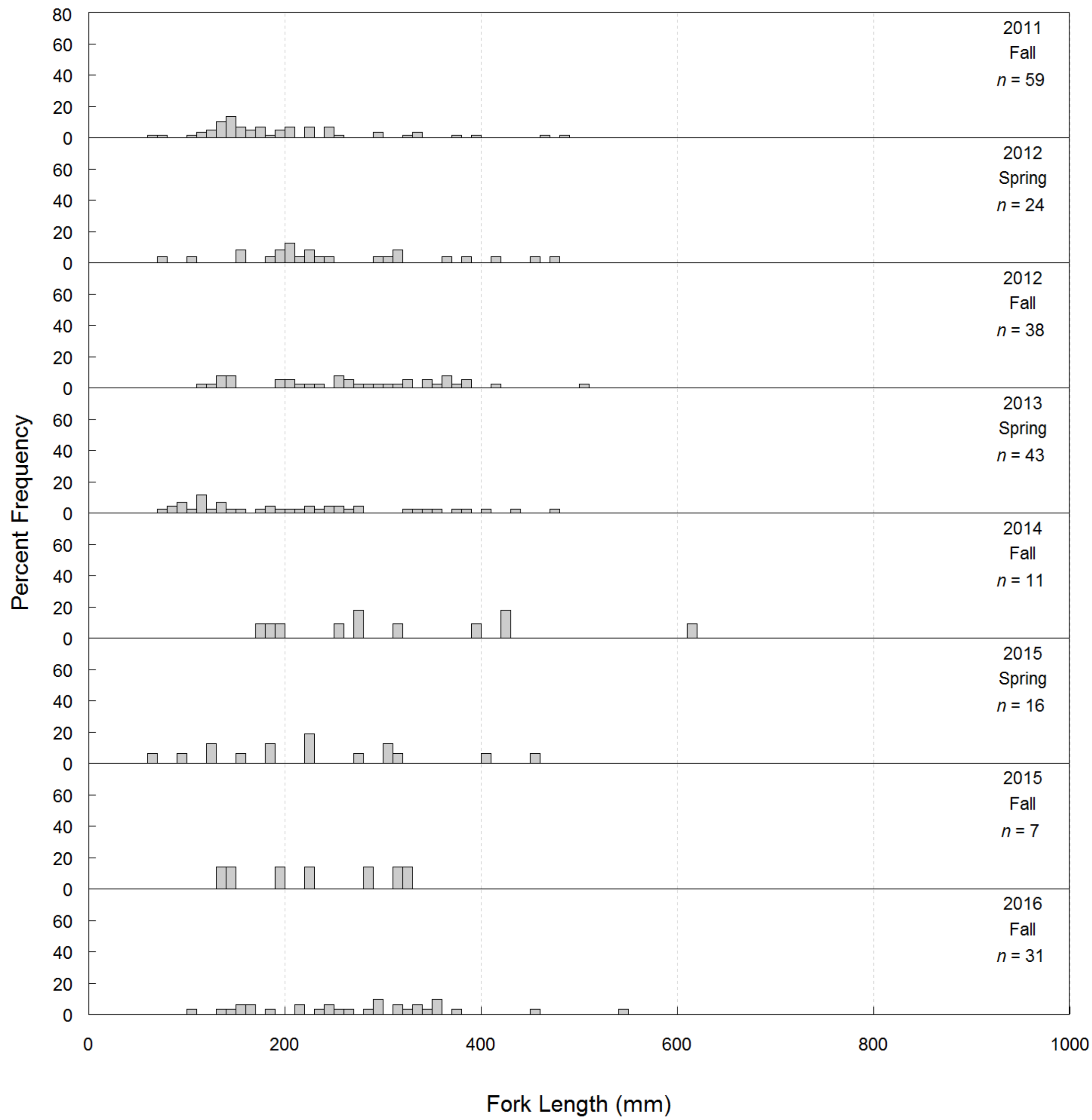
Figure E3 Length-frequency distributions for Rainbow Trout captured by boat electroshocking in Reaches 3 and 4 of the Middle Columbia River, 2001 to 2016. Rainbow Trout that were initially marked during an earlier year of the program were excluded from the analysis due to potential tagging effects on growth. Boat electroshocking surveys were not conducted downstream of Big Eddy for all years prior to 2007.



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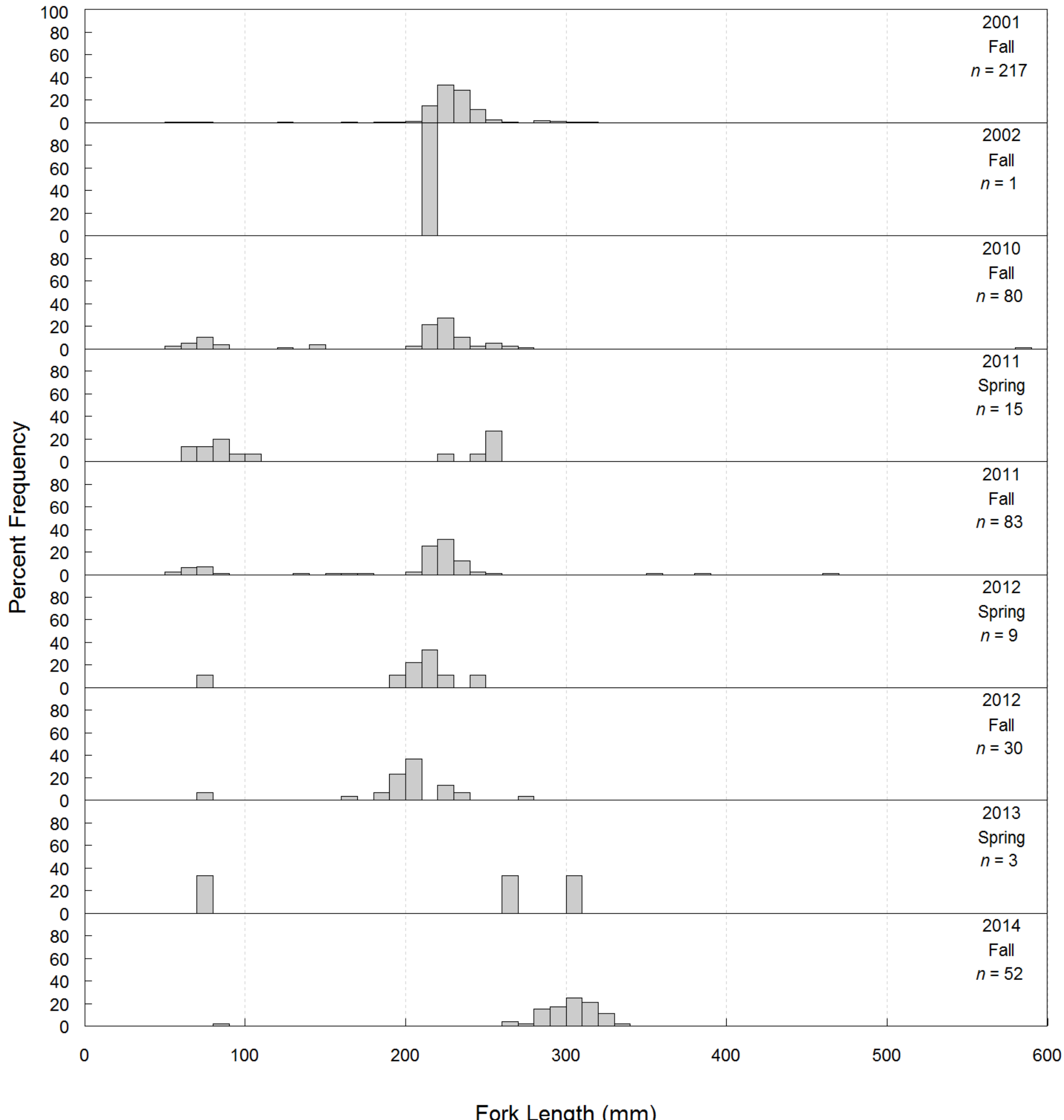

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Figure E4 Length-frequency distributions for Kokanee captured by boat electroshocking in Reaches 3 and 4 of the Middle Columbia River, 2001 to 2016.

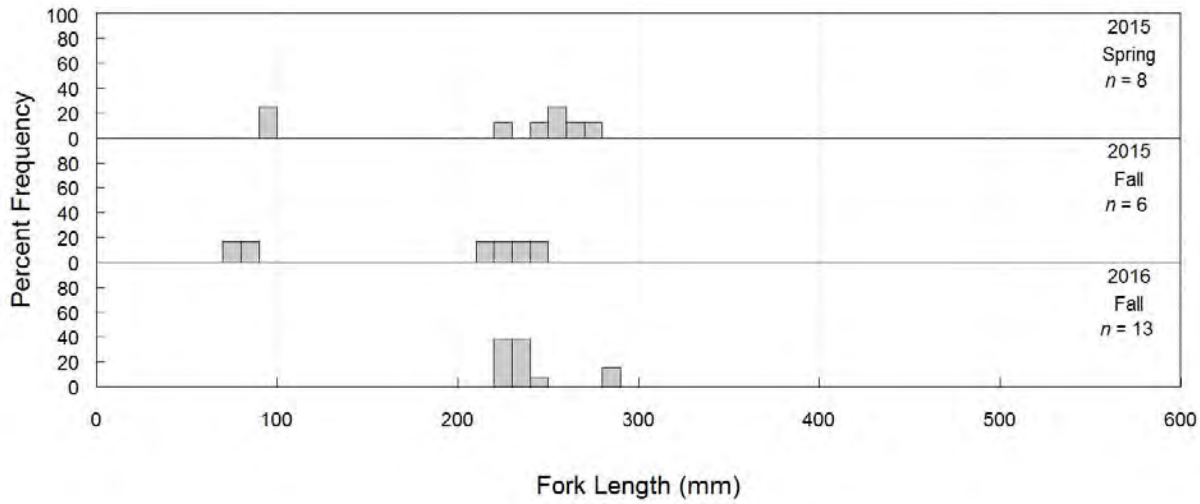

Figure E4 Concluded

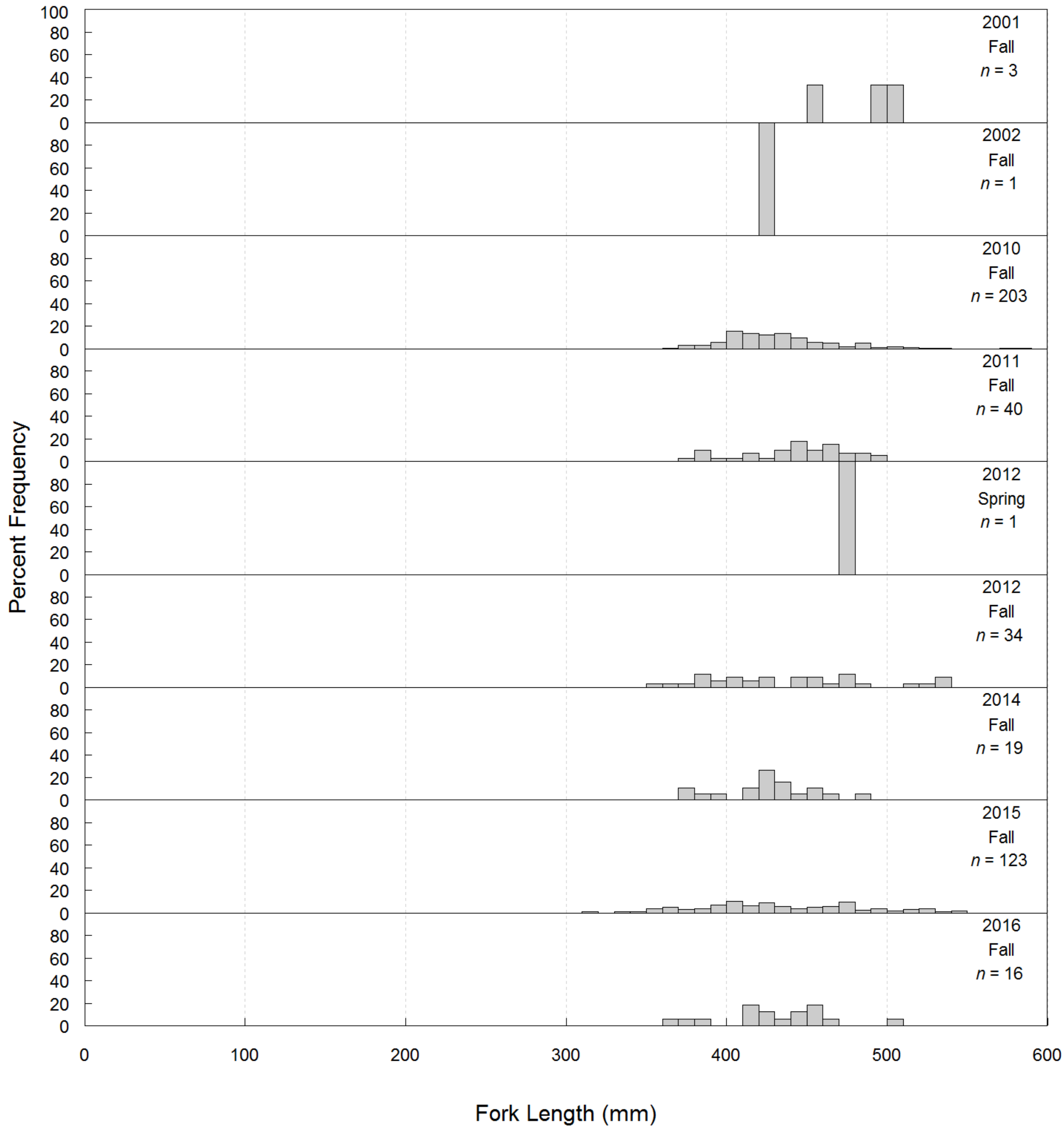

Figure E5 Length-frequency distributions for Lake Whitefish captured by boat electroshocking in Reaches 3 and 4 of the Middle Columbia River, 2001 to 2016. Lake Whitefish that were initially marked during an earlier year of the program were excluded from the analysis due to potential tagging effects on growth.

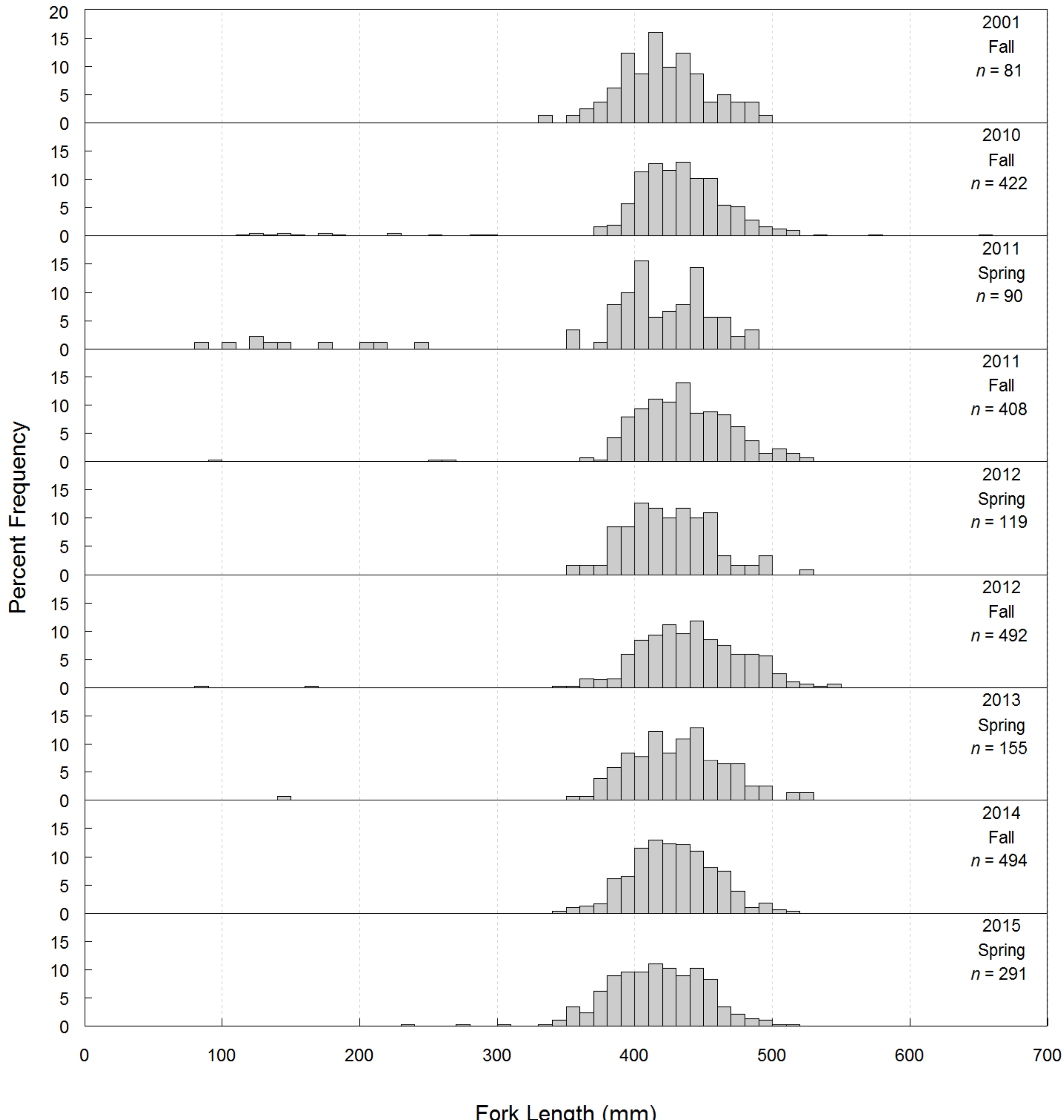

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Figure E6 Length-frequency distributions for Largescale Sucker captured by boat electroshocking in Reaches 3 and 4 of the Middle Columbia River, 2001 to 2016. Largescale Sucker that were initially marked during an earlier year of the program were excluded from the analysis due to potential tagging effects on growth.

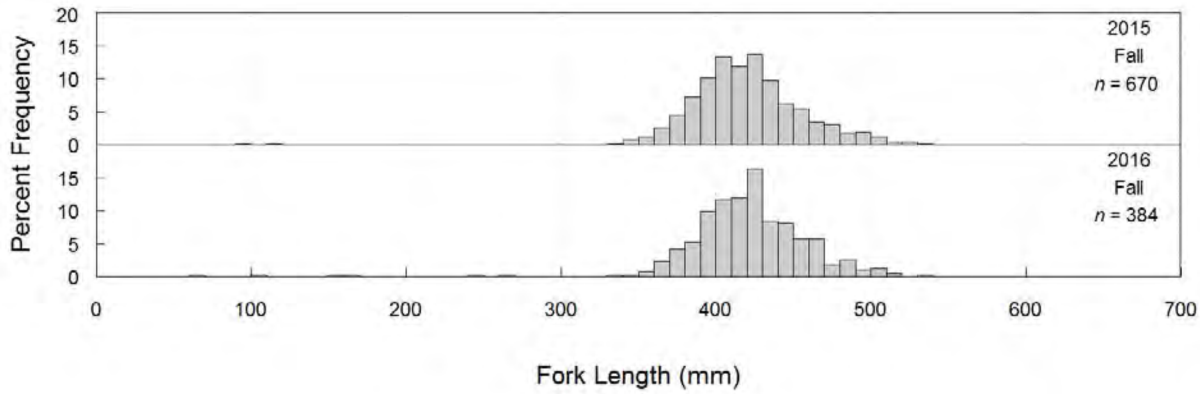

Figure E6 Concluded

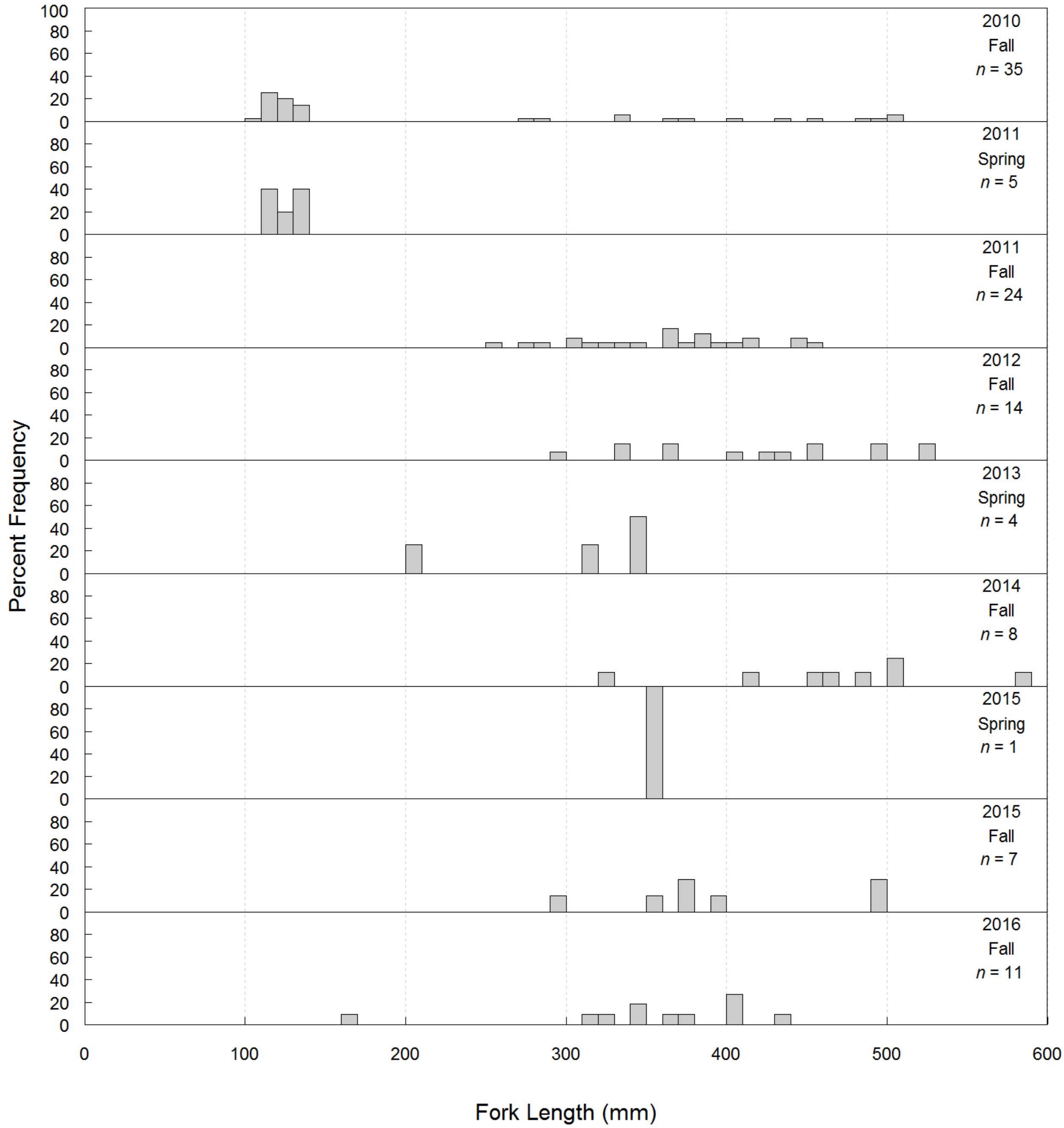

Figure E7 Length-frequency distributions for Northern Pikeminnow captured by boat electroshocking in Reaches 3 and 4 of the Middle Columbia River, 2010 to 2016. Northern Pikeminnow that were initially marked during an earlier year of the program were excluded from the analysis due to potential tagging effects on growth.

