Columbia River Project Water Use Plan

Revelstoke Flow Management Plan

Implementation Year 7

Reference: CLBMON-16

Middle Columbia River Fish Population Indexing Program

Study Period: 2013

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February 2015

CLBMON-16:
Middle Columbia River
Fish Population Indexing Survey

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February 2015

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Citation: Okanagan Nation Alliance, Golder Associates Ltd., and Poisson Consulting Ltd. 2014. CLBMON-16 Middle Columbia River Fish Population Indexing Survey. Report prepared for BC Hydro Generation, Water License Requirements, Revelstoke, BC.

Executive Summary

A year-round 142 m^3/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 1700 m^3/s to 2124 m^3/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 three years after (2011 to 2013) 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 life history characters of fish populations in the MCR. Sampling was conducted in the fall from 2001 to 2010, the spring and fall from 2010 to 2011, and in the spring only in 2013.

The study area encompassed the 12 km portion of the Columbia River between Revelstoke Dam and the Illecillewaet River confluence. Fishes were sampled by boat electroshocking at night within nearshore habitats. All captured fishes were measured for fork length and weighed. Select species were implanted with a Passive Integrated Transponder (PIT) tag for a 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*) 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. Although the results suggest that a substantial change in the fish community occurred between 2001 and 2008, reasons for the change are unknown, and densities of most of the fish species that increased were not correlated with discharge or reservoir elevation.

Lack of data from the fall season in 2013 means that results from this year's sampling provide little new information to assess the effects of the flow regime change because spring data were not collected prior to the change. With only two years of complete (spring and fall) data following the flow regime change, it is not possible to draw strong conclusions about its effect on fish populations. In general, the abundance of most species was stable or within the range of previously observed variability. However, there was some evidence to suggest that conditions for fish growth and abundance in the MCR may have declined in the years following the flow regime change. The four cohorts of juvenile Mountain Whitefish that were rearing in the MCR following the flow regime change (i.e., age-0 in 2011 and age-1 in 2012, and age-1 in 2012 and age-0 in 2013) were noticeably less abundant compared to previous years, based on density estimates and length-frequency distributions. In addition, the body condition of adult Mountain Whitefish and juvenile and adult Bull Trout all declined to low levels in the three years following the flow regime change. Estimates of biomass, which takes into account both abundance and size of individuals, decreased in the three years following the flow regime change for Bull Trout and Mountain Whitefish, although values were within the range of fluctuations prior to 2010. The similar trends in all these metrics suggest that growth was likely lower in 2011-2013 but the cause of the decline remains unclear. Additional years of data collection are required to assess the influence of environmental variables, and identify whether the flow regime change at REV contributed to any of the observed differences in fish populations.

Recommendations for future years of study include: 1) sampling during the fall to gather data comparable to years prior to the flow regime change; and, 2) conducting an additional electrofishing pass during which fish would be identified and enumerated but not captured to collect fine scale spatial distribution data.

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

Table E1: Status of management questions and hypotheses after Year 7 of the Middle Columbia River Fish Population Indexing Survey (CLBMON-16).

Objectives	Management Questions	Management Hypotheses	Year 7 (2013) 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.	Hypothesis cannot be rejected at this time. Two years of fall data have been collected since the implementation of the minimum flow release. Data collected to date do not suggest a substantial change in abundance or diversity of adult fish present in the MCR during indexing surveys. A hierarchical Bayesian model has been constructed that allows annual and spatial comparisons of the abundance and diversity of adult life stages of common fish species present in the MCR.
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 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.	Hypothesis cannot be rejected at this time. Two years of fall data have been collected since the implementation of the minimum flow release. Inter-annual growth of recaptured fishes did not suggest any significant changes in growth rate following the flow regime change.
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 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.	Hypothesis cannot be rejected at this time. Two years of fall data have been collected since the implementation of the minimum flow release. The body condition of Mountain Whitefish and Bull Trout declined after the flow regime change but reasons for the decline are unknown. A hierarchical Bayesian Model has been constructed that allows annual and spatial comparisons of the body condition of adult life stages of common fish species present in the MCR.

Objectives	Management Questions	Management Hypotheses	Year 7 (2013) 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 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.	Hypothesis cannot be rejected at this time. Two years of fall data have been collected since the implementation of the minimum flow release. Data collected to date do not suggest a substantial change in the distribution of any of the fish species present in the MCR during indexing surveys. A hierarchical Bayesian Model has been constructed that allows annual and spatial comparisons of the spatial distribution of adult life stages of common fish species present in the MCR.

Acknowledgements

The Middle Columbia River Fish Population Indexing Survey (CLBMON-16) is funded by BC Hydro's Columbia River Water Use Plan. The Okanagan Nation Alliance, Golder Associates Ltd., and Dr. Joseph Thorley of Poisson Consulting Ltd. would like to thank the following individuals for their contributions to the program:

BC Hydro

Jason Watson	Burnaby, BC
Guy Martel	Burnaby, BC

BC Ministry of Forests, Land, and Natural Resource Operations

Jeff Burrows	Nelson, BC
Albert Chirico	Nelson, BC

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

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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. BC Hydro implemented a Water Use Plan (WUP; BC Hydro 2007) for the Canadian portion of the Columbia River in 2007. 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 December 20, 2010. The addition of REV5 also increased the maximum generation discharge capacity of the REV from 1700 m^3/s to 2124 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 (2013) describes the third year of monitoring after an additional (i.e., fifth) generating unit was added to REV (REV5), and after the minimum flow release was established. The analyses presented in this report, which include changes in fish spatial distribution, represent refinements on the previous year's analyses.

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

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 gleaned from BC Hydro (2010) 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 when compared to the minimum flow release. Due to the inability to separate 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 Dam, Hugh L. Keenleyside Dam, 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 powerplant operating within BC Hydro's hydroelectric grid, and provides 21% of BC Hydro's total systems capacity (http://www.bchydro.com/energy_in_bc/projects/revelstoke_unit_5.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 very low flow 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 1700 m^3/s. With REV5, the maximum discharge through REV is 2124 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 2124 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 is 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 2010).

In 2013, the sample sites covered both banks of Reaches 3 and 4 (similar to 2007, 2008, 2009, 2010, 2011, and 2012). 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.

The locations of the eight sites sampled in Reach 4 and the seven sites sampled in Reach 3 in 2013 are illustrated in Appendix A, Figures A1 and A2, respectively. Site descriptions and UTM locations for all sites are listed in Appendix A, Table A1. In 2013, each site was sampled four times (i.e., four sessions) between May 27 and June 20 (spring; Table 2). The timing of the 2013 spring survey corresponded to the timing of spring surveys conducted in 2011 and 2012. Fall sample sessions (typically conducted from early October to late October) were conducted between 2001 and 2012. However, fall sampling was not conducted in 2013 due to concerns data gaps regarding the long-term impacts of boat electroshocking during the Bull Trout (*Salvelinus confluentus*) and Kokanee (*Oncorhynchus nerka*) spawning seasons.

Table 2: Annual study periods for boat electroshocking surveys conducted in the middle Columbia River, 2001 to 2013.

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

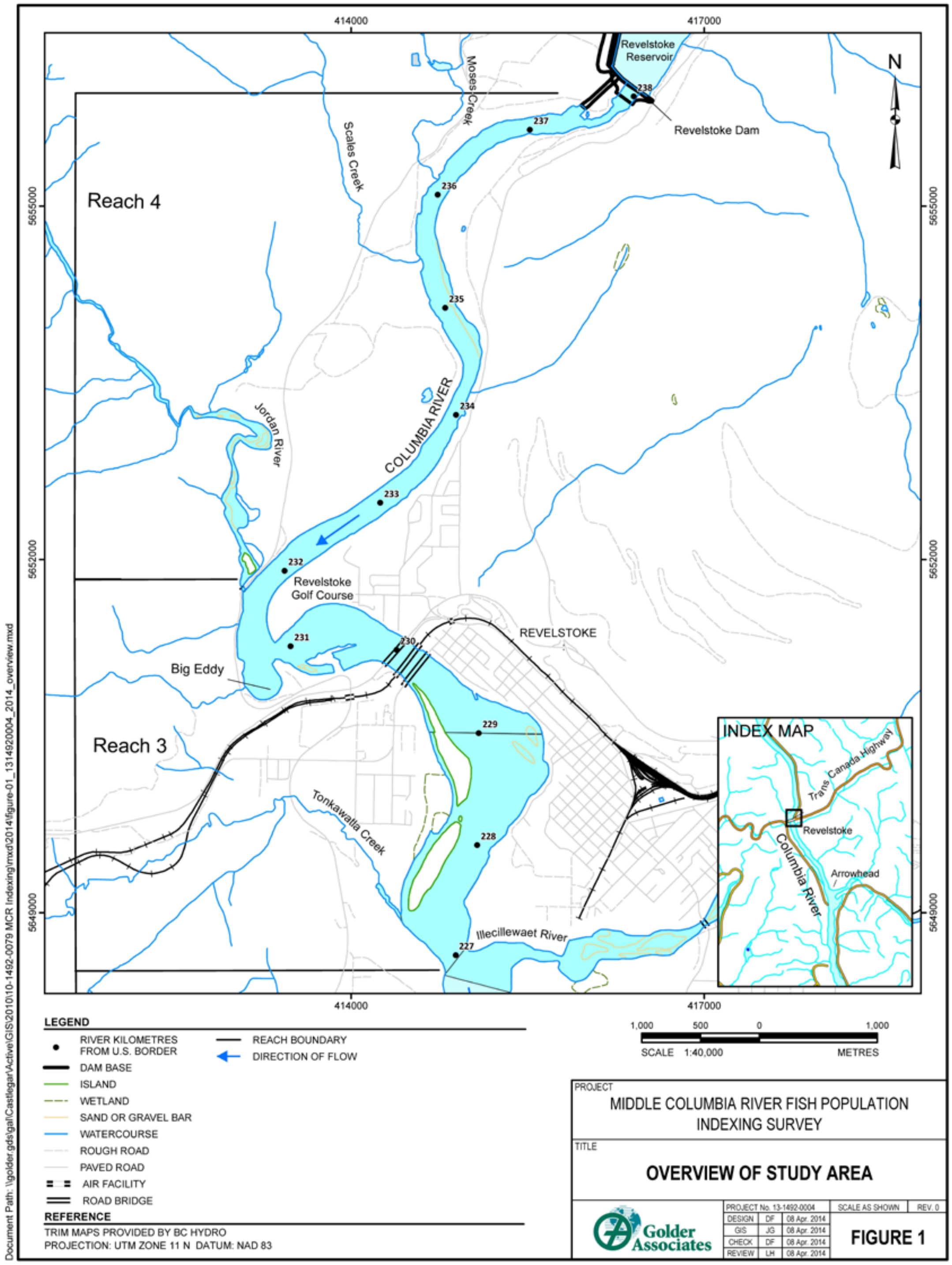

Figure 1: Overview of the middle Columbia River study area, 2013.

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 2013 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 2013 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

From 2007 to 2011, and for 2013, water temperatures for the mainstem Columbia River were obtained from BC Hydro's Tailrace7 station (located approximately 7 km downstream of REV). For 2012, water temperature data were not available for Tailrace7 (see Golder and Poisson 2013). For the 2012 study year, water temperatures were obtained from Station 2 of BC Hydro's MCR Physical Habitat Monitoring Program (CLBMON-15a), located approximately 4 km downstream of REV (RKm 234.0). 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 as a means to detect changes in habitat availability or suitability in the sample sites between study years. The data collected were not intended to quantify habitat availability or imply habitat preferences.

The type and amount of instream cover for fish 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 electrofishing. 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, 2013.

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

2.1.5 Fish Capture

In 2013, fishes were captured between May 27 and June 20 (i.e., the spring season) 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).

Boat electroshocking was conducted in Reaches 3 and 4 of the study area to capture fishes 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 140 HP outboard jet-drive riverboat manned 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 they were captured in and placed into 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 (*Richardsonius balteatus*), and Sculpin (*Cottidae*; all species combined) 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 and the Centennial Park Boat Launch areas of Reach 3 (Figure 1), 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 2009, 2010, 2011, 2012, 2013). For the above reasons, only 50 Kokanee, 50 Redside Shiner, and 50 Sculpin species were randomly 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 2270 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.

Amperage output was set at 1.9 A, at a frequency of 30 Hz direct current as these settings have been shown to result in low electroshocking-induced injury rates for Rainbow Trout (*Oncorhynchus mykiss*; 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 setting 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 a 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., adult Bull Trout or 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 [fish captured prior to tetanus (i.e., in taxis) are less likely to experience spinal hemorrhaging; Golder 2004b, 2005b), 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.

2.1.6 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 over a range of discharge levels from 200 to 1200 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.

2.1.7 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 fishes. Life history and other data collected for captured fishes 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 (Attachment A) using a laptop computer. All fish sampled were automatically assigned a unique identifying number by the database that provided a method of cataloguing associated ageing structures.

Table 4: List and description of variables recorded for each fish captured in the middle Columbia River, 2013.

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

All fish (with the exception of Kokanee, Redside Shiner, and Sculpin species as detailed in Section 2.1.5) between 120 and 170 mm FL that were in good condition following processing were marked with a Passive Integrated Transponder (PIT) tag (tag model Biomark 8.9 mm BIO9.B.01). These tags were implanted into the abdominal cavity of the fish just off the mid-line and anterior to the pelvic girdle using a single shot applicator (model MK7, Biomark Inc., Boise, Idaho, USA) or a No. 11 surgical scalpel (depending on the size of the fish). All fish >170 mm FL that were in good condition following processing were marked with a polymer encapsulated, gel-filled, Food Safe, PIT tag (12 mm x 2.25 mm, model T-IP8010, ISO, FDX-B, Datamars). These tags were inserted 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.

Scale samples were collected from Kokanee, 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, but were catalogued for potential future study.

Overall, sampling methods were very similar between 2001 and 2013, with major changes to the study identified in Table 5. Minor changes to the study's design between 2001 and 2013 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 2013.

Methodology Change	Years	Description
Number of sampling sessions	2002-2006, 2010-2013	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
	2009-2013	Reaches 3 and 4 were sampled
Fish tag type	2001-2004	T-bar anchor tags exclusively
	2005	T-bar anchor tags and PIT tags
	2006-2013	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
	2010-2013	All species except Kokanee, Redside Shiner, and Sculpin species
Electrofishing specifications and settings	2001-2004	Frequency was 60 Hz; boat hull used as the cathode
	2005-2013	Frequency was 30 Hz; array curtain was used as the cathode
Seasons sampled	2001-2010	Fall only
	2011-2012	Spring and Fall
	2013	Spring only

2.2 Data Analyses

2.2.1 Data Compilation and Validation

Data were entered directly into the Middle Columbia River Fish Indexing Database (Attachment A) using Microsoft® Access 2007 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 2013.

Species	Fry	Juvenile	Adult
Bull Trout	<120	120 to 399	≥400
Largescale Sucker	-	<350	≥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 - 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. 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. In short, a hierarchical Bayesian approach:

- allows complex models to be logically defined using the BUGS (Bayesian analysis Using Gibbs Sampling) language (Kery and Schaub 2011; p.41);
- permits the incorporation of prior information (Kery and Schaub 2011; p.41);
- readily handles missing values;
- provides readily interpretable parameter estimates whose reliability does not depend on the sample size;
- allows derived quantities to be calculated (Kery and Schaub 2011; p.41); an example would be the percent change in the expected weight of a 250 mm FL Mountain Whitefish at a particular site in a typical year;
- enables the efficient modelling of spatial and temporal variations and correlations (Kery and Schaub 2011; p.78-82); and,
- permits the separation of ecological and observational processes (Kery and Schaub 2011; p.44).

Hierarchical Bayesian models were fitted to the fish indexing data for the MCR using R version 3.0.2 (R Core Team 2013) and JAGS 3.3.0 (Plummer 2012) which interfaced with each other via jaggernaut 1.6 (Thorley 2014a). For additional information on hierarchical Bayesian modelling in the BUGS language, of which JAGS uses a dialect, the reader is referred to Kery and Schaub (2011) 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/111290438 (Thorley 2014b).

The results were displayed graphically by plotting the modeled relationship between a particular variable and the estimated mean response (with 95% credible intervals; CRIs) 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). Plots were produced using the ggplot2 R package (Wickam 2009).

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 nine species: Burbot (*Lota lota*), Kokanee, Lake Whitefish, Northern Pikeminnow, Peamouth (*Mylocheilus caurinus*), Rainbow Trout, Redside Shiner, and Sculpin species.

Key assumptions of the occupancy model included:

- occupancy (the probability of presence) varied with flow regime (period) and season;
- occupancy varied randomly with site, year, and the interaction between site and year;
- 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 2.2.7); and,
- observed presence was described by a Bernoulli distribution.

Species richness was estimated by summing the estimated occupancies for all species that had estimates of occupancy, except Kokanee. Kokanee were excluded because the large temporal variability in Kokanee presence and their abundance was not considered to be directly related to dam operations. 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 frequently encountered species add additional uncertainty. For instance, 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 or 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). The interaction between flow regime and river kilometre (distribution) was included in the models in 2013 in order to test the management hypothesis regarding effects of minimum flows on the distribution of fish. More specifically, the model quantified the distribution as a linear trend in density downstream from the dam and allowed the linear trend to vary by year, season and flow regime. A significant change in the linear trend with flow regime was interpreted as a change in the distribution of fish due to the flow regime.

Key assumptions of the count model included:

- count density (count/km) varied with flow regime (period), season, and river kilometre;
- count density (count/km) varied randomly with site, year, and the interaction between site and year;
- the relationship between count density and river kilometre (distribution) varied with flow regime and season.
- the relationship between count density and river kilometre (distribution) varied randomly among years.
- expected counts were the product of the count density (count/km) and the length of bank sampled;
- sites were closed (i.e., the expected count at a site was constant for all the sessions in a particular season of a year); and,
- observed counts were described by a Poisson-gamma distribution.

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, Shannon's diversity was calculated by using the estimated count densities from the HBM to calculate the proportional abundance of each species.

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 Catch Density

Catch data included all fish captured during electroshocking but did not include observed fish. The catch data were analyzed using the same overdispersed Poisson model as the count data. Estimates of relative density from this model are referred to as catch density, in units of fish captured per kilometre (catch/km).

2.2.7 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 binomial "t-test" (Kery 2010, p.211-213) 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.

Key assumptions of the site fidelity model included:

- the log-odds of site fidelity varied with season; and,
- observed site fidelity was described by a Bernoulli distribution.

2.2.8 Absolute Density

Catch data also were analyzed using a mark-recapture-based binomial mixture model (Kery and Schaub 2011, p.134-136, 384-388) to provide estimates of capture efficiency and absolute density. 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. Estimates of absolute abundance per kilometre from this model are referred to as absolute density, in the number of fish per kilometre (fish/km).

Key assumptions of the abundance model included:

- absolute density (fish/km) varied with flow regime (period), season, and river kilometre;
- absolute density (fish/km) varied randomly with site, year, and the interaction between site and year;
- 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;
- efficiency (the probability of capture) varied randomly by session within year and season;

- marked and unmarked fish had the same probability of capture;
- there was no tag loss, mortality, or misidentification of fish;
- sites were closed (i.e., no immigration or emigration of fish among sessions); and,
- the number of fish captured was described by a binomial distribution.

2.2.9 Capture Efficiency

In order to estimate capture efficiency independent of abundance, a recapture-based binomial model (Kery and Schaub 2011, p.134-136, 384-388) was fitted only to marked fish. This model was equivalent to the abundance model without the estimation of the numbers of unmarked fish. To maximize the number of recaptures the model grouped all the sites into a supersite.

Key assumptions of the efficiency model included:

- efficiency (the probability of capture) varied randomly by session within year and season;
- there was no tag loss, mortality, or misidentification of fish;
- the supersite was closed; and,
- the number of marked fish caught at a site was described by a binomial distribution.

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 and Mountain Whitefish only. Growth was based on the change in length between fall seasons. Growth for 2013 was not estimated because sampling was not conducted in the fall.

Key assumptions of the growth model included:

- 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 annual growth for a 500 mm FL Bull Trout or a 250 mm FL Mountain Whitefish. These fork lengths were selected as representative examples to illustrate changes in fork length over time for a standard size fish.

2.2.11 Length

Mean length was estimated from the measured lengths of captured fish. Length was modelled for six species/life-stage combinations: juvenile Bull Trout, adult Bull Trout, juvenile Mountain Whitefish, adult Mountain Whitefish, adult Rainbow Trout, and adult Largescale Sucker. The length model was used to provide mean lengths for estimating the total biomass of fish species.

Key assumptions of the length model include:

- Length varied with flow regime (period) and season;
- length varied randomly with site, year, and the interaction between site and year; and,
- length was log-normally distributed.

In previous years of this study, the effect of flow regime on length-at-age was assessed using a finite mixture distribution model (MacDonald and Pitcher 1979). However, length-at-age was only modelled for Mountain Whitefish because age-classes were not distinguishable for Bull Trout and data were limited for all other species. Furthermore, in 2013, measurements of fish size during the fall season were not available, such that new information regarding size-at-age during the fall were not available. Growth of recaptured individual fish, as described in Section 2.2.10, was considered a more reliable metric than length-at-age and was used to address the management question regarding the effects of the flow regime change on fish growth. Estimates of mean length were used to calculate biomass, which incorporates both the abundance and size of fish in the MCR to assess changes over time.

2.2.12 Body Condition

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

Key assumptions of the condition model included:

- weight varied with length, flow regime (period), and season;
- weight varied randomly with site, year, and the interaction between site and year; and,
- weight was log-normally distributed.

2.2.13 Biomass

Fish biomass was calculated from model estimates of length, body condition, and absolute density. The posterior distributions of length and body condition were used to calculate the distribution of weight, which was combined with absolute density estimates to calculate the distribution of biomass. Biomass was calculated for juvenile and adult Mountain Whitefish, and adult Bull Trout.

2.2.14 Environmental Correlations

Although the management questions are concerned with changes in abundance, growth, body condition, and distribution of adult life stages of common fish species related to the implementation of a year-round minimum flow, there also is interest in understanding relationships between fish population metrics and environmental variables. Knowledge of when and how discharge and water temperatures in the MCR and the elevation of ALR affect fish populations could be used to further refine operations.

To assess how the influence of environmental variables may vary by season, variables were summarized in tri-monthly periods (e.g., January to March). For each of the tri-monthly periods, three different descriptive statistics were calculated:

- mean of hourly discharge;
- mean of the hourly absolute difference in discharge, as a measure of hour-to-hour variability; and,
- mean reservoir elevation.

Multivariate analyses were used to examine relationships between environmental variables and fish population metrics. First, twelve environmental variables (the three variables split into four tri-monthly periods) were reduced to five eigenvectors using Principal Components Analysis (PCA). A Bayesian model was then used to estimate correlations between eigenvectors and environmental variables to interpret which of the variables the eigenvectors represented. The same Bayesian model was also used to quantify correlations between the eigenvectors and fish population metrics corresponding to the four key management questions, i.e., growth, abundance, condition and distribution. If an eigenvector was correlated with a fish population metric and an environmental variable, then it suggested that the two were related. The units of observation for fish population metrics were mean annual estimates from the fall season. Significant relationships between eigenvectors and variables were indicated using connectivity plots, where nodes were connected if relationships were significant, with positive relationships shown in black and negative relationships shown in red.

Because of the large number of environmental variables and fish population metrics, simple correlation or multiple regression analyses would be likely to result in spurious relationships. Correlation among multiple environmental variables can also confound interpretation. For these reasons, multivariate analyses provided a good way to analyze the data, as it reduced the number of variables, and the eigenvectors representing the environmental variables are not correlated with each other (Tabachnick and Fidell 2001).

3.0 RESULTS

3.1 Discharge

In 2013, mean daily discharge in the MCR was near average for most of the year (Appendix C, Figure C1) except in January to March when discharge was greater than the average (2001-2012). Discharge during sampling in late May and June was similar to the long-term average (Figure 2).

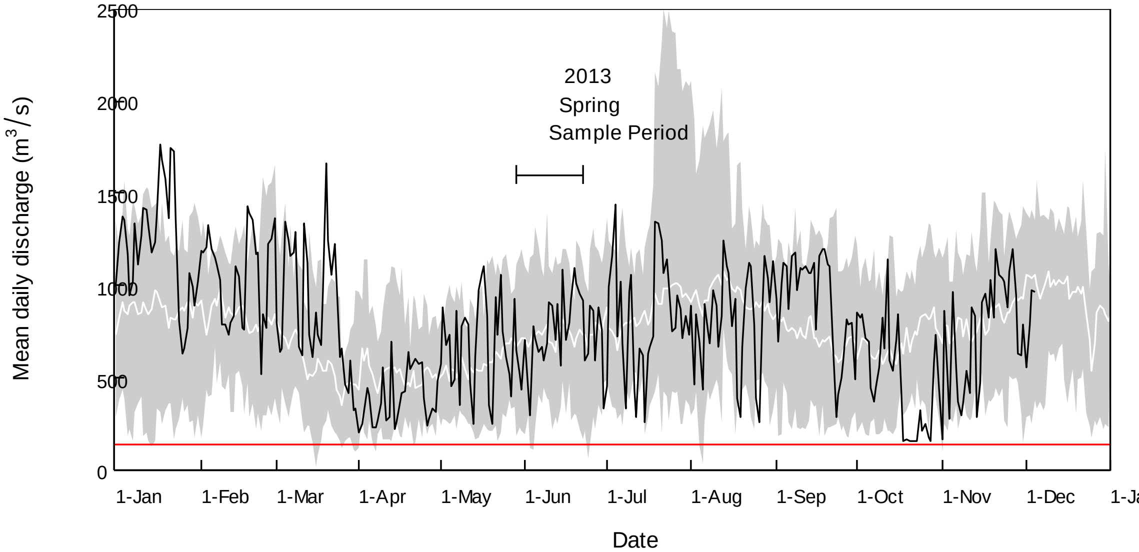

Figure 2: Mean daily discharge (m3/s) for the Columbia River at Revelstoke Dam, 2013. The shaded area represents minimum and maximum mean daily discharge values recorded at the dam from 2001 to 2012. The white line represents average mean daily discharge values over that same time period. The red line represents the minimum flow release of 142 m^3/s.

Similar to previous study years, discharge in 2013 exhibited large hourly fluctuations, a reflection of the primary use of the facility for daily peaking operations (Appendix C, Figure C2). During Session 1, discharge decreased to near minimum flows each night. During Sessions 2, 3, and 4, discharges decreased sharply each night but remained slightly greater than minimum flows during most nights. 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 are typically between 140 and 160 m^3/s. Peak daily flows during the spring sample period ranged between approximately 1000 and 1800 m^3/s (Appendix C, Figure C2).

3.2 Water Elevation

During the spring and early summer of 2013, mean daily water elevations in ALR were greater than average and near the maximum values observed since 2001 (Appendix C, Figure C3). Mean daily water elevation in ALR were near the long-term average (2001-2012) during the fall and winter.

During the 2013 study period, high ALR water elevations resulted in backwatering effects in the downstream portions of Reach 3. ALR water elevations increased over the duration of the spring sample period, resulting in increasing backwatering effects during each successive sample session.

Overall, water elevations in ALR were lower from 2001 to 2006 and higher from 2007 to 2013 (Appendix C, Figure C3).

3.3 Water Temperature

Water temperature data are not available for the MCR prior to 2007. In 2013, mean daily water temperature in January to May was warmer than the previous maximum from 2007 to 2012 (Figure 3; Appendix C, Figure C4). Water temperatures were higher than normal during sampling in late May and June 2013. Spot temperature readings taken at the time of sampling ranged between 5.8 and 8.8°C (Attachment A).

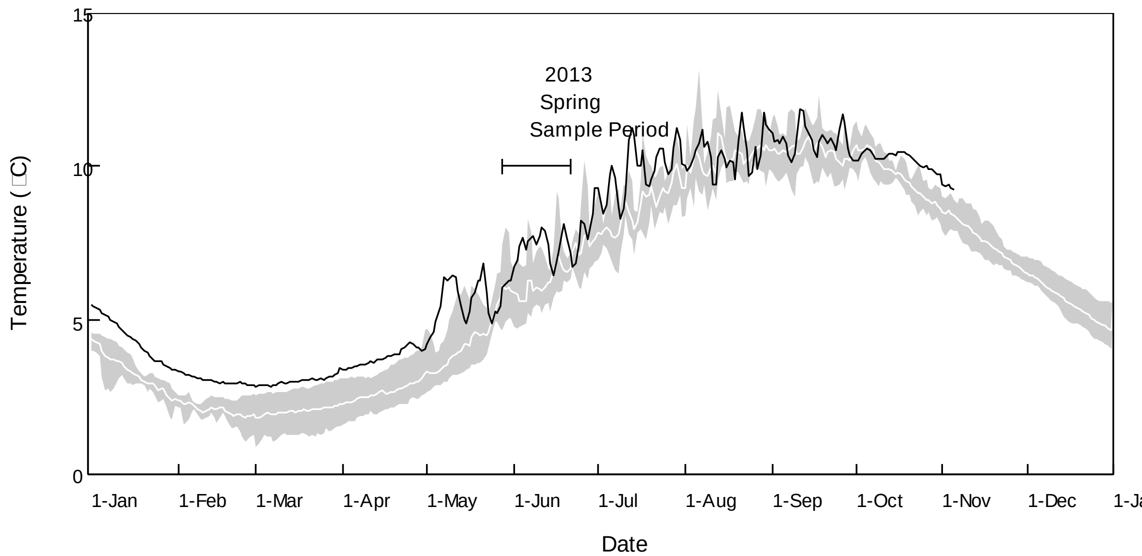

Figure 3: Mean daily water temperature (°C) for the Columbia River at Station 2 of the Physical Habitat Monitoring Program (CLBMON-15a), 2013. The shaded area represents minimum and maximum mean daily water temperature values recorded at Station 2 from 2007 to 2012. The white line represents average mean daily water temperature values over that same time period.

3.4 Catch

In total, 7706 fishes, comprising 11 taxa, were captured and recorded in the MCR during the spring 2013 sampling period (Appendix D, Table D2). These values include captured and observed fish identified to species. The total number of fish captured and observed during spring study periods from 2011 to 2013 is compared in Appendix D, Table D1. The total numbers of fish captured and observed during fall study periods from 2001 to 2012 are compared in Appendix D, Table D1.

Various metrics were used to provide background information for 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. However, these data are provided in the Appendices for reference. These data include:

- Captured and observed fish count data by site and Bank Habitat Type during the spring (Appendix B, Table B4);
- Catch-rates for all sportfish and non-sportfish during the spring sampling period (Appendix D, Tables D3 and D4);

- Inter-site movement summaries for Bull Trout, Largescale Sucker, Mountain Whitefish, and Rainbow Trout, for all years combined (Appendix D, Figures D1 to D4);
- Catch and recapture summaries by species for the spring 2013 study period (Appendix D, Table D5);
- Length-frequency histograms for Bull Trout (Appendix E, Figure E1) and Mountain Whitefish (Appendix E, Figure E2) from 2001 to 2013, and for Rainbow Trout from 2007 to 2013 (Appendix E, Figure E3);
- length-frequency histograms for Kokanee (Appendix E, Figure E4), Lake Whitefish (Appendix E, Figure E5), Largescale Sucker (Appendix E, Figure E6), Northern Pikeminnow (Appendix E, Figure E7), Prickly Sculpin (*Cottus asper*; Appendix E, Figure E8), and Redside Shiner (Appendix E, Figure E9) for 2010 to 2013 (where applicable);
- length-weight relationships for Bull Trout (Appendix E, Figure E10) and Mountain Whitefish (Appendix E, Figure E11) from 2001 to 2013, and for Rainbow Trout from 2010 to 2013 (Appendix E, Figure E12); and,
- length-weight relationships for Kokanee (Appendix E, Figure E13), Lake Whitefish (Appendix E, Figure E14), Largescale Sucker (Appendix E, Figure E15), Northern Pikeminnow (Appendix E, Figure E16), Prickly Sculpin (Appendix E, Figure E17), Redside Shiner (Appendix E, Figure E18), and Yellow Perch (Appendix E, Figure E19) for 2010 to 2013.

All data collected as part of the program between 2001 and 2013 are included in the Middle Columbia River Fish Indexing Database (Attachment A).

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 represent metrics of changes in species presence at a typical site and do not indicate the total number of species present (Figure 4). Species richness increased from 2001 to 2005, due to increasing occupancy of several species, including Burbot, Lake Whitefish, Redside Shiner, and Sculpin species (Appendix H, Figures H1-H7). In recent years, estimates of species richness have varied, with greater richness in 2008, 2010 and 2011, and lower richness in 2009 and 2012. Species richness was lower in the spring than in the fall (2011 and 2012), which was associated with lower probability of occupancy by Burbot, Lake Whitefish, and Northern Pikeminnow. In 2013, sampling was not conducted in the fall. Species richness was greater in spring 2013 when compared to spring 2011 and 2012.

Site estimates of species richness over river distance (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.

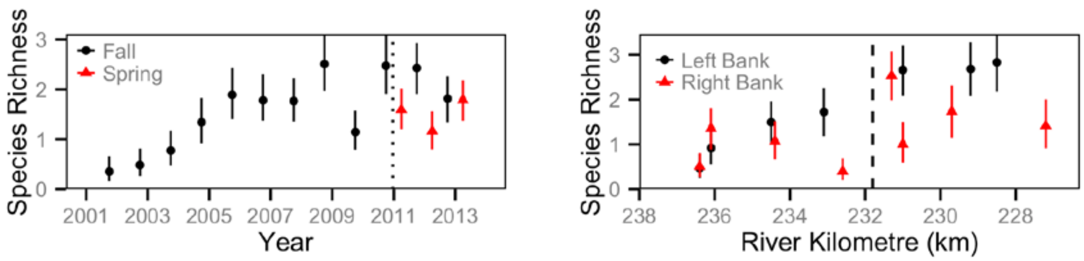

Figure 4: Species richness estimates (with 95% credible intervals) by year and season (left panel) and site (right panel) for the middle Columbia River study area, 2001 to 2013. The dotted line (left panel) represents the implementation of the minimum flow release and REV5 operations. The dashed line (right panel) represents the divide between Reaches 3 and 4 at the Jordan River confluence.

For estimates of species evenness, credible intervals overlapped for all years and season with no obvious directional trend (Figure 5). However, spring estimates were lower than fall estimates from 2011 to 2013. With the exception of Site 227.2-R (i.e., Salmon Rocks), species evenness was greater in Reach 3 on the left bank than on the right bank. 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 is likely due to lower Mountain Whitefish densities in this site when compared to neighbouring sites (see Section 3.6.4).

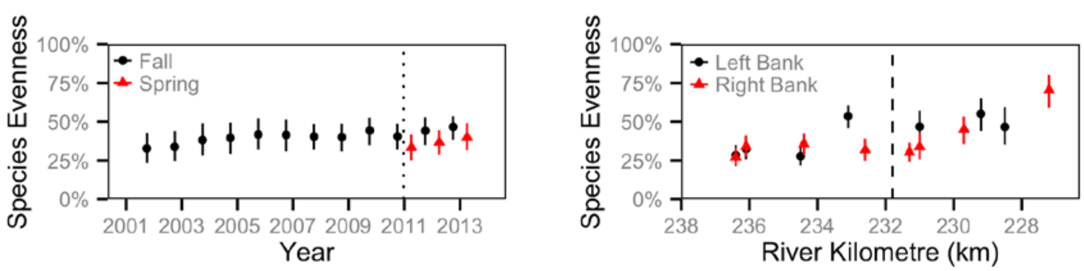

Figure 5: Species evenness estimates (with 95% credible intervals) by year and season (left panel) and site (right panel) for the middle Columbia River study area, 2001 to 2013. The dotted line (left panel) represents the implementation of the minimum flow release and REV5 operations. The dashed line (right panel) represents the divide between Reaches 3 and 4 at the Jordan River confluence.

3.6 Spatial Distribution and Abundance

Three 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;
2) Catch density estimates from a HBM using catch data (i.e., the number of fish captured per river kilometre) as an indicator of relative lineal density; and,
3) Absolute density estimates from a HBM of mark-recapture data as an indicator of absolute lineal density.

Estimates of catch density and absolute density were only possible for Bull Trout, Mountain Whitefish (juveniles and adults), and Largescale Sucker. Catch density also was estimated for Rainbow Trout and juvenile Bull Trout. Only count density was estimated for Burbot, Northern Pikeminnow, and Sucker species. 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 and are not provided.

Capture efficiencies for Bull Trout, juvenile Mountain Whitefish and adult Mountain Whitefish 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

For Bull Trout, count density estimates for all age-classes combined (Figure 6), catch density estimates for juveniles and adults (Figures 7 and 8, respectively) and absolute density estimates for adults (Figure 9) suggest that the number of juvenile Bull Trout in the MCR increased between 2001 and 2007. Count, catch, and absolute density estimates for adults generally declined between 2007 and 2013. Catch and absolute density estimates of Bull Trout were lower in 2013 than in the previous six years, although the credible intervals overlapped. Bull Trout densities in a typical year were highest immediately downstream of REV (between RKm 236 and 237) and downstream of the Jordan River confluence (between RKm 231 and 232). Count, catch, and absolute density of Bull Trout did not vary significantly with the flow regime change (all $P>0.2$) or season (all $P>0.05$). The interaction between river kilometre (distribution) and flow regime was not significant for any of the count, catch, or absolute density models for Bull Trout (all $P>0.5$), indicating that the relationship between river kilometre and abundance did not differ by flow regime.

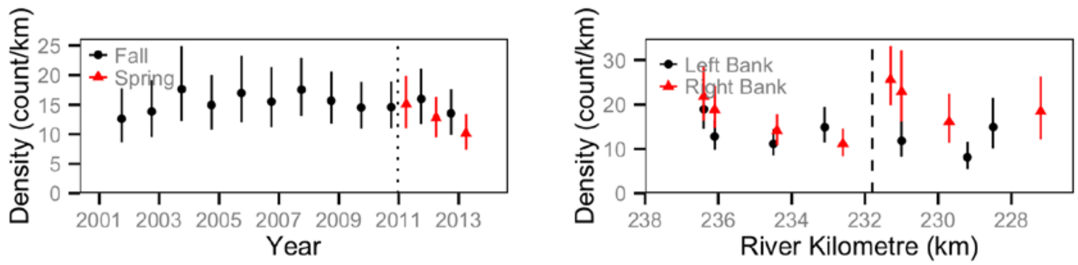

Figure 6: **Count density estimates (with 95% credible intervals) by year and season (left panel) and site (right panel) for Bull Trout in the middle Columbia River study area, 2001 to 2013. The dotted line (left panel) represents the implementation of the minimum flow release and REV5 operations. The dashed line (right panel) represents the divide between Reaches 3 and 4 at the Jordan River confluence.**

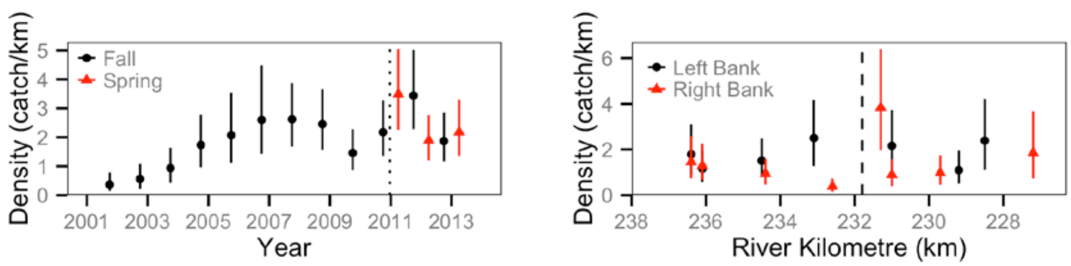

Figure 7: **Catch density estimates (with 95% credible intervals) by year and season (left panel) and site (right panel) for juvenile Bull Trout in the middle Columbia River study area, 2001 to 2013. The dotted line (left panel) represents the implementation of the minimum flow release and REV5 operations. The dashed line (right panel) represents the divide between Reaches 3 and 4 at the Jordan River confluence.**

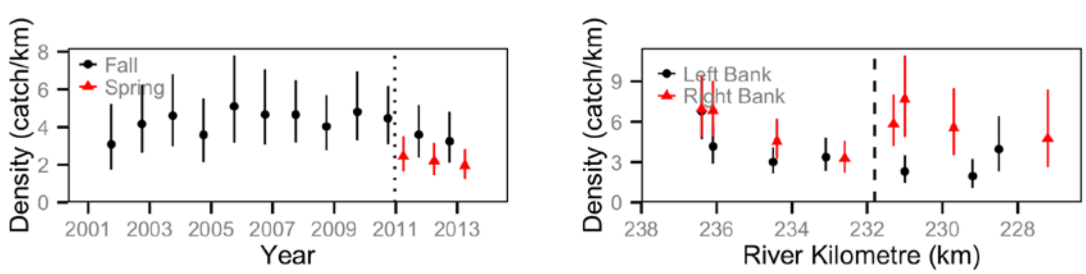

Figure 8: **Catch density estimates (with 95% credible intervals) by year and season (left panel) and site (right panel) for adult Bull Trout in the middle Columbia River study area, 2001 to 2013. The dotted line (left panel) represents the implementation of the minimum flow release and REV5 operations. The dashed line (right panel) represents the divide between Reaches 3 and 4 at the Jordan River confluence**

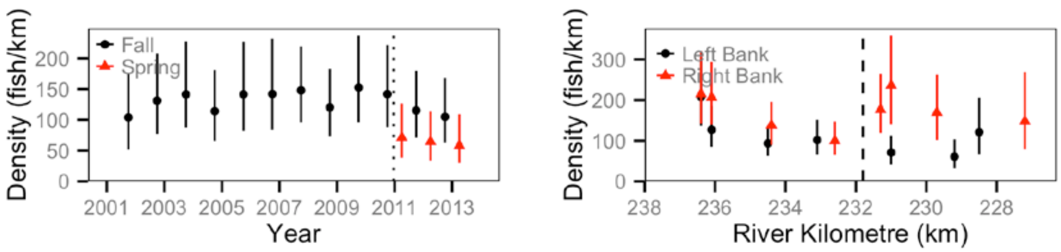

Figure 9: Absolute density estimates (with 95% credible intervals) by year and season (left panel) and site (right panel) for Bull Trout in the middle Columbia River study area, 2001 to 2013. The dotted line (left panel) represents the implementation of the minimum flow release and REV5 operations. The dashed line (right panel) represents the divide between Reaches 3 and 4 at the Jordan River confluence.