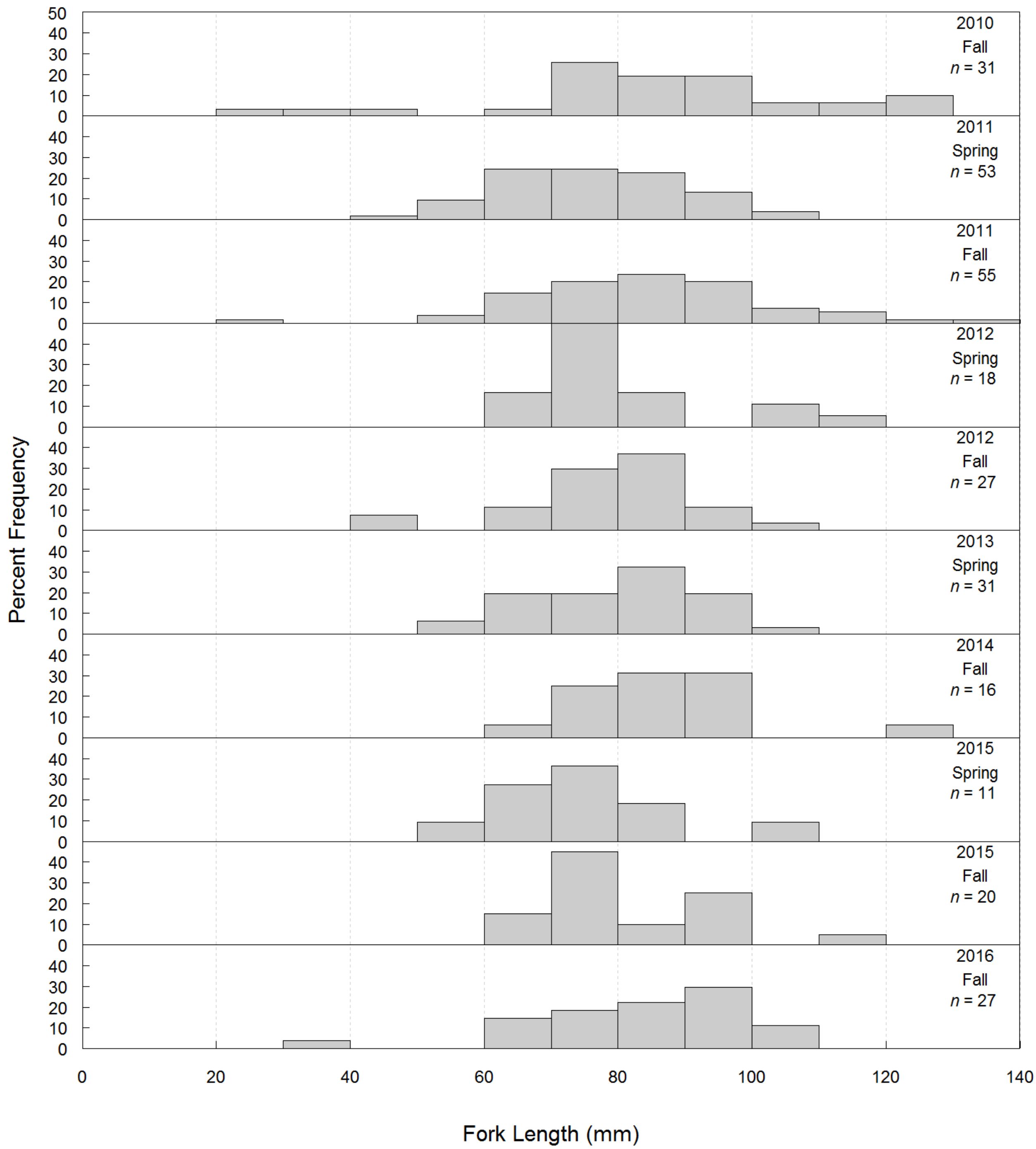

Figure E8 Length-frequency distributions for Prickly Sculpin captured by boat electroshocking in Reaches 3 and 4 of the Middle Columbia River, 2010 to 2016.

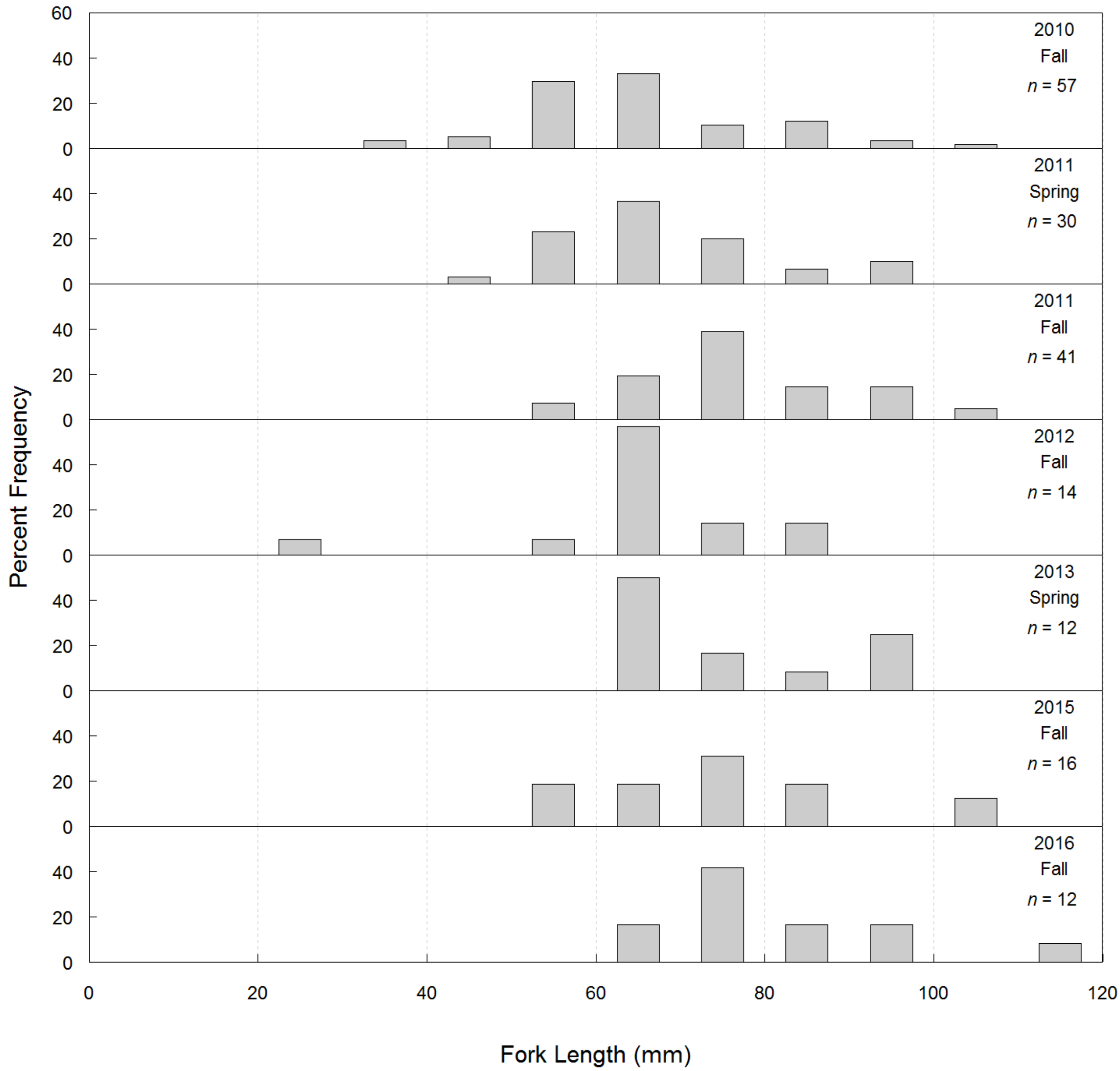

Figure E9 Length-frequency distributions for Redside Shiner captured by boat electroshocking in Reaches 3 and 4 of the Middle Columbia River, 2010 to 2016. Only one Redside Shiner was caught in 2014.

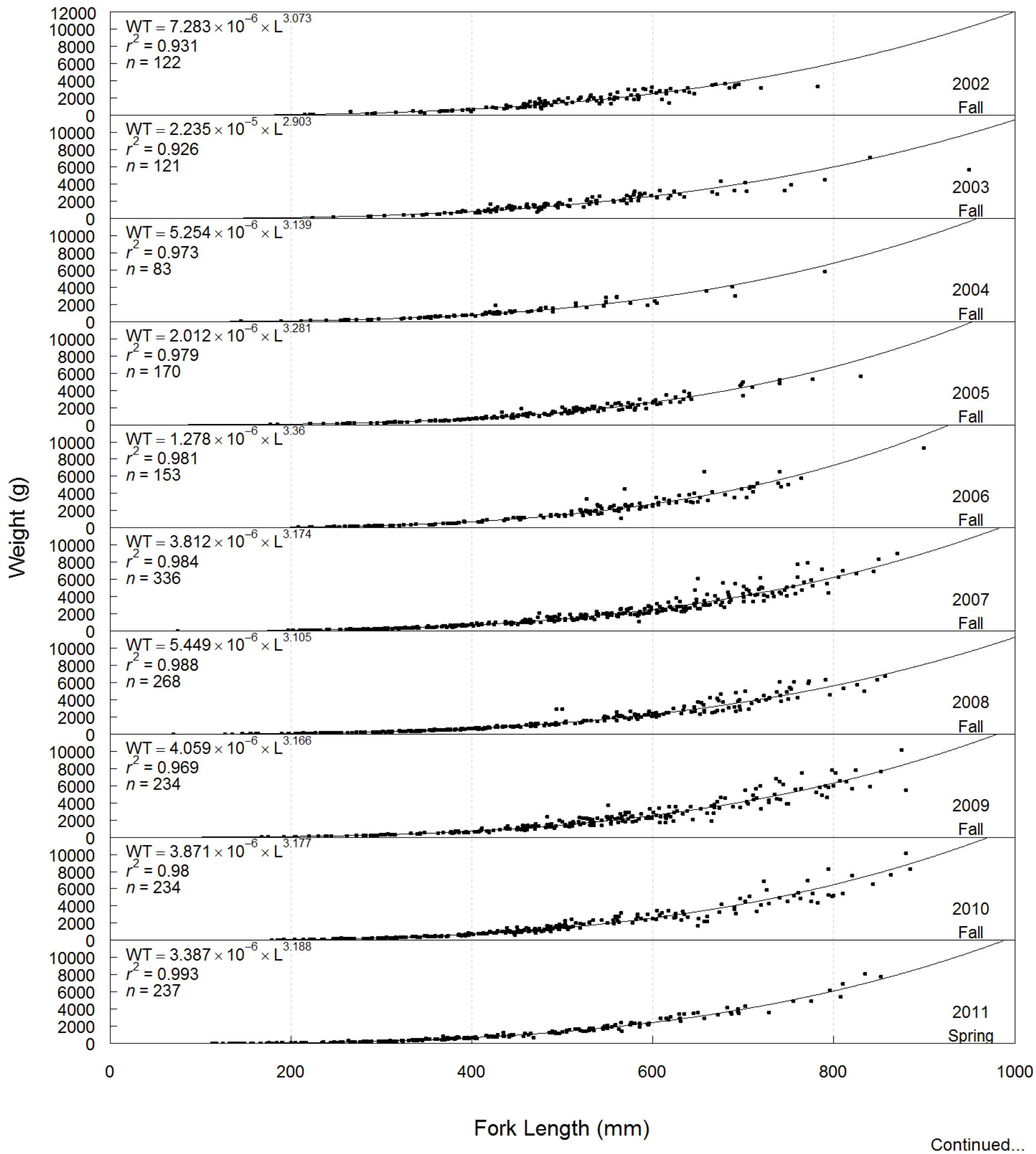

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Figure E10 Length-weight regression for Bull Trout captured by boat electroshocking in Reaches 3 and 4 of the Middle Columbia River, 2002 to 2016. Bull Trout that were initially marked during an earlier year of the program were excluded from the analysis due to potential tagging effects on growth. Boat electroshocking surveys were not conducted downstream of Big Eddy for all years prior to 2007.

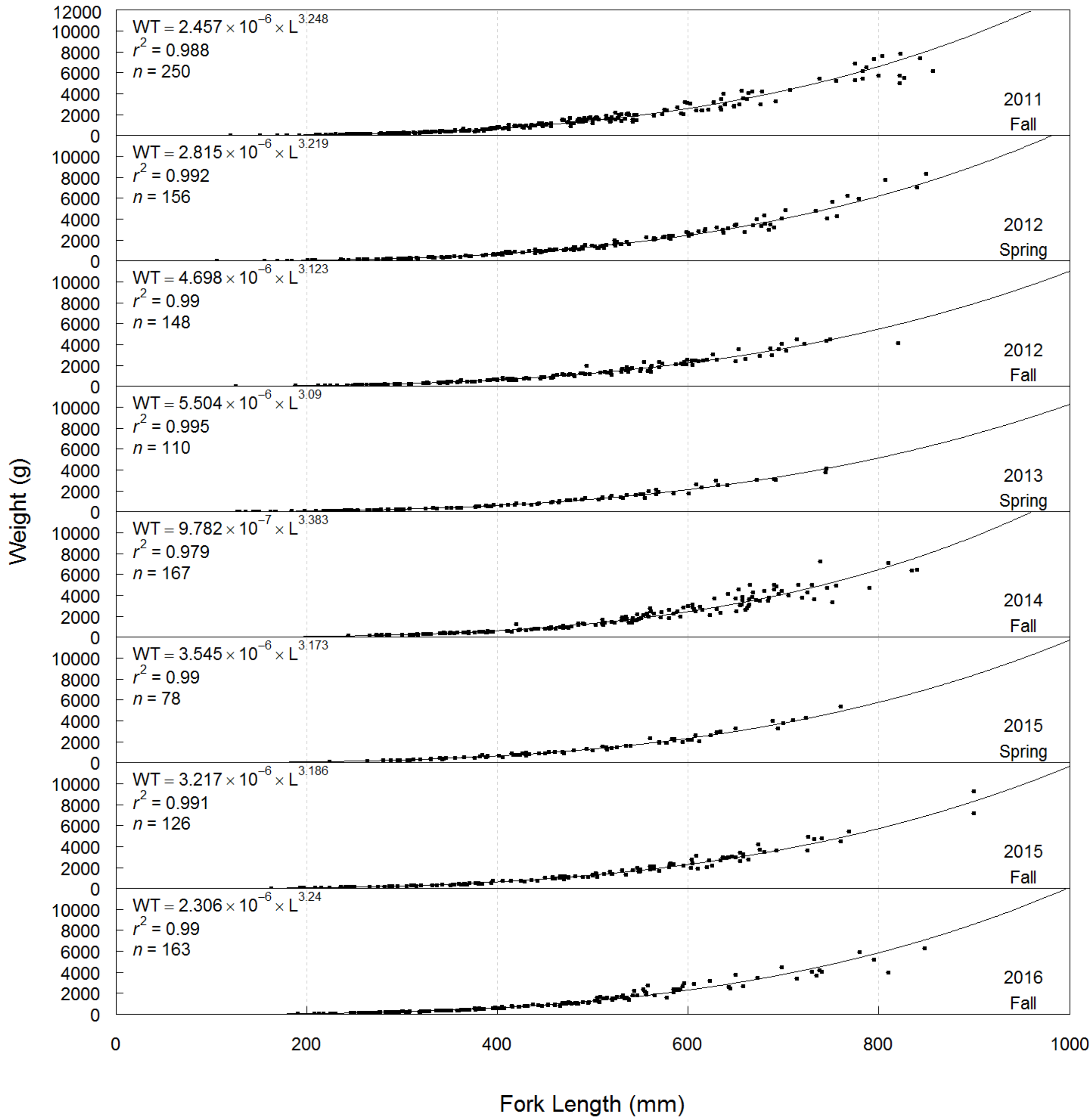

Figure E10 Concluded.

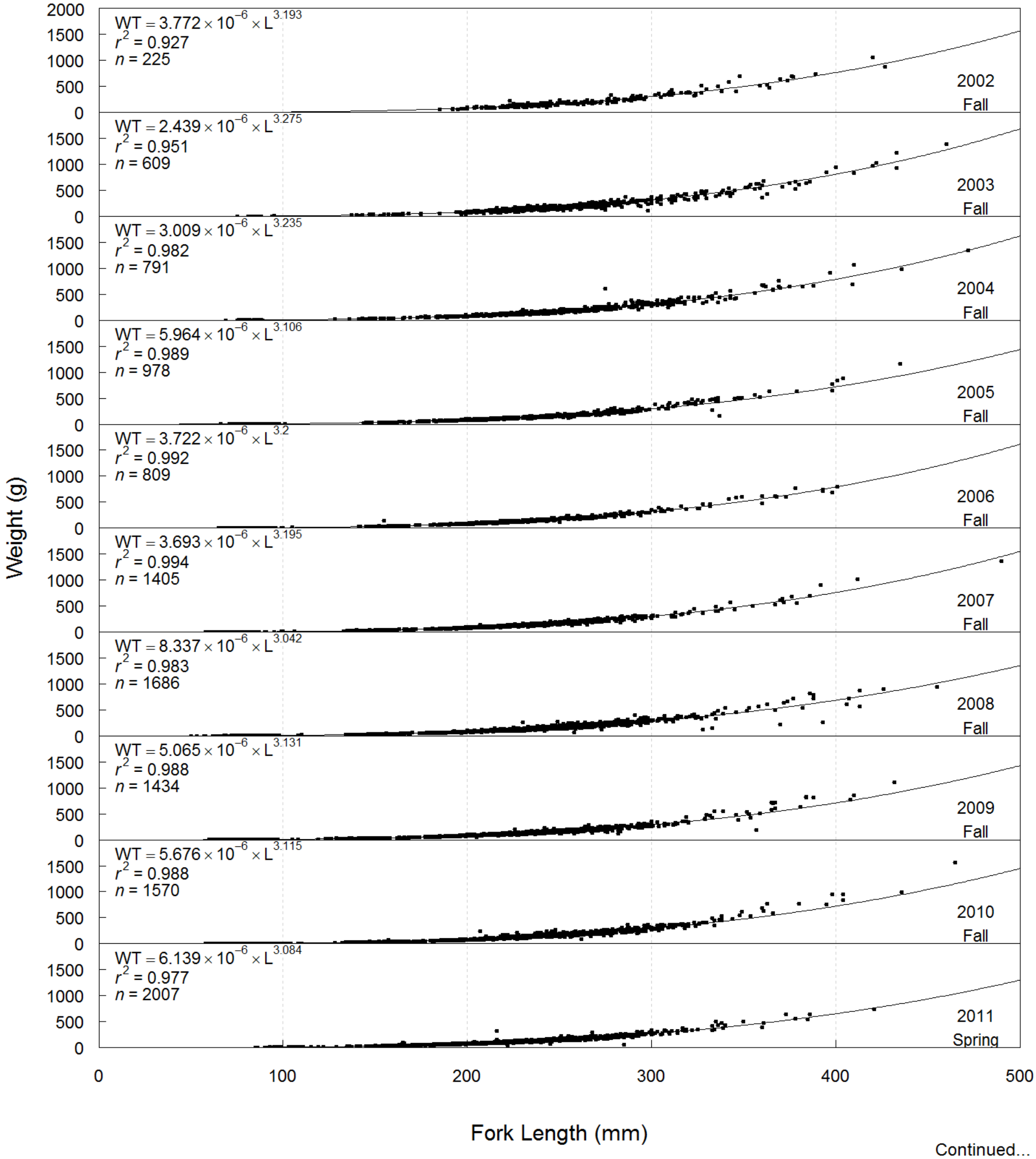

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Figure E11 Length-weight regression for Mountain Whitefish captured by boat electroshocking in Reaches 3 and 4 of the Middle Columbia River, 2002 to 2016. Mountain Whitefish that were initially marked during an earlier year of the program were excluded from the analysis due to potential tagging effects on growth. Boat electroshocking surveys were not conducted downstream of Big Eddy for all years prior to 2007.

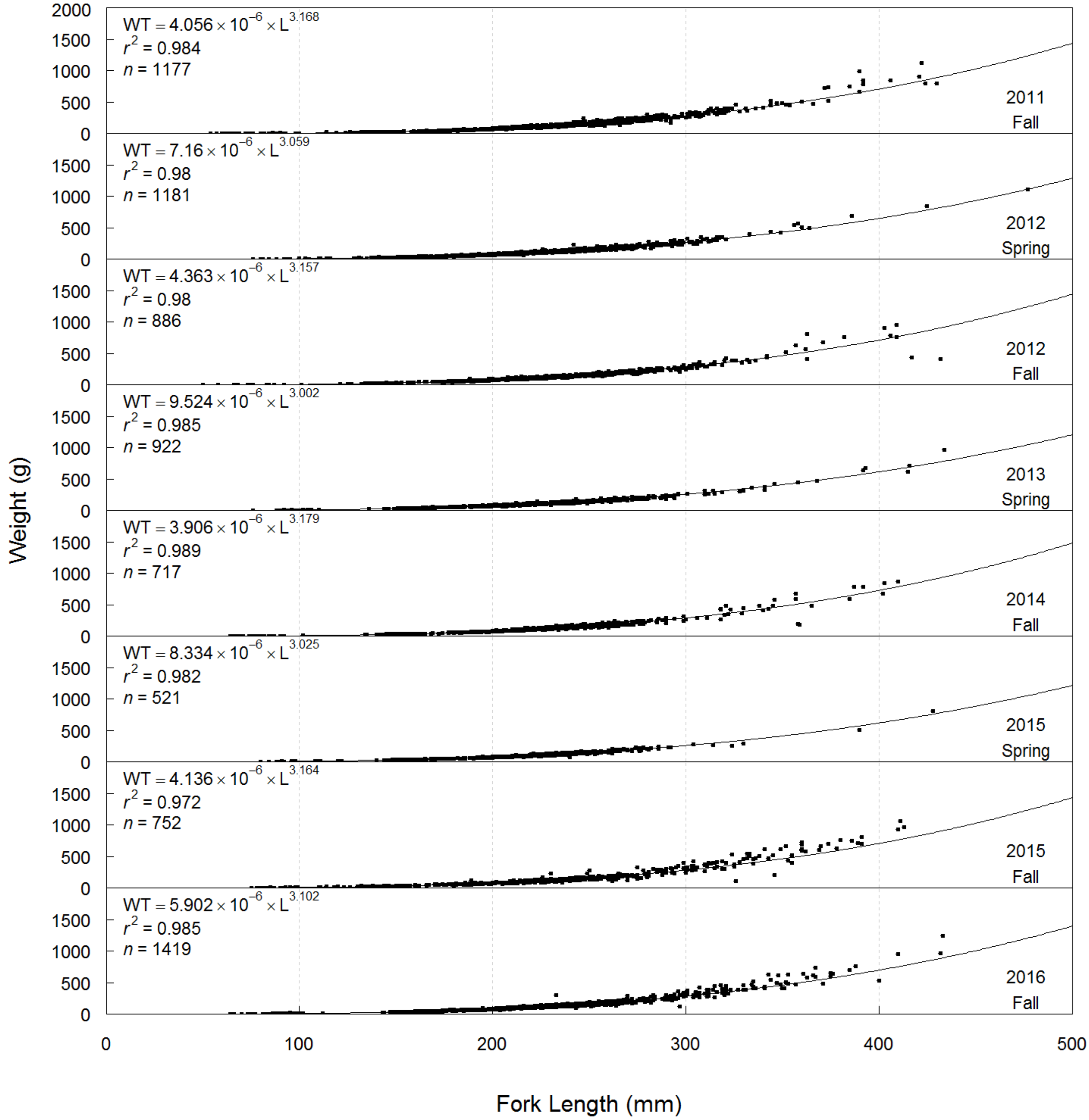

Figure E11 Concluded.

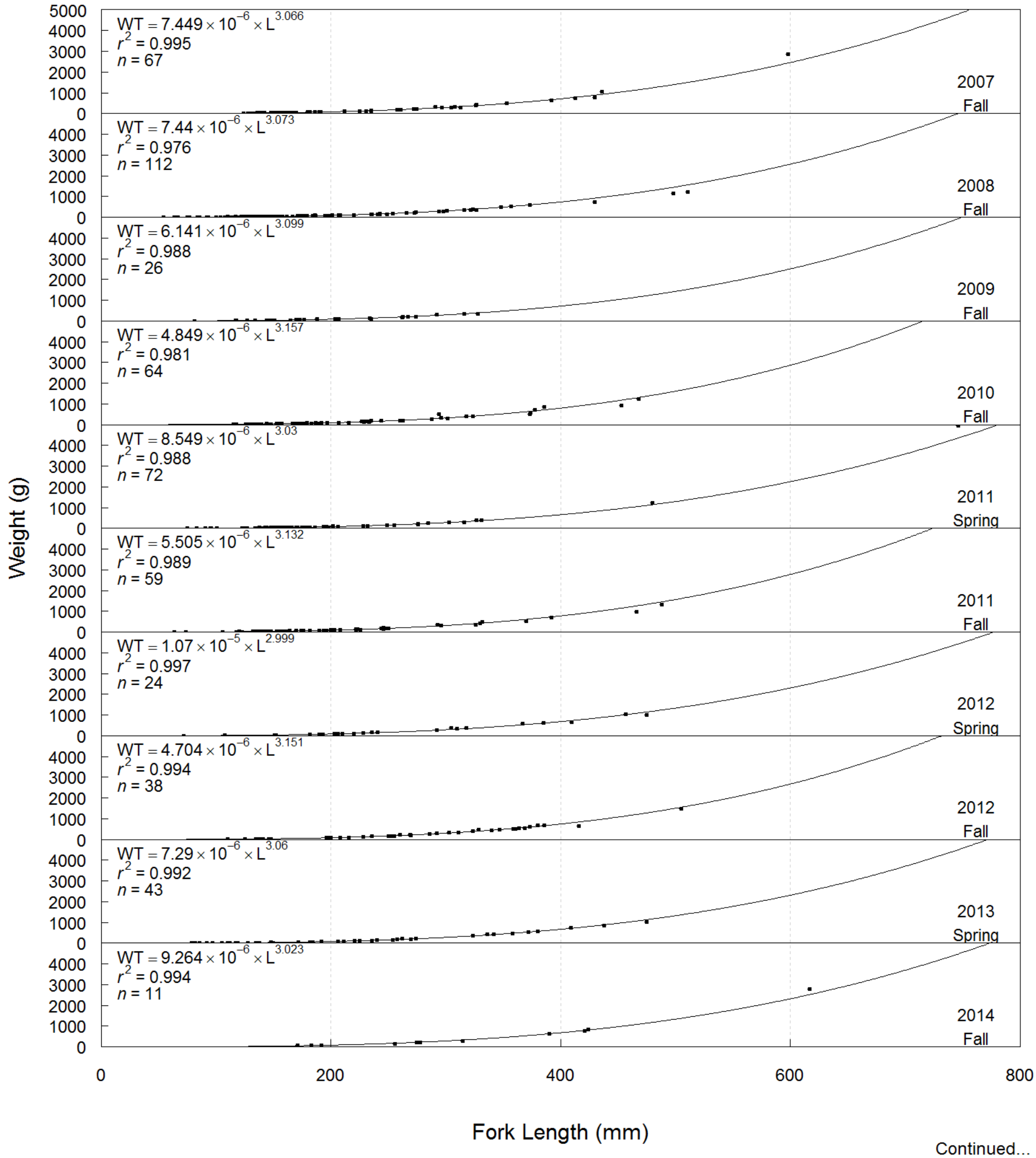

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Figure E12 Length-weight regression for Rainbow Trout captured by boat electroshocking in Reaches 3 and 4 of the Middle Columbia River, 2007 to 2016. Rainbow Trout that were initially marked during an earlier year of the program were excluded from the analysis due to potential tagging effects on growth. Boat electroshocking surveys were not conducted downstream of Big Eddy for all years prior to 2007.

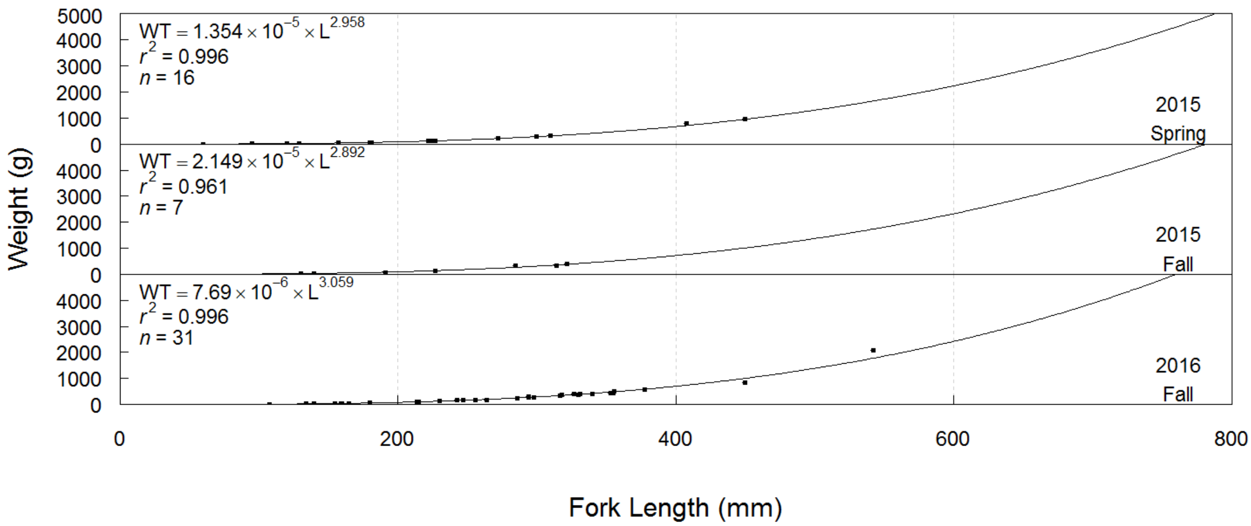

Figure E12 Concluded.

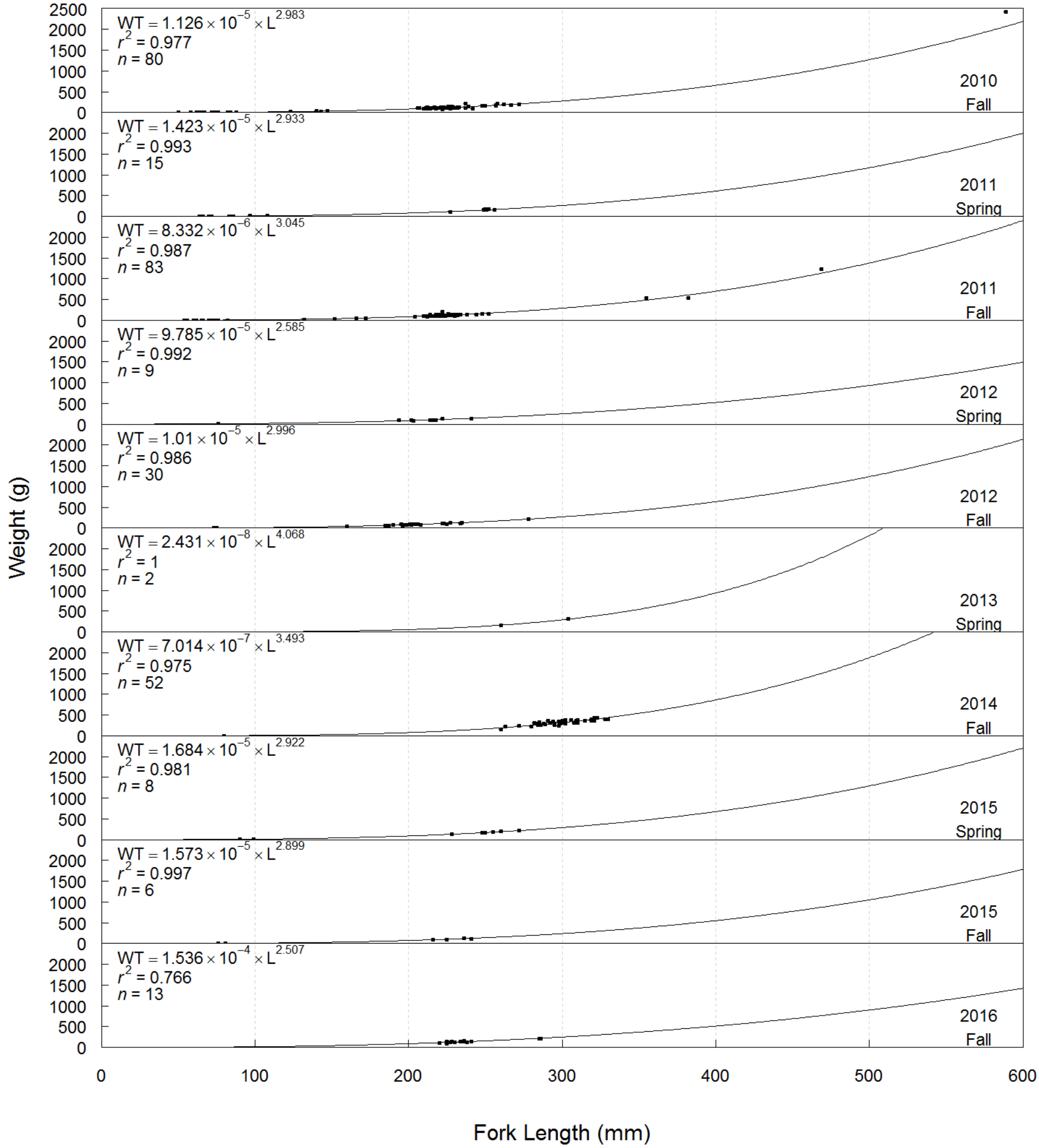

Figure E13 Length-weight regression for Kokanee captured by boat electroshocking in Reaches 3 and 4 of the Middle Columbia River, 2010 to 2016.

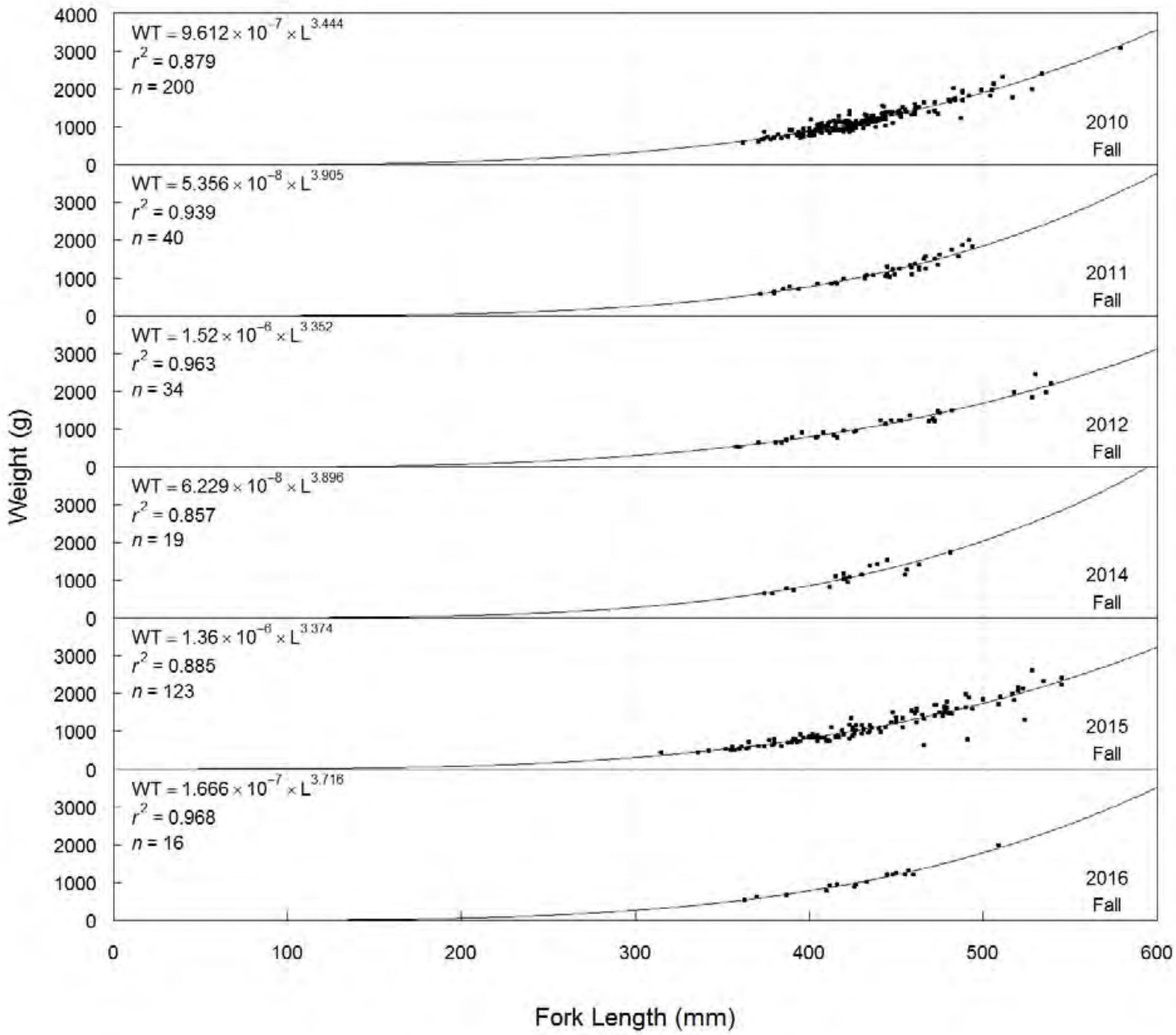

Figure E14 Length-weight regression for Lake Whitefish captured by boat electroshocking in Reaches 3 and 4 of the Middle Columbia River, 2010 to 2016. Lake Whitefish that were initially marked during an earlier year of the program were excluded from the analysis due to potential tagging effects on growth.

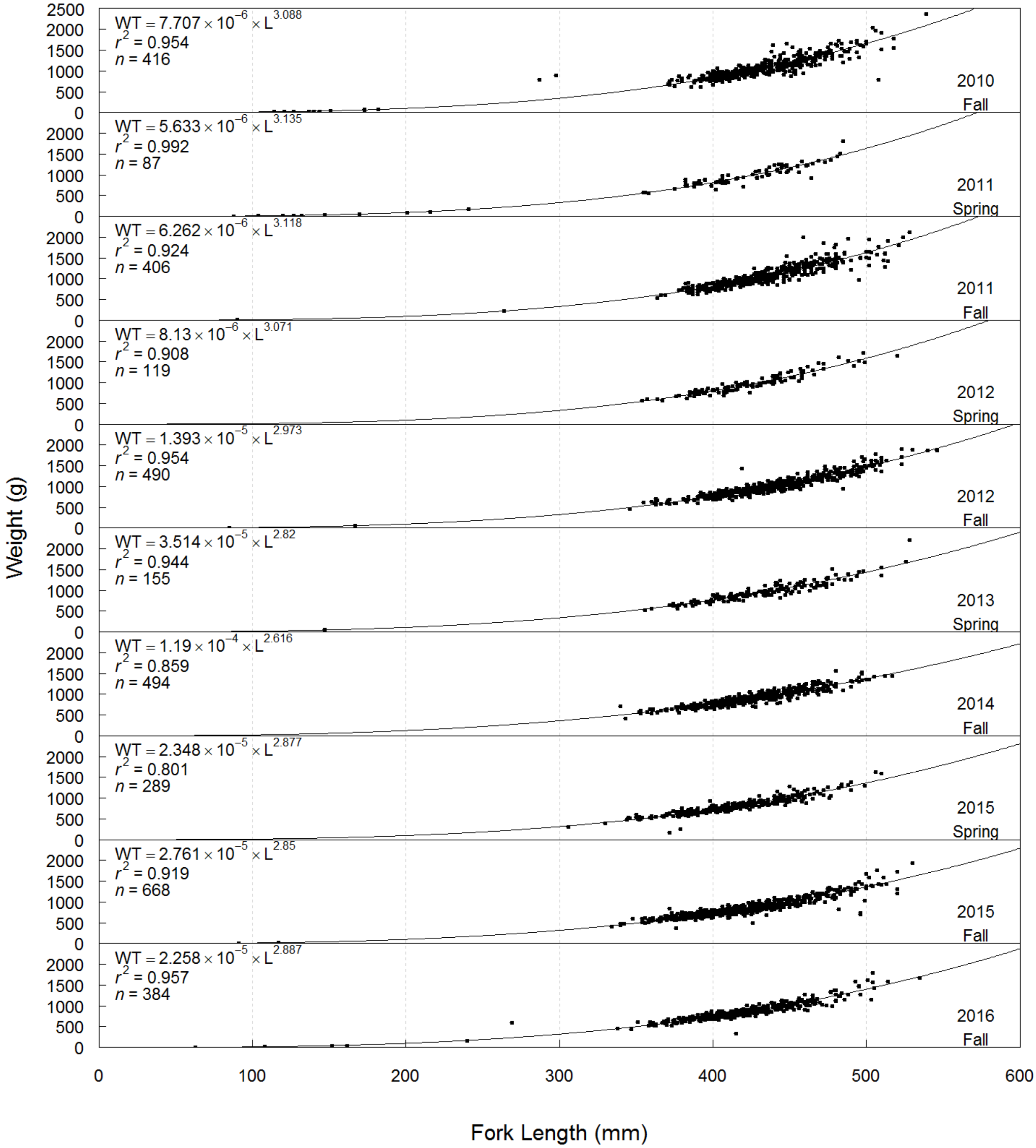

Figure E15 Length-weight regression for Largescale Sucker captured by boat electroshocking in Reaches 3 and 4 of the Middle Columbia River, 2010 to 2016. Largescale Sucker that were initially marked during an earlier year of the program were excluded from the analysis due to potential tagging effects on growth.

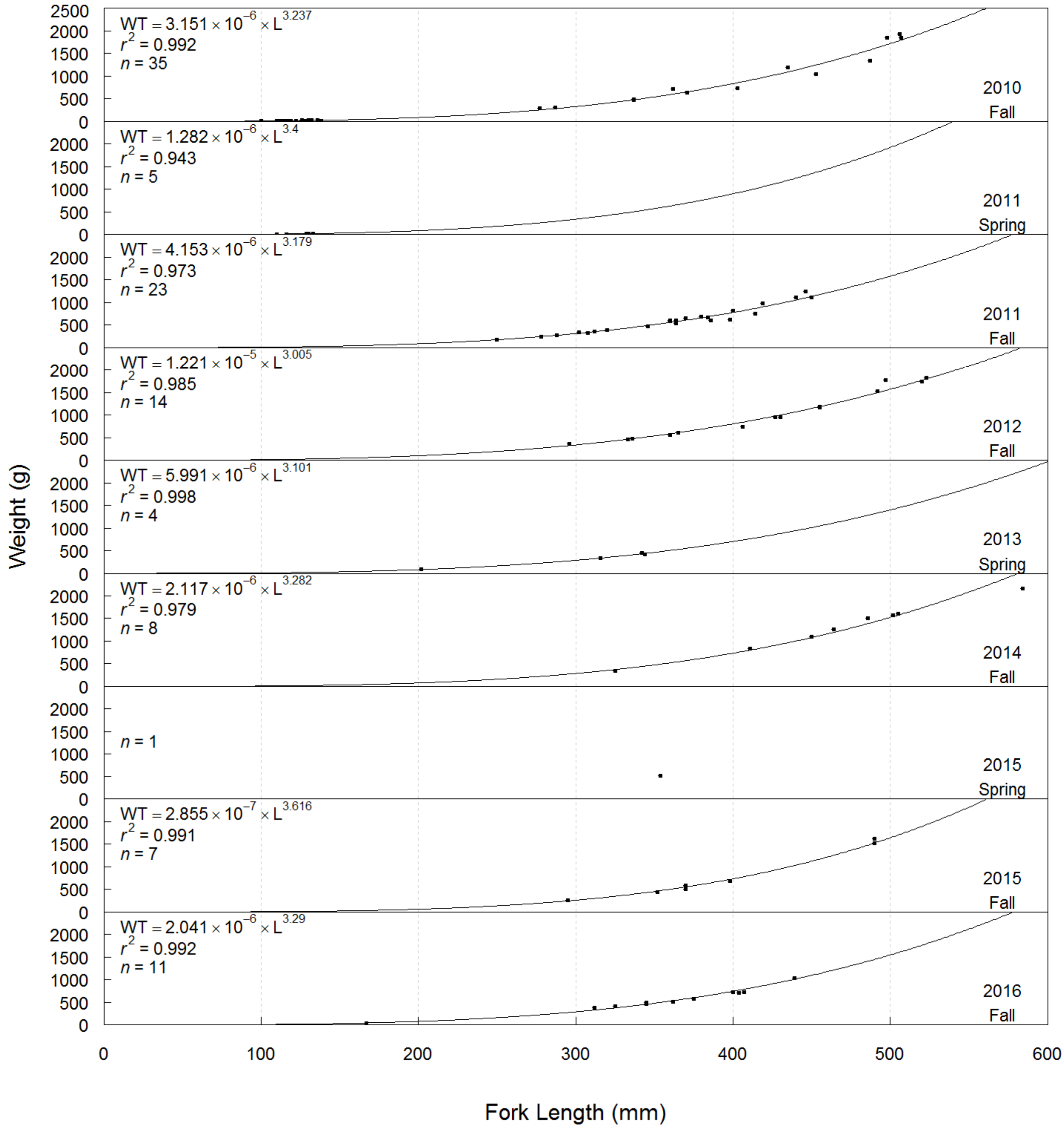

Figure E16 Length-weight regression for Northern Pikeminnow captured by boat electroshocking in Reaches 3 and 4 of the Middle Columbia River, 2010 to 2016. Northern Pikeminnow that were initially marked during an earlier year of the program were excluded from the analysis due to potential tagging effects on growth.

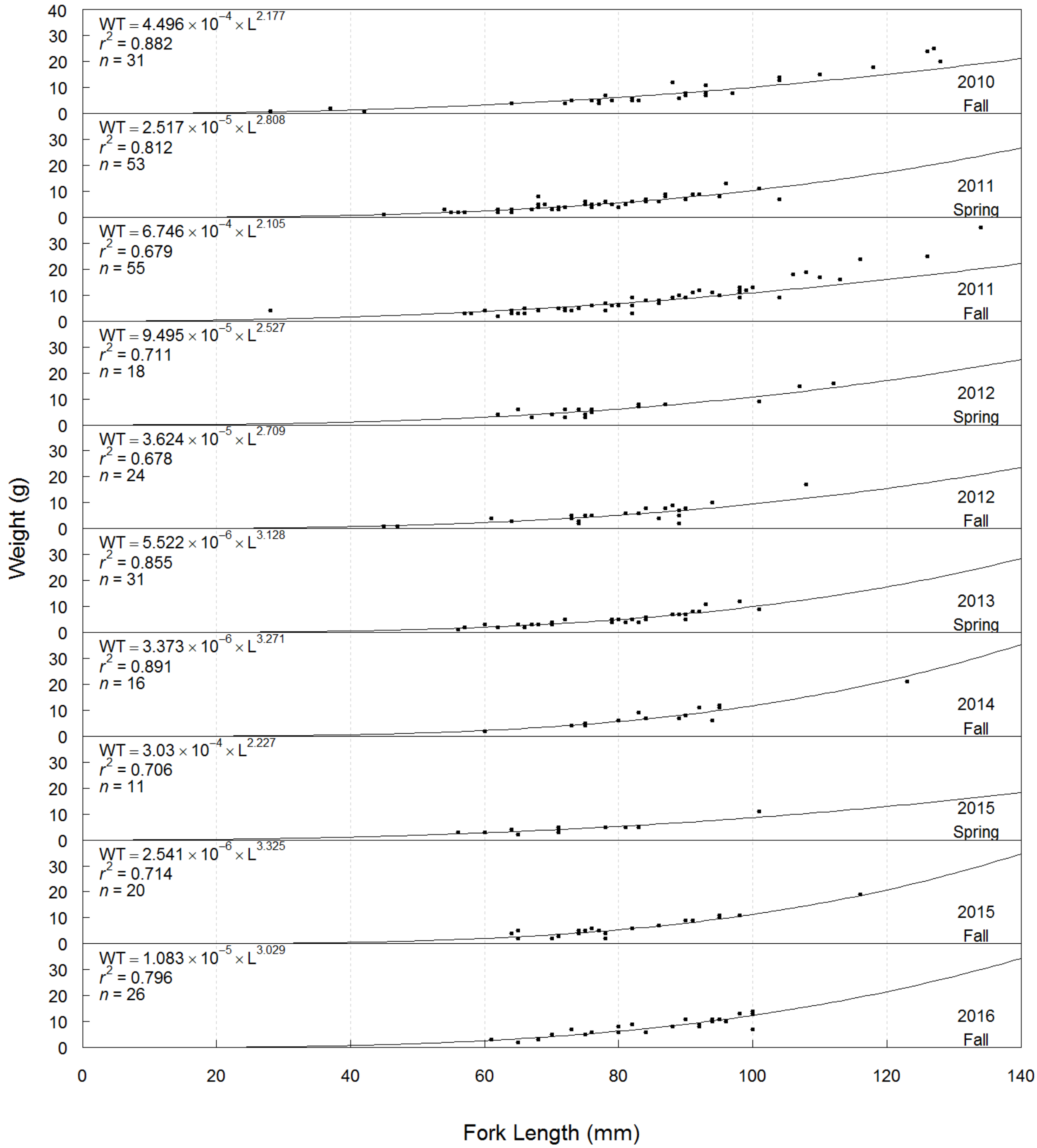

Figure E17 Length-weight regression for Prickly Sculpin captured by boat electroshocking in Reaches 3 and 4 of the Middle Columbia River, 2010 to 2016.

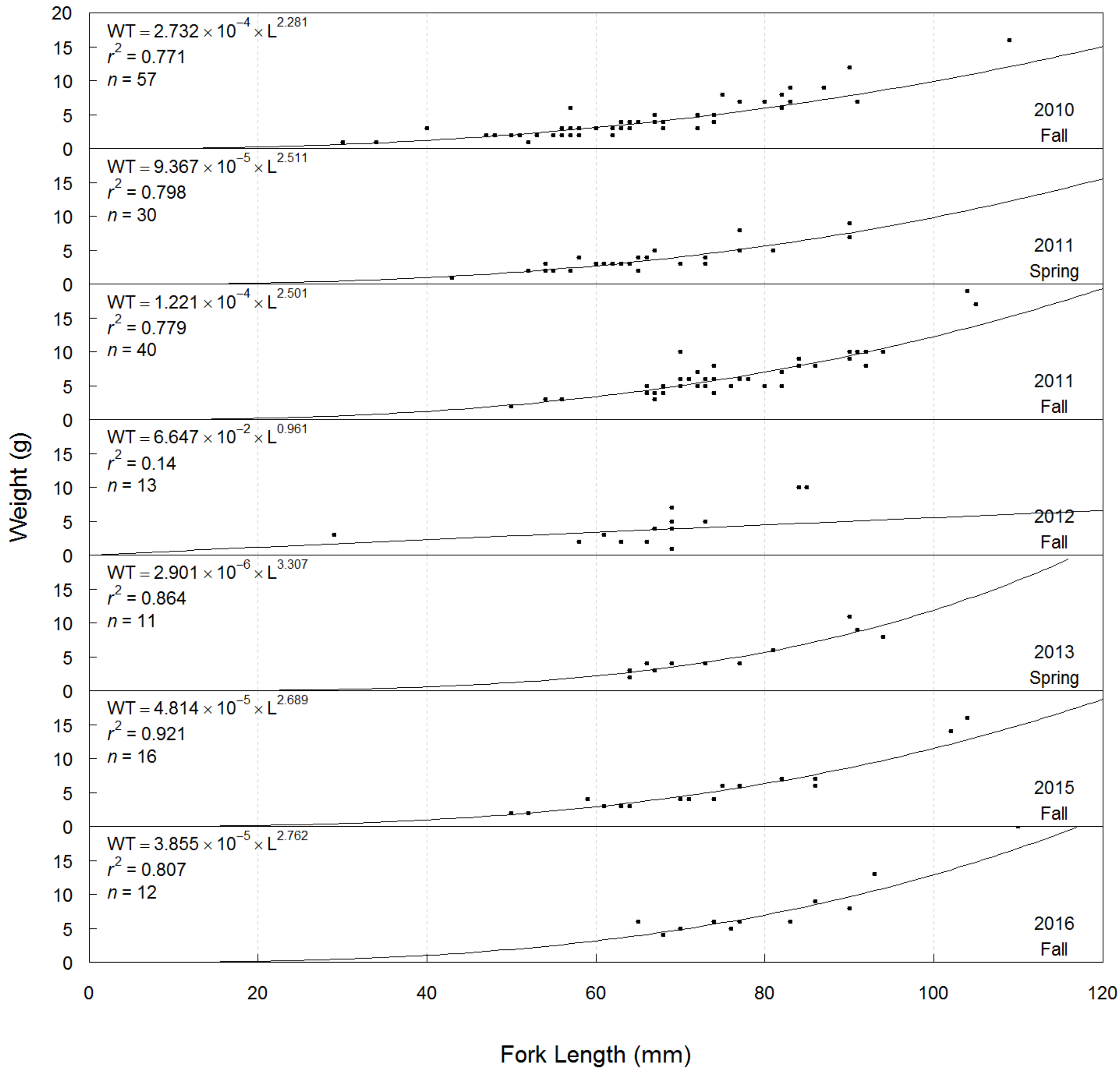

Figure E18 Length-weight regression for Redside Shiner captured by boat electroshocking in Reaches 3 and 4 of the Middle Columbia River, 2010 to 2016. Only one Redside Shiner was caught in 2014.