3.6.2 Burbot

Overall, count densities for Burbot were low compared to count densities of most other species caught during all study years. Count density estimates suggest that Burbot abundance may have been higher in 2008 and 2011 than in other study years (Figure 10). For 2011 and 2012, count density varied significantly by season (P=0.004) with higher densities in the fall than in the spring. Burbot density did not vary significantly with flow regime (P=0.1) or site (Figure 10). The interaction between river kilometre (distribution) and flow regime was not significant (P=0.8), indicating that the relationship between river kilometre and count density did not differ by flow regime.

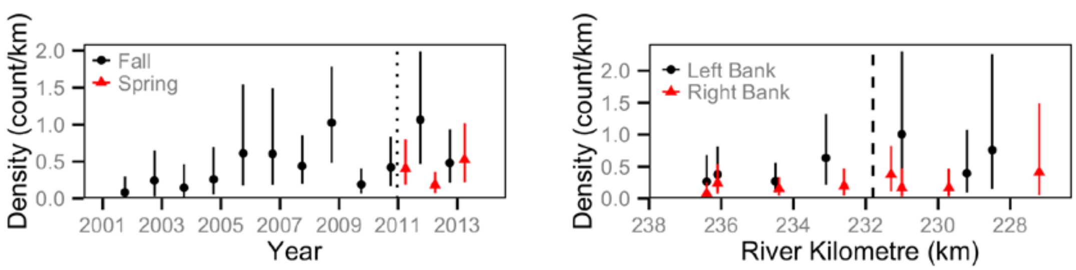

Figure 10: Count density estimates (with 95% credible intervals) by year and season (left panel) and site (right panel) for Burbot in the middle Columbia River study area, 2001 to 2013. The dotted line (left panel) represents the implementation of the minimum flow release and REV5 operations. The dashed 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. The probability of occupancy at a typical site also varied substantially among years (Appendix H, Figure H2).

3.6.4 Mountain Whitefish

Count density for all size-cohorts combined suggested stable Mountain Whitefish densities between 2001 and 2013 (Figure 11). The seasonal difference in Mountain Whitefish density in previous years' study was likely driven by juvenile fish, which were more abundant in spring than in fall (Figure 12).

Catch and absolute densities of juvenile Mountain Whitefish (Figures 12 and 13) decreased after the flow regime change in 2010. The density of adult Mountain Whitefish also declined after 2010, although values were comparable to years before the flow regime change (Figures 14 and 15). Prior to 2007, Mountain Whitefish less than 180 mm FL were rarely caught and marked, preventing the model from generating density estimates for juveniles between 2001 and 2006 (Figures 12 and 13). Flow regime was not a significant predictor of density for any age groups (all $P>0.4$). For juvenile Mountain Whitefish, catch density was significantly greater in the spring than fall ($P<0.0001$) but absolute density did not differ by season ($P=0.6$). For adults, catch density was greater in the spring than in the fall ($P<0.0001$; Figure 14), but absolute density was greater in the fall than in spring ($P<0.0001$; Figure 15). The interaction between river kilometre (distribution) and flow regime was not significant for any of the count, catch, or absolute density models for Mountain Whitefish (all $P>0.5$), indicating that the relationship between river kilometre and abundance did not differ by flow regime.

Densities of Mountain Whitefish (all size-cohorts combined) were generally greater along the right bank from upstream of the Jordan River confluence to the Tonkawatla Creek confluence and lower along the left bank from the upstream end of the Revelstoke Golf Club to the Centennial Park Boat Launch (Figure 11). High densities of Mountain Whitefish at sites on the right bank near the Jordan River confluence were related to large abundance estimates for adult fish at these sites (Figures 14 and 15). Site-level density estimates for juvenile Mountain Whitefish were more variable but suggest similar density patterns (Figures 12 and 13).

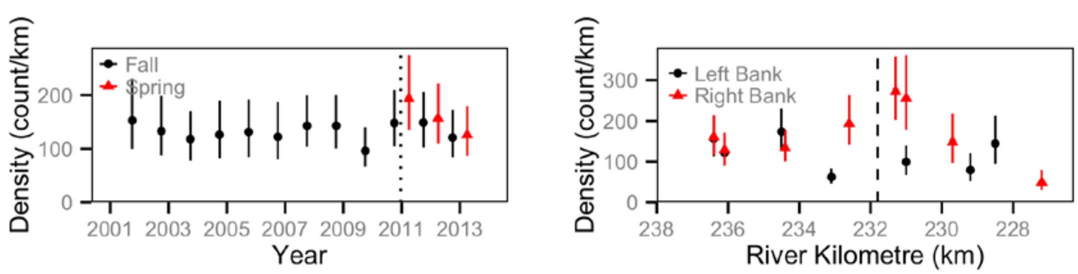

Figure 11: Count density estimates (with 95% credible intervals) by year and season (left panel) and site (right panel) for Mountain Whitefish (all size-cohorts combined) in the middle Columbia River study area, 2001 to 2013. The dotted line (left panel) represents the implementation of the minimum flow release and REV5 operations. The dashed line (right panel) represents the divide between Reaches 3 and 4 at the Jordan River confluence.

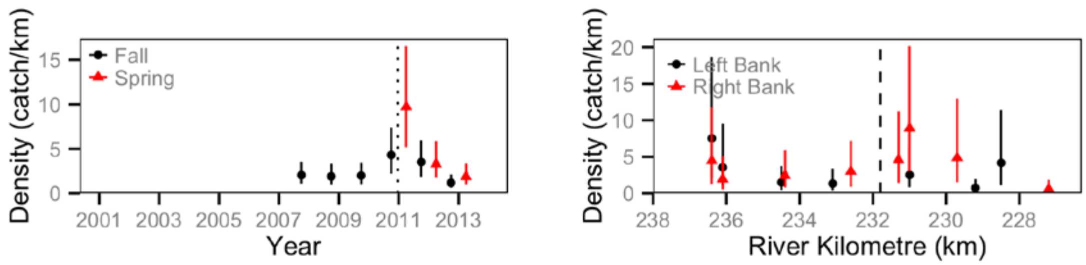

Figure 12: Catch density estimates (with 95% credible intervals) by year and season (left panel) and site (right panel) for juvenile Mountain Whitefish in the middle Columbia River study area, 2007 to 2013. The dotted line (left panel) represents the implementation of the minimum flow release and REV5 operations. The dashed line (right panel) represents the divide between Reaches 3 and 4 at the Jordan River confluence.

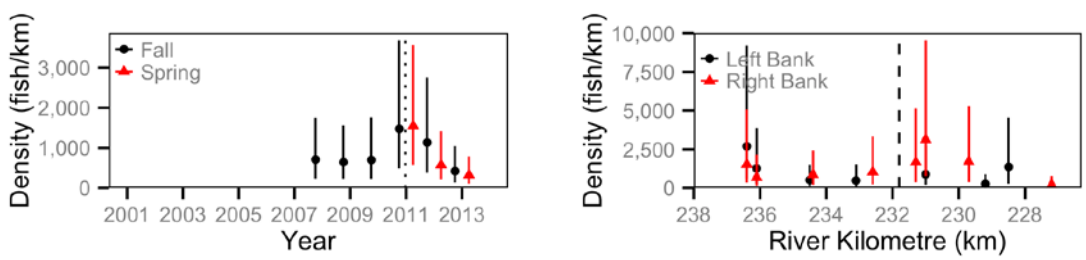

Figure 13: Absolute density estimates (with 95% credible intervals) by year and season (left panel) and site (right panel) for juvenile Mountain Whitefish in the middle Columbia River study area, 2007 to 2013. The dotted line (left panel) represents the implementation of the minimum flow release and REV5 operations. The dashed line (right panel) represents the divide between Reaches 3 and 4 at the Jordan River confluence.

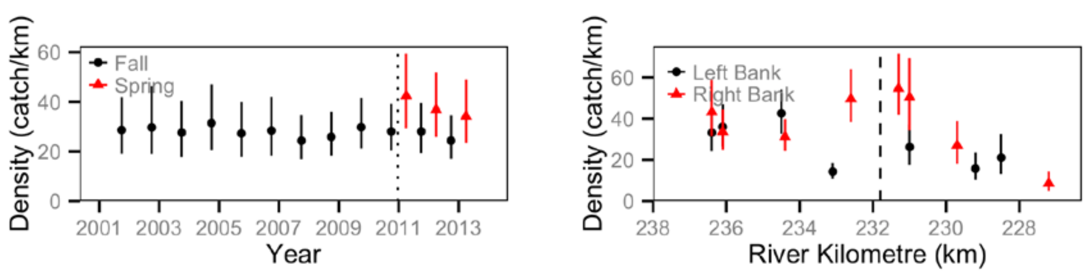

Figure 14: Catch density estimates (with 95% credible intervals) by year and season (left panel) and site (right panel) for adult Mountain Whitefish in the middle Columbia River study area, 2007 to 2013. The dotted line (left panel) represents the implementation of the minimum flow release and REV5 operations. The dashed line (right panel) represents the divide between Reaches 3 and 4 at the Jordan River confluence.

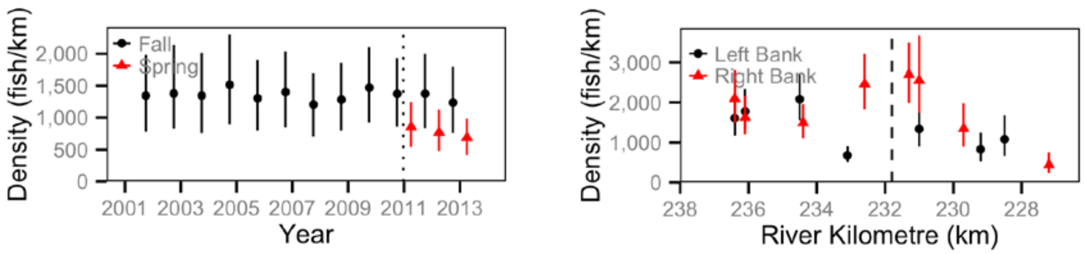

Figure 15: Absolute density estimates (with 95% credible intervals) by year and season (left panel) and site (right panel) for adult Mountain Whitefish in the middle Columbia River study area, 2007 to 2013. The dotted line (left panel) represents the implementation of the minimum flow release and REV5 operations. The dashed line (right panel) represents the divide between Reaches 3 and 4 at the Jordan River confluence.

3.6.5 Rainbow Trout

Rainbow Trout count density estimates suggested a gradual increase between 2001 and 2008 (Figure 16); however, this result is based on a small sample size. Count density of Rainbow Trout was low in 2009, increased in 2010 and 2011, and declined in 2012 (Figure 16).

Rainbow Trout catch density was only estimated for 2007 to 2012 because catches were very low prior to 2007. Catch density estimates increased in each year following the flow regime change in the fall and spring seasons (Figure 17). Season was not a significant predictor of Rainbow Trout count (P=0.7) or catch density (P=0.08). Flow regime was a significant predictor of count density (P=0.03) and was marginally significant for catch density (P=0.054), with greater values in years after the flow regime change. The interaction between river kilometre (distribution) and flow regime was not significant for count or catch density models (both P=0.1), indicating that the relationship between river kilometre and abundance did not differ by flow regime.

Rainbow Trout densities were greater in Reach 3 than in Reach 4, and generally greater at sites on the left bank than sites on the right bank (Figures 16 and 17). The left bank of Reach 3 is predominantly rip-rap substrate (Appendix A, Figure A2).

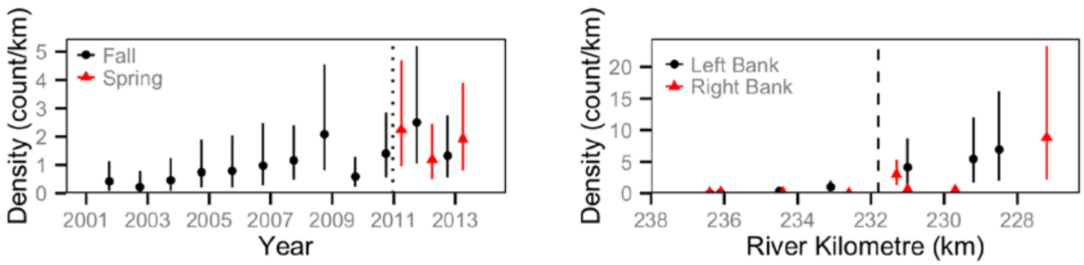

Figure 16: Count density estimates (with 95% credible intervals) by year and season (left panel) and site (right panel) for Rainbow Trout in the middle Columbia River study area, 2001 to 2013. The dotted line (left panel) represents the implementation of the minimum flow release and REV5 operations. The dashed line (right panel) represents the divide between Reaches 3 and 4 at the Jordan River confluence.

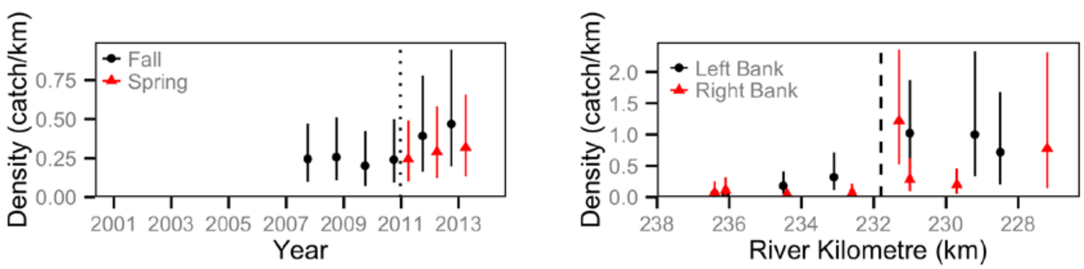

Figure 17: Catch density estimates (with 95% credible intervals) by year and season (left panel) and site (right panel) for Rainbow Trout in the middle Columbia River study area, 2007 to 2013. The dotted line (left panel) represents the implementation of the minimum flow release and REV5 operations. 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 2013, 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 (fall sample periods only), Largescale Sucker accounted for approximately 96% of the Sucker species catch; the remaining 4% were Longnose Sucker (*Catostomus catostomus*). During the spring sample periods (2011 to 2013), 57% of the Sucker species catch were Largescale Sucker and 43% were Longnose Sucker. Density for all Sucker species combined (count-based) was estimated from 2001 to 2013.

During the fall season, count density estimates for Sucker species increased from 2009 to 2012 (Figure 18). Catch density of Largescale Sucker also showed an increasing trend from 2010 to 2012 (fall and spring seasons; Figure 19).

Sucker species densities were generally lowest immediately downstream of REV and highest along the right bank in the upstream portion of Reach 3 (i.e., between the narrows downstream of Big Eddy and the Tonkawatla Creek confluence; Figure 18). Spatial distribution of Largescale Sucker was similar to that of the all Sucker species combined. However, there was less of a difference in density between the left and right banks in estimates of catch density of Largescale Sucker (Figure 19) when compared to the count-based model of all Sucker species.

Season was a significant predictor of Sucker species count density (*P*<0.0001) and of Largescale Sucker catch density (*P*<0. 0001), with higher values in the fall than in the spring. There was a significant relationship between Sucker species count density and flow regime (*P*=0.006), with greater densities after the flow regime change. Flow regime was not a significant predictor of Largescale Sucker catch density (*P*=0.3). The interaction between river kilometre (distribution) and flow regime was not significant for count or catch density models (both *P*>0.4), indicating that the relationship between river kilometre and abundance did not differ by flow regime.

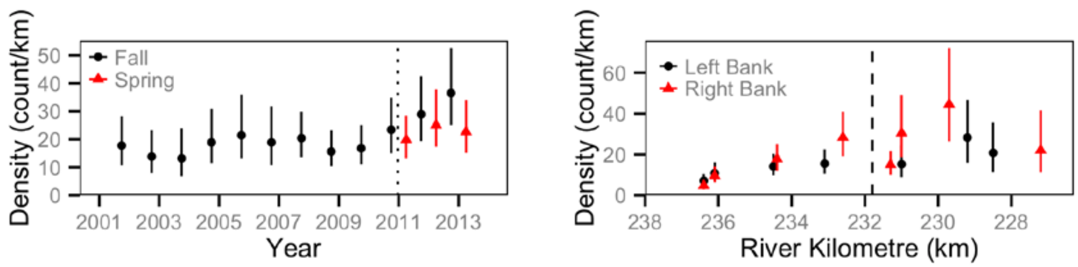

Figure 18: Count density estimates (with 95% credible intervals) by year and season (left panel) and site (right panel) for Sucker species in the middle Columbia River study area, 2001 to 2013. The dotted line (left panel) represents the implementation of the minimum flow release and REV5 operations. The dashed line (right panel) represents the divide between Reaches 3 and 4 at the Jordan River confluence.

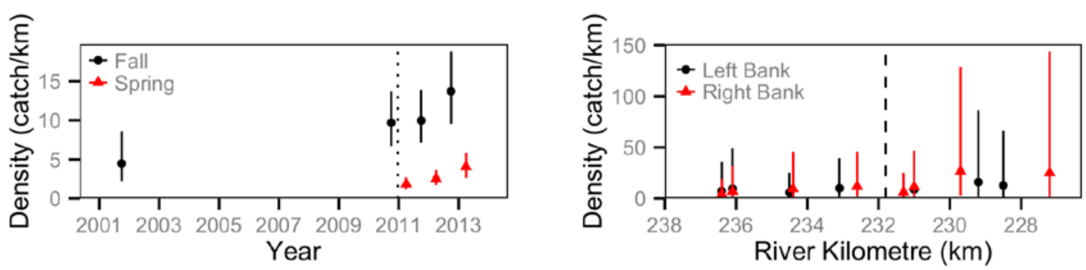

Figure 19: Catch density estimates (with 95% credible intervals) by year and season (left panel) and site (right panel) for Largescale Sucker in the middle Columbia River study area, 2001, and 2010 to 2013. The dotted line (left panel) represents the implementation of the minimum flow release and REV5 operations. The dashed line (right panel) represents the divide between Reaches 3 and 4 at the Jordan River confluence.

3.6.7 Northern Pikeminnow

Northern Pikeminnow densities in the MCR remained relatively low between 2001 and 2006, increased substantially between 2007 and 2010 and then declined from 2010 to 2013 (Figure 20). Northern Pikeminnow density was greater in Reach 3 than in Reach 4 (Figure 20). Season was a significant predictor of Northern Pikeminnow density (*P*=0.01), with fall densities approximately 10 times greater than spring densities. There was no relationship between Northern Pikeminnow density and flow regime (*P*=0.7). The interaction between river kilometre (distribution) and flow regime was not significant (both P=0.1), indicating that the relationship between river kilometre and count density did not differ by flow regime.

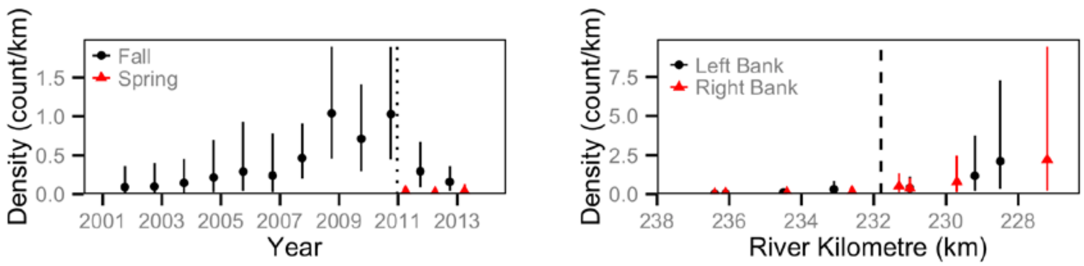

Figure 20: Count density estimates (with 95% credible intervals) by year and season (left panel) and site (right panel) for Northern Pikeminnow in the middle Columbia River study area, from 2001 to 2013. The dotted line (left panel) represents the implementation of the minimum flow release and REV5 operations. 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 with a HBM using mark-recapture data. Mean estimates of capture efficiency for Bull Trout were consistent over time, ranging from 2.5 to 9.5% across all sessions and years for juveniles and 1.9 to 5.6% for adults (Appendix H, Figures H8-H9).

Capture efficiency generally was lower for juvenile Mountain Whitefish (<1%), but stable across sampling sessions and years (Appendix H, Figure H10). 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 (~2 3%) in both 2011 and 2012. For the spring 2013; capture efficiency was similar to the spring 2011 and spring 2012 values (Appendix H, Figure H11). 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 4.6 to 6.8% in the fall and 5.9 to 11.9% in the spring (Appendix H, Figure H12). Although there were differences among species and life stages (for Mountain Whitefish), 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.

3.6.9 Site Fidelity

Site fidelity, defined as the probability of a fish recaptured within the same season being encountered at the same site as the previous capture, was used to evaluate the extent to which sites are closed within a sampling season (Appendix H, Figures H14 to H19). Of the four species that had enough recapture data for assessment, Rainbow Trout exhibited the highest site fidelity in both the fall (60%) and spring (82%) sessions; the difference between seasons was not significant (P=0.3). The spring site fidelity estimate for Rainbow Trout was based on relatively few data points (n = 13; Attachment A). Site fidelity of Bull Trout was low compared to other species and was different between the fall (35%) and spring (12%; *P*=0.04) for adults but not different among seasons for juveniles (*P*=0.6). Largescale Sucker had a site fidelity of 59% in the fall and 66% in the spring (*P*=0.7). For Mountain Whitefish, juvenile fish had much low site fidelity with no significant difference between fall (30%) and spring (27%) estimates (*P*=0.9), whereas adult Mountain Whitefish had much higher site fidelity than juveniles, and significantly greater fidelity in the spring (77%) than in the fall (49%; *P*<0.001).

3.7 Growth Rate

Limited mark-recapture data prevented detailed growth-related analysis for all species with the exception of Bull Trout (Section 3.7.1) and Mountain Whitefish (Section 3.7.2).

3.7.1 Bull Trout

Based on the HBM of annual growth of recaptured individuals, there was a substantial decline in Bull Trout growth rates between 2008 and 2009, followed by an increase from 2008 to 2012 (Figure 21). For a Bull Trout with a fork length of 500 mm, mean annual growth increased from approximately 41 mm in 2008 to approximately 57 mm in 2012 (Figure 21). The relationship between Bull Trout growth and flow regime was not significant (*P*=0.9).

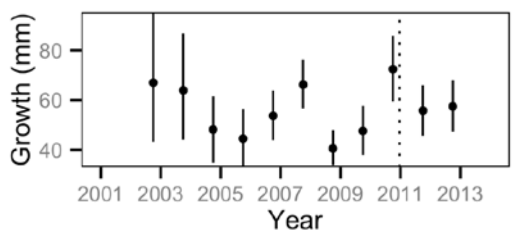

Figure 21: Annual growth estimates (with 95% credible intervals) by year for a 500 mm FL Bull Trout in the middle Columbia River study area, 2001 to 2012. The dotted line represents the implementation of the minimum flow release and REV5 operations.

3.7.2 Mountain Whitefish

Annual growth of recaptured Mountain Whitefish was similar from 2001 to 2012 with credible intervals overlapping for most estimates (Figure 22). There was no significant difference in growth before and after the flow regime change (*P*=0.95).

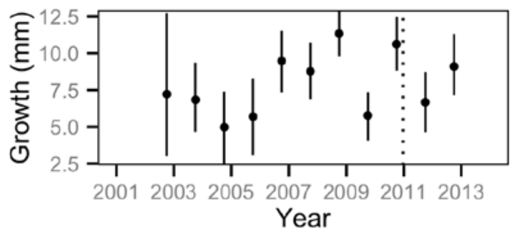

Figure 22: Annual growth estimates (with 95% credible intervals) by year for a 250 mm FL Mountain Whitefish in the middle Columbia River study area, 2001 to 2012. The dotted line represents the implementation of the minimum flow release and REV5 operations

3.8 Body Condition

Variation in body condition is presented in terms of the percent change in body weight of a mean length individual by 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.

The body condition of Bull Trout in the MCR has fluctuated since 2002. The body condition of juvenile Bull Trout was greatest in 2003 and 2004 and declined from 2010 to 2013 (Figure 23). For adult Bull Trout, the percent change in body condition relative to a typical year decreased from 2004 to 2008, increased in 2009 and 2010, and decreased from 2011 to 2013 (Figure 24). Body condition of Bull Trout decreased following the implementation of the flow regime change but the effect was only significant for adults (P=0.04) and not for juveniles (P=0.1).

Body condition of Bull Trout did not differ between spring and fall seasons for juveniles (P=0.2) or adults (P=0.7). For both juvenile and adult Bull Trout, there was little variation in condition among sample sites (Figures 23 and 24, respectively).

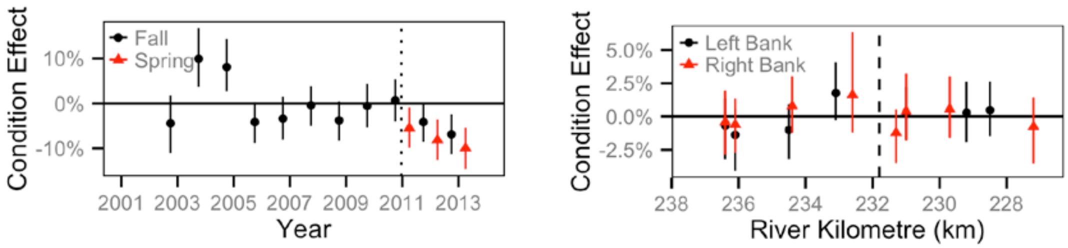

Figure 23: Body condition effect size estimates (with 95% credible intervals) by year and season (left panel) and site (right panel) for a 300 mm FL juvenile Bull Trout in the middle Columbia River study area, 2002 to 2013. The dotted line (left panel) represents the implementation of the minimum flow release and REV5 operations. The dashed line (right panel) represents the divide between Reaches 3 and 4 at the Jordan River confluence.

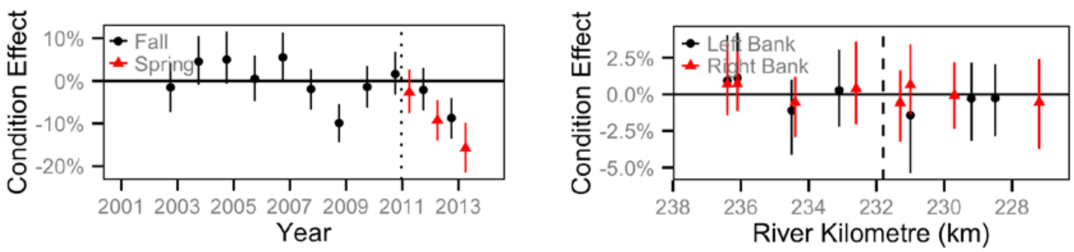

Figure 24: Body condition effect size estimates (with 95% credible intervals) by year and season (left panel) and site (right panel) for a 500 mm FL adult Bull Trout in the middle Columbia River study area, 2002 to 2013. The dotted line (left panel) represents the implementation of the minimum flow release 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). As was the case for Bull Trout, analyses in this report only included previously untagged fish to avoid potential effects of tagging on body condition.

Trends in body condition of Mountain Whitefish were similar to those for Bull Trout, with decreasing values in the late 2000s, increased body condition in 2010, and low body condition after the flow regime change for both juveniles and adults (Figures 25 and 26).

Body condition of Mountain Whitefish was greater before the flow regime change than after for adults ($P<0.0001$) but was not different for juveniles (P=0.4). Mountain Whitefish body condition was significantly greater in the fall than in the spring for adults ($P<0.0001$) but was not different between seasons for juveniles ($P=0.98$). For all study years combined, adult Mountain Whitefish body condition was lower in Reach 4 and higher in Reach 3 for all sample sites (Figure 26).

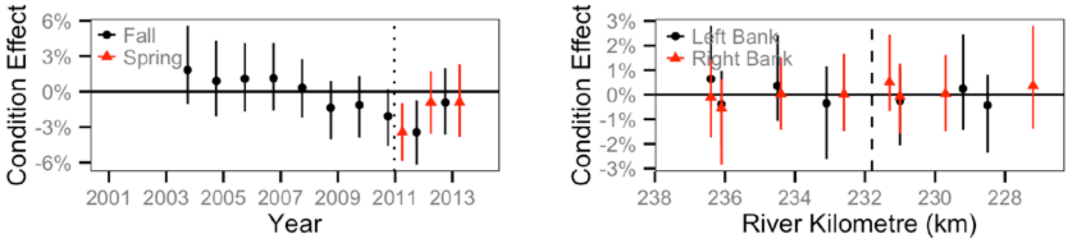

Figure 25: Body condition effect size estimates (with 95% credible intervals) by year and season (left panel) and site (right panel) for a 100 mm FL juvenile Mountain Whitefish in the middle Columbia River study area, 2002 to 2013. The dotted line (left panel) represents the implementation of the minimum flow release and REV5 operations. The dashed line (right panel) represents the divide between Reaches 3 and 4 at the Jordan River confluence.

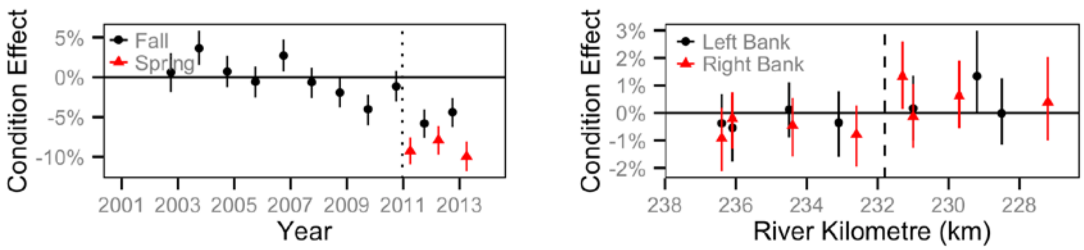

Figure 26: Body condition effect size estimates (with 95% credible intervals) by year and season (left panel) and site (right panel) for a 250 mm FL Mountain Whitefish in the middle Columbia River study area, 2002 to 2013. The dotted line (left panel) represents the implementation of the minimum flow 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

Sparse life history data for Rainbow Trout in the study area resulted in relatively uncertain body condition estimates for this species. 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 varied little among study years and credible intervals overlapped for all estimates (Figure 27). Body condition could not be estimated for Rainbow Trout at Site 232.6-R because this species has never been captured at that site.

Body condition of Rainbow Trout was significantly greater in the fall than in the spring (P=0.048). There was no change in body condition associated with the flow regime change (P=0.7).

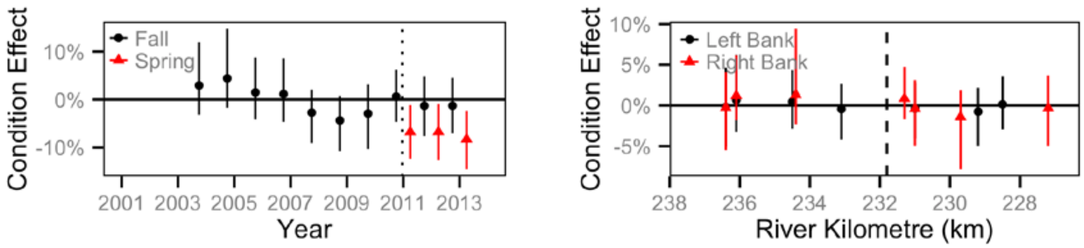

Figure 27: Body condition effect size estimates (with 95% credible intervals) by year and season (left panel) and site (right panel) for a 250 mm FL Rainbow Trout in the middle Columbia River study area, 2003 to 2013. The dotted line (left panel) represents the implementation of the minimum flow release 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 2013. In addition to Bull Trout, Mountain Whitefish, and Rainbow Trout, body condition also was analyzed for Lake Whitefish, Largescale Sucker, Northern Pikeminnow, Prickly Sculpin, and Redside Shiner. Wide credible intervals precluded any meaningful interpretation of the results for these species. Estimates from the HBM are expected to become more precise during future study years as additional data are collected.

3.9 Biomass

Biomass was calculated for juvenile and adult Mountain Whitefish and for adult Bull Trout based on the estimates of length, body condition, and absolute density.

Estimates of biomass of adult Bull Trout fluctuated up and down between 2001 and 2010 but decreased in each successive year after the flow regime change (Figure 28). The decrease in biomass since the flow regime change reflects corresponding decreases in both absolute density (Figure 9) and body condition (Figure 24). Bull Trout biomass was greatest at sites the closest to Revelstoke Dam (Rkm 236.4), between the Revelstoke Golf Course and the Trans-Canada highway bridge (Rkm 231-233), and at Salmon Rocks (Rkm 227.2). This spatial trend was associated with the trend in the density (Figure 9) whereas body condition of adult Bull Trout was similar among sites (Figure 24).

Estimates of juvenile Mountain Whitefish biomass were greater in 2010 and 2011 than during other years between 2007 and 2013 (Figure 29), which was associated with the greater density observed during those years (Figure 13). Biomass was greatest at sites the closest to Revelstoke Dam (Rkm 236.4) and between the Revelstoke Golf Course and the Trans-Canada highway bridge (Rkm 231-233), which also reflects trends in density of juvenile Mountain Whitefish (Figures 12 and 13).

Estimates of adult Mountain Whitefish biomass decreased from 2001 to 2007 (Figure 30), which was associated with decreases in body condition but similar values of absolute density. Adult Mountain Whitefish biomass was similar from 2008 to 2012.

The greater biomass of Mountain Whitefish in fall than in spring was related to greater density (Figure 15) and greater body condition (Figure 26). Spatial trends in the biomass of adult Mountain Whitefish were similar to those for juveniles with the greatest biomass between the Revelstoke Golf Course and the Trans-Canada highway bridge (Rkm 231-233).

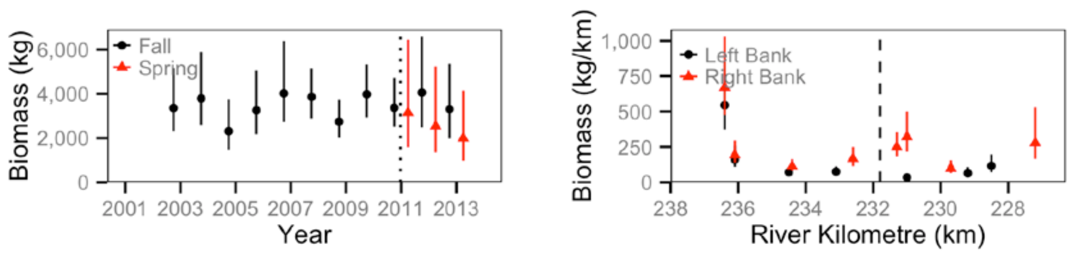

Figure 28: Biomass estimates (with 95% credible intervals) by year and season (left panel) and site (right panel) for adult Bull Trout in the middle Columbia River study area, 2003 to 2013. The dotted line (left panel) represents the implementation of the minimum flow release and REV5 operations. The dashed line (right panel) represents the divide between Reaches 3 and 4 at the Jordan River confluence.

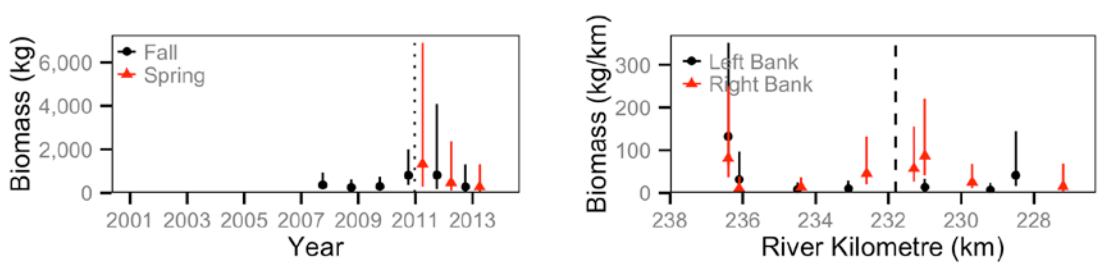

Figure 29: Biomass estimates (with 95% credible intervals) by year and season (left panel) and site (right panel) for juvenile Mountain Whitefish in the middle Columbia River study area, 2003 to 2013. The dotted line (left panel) represents the implementation of the minimum flow release and REV5 operations. The dashed line (right panel) represents the divide between Reaches 3 and 4 at the Jordan River confluence.

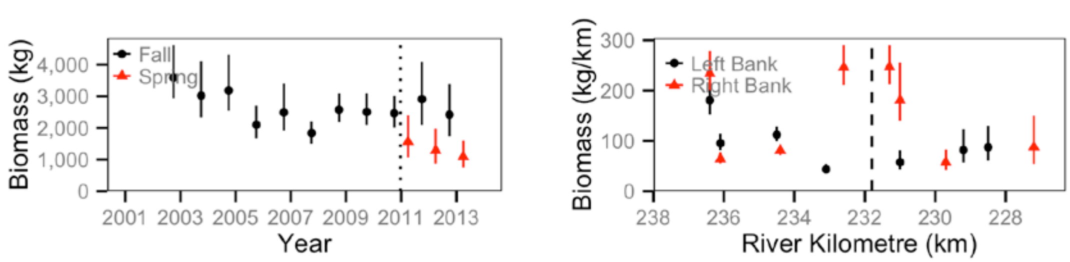

Figure 30: Biomass estimates (with 95% credible intervals) by year and season (left panel) and site (right panel) for adult Mountain Whitefish in the middle Columbia River study area, 2003 to 2013. The dotted line (left panel) represents the implementation of the minimum flow release and REV5 operations. The dashed line (right panel) represents the divide between Reaches 3 and 4 at the Jordan River confluence.

3.10 Environmental Variables

The 12 tri-monthly variables for reservoir elevation, mean hourly discharge, and mean hourly discharge difference, were reduced to five uncorrelated eigenvectors using PCA. The eigenvectors can be interpreted as new variables that represent the environmental variables with which they had significant correlations. The Bayesian model used to estimate correlation coefficients between the eigenvectors and the environmental variables indicated that eigenvectors 1, 4 and 5 had significant correlations with some of the environmental variables (Table 7; Figure 31). Eigenvectors 2 and 3 were not significantly correlated with any of the environmental variables.

The Bayesian model used to estimate correlation coefficients between the eigenvectors and the fish population metrics indicated that eigenvector 1 was positively correlated with the count density and distribution of Rainbow Trout, and the count density of Sucker species, and negatively correlated the body condition of adult Mountain Whitefish (Table 7; Figure 32). None of the other four eigenvectors had significant correlations with any of the fish population metrics.

The correlations with eigenvector 1 indicate that discharge (mean and hourly difference) during the winter (January - March) and reservoir elevation during all seasons were positively associated with Rainbow Trout count density and distribution and Sucker species density, but negatively associated with the body condition of adult Mountain Whitefish. The multivariate analyses did not indicate any other significant relationships between environmental and fish population metrics.

Table 7: Significant correlations among the eigenvectors, and environmental and fish population variables.