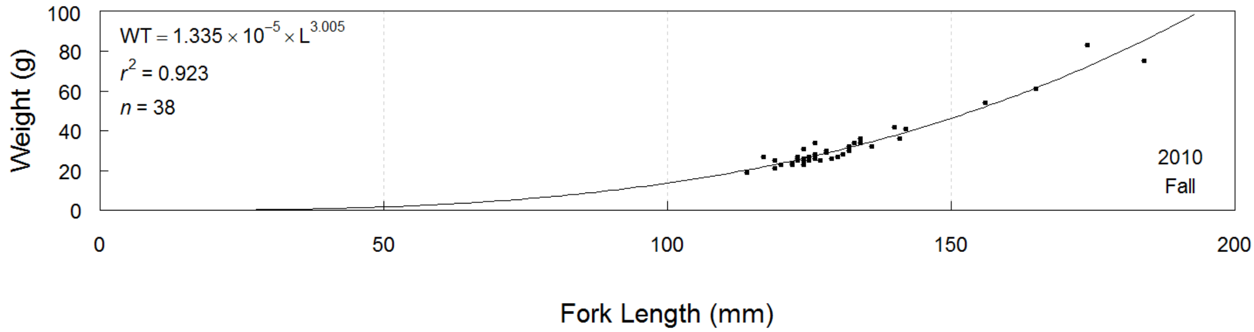

Figure E19 Length-weight regression for Yellow Perch captured by boat electroshocking in Reaches 3 and 4 of the Middle Columbia River, 2010. Yellow Perch that were initially marked during an earlier year of the program were excluded from the analysis due to potential tagging effects on growth.

Appendix F – HBA Methods

Middle Columbia River Fish Indexing Analysis 2016

Thorley, J.L. and Campos M.

The suggested citation for this analytic report is:

Thorley, J.L. and Campos M. (2017) Middle Columbia River Fish Indexing Analysis 2016. A Poisson Consulting Analysis Report. URL: http://www.poissonconsulting.ca/f/577548349.

Methods

Data Preparation

The data were provided by Golder Associates.

Life-Stage

The four primary fish species were categorized as fry, juvenile or adult based on their lengths.

Table 1. Length cutoffs by species and stage.

Species	Fry	Juvenile
Bull Trout	<120	<400
Mountain Whitefish	<120	<175
Rainbow Trout	<120	<250
Largescale Sucker	<120	<350

Statistical Analysis

Model parameters were estimated using Bayesian methods. The estimates were produced using JAGS (Plummer 2015). For additional information on Bayesian modelling in the BUGS language, of which JAGS uses a dialect, the reader is referred to Kery and Schaub (2011).

Unless indicated otherwise, the Bayesian analyses used uninformative normal prior distributions (Kery and Schaub 2011, 36). The posterior distributions were estimated from 2,000 Markov Chain Monte Carlo (MCMC) samples thinned from the second halves of four chains (Kery and Schaub 2011, 38–40). Model convergence was confirmed by ensuring that $\hat{R} < 1.1$ (Kery and Schaub 2011, 40) for each of the monitored parameters (Kery and Schaub 2011, 61).

The parameters are summarised in terms of the point *estimate*, standard deviation (*sd*), the *z-score*, *lower* and *upper* 95% confidence/credible limits (CLs) and the *p-value* (Kery and Schaub 2011, 37, 42). The estimate is the median (50th percentile) of the MCMC samples, the z-score is $\mathrm{sd}/\mathrm{mean}$ and the 95% CLs are the 2.5th and 97.5th percentiles. A p-value of 0.05 indicates that the lower or upper 95% CL is 0.

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

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

The analyses were implemented using R version 3.3.2 (R Core Team 2016) and the `jmbr` package.

Growth

Annual growth was estimated from the inter-annual recaptures using the Fabens method (Fabens 1965) for estimating the von Bertalanffy (VB) growth curve (von Bertalanffy 1938). The VB curves is based on the premise that

$$\frac{dl}{dt} = k(L_{\infty} - l)$$

where l is the length of the individual, k is the growth coefficient and L_{∞} is the mean maximum length.

Integrating the above equation gives

$$l_t = L_{\infty}(1 - e^{-k(t-t0)})$$

where l_t is the length at time t and $t0$ is the time at which the individual would have had no length.

The Fabens form allows

$$l_r = l_c + (L_{\infty} - l_c)(1 - e^{-kT})$$

where l_r is the length at recapture, l_c is the length at capture and T is the time at large.

Key assumptions of the growth model include:

- L_{∞} is constant.
- k can vary with discharge regime.
- k can vary randomly with year.
- The residual variation in growth is normally distributed.

Condition

Condition was estimated via an analysis of mass-length relations (He et al. 2008).

More specifically the model was based on the allometric relationship

$$W = \alpha L^{\beta}$$

where W is the weight (mass), α is the coefficent, β is the exponent and L is the length.

To improve chain mixing the relation was log-transformed, i.e.,

$$\log(W) = \log(\alpha) + \beta\log(L)$$

and the logged lengths centered, i.e., $\log(L) - \overline{\log(L)}$, prior to model fitting.

Preliminary analyses indicated that the variation in the exponent β with respect to year was not informative.

Key assumptions of the final condition model include:

- The expected weight varies with length as an allometric relationship.
- The intercept of the log-transformed allometric relationship is described by a linear mixed model.
- The intercept of the log-transformed allometric relationship varies with discharge regime and season.
- The intercept of the log-transformed allometric relationship varies randomly with year, site and the interaction between year and site.
- The slope of the log-transformed allometric relationship is described by a linear mixed model.
- The slope of the log-transformed allometric relationship varies with discharge regime and season.
- The slope of the log-transformed allometric relationship varies randomly with year.
- The residual variation in weight for the log-transformed allometric relationship is independently and identically normally distributed.

Occupancy

Occupancy, which is the probability that a particular species was present at a site, was estimated from the temporal replication of detection data (Kery, 2010; Kery and Schaub, 2011, pp. 238-242 and 414-418), i.e., each site was surveyed multiple times within a season. A species was considered to have been detected if one or more individuals of the species were caught or counted. It is important to note that the model estimates the probability that the species was present at a given (or typical) site in a given (or typical) year as opposed to the probability that the species was present in the entire study area. We focused on Northern Pikeminnow, Burbot, Lake Whitefish, Rainbow Trout, Redside Shiner and Sculpins because they were low enough density to not to be present at all sites at all times yet were encountered sufficiently often to provide information on spatial and temporal changes.

Key assumptions of the occupancy model include:

- Occupancy (probability of presence) is described by a generalized linear mixed model with a logit link.
- Occupancy varies with season.
- Occupancy varies randomly with site.
- The effect of year on occupancy is autoregressive with a lag of one year and varies with discharge regime.
- Sites are closed, i.e., the species is present or absent at a site for all the sessions in a particular season of a year.
- Observed presence is described by a bernoulli distribution, given occupancy.

Species Richness

The estimated probabilities of presence for the six species considered in the occupany analyses were summed to give the expected species richnesses by site and year.

Count

The count data were analysed using an overdispersed Poisson model (Kery, 2010; Kery and Schaub, 2011, pp. 168-170,180 and 55-56) to provide estimates of the lineal river count density (count/km) by year and site. Unlike Kery (2010) and Kery and Schaub (2011), which used a log-normal distribution to account for the extra-Poisson variation, the current model used a gamma distribution with identical shape and scale parameters because it has a mean of 1 and therefore no overall effect on the expected count. The count data does not enable us to estimate abundance nor observer efficiency, but it enables us to estimate an expected count, which is the product of the two. As such it is necessary to assume that changes in observer efficiency are negligible in order to interpret the estimates as relative density.

Key assumptions of the count model include:

- Lineal density (fish/km) is described by an autoregressive generalized linear mixed model with a logarithm link.
- Lineal density (fish/km) varies with season.
- Lineal density (fish/km) varies randomly with year, site and the interaction between site and year.
- The effect of year on lineal density (fish/km) is autoregressive with a lag of one year and varies with discharge regime.
- The counts are gamma-Poisson distributed, given the mean count.

Movement

The extent to which sites are closed, i.e., fish remain at the same site between sessions, was evaluated from a logistic ANCOVA (Kery 2010). The model estimated the probability that intra-annual recaptures were caught at the same site versus a different one.

Key assumptions of the site fidelity model include:

- Site fidelity varies with season, length and the interaction between season and length.
- Observed site fidelity is Bernoulli distributed.

Observer Length Correction

The bias (accuracy) and error (precisions) in observer's fish length estimates were quantified using a model with a categorical distribution that compared the proportions of fish in different length-classes for each observer to the equivalent proportions for the measured fish.

Key assumptions of the observer length correction model include:

- The expected length bias can vary by observer.
- The expected length error can vary by observer.
- The residual variation in length is independently and identically normally distributed.

The observed fish lengths were corrected for the estimated length biases.

Abundance

The catch and geo-referenced count data were analysed using a capture-recapture-based overdispersed gamma-Poisson model to provide estimates of capture efficiency and absolute abundance. To maximize the number of recaptures the model grouped all the sites into a supersite for the purposes of estimating the number of marked fish but analysed the total captures at the site level.

Key assumptions of the full abundance model include:

- Lineal density (fish/km) varies by season.
- Lineal density varies randomly with site and the interaction between site and year.
- Lineal density varies by river km (distribution).
- The effect of river km on lineal density varies with discharge regime and season.
- The effect of river km on lineal density varies randomly with year.
- Lineal density varies by year as a first-order autoregressive term.
- The change in the annual lineal density varies by discharge regime.
- The change in the annual lineal density varies randomly by year.
- Efficiency (probability of capture) varies by season and method (capture versus count).
- Efficiency varies randomly by session within season within year.
- Marked and unmarked fish have the same probability of capture.
- Observed fish are encountered at a different rate to captured fish.
- There is no tag loss, migration (at the supersite level), mortality or misidentification of fish.
- The number of fish caught is gamma-Poisson distributed.
- The overdispersion varies by encounter type (count versus capture).

Adult Large-Scale Suckers and Adult Rainbow Trout were analysed using a reduced model with 1) no effect of regime or river km on lineal density; 2) no difference in the error or efficiency between encounter types and 3) no autoregressive component, i.e., with the lineal density varying randomly by year as a straight random effect.

Species Evenness

The site and year estimates of the lineal bank count densities from the count model for Rainbow Trout, Suckers, Burbot and Northern Pikeminnow were combined with the equivalent count estimates for Bull Trout and Adult Mountain Whitefish from the abundance model to calculate the shannon index of evenness (E). The index was calculated using the following formula where S is the number of species and p_i is the proportion of the total count belonging to the i*th* species.

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

Model Code

Growth

```
model {

  bKIntercept ~ dnorm (0, 5^-2)

  bKRegime[1] <- 0
  for(i in 2:nRegime) {
    bKRegime[i] ~ dnorm(0, 5^-2)
  }

  sKYear ~ dunif (0, 5)
  for (i in 1:nYear) {
    bKYear[i] ~ dnorm(0, sKYear^-2)
    bK[i] <- exp(bKIntercept + bKRegime[step(i - Threshold) + 1] + bKYear[i])
  }

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

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

    eGrowth[i] <- (bLinf - LengthAtRelease[i]) * (1 - exp(-sum(bK[Year[i]:(Ye
ar[i] + Years[i] - 1)])))

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

Template 1.

Condition

```
model {

  bWeightIntercept ~ dnorm(5, 5^-2)
  bWeightSlope ~ dnorm(3, 5^-2)

  bWeightRegimeIntercept[1] <- 0
  bWeightRegimeSlope[1] <- 0

  for(i in 2:nRegime) {
    bWeightRegimeIntercept[i] ~ dnorm(0, 5^-2)
    bWeightRegimeSlope[i] ~ dnorm(0, 5^-2)
  }

  bWeightSeasonIntercept[1] <- 0
  bWeightSeasonSlope[1] <- 0
  for(i in 2:nSeason) {
    bWeightSeasonIntercept[i] ~ dnorm(0, 5^-2)
    bWeightSeasonSlope[i] ~ dnorm(0, 5^-2)
  }

  sWeightYearIntercept ~ dunif(0, 5)
  sWeightYearSlope ~ dunif(0, 5)
  for(yr in 1:nYear) {
    bWeightYearIntercept[yr] ~ dnorm(0, sWeightYearIntercept^-2)
    bWeightYearSlope[yr] ~ dnorm(0, sWeightYearSlope^-2)
  }

  sWeightSiteIntercept ~ dunif(0, 5)
  sWeightSiteYearIntercept ~ dunif(0, 5)
  for(st in 1:nSite) {
    bWeightSiteIntercept[st] ~ dnorm(0, sWeightSiteIntercept^-2)
    for(yr in 1:nYear) {
      bWeightSiteYearIntercept[st, yr] ~ dnorm(0, sWeightSiteYearIntercept^-2
)
    }
  }

  sWeight ~ dunif(0, 5)
  for(i in 1:length(Year)) {

    eWeightIntercept[i] <- bWeightIntercept + bWeightRegimeIntercept[Regime[i
]] + bWeightSeasonIntercept[Season[i]] + bWeightYearIntercept[Year[i]] + bWei
ghtSiteIntercept[Site[i]] + bWeightSiteYearIntercept[Site[i],Year[i]]

    eWeightSlope[i] <- bWeightSlope + bWeightRegimeSlope[Regime[i]] + bWeight
SeasonSlope[Season[i]] + bWeightYearSlope[Year[i]]

    log(eWeight[i]) <- eWeightIntercept[i] + eWeightSlope[i] * LogLength[i]
    Weight[i] ~ dlnorm(log(eWeight[i]) , sWeight^-2)
```

```
  }
  tCondition1 <- bWeightRegimeIntercept[2]
  tCondition2 <- bWeightRegimeSlope[2]
..
```

Template 2.

Occupancy

```
model {

bOccupancySeason[1] <- 0
for(i in 2:nSeason) {
  bOccupancySeason[i] ~ dnorm(0, 5^-2)

sOccupancySite ~ dunif(0, 5)
for (st in 1:nSite) {
  bOccupancySite[st] ~ dnorm(0, sOccupancySite^-2)

bRate ~ dnorm(0, 5^-2)

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

bRateRegime[1] <- 0
for(i in 2:nRegime) {
  bRateRegime[i] ~ dnorm(0, 5^-2)

bOccupancyYear[1] ~ dnorm(0, 5^-2)
for (i in 2:nYear) {
  eRateYear[i-1] <- bRate + bRateYear[i-1] + bRateRegime[YearRegime[i-1]]
  bOccupancyYear[i] <- bOccupancyYear[i-1] + eRateYear[i-1]

for (i in 1:length(Year)) {
  logit(eObserved[i]) <- bOccupancyYear[Year[i]] + bOccupancySeason[Season[i]
] + bOccupancySite[Site[i]]
  Observed[i] ~ dbern(eObserved[i])
  }
..
```

Template 3.

Count

```
model {
  bRateRegime[1] <- 0
  for(i in 2:nRegime) {
    bRateRegime[i] ~ dnorm(0, 5^-2)
  }

  bDensitySeason[1] <- 0
```

```
  for(i in 2:nSeason) {
    bDensitySeason[i] ~ dnorm(0, 5^-2)
  }

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

  bDensityYear[1] ~ dnorm(0, 5^-2)
  for (i in 2:nYear) {
    eRateYear[i-1] <- bRate + bRateYear[i-1] + bRateRegime[YearRegime[i-1]]
    bDensityYear[i] <- bDensityYear[i-1] + eRateYear[i-1]
  }

  sDensitySite ~ dunif(0, 5)
  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(Year)) {

    log(eDensity[i]) <- bDensityYear[Year[i]] + bDensitySeason[Season[i]] + b
DensitySite[Site[i]] + bDensitySiteYear[Site[i],Year[i]]

    eCount[i] <- eDensity[i] * SiteLength[i] * ProportionSampled[i]
    eDispersion[i] ~ dgamma(1 / sDispersion^2, 1 / sDispersion^2)
    Count[i] ~ dpois(eCount[i] * eDispersion[i])
  }
  tCount <- bRateRegime[2]
..
```

Template 4.

Movement

```
model {
  bMoved ~ dnorm(0, 5^-2)
  bLength ~ dnorm(0, 5^-2)
  bMovedSeason[1] <- 0
  bLengthSeason[1] <- 0

  for(i in 2:nSeason) {
    bMovedSeason[i] ~ dnorm(0, 5^-5)
    bLengthSeason[i] ~ dnorm(0, 5^-5)
```

```
  }

  for (i in 1:length(Season)) {
    logit(eMoved[i]) <- bMoved + bMovedSeason[Season[i]] + (bLength + bLength
Season[Season[i]]) * Length[i]
    Moved[i] ~ dbern(eMoved[i])
  }
..
```

Template 5.

Observer Length Correction

```
model {
  for(i in 1:nClass) {
    dClass[i] <- 1
  }
  pClass[1:nClass] ~ ddirch(dClass[])

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

  for(i in 2:nObserver) {
    bLength[i] ~ dunif(0.5, 2)
    sLength[i] ~ dunif(1, 50)
  }
  for(i in 1:length(Length))  {
    eClass[i] ~ dcat(pClass[])
    eLength[i] <- bLength[Observer[i]] * ClassLength[eClass[i]]
    eSLength[i] <- sLength[Observer[i]] * ClassSD
    Length[i] ~ dnorm(eLength[i], eSLength[i]^-2)
  }
..
```

Template 6.

Abundance

```
model {

  bEfficiency ~ dnorm(0, 5^-2)
  bDistribution ~ dnorm(0, 5^-2)

  bRateRegime[1] <- 0
  bDistributionRegime[1] <- 0
  for(i in 2:nRegime) {
    bRateRegime[i] ~ dnorm(0, 5^-2)
    bDistributionRegime[i] ~ dnorm(0, 5^-2)
  }

  bEfficiencySeason[1] <- 0
  bDensitySeason[1] <- 0
```

```
  bDistributionSeason[1] <- 0
  for(i in 2:nSeason) {
    bEfficiencySeason[i] ~ dnorm(0, 5^-2)
    bDensitySeason[i] ~ dnorm(0, 5^-2)
    bDistributionSeason[i] ~ dnorm(0, 5^-2)
  }

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

  bDensityYear[1] ~ dnorm(0, 5^-2)
  for (i in 2:nYear) {
    eRateYear[i-1] <- bRate + bRateYear[i-1] + bRateRegime[YearRegime[i-1]]
    bDensityYear[i] <- bDensityYear[i-1] + eRateYear[i-1]
  }

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

  sDensitySite ~ dunif(0, 5)
  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)
    }
  }

  sEfficiencySessionSeasonYear ~ dunif(0, 5)
  for (i in 1:nSession) {
    for (j in 1:nSeason) {
      for (k in 1:nYear) {
        bEfficiencySessionSeasonYear[i, j, k] ~ dnorm(0, sEfficiencySessionSe
asonYear^-2)
      }
    }
  }

  bMultiplier <- 0
  sDispersion ~ dnorm(0, 2^-2)
  bMultiplierType[1] <- 0
  sDispersionType[1] <- 0
  for (i in 2:nType) {
    bMultiplierType[i] ~ dnorm(0, 2^-2)
    sDispersionType[i] ~ dnorm(0, 2^-2)
```

```
  }

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

    logit(eEff[i]) <- bEfficiency + bEfficiencySeason[Season[EffIndex[i]]] +
bEfficiencySessionSeasonYear[Session[EffIndex[i]],Season[EffIndex[i]],Year[Ef
fIndex[i]]]

    Marked[EffIndex[i]] ~ dbin(eEff[i], Tagged[EffIndex[i]])
  }

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

    logit(eEfficiency[i]) <- bEfficiency + bEfficiencySeason[Season[i]] + bEf
ficiencySessionSeasonYear[Session[i], Season[i], Year[i]]

    eDistribution[i] <- bDistribution + bDistributionRegime[Regime[i]] + bDis
tributionSeason[Season[i]] + bDistributionYear[Year[i]]

    log(eDensity[i]) <- bDensityYear[Year[i]] + eDistribution[i] * RiverKm[i]
      + bDensitySeason[Season[i]] + bDensitySite[Site[i]] + bDensitySiteYear[
Site[i], Year[i]]

  log(eMultiplier[i]) <- bMultiplier + bMultiplierType[Type[i]]

    eCatch[i] <- eDensity[i] * SiteLength[i] * ProportionSampled[i] * eEffici
ency[i] * eMultiplier[i]

    log(esDispersion[i]) <- sDispersion + sDispersionType[Type[i]]

    eDispersion[i] ~ dgamma(esDispersion[i]^-2 + 0.1, esDispersion[i]^-2 + 0.
1)