Eigenvector	Correlated Environmental Variables	Correlated Fish Population Variables
1	Hourly discharge difference (January – March) Mean discharge (January – March) Mean reservoir elevation (all four time periods)	Rainbow Trout count density Rainbow Trout distribution Sucker species count density Adult Mountain Whitefish body condition
2	None	None
3	None	None
4	Mean reservoir elevation (April – June)	None
5	Hourly discharge difference (April – June, July – September, and October – December) Mean discharge (October – December) Mean reservoir elevation (July - September)	None

Note: red text indicates a negative correlation; black text indicates a positive correlation

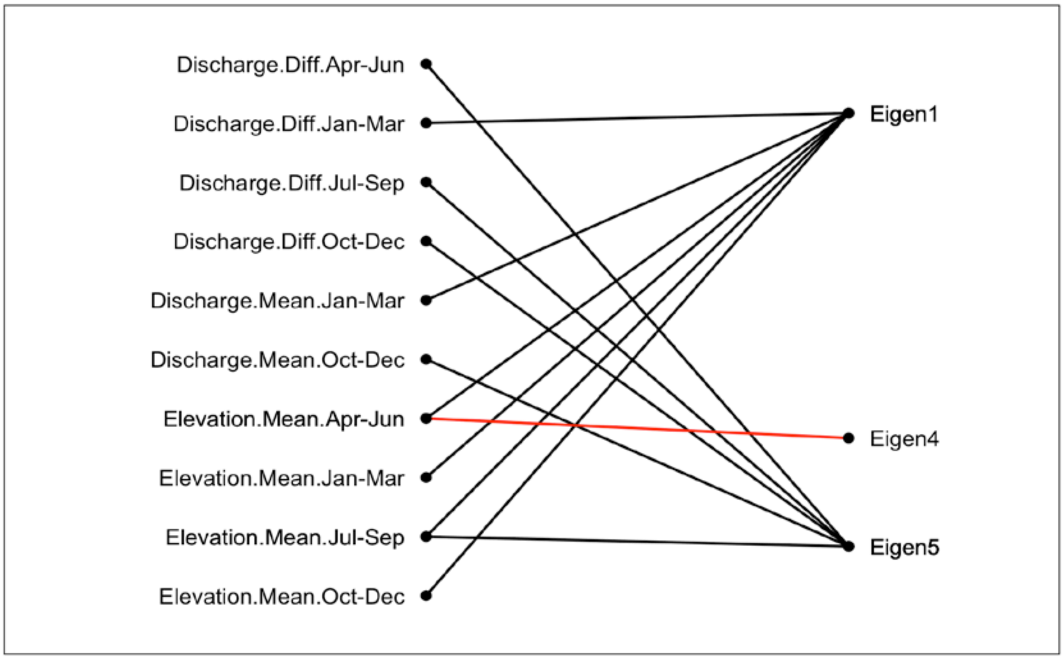

Figure 31: Significant relationships between environmental variables and the eigenvectors used to represent these variables. Black lines indicate a positive relationship and red lines indicate a negative relationship.

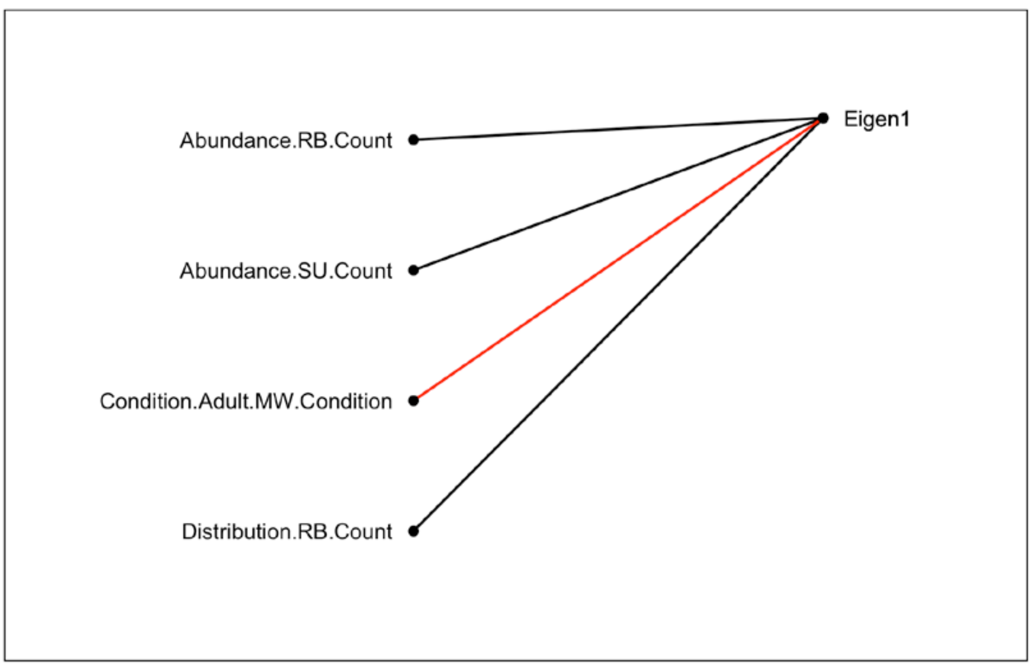

Figure 32: Significant relationships between fish population metrics and the eigenvectors used to represent the environmental variables. Black lines indicate a positive relationship and red lines indicate a negative relationship.

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.

4.1 Discharge, Temperature, and Revelstoke Dam Operations

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 in years past was a predicted 32% increase in permanently wetted riverbed area, based on modelling results, 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 0-1700 m^3/s to 142-2124 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 change in flow regime at REV resulted in significant differences in physical habitat in the MCR including a greater permanently wetted river channel area, greater peak flows and higher flow variability. These changes have the potential to affect fish populations. Additional studies are required to determine which physical habitat variables and components of dam operations influence fish populations in the MCR (see below). The first two years of data collected since the flow regime change (2011 and 2012) were characterized by greater than average river discharge. In 2013, discharge was near average but sampling for the fish population indexing program was only conducted in the spring and not in the fall. Additional years of data are required to determine whether changes in flow variability and fish populations are related to the flow regime change or other environmental factors.

The implementation of the minimum flow release coincided with an additional unit (REV5) going online at REV. The increased capacity at REV due to REV5 resulted in both increased daily flow variability and higher peak daily discharge levels. During periods of high electricity demand, REV operates at full or near full capacity to maximize power generation, which results in higher discharge levels in the MCR. In order to compensate for the additional water released through REV, the dam operates at lower discharge levels during periods of low energy demand for longer durations (typically at night). This operational change makes it difficult to determine if changes identified in the fish community downstream of REV are the result of the minimum flow release or the result of higher daily peak discharge levels (or a combination of both).

One way to determine which input (i.e., the higher peak daily discharge or the minimum flow release) affects the fish community could involve a multi-year study with different input combinations. As an example:

- operate REV5 with the minimum flow release; and,
- operate REV5 without the minimum flow release.

Operating REV in this manner would require significant changes to the WUP. In addition, the duration of time required under each scenario would be different for each fish species of interest and each management question to be answered. For example, measuring a change in the body condition of Sucker species may require as little as one year under each scenario as food availability for these species would be directly related to primary and secondary productivity. Determining the body condition of Bull Trout would require several years of operation under each scenario as body condition for this species are partially dependent on prey fish abundance, and prey fish abundance would likely require several years to stabilize.

4.2 Species Richness and Diversity

Estimates of species richness increased from 2001 to 2008. The change in richness was related to increases in the probability of occupancy of several species, including Burbot, Lake Whitefish, Redside Shiner, Rainbow Trout, and Sculpin species. 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. Species richness was lower in Site 232.6-R (upstream of the Jordan River confluence) than in neighbouring sites. Habitat within this site is very homogenous, encompassing a large, flat, gravel/cobble fan upstream of the confluence. Shallower water depths, a lack of suitable cover, and the uniform nature of the substrate result in a low habitat diversity that would reduce the suitability of the area for certain species.

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 (85%) than the right bank (57%; Appendix B, Table B2).

Species evenness increased from 2001 to 2008. The increase in evenness resulted from the less common species becoming relatively more common during this 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. Both richness and evenness were lower in the spring than in the fall, which was related to lower probability of occupancy and/or density of Burbot, Northern Pikeminnow, Lake Whitefish, and Sucker species.

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.

Reach 3 represents a transition zone between lacustrine and riverine habitats, particularly during the fall study period when ALR water elevations levels are higher. The complex species assemblage (higher species richness and evenness) in that portion of the study area reflects the greater habitat diversity in the transition zone.

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. Overall, the results do not suggest a change in species richness or evenness related to the flow regime change, as these metrics fluctuated with no increasing or decreasing trend from 2009 to 2013 when the flow regime change occurred.

4.3 Management Question #1 – Abundance

4.3.1 Bull Trout

Bull Trout density generally increased from 2001 to 2007 and decreased from 2007 to 2013, with lower values in 2012 and the 2013 spring sampling session . Three years of post-flow regime change monitoring data do not suggest a significant change in Bull Trout abundance related to the flow regime change, as the declining trend in density started around 2007 (i.e., before the flow regime change). The biomass of Bull Trout, which takes into account both the abundance and size of individuals, decreased in each successive year following the flow regime change although estimates were within the range of fluctuations observed prior to 2010. The period of increasing Bull Trout density from 2001 to 2006 was associated with generally lower river discharge and ALR water levels, whereas the period of higher then declining abundance was associated with higher discharges and reservoir elevations. However, based on the environmental analyses, there were no significant associations between Bull Trout abundance and discharge or reservoir elevation, indicating that there was not a consistent relationship between these variables.

Given the magnitude of changes observed from 2001 to 2007, these differences in density may not reflect actual changes in abundance in the overall population in ALR and may reflect differences in migration rates out of ALR and into 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. Catch and absolute density estimates of adult Bull Trout were greater in the fall than in the spring, which supports the notion of migration into the study area during the fall. However, large numbers of adults also were caught in the study area in the spring, and juvenile catch density and count density (all age-classes) were similar in spring and fall, suggesting that many juvenile and adults likely reside in the MCR study area year-round. Site fidelity of adult Bull Trout was lower in spring (12%) than in fall (35%), which suggests that Bull Trout are likely moving between areas of the MCR frequently in both seasons. Paired sampling sessions in both spring and fall in 2014 should improve understanding of Bull Trout movements in the MCR, and the potential effects of these movements on abundance estimates.

4.3.2 Burbot

Count density estimates for Burbot were higher in 2008 and 2011 than in other study years. 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, 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, although the environmental analyses did not suggest a signification relationship between Burbot density and reservoir level.

Burbot count densities increased from 2001 to 2006, and fluctuated between 2007 and 2012 with no obvious trend. In 2013, densities were similar to that from the fall 2012 sampling session. These results do not suggest a significant impact of the flow regime change on Burbot density in the MCR.

4.3.3. Kokanee

Density of Kokanee was not estimated because the extremely variable counts of this species prevented the model from converging. Probability of occupancy at a typical site varied substantially among years (Appendix H, Figure H2). 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 failure of the density model to converge. 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.

4.3.4 Mountain Whitefish

Densities of adult Mountain Whitefish and of all cohorts combined indicated stable abundance between 2001 and 2013. There were relatively higher densities of juvenile Mountain Whitefish in 2010 and 2011 compared to other study years, which was supported by larger 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).

Count density (all age-classes) and catch density of juvenile Mountain Whitefish were greater in the spring compared to the subsequent fall in 2011 and 2012. These seasonal differences in abundance suggest that many juvenile Mountain Whitefish likely migrate into the MCR from ALR or tributaries during the spring and leave the MCR in the fall. For adult Mountain Whitefish, absolute density was greater in the fall than in the spring, but catch density was greater in the spring than in fall. This difference is explained by the capture efficiency estimates (Appendix H, Figure H11), which were approximately two times greater in the spring than in the fall. Thus, the trend shown by absolute density, with greater density of adult Mountain Whitefish in the fall is likely more reflective of actual seasonal abundance, whereas the higher catch density in spring was likely because of greater capture efficiency compared to the fall season.

Catch and absolute density of juvenile Mountain Whitefish decreased from 2011 to 2013, a trend that was also supported by decreasing biomass of juveniles and adults during this time period. Juveniles captured during 2011 to 2013 represent cohorts that hatched since the winter of 2010/2011 when REV5 went online and the minimum flow release was implemented. Juvenile Mountain Whitefish in 2013, which represent the second cohort since the flow regime change, also had very low densities, as was observed for the first cohort in 2012. Since the flow regime change, discharge from REV has been more variable (Appendix C, Figure C1) and water level elevations in ALR were relatively high (Appendix C, Figure C3) compared to earlier study years. However, multivariate environmental analyses did not suggest any significant relationships between juvenile Mountain Whitefish abundance and discharge.

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). 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 (Attachment A), although spawning locations are unknown.

In 2011 and 2012, recapture rates of adult Mountain Whitefish were higher in the spring (~2-4%) than in the fall (~3-6%; Appendix H, Figure H11); recapture rates in the spring of 2013 were similar to previous spring sessions (~3-6%). Reasons for the large increase in capture efficiency in the spring, especially in 2011, 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 H18). 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 spring abundance would have been overestimated.

4.3.5 Rainbow Trout

Density estimates for Rainbow Trout gradually increased from 2001 to 2008. Densities of Rainbow Trout were low in 2009 but there was no clear directional trend between 2008 and 2013. Overall, densities estimates for this species were quite low, with wide credible intervals. There were no differences in Rainbow Trout density between spring and fall seasons. The results suggested a significant effect of flow regime on Rainbow Trout density, with greater count and catch density after minimum flows. However, this difference was likely related to the much lower density estimates in the early 2000s, whereas densities were more similar between from 2008 to 2013. Low catches of this species resulted in high uncertainty in density estimates, and prior to the flow regime change sampling of this species was conducted in the fall rather than in both seasons.

The count density of Rainbow Trout was positively associated with the mean and variability in discharge during winter months (January to March), and with reservoir elevation (all seasons). These results suggest greater densities of Rainbow Trout result from greater and more variable discharge and higher reservoir levels. The greatest densities of Rainbow Trout were observed at sites further downstream, closest to ALR (Figures 16 and 17). It could be that high reservoir levels and discharge extend the area preferred by Rainbow Trout a greater distance upstream from ALR and result in greater overall densities, compared to years with lower reservoir levels. However, uncertainty in Rainbow Trout density estimates was high; therefore, these relationships should be interpreted with caution.

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, springs surveys in 2011, 2012, and 2013 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; Attachment A). None of the Rainbow Trout caught during the spring 2012 or 2013 surveys 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

Sucker species density was stable from 2001 to 2008, but steadily increased from 2009 to 2012, more than doubling from 7.2 to 16.2 fish counted per kilometre during this period, and this density was similar to counts from 2013 (Figure 18). This result is suspect. 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) means it is unlikely that the population increased so dramatically since 2010. An alternate explanation for the increase is changes in sampling methods. Field crews did not attempt to capture Sucker species from 2002 to 2009. Density estimates for those years were based entirely on netter observations and Sucker species may have been consistently misidentified or under estimated. However, Sucker species generally react to electricity by rapidly swimming to the surface and rolling onto their backs with their lips distended. This behaviour makes their identification relatively easy, suggesting that netters did not consistently misidentify them. A more probable hypothesis is that in past survey years, the netters underestimated numbers observed. Sucker species tend to aggregate in large groups and when the electrofishing boat passes over these groups, large numbers of fish tend to rise to the surface at once, making enumeration more difficult and therefore, less accurate. Unfortunately, the change in sampling protocols in 2010 and the potential effect on density estimates limit inferences about the effect of the flow regime change on Sucker species.

Of the Sucker species captured in the spring sessions, 42% of those captured in 2011, 27% of those captured in 2012, and 26% of those captured in 2013 were identified as spawners, through the release of eggs or milt or the presence of tubercles (both species combined, Attachment A). 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

Density of Northern Pikeminnow in the MCR increased from 2007 to 2010 but drastically decreased from 2011 to 2013. The period of increasing density coincided with higher than average reservoir elevation in ALR from 2007 to 2010, but there was no significant correlation between count density and reservoir elevation in the analysis including all study years. The decrease in the density of Northern Pikeminnow coincided with the implementation of the flow regime change but the HBM indicated no significant effect of the flow change.

Northern Pikeminnow density was approximately 10 times greater in the fall than in spring of 2011, 2012, and 2013, 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 in streams at sites 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. Occupancy remained at intermediate levels from 2009 to 2013, with similar values before and after the flow regime change. 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 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; Attachment A) did not indicate poorer observational conditions during any particular study year.

Occupancy estimates for Sculpin species do not suggest a significant impact of the flow regime change on Sculpin species. However, given their small-bodied nature 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 2009, 2010, 2011, 2012, 2013). 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 Mountain Whitefish and Bull Trout.

Information on annual growth rates for species other than Bull Trout and Mountain Whitefish 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 Mountain Whitefish and Bull 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

Although there was no significant relationship between Bull Trout growth and flow regime, there was a consistent increase in growth between 2008 and 2012 for this species. Changes in growth were not significantly associated with discharge or reservoir elevation based on the multivariate analysis.

Reasons for the decline in Bull Trout growth from 2007 to 2008 are unknown but could have been related to the unusually high ALR levels in 2008 (Appendix C, Figure C3). The increase in Bull Trout growth rates started several years before the flow regime change; therefore, the results do not suggest a significant impact of flow regime on Bull Trout growth.

4.4.2 Mountain Whitefish

The length-at-age analyses in previous years of this study indicated a substantial decline in the length-at-age of age-1 Mountain Whitefish following the flow regime change in 2010 (Golder and Poisson 2013). Growth rate, modelled as the annual increase in fork length using the von Bertalanffy equation, decreased from 2002 to 2004 and increased from 2004 to 2008 but was not significantly different before and after the flow regime change.

It is unclear whether the decrease in length-at-age juvenile Mountain Whitefish was caused in part by the flow regime change or simply represents unusual year-effects or natural random variation (Golder and Poisson 2013). Additional years of data are required to confirm a link between length and flow regime for this species.

The growth of Mountain Whitefish was not significantly associated with discharge or reservoir elevation based on the multivariate analyses. In the Skeena River, another large river in British Columbia, food abundance was the main factor limiting growth and abundance for Mountain Whitefish (Godfrey 1995 as cited by Ford et al. 1995).

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. Relationships between body condition and flow regime were not evident for these species. Life history data were collected for these species from 2010 to 2013 only, as such, credible intervals surrounding body condition estimates were extremely wide. Uncertainties surrounding these estimates will likely decrease over time as data becomes available. 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

Bull Trout body condition started decreasing in the mid-2000s, increased slightly in 2009 and 2010, and decreased again from 2011 to 2013 following the flow regime change. A similar trend was observed over the same time period in the body condition of Mountain Whitefish. There were no significant correlations between Bull Trout condition and reservoir elevation or river discharge that could help explain the body condition trends observed. Overall, Bull Trout condition in the MCR could not be reliably associated with any of the environmental variables examined.

For Bull Trout, there was very little variation in 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.

In previous years of this study, gastric lavage and observations of Bull Trout feeding on Kokanee in the fall suggested that recently ingested Kokanee could have increased Bull Trout body weights by up to 20%, which could influence or bias body condition estimates for fish captured in the fall (Ford and Thorley 2012). The effect of recently ingested Kokanee was suggested as a factor that could have contributed to observed differences in body condition between tag types (i.e., PIT or T-bar) and a declining trend of body condition with day of the year during the fall (Ford and Thorley 2012). If true, body condition in the spring (when Kokanee are less abundant and potential effects of gut fullness on body condition are reduced) should be lower. However, analyses in this report indicate no differences between fall and spring estimates of Bull Trout body condition, which suggests that the effect of gut fullness from Kokanee, while dramatic in some cases, is unlikely to have severely affected overall estimates of Bull Trout condition in the fall.

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 significant effect on body condition for the species in the HBM. As body condition varied substantially prior to the flow regime change, it is difficult to determine whether the low body condition values observed between 2011 and 2013 were related to the flow regime change or natural variability caused by environmental factors (e.g., high discharge). The similar decline in the body condition of Mountain Whitefish after the flow regime change supports the idea that Bull Trout body condition was indeed lower in 2011-2013. However, additional years of data after the flow regime change are required to determine whether the change in body condition was related to flow.

4.5.2 Mountain Whitefish

The body condition of Mountain Whitefish was lower after the flow regime change than before for both juvenile and adults life-stages, although the difference was only statistically significant for adults. These declines in body condition also corresponded with a similar decline in Bull Trout body condition starting in 2010. Whether declines in body condition were in response to the flow regime change is not known. The body condition of Mountain Whitefish was substantially lower after the flow regime change when compared to pre-flow regime change estimates. However, the decline appeared to have started in 2006, several years before the flow regime change. The finding that the flow regime change began during a period when body condition was already changing due to some other unknown factor(s) makes it more difficult to assess the effects of the flow regime change on this parameter. Additional years of data are required to determine if the decline is due to annual variation or reflects a relationship between Mountain Whitefish body condition and flow regime.

Multivariate analyses suggested a negative association between the body condition of adult Mountain Whitefish and mean discharge, variability in discharge (January to March), and reservoir elevation (all seasons). 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. This supports the possibility that reduced body condition of Mountain Whitefish after the flow regime change was related to higher and more variable discharge. 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 for the past two years of study. 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 insight 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 conditions for Mountain Whitefish in the fall compared to the spring likely reflects greater food availability during summer when compared to winter.

4.5.3 Rainbow Trout

Limited life history data for Rainbow Trout resulted in large uncertainty surrounding body condition estimates. Long-term patterns or trends were not evident in annual estimates. Body condition was similar before and after the implementation of minimum flows, which suggested no effect of the flow regime change on Rainbow Trout condition, based on the limited data set. 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.

In 2013, body condition was slightly higher in Reach 4 than Reach 3. Boat electroshocking surveys were conducted in Reach 2 in 2008 and 2009. During those surveys, 42 Rainbow Trout were measured for length and weight (Attachment A). 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 effects of the flow regime change on the spatial distribution of fish in the MCR was evaluated by testing whether the linear relationship between density and river kilometre varied by flow regime. In the models estimating count, catch, and absolute density, if the interaction between river kilometre (distribution) and flow regime was significant, the interpretation was that the flow regime change had a significant effect on the spatial distribution of fish in the MCR. The interaction between river kilometre and flow regime was not significant in the models of count, catch, or absolute density for any of the species assessed, which suggests that the flow regime change did not have a significant effect on the spatial distribution of fish in the MCR. In 2012, the effect of the flow regime change on the spatial distribution of fish was assessed graphically by comparing site-specific densities among years before and after the flow regime change (Golder and Poisson 2013). Previous graphical assessment presented in Golder and Poisson (2013) agree with the results in this report and do not suggest a significant effect of the flow regime change on the spatial distribution of adult fish in the MCR. The spatial distribution within the MCR is discussed for each species in the following sections.

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 increased downstream distance 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.

4.6.2 Burbot

For Burbot, credible intervals overlapped for all site-level density estimates. Similar to results reported in previous years (e.g. Ford and Thorley 2012, Golder and Poisson 2013), density was slightly higher 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, Figure D3) 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).

Kokanee are in the study area primarily during the fall season for spawning purposes; for that reason, densities are higher near these tributaries (either spawning at the creek mouths or migrating into the creeks to spawn). Based on field observations, densities generally decreased with distance downstream from the confluences of tributaries.

4.6.4 Mountain Whitefish

Mountain Whitefish was the only species with adequate data to robustly analyze differences amongst age groups. 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.

Analysis did not suggest a significant interaction between the distribution of Mountain Whitefish and the flow regime change in the MCR. Golder and Poisson (2013) reported an increase in the density of adult Mountain Whitefish at Site 233.1-L near the Revelstoke Golf Course following the flow regime change, which may have been related to the habitat enhancements at that site in 2009. The results do not suggest a significant change in spatial distribution related to the flow regime change.

4.6.5 Rainbow Trout

Between 2001 and 2013, 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 2.5 km section of the bank along the Revelstoke Golf Course (Site 233.1-L; Appendix A, Figure A2). Prior to bank stabilization, a total of 23 Rainbow Trout were recorded in eight study seasons (this portion of the river was not sampled in 2009 due to construction of the bank stabilization works). During the 2010 and 2011 (fall only) surveys, 20 and 28 Rainbow Trout, respectively, were recorded in this portion of the river. Rainbow Trout were not caught or observed at Site 233.1-L in the fall of 2012 and only two were recorded in during sampling in the spring of 2013.

Although based on only four years of data, preliminary results indicate that the bank stabilization work conducted by BC Hydro in 2009 adjacent to Site 233.1-L has made the area more suitable for Rainbow Trout. Overall, 80% of the Rainbow Trout captured in Site 233.1-L since bank stabilization were classified as immature; 20% were classified as adult (Attachment A). The reason for lower Rainbow Trout catch and observations at Site 233.1-L in 2012 and 2013 than in 2010 and 2011 is not known, but the much higher than normal river discharge during sampling in October 2012 could have influenced catchability or suitability of the habitat for this species.

Overall, results suggest that the flow regime change likely did not have a significant impact on Rainbow Trout distribution in the MCR.

4.6.6 Sucker Species

For all Sucker species combined, density generally increased with increased distance downstream of the dam. Sucker species generally prefer lower water velocity area (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.

4.6.7 Northern Pikeminnow

Overall, Northern Pikeminnow densities were low compared to other species, although they were slightly higher in Reach 3 than in Reach 4. 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), and was observed in both 2012 and 2013 (Golder 2013).

In previous years, Northern Pikeminnow were more abundant in the MCR during the fall season than during the spring season (Golder and Poisson 2013). 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.

4.6.8 Sculpin Species

Overall, Sculpin species densities were highest in Big Eddy and along the rip-rap on the left bank of Reach 3. Of the Sculpin species captured in the fall since 2010, 98% were Prickly Sculpin ($n = 113$) and 2% were Slimy Sculpin (*Cottus bairdii*) ($n = 2$). Of all Sculpin caught since 2010, 80% of the Slimy Sculpin were caught in Reach 3. Slimy Sculpin could be more common in Reach 3 than in Reach 4, or, alternatively, slower water velocity or other habitat differences may 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 3 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. Data were collected in the fall season only prior the flow regime change, in spring and fall during 2011 and 2012, and in the spring only during 2013. Lack of data from the fall season in 2013 means that results from this year's sampling provide little new information to assess the effects of the flow regime change because spring data were not collected prior to the change. With only two years of fall data since 2010, additional sampling in the fall is required in order to address the management questions regarding the effects of minimum flow and the changes in maximum and daily variation of flow.

There was an increase in species richness between 2001 and 2008 that was attributed to significant increases in the abundance of several less common species. The density and/or probability of occupancy of Burbot, Lake Whitefish, Northern Pikeminnow, Rainbow Trout and Sculpin species all increased, while densities 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, and increasing fish densities were not strongly correlated with environmental variables including discharge and reservoir elevation.

With only two years of complete fisheries data following the flow regime change, it is not possible to draw strong conclusions about its effect on fish populations. In general, the abundance of most species was stable or within the range of previously observed fluctuations. However, there was some evidence to suggest that conditions for growth or abundance of fish in the MCR may have declined in the three years following the flow regime change. The four cohorts of juvenile Mountain Whitefish that were rearing in the MCR following the flow regime change (i.e., age-0 in 2011 and age-1 in 2012, and age-1 in 2012 and age-0 in 2013) were noticeably less abundant compared to previous years, based on density estimates and length-frequency distributions. In addition, the body condition of adult Mountain Whitefish and juvenile and adult Bull Trout all declined to low levels in the three years following the flow regime change. Estimates of biomass, which takes into account both abundance and size of individuals, decreased in the three years following the flow regime change for Bull Trout and Mountain Whitefish, although values were within the range of fluctuations prior to 2010.

The similar trends in all these variables suggest that growth was likely lower in 2011-2013 but the cause of the decline remains unclear. The negative association between the condition of adult Mountain Whitefish and the mean and hourly difference in discharge suggests that the flow regime change could have contributed to the observed declines in growth and abundance. Additional years of data collection are required to assess the influence of environmental variables, and whether the change in operations at REV contributed to any of the observed differences in fish populations.

Large data gaps still exist for all fish species that were not intensively monitored from 2001 to 2009 (i.e., all species except Bull Trout, Mountain Whitefish, and Rainbow Trout); however, long-term patterns and trends for these species are expected to become clearer with each successive sample year. Low catch-rates for Brook Trout, Cutthroat Trout, Peamouth, Pygmy Whitefish, Yellow Perch and White Sturgeon will hamper the detection of changes for these species. In addition, the sample methods used limit the amount of data collected, and this lack of data limits the conclusions that can be made about the effects of the flow regime change on the status of Kokanee, Redside Shiner, and Sculpin species.

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.
- The feasibility of operating REV5 for extended time periods without maintaining the minimum flow release should be examined. This would provide insight into the effect on the downstream fish community of both the minimum flow release and the higher peak daily discharges associated with REV5.
- An additional electrofishing pass should be conducted at each site during which fish would be enumerated but not captured. This enumeration pass would allow the collection of fine-scale spatial distribution data (by geo-referencing the location of fish within the site using a hand-held GPS) and more accurate count data (observers would focus on counting instead of capturing). This approach would provide valuable information on the fine-scale abundance, diversity, and distribution of fish. In addition, if several years of enumeration are conducted in parallel with mark-recapture, it may eventually prove possible to calibrate the efficiency of the method and reduce the number of mark-recapture passes needed during each sample season.
- A Mountain Whitefish spawning assessment should be conducted to confirm and/or identify local spawning activity and assist in identifying the source of age-0 Mountain Whitefish found in the study area. This information would confirm whether flow regime changes or other dam operations influence spawning success of Mountain Whitefish, which would be expected to influence abundance of this species in the MCR.
- Aerial surveys should be conducted during the Rainbow Trout spawning season to determine the extent of mainstem spawning for this species. This would provide insight into whether Rainbow Trout are spawning in the MCR or migrating into tributaries to spawn, which is important when assessing whether minimum flows or other dam operations influence spawning and early life history survival of Rainbow Trout.

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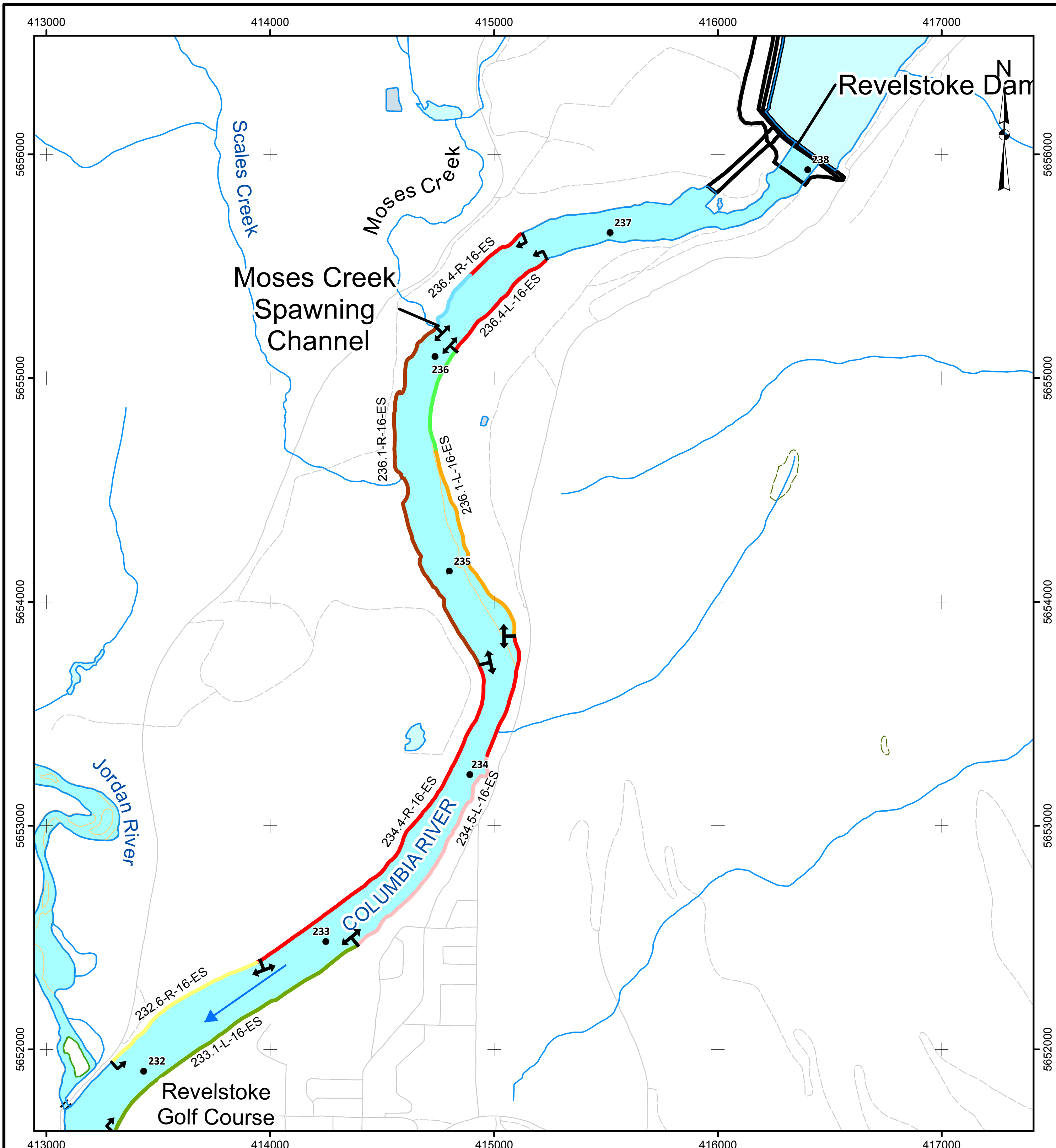
Appendix A - Maps



LEGEND

- RIVER KILOMETRES FROM U.S. BORDER
- DAM BASE
- ISLAND
- WETLAND
- SAND OR GRAVEL BAR
- WATERCOURSE
- ROUGH ROAD
- PAVED ROAD
- AIR FACILITY
- ROAD BRIDGE

- DIRECTION OF FLOW

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

500 250 0 500

SCALE 1:24,000 METRES

REFERENCE

TRIM MAPS PROVIDED BY BC HYDRO
PROJECTION: UTM ZONE 11 N DATUM: NAD 83

PROJECT
MIDDLE COLUMBIA RIVER FISH POPULATION INDEXING SURVEY

TITLE
BANK HABITAT TYPE AND SAMPLE LOCATIONS REACH 4

PROJECT No. 13-1492-0004			SCALE AS SHOWN	REV. 0
DESIGN	DF	11 Apr. 2014	**FIGURE A1**	
GIS	AL	11 Apr. 2014		
CHECK	DF	11 Apr. 2014		
REVIEW	LH	11 Apr. 2014		

Golder Associates

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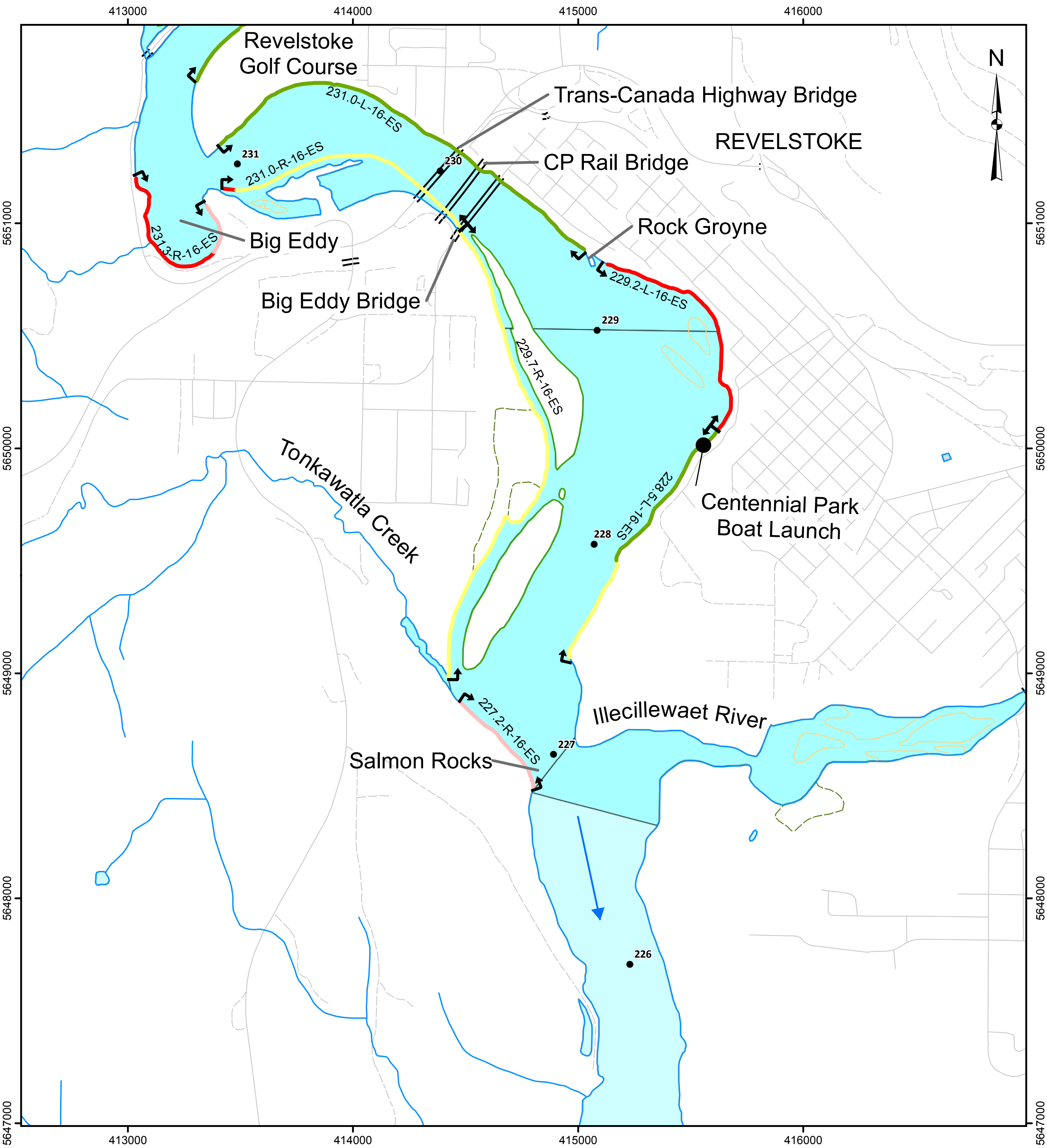

LEGEND

- • RIVER KILOMETRES FROM U.S. BORDER
- DAM BASE
- ISLAND
- WETLAND
- SAND OR GRAVEL BAR
- WATERCOURSE
- ROUGH ROAD
- PAVED ROAD
- AIR FACILITY
- ROAD BRIDGE

DIRECTION OF FLOW

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

REFERENCE

TRIM MAPS PROVIDED BY BC HYDRO
PROJECTION: UTM ZONE 11 N DATUM: NAD 83

500 250 0 500
SCALE 1:24,000 METRES

PROJECT
MIDDLE COLUMBIA RIVER FISH POPULATION INDEXING SURVEY

TITLE
BANK HABITAT TYPE AND SAMPLE LOCATIONS REACH 3

Golder Associates

PROJECT No. 13-1492-0004			SCALE AS SHOWN	REV. 0
DESIGN	DF	11 Apr. 2014	**FIGURE A2**	
GIS	AL	11 Apr. 2014		
CHECK	DF	11 Apr. 2014		
REVIEW	LH	11 Apr. 2014		

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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, 2013.

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, 27 May to 20 June 2013.