    Catch[i] ~ dpois(eCatch[i] * eDispersion[i])
  }
  tAbundance <- bRateRegime[2]
  tDistribution <- bDistributionRegime[2]
..
```

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Appendix G – HBA Results

Hierarchical Bayesian Analyses 2016 - Results

Results

Model Parameters

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

Growth - Bull Trout

Parameter	Estimate	SD	Z-score	Lower	Upper	Significance
bKIntercept	-1.8641739	0.1054579	-17.7080475	-2.0727196	-1.661006	0.0005
bKRegime	0.1068986	4.9147096	0.0093809	-9.2812376	9.516509	0.9860
bLinf	857.8394479	28.6424411	30.0296806	808.8380004	920.834623	0.0005
sGrowth	31.1828861	1.4089127	22.1873377	28.5533490	34.191604	0.0005
sKYear	0.2493117	0.0752564	3.4608626	0.1432783	0.437170	0.0005
tGrowth	0.1068986	4.9147096	0.0093809	-9.2812376	9.516509	0.9860

n	K	nsamples	nchains	nsims	duration	rhat	converged
260	6	2000	4	40000	7.916979	1	TRUE

Growth - Mountain Whitefish

Parameter	Estimate	SD	Z-score	Lower	Upper	Significance
bKIntercept	-2.6127914	0.1352452	-19.3441983	-2.8905518	-2.3589141	0.0005
bKRegime	-0.1442619	4.9119432	-0.0419278	-9.6515815	9.5267152	0.9730
bLinf	355.1710280	8.1490568	43.6293579	340.7860764	372.5956513	0.0005
sGrowth	10.6877991	0.2428641	44.0263825	10.2439891	11.1882805	0.0005
sKYear	0.3505649	0.1112995	3.3281477	0.2104646	0.6355877	0.0005
tGrowth	-0.1442619	4.9119432	-0.0419278	-9.6515815	9.5267152	0.9730

n	K	nsamples	nchains	nsims	duration	rhat	converged
1000	6	2000	4	40000	29.70091	1.01	TRUE

Growth - Rainbow Trout

Parameter	Estimate	SD	Z-score	Lower	Upper	Significance
bKIntercept	-1.8943749	0.4945770	-3.9365546	-2.9571878	-1.116554	0.0005
bKRegime	0.0560165	4.9793517	0.0015026	-9.8213993	10.068428	0.9880
Linf	571.8868548	132.6802529	4.5985788	438.8368763	945.168842	0.0005
sGrowth	25.3967997	6.2181659	4.2508564	17.1872513	41.000639	0.0005
sKYear	0.3052896	0.3990389	1.0444827	0.0297265	1.494123	0.0005
tGrowth	0.0560165	4.9793517	0.0015026	-9.8213993	10.068428	0.9880

n	K	nsamples	nchains	nsims	duration	rhat	converged
16	6	2000	4	40000	0.7223349	1.03	TRUE

Condition - Bull Trout

Parameter	Estimate	SD	Z-score	Lower	Upper	Significance
bWeightIntercept	6.8224727	0.0184439	369.8938491	6.7839311	6.8584054	0.0005
bWeightRegimeIntercept	-0.1061049	0.0286127	-3.6768983	-0.1595558	-0.0450472	0.0005
bWeightRegimeSlope	0.0457349	0.0571055	0.8369983	-0.0623809	0.1626876	0.3690
bWeightSeasonIntercept	0.0014480	0.0092923	0.1386271	-0.0167606	0.0197889	0.8630
bWeightSeasonSlope	0.0116925	0.0236088	0.4968422	-0.0335823	0.0584057	0.6110
bWeightSlope	3.1612666	0.0374257	84.4896154	3.0857082	3.2373123	0.0005
sWeight	0.1372626	0.0018490	74.2445946	0.1337674	0.1408549	0.0005
sWeightSiteIntercept	0.0110831	0.0057811	1.9514451	0.0011294	0.0240219	0.0005
sWeightSiteYearIntercept	0.0173022	0.0054113	3.1187082	0.0039206	0.0264252	0.0005
sWeightYearIntercept	0.0498527	0.0123718	4.1864850	0.0331467	0.0821260	0.0005
sWeightYearSlope	0.0974516	0.0256138	3.9272937	0.0614732	0.1602472	0.0005
tCondition1	-0.1061049	0.0286127	-3.6768983	-0.1595558	-0.0450472	0.0005
tCondition2	0.0457349	0.0571055	0.8369983	-0.0623809	0.1626876	0.3690

n	K	nsamples	nchains	nsims	duration	rhat	converged
3013	13	2000	4	640000	7361.41509962082s (~2.04 hours)	1.02	TRUE

Condition - Mountain Whitefish

Parameter	Estimate	SD	Z-score	Lower	Upper	Significance
bWeightIntercept	4.7881401	0.0082425	580.9473113	4.7730303	4.8056091	0.0005
bWeightRegimeIntercept	-0.0382501	0.0123472	-3.1213338	-0.0634617	-0.0153703	0.0050
bWeightRegimeSlope	-0.0257996	0.0270373	-0.9529919	-0.0810421	0.0268842	0.3110
bWeightSeasonIntercept	-0.0444107	0.0039602	-11.2071809	-0.0523081	-0.0365914	0.0005
bWeightSeasonSlope	-0.1015766	0.0175103	-5.7976748	-0.1353067	-0.0666228	0.0005
bWeightSlope	3.2101925	0.0177418	180.9159728	3.1742461	3.2445277	0.0005
sWeight	0.0985979	0.0008188	120.4330214	0.0969835	0.1001991	0.0005
sWeightSiteIntercept	0.0062915	0.0027945	2.3246821	0.0013797	0.0126423	0.0005
sWeightSiteYearIntercept	0.0135861	0.0018326	7.4197902	0.0101365	0.0172210	0.0005
sWeightYearIntercept	0.0228453	0.0059260	4.0204448	0.0152810	0.0382084	0.0005
sWeightYearSlope	0.0423574	0.0139876	3.1614422	0.0226610	0.0759205	0.0005
tCondition1	-0.0382501	0.0123472	-3.1213338	-0.0634617	-0.0153703	0.0050
tCondition2	-0.0257996	0.0270373	-0.9529919	-0.0810421	0.0268842	0.3110

n	K	nsamples	nchains	nsims	duration	rhat	converged
7458	13	2000	4	40000	1338.432	1.02	TRUE

Condition - Rainbow Trout

Parameter	Estimate	SD	Z-score	Lower	Upper	Significance
bWeightIntercept	4.6176353	0.0153242	301.3392645	4.5888573	4.6487672	0.0005
bWeightRegimeIntercept	-0.0105954	0.0212952	-0.5219893	-0.0560419	0.0289769	0.5840
bWeightRegimeSlope	-0.0342521	0.0572297	-0.6200595	-0.1476211	0.0723243	0.5300
bWeightSeasonIntercept	-0.0682439	0.0146064	-4.6786801	-0.0963354	-0.0401625	0.0005
bWeightSeasonSlope	0.0042373	0.0408189	0.1270415	-0.0713895	0.0888590	0.9080
bWeightSlope	3.0907217	0.0373988	82.7121557	3.0239487	3.1700691	0.0005

sWeight	0.1080384	0.0035052	30.8339165	0.1011158	0.1151982	0.0005
sWeightSiteIntercept	0.0171618	0.0114959	1.6089359	0.0007372	0.0454984	0.0005
sWeightSiteYearIntercept	0.0195131	0.0108562	1.8618730	0.0029640	0.0416312	0.0005
sWeightYearIntercept	0.0217561	0.0134809	1.7602155	0.0029458	0.0545759	0.0005
sWeightYearSlope	0.0733275	0.0263202	2.9585403	0.0385498	0.1391262	0.0005
tCondition1	-0.0105954	0.0212952	-0.5219893	-0.0560419	0.0289769	0.5840
tCondition2	-0.0342521	0.0572297	-0.6200595	-0.1476211	0.0723243	0.5300

n	K	nsamples	nchains	nsims	duration	rhat	converged
546	13	2000	4	80000	86.5664749145508s (~1.44 minutes)	1.07	TRUE

Condition - Largescale Sucker

Parameter	Estimate	SD	Z-score	Lower	Upper	Significance
bWeightIntercept	6.8090532	0.0315213	216.065780	6.7533875	6.8741236	5e-04
bWeightSeasonIntercept	0.0214070	0.0054512	3.914817	0.0111581	0.0319266	5e-04
bWeightSeasonSlope	0.1753231	0.0477888	3.647121	0.0782321	0.2657080	5e-04
bWeightSlope	2.8715268	0.1148855	24.992947	2.6488541	3.0997607	5e-04
sWeight	0.0824593	0.0012222	67.514292	0.0801789	0.0850479	5e-04
sWeightSiteIntercept	0.0058696	0.0035599	1.721824	0.0003922	0.0137578	5e-04
sWeightSiteYearIntercept	0.0099943	0.0033401	2.914380	0.0023342	0.0156410	5e-04
sWeightYearIntercept	0.0687345	0.0304800	2.490380	0.0409592	0.1434882	5e-04
sWeightYearSlope	0.2447352	0.1190849	2.303969	0.1406327	0.5794410	5e-04

n	K	nsamples	nchains	nsims	duration	rhat	converged
2303	9	2000	4	2560000	13246.787014246s (~3.68 hours)	1.01	TRUE

Occupancy - Rainbow Trout

Parameter	Estimate	SD	Z-score	Lower	Upper	Significance
bOccupancySeason	-0.0441430	0.2915208	-0.1708046	-0.6390309	0.4998309	0.8820
bRate	0.1674582	0.4529931	0.2846738	-0.9314858	0.9347612	0.6640
bRateRegime	-0.2266203	0.7641868	-0.2506344	-1.6226028	1.4674321	0.7290
sOccupancySite	2.0798967	0.5124052	4.2201985	1.3927839	3.4513820	0.0005
sRateYear	1.1922660	0.4346520	2.9070743	0.6336904	2.3222262	0.0005

n	K	nsamples	nchains	nsims	duration	rhat	converged
969	5	2000	4	320000	268.80225276947s (~4.48 minutes)	1.01	TRUE

Occupancy - Burbot

Parameter	Estimate	SD	Z-score	Lower	Upper	Significance
bOccupancySeason	-0.4620141	0.3136597	-1.496502	-1.0958380	0.1373124	0.1340
bRate	0.4578239	0.4878937	1.092664	-0.3184839	1.7031044	0.2080
bRateRegime	-1.1638224	0.7380314	-1.604433	-2.8300107	0.3062082	0.0960
sOccupancySite	0.9581696	0.2568683	3.863209	0.5895874	1.6206694	0.0005
sRateYear	1.0661645	0.4140664	2.745384	0.5268541	2.1326053	0.0005

n	K	nsamples	nchains	nsims	duration	rhat	converged
969	5	2000	4	160000	136.861769199371s (~2.28 minutes)	1.1	TRUE

Occupancy - Lake Whitefish

Parameter	Estimate	SD	Z-score	Lower	Upper	Significance
bOccupancySeason	-4.8610298	0.8170743	-6.0436608	-6.729908	-3.5350161	0.0005
bRate	0.2263339	0.5772797	0.3193839	-1.000189	1.2968137	0.6760
bRateRegime	-0.3982608	0.9016562	-0.4806933	-2.144271	1.3748100	0.6400
sOccupancySite	0.4687208	0.1709773	2.8065144	0.176911	0.8683258	0.0005
sRateYear	1.7872412	0.4652836	3.9738154	1.141766	2.9399117	0.0005

n	K	nsamples	nchains	nsims	duration	rhat	converged
969	5	2000	4	160000	133.611914157867s (~2.23 minutes)	1.07	TRUE

Occupancy - Northern Pikeminnow

Parameter	Estimate	SD	Z-score	Lower	Upper	Significance
bOccupancySeason	-2.0446042	0.4132843	-4.964727	-2.8447114	-1.2730866	0.0005
bRate	0.3893736	0.2700138	1.481535	-0.1127161	0.9666526	0.1160
bRateRegime	-0.4623232	0.4427830	-1.063541	-1.3694467	0.4010425	0.2560
sOccupancySite	1.2954298	0.3630245	3.712130	0.7974610	2.1987692	0.0005
sRateYear	0.7211602	0.2760132	2.767365	0.3524526	1.3854180	0.0005

n	K	nsamples	nchains	nsims	duration	rhat	converged
969	5	2000	4	160000	132.825829982758s (~2.21 minutes)	1.03	TRUE

Occupancy - Redside Shiner

Parameter	Estimate	SD	Z-score	Lower	Upper	Significance
bOccupancySeason	-0.9425609	0.3646064	-2.6128776	-1.7072231	-0.2768414	0.0080
bRate	0.4374469	0.4668138	0.9401063	-0.4845830	1.4254734	0.3160
bRateRegime	-0.5191104	0.8430247	-0.6537988	-2.3532710	1.1045241	0.4790
sOccupancySite	2.1613548	0.5989423	3.7590343	1.3514431	3.7588346	0.0005
sRateYear	1.4990505	0.4964205	3.1823567	0.8319064	2.7345524	0.0005

n	K	nsamples	nchains	nsims	duration	rhat	converged
969	5	2000	4	320000	258.049988031387s (~4.3 minutes)	1.04	TRUE

Occupancy - Sculpins

Parameter	Estimate	SD	Z-score	Lower	Upper	Significance
bOccupancySeason	-0.3573008	0.2716340	-1.318421	-0.8740651	0.1831799	0.1790
bRate	0.4900018	0.3408342	1.373709	-0.2558886	1.0852118	0.1890
bRateRegime	-0.8687456	0.7312247	-1.172275	-2.2202616	0.6533350	0.2220
sOccupancySite	1.2830207	0.3115779	4.266274	0.8582813	2.0429250	0.0005
sRateYear	1.3498246	0.3537100	3.959291	0.8564961	2.2655003	0.0005

n	K	nsamples	nchains	nsims	duration	rhat	converged
969	5	2000	4	160000	141.722540855408s (~2.36 minutes)	1.07	TRUE

Count - Rainbow Trout

Parameter	Estimate	SD	Z-score	Lower	Upper	Significance
bDensitySeason	-0.0558554	0.1581371	-0.3617073	-0.3643737	0.2662402	0.7210

bRate	0.3097245	0.2203194	1.4084916	-0.1392948	0.7741460	0.1700
bRateRegime	-0.5228539	0.4377085	-1.2193071	-1.3973239	0.3197493	0.2060
sDensitySite	1.6865947	0.4212903	4.1656691	1.1318535	2.7494199	0.0005
sDensitySiteYear	0.7651275	0.0933484	8.2263266	0.5961492	0.9668685	0.0005
sDispersion	0.8443905	0.0574568	14.7304306	0.7382854	0.9631970	0.0005
sRateYear	0.7548222	0.2675483	2.9365686	0.3623827	1.3600096	0.0005
tCount	-0.5228539	0.4377085	-1.2193071	-1.3973239	0.3197493	0.2060

n	K	nsamples	nchains	nsims	duration	rhat	converged
969	8	2000	4	8e+05	4211.07110714912s (~1.17 hours)	1.04	TRUE

Count - Burbot

Parameter	Estimate	SD	Z-score	Lower	Upper	Significance
bDensitySeason	-0.7008740	0.2829301	-2.4583869	-1.2222639	-0.1576417	0.0150
bRate	0.3457599	0.4179139	0.8351192	-0.5379906	1.1403800	0.3660
bRateRegime	-1.0494175	0.7563619	-1.3667513	-2.5285938	0.6490754	0.1530
sDensitySite	0.7770214	0.2460972	3.3195278	0.4582638	1.4287828	0.0005
sDensitySiteYear	0.4302179	0.1930011	2.1941856	0.0573630	0.7871522	0.0005
sDispersion	1.2101743	0.1418903	8.5651207	0.9409837	1.5045709	0.0005
sRateYear	1.2128722	0.4244377	3.0165039	0.6137706	2.3191154	0.0005
tCount	-1.0494175	0.7563619	-1.3667513	-2.5285938	0.6490754	0.1530

n	K	nsamples	nchains	nsims	duration	rhat	converged
969	8	2000	4	8e+05	4453.63915920258s (~1.24 hours)	1.04	TRUE

Count - Northern Pikeminnow

Parameter	Estimate	SD	Z-score	Lower	Upper	Significance
bDensitySeason	-2.1944847	0.4198386	-5.258263	-3.0621880	-1.3987577	0.0005
bRate	0.3782332	0.2290669	1.665998	-0.0723541	0.8551925	0.0940
bRateRegime	-0.4745792	0.4315332	-1.104948	-1.4151222	0.3749522	0.2260
sDensitySite	1.2618458	0.3686478	3.558548	0.7418742	2.1712440	0.0005
sDensitySiteYear	0.7494810	0.1873177	3.979125	0.3547730	1.1086029	0.0005
sDispersion	1.3409528	0.1319098	10.200577	1.1030656	1.6164564	0.0005
sRateYear	0.6680811	0.2510400	2.828973	0.3459029	1.3331360	0.0005
tCount	-0.4745792	0.4315332	-1.104948	-1.4151222	0.3749522	0.2260

n	K	nsamples	nchains	nsims	duration	rhat	converged
969	8	2000	4	4e+05	1737.69567394257s (~28.96 minutes)	1.06	TRUE

Count - Suckers

Parameter	Estimate	SD	Z-score	Lower	Upper	Significance
bDensitySeason	-0.1043625	0.1084576	-0.9767647	-0.3150610	0.0997476	0.3410
bRate	0.0272163	0.2049856	0.2073784	-0.3128084	0.4364884	0.8670
bRateRegime	-0.1173087	0.3499090	-0.3202261	-0.7991742	0.5485687	0.7600
sDensitySite	0.5379528	0.1409113	3.9748213	0.3531519	0.8806989	0.0005
sDensitySiteYear	0.5355914	0.0559827	9.6034547	0.4333479	0.6506571	0.0005
sDispersion	0.8414728	0.0258002	32.6535746	0.7936624	0.8939800	0.0005

sRateYear	0.6234944	0.1739960	3.7148641	0.3832156	1.0642525	0.0005
tCount	-0.1173087	0.3499090	-0.3202261	-0.7991742	0.5485687	0.7600

n	K	nsamples	nchains	nsims	duration	rhat	converged
969	8	2000	4	3200000	12144.5328521729s (~3.37 hours)	1.03	TRUE

Movement - Bull Trout

Parameter	Estimate	SD	Z-score	Lower	Upper	Significance
bLength	0.0047745	0.0015523	3.0964570	0.0018221	0.0078775	0.0005
bLengthSeason	0.0025145	0.0057703	0.5070124	-0.0072400	0.0158471	0.6450
bMoved	-1.9223766	0.6872842	-2.7916148	-3.3285555	-0.6264036	0.0005
bMovedSeason	-0.2097086	2.4943308	-0.1151158	-5.5714534	4.3615303	0.9350

n	K	nsamples	nchains	nsims	duration	rhat	converged
139	4	2000	4	40000	3.592058	1.01	TRUE

Movement - Mountain Whitefish

Parameter	Estimate	SD	Z-score	Lower	Upper	Significance
bLength	-0.0000585	0.0031176	-0.0188312	-0.0058705	0.0060392	0.9780
bLengthSeason	-0.0287949	0.0071939	-4.0197767	-0.0431402	-0.0147266	0.0005
bMoved	-0.0752615	0.7955858	-0.0869078	-1.6451885	1.4199044	0.9290
bMovedSeason	6.0035221	1.7007025	3.5579101	2.7051475	9.2529943	0.0005

n	K	nsamples	nchains	nsims	duration	rhat	converged
455	4	2000	4	40000	11.02264	1.06	TRUE

Movement - Rainbow Trout

Parameter	Estimate	SD	Z-score	Lower	Upper	Significance
bLength	0.0066614	0.0066712	1.040321	-0.0055244	0.0207671	0.300
bLengthSeason	0.2206368	0.1230785	1.866868	0.0255527	0.4914047	0.005
bMoved	-2.5320647	1.7059594	-1.526541	-6.1421186	0.5783143	0.105
bMovedSeason	-67.9724496	37.2760096	-1.878494	-149.6658038	-8.7183550	0.004

n	K	nsamples	nchains	nsims	duration	rhat	converged
23	4	2000	4	40000	0.8048799	1.05	TRUE

Movement - Largescale Sucker

Parameter	Estimate	SD	Z-score	Lower	Upper	Significance
bLength	-0.0109916	0.0058396	-1.881884	-0.0228363	0.0008265	0.076
bLengthSeason	-0.2056773	0.0932733	-2.182091	-0.3865780	-0.0231405	0.021
bMoved	4.5674208	2.5235068	1.810952	-0.5522363	9.7472728	0.080
bMovedSeason	90.1037990	41.0239003	2.178425	9.3551793	170.5578463	0.023

n	K	nsamples	nchains	nsims	duration	rhat	converged
70	4	2000	4	160000	5.18621802330017	1.06	TRUE

Observer Length Correction - Bull Trout

Parameter	Estimate	SD	Z-score	Lower	Upper	Significance
bLength	0.8295510	0.0587294	14.767478	0.8250688	0.9812908	5e-04
bLength	1.0905234	0.0751906	14.511789	0.9446459	1.2353038	5e-04
bLength	0.9982138	0.0392980	25.985577	0.9532832	1.0926534	5e-04
bLength	0.8487111	0.0367764	23.255621	0.7921152	0.9433502	5e-04
bLength	0.9921179	0.0493985	19.583259	0.8439292	0.9969706	5e-04
bLength	0.9605280	0.0759563	13.000224	0.9103218	1.0903138	5e-04
bLength	1.0169095	0.0537331	18.958199	0.9108885	1.1173630	5e-04
sLength	1.0413350	1.2949400	1.160473	1.0013062	5.2950826	5e-04
sLength	6.3852291	4.9522513	1.507112	1.3925108	20.0853509	5e-04
sLength	1.3653024	2.2831090	1.104397	1.0024408	8.7580734	5e-04
sLength	3.0746659	2.8720854	1.389820	1.0322016	11.2835228	5e-04
sLength	1.0300262	1.3582406	1.177558	1.0009804	6.1623492	5e-04
sLength	1.1668169	1.1535121	1.268215	1.0072669	5.1107757	5e-04
sLength	7.0935713	4.7057892	1.667923	1.3398539	18.7089936	5e-04

n	K	nsamples	nchains	nsims	duration	rhat	converged
1058	14	2000	4	5120000	21891.7364845276s (~6.08 hours)	1.41	FALSE

Observer Length Correction - Mountain Whitefish

Parameter	Estimate	SD	Z-score	Lower	Upper	Significance
bLength	0.9239473	0.0075053	123.112458	0.9094790	0.9367955	5e-04
bLength	0.9137584	0.0156839	58.256684	0.8823468	0.9442200	5e-04
bLength	1.0083762	0.0091092	110.700216	0.9903784	1.0265663	5e-04
bLength	0.9307453	0.0049084	189.551196	0.9200066	0.9388649	5e-04
bLength	0.7627435	0.0051445	148.271709	0.7526195	0.7728329	5e-04
bLength	0.9784577	0.0101676	96.252021	0.9584882	0.9978365	5e-04
bLength	0.8497020	0.0157436	53.981561	0.8188708	0.8812846	5e-04
sLength	2.6767563	0.6596459	3.751118	1.1847571	3.3681802	5e-04
sLength	4.5891462	0.8363494	5.472418	2.9277363	6.2051080	5e-04
sLength	4.0824229	0.4050702	10.099657	3.3107849	4.9000491	5e-04
sLength	1.2634793	0.1900469	6.849920	1.0532771	1.8038236	5e-04
sLength	3.2271668	0.1891921	17.059692	2.8691190	3.6185026	5e-04
sLength	4.1329454	0.3829660	10.791872	3.3782864	4.8733304	5e-04
sLength	6.6058955	0.6543448	10.092474	5.3297159	7.8958873	5e-04

n	K	nsamples	nchains	nsims	duration	rhat	converged
7463	14	2000	4	160000	2951.50112128258s (~49.19 minutes)	1.06	TRUE

Observer Length Correction - Suckers

Parameter	Estimate	SD	Z-score	Lower	Upper	Significance
bLength	0.8200547	0.0122134	67.116151	0.7950339	0.8428677	5e-04
bLength	1.1119342	0.0325977	34.105340	1.0449897	1.1773771	5e-04
bLength	0.9507303	0.0057486	165.448619	0.9410518	0.9622337	5e-04
bLength	0.9018186	0.0017900	503.802139	0.8982251	0.9052863	5e-04

bLength	0.7499056	0.0058935	127.245130	0.7382510	0.7614752	5e-04
bLength	0.9224197	0.0113655	81.178089	0.9000950	0.9452503	5e-04
bLength	0.7085999	0.0188290	37.631013	0.6721234	0.7456156	5e-04
sLength	5.0507029	1.0358079	4.899389	3.0787038	7.1386204	5e-04
sLength	9.0276187	2.3308736	3.970438	5.3509156	14.3878126	5e-04
sLength	2.9661280	1.0638723	2.607776	1.0468088	4.5527721	5e-04
sLength	1.0212649	0.0299129	34.440664	1.0008292	1.1084714	5e-04
sLength	5.4572978	0.4315599	12.648395	4.6128940	6.2992004	5e-04
sLength	6.4705785	0.7831361	8.259786	4.9504104	8.0090055	5e-04
sLength	12.3621281	0.9936523	12.474686	10.5690973	14.4383197	5e-04

n	K	nsamples	nchains	nsims	duration	rhat	converged
3467	14	2000	4	40000	324.3198	1.02	TRUE

Abundance - Juvenile Bull Trout

Parameter	Estimate	SD	Z-score	Lower	Upper	Significance
bDensitySeason	0.2533460	0.3526480	0.7075806	-0.4234096	0.9637902	0.4750
bDistribution	-0.0233601	0.0693394	-0.3429197	-0.1703516	0.1155390	0.7310
bDistributionRegime	0.0178055	0.0495882	0.3369297	-0.0878477	0.1129369	0.6890
bDistributionSeason	-0.0053668	0.0330636	-0.1497046	-0.0673432	0.0603336	0.8880
bEfficiency	-3.1456925	0.1503743	-20.9322654	-3.4414052	-2.8628312	0.0005
bEfficiencySeason	-0.3680849	0.3521946	-1.0626181	-1.0710439	0.3097583	0.2830
bMultiplierType	0.0061974	0.2486555	0.0647286	-0.4353917	0.5237342	0.9850
bRate	0.2398310	0.1246984	1.9257873	-0.0254257	0.4808559	0.0750
bRateRegime	-0.2953578	0.2231386	-1.3395355	-0.7454213	0.1305092	0.1640
sDensitySite	0.6256241	0.1618852	4.0192569	0.4141142	1.0325745	0.0005
sDensitySiteYear	0.1821771	0.0685620	2.5884171	0.0437079	0.3051739	0.0005
sDispersion	-0.9557252	0.1600824	-6.0504939	-1.3264700	-0.6976038	0.0005
sDispersionType	1.1719990	0.2645835	4.4419450	0.6591284	1.7018247	0.0005