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
4	236.4-L-16-ES	1	14	5.8	160	Clear	High	High	High	100	0	0	0	0	0	0
4	236.4-L-16-ES	2	13	7.5	150	Clear	High	Low	High	100	0	0	0	0	0	0
4	236.4-L-16-ES	3	14	8.1	150	Partly cloudy	High	High	High	80	0	0	0	0	0	20
4	236.4-L-16-ES	4	11	8.4	140	Clear	High	High	High	30	0	0	0	35	35	0
4	236.4-R-16-ES	1	12	6.9	160	Overcast	Low	Medium	High	100	0	0	0	0	0	0
4	236.4-R-16-ES	2	13	7.5	150	Clear	High	High	High	90	0	5	0	5	0	0
4	236.4-R-16-ES	3	14	8.1	150	Partly cloudy	High	High	High	80	0	10	0	5	5	0
4	236.4-R-16-ES	4	11	8.4	140	Clear	High	High	High	60	0	5	0	0	35	0
4	236.1-L-16-ES	1	10	6.9	160	Overcast	Low	Medium	High	100	0	0	0	0	0	0
4	236.1-L-16-ES	2	9	7.5	150	Overcast	High	Low	High	100	0	0	0	0	0	0
4	236.1-L-16-ES	3	13	8.1	150	Partly cloudy	High	High	High	100	0	0	0	0	0	0
4	236.1-L-16-ES	4	11	8.4	140	Clear	High	Low	High	0	0	0	0	100	0	0
4	236.1-R-16-ES	1	13	5.8	160	Clear	High	Medium	High	85	5	5	0	5	0	0
4	236.1-R-16-ES	2	13	7.5	150	Partly cloudy	High	Low	High	80	0	5	0	10	5	0
4	236.1-R-16-ES	3	13	8.1	150	Clear	High	High	High	80	0	0	0	20	0	0
4	236.1-R-16-ES	4	11	8.4	140	Clear	High	Low	High	50	5	0	0	25	20	0
4	234.4-R-16-ES	1	9	6.9	160	Overcast	Low	Low	High	70	30	0	0	0	0	0
4	234.4-R-16-ES	2	12	8.8	150	Clear	High	Medium	High	60	30	0	0	10	0	0
4	234.4-R-16-ES	3	14	7.9	150	Clear	High	High	High	20	40	0	0	40	0	0
4	234.4-R-16-ES	4	12	8.4	140	Overcast	Low	Low	Medium	20	5	0	0	20	55	0
4	234.5-L-16-ES	1	10	5.8	160	Overcast	High	High	High	60	0	10	0	10	20	0
4	234.5-L-16-ES	2	13	8.8	150	Partly cloudy	High	High	High	50	5	5	0	10	30	0
4	234.5-L-16-ES	3	16	7.9	150	Clear	High	High	High	30	10	0	0	20	40	0
4	234.5-L-16-ES	4	14	8.3	140	Overcast	Low	Medium	Medium	80	0	0	0	0	20	0
4	232.6-R-16-ES	1	9	5.8	160	Overcast	High	Low	High	100	0	0	0	0	0	0
4	232.6-R-16-ES	2	10	8.8	150	Clear	High	Medium	High	100	0	0	0	0	0	0
4	232.6-R-16-ES	3	15	8.3	150	Mostly cloudy	Medium	High	High	800	5	0	0	10	0	0
4	232.6-R-16-ES	4	10	8.4	140	Overcast	Medium	Low	High	20	5	0	0	75	0	0
4	233.1-L-16-ES	1	9	6.9	160	Overcast	Low	Low	High	80	20	0	0	0	0	0
4	233.1-L-16-ES	2	15	7.8	150	Clear	High	Medium	High	100	0	0	0	0	0	0

continued…

[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 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
4	233.1-L-16-ES	3	12	7.9	150	Clear	High	High	High	80	5	0	0	10	5	0
4	233.1-L-16-ES	4	9	8.4	140	Overcast	High	Low	High	30	5	0	0	60	5	0
3	231.3-R-16-ES	1	15	6.5	120	Overcast	High	Low	High	20	60	0	0	10	10	0
3	231.3-R-16-ES	2	10	8.8	150	Clear	High	Low	High	70	10	0	0	10	10	0
3	231.3-R-16-ES	3	16	8.3	130	Overcast	High	Low	High	20	30	0	0	20	30	0
3	231.3-R-16-ES	4	17	7.6	130	Mostly cloudy	High	Medium	Medium	30	30	0	0	0	10	30
3	231.0-L-16-ES	1	14	6.7	130	Overcast	High	Low	High	90	5	0	0	0	5	0
3	231.0-L-16-ES	2	14	7.8	150	Clear	High	High	High	90	5	5	0	0	0	0
3	231.0-L-16-ES	3	14	8.3		Overcast	High	High	High	60	5	0	0	10	25	0
3	231.0-L-16-ES	4	11	8.2	120	Partly cloudy	High	Low	High	80	20	0	0	0	0	0
3	231.0-R-16-ES	1	10	6.4	160	Overcast	High	Low	High	80	20	0	0	0	0	0
3	231.0-R-16-ES	2	15	8.1	140	Clear	High	High	High	95	5	0	0	0	0	0
3	231.0-R-16-ES	3	12	7.9	150	Clear	High	Medium	High	60	10	0	0	15	15	0
3	231.0-R-16-ES	4	13	7.6	120	Clear	Medium	Medium	High	30	0	0	0	70	0	0
3	229.7-R-16-ES	1	15	8.7	180	Mostly cloudy	High	Low	High	0	50	0	0	50	0	0
3	229.7-R-16-ES	2	13	8.1	140	Clear	High	Low	High	30	10	0	0	55	0	5
3	229.7-R-16-ES	3	15	7.8	140	Overcast	High	Low	High	5	10	0	5	75	0	5
3	229.7-R-16-ES	4	16	7.7	140	Overcast	High	Low	High	0	20	0	50	0	30	0
3	229.2-L-16-ES	1	12	6.7	130	Overcast	High	Low	Medium	80	5	0	5	10	0	0
3	229.2-L-16-ES	2	12	7.8	150	Clear	High	Low	Medium	80	5	0	0	0	15	0
3	229.2-L-16-ES	3	13	8.2	140	Overcast	High	Low	High	20	10	0	0	10	60	0
3	229.2-L-16-ES	4	14	7.7	140	Overcast	High	Low	High	0	20	0	20	0	60	0
3	228.5-L-16-ES	1	10	6.7	130	Overcast	High	Low	High	50	25	0	0	10	5	10
3	228.5-L-16-ES	2	12	7.6	130	Partly cloudy	High	Medium	Medium	98	2	0	0	0	0	0
3	228.5-L-16-ES	3	15	7.8	140	Overcast	High	Low	High	80	5	0	0	10	0	5
3	228.5-L-16-ES	4	14	7.7	140	Overcast	High	Low	High	50	5	0	20	0	25	0
3	227.2-R-16-ES	1	12	7.1	120	Overcast	High	Low	High	50	0	0	0	0	50	0
3	227.2-R-16-ES	2	12	7.6	130	Clear	High	Low	Medium	50	0	0	0	0	50	0
3	227.2-R-16-ES	3	15	7.7	130	Overcast	High	Low	High	50	0	0	0	0	50	0
3	227.2-R-16-ES	4	15	7.7	140	Overcast	High	Low	High	50	0	0	0	0	50	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 during the spring season, 27 May to 20 June 2013.

Reach	Site[a]	Species	Size Class	Bank Habitat Type[b]								Total
				A1	A3	A4	A5	A6	A1+A2	D1	D2	
4	236.4-R-16-ES	Bull Trout	Adult	5		1						6
	236.4-R-16-ES	Kokanee	Immature			1						1
	236.4-R-16-ES	Largescale Sucker	Adult			3						3
	236.4-R-16-ES	Longnose Sucker	Adult	1								1
	236.4-R-16-ES	Mountain Whitefish	Adult	8		6						14
	236.4-R-16-ES	Mountain Whitefish	Immature	67		73						140
	236.4-R-16-ES	Prickly Sculpin	All	1								1
	236.4-R-16-ES	Rainbow Trout	Adult	1								1
	236.4-R-16-ES	Sculpin spp.	All	1		8						9
	236.4-R-16-ES	Sucker spp.	Adult	6		8						14
	Site 236.4-R-16-ES Total			**90**	**0**	**100**	**0**	**0**	**0**	**0**	**0**	**190**
	236.4-L-16-ES	Bull Trout	Adult	10								10
	236.4-L-16-ES	Bull Trout	Immature	1								1
	236.4-L-16-ES	Largescale Sucker	Adult	3								3
	236.4-L-16-ES	Mountain Whitefish	Adult	1								1
	236.4-L-16-ES	Mountain Whitefish	Immature	57								57
	236.4-L-16-ES	Prickly Sculpin	All	1								1
	236.4-L-16-ES	Sculpin spp.	All	9								9
	236.4-L-16-ES	Sucker spp.	Adult	7								7
	Site 236.4-L-16-ES Total			**89**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**89**
	236.1-R-16-ES	Bull Trout	Immature						3			3
	236.1-R-16-ES	Bull Trout	Adult					11	39			50
	236.1-R-16-ES	Kokanee	Immature						1			1
	236.1-R-16-ES	Largescale Sucker	Immature						1			1
	236.1-R-16-ES	Largescale Sucker	Adult						6			6
	236.1-R-16-ES	Longnose Sucker	Adult						1			1
	236.1-R-16-ES	Mountain Whitefish	Immature					145	593			738
	236.1-R-16-ES	Mountain Whitefish	Adult					12	58			70
	236.1-R-16-ES	Prickly Sculpin	All						2			2
	236.1-R-16-ES	Rainbow Trout	Immature						1			1
	236.1-R-16-ES	Rainbow Trout	Adult					1	4			5
	236.1-R-16-ES	Redside Shiner	All						1			1
	236.1-R-16-ES	Sculpin spp.	All					6	46			52
	236.1-R-16-ES	Sucker spp.	Immature					1	3			4
	236.1-R-16-ES	Sucker spp.	Adult					3	9			12
	236.1-R-16-ES	Sucker spp.	All						2			2
	Site 236.1-R-16-ES Total			**0**	**0**	**0**	**0**	**179**	**770**	**0**	**0**	**949**
	236.1-L-16-ES	Bull Trout	Adult	3	5					12	30	50
	236.1-L-16-ES	Bull Trout	Immature		1							1
	236.1-L-16-ES	Largescale Sucker	Adult		4						11	15
	236.1-L-16-ES	Longnose Sucker	Adult		1						1	2
	236.1-L-16-ES	Mountain Whitefish	Adult		2					13	28	43
	236.1-L-16-ES	Mountain Whitefish	Immature	6	17					55	100	178
	236.1-L-16-ES	Prickly Sculpin	All								2	2
	236.1-L-16-ES	Rainbow Trout	Immature	2								2
	236.1-L-16-ES	Sculpin spp.	All	1	20					5	23	49
	236.1-L-16-ES	Sucker spp.	Immature							3		3
	236.1-L-16-ES	Sucker spp.	Adult	4	2					20	6	32
	Site 236.1-L-16-ES Total			**16**	**52**	**0**	**0**	**0**	**0**	**108**	**201**	**377**

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

Continued…

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

Table B4 Continued.

Reach	Site[a]	Species	Size Class	Bank Habitat Type[b]								Total
				A1	A3	A4	A5	A6	A1+A2	D1	D2	
4	234.5-L-16-ES	Bull Trout	Immature				5					5
	234.5-L-16-ES	Bull Trout	Adult	2			10					12
	234.5-L-16-ES	Largescale Sucker	Adult				4					4
	234.5-L-16-ES	Mountain Whitefish	Adult	13			25			1		39
	234.5-L-16-ES	Mountain Whitefish	Immature	57			277			6		340
	234.5-L-16-ES	Peamouth	All				4					4
	234.5-L-16-ES	Prickly Sculpin	All				3					3
	234.5-L-16-ES	Rainbow Trout	Adult	1			3					4
	234.5-L-16-ES	Rainbow Trout	Immature				2					2
	234.5-L-16-ES	Sculpin spp.	All	16			29			5		50
	234.5-L-16-ES	Sucker spp.	Adult				2			1		3
	Site 234.5-L-16-ES Total			**89**	**0**	**0**	**364**	**0**	**0**	**13**	**0**	**466**
	234.4-R-16-ES	Bull Trout	Adult	26								26
	234.4-R-16-ES	Bull Trout	Immature	4								4
	234.4-R-16-ES	Burbot	Adult	4								4
	234.4-R-16-ES	Largescale Sucker	Adult	4								4
	234.4-R-16-ES	Longnose Sucker	Adult	4								4
	234.4-R-16-ES	Mountain Whitefish	Adult	42								42
	234.4-R-16-ES	Mountain Whitefish	Immature	247								247
	234.4-R-16-ES	Prickly Sculpin	All	2								2
	234.4-R-16-ES	Redside Shiner	All	1								1
	234.4-R-16-ES	Sculpin spp.	All	56								56
	234.4-R-16-ES	Sucker spp.	Adult	19								19
	Site 234.4-R-16-ES Total			**409**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**409**
	233.1-L-16-ES	Bull Trout	Immature					2				2
	233.1-L-16-ES	Bull Trout	Adult					28				28
	233.1-L-16-ES	Burbot	Immature					2				2
	233.1-L-16-ES	Burbot	Adult					1				1
	233.1-L-16-ES	Largescale Sucker	Adult					7				7
	233.1-L-16-ES	Longnose Sucker	Immature					3				3
	233.1-L-16-ES	Longnose Sucker	Adult					1				1
	233.1-L-16-ES	Mountain Whitefish	Adult					39				39
	233.1-L-16-ES	Mountain Whitefish	Immature					239				239
	233.1-L-16-ES	Peamouth	All					1				1
	233.1-L-16-ES	Prickly Sculpin	All					6				6
	233.1-L-16-ES	Rainbow Trout	Adult					2				2
	233.1-L-16-ES	Rainbow Trout	Immature					2				2
	233.1-L-16-ES	Redside Shiner	All					1				1
	233.1-L-16-ES	Sculpin spp.	All					138				138
	233.1-L-16-ES	Sucker spp.	Adult					11				11
	Site 233.1-L-16-ES Total			**0**	**0**	**0**	**0**	**483**	**0**	**0**	**0**	**483**
	232.6-R-16-ES	Bull Trout	Adult							14		14
	232.6-R-16-ES	Burbot	Adult							1		1
	232.6-R-16-ES	Largescale Sucker	Adult							16		16
	232.6-R-16-ES	Longnose Sucker	Adult							9		9
	232.6-R-16-ES	Mountain Whitefish	Immature							102		102
	232.6-R-16-ES	Mountain Whitefish	Adult							6		6
	232.6-R-16-ES	Rainbow Trout	Adult							1		1
	232.6-R-16-ES	Sucker spp.	Immature							7		7
	232.6-R-16-ES	Sucker spp.	Adult							83		83
	Site 232.6-R-16-ES Total			**0**	**0**	**0**	**0**	**0**	**0**	**239**	**0**	**239**
Reach 4 Total				**693**	**52**	**100**	**364**	**662**	**770**	**360**	**201**	**3202**

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

Continued…

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

Table B4 Continued.

Reach	Site[a]	Species	Size Class	Bank Habitat Type[b]								Total
				A1	A3	A4	A5	A6	A1+A2	D1	D2	
3	231.3-R-16-ES	Brook Trout	All	1								1
	231.3-R-16-ES	Bull Trout	Immature	8			1					9
	231.3-R-16-ES	Bull Trout	Adult	14			2					16
	231.3-R-16-ES	Burbot	Adult	1								1
	231.3-R-16-ES	Kokanee	Adult	1								1
	231.3-R-16-ES	Longnose Sucker	Immature	2								2
	231.3-R-16-ES	Longnose Sucker	Adult	5								5
	231.3-R-16-ES	Mountain Whitefish	Immature	258			8					266
	231.3-R-16-ES	Mountain Whitefish	Adult	61			4					65
	231.3-R-16-ES	Prickly Sculpin	All	1			1					2
	231.3-R-16-ES	Rainbow Trout	Immature				1					1
	231.3-R-16-ES	Rainbow Trout	Adult	15								15
	231.3-R-16-ES	Redside Shiner	All	59			1					60
	231.3-R-16-ES	Sculpin spp.	All	282			11					293
	231.3-R-16-ES	Sucker spp.	Immature	6								6
	231.3-R-16-ES	Sucker spp.	Adult	17			12					29
	Site 231.3-R-16-ES Total			**731**	**0**	**0**	**41**	**0**	**0**	**0**	**0**	**772**
	231.0-R-16-ES	Bull Trout	Adult	1						12		13
	231.0-R-16-ES	Bull Trout	Immature							3		3
	231.0-R-16-ES	Burbot	Immature	1								1
	231.0-R-16-ES	Largescale Sucker	Adult	1						10		11
	231.0-R-16-ES	Longnose Sucker	Adult							4		4
	231.0-R-16-ES	Mountain Whitefish	Adult	2						24		26
	231.0-R-16-ES	Mountain Whitefish	Immature	20						281		301
	231.0-R-16-ES	Peamouth	All							1		1
	231.0-R-16-ES	Rainbow Trout	Adult							2		2
	231.0-R-16-ES	Redside Shiner	All							1		1
	231.0-R-16-ES	Sculpin spp.	All							4		4
	231.0-R-16-ES	Sucker spp.	Adult	3						42		45
	Site 231.0-R-16-ES Total			**28**	**0**	**0**	**0**	**0**	**0**	**384**	**0**	**412**
	231.0-L-16-ES	Bull Trout	Adult					23				23
	231.0-L-16-ES	Bull Trout	Immature					9				9
	231.0-L-16-ES	Burbot	Adult					5				5
	231.0-L-16-ES	Burbot	Immature					1				1
	231.0-L-16-ES	Kokanee	Adult					1				1
	231.0-L-16-ES	Largescale Sucker	Adult					11				11
	231.0-L-16-ES	Longnose Sucker	Adult					4				4
	231.0-L-16-ES	Mountain Whitefish	Adult					110				110
	231.0-L-16-ES	Mountain Whitefish	Immature					437				437
	231.0-L-16-ES	Prickly Sculpin	All					3				3
	231.0-L-16-ES	Rainbow Trout	Immature					8				8
	231.0-L-16-ES	Rainbow Trout	Adult					16				16
	231.0-L-16-ES	Sculpin spp.	All					94				94
	231.0-L-16-ES	Sucker spp.	Adult					94				94
	Site 231.0-L-16-ES Total			**0**	**0**	**0**	**0**	**816**	**0**	**0**	**0**	**816**

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

Continued…

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

Table B4 Continued.

Reach	**Site**[a]	**Species**	**Size Class**	**Bank Habitat Type**[b]								**Total**
				A1	**A3**	**A4**	**A5**	**A6**	**A1+A2**	**D1**	**D2**	
3	229.7-R-16-ES	Bull Trout	Adult							30		30
	229.7-R-16-ES	Bull Trout	Immature							7		7
	229.7-R-16-ES	Largescale Sucker	Adult							61		61
	229.7-R-16-ES	Longnose Sucker	Adult							16		16
	229.7-R-16-ES	Mountain Whitefish	Immature							264		264
	229.7-R-16-ES	Mountain Whitefish	Adult							101		101
	229.7-R-16-ES	Peamouth	All							3		3
	229.7-R-16-ES	Prickly Sculpin	All							1		1
	229.7-R-16-ES	Rainbow Trout	Immature							1		1
	229.7-R-16-ES	Rainbow Trout	Adult							1		1
	229.7-R-16-ES	Redside Shiner	All							3		3
	229.7-R-16-ES	Sculpin spp.	All							147		147
	229.7-R-16-ES	Sculpin spp.	Adult							16		16
	229.7-R-16-ES	Slimy Sculpin	All							1		1
	229.7-R-16-ES	Sucker spp.	Adult							153		153
	229.7-R-16-ES	Sucker spp.	Immature							1		1
	Site 229.7-R-16-ES Total			**0**	**0**	**0**	**0**	**0**	**0**	**806**	**0**	**806**
	229.2-L-16-ES	Bull Trout	Immature	4								4
	229.2-L-16-ES	Bull Trout	Adult	2								2
	229.2-L-16-ES	Burbot	Immature	3								3
	229.2-L-16-ES	Largescale Sucker	Adult	13								13
	229.2-L-16-ES	Longnose Sucker	Adult	1								1
	229.2-L-16-ES	Mountain Whitefish	Immature	195								195
	229.2-L-16-ES	Mountain Whitefish	Adult	99								99
	229.2-L-16-ES	Prickly Sculpin	All	1								1
	229.2-L-16-ES	Rainbow Trout	Immature	2								2
	229.2-L-16-ES	Rainbow Trout	Adult	5								5
	229.2-L-16-ES	Redside Shiner	All	29								29
	229.2-L-16-ES	Sculpin spp.	All	278								278
	229.2-L-16-ES	Sucker spp.	Adult	35								35
	Site 229.2-L-16-ES Total			**667**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**667**
	228.5-L-16-ES	Bull Trout	Immature					1		2		3
	228.5-L-16-ES	Bull Trout	Adult					7		4		11
	228.5-L-16-ES	Burbot	Immature					1		2		3
	228.5-L-16-ES	Burbot	Adult					2		2		4
	228.5-L-16-ES	Largescale Sucker	Adult					1		3		4
	228.5-L-16-ES	Longnose Sucker	Adult							2		2
	228.5-L-16-ES	Mountain Whitefish	Immature					57		127		184
	228.5-L-16-ES	Mountain Whitefish	Adult					11		33		44
	228.5-L-16-ES	Northern Pikeminnow	Adult					1		6		7
	228.5-L-16-ES	Prickly Sculpin	All					4				4
	228.5-L-16-ES	Rainbow Trout	Immature					10		1		11
	228.5-L-16-ES	Rainbow Trout	Adult					1		2		3
	228.5-L-16-ES	Redside Shiner	All					6		5		11
	228.5-L-16-ES	Sculpin spp.	All					207		122		329
	228.5-L-16-ES	Sucker spp.	Adult					8		13		21

	Site 228.5-L-16-ES Total			0	0	0	0	317	0	324	0	641

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

Continued…

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

Table B4 Concluded.

Reach	Site[a]	Species	Size Class	Bank Habitat Type[b]								Total
				A1	A3	A4	A5	A6	A1+A2	D1	D2	
	227.2-R-16-ES	Bull Trout	Immature				1					1
	227.2-R-16-ES	Bull Trout	Adult				7					7
	227.2-R-16-ES	Largescale Sucker	Adult				14					14
	227.2-R-16-ES	Longnose Sucker	Adult				1					1
	227.2-R-16-ES	Longnose Sucker	Immature				1					1
	227.2-R-16-ES	Mountain Whitefish	Immature				35					35
	227.2-R-16-ES	Northern Pikeminnow	Immature				1					1
	227.2-R-16-ES	Prickly Sculpin	All				3					3
	227.2-R-16-ES	Rainbow Trout	Immature				20					20
	227.2-R-16-ES	Rainbow Trout	Adult				1					1
	227.2-R-16-ES	Redside Shiner	All				1					1
	227.2-R-16-ES	Sculpin spp.	All				270					270
	227.2-R-16-ES	Slimy Sculpin	All				2					2
	227.2-R-16-ES	Sucker spp.	Adult				32					32
	227.2-R-16-ES	Sucker spp.	Immature				1					1
	Site 227.2-R-16-ES Total			**0**	**0**	**0**	**390**	**0**	**0**	**0**	**0**	**390**
Reach 3 Total				**1426**	**0**	**0**	**431**	**1133**	**0**	**1514**	**0**	**4504**
Grand Total				**2119**	**52**	**100**	**795**	**1795**	**770**	**1874**	**201**	**7706**

[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

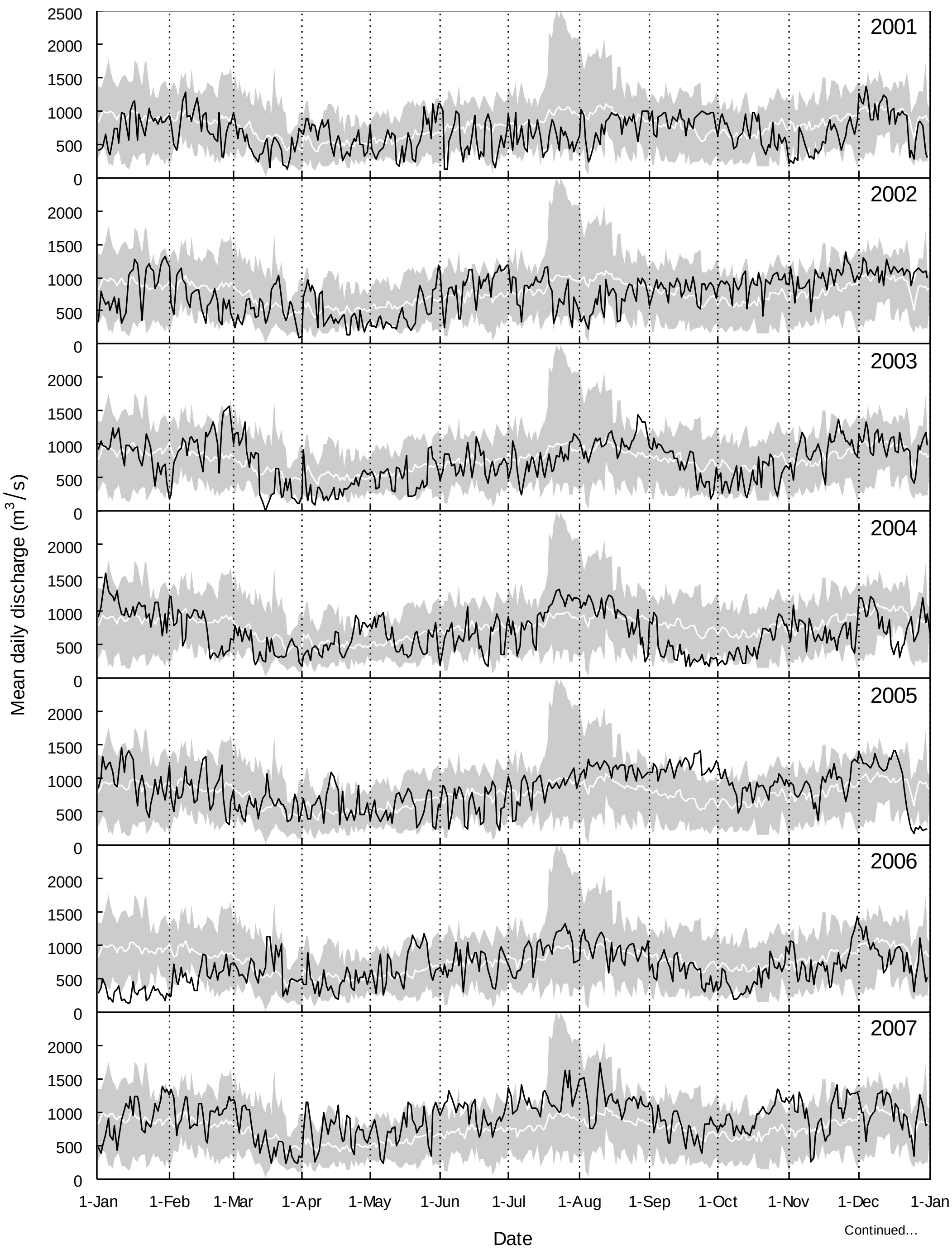


Figure C1 Mean daily discharge (m³/s) for the Columbia River at Revelstoke Dam, 2001 to 2013. The shaded area represents minimum and maximum mean daily discharge values recorded at Revelstoke Dam during other study years (between 2001 and 2013). The white line represents average mean daily discharge values over the same time period.

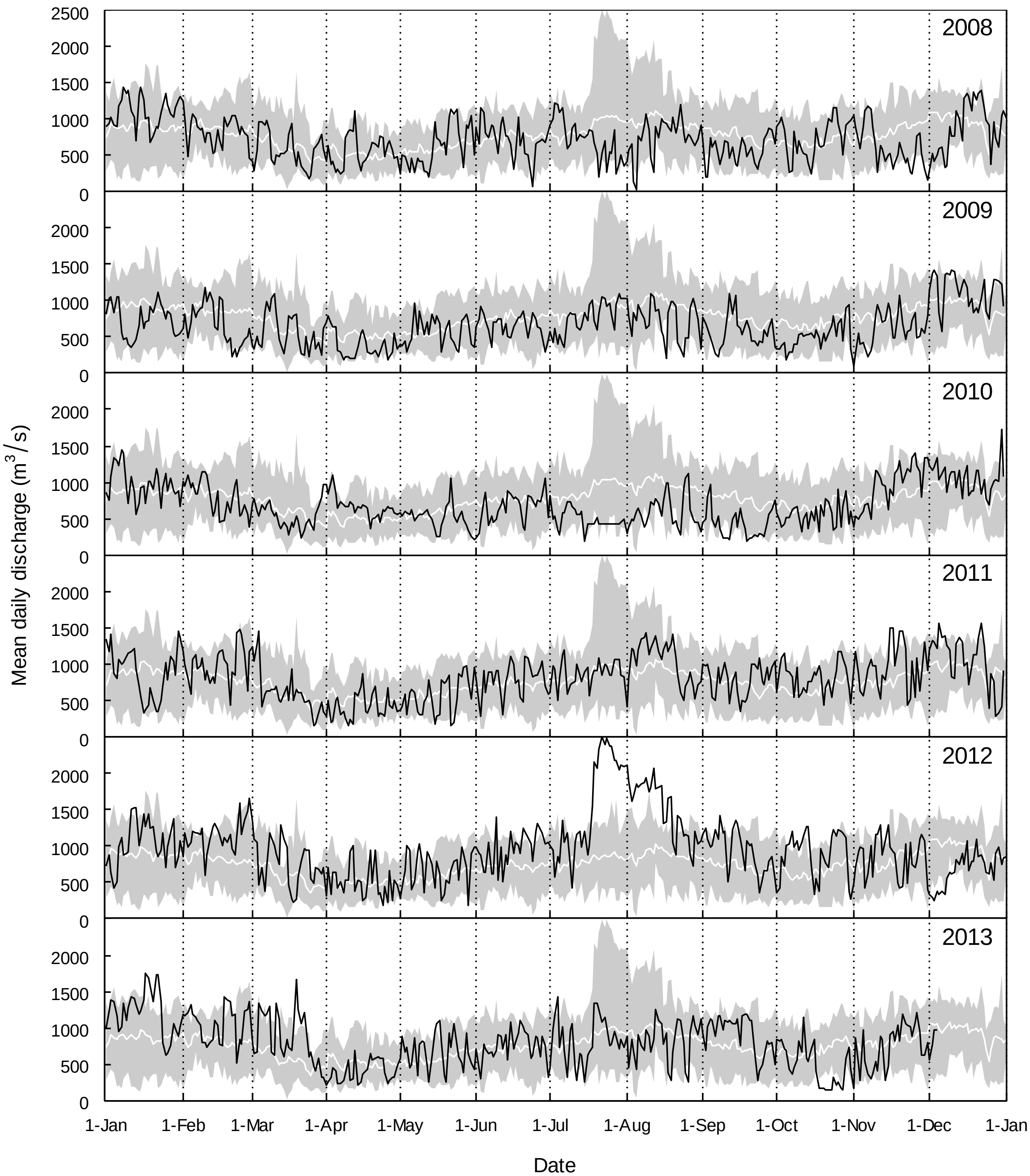


Figure C1 Concluded.

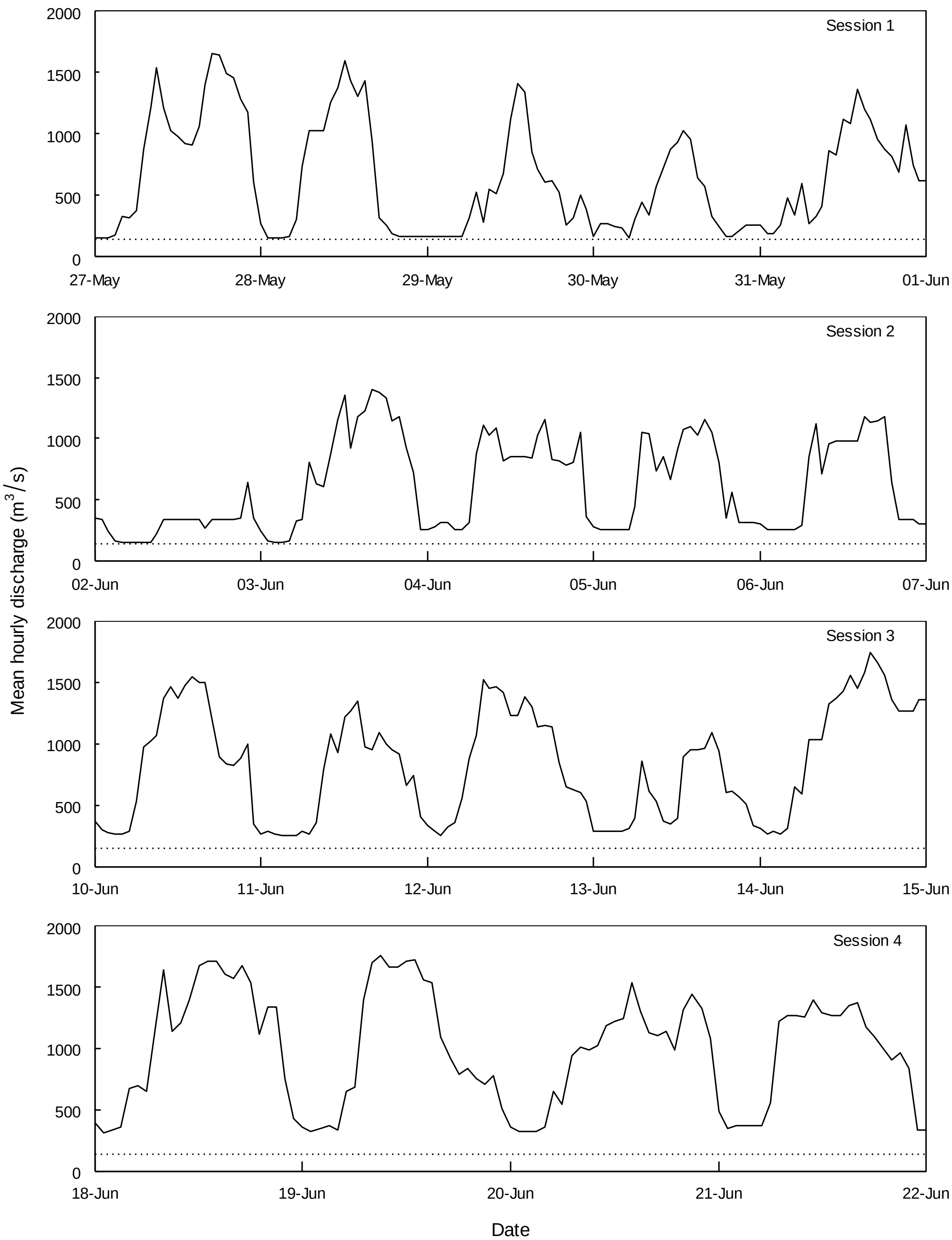


Figure C2 Mean hourly discharge (m^3/s) for the Columbia River at Revelstoke Dam by sample session, May 27 to June 20, 2013. The dotted line denotes the 142 m^3/s minimum flow release.

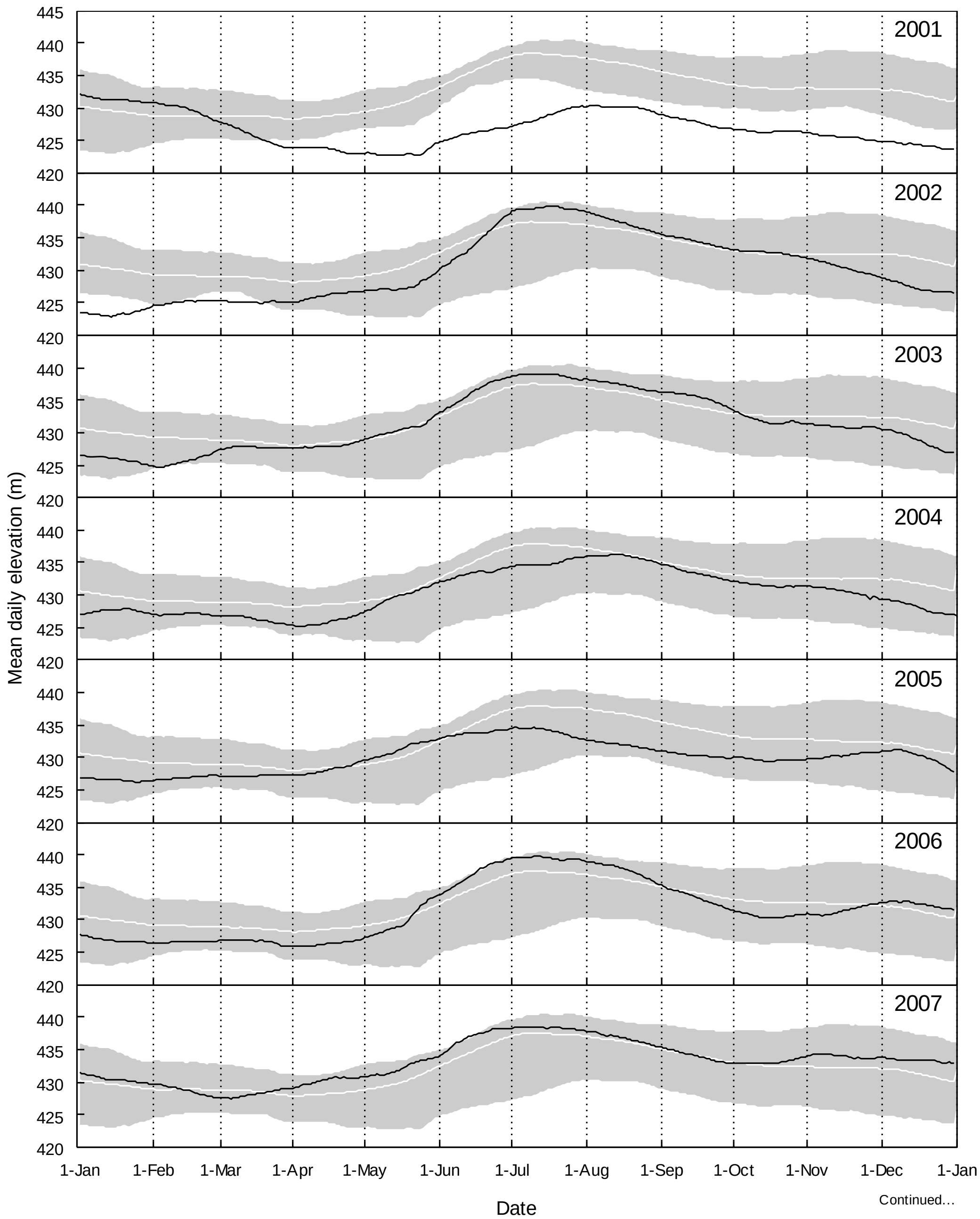


Figure C3 Mean daily water level elevation (in metres above sea level) for the Columbia River at Nakusp, 2001 to 2013. The shaded area represents minimum and maximum mean daily water elevations recorded at Nakusp during other study years (between 2001 and 2013). The white line represents average mean daily water elevation over the same time period.

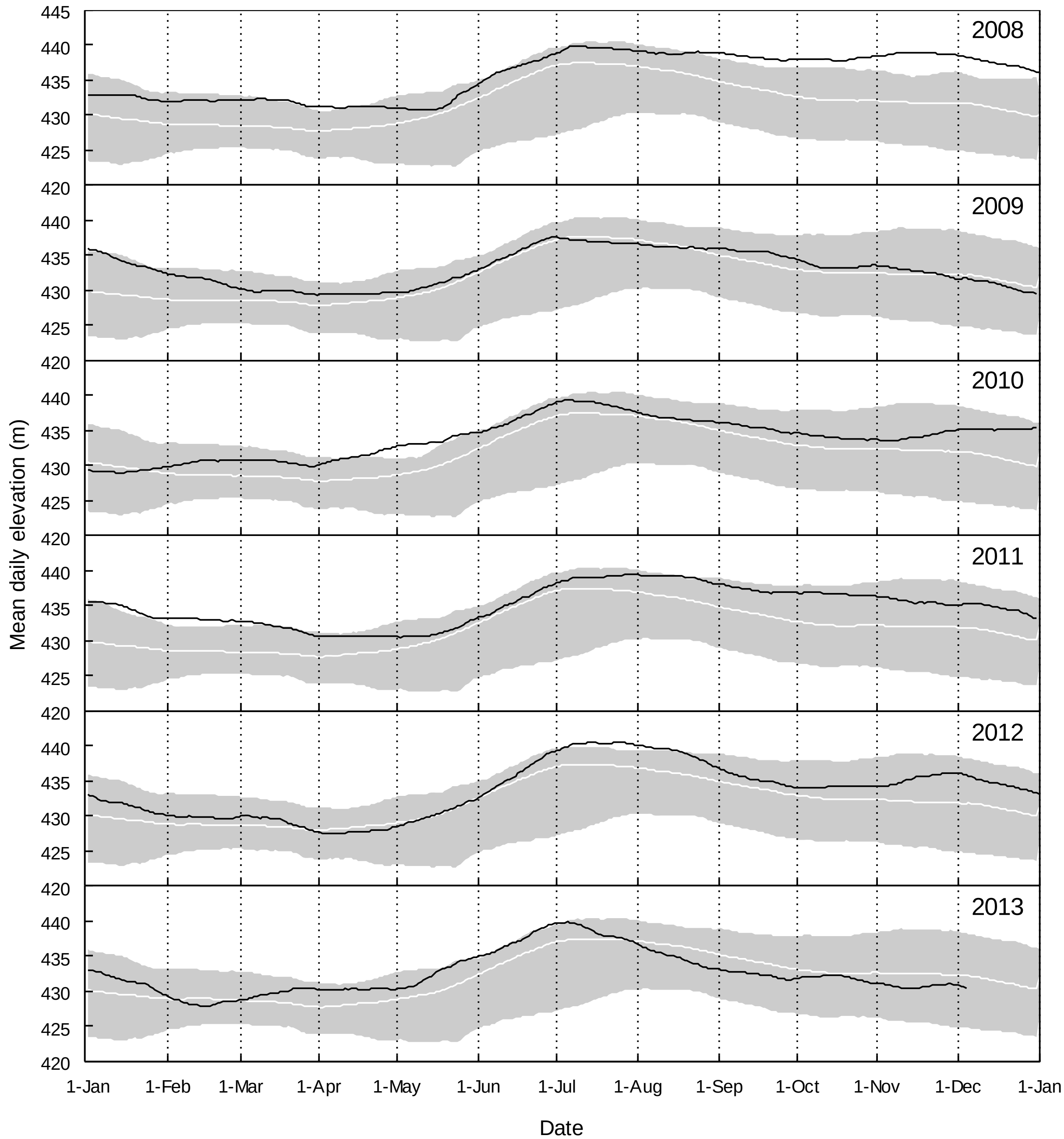


Figure C3 Concluded.

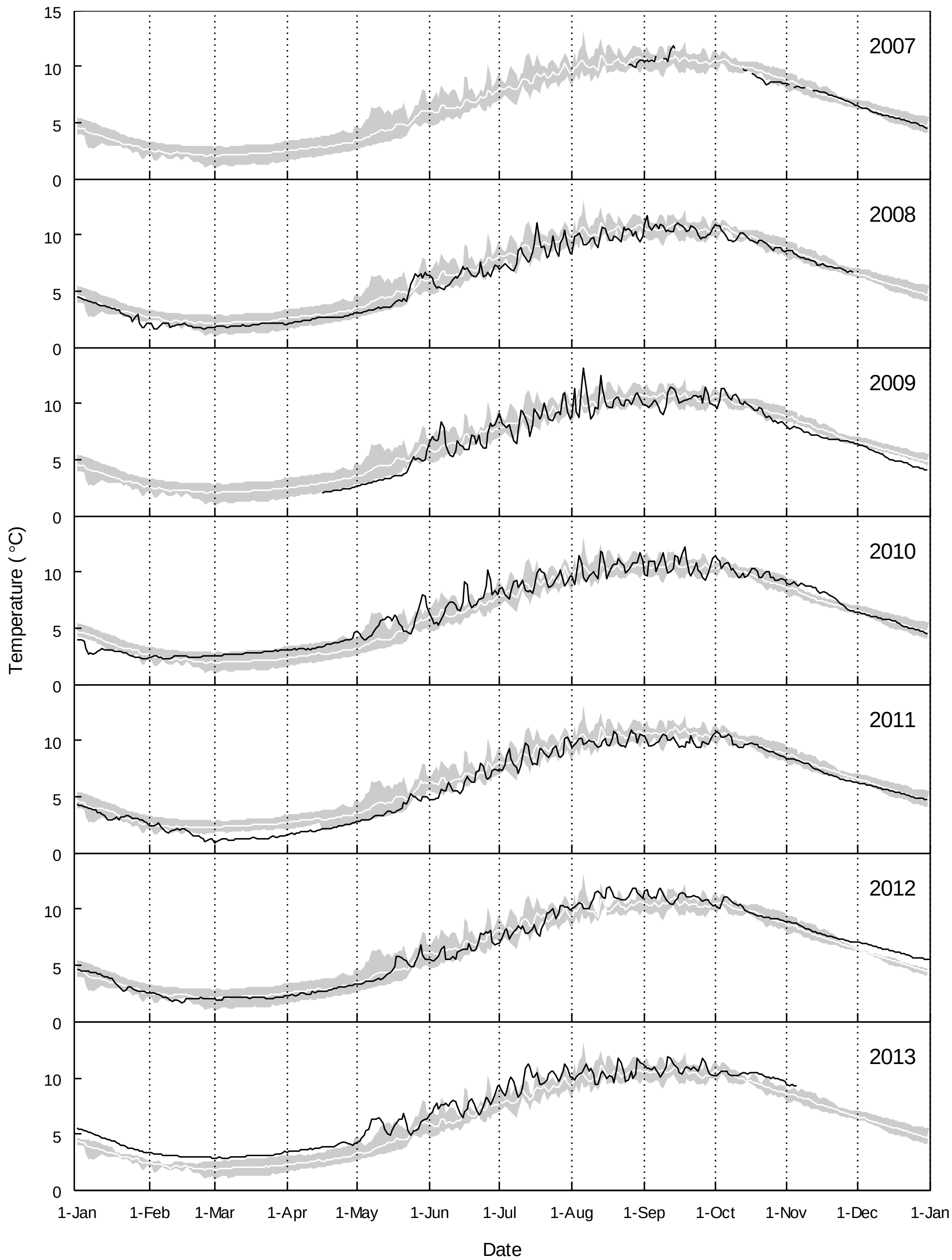


Figure C4 Mean daily water temperature (°C) for the Columbia River at Revelstoke Dam, 2007 to 2013. The shaded area represents minimum and maximum mean daily water temperatures recorded at Revelstoke Dam during other study years (between 2007 and 2013). The white line represents average mean daily water temperature over the same time period. Temperature data are from Station 2 of the Middle Columbia River Physical Habitat Monitoring Program (CLBMON-15a).

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 2012.

	2001[a]		2002[a]		2003[a]		2004[a]		2005[a]		2006[a]		2007[a]		2008[a]		2009[a]		2010[a]		2011[a]		2012[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]
Sportfish																								
Brook Trout					1	<1	1	<1					1	<1					1	<1	3	<1		
Bull Trout	353	3	350	7	413	12	333	9	419	7	346	4	856	3	740	7	567	3	520	2	639	4	489	8
Burbot			7	<1	1	<1	6	<1	14	<1	14	<1	32	<1	61	1	9	<1	22	<1	61	<1	27	
Cutthroat Trout													1	<1					1	<1				
Kokanee	5344	45	48	1	263	8	107	3	1861	31	5874	62	20 602	70	1890	17	17 275	79	18 304	68	8173	53	86	1
Lake Whitefish	6	<1	34	1	53	2	63	2	275	5	60	1	12	<1	42	<1	17	<1	983	4	230	2	92	2
Mountain Whitefish	6279	52	4361	91	2685	78	3317	86	3475	57	3115	33	7811	27	8165	72	3936	18	6688	25	5987	39	5025	87
Pygmy Whitefish			1	<1																				
Rainbow Trout	5	<1			5	<1	13	<1	11	<1	13	<1	151	1	296	3	48	<1	111	<1	212	1	67	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	
Sportfish subtotal	11 988	100	4801	100	3421	100	3848	100	6057	100	9425	100	29 475	100	11 328	100	21 854	100	26 734	100	15 307	100	5788	100
Non-sportfish																								
Northern Pikeminnow					1	<1	2	<1	3	<1	2	<1	35	1	78	1	62	4	52	2	38	1	17	1
Peamouth											1	<1	1	<1			1	<1			1	<1		
Redside Shiner			11	6	1	<1	239	26	246	29	97	8	553	18	2050	26	146	10	976	33	237	8	286	9
Sculpin spp.[e]	1	<1	7	4	4	2	268	30	179	21	849	67	1387	45	4801	62	469	31	772	26	1807	60	1010	32
Sucker spp.[e]	419	100	170	90	206	97	393	44	426	50	318	25	1088	36	845	11	818	55	1150	39	953	31	1819	58
Non-sportfish subtotal	420	100	188	100	212	100	902	100	854	100	1267	100	3064	100	7774	100	1496	100	2950	100	3036	100	3132	100
All species	12 408		4989		3633		4750		6911		10 692		32 539		19 102		23 350		29 684		18 343		8920	

[a] From 2001 to 2006, the study area included all of Reach 4 and the Big Eddy section of Reach; from 2007 to 2010 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 Number of fish caught and observed during boat electroshocking surveys conducted during the spring season and their frequency of occurrence in sampled sections of the Middle Columbia River, 2011 to 2013.

	2011		2012		2013	
Species	n^a	%[b]	n^a	%[b]	n^a	%[b]
Sportfish						
Brook Trout	5	<1	1	<1	1	
Bull Trout	661	7	641	10	340	7
Burbot	30	<1	6	<1	26	1
Cutthroat Trout			1	<1		
Kokanee	26	<1	14	<1	4	
Lake Whitefish	1	<1	1	<1		
Mountain Whitefish	8568	90	5971	89	4326	90
Rainbow Trout	198	2	56	1	99	2
Yellow Perch	1	<1				
Sportfish subtotal	9490	100	6691	100	4796	100
Non-sportfish						
Northern Pikeminnow	5	<1			8	
Peamouth	30	1	3	<1	9	
Redside Shiner	170	5	10	1	108	4
Sculpin spp.[c]	1883	57	445	28	1828	65
Sucker spp.[c]	1231	37	1125	71	842	30
Non-sportfish subtotal	3319	100	1583	100	2795	100
All species	12 809		8274		7591	

[a] Includes fish observed and identified to species.
[b] Percent composition of sportfish or non-sportfish catch.
[c] Species combined for table or not identified to species.

Table D3 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 spring season in the Middle Columbia River, 27 May to 20 June 2013.

Reach	Section	Session	Site	Date	Time Sampled (s)	Length Sampled (km)	Number Caught (CPUE=no. fish/km/hr)													
							Brook Trout		Bull Trout		Burbot		Kokanee		Mountain Whitefish		Rainbow Trout		All Species	
							No.	*CPUE*	No.	*CPUE*	No.	*CPUE*	No.	*CPUE*	No.	*CPUE*	No.	*CPUE*	No.	*CPUE*
4	Upper																			
		1	232.6-R	28-May-13	577	0.80	0	*0.00*	1	*7.80*	0	*0.00*	0	*0.00*	18	*140.38*	1	*7.80*	**20**	***155.98***
			233.1-L	29-May-13	834	1.41	0	*0.00*	12	*36.74*	0	*0.00*	0	*0.00*	82	*251.03*	0	*0.00*	**94**	***287.77***
			234.4-R	29-May-13	885	1.74	0	*0.00*	9	*21.04*	0	*0.00*	0	*0.00*	57	*133.26*	0	*0.00*	**66**	***154.30***
			234.5-L	28-May-13	1110	1.65	0	*0.00*	7	*13.76*	0	*0.00*	0	*0.00*	152	*298.77*	3	*5.90*	**162**	***318.43***
			236.1-L	29-May-13	863	0.48	0	*0.00*	16	*139.05*	0	*0.00*	0	*0.00*	47	*408.46*	0	*0.00*	**63**	***547.51***
			236.1-R	27-May-13	785	1.73	0	*0.00*	8	*21.21*	0	*0.00*	0	*0.00*	61	*161.70*	3	*7.95*	**72**	***190.86***
			236.4-L	27-May-13	343	0.58	0	*0.00*	0	*0.00*	0	*0.00*	0	*0.00*	11	*199.05*	0	*0.00*	**11**	***199.05***
			236.4-R	29-May-13	212	0.59	0	*0.00*	2	*57.56*	0	*0.00*	0	*0.00*	34	*978.57*	0	*0.00*	**36**	***1036.14***
		Session Summary			**701**	**9.0**	**0**	***0.00***	**55**	***31.45***	**0**	***0.00***	**0**	***0.00***	**462**	***264.16***	**7**	***4.00***	**524**	***299.61***
		2	232.6-R	04-Jun-13	672	0.80	0	*0.00*	8	*53.57*	1	*6.70*	0	*0.00*	43	*287.95*	0	*0.00*	**52**	***348.21***
			233.1-L	05-Jun-13	833	1.29	0	*0.00*	3	*10.05*	0	*0.00*	0	*0.00*	58	*194.31*	1	*3.35*	**62**	***207.71***
			234.4-R	03-Jun-13	1017	1.74	0	*0.00*	9	*18.31*	2	*4.07*	0	*0.00*	57	*115.96*	0	*0.00*	**68**	***138.34***
			234.5-L	03-Jun-13	1067	1.65	0	*0.00*	3	*6.13*	0	*0.00*	0	*0.00*	49	*100.20*	1	*2.04*	**53**	***108.38***
			236.1-L	03-Jun-13	986	0.48	0	*0.00*	18	*136.92*	0	*0.00*	0	*0.00*	72	*547.67*	0	*0.00*	**90**	***684.58***
			236.1-R	02-Jun-13	1271	1.73	0	*0.00*	6	*9.82*	0	*0.00*	0	*0.00*	101	*165.36*	2	*3.27*	**109**	***178.46***
			236.4-L	02-Jun-13	370	0.58	0	*0.00*	1	*16.78*	0	*0.00*	0	*0.00*	13	*218.08*	0	*0.00*	**14**	***234.86***
			236.4-R	02-Jun-13	284	0.59	0	*0.00*	1	*21.48*	0	*0.00*	0	*0.00*	19	*408.21*	0	*0.00*	**20**	***429.70***
		Session Summary			**813**	**8.9**	**0**	***0.00***	**49**	***24.50***	**3**	***1.50***	**0**	***0.00***	**412**	***206.04***	**4**	***2.00***	**468**	***234.04***
		3	232.6-R	11-Jun-13	448	0.80	0	*0.00*	2	*20.09*	0	*0.00*	0	*0.00*	18	*180.80*	0	*0.00*	**20**	***200.89***
			233.1-L	13-Jun-13	879	1.41	0	*0.00*	8	*23.24*	0	*0.00*	0	*0.00*	65	*188.80*	2	*5.81*	**75**	***217.85***
			234.4-R	12-Jun-13	896	1.74	0	*0.00*	3	*6.93*	2	*4.62*	0	*0.00*	77	*177.80*	0	*0.00*	**82**	***189.35***
			234.5-L	12-Jun-13	1065	1.65	0	*0.00*	4	*8.19*	0	*0.00*	0	*0.00*	69	*141.36*	2	*4.10*	**75**	***153.65***
			236.1-L	10-Jun-13	853	0.48	0	*0.00*	7	*61.55*	0	*0.00*	0	*0.00*	55	*483.59*	2	*17.58*	**64**	***562.72***
			236.1-R	11-Jun-13	1239	1.73	0	*0.00*	24	*40.31*	0	*0.00*	1	*1.68*	423	*710.44*	0	*0.00*	**448**	***752.42***
			236.4-L	10-Jun-13	213	0.58	0	*0.00*	1	*29.14*	0	*0.00*	0	*0.00*	14	*407.97*	0	*0.00*	**15**	***437.11***
			236.4-R	10-Jun-13	305	0.59	0	*0.00*	2	*40.01*	0	*0.00*	1	*20.01*	70	*1400.39*	0	*0.00*	**73**	***1460.41***
		Session Summary			**737**	**9.0**	**0**	***0.00***	**51**	***27.73***	**2**	***1.09***	**2**	***1.09***	**791**	***430.12***	**6**	***3.26***	**852**	***463.29***
		4	232.6-R	20-Jun-13	456	0.80	0	*0.00*	3	*29.61*	0	*0.00*	0	*0.00*	29	*286.18*	0	*0.00*	**32**	***315.79***
			233.1-L	20-Jun-13	1232	1.41	0	*0.00*	7	*14.51*	3	*6.22*	0	*0.00*	73	*151.28*	1	*2.07*	**84**	***174.08***
			234.4-R	20-Jun-13	1210	1.74	0	*0.00*	9	*15.39*	0	*0.00*	0	*0.00*	98	*167.57*	0	*0.00*	**107**	***182.96***
			234.5-L	19-Jun-13	680	1.65	0	*0.00*	3	*9.63*	0	*0.00*	0	*0.00*	109	*349.73*	0	*0.00*	**112**	***359.36***
			236.1-L	18-Jun-13	1053	0.48	0	*0.00*	10	*71.23*	0	*0.00*	0	*0.00*	47	*334.76*	0	*0.00*	**57**	***405.98***
			236.1-R	19-Jun-13	1197	1.73	0	*0.00*	15	*26.08*	0	*0.00*	0	*0.00*	223	*387.67*	1	*1.74*	**239**	***415.49***
			236.4-L	18-Jun-13	399	0.58	0	*0.00*	9	*140.01*	0	*0.00*	0	*0.00*	20	*311.12*	0	*0.00*	**29**	***451.13***
			236.4-R	18-Jun-13	333	0.59	0	*0.00*	1	*18.32*	0	*0.00*	0	*0.00*	31	*568.03*	1	*18.32*	**33**	***604.67***
		Session Summary			**820**	**9.0**	**0**	***0.00***	**57**	***27.87***	**3**	***1.47***	**0**	***0.00***	**630**	***308.00***	**3**	***1.47***	**693**	***338.80***
	Upper Section Total All Samples				**24567**	**35.80**	**0**		**212**		**8**		**2**		**2295**		**20**		**2537**	
	Upper Section Average All Samples				**768**	**1.12**	**0**	***0.00***	**7**	***27.77***	**0**	***1.05***	**0**	***0.26***	**72**	***300.61***	**1**	***2.62***	**79**	***378.25***
	Upper Section Standard Error of Mean						**0.00**	***0.00***	**1.00**	***6.70***	**0.13**	***0.33***	**0.04**	***0.63***	**13.69**	***48.21***	**0.17**	***0.83***	**14.44**	***51.12***

Table D3 Continued.

Reach	Section	Session	Site	Date	Time Sampled (s)	Length Sampled (km)	Number Caught (CPUE=no. fish/km/hr)													
							Brook Trout		Bull Trout		Burbot		Kokanee		Mountain Whitefish		Rainbow Trout		All Species	
							No.	*CPUE*	No.	*CPUE*	No.	*CPUE*	No.	*CPUE*	No.	*CPUE*	No.	*CPUE*	No.	*CPUE*
3	Eddy																			
		1	231.3-R	28-May-13	951	0.90	1	*4.21*	1	*4.21*	0	*0.00*	0	*0.00*	32	*134.60*	6	*25.24*	**40**	***168.24***
		Session Summary			**951**	**0.9**	**1**	***4.21***	**1**	***4.21***	**0**	***0.00***	**0**	***0.00***	**32**	***134.60***	**6**	***25.24***	**40**	***168.24***
		2	231.3-R	04-Jun-13	1060	0.90	0	*0.00*	15	*56.60*	1	*3.77*	0	*0.00*	156	*588.68*	4	*15.09*	**176**	***664.15***
		Session Summary			**1060**	**0.9**	**0**	***0.00***	**15**	***56.60***	**1**	***3.77***	**0**	***0.00***	**156**	***588.68***	**4**	***15.09***	**176**	***664.15***
		3	231.3-R	11-Jun-13	1320	0.90	0	*0.00*	3	*9.09*	0	*0.00*	1	*3.03*	61	*184.85*	5	*15.15*	**70**	***212.12***
		Session Summary			**1320**	**0.9**	**0**	***0.00***	**3**	***9.09***	**0**	***0.00***	**1**	***3.03***	**61**	***184.85***	**5**	***15.15***	**70**	***212.12***
		4	231.3-R	18-Jun-13	884	0.90	0	*0.00*	6	*27.15*	0	*0.00*	0	*0.00*	82	*371.04*	1	*4.52*	**89**	***402.71***
		Session Summary			**884**	**0.9**	**0**	***0.00***	**6**	***27.15***	**0**	***0.00***	**0**	***0.00***	**82**	***371.04***	**1**	***4.52***	**89**	***402.71***
	Eddy Section Total All Samples				**4215**	**3.60**	**1**		**25**		**1**		**1**		**331**		**16**		**375**	
	Eddy Section Average All Samples				**1054**	**0.90**	**0**	***0.95***	**6**	***23.72***	**0**	***0.95***	**0**	***0.95***	**83**	***314.12***	**4**	***15.18***	**94**	***361.81***
	Eddy Section Standard Error of Mean						**0.25**	***1.05***	**3.09**	***11.86***	**0.25**	***0.94***	**0.25**	***0.76***	**26.48**	***103.05***	**1.08**	***4.23***	**29.21**	***112.90***
3	Middle																			
		1	227.2-R	30-May-13	512	0.52	0	*0.00*	2	*27.04*	0	*0.00*	0	*0.00*	21	*283.95*	4	*54.09*	**27**	***365.08***
			228.5-L	29-May-13	1107	1.23	0	*0.00*	2	*5.29*	0	*0.00*	0	*0.00*	90	*237.95*	8	*21.15*	**100**	***264.39***
			229.2-L	29-May-13	1087	1.10	0	*0.00*	3	*9.03*	0	*0.00*	0	*0.00*	103	*310.11*	3	*9.03*	**109**	***328.18***
			229.7-R	30-May-13	1152	0.99	0	*0.00*	3	*9.47*	0	*0.00*	0	*0.00*	43	*135.73*	0	*0.00*	**46**	***145.20***
			231.0-L	28-May-13	1181	1.96	0	*0.00*	10	*15.55*	0	*0.00*	1	*1.56*	162	*251.95*	7	*10.89*	**180**	***279.94***
			231.0-R	31-May-13	709	1.19	0	*0.00*	0	*0.00*	0	*0.00*	0	*0.00*	132	*561.81*	0	*0.00*	**132**	***561.81***
		Session Summary			**958**	**7.0**	**0**	***0.00***	**20**	***10.75***	**0**	***0.00***	**1**	***0.54***	**551**	***296.09***	**22**	***11.82***	**594**	***319.20***
		2	227.2-R	05-Jun-13	457	0.52	0	*0.00*	4	*60.60*	0	*0.00*	0	*0.00*	5	*75.74*	2	*30.30*	**11**	***166.64***
			228.5-L	05-Jun-13	1044	1.23	0	*0.00*	7	*19.62*	1	*2.80*	0	*0.00*	92	*257.92*	3	*8.41*	**103**	***288.76***
			229.2-L	06-Jun-13	1033	1.10	0	*0.00*	1	*3.17*	3	*9.50*	0	*0.00*	92	*291.47*	2	*6.34*	**98**	***310.48***
			229.7-R	04-Jun-13	1146	1.42	0	*0.00*	15	*33.18*	0	*0.00*	0	*0.00*	178	*393.78*	1	*2.21*	**194**	***429.17***
			231.0-L	05-Jun-13	1100	1.96	0	*0.00*	8	*13.36*	1	*1.67*	0	*0.00*	145	*242.12*	10	*16.70*	**164**	***273.84***
			231.0-R	04-Jun-13	666	1.15	0	*0.00*	4	*18.75*	0	*0.00*	0	*0.00*	55	*257.85*	1	*4.69*	**60**	***281.29***
		Session Summary			**908**	**7.4**	**0**	***0.00***	**39**	***20.95***	**5**	***2.69***	**0**	***0.00***	**567**	***304.60***	**19**	***10.21***	**630**	***338.44***
		3	227.2-R	13-Jun-13	471	0.52	0	*0.00*	1	*14.70*	0	*0.00*	0	*0.00*	3	*44.10*	15	*220.48*	**19**	***279.27***
			228.5-L	14-Jun-13	1215	1.23	0	*0.00*	3	*7.23*	3	*7.23*	0	*0.00*	23	*55.40*	3	*7.23*	**32**	***77.09***
			229.2-L	12-Jun-13	1254	1.10	0	*0.00*	2	*5.22*	0	*0.00*	0	*0.00*	67	*174.86*	1	*2.61*	**70**	***182.69***
			229.7-R	13-Jun-13	2080	2.27	0	*0.00*	11	*8.39*	0	*0.00*	0	*0.00*	75	*57.18*	1	*0.76*	**87**	***66.33***
			231.0-L	12-Jun-13	1285	1.96	0	*0.00*	7	*10.01*	3	*4.29*	0	*0.00*	129	*184.39*	3	*4.29*	**142**	***202.97***
			231.0-R	13-Jun-13	881	1.19	0	*0.00*	11	*37.77*	0	*0.00*	0	*0.00*	118	*405.19*	1	*3.43*	**130**	***446.40***
		Session Summary			**1198**	**8.3**	**0**	***0.00***	**35**	***12.72***	**6**	***2.18***	**0**	***0.00***	**415**	***150.84***	**24**	***8.72***	**480**	***174.46***
		4	227.2-R	21-Jun-13	414	0.52	0	*0.00*	1	*16.72*	0	*0.00*	0	*0.00*	6	*100.33*	0	*0.00*	**7**	***117.06***
			228.5-L	21-Jun-13	1045	1.23	0	*0.00*	2	*5.60*	3	*8.40*	0	*0.00*	23	*64.42*	0	*0.00*	**28**	***78.42***
			229.2-L	21-Jun-13	1045	1.10	0	*0.00*	0	*0.00*	0	*0.00*	0	*0.00*	32	*100.22*	1	*3.13*	**33**	***103.35***
			229.7-R	20-Jun-13	1828	2.27	0	*0.00*	8	*6.94*	0	*0.00*	0	*0.00*	69	*59.86*	0	*0.00*	**77**	***66.80***
			231.0-L	19-Jun-13	1819	1.96	0	*0.00*	7	*7.07*	2	*2.02*	0	*0.00*	111	*112.08*	4	*4.04*	**124**	***125.21***
			231.0-R	18-Jun-13	974	1.19	0	*0.00*	1	*3.11*	1	*3.11*	0	*0.00*	22	*68.33*	0	*0.00*	**24**	***74.54***
		Session Summary			**1188**	**8.3**	**0**	***0.00***	**19**	***6.96***	**6**	***2.20***	**0**	***0.00***	**263**	***96.41***	**5**	***1.83***	**293**	***107.41***
	Middle Section Total All Samples				**25505**	**30.92**	**0**		**113**		**17**		**1**		**1796**		**70**		**1997**	
	Middle Section Average All Samples				**1063**	**1.29**	**0**	***0.00***	**5**	***12.38***	**1**	***1.86***	**0**	***0.11***	**75**	***196.79***	**3**	***7.67***	**83**	***229.79***
	Middle Section Standard Error of Mean						**0.00**	***0.00***	**0.84**	***2.83***	**0.24**	***0.59***	**0.04**	***0.06***	**10.71**	***27.57***	**0.76**	***9.19***	**11.39**	***27.68***
All Sections Total All Samples					**54287**	**70.32**	**1**	***0.00***	**350**	***0.33***	**26**	***0.02***	**4**	***0.00***	**4422**	***4.17***	**106**	***0.10***	**4909**	***4.63***
All Sections Average All Samples							**0**	***0.06***	**6**	***19.80***	**0**	***1.47***	**0**	***0.23***	**74**	***250.22***	**2**	***6.00***	**82**	***277.78***
All Sections Standard Error of Mean							**0.02**	***0.07***	**0.66**	***4.01***	**0.12**	***0.30***	**0.03**	***0.34***	**8.54**	***29.77***	**0.36**	***3.78***	**9.04**	***31.35***

Table D4 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 spring season in the Middle Columbia River, 27 May to 20 June 2013.

Reach	Section	Session	Site	Date	Time Sampled (seconds)	Length Sampled (km)	Number Caught (CPUE=no. fish/km/h)											
							Northern Pikeminnow		Peamouth		Redside Shiner		Sculpin spp.		Sucker spp.		All Species	
							No.	*CPUE*	No.	*CPUE*	No.	*CPUE*	No.	*CPUE*	No.	*CPUE*	No.	*CPUE*
4	Upper																	
		1	232.6-R	28-May-13	577	0.80	0	*0.00*	0	*0.00*	0	*0.00*	0	*0.00*	11	*85.79*	11	*85.79*
			233.1-L	29-May-13	834	1.41	0	*0.00*	0	*0.00*	0	*0.00*	15	*45.92*	8	*24.49*	23	*70.41*
			234.4-R	29-May-13	885	1.74	0	*0.00*	0	*0.00*	0	*0.00*	1	*2.34*	8	*18.70*	9	*21.04*
			234.5-L	28-May-13	1110	1.65	0	*0.00*	0	*0.00*	0	*0.00*	2	*3.93*	1	*1.97*	3	*5.90*
			236.1-L	29-May-13	863	0.48	0	*0.00*	0	*0.00*	0	*0.00*	5	*43.45*	17	*147.74*	22	*191.19*
			236.1-R	27-May-13	785	1.73	0	*0.00*	0	*0.00*	0	*0.00*	1	*2.65*	5	*13.25*	6	*15.91*
			236.4-R	29-May-13	212	0.59	0	*0.00*	0	*0.00*	0	*0.00*	5	*143.91*	0	*0.00*	5	*143.91*
		Session 1 Summary			**752**	**8.40**	**0**	***0.00***	**0**	***0.00***	**0**	***0.00***	**29**	***16.52***	**50**	***28.48***	**79**	***45.01***
		2	232.6-R	04-Jun-13	672	0.80	0	*0.00*	0	*0.00*	0	*0.00*	0	*0.00*	67	*448.66*	67	*448.66*
			233.1-L	05-Jun-13	833	1.29	0	*0.00*	0	*0.00*	0	*0.00*	6	*20.10*	5	*16.75*	11	*36.85*
			234.4-R	03-Jun-13	1017	1.74	0	*0.00*	0	*0.00*	1	*2.03*	49	*99.68*	8	*16.28*	58	*117.99*
			234.5-L	03-Jun-13	1067	1.65	0	*0.00*	0	*0.00*	0	*0.00*	14	*28.63*	1	*2.04*	15	*30.67*
			236.1-L	03-Jun-13	986	0.48	0	*0.00*	0	*0.00*	0	*0.00*	11	*83.67*	4	*30.43*	15	*114.10*
			236.1-R	02-Jun-13	1271	1.73	0	*0.00*	0	*0.00*	1	*1.64*	46	*75.31*	4	*6.55*	51	*83.50*
			236.4-L	02-Jun-13	370	0.58	0	*0.00*	0	*0.00*	0	*0.00*	10	*167.75*	0	*0.00*	10	*167.75*
			236.4-R	02-Jun-13	284	0.59	0	*0.00*	0	*0.00*	0	*0.00*	5	*107.42*	2	*42.97*	7	*150.39*
		Session 2 Summary			**813**	**8.86**	**0**	***0.00***	**0**	***0.00***	**2**	***1.00***	**141**	***70.51***	**91**	***45.51***	**234**	***117.02***
		3	232.6-R	11-Jun-13	448	0.80	0	*0.00*	0	*0.00*	0	*0.00*	0	*0.00*	29	*291.29*	29	*291.29*
			233.1-L	13-Jun-13	879	1.41	0	*0.00*	0	*0.00*	0	*0.00*	14	*40.67*	6	*17.43*	20	*58.09*
			234.4-R	12-Jun-13	896	1.74	0	*0.00*	0	*0.00*	0	*0.00*	3	*6.93*	5	*11.55*	8	*18.47*
			234.5-L	12-Jun-13	1065	1.65	0	*0.00*	3	*6.15*	0	*0.00*	22	*45.07*	0	*0.00*	25	*51.22*
			236.1-L	10-Jun-13	853	0.48	0	*0.00*	0	*0.00*	0	*0.00*	1	*8.79*	23	*202.23*	24	*211.02*
			236.1-R	11-Jun-13	1239	1.73	0	*0.00*	0	*0.00*	0	*0.00*	0	*0.00*	10	*16.80*	10	*16.80*
			236.4-L	10-Jun-13	213	0.58	0	*0.00*	0	*0.00*	0	*0.00*	0	*0.00*	3	*87.42*	3	*87.42*
			236.4-R	10-Jun-13	305	0.59	0	*0.00*	0	*0.00*	0	*0.00*	0	*0.00*	16	*320.09*	16	*320.09*
		Session 3 Summary			**737**	**8.98**	**0**	***0.00***	**3**	***1.63***	**0**	***0.00***	**40**	***21.75***	**92**	***50.03***	**135**	***73.41***
		4	232.6-R	20-Jun-13	456	0.80	0	*0.00*	0	*0.00*	0	*0.00*	0	*0.00*	8	*78.95*	8	*78.95*
			233.1-L	20-Jun-13	1232	1.41	0	*0.00*	1	*2.07*	1	*2.07*	109	*225.89*	3	*6.22*	114	*236.25*
			234.4-R	20-Jun-13	1210	1.74	0	*0.00*	0	*0.00*	0	*0.00*	5	*8.55*	6	*10.26*	11	*18.81*
			234.5-L	19-Jun-13	680	1.65	0	*0.00*	1	*3.21*	0	*0.00*	15	*48.13*	5	*16.04*	21	*67.38*
			236.1-L	18-Jun-13	1053	0.48	0	*0.00*	0	*0.00*	0	*0.00*	34	*242.17*	8	*56.98*	42	*299.15*
			236.1-R	19-Jun-13	1197	1.73	0	*0.00*	0	*0.00*	0	*0.00*	7	*12.17*	7	*12.17*	14	*24.34*
			236.4-L	18-Jun-13	399	0.58	0	*0.00*	0	*0.00*	0	*0.00*	0	*0.00*	7	*108.89*	7	*108.89*
		Session 4 Summary			**890**	**8.39**	**0**	***0.00***	**2**	***0.96***	**1**	***0.48***	**170**	***82.00***	**44**	***21.22***	**217**	***104.67***
	Upper Section Total All Samples				**23891**	**34.63**	**0**		**5**		**3**		**380**		**277**		**665**	
	Upper Section Average All Samples				**796**	**1.15**	**0**	***0.00***	**0**	***0.65***	**0**	***0.39***	**13**	***49.60***	**9**	***36.16***	**22**	***86.81***
	Upper Section Standard Error of Mean						**0.00**	***0.00***	**0.11**	***0.23***	**0.06**	***0.11***	**4.08**	***12.36***	**2.33**	***19.99***	**4.32**	***20.01***
3	Eddy																	
		1	231.3-R	28-May-13	951	0.90	0	*0.00*	0	*0.00*	27	*113.56*	111	*466.88*	1	*4.21*	139	*584.65*
		Session 1 Summary			**951**	**0.90**	**0**	***0.00***	**0**	***0.00***	**27**	***113.56***	**111**	***466.88***	**1**	***4.21***	**139**	***584.65***
		2	231.3-R	04-Jun-13	1060	0.90	0	*0.00*	0	*0.00*	29	*109.43*	175	*660.38*	28	*105.66*	232	*875.47*
		Session 2 Summary			**1060**	**0.90**	**0**	***0.00***	**0**	***0.00***	**29**	***109.43***	**175**	***660.38***	**28**	***105.66***	**232**	***875.47***
		3	231.3-R	11-Jun-13	1320	0.90	0	*0.00*	0	*0.00*	1	*3.03*	4	*12.12*	7	*21.21*	12	*36.36*
		Session 3 Summary			**1320**	**0.90**	**0**	***0.00***	**0**	***0.00***	**1**	***3.03***	**4**	***12.12***	**7**	***21.21***	**12**	***36.36***
		4	231.3-R	18-Jun-13	884	0.90	0	*0.00*	0	*0.00*	3	*13.57*	5	*22.62*	6	*27.15*	14	*63.35*
		Session 4 Summary			**884**	**0.90**	**0**	***0.00***	**0**	***0.00***	**3**	***13.57***	**5**	***22.62***	**6**	***27.15***	**14**	***63.35***
	Eddy Section Total All Samples				**4215**	**3.60**	**0**		**0**		**60**		**295**		**42**		**397**	
	Eddy Section Average All Samples				**1054**	**0.90**	**0**	***0.00***	**0**	***0.00***	**15**	***56.94***	**74**	***279.95***	**11**	***39.86***	**99**	***376.75***
	Eddy Section Standard Error of Mean						**0.00**	***0.00***	**0.00**	***0.00***	**7.53**	***29.88***	**42.06**	***162.58***	**5.98**	***22.56***	**53.29**	***205.21***
3	Middle																	
		1	227.2-R	30-May-13	512	0.52	0	*0.00*	0	*0.00*	0	*0.00*	118	*1595.55*	16	*216.35*	134	*1811.90*
			228.5-L	29-May-13	1107	1.23	0	*0.00*	0	*0.00*	5	*13.22*	179	*473.26*	13	*34.37*	197	*520.85*
			229.2-L	29-May-13	1087	1.10	0	*0.00*	0	*0.00*	2	*6.02*	215	*647.32*	8	*24.09*	225	*677.43*
			229.7-R	30-May-13	1152	0.99	0	*0.00*	0	*0.00*	0	*0.00*	42	*132.58*	26	*82.07*	68	*214.65*
			231.0-L	28-May-13	1181	1.96	0	*0.00*	0	*0.00*	0	*0.00*	40	*62.21*	45	*69.99*	85	*132.20*
			231.0-R	31-May-13	709	1.19	0	*0.00*	0	*0.00*	0	*0.00*	2	*8.51*	20	*85.12*	22	*93.64*
		Session 1 Summary			**958**	**6.99**	**0**	***0.00***	**0**	***0.00***	**7**	***3.76***	**596**	***320.27***	**128**	***68.78***	**731**	***392.82***
		2	227.2-R	05-Jun-13	457	0.52	0	*0.00*	0	*0.00*	1	*15.15*	102	*1545.19*	22	*333.28*	125	*1893.62*
			228.5-L	05-Jun-13	1044	1.23	0	*0.00*	0	*0.00*	6	*16.82*	121	*339.22*	6	*16.82*	133	*372.86*
			229.2-L	06-Jun-13	1033	1.10	0	*0.00*	0	*0.00*	26	*82.37*	56	*177.42*	19	*60.20*	101	*319.99*
			229.7-R	04-Jun-13	1146	1.42	0	*0.00*	1	*2.21*	3	*6.64*	16	*35.40*	127	*280.95*	147	*325.20*
			231.0-L	05-Jun-13	1100	1.96	0	*0.00*	0	*0.00*	0	*0.00*	4	*6.68*	45	*75.14*	49	*81.82*
			231.0-R	04-Jun-13	666	1.15	0	*0.00*	1	*4.69*	1	*4.69*	1	*4.69*	27	*126.58*	30	*140.64*
		Session 2 Summary			**908**	**7.38**	**0**	***0.00***	**2**	***1.07***	**37**	***19.88***	**300**	***161.16***	**246**	***132.15***	**585**	***314.27***
		3	227.2-R	13-Jun-13	471	0.52	1	*14.70*	0	*0.00*	0	*0.00*	52	*764.33*	3	*44.10*	56	*823.13*
			228.5-L	14-Jun-13	1215	1.23	6	*14.45*	0	*0.00*	0	*0.00*	33	*79.49*	8	*19.27*	47	*113.22*
			229.2-L	12-Jun-13	1254	1.10	0	*0.00*	0	*0.00*	1	*2.61*	8	*20.88*	13	*33.93*	22	*57.42*
			229.7-R	13-Jun-13	2080	2.27	0	*0.00*	0	*0.00*	0	*0.00*	89	*67.86*	9	*6.86*	98	*74.72*
			231.0-L	12-Jun-13	1285	1.96	0	*0.00*	0	*0.00*	0	*0.00*	32	*45.74*	7	*10.01*	39	*55.75*
			231.0-R	13-Jun-13	881	1.19	0	*0.00*	0	*0.00*	0	*0.00*	1	*3.43*	9	*30.90*	10	*34.34*
		Session 3 Summary			**1198**	**8.27**	**7**	***2.54***	**0**	***0.00***	**1**	***0.36***	**215**	***78.14***	**49**	***17.81***	**272**	***98.86***
		4	227.2-R	21-Jun-13	414	0.52	0	*0.00*	0	*0.00*	0	*0.00*	3	*50.17*	8	*133.78*	11	*183.95*
			228.5-L	21-Jun-13	1045	1.23	1	*2.80*	0	*0.00*	0	*0.00*	0	*0.00*	0	*0.00*	1	*2.80*
			229.2-L	21-Jun-13	1045	1.10	0	*0.00*	0	*0.00*	0	*0.00*	0	*0.00*	9	*28.19*	9	*28.19*
			229.7-R	20-Jun-13	1828	2.27	0	*0.00*	2	*1.74*	0	*0.00*	18	*15.62*	69	*59.86*	89	*77.21*
			231.0-L	19-Jun-13	1819	1.96	0	*0.00*	0	*0.00*	0	*0.00*	21	*21.20*	12	*12.12*	33	*33.32*
			231.0-R	18-Jun-13	974	1.19	0	*0.00*	0	*0.00*	0	*0.00*	0	*0.00*	4	*12.42*	4	*12.42*
		Session 4 Summary			**1188**	**8.27**	**1**	***0.37***	**2**	***0.73***	**0**	***0.00***	**42**	***15.40***	**102**	***37.39***	**147**	***53.89***
	Middle Section Total All Samples				**25505**	**30.92**	**8**		**4**		**45**		**1153**		**525**		**1735**	
	Middle Section Average All Samples				**1063**	**1.29**	**0**	***0.88***	**0**	***0.44***	**2**	***4.93***	**48**	***126.34***	**22**	***57.53***	**72**	***190.11***
	Middle Section Standard Error of Mean						**0.25**	***0.84***	**0.10**	***0.22***	**1.10**	***3.48***	**12.20**	***93.23***	**5.61**	***17.84***	**12.70**	***104.86***
All Sections Total All Samples					**53611**	**69.15**	**8**		**9**		**108**		**1828**		**844**		**2797**	
All Sections Average All Samples					**924**	**1.19**	**0**	***0.45***	**0**	***0.51***	**2**	***6.08***	**32**	***102.96***	**15**	***47.54***	**48**	***157.54***
All Sections Standard Error of Mean							**0.11**	***0.35***	**0.07**	***0.15***	**0.80**	***3.01***	**6.56**	***42.22***	**2.74**	***12.71***	**7.46**	***48.16***

Table D5 Summary of the number (N) of fish captured and recaptured in sampled sections of the Middle Columbia River during the spring season, 27 May to 20 June 2013.