sDistributionYear	0.0588833	0.0377955	1.6893004	0.0066366	0.1534442	0.0005
sEfficiencySessionSeasonYear	0.2616722	0.0546470	4.8175419	0.1614897	0.3780271	0.0005
sRateYear	0.3999705	0.1237228	3.3837426	0.2380854	0.7120449	0.0005
tAbundance	-0.2953578	0.2231386	-1.3395355	-0.7454213	0.1305092	0.1640
tDistribution	0.0178055	0.0495882	0.3369297	-0.0878477	0.1129369	0.6890

n	K	nsamples	nchains	nsims	duration	rhat	converged
1044	18	2000	4	320000	2270.38351392s (~37.84 minutes)	1.09	TRUE

Abundance - Adult Bull Trout

Parameter	Estimate	SD	Z-score	Lower	Upper	Significance
bDensitySeason	-0.2882166	0.3631732	-0.6931211	-0.8930392	0.5449565	0.4590
bDistribution	0.0582116	0.0477049	1.2135668	-0.0404665	0.1443064	0.2350
bDistributionRegime	0.0426375	0.0378211	1.1245778	-0.0355627	0.1151198	0.2390
bDistributionSeason	0.1345567	0.0300632	4.4722849	0.0744979	0.1923452	0.0005
bEfficiency	-3.6436894	0.1175444	-30.9586278	-3.8615137	-3.4078391	0.0005
bEfficiencySeason	-0.0278121	0.3601965	-0.1923717	-0.8859242	0.5592198	0.9160
bMultiplierType	0.6207753	0.1884473	3.2836396	0.2474707	0.9902832	0.0020
bRate	0.0392847	0.0362042	1.1615108	-0.0235794	0.1210203	0.1890
bRateRegime	-0.0852672	0.0874156	-1.0154568	-0.2865160	0.0750505	0.2730
sDensitySite	0.4525169	0.1191209	3.9748294	0.2944337	0.7601694	0.0005
sDensitySiteYear	0.4107809	0.0443360	9.2956743	0.3260812	0.5028637	0.0005
sDispersion	-0.9387993	0.1042657	-9.0556224	-1.1721705	-0.7530630	0.0005
sDispersionType	0.7603995	0.1914199	3.9530481	0.3746911	1.1162625	0.0005
sDistributionYear	0.0287660	0.0208965	1.5181003	0.0021586	0.0780286	0.0005
sEfficiencySessionSeasonYear	0.2291219	0.0415293	5.5300904	0.1532975	0.3167081	0.0005
sRateYear	0.1318066	0.0768006	1.8128623	0.0181214	0.3089119	0.0005
tAbundance	-0.0852672	0.0874156	-1.0154568	-0.2865160	0.0750505	0.2730
tDistribution	0.0426375	0.0378211	1.1245778	-0.0355627	0.1151198	0.2390

n	K	nsamples	nchains	nsims	duration	rhat	converged
1044	18	2000	4	40000	466.533728837967s (~7.78 minutes)	1.1	TRUE

Abundance - Juvenile Mountain Whitefish

Parameter	Estimate	SD	Z-score	Lower	Upper	Significance
bDensitySeason	0.4862685	0.6922579	0.7001886	-0.8450878	1.8823028	0.4790
bDistribution	0.0925140	0.1035882	0.8815221	-0.1046683	0.2989867	0.3840
bDistributionRegime	0.0592829	0.0767315	0.7893818	-0.0827539	0.2188564	0.3820
bDistributionSeason	-0.0927744	0.0346993	-2.6870507	-0.1619466	-0.0267106	0.0080
bEfficiency	-5.6909935	0.4475851	-12.7940782	-6.6846042	-4.9461266	0.0005
bEfficiencySeason	0.0854189	0.6929100	0.1075346	-1.3297729	1.4144776	0.9040

bMultiplierType	0.3644342	0.2513478	1.4489947	-0.1430174	0.8561175	0.1580
bRate	0.1757425	0.3396964	0.6057143	-0.3796173	0.9408574	0.5570
bRateRegime	-0.2949386	0.5903909	-0.5254461	-1.5057016	0.8348206	0.5500
sDensitySite	0.8849467	0.2266866	4.0854721	0.5899266	1.4592510	0.0005
sDensitySiteYear	0.4996290	0.0693170	7.2209988	0.3684122	0.6423932	0.0005
sDispersion	-0.6196515	0.0922471	-6.7298350	-0.8058056	-0.4495254	0.0005
sDispersionType	0.9069275	0.1816135	5.0131306	0.5538005	1.2843566	0.0005
sDistributionYear	0.0804613	0.0441286	1.9433969	0.0110435	0.1903641	0.0005
sEfficiencySessionSeasonYear	0.2879750	0.0658752	4.4281369	0.1658714	0.4345835	0.0005
sRateYear	0.6751302	0.3704022	2.0605684	0.3271509	1.8223557	0.0005
tAbundance	-0.2949386	0.5903909	-0.5254461	-1.5057016	0.8348206	0.5500
tDistribution	0.0592829	0.0767315	0.7893818	-0.0827539	0.2188564	0.3820

n	K	nsamples	nchains	nsims	duration	rhat	converged
815	18	2000	4	1280000	6681.29352998734s (~1.86 hours)	1.06	TRUE

Abundance - Adult Mountain Whitefish

Parameter	Estimate	SD	Z-score	Lower	Upper	Significance
bDensitySeason	-0.6868749	0.1226750	-5.5925381	-0.9343428	-0.4451391	0.0005
bDistribution	0.0886822	0.0526896	1.7049560	-0.0126144	0.1913519	0.0920
bDistributionRegime	0.0420695	0.0409475	1.0423150	-0.0381254	0.1265885	0.2620
bDistributionSeason	-0.0634293	0.0196418	-3.2163562	-0.1015703	-0.0241077	0.0010
bEfficiency	-4.0053718	0.0658635	-60.7929739	-4.1304451	-3.8727384	0.0005
bEfficiencySeason	0.8860861	0.1256474	7.0727832	0.6472767	1.1345090	0.0005
bMultiplierType	0.4903411	0.1899299	2.5879390	0.1368843	0.8875594	0.0090
bRate	0.0063572	0.0489622	0.2945439	-0.0605749	0.1407975	0.8480
bRateRegime	-0.0217268	0.0831710	-0.3367701	-0.2258688	0.1238516	0.7370
sDensitySite	0.4817200	0.1199897	4.2086238	0.3275907	0.8043769	0.0005
sDensitySiteYear	0.3702445	0.0305688	12.1085225	0.3107628	0.4295677	0.0005
sDispersion	-0.8187999	0.0387121	-21.1373592	-0.8964936	-0.7413720	0.0005
sDispersionType	0.9273884	0.1211654	7.6386926	0.6788134	1.1644392	0.0005

sDistributionYear	0.0517590	0.0228657	2.3285342	0.0115348	0.1005678	0.0005
sEfficiencySessionSeasonYear	0.2546918	0.0347120	7.3610053	0.1916124	0.3307661	0.0005
sRateYear	0.0894262	0.0724479	1.4062163	0.0040934	0.2791827	0.0005
tAbundance	-0.0217268	0.0831710	-0.3367701	-0.2258688	0.1238516	0.7370
tDistribution	0.0420695	0.0409475	1.0423150	-0.0381254	0.1265885	0.2620

n	K	nsamples	nchains	nsims	duration	rhat	converged
1044	18	2000	4	1280000	7749.5605905056s (~2.15 hours)	1.1	TRUE

Abundance - Rainbow Trout

Parameter	Estimate	SD	Z-score	Lower	Upper	Significance
bDensity	0.6533293	0.4609334	1.3877529	-0.3073958	1.5434404	0.1640
bDensitySeason	0.1720165	0.6778927	0.3018074	-1.0095224	1.6585467	0.7950
bEfficiency	-2.6346217	0.2949553	-8.9435060	-3.2258291	-2.0674508	0.0005
bEfficiencySeason	-0.3641696	0.6892913	-0.6109407	-1.8874158	0.8291461	0.5550
sDensitySite	1.1591075	0.3454002	3.5174602	0.7154463	2.0348782	0.0005
sDensitySiteYear	0.4936966	0.1503454	3.2774872	0.1919907	0.7889074	0.0005
sDensityYear	0.2497891	0.1971106	1.4120786	0.0174696	0.7465993	0.0005
sDispersion	-1.2339171	0.9378023	-1.5792869	-4.1051578	-0.3330295	0.0005
sEfficiencySessionSeasonYear	0.3143309	0.1553879	1.9702533	0.0124534	0.6138537	0.0005

n	K	nsamples	nchains	nsims	duration	rhat	converged
740	9	2000	4	320000	467.732274055481s (~7.8 minutes)	1.04	TRUE

Abundance - Largescale Sucker

Parameter	Estimate	SD	Z-score	Lower	Upper	Significance
bDensity	5.2807106	0.2670364	19.7358861	4.7371381	5.7875626	0.0005
bDensitySeason	0.0043752	0.5339726	0.0447323	-0.9464182	1.1476755	0.9910
bEfficiency	-3.3755875	0.1625481	-20.7593640	-3.6988653	-3.0548126	0.0005
bEfficiencySeason	-1.2491326	0.5488653	-2.2899028	-2.3936702	-0.2555397	0.0110
sDensitySite	0.4422012	0.1264301	3.6323013	0.2578177	0.7503333	0.0005

sDensitySiteYear	0.4872211	0.0648153	7.5507728	0.3678700	0.6237233	0.0005
sDensityYear	0.4375645	0.2431456	2.0125583	0.1675406	1.0840311	0.0005
sDispersion	-0.5288058	0.0618686	-8.5826487	-0.6594010	-0.4103021	0.0005
sEfficiencySessionSeasonYear	0.5601213	0.0860905	6.6103831	0.4176117	0.7566112	0.0005

n	K	nsamples	nchains	nsims	duration	rhat	converged
600	9	2000	4	320000	398.652538061142s (~6.64 minutes)	1.03	TRUE

Appendix H – Additional Results

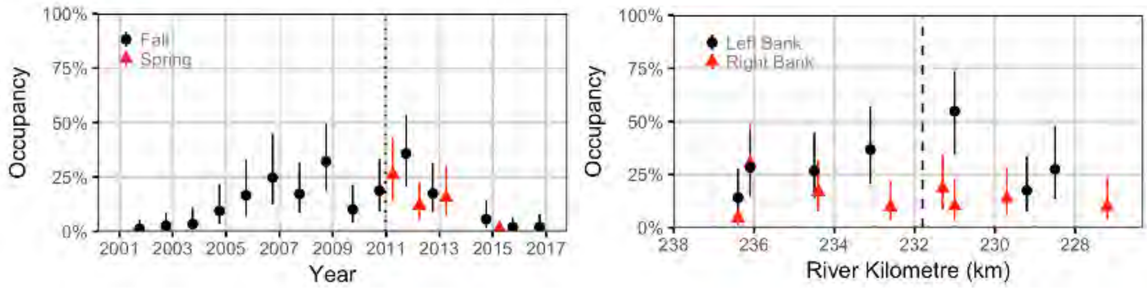


Figure H1. Occupancy estimates (with 95% credible intervals) by year and season (left panel) and site (right panel) for Burbot in the Middle Columbia River study area, 2001 to 2016. The dotted line (left panel) represents the implementation of the minimum flow release and REV5 operations. The dashed line (right panel) represents the divide between Reaches 3 and 4 at the Jordan River confluence.

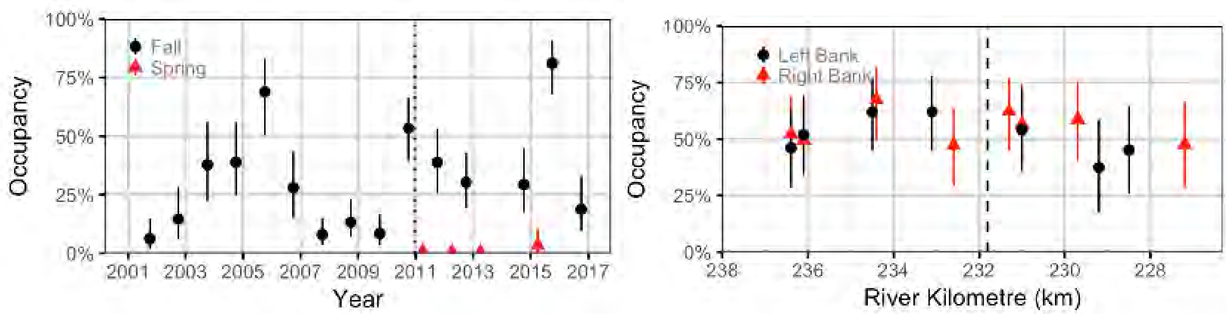


Figure H2. Occupancy estimates (with 95% credible intervals) by year and season (left panel) and site (right panel) for Lake Whitefish in the Middle Columbia River study area, 2001 to 2016. The dotted line (left panel) represents the implementation of the minimum flow release and REV5 operations. The dashed line (right panel) represents the divide between Reaches 3 and 4 at the Jordan River confluence.

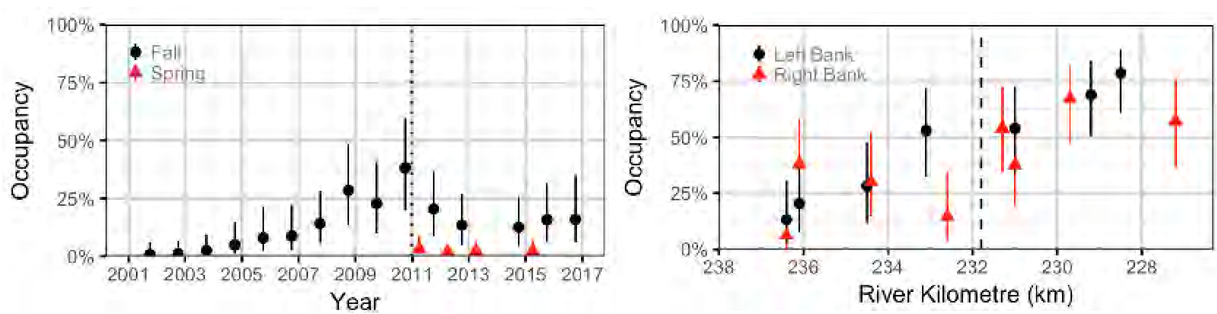


Figure H3. Occupancy estimates (with 95% credible intervals) by year and season (left panel) and site (right panel) for Northern Pikeminnow in the Middle Columbia River study area, 2001 to 2016. The dotted line (left panel) represents the implementation of the minimum flow release and REV5 operations. The dashed line (right panel) represents the divide between Reaches 3 and 4 at the Jordan River confluence.

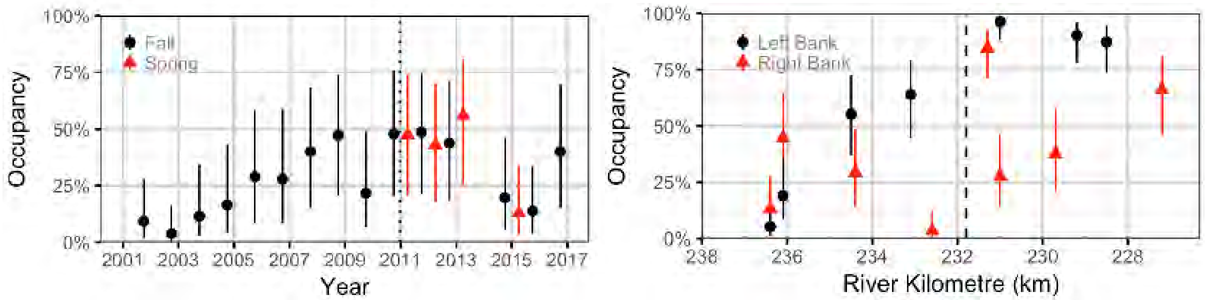


Figure H4. Occupancy estimates (with 95% credible intervals) by year and season (left panel) and site (right panel) for Rainbow Trout in the Middle Columbia River study area, 2001 to 2016. The dotted line (left panel) represents the implementation of the minimum flow release and REV5 operations. The dashed line (right panel) represents the divide between Reaches 3 and 4 at the Jordan River confluence.

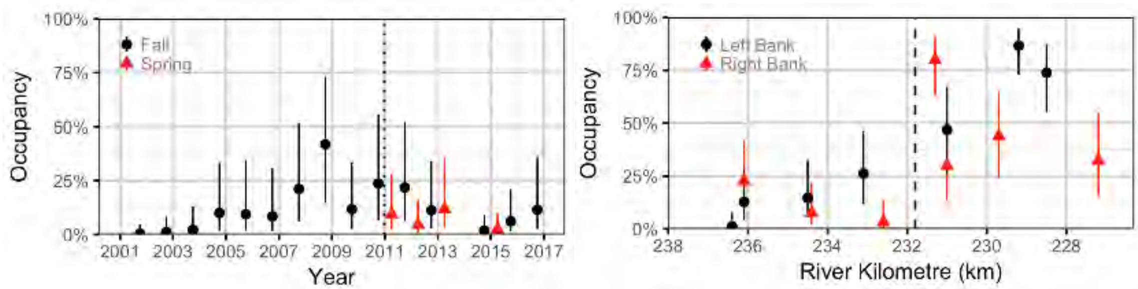


Figure H5. Occupancy estimates (with 95% credible intervals) by year and season (left panel) and site (right panel) for Redside Shiner in the Middle Columbia River study area, 2001 to 2016. The dotted line (left panel) represents the implementation of the minimum flow release and REV5 operations. The dashed line (right panel) represents the divide between Reaches 3 and 4 at the Jordan River confluence.

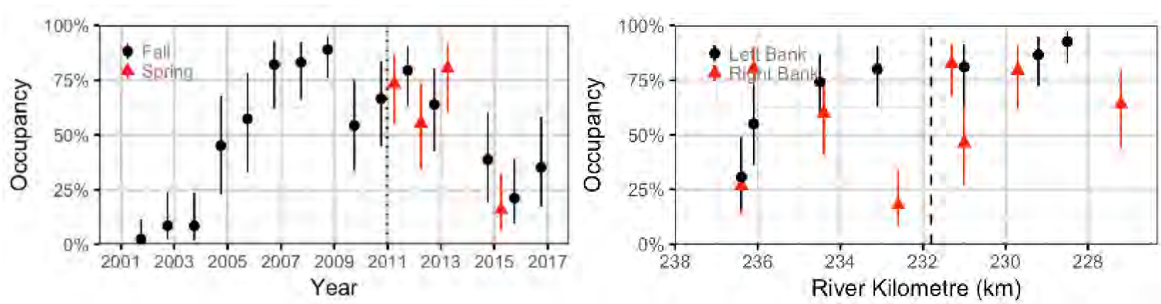


Figure H6. Occupancy estimates (with 95% credible intervals) by year and season (left panel) and site (right panel) for Sculpin species in the Middle Columbia River study area, 2001 to 2016. The dotted line (left panel) represents the implementation of the minimum flow release and REV5 operations. The dashed line (right panel) represents the divide between Reaches 3 and 4 at the Jordan River confluence.