Species	Size-class	Session	N Captured	N Marked	N Recaptured (within year)	N Recaptured (between years)
Bull Trout	All	1	32	23	-	9
		2	41	28	2	11
		3	50	31	3	16
		4	42	28	5	9
Bull Trout Total			165	110	10	45
Burbot	All	1	0	0	-	0
		2	2	2	0	0
		3	1	1	0	0
		4	2	2	0	0
Burbot Total			5	5	0	0
Mountain Whitefish	All	1	276	185	-	91
		2	371	265	14	92
		3	360	233	30	97
		4	370	238	52	80
Mountain Whitefish Total			1377	921	96	360
Northern Pikeminnow	All	1	0	0	-	0
		2	0	0	0	0
		3	4	4	0	0
		4	0	0	0	0
Northern Pikeminnow Total			4	4	0	0
Rainbow Trout	All	1	17	15	-	2
		2	18	14	3	1
		3	17	12	4	1
		4	4	2	0	2
Rainbow Trout Total			56	43	7	6
Sucker spp.	All	1	30	28	-	2
		2	85	73	0	12
		3	45	41	1	3
		4	70	67	1	2
Sucker spp. Total			230	209	2	19

Appendix E – Life History

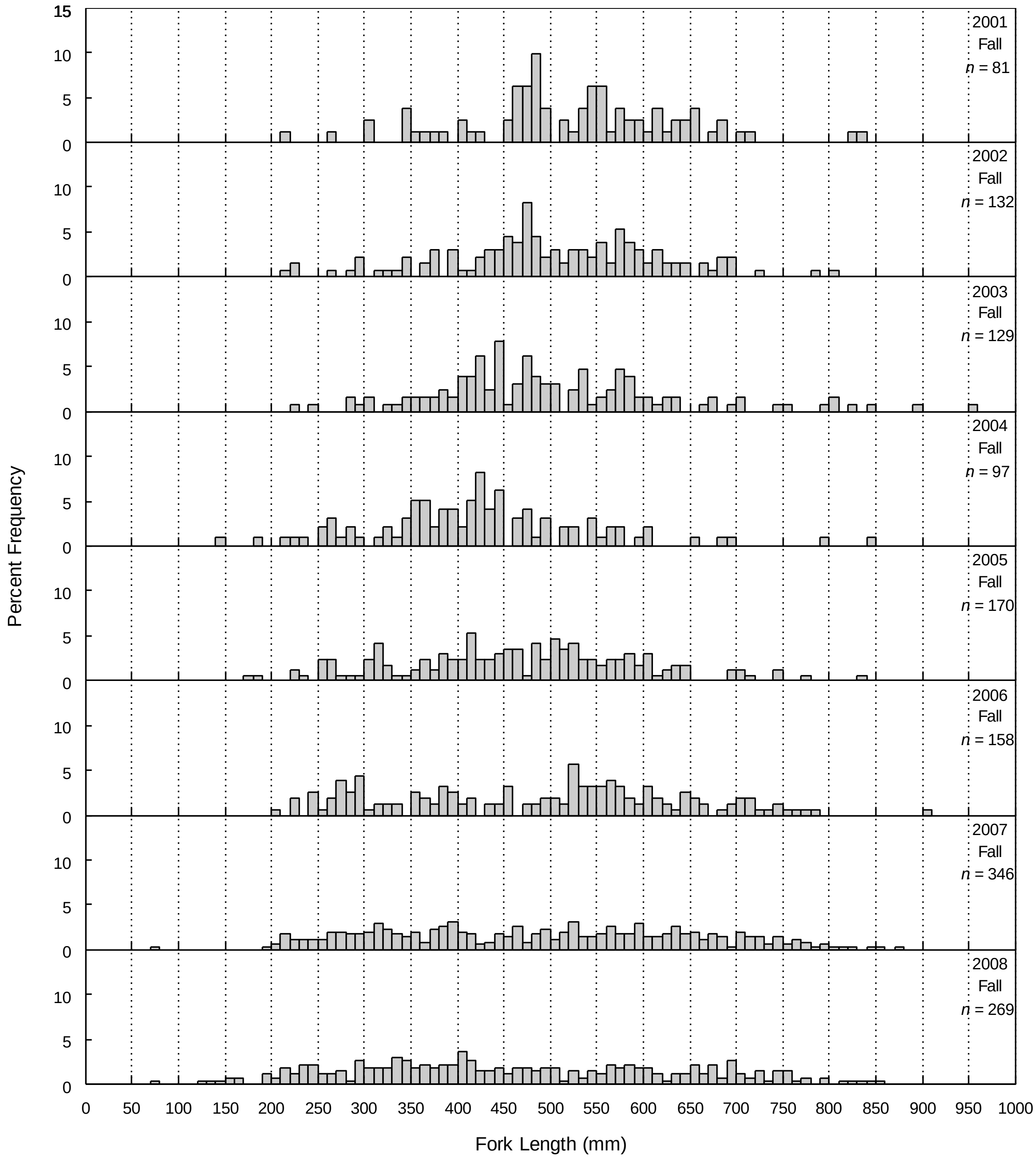


Figure E1 Length-frequency distributions for Bull Trout captured by boat electroshocking in Reaches 3 and 4 of the Middle Columbia River, 2001 to 2013. Bull Trout that were initially marked during an earlier year of the program were excluded from the analysis due to potential tagging effects on growth. Boat electroshocking surveys were not conducted downstream of Big Eddy for all years prior to 2007.

Continued…

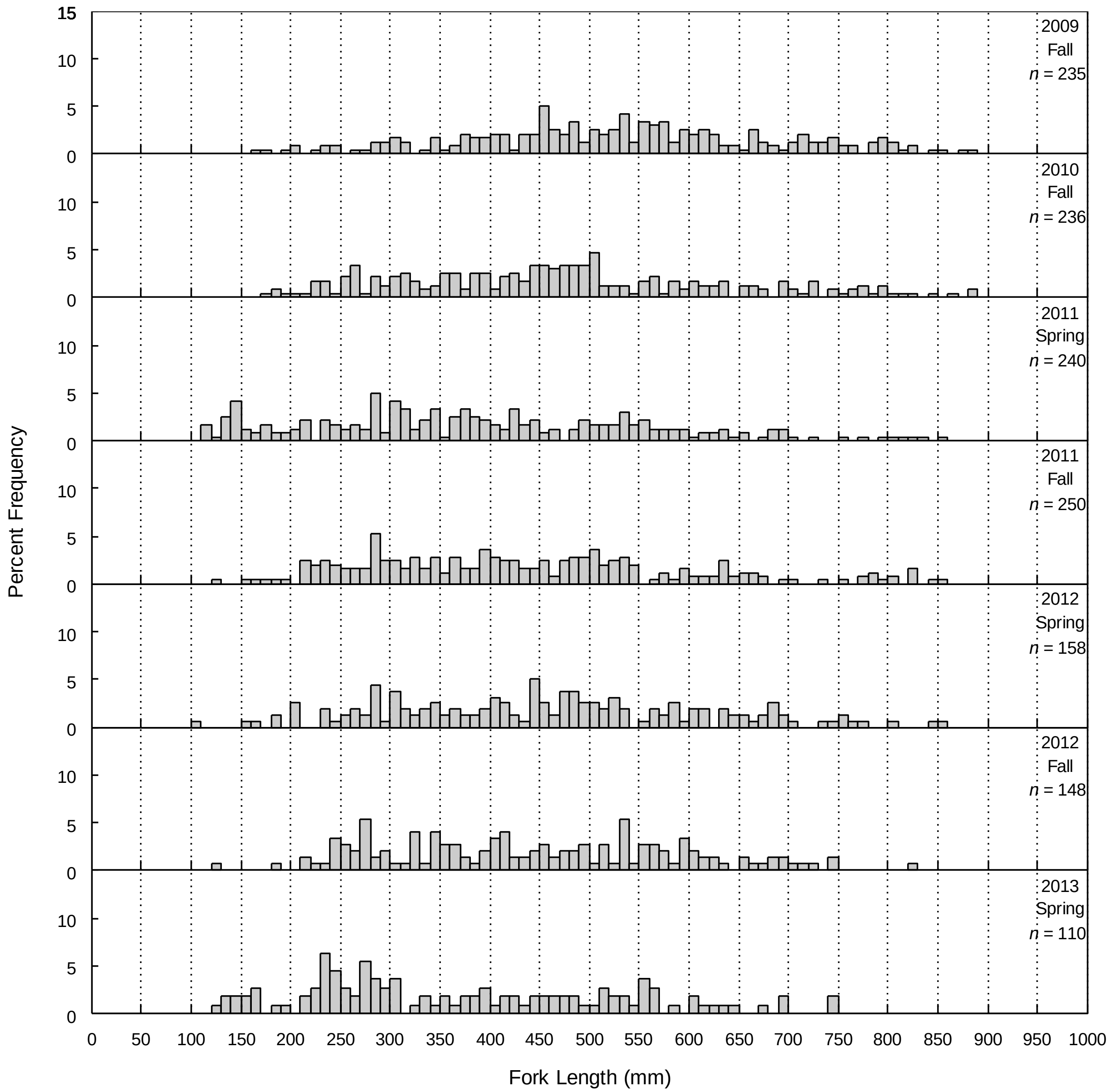


Figure E1 Concluded.

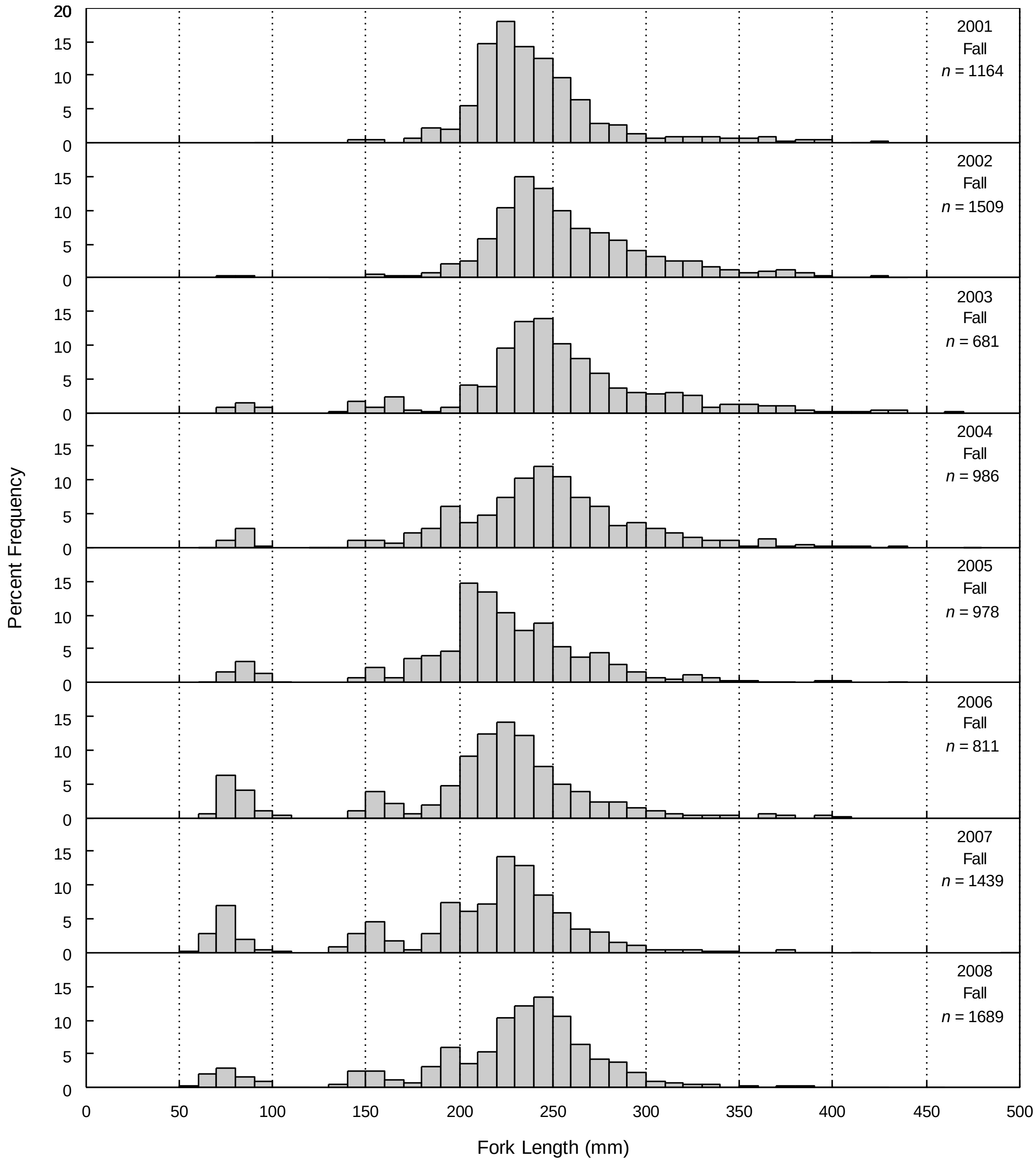


Figure E2 Length-frequency distributions for Mountain Whitefish captured by boat electroshocking in Reaches 3 and 4 of the Middle Columbia River, 2001 to 2013. Mountain Whitefish that were initially marked during an earlier year of the program were excluded from the analysis due to potential tagging effects on growth. Boat electroshocking surveys were not conducted downstream of Big Eddy for all years prior to 2007.

Continued…

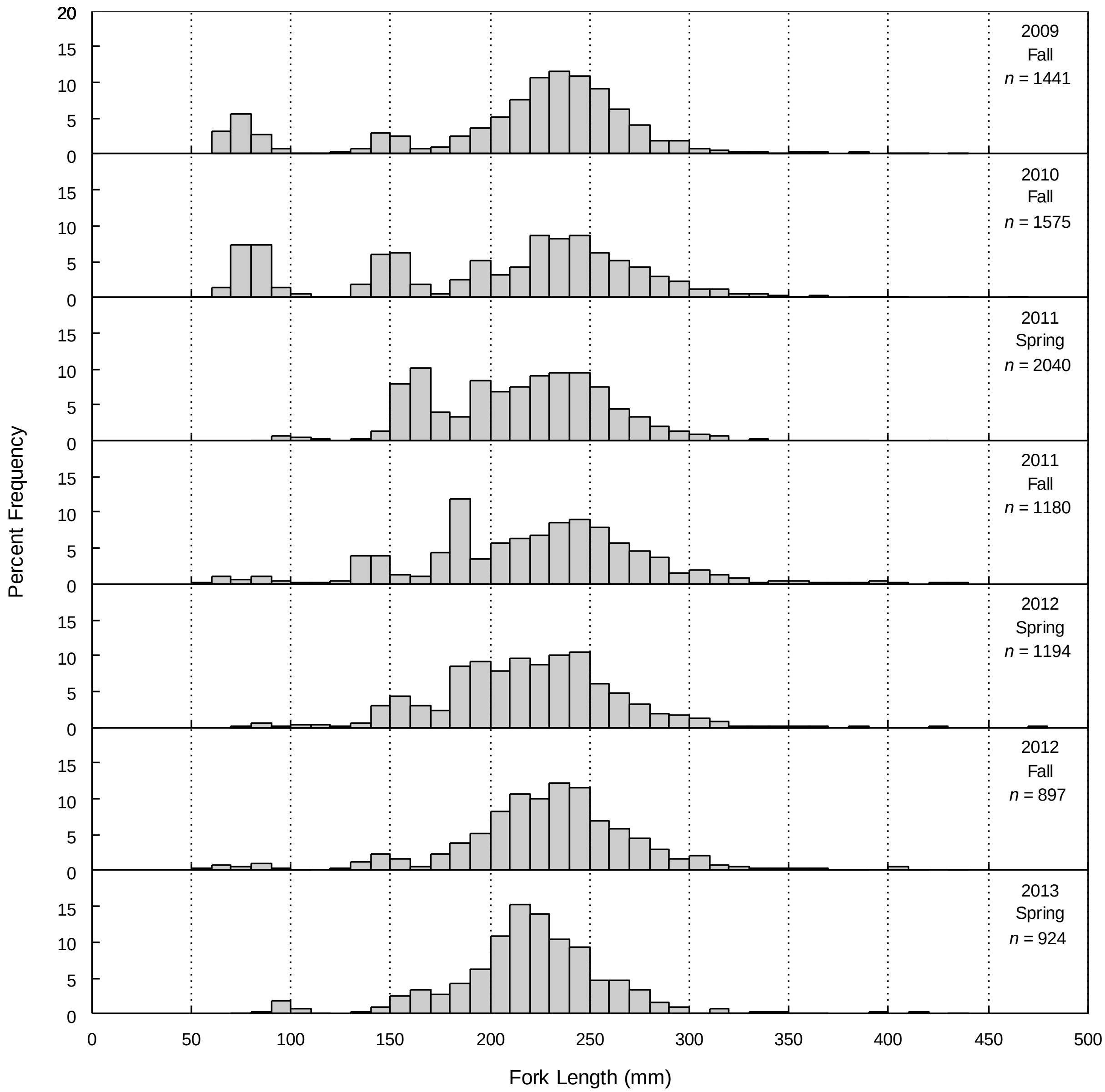


Figure E2 Concluded.

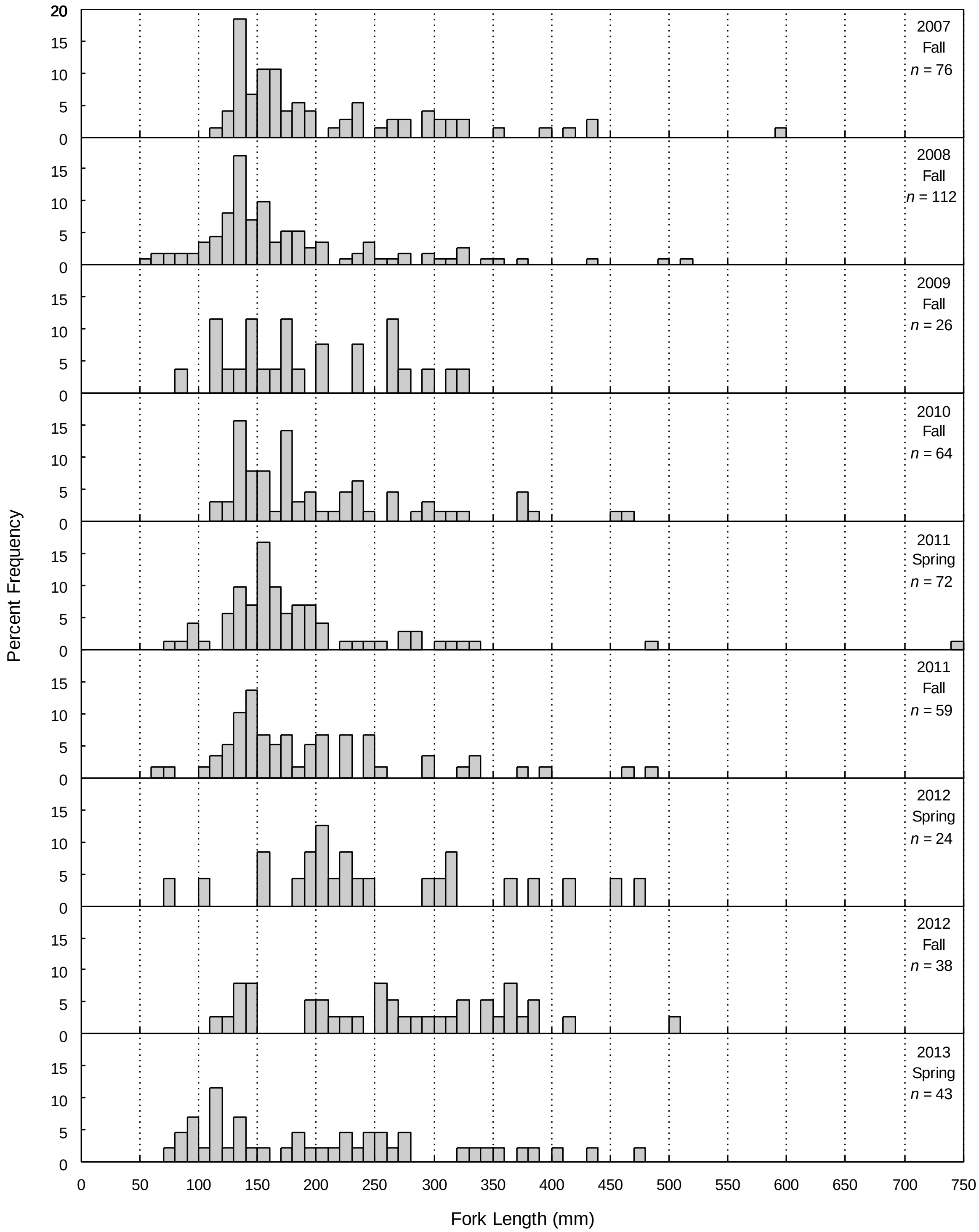


Figure E3 Length-frequency distributions for Rainbow Trout captured by boat electroshocking in Reaches 3 and 4 of the Middle Columbia River, 2007 to 2013. Rainbow Trout that were initially marked during an earlier year of the program were excluded from the analysis due to potential tagging effects on growth. Boat electroshocking surveys were not conducted downstream of Big Eddy for all years prior to 2007.

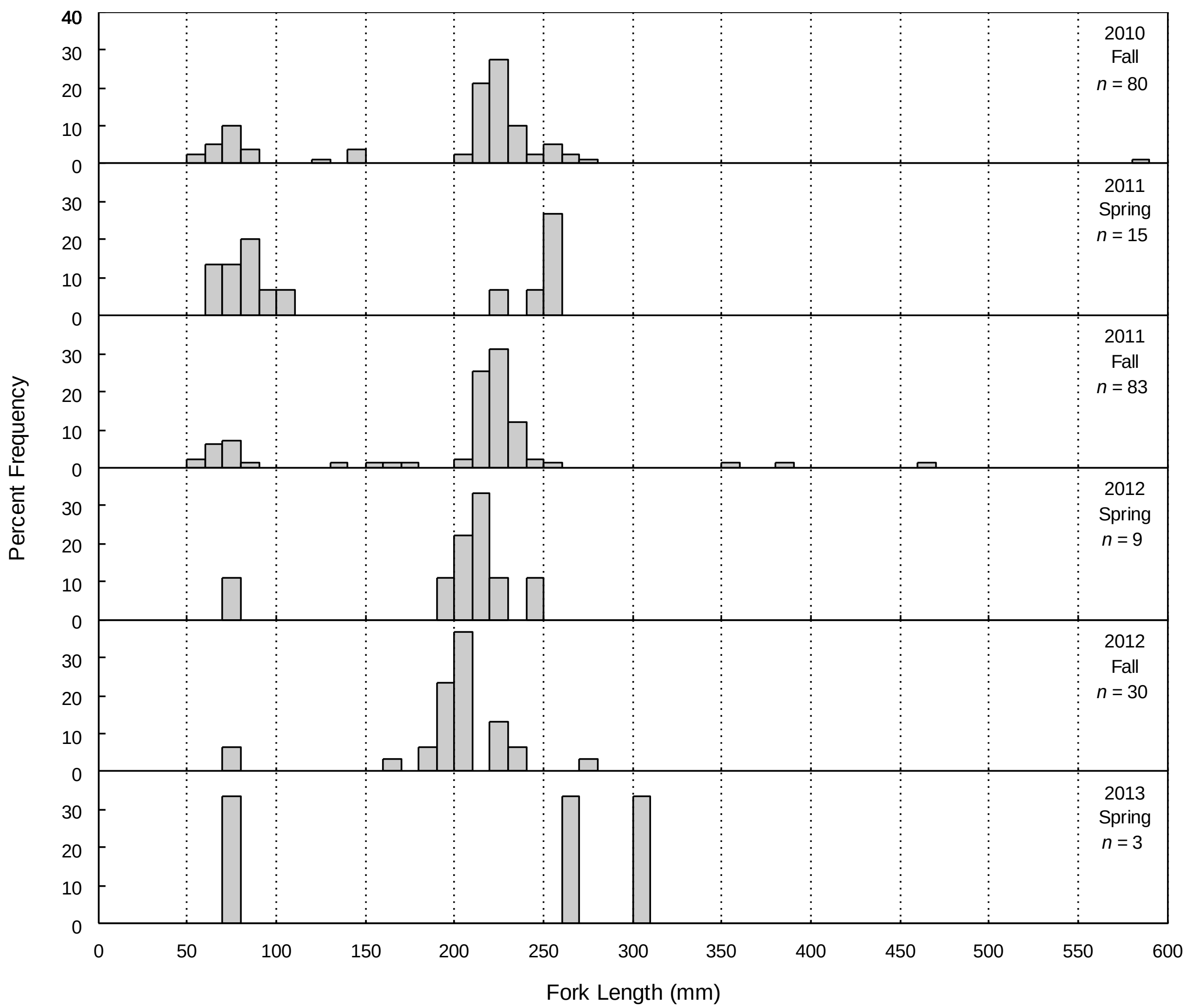


Figure E4 Length-frequency distributions for Kokanee captured by boat electroshocking in Reaches 3 and 4 of the Middle Columbia River, 2010 to 2013.

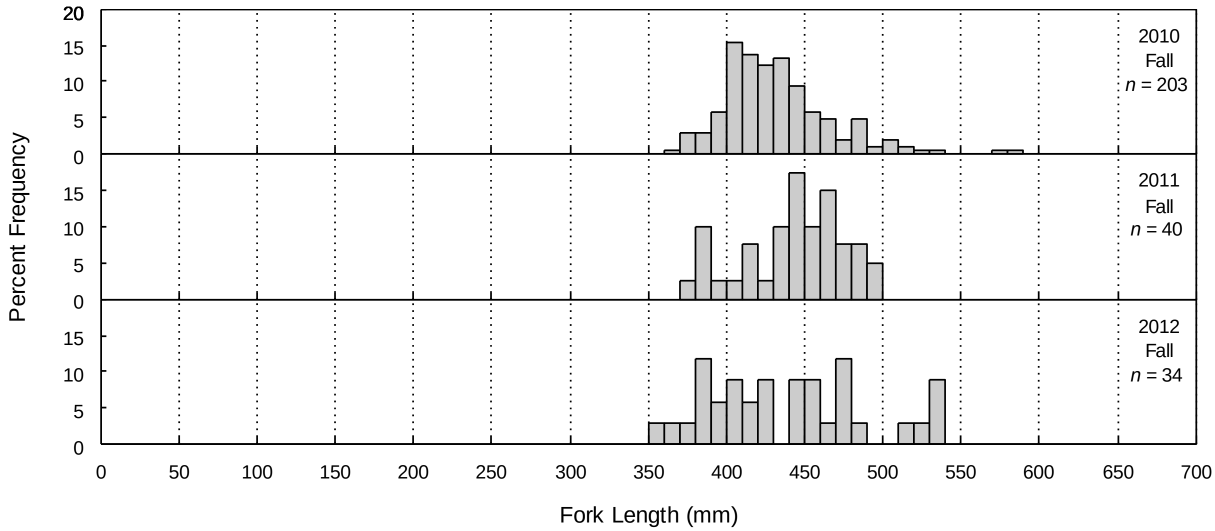


Figure E5 Length-frequency distributions for Lake Whitefish captured by boat electroshocking in Reaches 3 and 4 of the Middle Columbia River, 2010 to 2012. Lake Whitefish that were initially marked during an earlier year of the program were excluded from the analysis due to potential tagging effects on growth. Lake Whitefish were not captured during the spring of 2013.

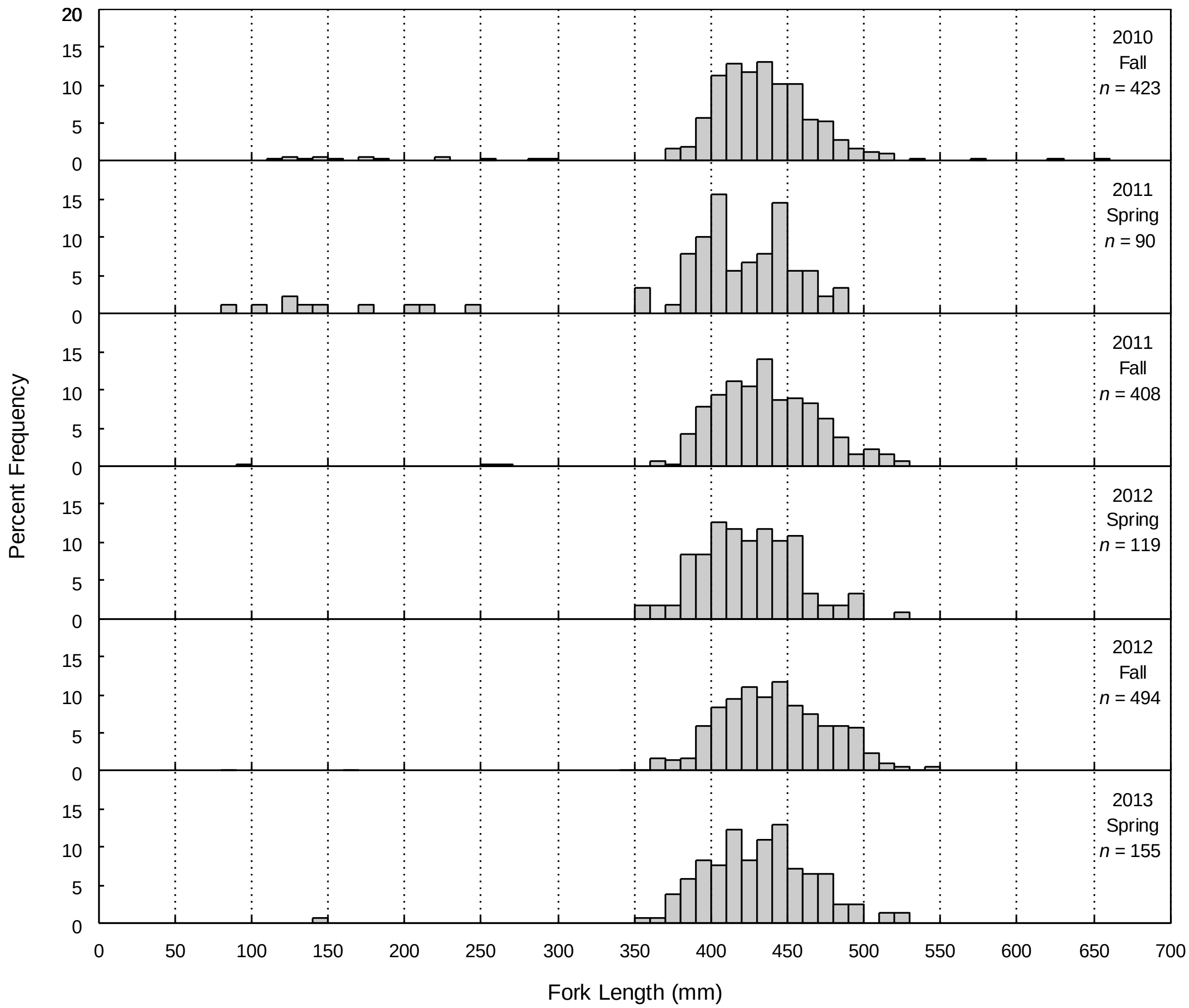


Figure E6 Length-frequency distributions for Largescale Sucker captured by boat electroshocking in Reaches 3 and 4 of the Middle Columbia River, 2010 to 2013. Largescale Sucker that were initially marked during an earlier year of the program were excluded from the analysis due to potential tagging effects on growth.

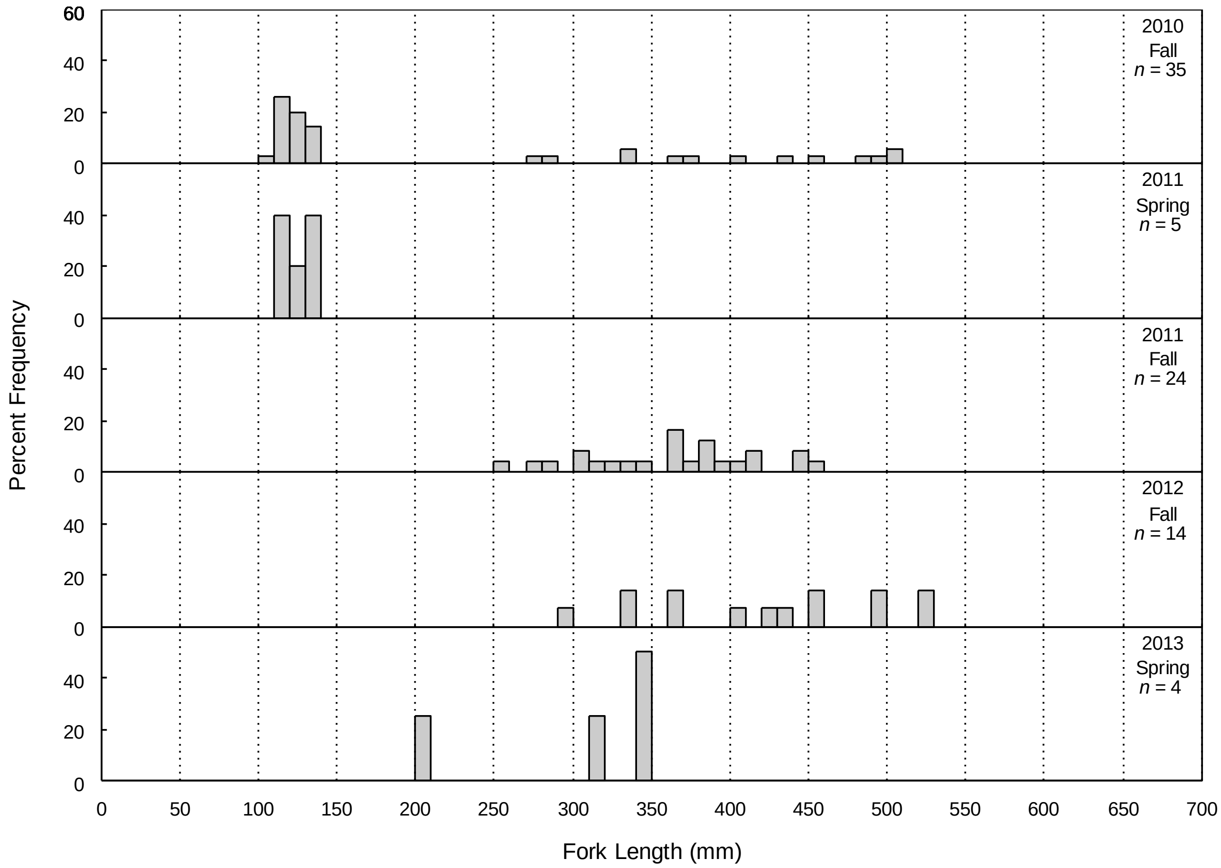


Figure E7 Length-frequency distributions for Northern Pikeminnow captured by boat electroshocking in Reaches 3 and 4 of the Middle Columbia River, 2010 to 2013. Northern Pikeminnow that were initially marked during an earlier year of the program were excluded from the analysis due to potential tagging effects on growth.

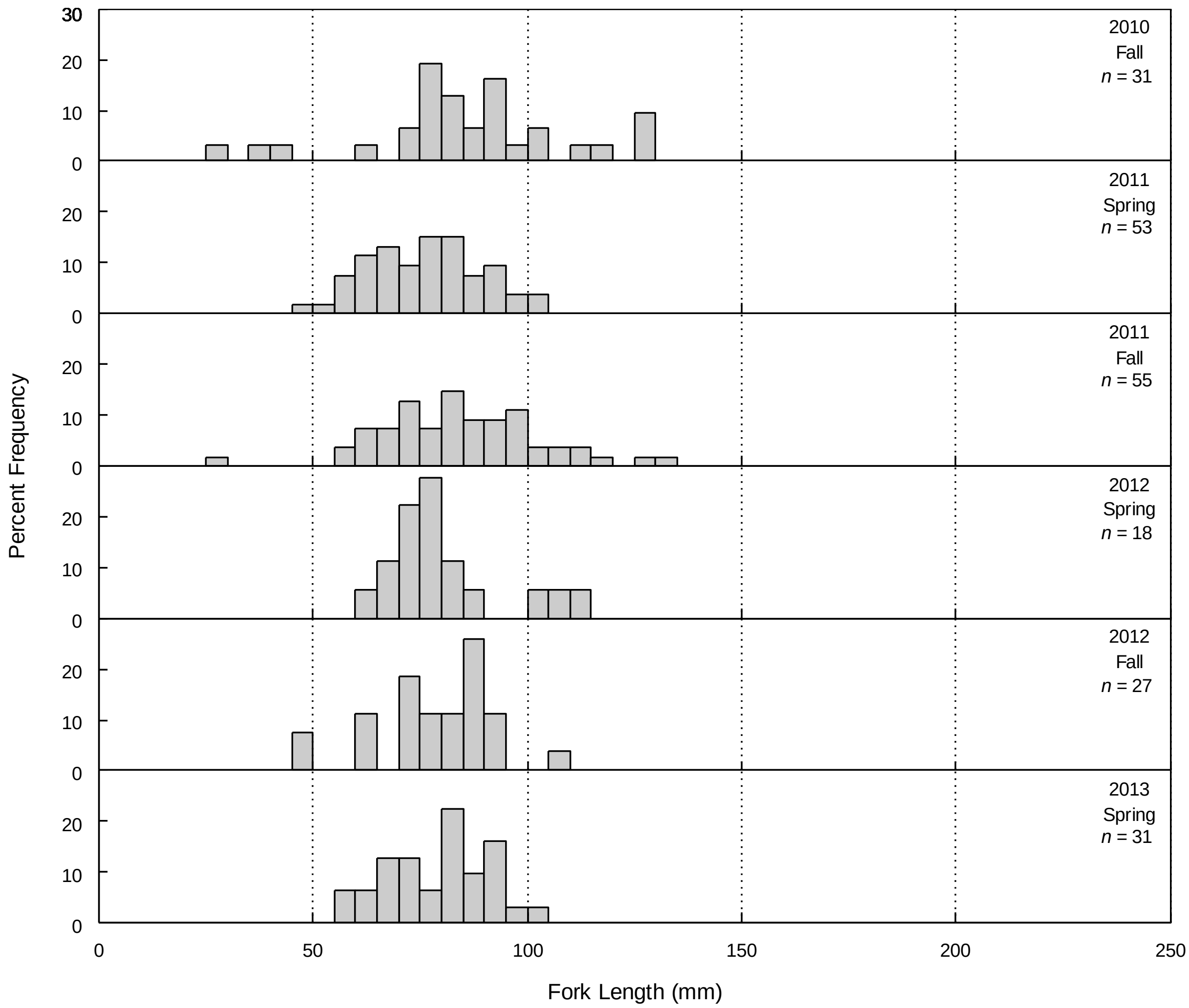


Figure E8 Length-frequency distributions for Prickly Sculpin captured by boat electroshocking in Reaches 3 and 4 of the Middle Columbia River, 2010 to 2013.

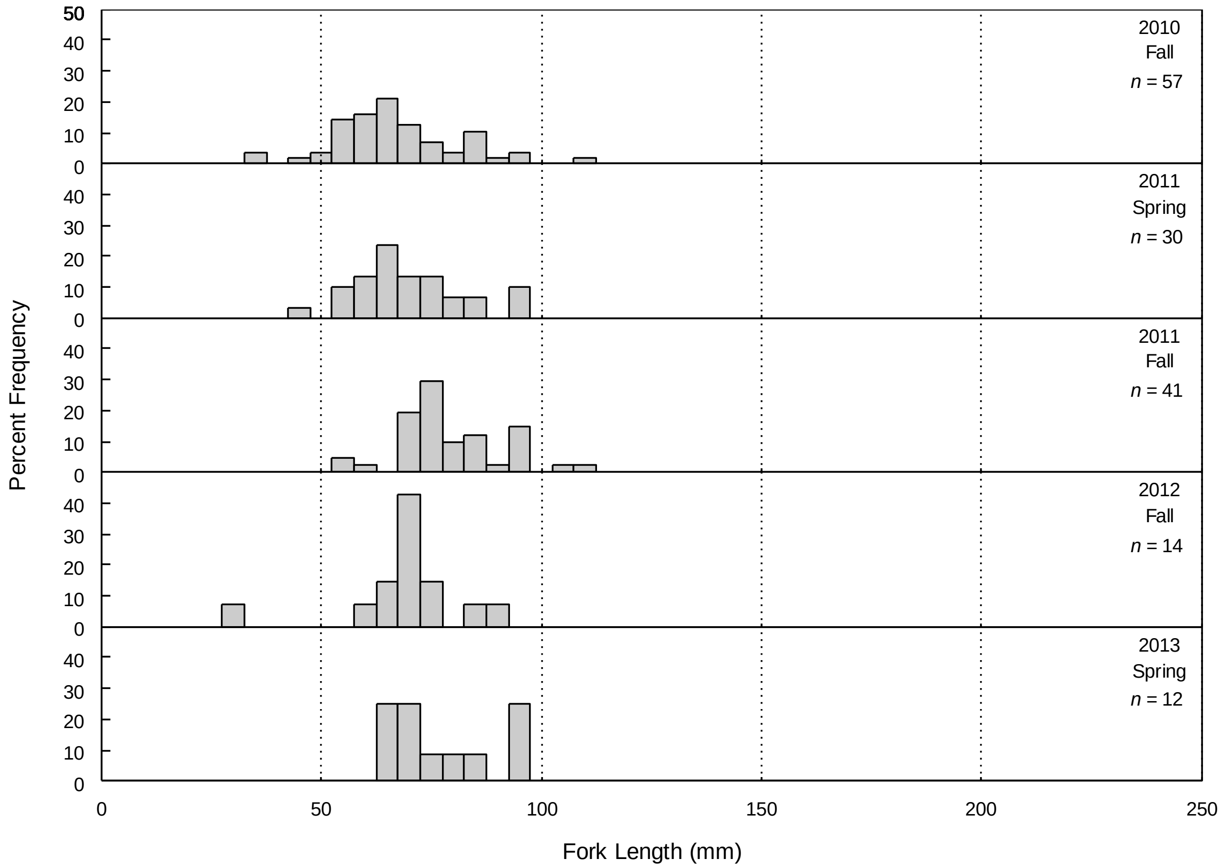
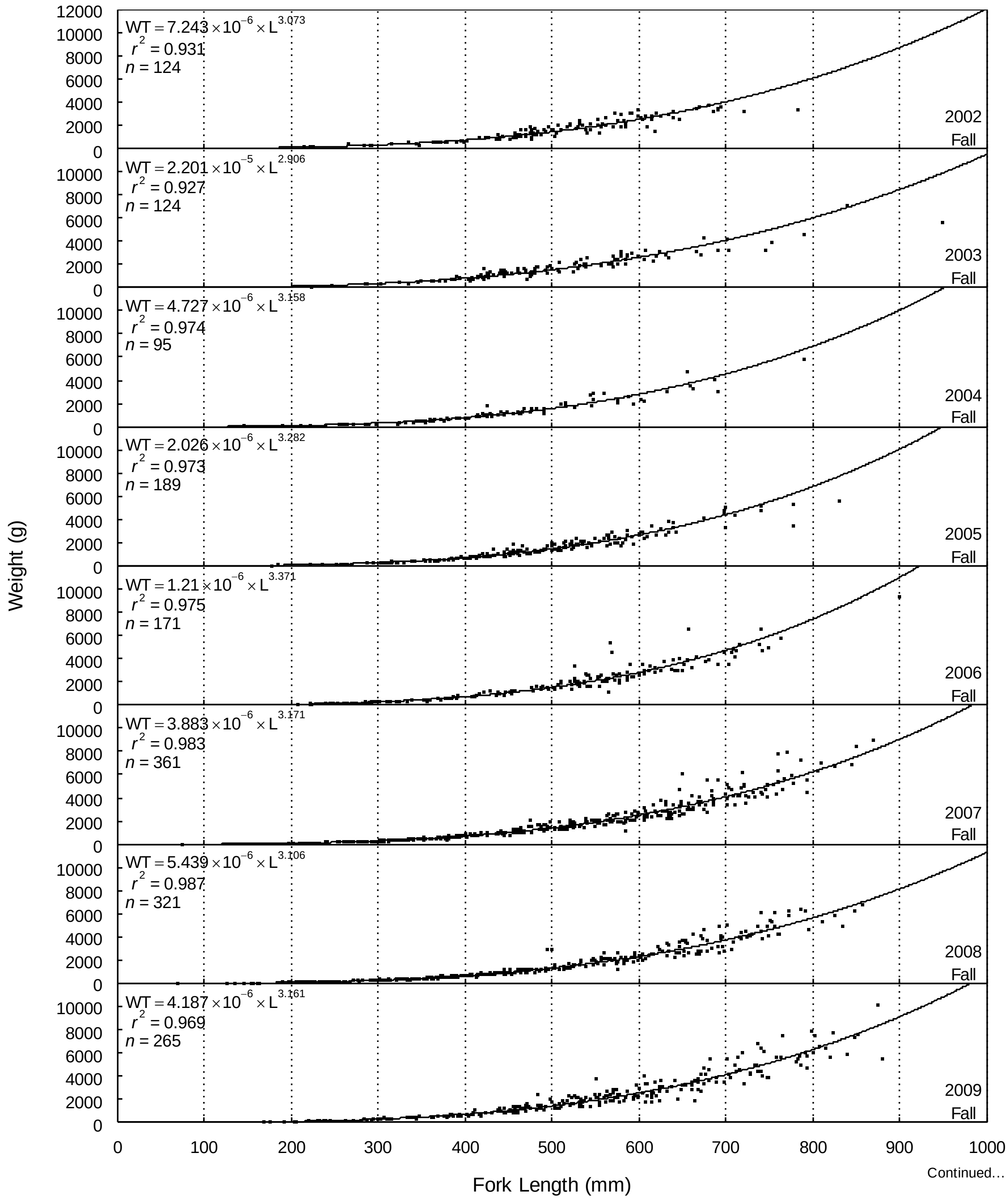


Figure E9 Length-frequency distributions for Redside Shiner captured by boat electroshocking in Reaches 3 and 4 of the Middle Columbia River, 2010 to 2013.



Continued…

Figure E10 Length-weight regression for Bull Trout captured by boat electroshocking in Reaches 3 and 4 of the Middle Columbia River, 2001 to 2013. 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.

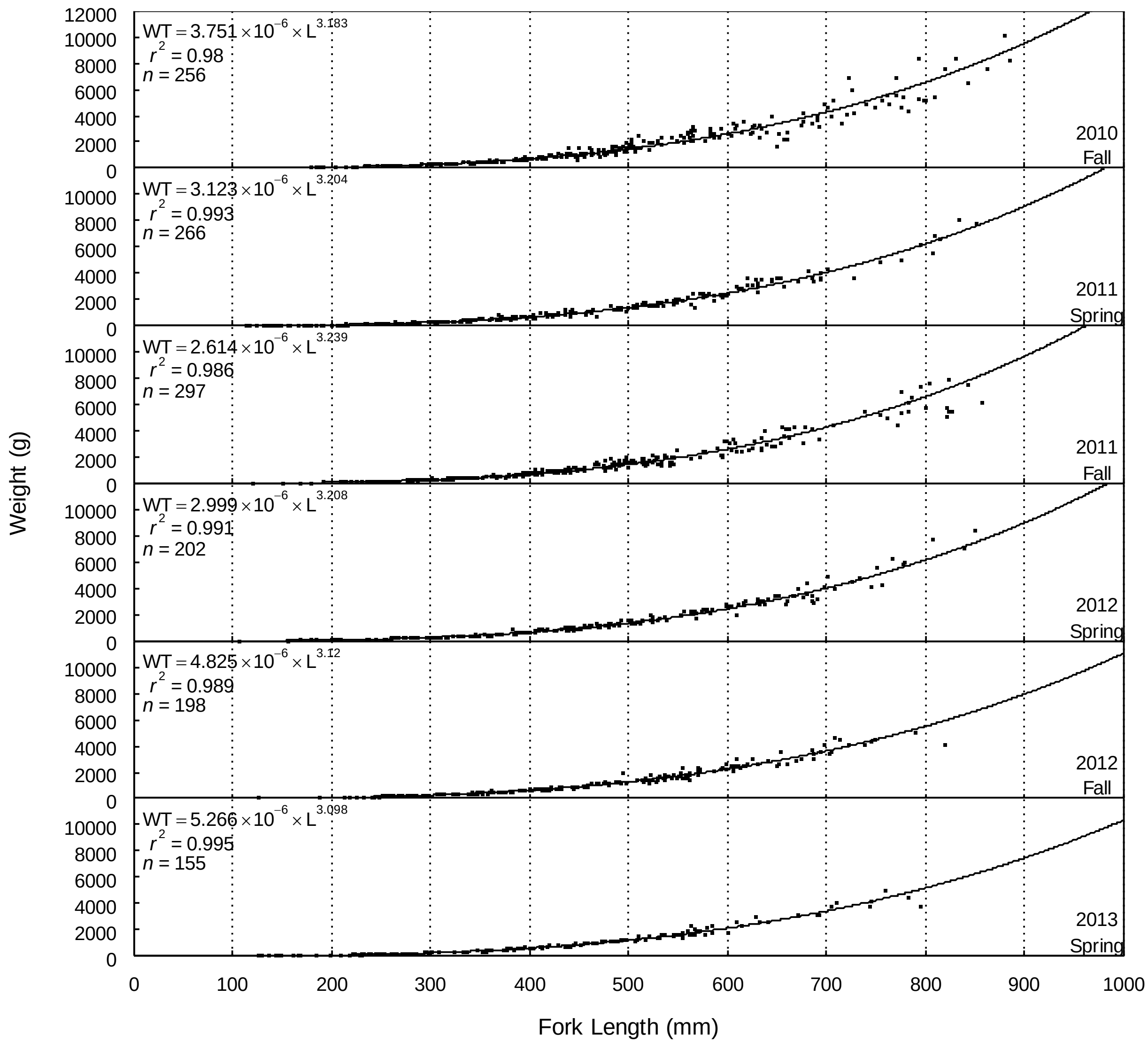
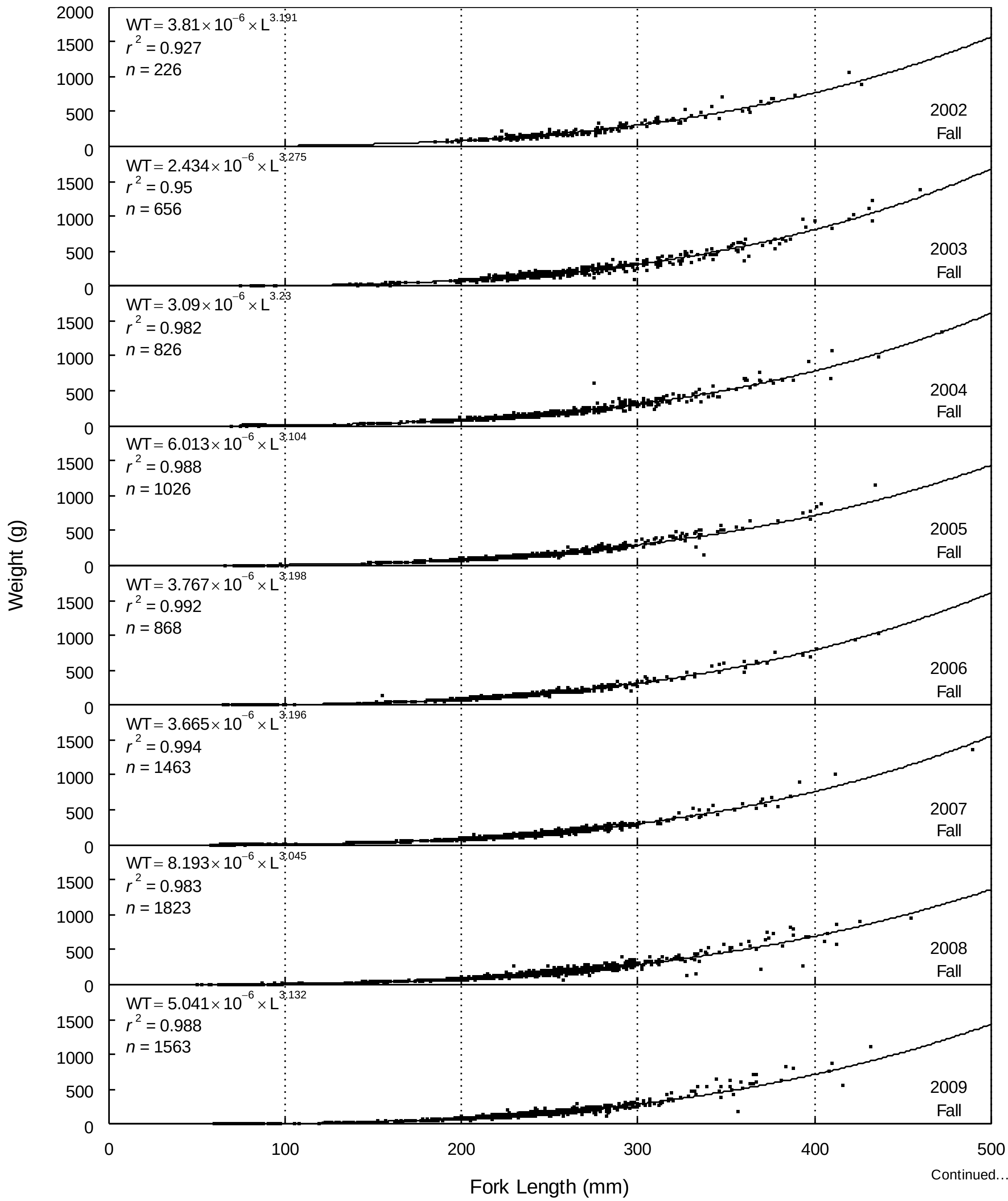


Figure E10 Concluded.



Continued…

Figure E11 Length-weight regression for Mountain Whitefish captured by boat electroshocking in Reaches 3 and 4 of the Middle Columbia River, 2001 to 2013. 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.

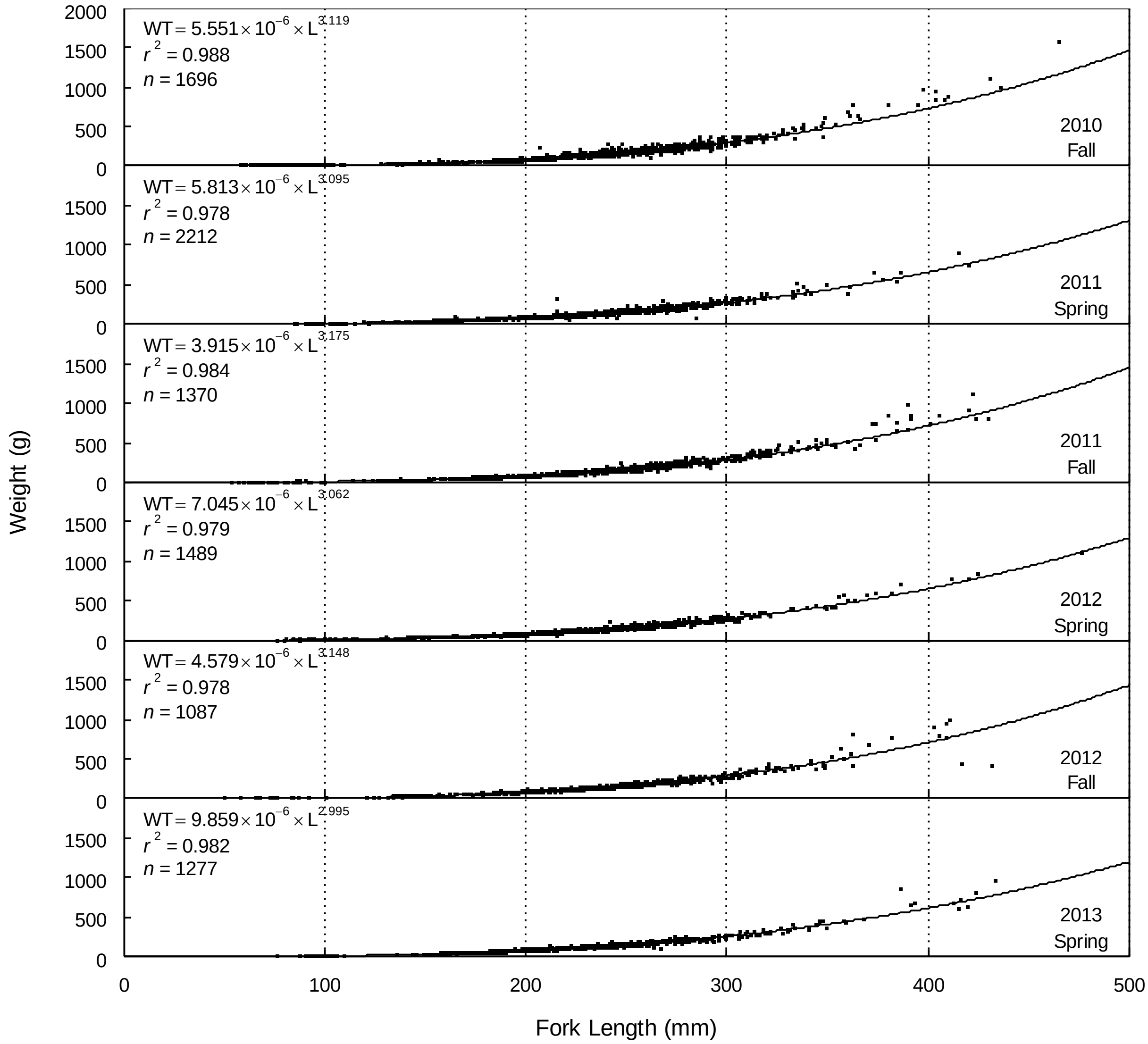


Figure E11 Concluded.

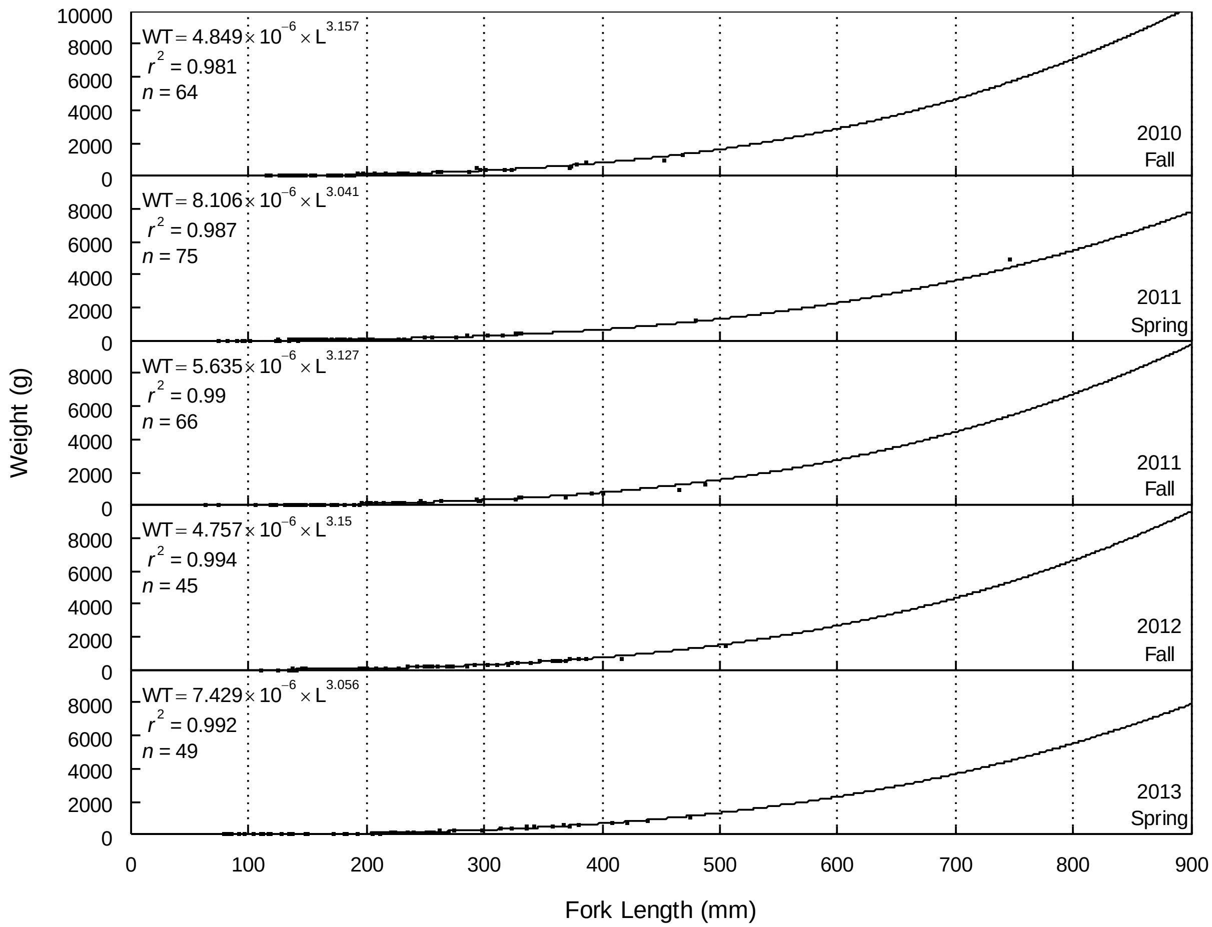


Figure E12 Length-weight regression for Rainbow Trout captured by boat electroshocking in Reaches 3 and 4 of the Middle Columbia River, 2010 to 2013. Rainbow Trout that were initially marked during an earlier year of the program were excluded from the analysis due to potential tagging effects on growth. Boat electroshocking surveys were not conducted downstream of Big Eddy for all years prior to 2007.

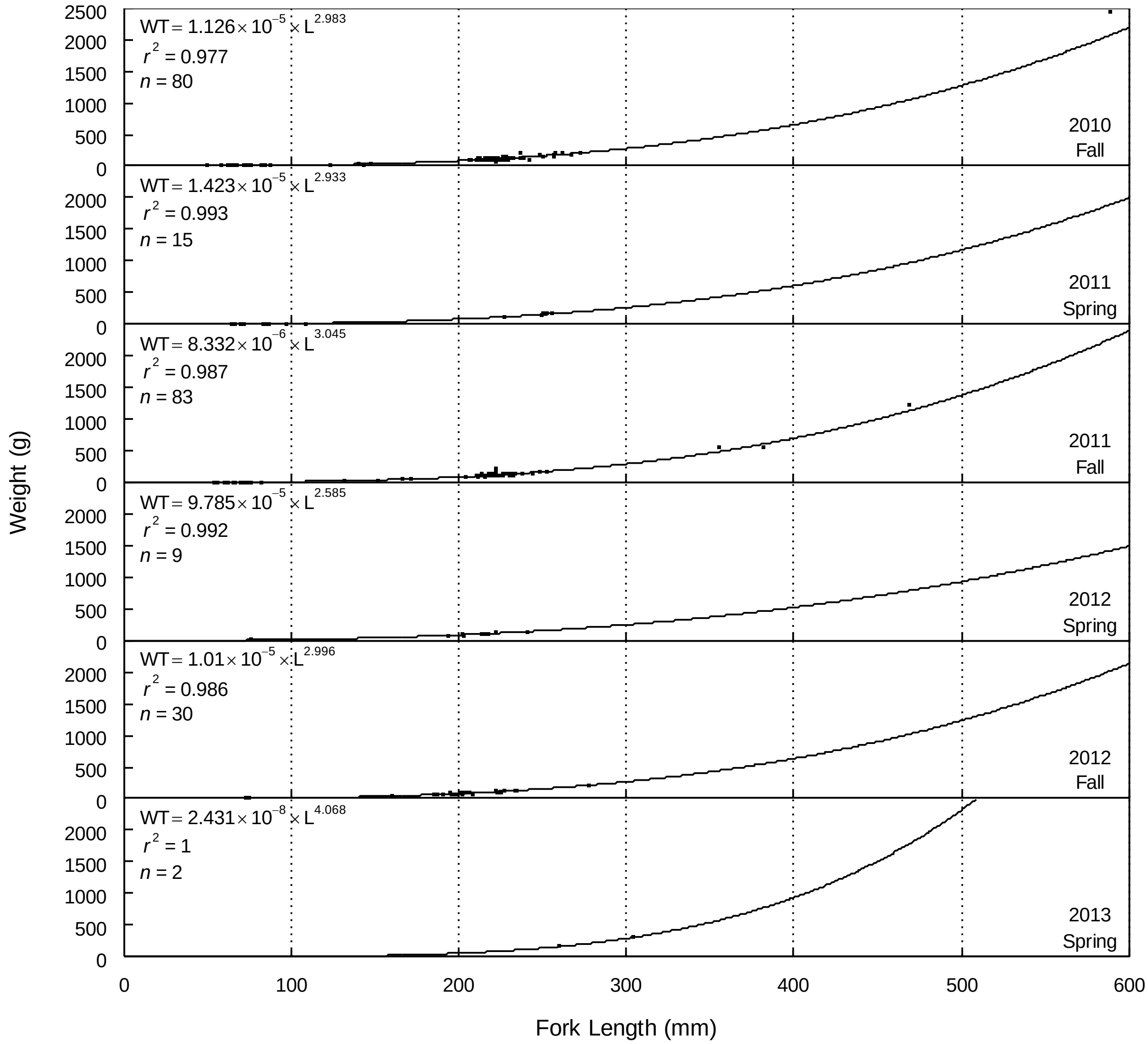


Figure E13 Length-weight regression for Kokanee captured by boat electroshocking in Reaches 3 and 4 of the Middle Columbia River, 2010 to 2013.

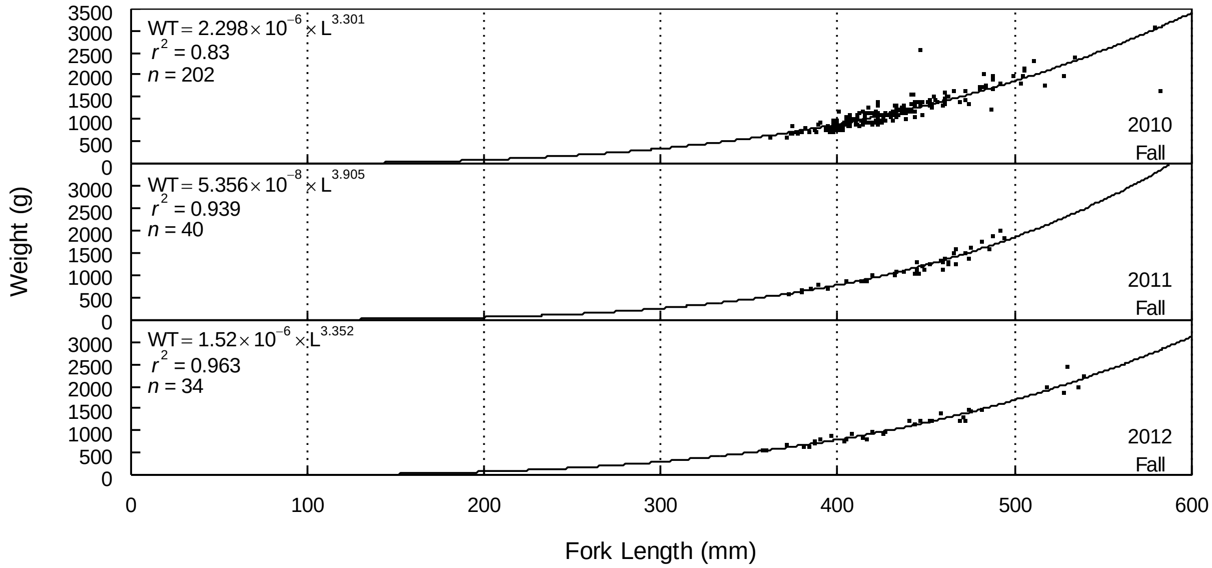


Figure E14 Length-weight regression for Lake Whitefish captured by boat electroshocking in Reaches 3 and 4 of the Middle Columbia River, 2010 to 2013. Lake Whitefish that were initially marked during an earlier year of the program were excluded from the analysis due to potential tagging effects on growth. Lake Whitefish were not captured during the spring of 2013.

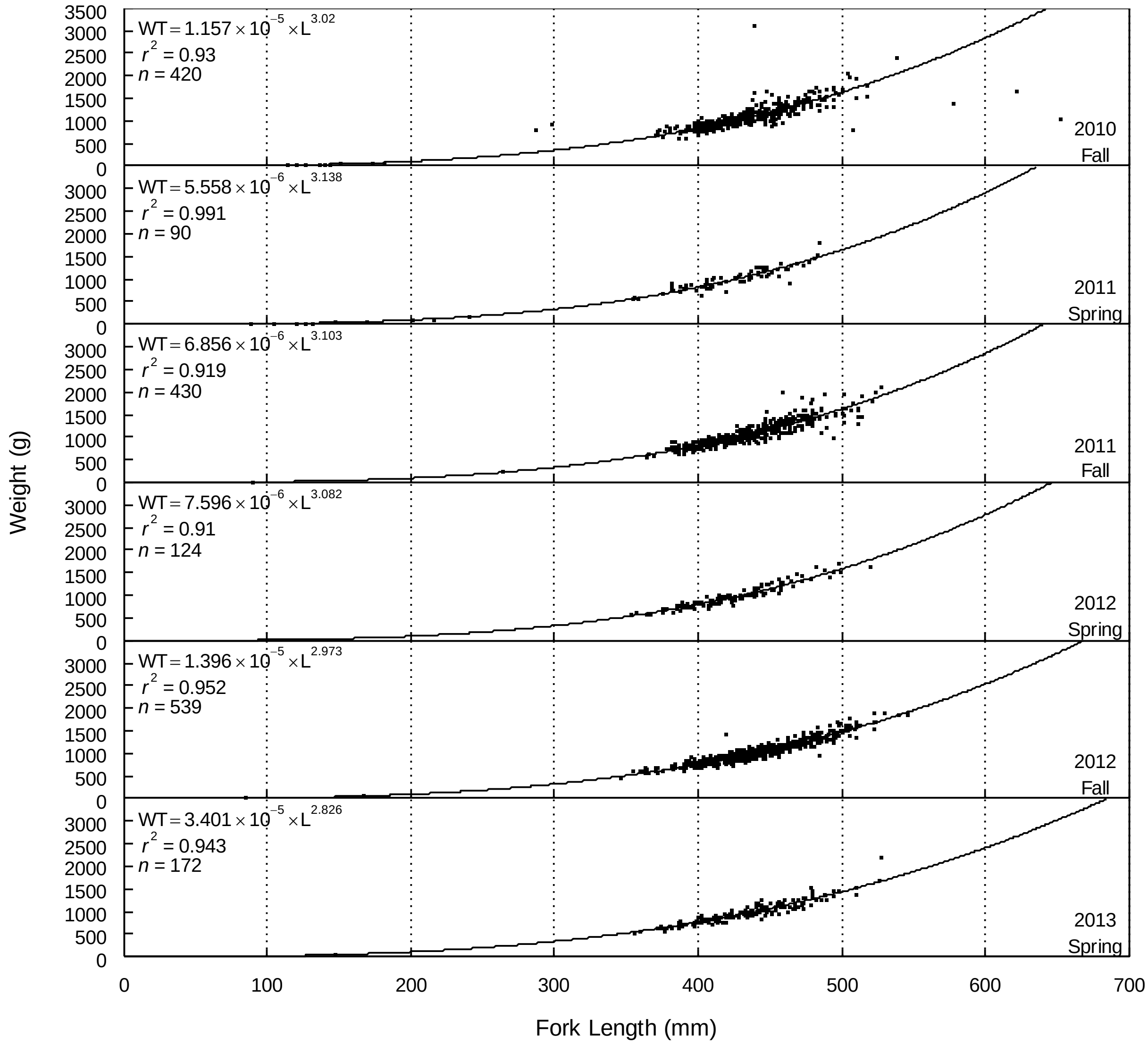


Figure E15 Length-weight regression for Largescale Sucker captured by boat electroshocking in Reaches 3 and 4 of the Middle Columbia River, 2010 to 2013. Largescale Sucker that were initially marked during an earlier year of the program were excluded from the analysis due to potential tagging effects on growth.

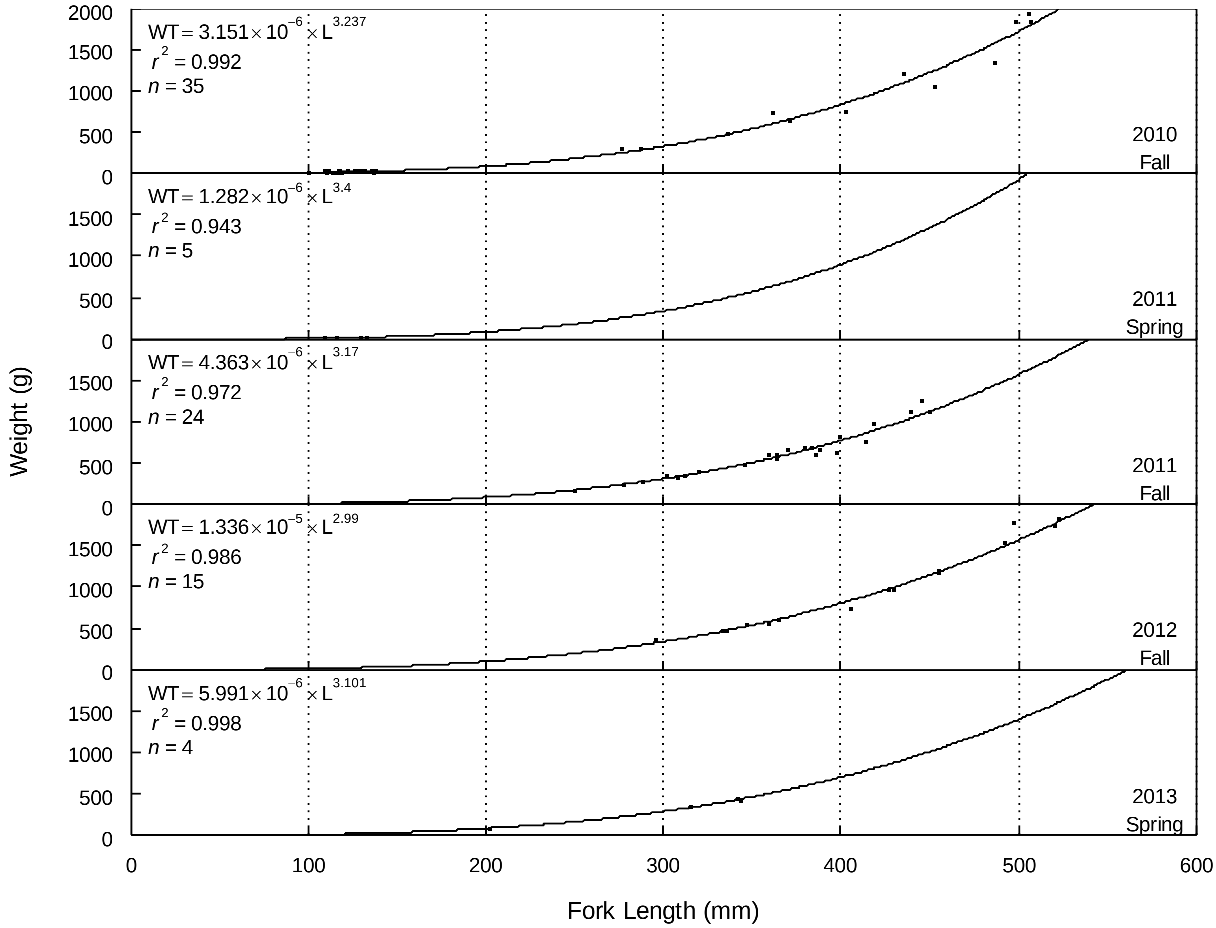


Figure E16 Length-weight regression for Northern Pikeminnow captured by boat electroshocking in Reaches 3 and 4 of the Middle Columbia River, 2010 to 2013. Northern Pikeminnow that were initially marked during an earlier year of the program were excluded from the analysis due to potential tagging effects on growth.

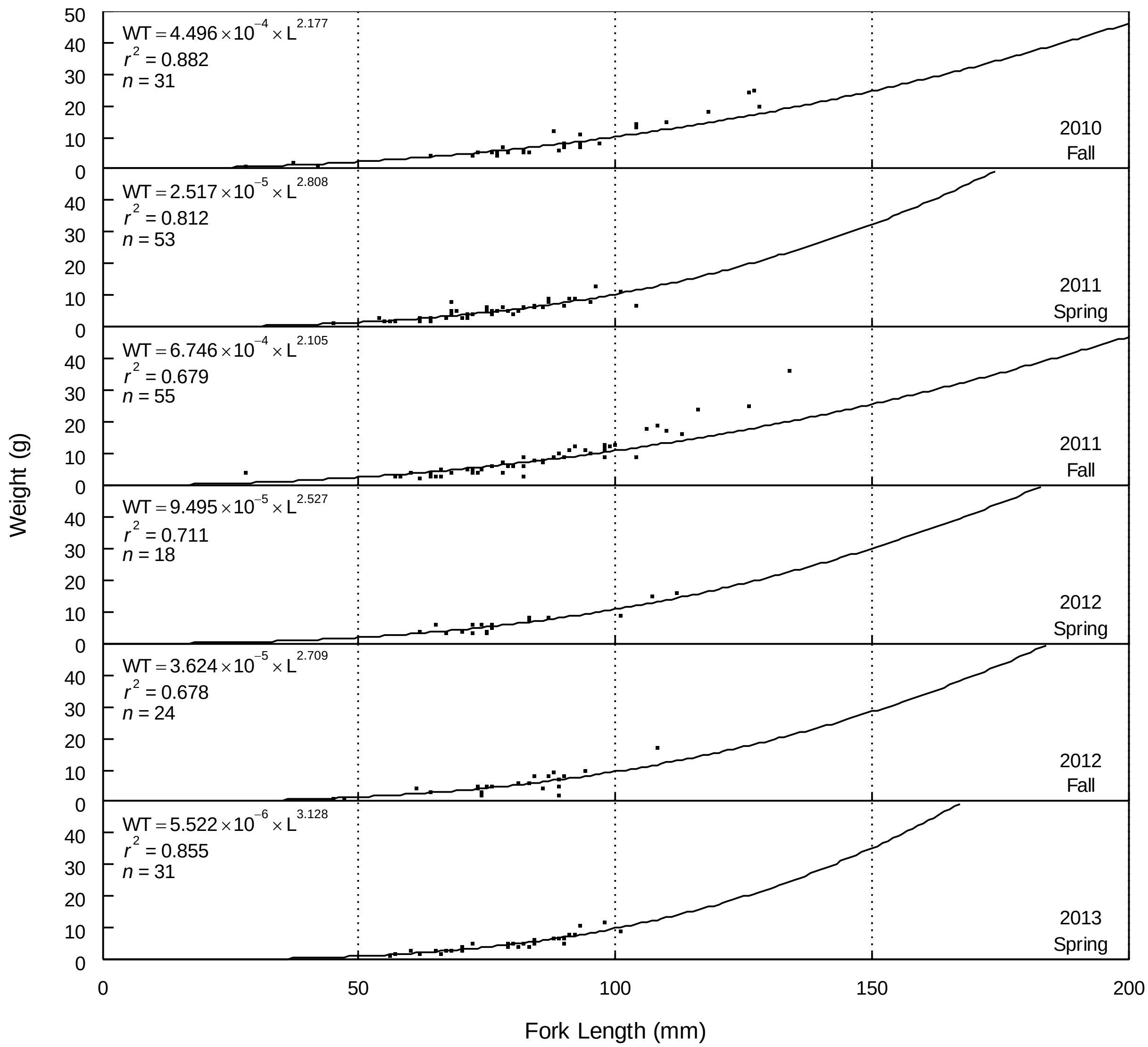


Figure E17 Length-weight regression for Prickly Sculpin captured by boat electroshocking in Reaches 3 and 4 of the Middle Columbia River, 2010 to 2013.

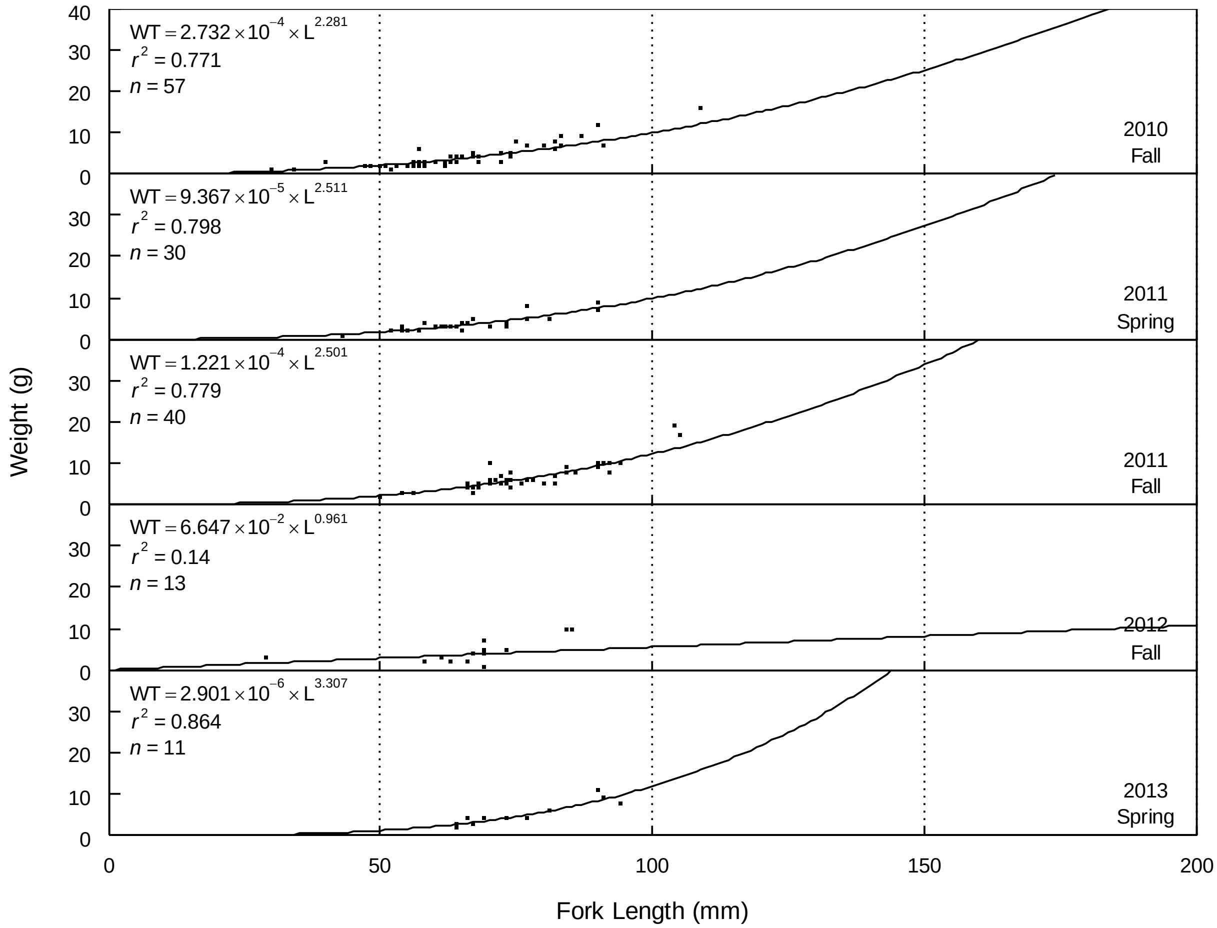


Figure E18 Length-weight regression for Redside Shiner captured by boat electroshocking in Reaches 3 and 4 of the Middle Columbia River, 2010 to 2013.

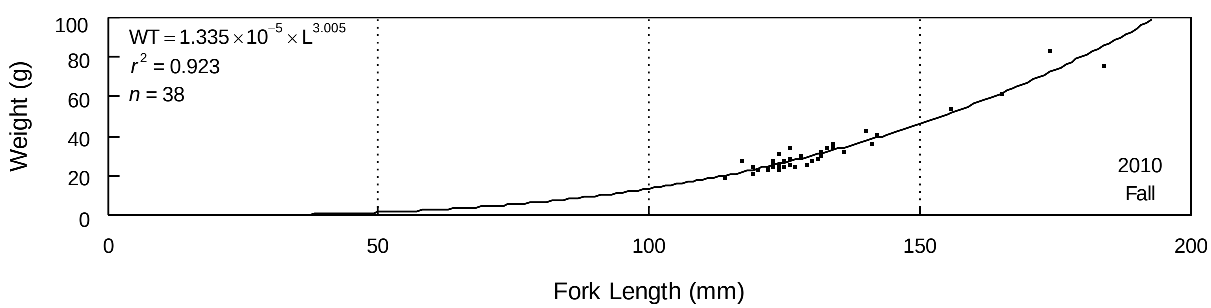


Figure E19 Length-weight regression for Yellow Perch captured by boat electroshocking in Reaches 3 and 4 of the Middle Columbia River, 2010. Yellow Perch that were initially marked during an earlier year of the program were excluded from the analysis due to potential tagging effects on growth.