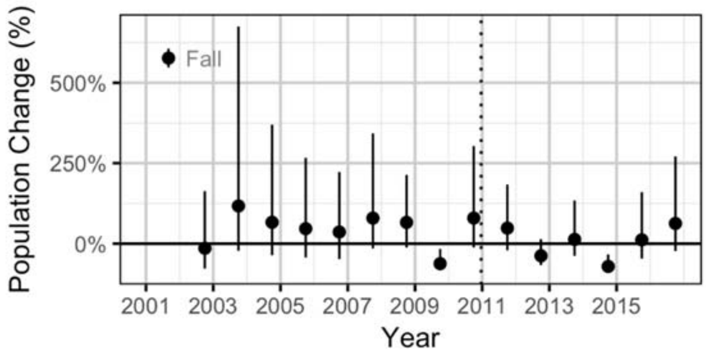


Figure H7. Estimated population growth rate of Rainbow Trout based on count density by year (with 95% credible intervals) in the Middle Columbia River study area, 2001 to 2016. The dotted line represents the implementation of the minimum flow release and REV5 operations.

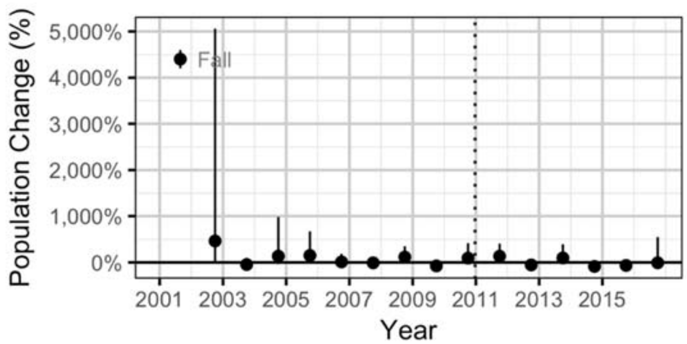


Figure H8. Estimated population growth rate of Burbot by year (with 95% credible intervals) in the Middle Columbia River study area, 2001 to 2016. The dotted line represents the implementation of the minimum flow release and REV5 operations.

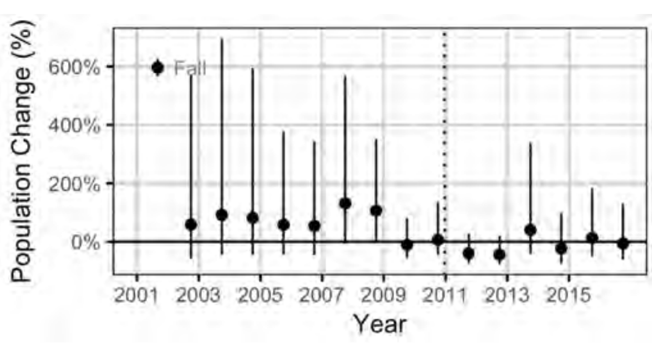


Figure H9. Estimated population growth rate of Northern Pikeminnow by year (with 95% credible intervals) in the Middle Columbia River study area, 2001 to 2016. The dotted line represents the implementation of the minimum flow release and REV5 operations.

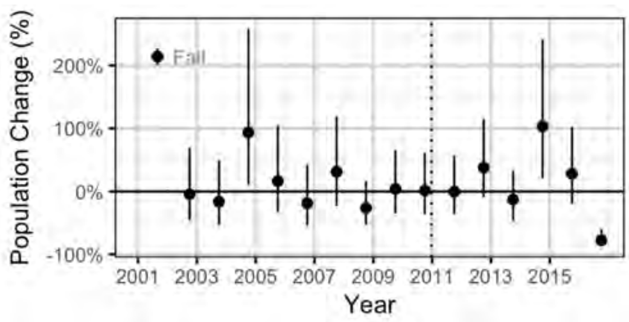


Figure H10. Estimated population growth rate of Suckers by year (with 95% credible intervals) in the Middle Columbia River study area, 2001 to 2016. The dotted line represents the implementation of the minimum flow release and REV5 operations.

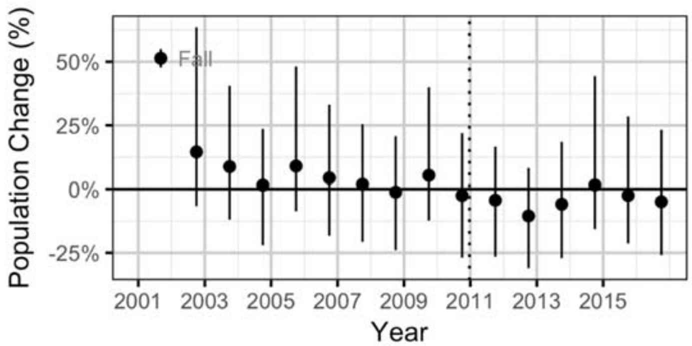


Figure H11. Estimated population growth rate of adult Bull Trout by year (with 95% credible intervals) in the Middle Columbia River study area, 2001 to 2016. The dotted line represents the implementation of the minimum flow release and REV5 operations.

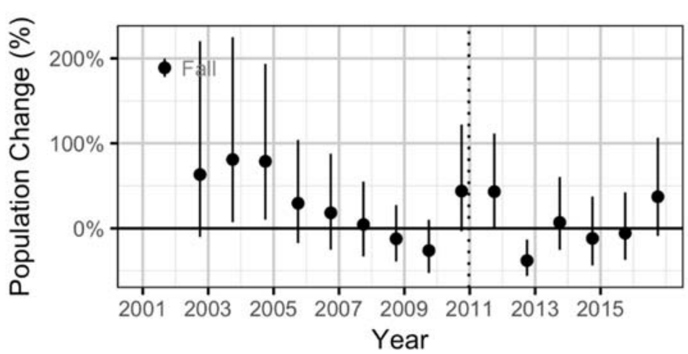


Figure H12. Estimated population growth rate of juvenile Bull Trout by year (with 95% credible intervals) in the Middle Columbia River study area, 2001 to 2016. The dotted line represents the implementation of the minimum flow release and REV5 operations.

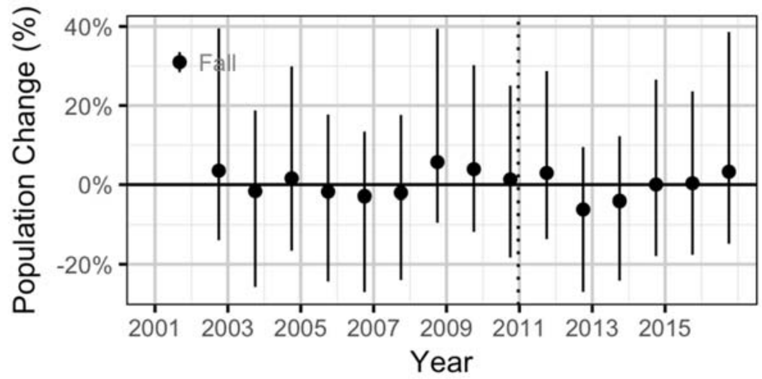


Figure H13. Estimated population growth rate of adult Mountain Whitefish by year (with 95% credible intervals) in the Middle Columbia River study area, 2001 to 2016. The dotted line represents the implementation of the minimum flow release and REV5 operations.

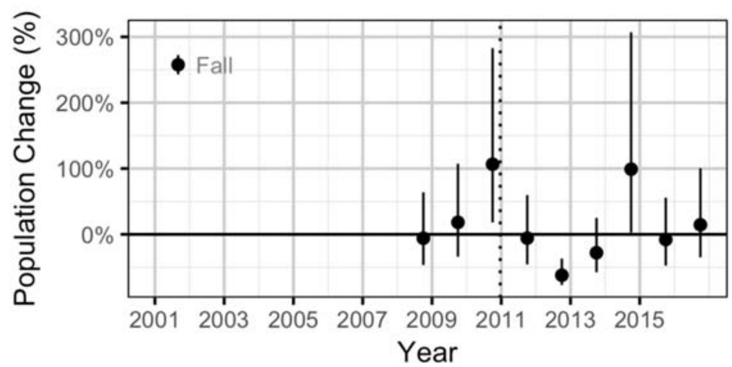


Figure H14. Estimated population growth rate of juvenile Mountain Whitefish by year (with 95% credible intervals) in the Middle Columbia River study area, 2001 to 2016. The dotted line represents the implementation of the minimum flow release and REV5 operations.

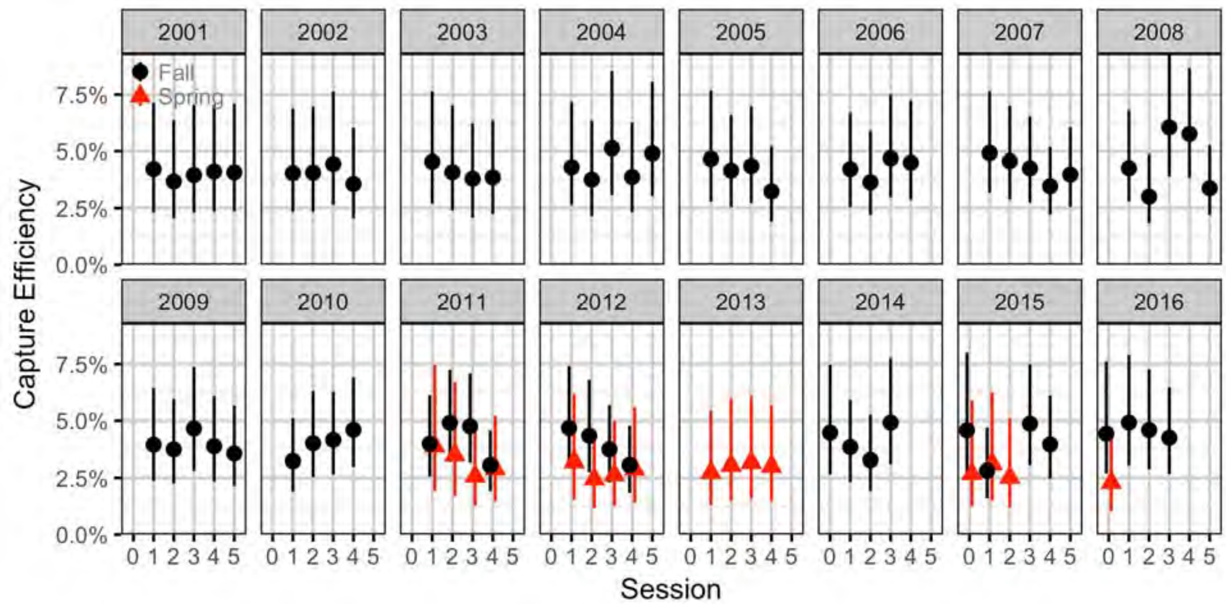


Figure H15. Capture efficiency estimates (with 95% credible intervals) by year, season, and session for juvenile Bull Trout in the Middle Columbia River study area, 2001 to 2016. Efficiency was calculated in the hierarchical Bayesian model estimating absolute abundance using mark-recapture data.

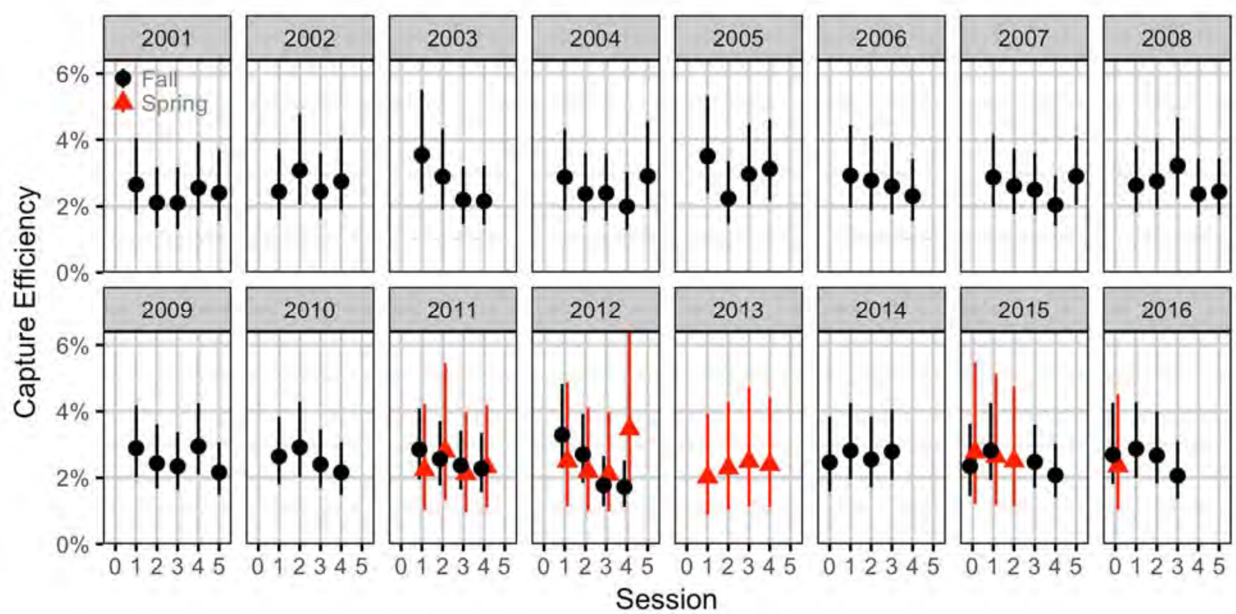


Figure H16. Capture efficiency estimates (with 95% credible intervals) by year, season, and session for adult Bull Trout in the Middle Columbia River study area, 2001 to 2016. Efficiency was calculated in the hierarchical Bayesian model estimating absolute abundance using mark-recapture data.

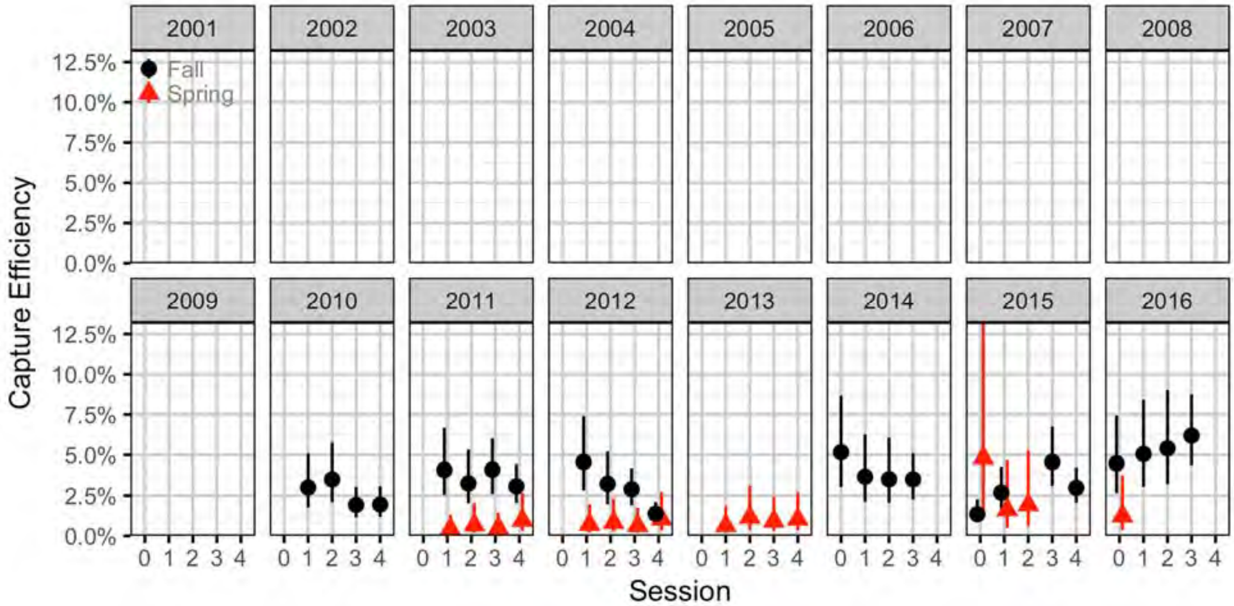


Figure H17. Capture efficiency estimates (with 95% credible intervals) by year, season, and session for Largescale Sucker in the Middle Columbia River study area, 2001 to 2016. Efficiency was calculated in the hierarchical Bayesian model estimating absolute abundance using mark-recapture data.

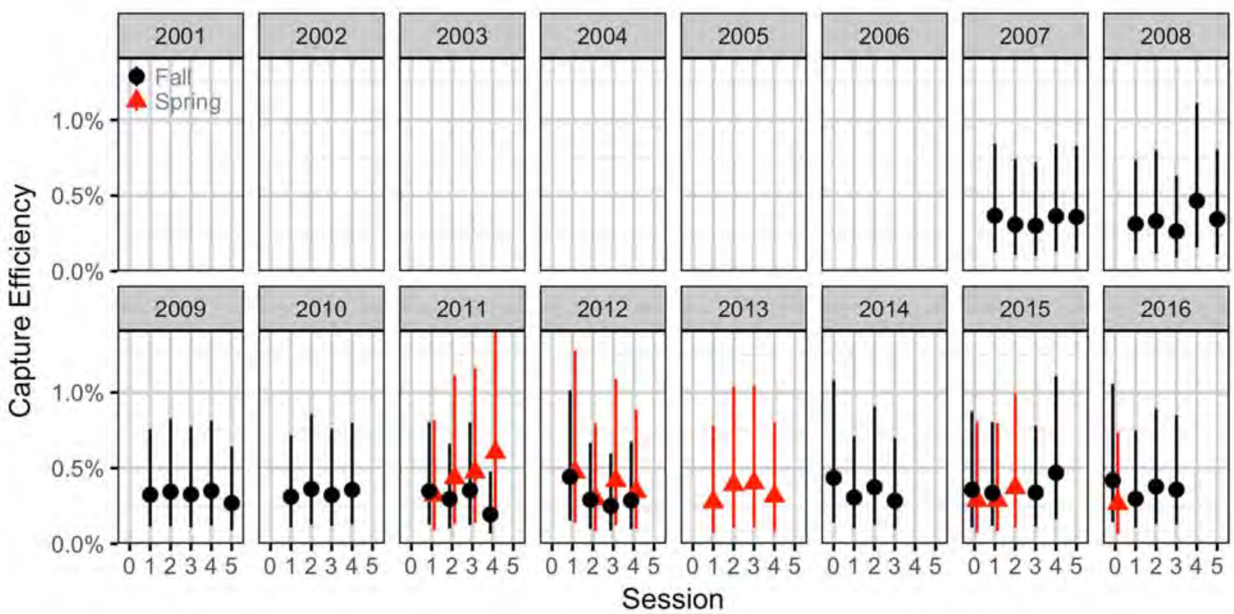


Figure H18. Capture efficiency estimates (with 95% credible intervals) by year, season, and session for juvenile Mountain Whitefish in the Middle Columbia River study area, 2001 to 2016. Efficiency was calculated in the hierarchical Bayesian model estimating absolute abundance using mark-recapture data.

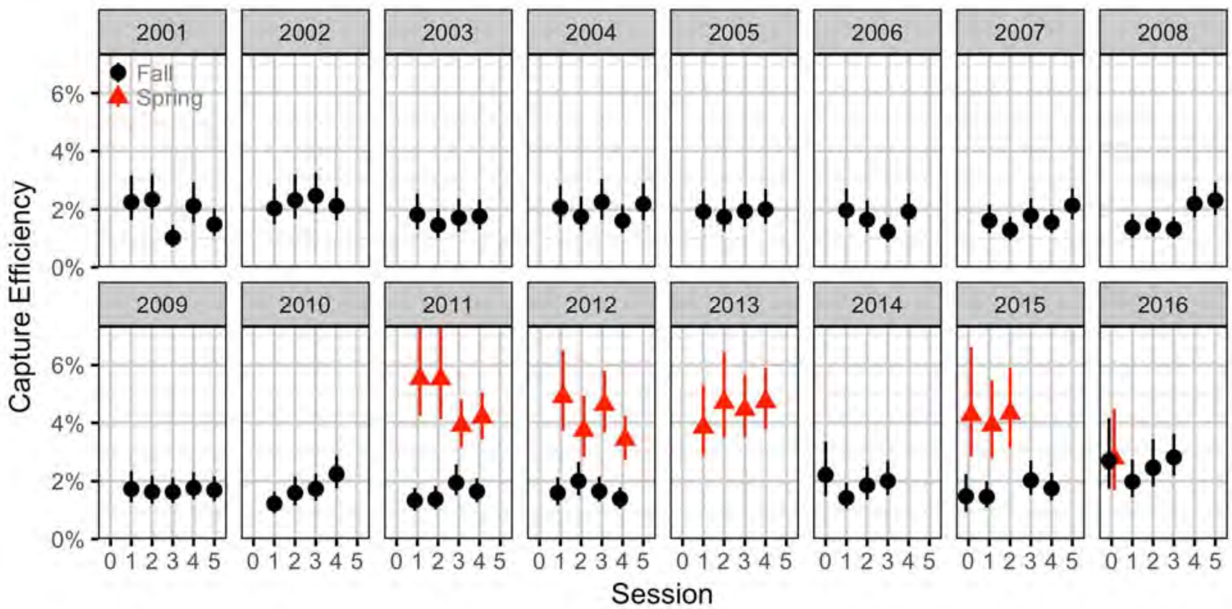


Figure H19. Capture efficiency estimates (with 95% credible intervals) by year, season, and session for adult Mountain Whitefish in the Middle Columbia River study area, 2001 to 2016. Efficiency was calculated in the hierarchical Bayesian model estimating absolute abundance using mark-recapture data.

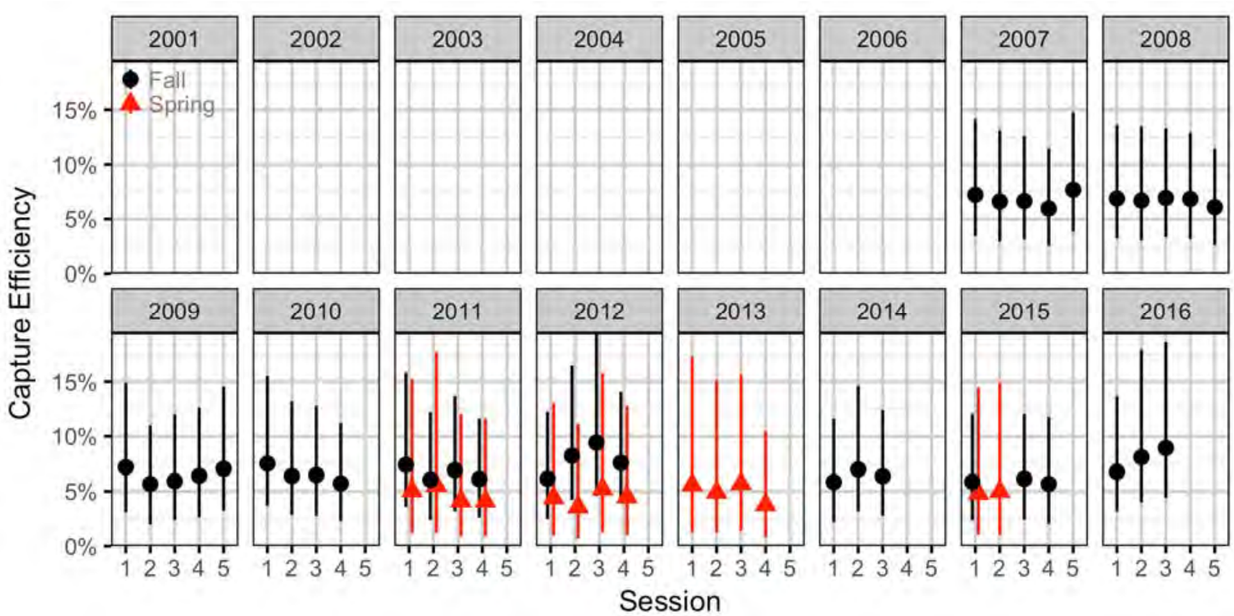


Figure H20. Capture efficiency estimates (with 95% credible intervals) by year, season, and session for adult Rainbow Trout in the Middle Columbia River study area, 2007 to 2016. Efficiency was calculated in the hierarchical Bayesian model estimating absolute abundance using mark-recapture data.

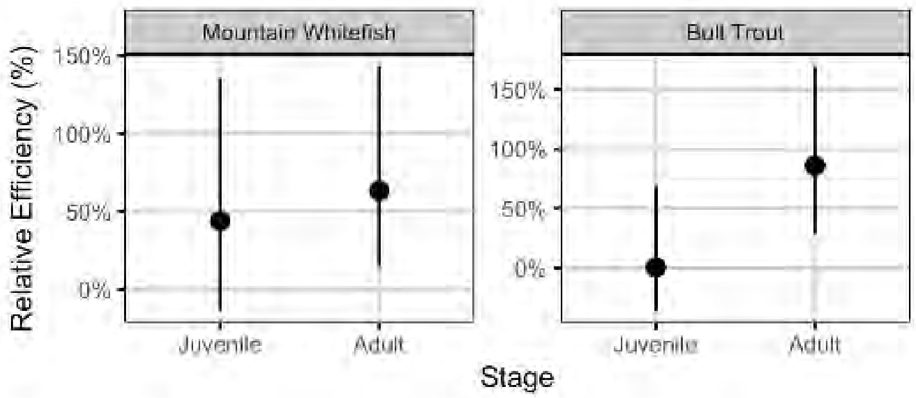


Figure H21. Relative efficiency estimates (with 95% credible intervals) for Mountain Whitefish and Bull Trout based on life stage. Percentages describe the relative number of fish counted to fish captured in the abundance model.

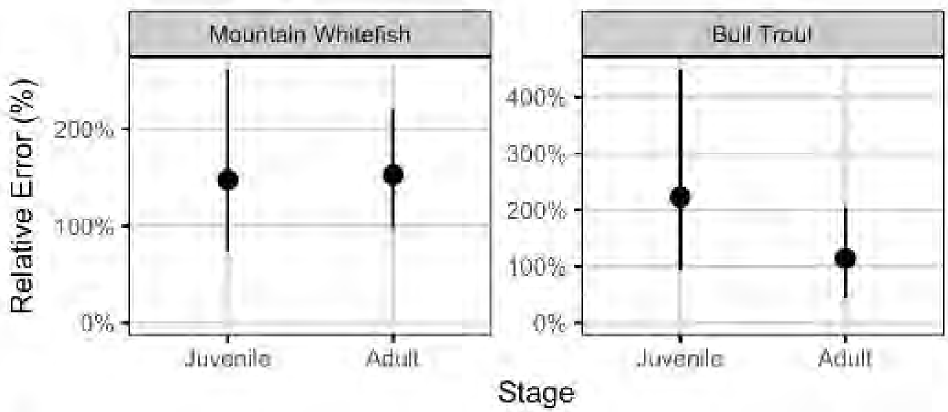


Figure H22. Estimated count overdispersion relative to capture overdispersion by species and stage (with 95% CIs).

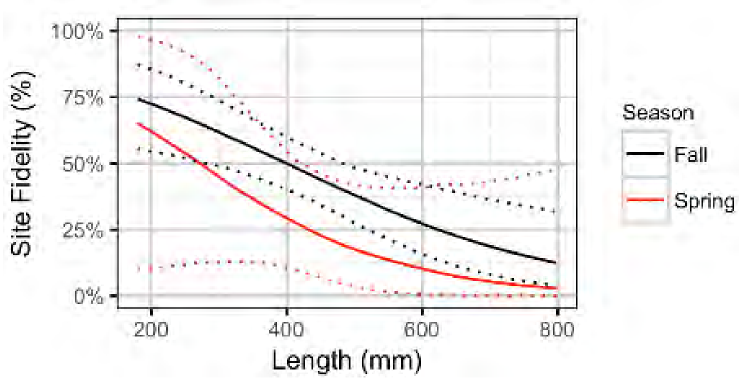


Figure H23. Site fidelity estimates (with 95% credible intervals) by season and fish length for intra-year recaptured Bull Trout in the Middle Columbia River study area, 2001-2016.

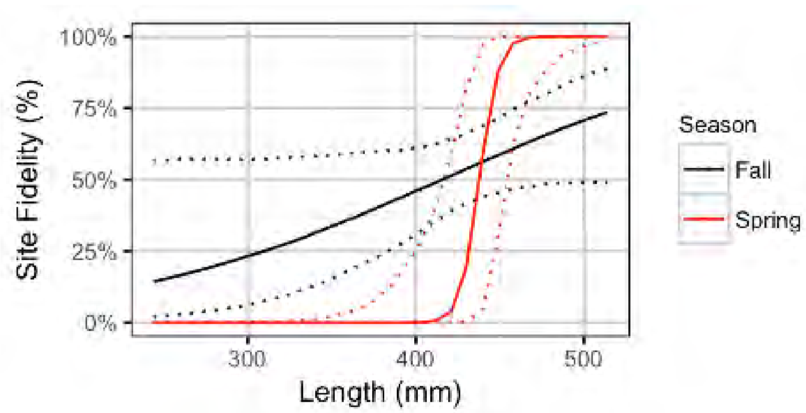


Figure H24. Site fidelity estimates (with 95% credible intervals) by season and fish length for intra-year recaptured Largescale Sucker in the Middle Columbia River study area, 2001-2016.

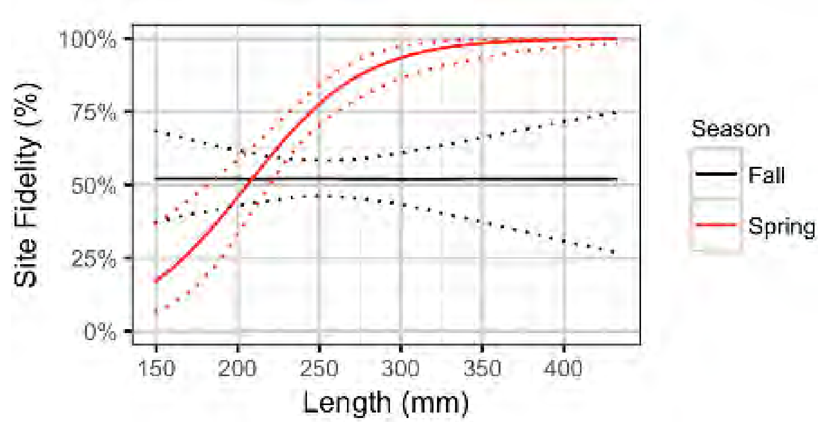


Figure H25. Site fidelity estimates (with 95% credible intervals) by season and fish length for intra-year recaptured Mountain Whitefish in the Middle Columbia River study area, 2001-2016.

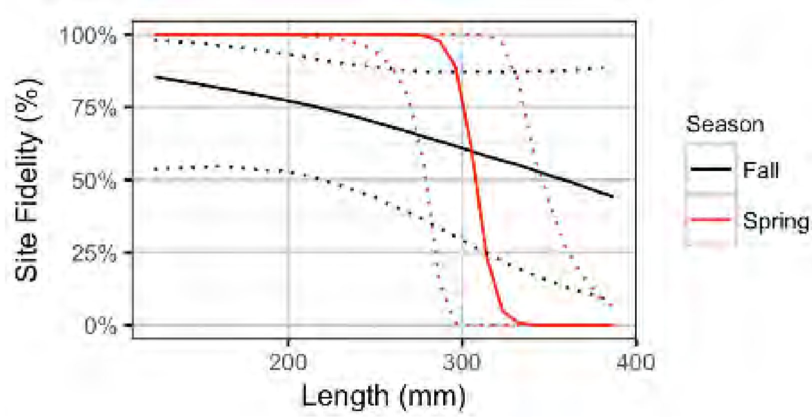
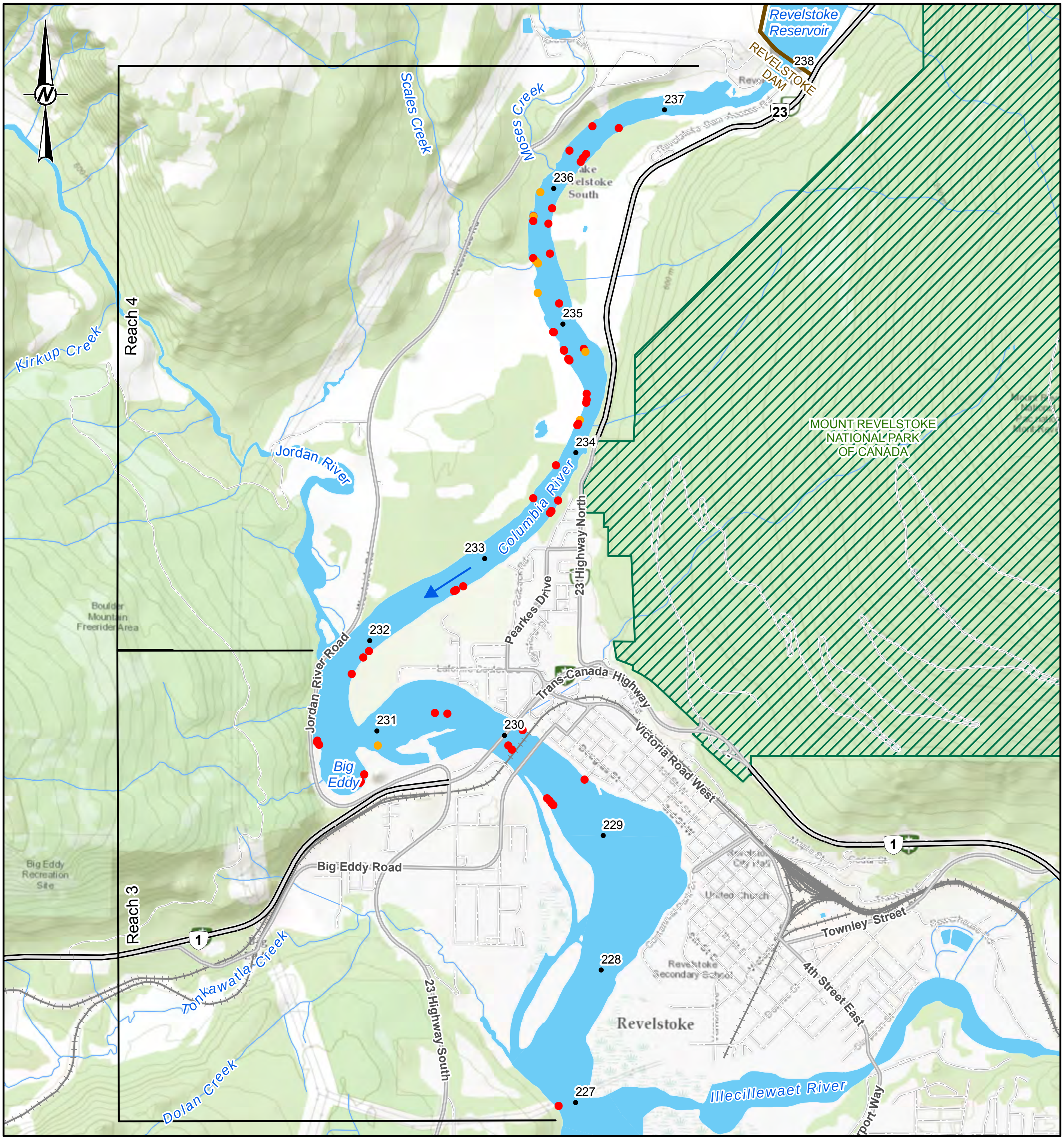


Figure H26. Site fidelity estimates (with 95% credible intervals) by season and fish length for intra-year recaptured Rainbow Trout in the Middle Columbia River study area, 2001-2016.

Appendix I – Spatial Distribution Maps



LEGEND

- RIVER KMS FROM U.S. BORDER
- REACH BOUNDARY
- DAM BASE
- HIGHWAY
- MAJOR ROAD
- LOCAL ROAD
- RAILWAY
- WATERCOURSE
- NATIONAL PARK
- WATERBODY

BULL TROUT - SPRING

- JUVENILE
- ADULT

0 800 1,600

1:40,000 METRES

REFERENCES

1. ROAD AND WATERBODY DATA OBTAINED FROM CANVEC © DEPARTMENT OF NATURAL RESOURCES CANADA. ALL RIGHTS RESERVED.
2. RAILWAYS OBTAINED FROM IHS ENERGY INC.
3. DAM BASE, WATERCOURSE, NATIONAL PARK DATA CONTAINS INFORMATION LICENSED UNDER THE OPEN GOVERNMENT LICENSE – BRITISH COLUMBIA.
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5. COORDINATE SYSTEM: NAD 1983 UTM ZONE 11N

CLIENT
BC HYDRO

PROJECT
MIDDLE COLUMBIA RIVER FISH POPULATION INDEXING STUDY

TITLE
BULL TROUT - SPRING

CONSULTANT
Golder Associates

YYYY-MM-DD	2017-03-01
DESIGNED	DR
PREPARED	CD/RC
REVIEWED	DR
APPROVED	DS

PROJECT NO.	PHASE	REV.	FIGURE
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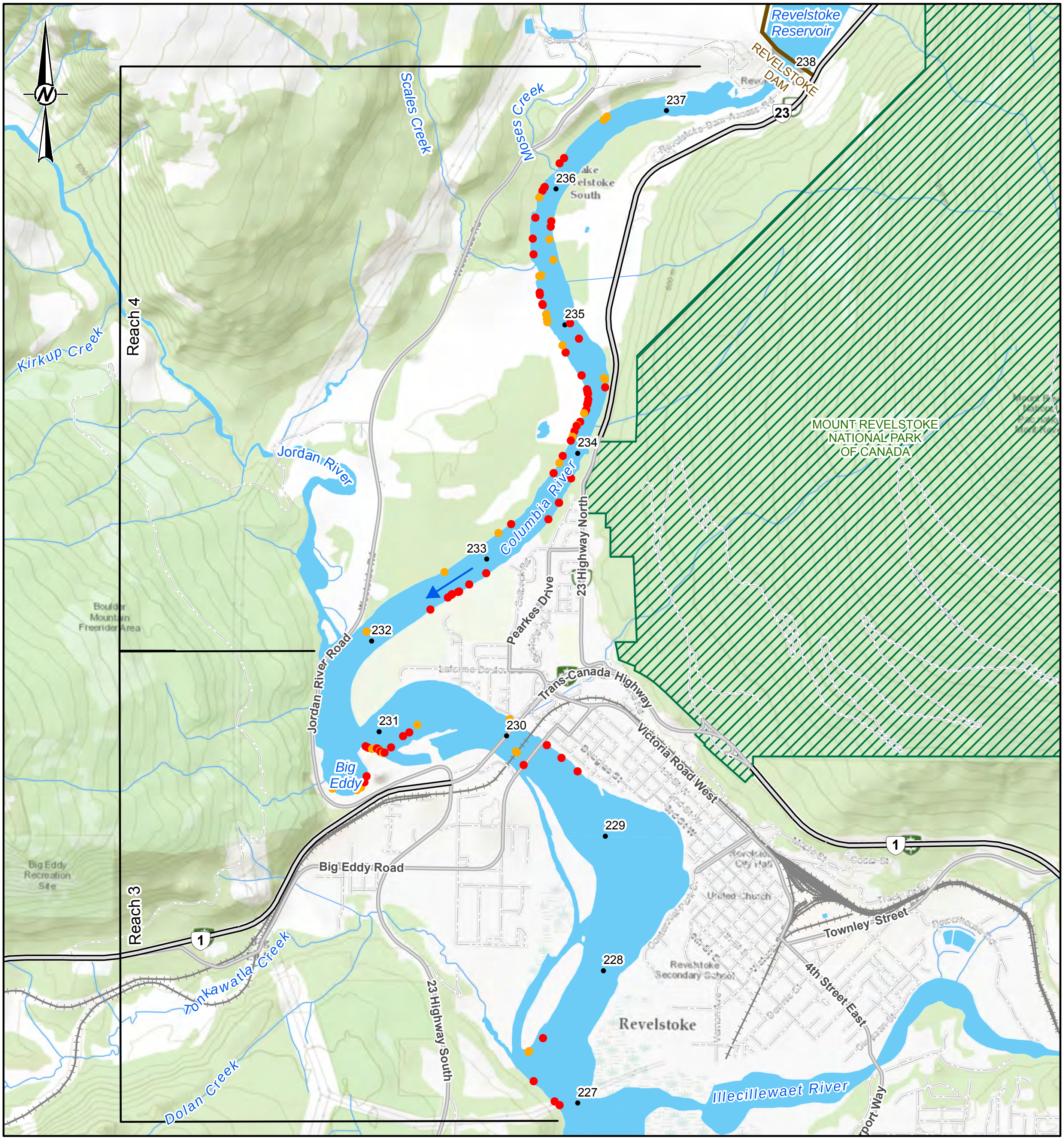

LEGEND

- RIVER KMS FROM U.S. BORDER
- REACH BOUNDARY
- DAM BASE
- HIGHWAY
- MAJOR ROAD
- LOCAL ROAD
- RAILWAY
- WATERCOURSE
- NATIONAL PARK
- WATERBODY

BULL TROUT - FALL

- JUVENILE
- ADULT

0 800 1,600

1:40,000 METRES

REFERENCES

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BC HYDRO

PROJECT
MIDDLE COLUMBIA RIVER FISH POPULATION INDEXING STUDY

TITLE
BULL TROUT - FALL

CONSULTANT
Golder Associates

YYYY-MM-DD	2017-03-01
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PREPARED	CD/RC
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APPROVED	DS

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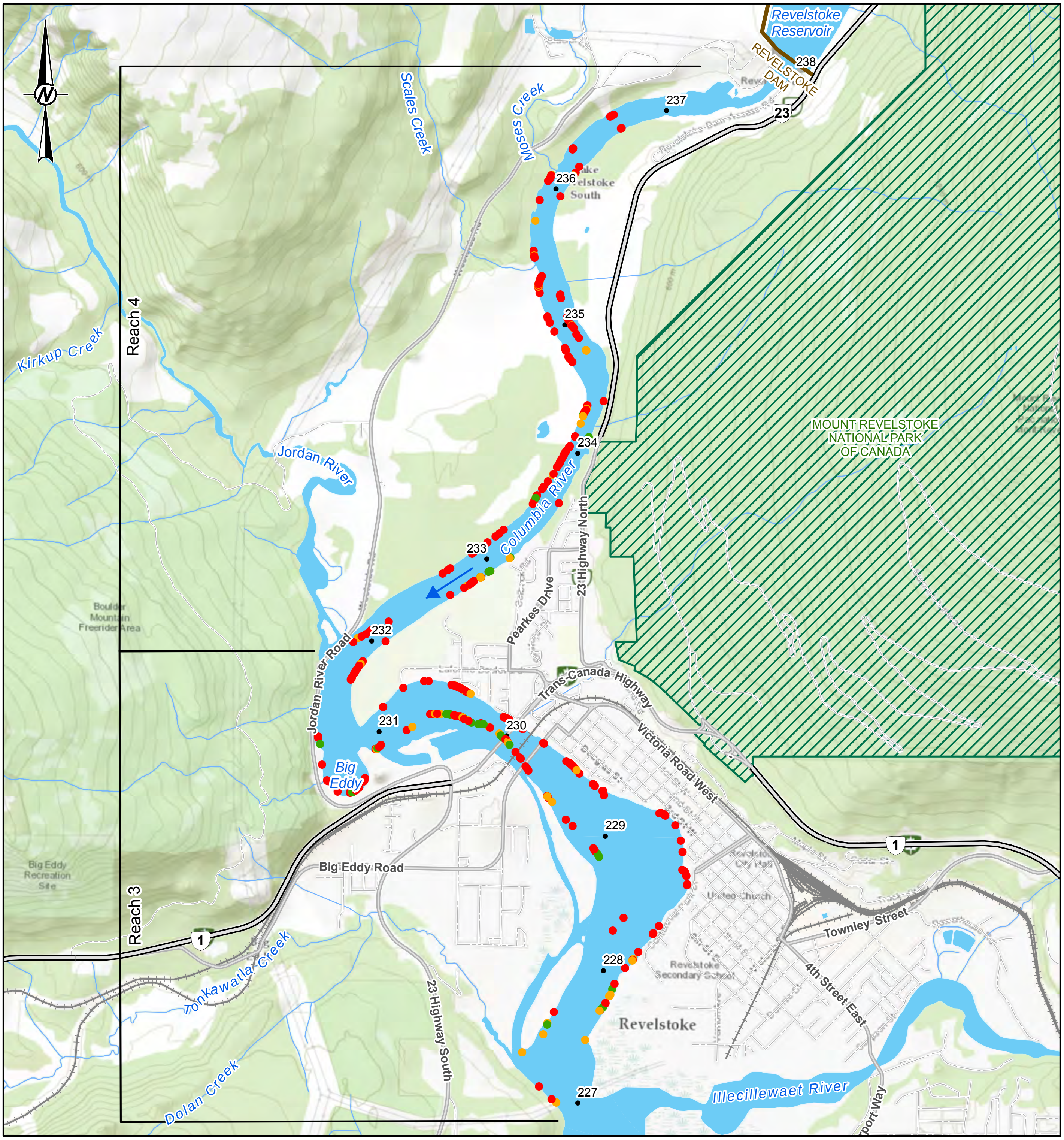

LEGEND

- • RIVER KMS FROM U.S. BORDER
- REACH BOUNDARY
- DAM BASE
- HIGHWAY
- MAJOR ROAD
- LOCAL ROAD
- RAILWAY
- WATERCOURSE
- NATIONAL PARK
- WATERBODY

MOUNTAIN WHITEFISH - SPRING

- FRY
- JUVENILE
- ADULT

0 800 1,600

1:40,000 METRES

REFERENCES

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PROJECT
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TITLE
MOUNTAIN WHITEFISH - SPRING

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Golder Associates

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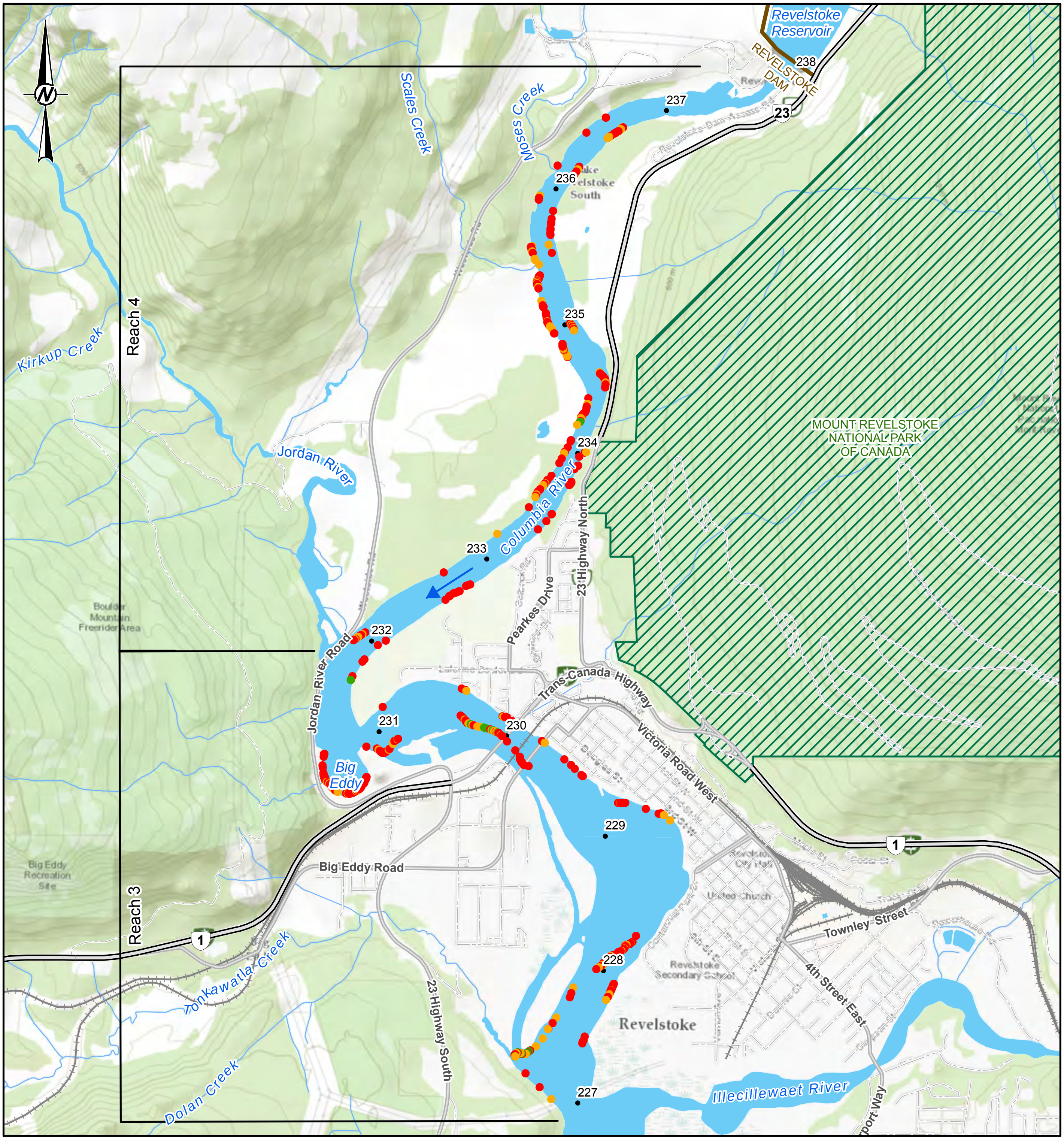

LEGEND

- RIVER KMS FROM U.S. BORDER
- REACH BOUNDARY
- DAM BASE
- HIGHWAY
- MAJOR ROAD
- LOCAL ROAD
- RAILWAY
- WATERCOURSE
- NATIONAL PARK
- WATERBODY

MOUNTAIN WHITEFISH - FALL

- FRY
- JUVENILE
- ADULT

0 800 1,600

1:40,000 METRES

REFERENCES

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PROJECT
MIDDLE COLUMBIA RIVER FISH POPULATION INDEXING STUDY

TITLE
MOUNTAIN WHITEFISH - FALL

CONSULTANT
Golder Associates

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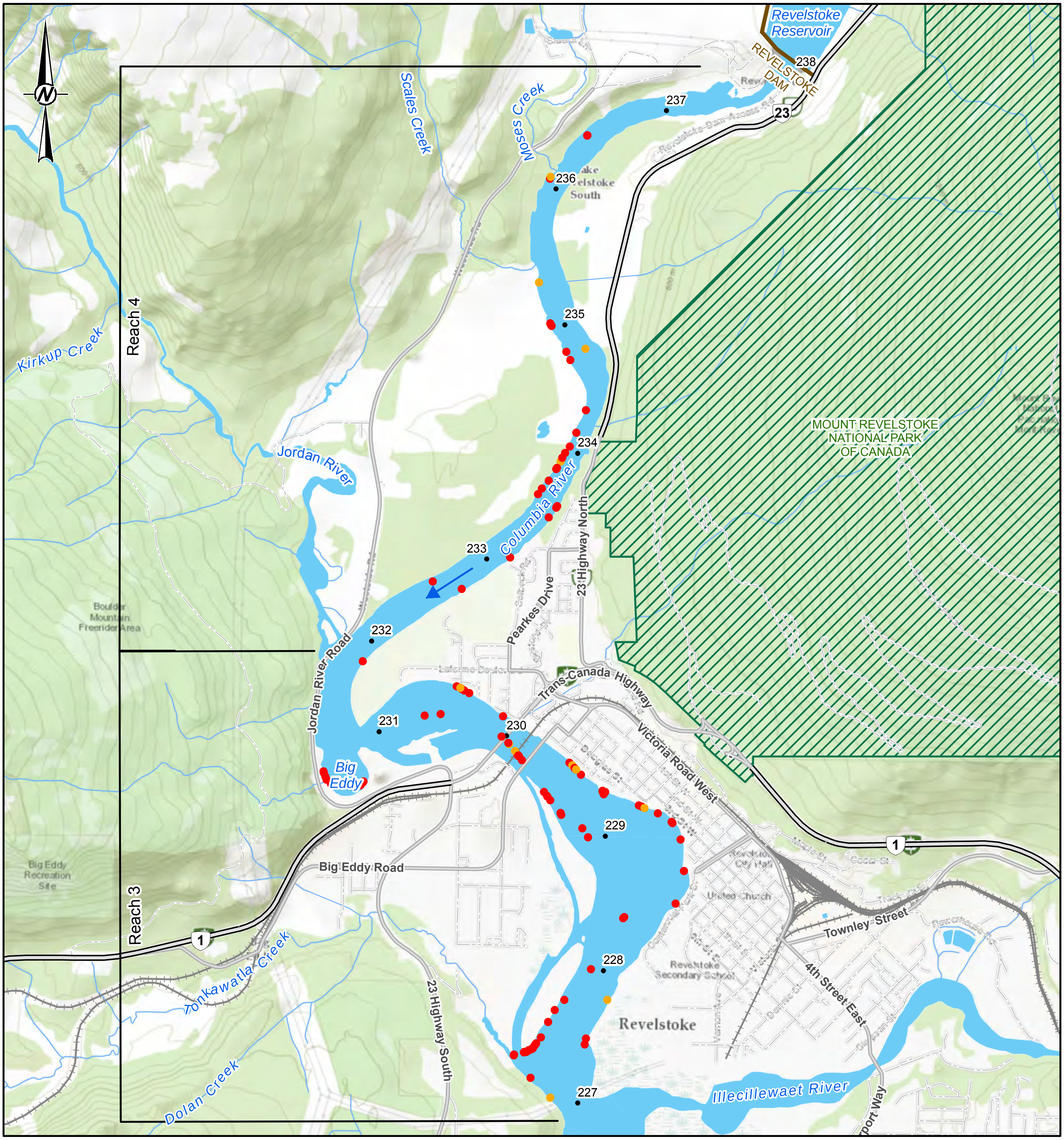

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- RIVER KMS FROM U.S. BORDER
- REACH BOUNDARY
- DAM BASE
- HIGHWAY
- MAJOR ROAD
- LOCAL ROAD
- RAILWAY
- WATERCOURSE
- NATIONAL PARK
- WATERBODY

SUCKER SPECIES - SPRING

- JUVENILE
- ADULT

0 800 1,600

1:40,000 METRES

REFERENCES

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PROJECT
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TITLE
SUCKER SPECIES - SPRING

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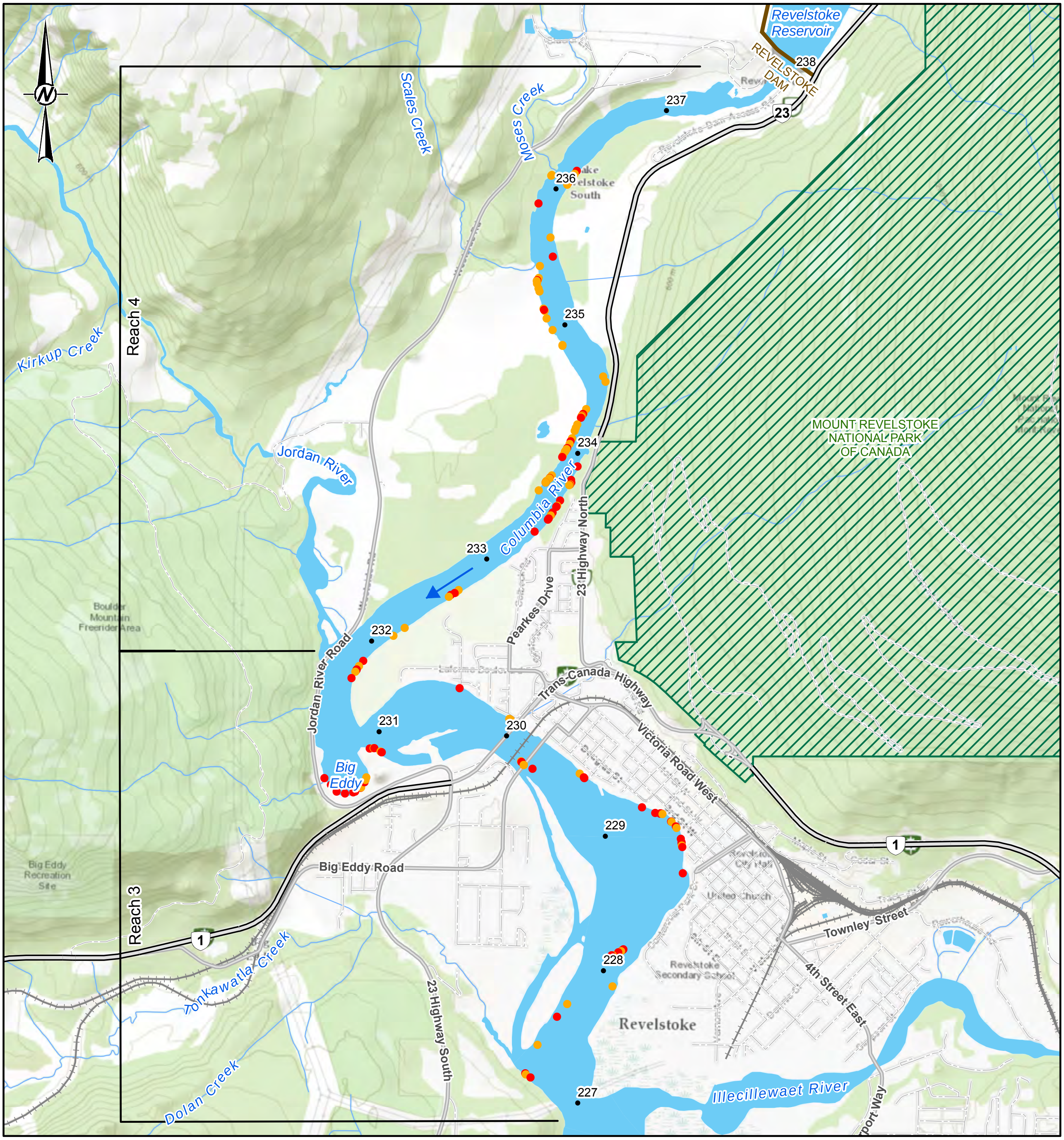

LEGEND

- RIVER KMS FROM U.S. BORDER
- REACH BOUNDARY
- DAM BASE
- HIGHWAY
- MAJOR ROAD
- LOCAL ROAD
- RAILWAY
- WATERCOURSE
- NATIONAL PARK
- WATERBODY

SUCKER SPECIES - FALL

- JUVENILE
- ADULT

0 800 1,600

1:40,000 METRES

REFERENCES

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