Appendix F – HBA Methods

Hierarchical Bayesian Analyses - Methods

General Approach

Hierarchical Bayesian models were fitted to the fish indexing data for the MCR using R version 3.0.2 (Team, 2013) and JAGS 3.3.0 (Plummer, 2012) which interfaced with each other via jaggernaut 1.6 (Thorley, 2014). For additional information on hierarchical Bayesian modelling in the BUGS language, of which JAGS uses a dialect, the reader is referred to Kery and Schaub (2011) pages 41-44.

Unless specified, the models assumed vague (low information) prior distributions (Kery and Schaub, 2011, p. 36). The posterior distributions were estimated from a minimum of 1,000 Markov Chain Monte Carlo (MCMC) samples thinned from the second halves of three chains (Kery and Schaub, 2011, pp. 38-40). Model convergence was confirmed by ensuring that Rhat (Kery and Schaub, 2011, p. 40) was less than 1.1 for each of the parameters in the model (Kery and Schaub, 2011, p. 61). Model adequacy was confirmed by examination of residual plots.

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

The results are displayed graphically by plotting the modeled relationships between particular variables and the response (with 95% credible intervals) 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, pp. 77-82). Where informative the influence of particular variables is expressed in terms of the *effect size* (i.e., percent change in the response variable) with 95% credible intervals (Bradford et al. 2005). Plots were produced using the ggplot2 R package (Wickham, 2009).

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, 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. Its 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. The estimated occupancies for multiple species were summed to give the expected species richnesses.

Key assumptions of the occupancy model include:

- Occupancy (probability of presence) varies with discharge regime and season.
- Occupancy varies randomly with site, year, and the interaction between site and year.
- 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.

Count and Species Evenness

The count data were analysed using an overdispersed Poisson model (Kery, 2010; Kery and Schaub, 2011, pp. 168-170,180 and 55-56). 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 model does not distinguish between the abundance and observer efficiency, i.e., it estimates the 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 abundance. The shannon index of evenness (E) 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 ith species.

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

Key assumptions of the count model include:

- Count density (count/km) varies with discharge regime, season and river kilometre.
- Count density (count/km) varies randomly with site, year, and the interaction between site and year.
- The relationship between count density and river kilometre (distribution) varies with discharge regime and season.
- The relationship between count density and river kilometre (distribution) varies randomly with year.
- Expected counts are the product of the count density (count/km) and the length of bank sampled.
- Sites are closed, i.e., the predicted count at a site is constant for all the sessions in a particular season of a year.
- Observed counts are described by a Poisson-gamma distribution.

Catch

The catch data were analysed using the same overdispersed Poisson model as the count data to provide estimates of relative abundance.

Site Fidelity

The extent to which sites are closed, i.e., fish remain at the same site between sessions, was evaluated from a binomial "t-test" (Kery, 2010, pp. 211-213). The "t-test" estimated the probability that intra-annual recaptures were caught at a different site as previously encountered.

Key assumptions of the site fidelity model include:

- Site fidelity varies with season.
- Observed site fidelity is described by a bernoulli distribution.

Abundance

The catch data were also analysed using a capture-recapture-based binomial mixture model (Kery, 2010; Kery and Schaub, 2011, pp. 253-257 and 134-136, 384-388) 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 abundance model include:

- Lineal density (fish/km) varies with discharge regime, season and river km.
- Lineal density (fish/km) varies randomly with site, year and the interaction between site and year.
- The relationship between density and river kilometre (distribution) varies with discharge regime and season.
- The relationship between density and river kilometre (distribution) varies randomly with year.
- Efficiency (probability of capture) varies randomly by session within season and year.
- Marked and unmarked fish have the same probability of capture.
- There is no tag loss, mortality or misidentification of fish.
- Sites are closed.
- The number of fish captured are described by binomial distributions.

Capture Efficiency

In order to estimate the capture efficiency independent of abundance a recapture-based binomial model (Kery, 2010; Kery and Schaub, 2011, pp. 253-257 and 134-136,384-388) was fitted to just the marked fish. To maximize the number of recaptures the model grouped all the sites into a supersite.

Key assumptions of the efficiency model include:

- Efficiency (probability of capture) varies randomly by session within season and year.
- There is no tag loss, mortality or misidentification of fish.
- The supersite is closed.

- The number of marked fish caught is described by a binomial distribution.

Growth

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

Key assumptions of the growth model include:

- The growth coefficient varies with discharge regime.
- The growth coefficient varies randomly with year.
- Observed growth (change in length) is normally distributed.

Condition

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

Key assumptions of the condition model include:

- Weight varies with length, discharge regime and season.
- Weight varies randomly with site, year and the interaction between site and year.
- Weight is log-normally distributed.

Length

Mean length was estimated from the measured lengths.

Key assumptions of the length model include:

- Length varies with discharge regime and season.
- Length varies randomly with site, year and the interaction between site and year.
- Length is log-normally distributed.

Biomass

The biomass was calculated from the posterior distributions for the Length, Condition and Abundance analyses.

Multivariate Analyses

In order to examine the relationships between environmental variables and the fish indexing metrics multivariate analyses were performed. More specifically the trimonthly mean discharge and elevation and the trimonthly mean absolute hourly discharge change were analysed to get their five primary eigenvectors. Next the correlations between the trimonthly environmental time series and the eigenvectors was quantified using a Bayesian model. The same model was also used to quantify the correlations between the eigenvectors and fish indexing time series related to the management hypotheses. Significant relationships were indicated using time series/eigenvector connectivity plots were nodes are connected if the relationship is significant and positive relationships are in black and negative ones in red.

Model Code

The first three tables describe the JAGS distributions, functions and operators used in the models. For additional information on the JAGS dialect of the BUGS language see the JAGS User Manual (Plummer, 2012).

JAGS Distributions

Distribution	Description
`dbern(p)`	Bernoulli distribution
`dbin(p, n)`	Binomial distribution
`dgamma(shape, rate)`	Gamma distribution
`dlnorm(mu, sd^-2)`	Log-normal distribution
`dnorm(mu, sd^-2)`	Normal distribution
`dpois(lambda)`	Poisson distribution
`dunif(a, b)`	Uniform distribution

JAGS Functions

Function	Description
`exp(x)`	Exponential of *x*
`inprod(x,y)`	Inner product of *x* and *y*
`length(x)`	Length of vector *x*
`log(x)`	Natural logarithm of *x*
`logit(x)`	Log-odds of *x*
`max(x,y)`	Maximum of *x* and *y*
`min(x,y)`	Minimum of *x* and *y*
`step(x)`	Test for *x* >= 0
`sum(a)`	Sum of elements of *a*
`T(x,y)`	Truncate distribution so that values lie between *x* and *y*

JAGS Operators

Operator	Description
`<-`	Deterministic relationship
`~`	Stochastic relationship
`1:n`	Vector of integers from *1* to *n*
`a[1:n]`	Subset of first *n* values in *a*
`for (i in 1:n) {...}`	Repeat *...* for *1* to *n* times incrementing *i* each time
`x^y`	Power where *x* is raised to the power of *y*

Variable and parameter definitions and JAGS model code for the analyses are presented below.

The model code adopts the following naming conventions:

- data variables are named using upper camel case, i.e., site length is `SiteLength`
- the number of levels of a discrete data variable `Factor` is referenced by `nFactor`
- estimated parameters are named using upper camel case prefixed by a lower case character, i.e., `bDensityRegime`
- the SD of a vector of estimated random effects `bRandom` is indicated by `sRandom`
- unless stated otherwise all effects are linear

All fish lengths are in mm.

Occupancy

Variable/Parameter	Description
`bOccupancy`	Intercept of `logit(eOccupancy)`
`bOccupancyRegime[i]`	Effect of *ith* regime on `logit(eOccupancy)`
`bOccupancySeason[i]`	Effect of *ith* season on `logit(eOccupancy)`
`bOccupancySite[i]`	Effect of *ith* site on `logit(eOccupancy)`
`bOccupancySiteYear[i, j]`	Effect of *ith* site in *jth* year on `logit(eOccupancy)`
`bOccupancyYear[i]`	Effect of *ith* year on `logit(eOccupancy)`
`eObserved[i]`	Predicted probability of observing species on *ith* site visit
`eOccupancy[i]`	Predicted occupancy (species presence versus absence) on *ith* site visit
`Observed[i]`	Whether the species was observed on *ith* site visit

Occupancy - Model 1

```
model {

  bOccupancy ~ dnorm(0, 5^-2)

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

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

  sOccupancyYear ~ dunif(0, 5)
```

```
  for (yr in 1:nYear) {
    bOccupancyYear[yr] ~ dnorm(0, sOccupancyYear^-2)
  }

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

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

    logit(eOccupancy[i]) <- bOccupancy
      + bOccupancyRegime[Regime[i]] + bOccupancySeason[Season[i]]
      + bOccupancySite[Site[i]] + bOccupancyYear[Year[i]]
      + bOccupancySiteYear[Site[i],Year[i]]

    eObserved[i] <- eOccupancy[i]

    Observed[i] ~ dbern(eObserved[i])
  }
}
```

Count

Variable/Parameter	Description
`bDensity`	Intercept of `log(eDensity)`
`bDensityRegime[i]`	Effect of *ith* regime on `log(eDensity)`
`bDensitySeason[i]`	Effect of *ith* season on `log(eDensity)`
`bDensitySite[i]`	Effect of *ith* site on `log(eDensity)`
`bDensitySiteYear[i, j]`	Effect of *ith* site in *jth* year on `log(eDensity)`
`bDensityYear[i]`	Effect of *ith* year on `log(eDensity)`
`bDispersion`	Overdispersion parameter
`bDistribution`	Intercept of `eDistribution`
`bDistributionRegime[i]`	Effect of *ith* regime on `eDistribution`
`bDistributionSeason[i]`	Effect of *ith* season on `eDistribution`
`bDistributionYear[i]`	Effect of *ith* year on `eDistribution`
`Count[i]`	Count on *ith* site visit
`eCount[i]`	Predicted count on *ith* site visit
`eDensity[i]`	Predicted lineal count density on *ith* site visit
`eDispersion[i]`	Predicted dispersion on *ith* site visit

`eDistribution[i]`	Predicted effect of centred river kilometre on *ith* site visit on `log(eDensity)`

Count - Model 1

```
model {

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

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

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

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

  bDispersion ~ dgamma(0.1, 0.1)

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

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

    log(eDensity[i]) <- bDensity
```

```
      + eDistribution[i] * RiverKm[i]
      + bDensityRegime[Regime[i]] + bDensitySeason[Season[i]]
      + bDensitySite[Site[i]] + bDensityYear[Year[i]]
      + bDensitySiteYear[Site[i],Year[i]]

    eCount[i] <- eDensity[i] * SiteLength[i] * ProportionSampled[i]

    eDispersion[i] ~ dgamma(bDispersion, bDispersion)

    Count[i] ~ dpois(eCount[i] * eDispersion[i])
  }
  tAbundance <- bDensityRegime[2]
  tDistribution <- bDistributionRegime[2]
}
```

Catch

Variable/Parameter	Description
`bDensity`	Intercept of `log(eDensity)`
`bDensityRegime[i]`	Effect of *ith* regime on `log(eDensity)`
`bDensitySeason[i]`	Effect of *ith* season on `log(eDensity)`
`bDensitySite[i]`	Effect of *ith* site on `log(eDensity)`
`bDensitySiteYear[i, j]`	Effect of *ith* site in *jth* year on `log(eDensity)`
`bDensityYear[i]`	Effect of *ith* year on `log(eDensity)`
`bDispersion`	Overdispersion parameter
`bDistribution`	Intercept of `eDistribution`
`bDistributionRegime[i]`	Effect of *ith* regime on `eDistribution`
`bDistributionSeason[i]`	Effect of *ith* season on `eDistribution`
`bDistributionYear[i]`	Effect of *ith* year on `eDistribution`
`Catch[i]`	Catch on *ith* site visit
`eCatch[i]`	Predicted catch on *ith* site visit
`eDensity[i]`	Predicted lineal catch density on *ith* site visit
`eDispersion[i]`	Predicted dispersion on *ith* site visit
`eDistribution[i]`	Predicted effect of centred river kilometre on *ith* site visit on `log(eDensity)`

Catch - Model 1

```
model {

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

  bDensityRegime[1] <- 0
```

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

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

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

bDispersion ~ dgamma(0.1, 0.1)

for (i in 1:length(Year)) {
  eDistribution[i] <- bDistribution
    + bDistributionRegime[Regime[i]]
    + bDistributionSeason[Season[i]]
    + bDistributionYear[Year[i]]

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

  eCatch[i] <- eDensity[i] * SiteLength[i] * ProportionSampled[i]

  eDispersion[i] ~ dgamma(bDispersion, bDispersion)

  Catch[i] ~ dpois(eCatch[i] * eDispersion[i])
}
```

```
  tAbundance <- bDensityRegime[2]
  tDistribution <- bDistributionRegime[2]
}
```

Site Fidelity

Variable/Parameter	Description
bMoved	Intercept for `logit(eMoved)`
bMovedSeason[i]	Effect of *ith* season on `logit(eMoved)`
eMoved[i]	Predicted probability of different site for *i*th recapture
Moved[i]	Was *ith* recapture recorded at a different site as previously encountered

Site Fidelity - Model 1

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

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

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

    logit(eMoved[i]) <- bMoved + bMovedSeason[Season[i]]

    Moved[i] ~ dbern(eMoved[i])
  }
}
```

Abundance

Variable/Parameter	Description
`bDensity`	Intercept for `log(eDensity)`
`bDensityRegime[i]`	Effect of *ith* regime on `log(eDensity)`
`bDensitySeason[i]`	Effect of *ith* season on `log(eDensity)`
`bDensitySite[i]`	Effect of *ith* site on `log(eDensity)`
`bDensitySiteYear[i, j]`	Effect of *ith* site in *jth* year on `log(eDensity)`
`bDensityYear[i]`	Effect of *ith* year on `log(eDensity)`
`bDistribution`	Intercept for `eDistribution`
`bDistributionRegime[i]`	Effect of *ith* regime on `eDistribution`
`bDistributionSeason[i]`	Effect of *ith* season on `eDistribution`
`bDistributionYear[i]`	Effect of *ith* year on `eDistribution`
`bEfficiency`	Intercept for `logit(eEfficiency)`

`bEfficiencySessionSeasonYear[i, j, k]`	Effect of i*th* session in j*th* season of k*th* year on `logit(eEfficiency)`
`Catch[i]`	Number of fish caught on i*th* site visit
`eAbundance[i]`	Predicted abundance on i*th* site visit
`eDensity[i]`	Predicted lineal density on i*th* site visit
`eDistribution[i]`	Predicted effect of centred river kilometre on i*th* site visit on `log(eDensity)`
`eEfficiency[i]`	Predicted efficiency during i*th* site visit
`Marked[i]`	Number of marked fish caught in i*th* river visit
`Tagged[i]`	Number of fish tagged prior to i*th* river visit

Abundance - Model 1

```
model {

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

  bDensityRegime[1] <- 0
  bDistributionRegime[1] <- 0
  for(i in 2:nRegime) {
    bDensityRegime[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)
  }

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

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

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

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

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

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

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

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

    eSamplingEfficiency[i] <- min(eEfficiency[i] * ProportionSampled[i], 0.9)

    eAbundance[i] <- max(round(eDensity[i] * SiteLength[i]), MinAbundance[i])

    Catch[i] ~ dbin(eSamplingEfficiency[i], eAbundance[i])
```

```
  }
  tAbundance <- bDensityRegime[2]
  tDistribution <- bDistributionRegime[2]
}
```

Capture Efficiency

Variable/Parameter	Description
`bEfficiency`	Intercept of `logit(eEfficiency)`
`bEfficiencySeason[i]`	Effect of *ith* season on `logit(eEfficiency)`
`bEfficiencySessionSeasonYear[i, j, k]`	Effect of i*th session within j*th season and k*th* year on `logit(eEfficiency)`
`eEfficiency[i]`	Predicted efficiency during i*th* vist
`Marked[i]`	Number of marked fish recaught during i*th* visit
`Tagged[i]`	Number of marked fish tagged prior to i*th* visit

Capture Efficiency - Model 1

```
model {

  bEfficiency ~ dnorm(0, 5^-2)

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

  for(i in 1:length(Year)) {
    logit(eEfficiency[i]) <- bEfficiency
        + bEfficiencySeason[Season[i]]
        + bEfficiencySessionSeasonYear[Session[i], Season[i], Year[i]]

    Marked[i] ~ dbin(eEfficiency[i], Tagged[i])
  }
}
```

Growth

Variable/Parameter	Description
bK	Intercept of `log(eK)`
bKRegime[i]	Effect of *ith* regime on `log(eK)`
bKYear[i]	Effect of *ith* year on `log(eK)`
bLinf	Mean maximum length (von Bertalanffy length-at-infinity)
eGrowth[i]	Predicted growth (change in length) of the *ith* recapture between release and recapture
eK[i]	Predicted von Bertalanffy growth coefficient for *ith* year
Growth[i]	Growth (change in length) of the *ith* recapture between release and recapture
LengthAtRelease[i]	Length of the *ith* recapture when released in a previous year
sGrowth	SD of residual variation in `Growth`
Year[i]	Year the *ith* recapture was released
Years[i]	Number of years between release and recapture for the *ith* recapture

Growth - Model 1

```
model {

  bK ~ dnorm (0, 5^-2)

  bKRegime[1] <- 0
  for(i in 2:nThreshold) {
    bKRegime[i] ~ dunif(-100, 100)
  }

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

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

Condition

Variable/Parameter	Description
`bWeight`	Intercept for `eWeightSlope`
`bWeightLength`	Intercept for `eWeightIntercept`
`bWeightRegime[i]`	Effect of *ith* regime on `eWeightIntercept`
`bWeightSeason[i]`	Effect of *ith* season on `eWeightIntercept`
`bWeightSite[i]`	Effect of *ith* site on `eWeightIntercept`
`bWeightSiteYear[i]`	Effect of *ith* site in *jth* year on `eWeightIntercept`
`bWeightYear[i]`	Effect of *ith* year on `eWeightIntercept`
`eWeightIntercept[i]`	Predicted intercept for `log(eWeight)`
`eWeightSlope[i]`	Predicted effect of centred log length on `log(eWeight)`
`sWeight`	SD of residual variation in `log(Weight)`
`Weight[i]`	Weight of *ith* fish

Condition - Model 1

```
model {

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

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

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

  sWeightYear ~ dunif(0, 5)
  for(yr in 1:nYear) {
    bWeightYear[yr] ~ dnorm(0, sWeightYear^-2)
  }

  sWeightSite ~ dunif(0, 5)
  sWeightSiteYear ~ dunif(0, 5)
  for(st in 1:nSite) {
    bWeightSite[st] ~ dnorm(0, sWeightSite^-2)
    for(yr in 1:nYear) {
      bWeightSiteYear[st, yr] ~ dnorm(0, sWeightSiteYear^-2)
    }
  }
```

```
  sWeight ~ dunif(0, 5)

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

    eWeightIntercept[i] <- bWeight
        + bWeightRegime[Regime[i]]
        + bWeightSeason[Season[i]]
        + bWeightYear[Year[i]] + bWeightSite[Site[i]]
        + bWeightSiteYear[Site[i],Year[i]]

    eWeightSlope[i] <- bWeightLength

    log(eWeight[i]) <- eWeightIntercept[i] + eWeightSlope[i] * Length[i]

    Weight[i] ~ dlnorm(log(eWeight[i]), sWeight^-2)
  }
  tCondition <- bWeightRegime[2]
}
```

Length

Variable/Parameter	Description
`bLength`	Intercept for `log(eLength)`
`bLengthRegime[i]`	Effect of *ith* regime on `log(eLength)`
`bLengthSeason[i]`	Effect of *ith* season on `log(eLength)`
`bLengthSite[i]`	Effect of *ith* site on `log(eLength)`
`bLengthSiteYear[i, j]`	Effect of *ith* site in *jth* year on `log(eLength)`
`bLengthYear[i]`	Effect of *ith* year on `log(eLength)`
`eLength[i]`	Predicted length of *ith* fish
`Length[i]`	Length of *ith* fish
`sLength`	SD of residual variation in `log(Length)`

Length - Model 1

```
model {

  bLength ~ dnorm(5, 5^-2)

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

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

```
  sLengthYear ~ dunif(0, 5)
  for(yr in 1:nYear) {
    bLengthYear[yr] ~ dnorm(0, sLengthYear^-2)
  }

  sLengthSite ~ dunif(0, 5)
  sLengthSiteYear ~ dunif(0, 5)
  for(st in 1:nSite) {
    bLengthSite[st] ~ dnorm(0, sLengthSite^-2)
    for(yr in 1:nYear) {
      bLengthSiteYear[st, yr] ~ dnorm(0, sLengthSiteYear^-2)
    }
  }

  sLength ~ dunif(0, 5)

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

    log(eLength[i]) <- bLength
      + bLengthRegime[Regime[i]]
      + bLengthSeason[Season[i]]
      + bLengthYear[Year[i]] + bLengthSite[Site[i]]
      + bLengthSiteYear[Site[i],Year[i]]

    Length[i] ~ dlnorm(log(eLength[i]), sLength^-2)
  }
}
```

Multivariate Analysis

Variable/Parameter	Description
Growth[i]	Growth (change in length) of the *ith* recapture between release and recapture

Multivariate Analysis - Model 1

```
model {

  sValue ~ dunif(0, 2)

  for(k in 1:nEigen) {
    sWeight[k] ~ dunif(0, 5)
  }

  for (i in 1:nSeries) {
    for (k in 1:nEigen) {
      Weight[i, k] ~ dnorm(0, sWeight[k]^-2)
    }
```

```
    for (t in 1:nYear) {
      Fit[i, t] <- inprod(Weight[i,], Eigen[,t])
      Value[i, t] ~ dnorm(Fit[i, t], sValue^-2)
    }
  }
}
```

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Appendix G – HBA Results

Hierarchical Bayesian Analyses - Results

Parameter Estimates

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

Occupancy - Burbot

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bOccupancy	-2.2243	-3.2268	-1.26453	0.4998	44	0.0000
bOccupancyRegime[2]	1.2182	-0.3243	2.78136	0.7831	127	0.1158
bOccupancySeason[2]	-0.7246	-1.3942	-0.06423	0.3401	92	0.0299
sOccupancySite	0.9846	0.5684	1.58687	0.2708	52	0.0000
sOccupancySiteYear	0.6540	0.3292	1.03038	0.1851	54	0.0000
sOccupancyYear	1.1530	0.5801	2.03171	0.3927	63	0.0000

Rhat	Iterations
1.05	10000

Occupancy - Kokanee

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bOccupancy	2.0280	0.85462	3.3224	0.6438	61	0.0039
bOccupancyRegime[2]	-1.6457	-4.03807	0.5482	1.1634	139	0.1604
bOccupancySeason[2]	-2.5954	-3.28585	-1.9448	0.3472	26	0.0000
sOccupancySite	0.6502	0.34196	1.1364	0.2036	61	0.0000
sOccupancySiteYear	0.2155	0.01424	0.5630	0.1410	127	0.0000
sOccupancyYear	1.8386	1.06723	3.2947	0.5555	61	0.0000

Rhat	Iterations
1.07	20000

Occupancy - Lake Whitefish

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bOccupancy	-1.2322	-2.21867	-0.3010	0.4829	78	0.0213
bOccupancyRegime[2]	0.1281	-2.00776	1.9421	0.9928	1542	0.8193
bOccupancySeason[2]	-3.9651	-5.84419	-2.5271	0.8241	42	0.0000
sOccupancySite	0.5363	0.13484	0.9556	0.2106	77	0.0000
sOccupancySiteYear	0.2410	0.01188	0.6532	0.1696	133	0.0000
sOccupancyYear	1.3843	0.82480	2.4161	0.4094	57	0.0000

Rhat	Iterations
1.08	20000

Occupancy - Northern Pikeminnow

Parameter	Estimate	Lower	Upper	SD	Error	Significance

bOccupancy	-2.3587	-3.89496	-1.014	0.7355	61	0.0019
bOccupancyRegime[2]	0.3746	-1.63687	2.452	1.0427	546	0.6800
bOccupancySeason[2]	-2.1280	-3.19415	-1.163	0.5191	48	0.0000
sOccupancySite	1.7535	1.03826	2.905	0.4919	53	0.0000
sOccupancySiteYear	0.5397	0.05011	1.068	0.2827	94	0.0000
sOccupancyYear	1.3796	0.66794	2.636	0.5143	71	0.0000

Rhat	Iterations
1.05	40000

Occupancy - Rainbow Trout

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bOccupancy	-1.3013	-2.9073	0.1926	0.7922	119	0.0798
bOccupancyRegime[2]	1.4558	-0.2357	3.0956	0.8237	114	0.0878
bOccupancySeason[2]	-0.2133	-0.8535	0.4149	0.3288	297	0.5250
sOccupancySite	2.4533	1.5918	3.8068	0.5722	45	0.0000
sOccupancySiteYear	0.6737	0.3027	1.0381	0.1939	55	0.0000
sOccupancyYear	1.0899	0.5154	2.0154	0.4117	69	0.0000

Rhat	Iterations
1.1	10000

Occupancy - Redside Shiner

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bOccupancy	-2.3716	-4.23982	-0.7949	0.8313	73	0.0057
bOccupancyRegime[2]	0.7752	-1.06899	2.9853	1.0379	261	0.4406
bOccupancySeason[2]	-0.8266	-1.63757	-0.1026	0.3955	93	0.0190
sOccupancySite	2.3121	1.45116	3.7791	0.6041	50	0.0000
sOccupancySiteYear	0.3160	0.03113	0.7517	0.1896	114	0.0000
sOccupancyYear	1.4292	0.72702	2.5563	0.5003	64	0.0000

Rhat	Iterations
1.03	40000

Occupancy - Sculpin

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bOccupancy	-0.1261	-2.08105	1.5862	0.8813	1454	0.8663
bOccupancyRegime[2]	1.6179	-1.04718	4.2916	1.3942	165	0.2535
bOccupancySeason[2]	-0.4067	-1.03214	0.2153	0.3243	153	0.2076
sOccupancySite	1.3817	0.89407	2.2541	0.3405	49	0.0000
sOccupancySiteYear	0.3106	0.05895	0.6656	0.1605	98	0.0000
sOccupancyYear	2.1245	1.25940	3.3939	0.5627	50	0.0000

Rhat	Iterations
1.04	10000

Count - Bull Trout

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bDensity	2.03514	1.782146	2.30310	0.12550	13	0.0000
bDensityRegime[2]	-0.15827	-0.478551	0.15737	0.16100	201	0.2914
bDensitySeason[2]	0.09524	-0.082556	0.26270	0.08883	181	0.2854
bDispersion	3.18282	2.731092	3.66853	0.24956	15	0.0000
bDistribution	0.01406	-0.067522	0.09333	0.04073	572	0.7425
bDistributionRegime[2]	-0.01865	-0.088326	0.06215	0.03880	403	0.5788
bDistributionSeason[2]	0.14192	0.080945	0.19839	0.02885	41	0.0000
sDensitySite	0.38367	0.237572	0.61871	0.10004	50	0.0000
sDensitySiteYear	0.28498	0.209772	0.36443	0.04005	27	0.0000
sDensityYear	0.18516	0.069146	0.34949	0.07042	76	0.0000
sDistributionYear	0.02571	0.001211	0.07043	0.01961	135	0.0000
tAbundance	-0.15827	-0.478551	0.15737	0.16100	201	0.2914
tDistribution	-0.01865	-0.088326	0.06215	0.03880	403	0.5788

Rhat	Iterations
1.03	1e+05

Count - Burbot

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bDensity	-2.12106	-3.07045	-1.3163	0.4515	41	0.0000
bDensityRegime[2]	1.16720	-0.33222	2.6961	0.7478	130	0.1058
bDensitySeason[2]	-0.90226	-1.47500	-0.3325	0.2903	63	0.0040
bDispersion	0.72088	0.45354	1.1193	0.1762	46	0.0000
bDistribution	-0.08595	-0.33491	0.1597	0.1213	288	0.4232
bDistributionRegime[2]	0.02611	-0.32944	0.3514	0.1719	1304	0.8283
bDistributionSeason[2]	0.06740	-0.15507	0.2853	0.1134	327	0.5649
sDensitySite	0.83747	0.43729	1.3956	0.2585	57	0.0000
sDensitySiteYear	0.43676	0.04984	0.8185	0.1989	88	0.0000
sDensityYear	1.03620	0.48952	1.8225	0.3377	64	0.0000
sDistributionYear	0.15921	0.01340	0.4136	0.1051	126	0.0000
tAbundance	1.16720	-0.33222	2.6961	0.7478	130	0.1058
tDistribution	0.02611	-0.32944	0.3514	0.1719	1304	0.8283

Rhat	Iterations
1.05	1e+05

Count - Mountain Whitefish

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bDensity	4.20214	3.894438	4.52789	0.16448	8	0.0000
bDensityRegime[2]	-0.06864	-0.456495	0.30495	0.18422	555	0.7063
bDensitySeason[2]	0.21478	0.059809	0.37173	0.07941	73	0.0079
bDispersion	2.95799	2.640761	3.29659	0.16811	11	0.0000

bDistribution	0.04481	-0.062326	0.15218	0.05280	239	0.3651
bDistributionRegime[2]	0.01093	-0.067755	0.10829	0.04469	806	0.8373
bDistributionSeason[2]	-0.04340	-0.093992	0.01247	0.02662	123	0.0992
sDensitySite	0.54857	0.355798	0.86988	0.13526	47	0.0000
sDensitySiteYear	0.37655	0.307390	0.45473	0.03812	20	0.0000
sDensityYear	0.21846	0.098504	0.38661	0.07674	66	0.0000
sDistributionYear	0.03029	0.001631	0.09321	0.02307	151	0.0000
tAbundance	-0.06864	-0.456495	0.30495	0.18422	555	0.7063
tDistribution	0.01093	-0.067755	0.10829	0.04469	806	0.8373

Rhat	Iterations
1.04	4e+05

Count - Northern Pikeminnow

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bDensity	-2.61448	-3.879746	-1.6147	0.5558	43	0.0000
bDensityRegime[2]	-0.46532	-2.366936	1.6239	1.0200	429	0.6707
bDensitySeason[2]	-2.14169	-4.330803	-0.4254	1.0217	91	0.0100
bDispersion	0.57842	0.382244	0.8508	0.1203	41	0.0000
bDistribution	-0.43927	-0.712322	-0.2342	0.1245	54	0.0000
bDistributionRegime[2]	-0.30751	-0.741164	0.1251	0.2190	141	0.1277
bDistributionSeason[2]	0.09878	-0.459409	0.6001	0.2709	536	0.7385
sDensitySite	0.45656	0.022681	1.0036	0.2517	107	0.0000
sDensitySiteYear	0.68946	0.229965	1.1685	0.2291	68	0.0000
sDensityYear	1.26637	0.594101	1.9173	0.3654	52	0.0000
sDistributionYear	0.15787	0.006018	0.4540	0.1214	142	0.0000
tAbundance	-0.46532	-2.366936	1.6239	1.0200	429	0.6707
tDistribution	-0.30751	-0.741164	0.1251	0.2190	141	0.1277

Rhat	Iterations
1.02	1e+05

Count - Rainbow Trout

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bDensity	-1.71862	-2.68787	-0.7926	0.48508	55	0.0020
bDensityRegime[2]	1.21956	0.11475	2.3342	0.58085	91	0.0279
bDensitySeason[2]	-0.07506	-0.48545	0.2991	0.19700	523	0.6866
bDispersion	1.44187	1.06036	1.9316	0.21918	30	0.0000
bDistribution	-0.53060	-0.80835	-0.2836	0.13418	49	0.0000
bDistributionRegime[2]	0.20183	-0.04976	0.4657	0.13583	128	0.1018
bDistributionSeason[2]	0.02819	-0.09323	0.1431	0.06079	419	0.6307
sDensitySite	1.25142	0.76876	2.0409	0.33948	51	0.0000
sDensitySiteYear	0.54744	0.37034	0.7580	0.10009	35	0.0000
sDensityYear	0.84055	0.35428	1.5612	0.30746	72	0.0000

sDistributionYear	0.13308	0.02558	0.3071	0.06994	106	0.0000
tAbundance	1.21956	0.11475	2.3342	0.58085	91	0.0279
tDistribution	0.20183	-0.04976	0.4657	0.13583	128	0.1018

	Rhat	Iterations
	1.04	1e+05

Count - Suckers

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bDensity	2.00579	1.647942	2.36984	0.17535	18	0.0000
bDensityRegime[2]	0.66181	0.234254	1.08487	0.20776	64	0.0060
bDensitySeason[2]	-0.51602	-0.752171	-0.27660	0.12388	46	0.0000
bDispersion	1.53388	1.329000	1.73733	0.10764	13	0.0000
bDistribution	-0.14356	-0.264984	-0.04295	0.05643	77	0.0080
bDistributionRegime[2]	0.05502	-0.062730	0.20398	0.06801	242	0.3752
bDistributionSeason[2]	-0.13029	-0.214682	-0.05513	0.04183	61	0.0020
sDensitySite	0.48648	0.284109	0.82393	0.14317	55	0.0000
sDensitySiteYear	0.44806	0.331650	0.56767	0.05974	26	0.0000
sDensityYear	0.26785	0.064797	0.53524	0.11556	88	0.0000
sDistributionYear	0.05421	0.004028	0.14324	0.03714	128	0.0000
tAbundance	0.66181	0.234254	1.08487	0.20776	64	0.0060
tDistribution	0.05502	-0.062730	0.20398	0.06801	242	0.3752

	Rhat	Iterations
	1.03	1e+05

Catch - Juvenile Bull Trout

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bDensity	-0.41950	-1.146359	0.20692	0.32877	161	0.1796
bDensityRegime[2]	0.52515	-0.503355	1.66320	0.54884	206	0.3194
bDensitySeason[2]	0.04370	-0.189475	0.28269	0.11955	540	0.7465
bDispersion	5.42367	3.431977	8.88822	1.34990	50	0.0000
bDistribution	-0.02235	-0.154525	0.11542	0.06625	604	0.7046
bDistributionRegime[2]	-0.03931	-0.187350	0.09012	0.06723	353	0.4930
bDistributionSeason[2]	0.02573	-0.049026	0.10159	0.03930	293	0.5190
sDensitySite	0.65279	0.406477	1.07973	0.16925	52	0.0000
sDensitySiteYear	0.13048	0.003729	0.28469	0.08052	108	0.0000
sDensityYear	0.78113	0.445743	1.33116	0.22610	57	0.0000
sDistributionYear	0.05395	0.002564	0.18482	0.04897	169	0.0000
tAbundance	0.52515	-0.503355	1.66320	0.54884	206	0.3194
tDistribution	-0.03931	-0.187350	0.09012	0.06723	353	0.4930

	Rhat	Iterations
	1.05	1e+05

Catch - Juvenile Mountain Whitefish

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bDensity	0.16276	-0.78433	1.24596	0.49411	624	0.7166
bDensityRegime[2]	-0.36635	-1.92367	1.72488	0.84939	498	0.5210
bDensitySeason[2]	0.97123	0.73845	1.19147	0.11588	23	0.0000
bDispersion	3.55936	2.50852	5.13174	0.67879	37	0.0000
bDistribution	0.08046	-0.14256	0.29649	0.11146	273	0.4491
bDistributionRegime[2]	0.03091	-0.18802	0.26359	0.11392	731	0.7645
bDistributionSeason[2]	-0.09298	-0.17787	-0.01611	0.04195	87	0.0120
sDensitySite	0.90675	0.58063	1.47701	0.21766	49	0.0000
sDensitySiteYear	0.48345	0.32964	0.64415	0.08038	33	0.0000
sDensityYear	0.86916	0.40454	1.75268	0.35388	78	0.0000
sDistributionYear	0.10919	0.01236	0.28871	0.08381	127	0.0000
tAbundance	-0.36635	-1.92367	1.72488	0.84939	498	0.5210
tDistribution	0.03091	-0.18802	0.26359	0.11392	731	0.7645

Rhat	Iterations
1.09	1e+05

Catch - Adult Bull Trout

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bDensity	0.78732	0.457109	1.149900	0.17129	44	0.0000
bDensityRegime[2]	-0.26182	-0.656633	0.122127	0.19566	149	0.1697
bDensitySeason[2]	-0.21097	-0.431215	0.004242	0.10908	103	0.0619
bDispersion	4.49381	3.209098	6.261625	0.76510	34	0.0000
bDistribution	0.04665	-0.061424	0.157822	0.05351	235	0.3653
bDistributionRegime[2]	0.02317	-0.084402	0.130666	0.05409	464	0.6826
bDistributionSeason[2]	0.16037	0.077826	0.245413	0.04080	52	0.0000
sDensitySite	0.48746	0.295988	0.775417	0.12735	49	0.0000
sDensitySiteYear	0.38464	0.279302	0.500791	0.05477	29	0.0000
sDensityYear	0.22193	0.029268	0.437854	0.10279	92	0.0000
sDistributionYear	0.03751	0.002177	0.096973	0.02580	126	0.0000
tAbundance	-0.26182	-0.656633	0.122127	0.19566	149	0.1697
tDistribution	0.02317	-0.084402	0.130666	0.05409	464	0.6826

Rhat	Iterations
1.02	1e+05

Catch - Adult Mountain Whitefish

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bDensity	2.72254	2.409243	3.052607	0.15567	12	0.0000
bDensityRegime[2]	-0.08813	-0.371264	0.177327	0.14015	311	0.5170
bDensitySeason[2]	0.35130	0.212342	0.500749	0.07282	41	0.0000
bDispersion	4.23060	3.640658	4.880453	0.30392	15	0.0000

bDistribution	0.09529	-0.012867	0.211395	0.05517	118	0.0878
bDistributionRegime[2]	0.02350	-0.098944	0.153396	0.06555	537	0.6946
bDistributionSeason[2]	-0.05805	-0.111677	-0.003328	0.02630	93	0.0379
sDensitySite	0.52305	0.340636	0.815730	0.12414	45	0.0000
sDensitySiteYear	0.34517	0.276420	0.420760	0.03622	21	0.0000
sDensityYear	0.12532	0.009733	0.286938	0.07014	111	0.0000
sDistributionYear	0.07254	0.016579	0.142725	0.03123	87	0.0000
tAbundance	-0.08813	-0.371264	0.177327	0.14015	311	0.5170
tDistribution	0.02350	-0.098944	0.153396	0.06555	537	0.6946

Rhat	Iterations
1.05	1e+05

Catch - Adult Rainbow Trout

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bDensity	-2.39475	-3.256340	-1.60981	0.4150	34	0.0000
bDensityRegime[2]	0.78385	-0.036726	1.57844	0.4011	103	0.0539
bDensitySeason[2]	-0.48276	-1.032504	0.06893	0.2704	114	0.0758
bDispersion	3.87290	1.160833	12.62729	2.9172	148	0.0000
bDistribution	-0.34522	-0.635832	-0.03433	0.1561	87	0.0319
bDistributionRegime[2]	0.21841	-0.104383	0.56106	0.1681	152	0.1457
bDistributionSeason[2]	-0.01177	-0.222400	0.17702	0.1015	1697	0.9242
sDensitySite	1.07260	0.604075	1.91570	0.3374	61	0.0000
sDensitySiteYear	0.43798	0.041438	0.84705	0.2099	92	0.0000
sDensityYear	0.29111	0.006331	0.92494	0.2477	158	0.0000
sDistributionYear	0.13233	0.007455	0.42741	0.1138	159	0.0000
tAbundance	0.78385	-0.036726	1.57844	0.4011	103	0.0539
tDistribution	0.21841	-0.104383	0.56106	0.1681	152	0.1457

Rhat	Iterations
1.09	1e+05

Catch - Adult Sucker (Largescale)

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bDensity	1.11165	-0.34196	2.93510	0.73401	147	0.0995
bDensityRegime[2]	0.79642	-1.47291	2.69679	0.94959	262	0.3005
bDensitySeason[2]	-1.81915	-2.08174	-1.55303	0.13415	15	0.0000
bDispersion	2.89590	2.04700	4.06981	0.51552	35	0.0000
bDistribution	-0.11689	-0.41797	0.16425	0.14137	249	0.2846
bDistributionRegime[2]	0.06797	-0.34436	0.44484	0.18312	581	0.5891
bDistributionSeason[2]	-0.17724	-0.26282	-0.09096	0.04482	48	0.0000
sDensitySite	0.43466	0.22877	0.76316	0.13558	61	0.0000
sDensitySiteYear	0.32996	0.14991	0.51288	0.09726	55	0.0000
sDensityYear	0.83043	0.29912	1.85495	0.40558	94	0.0000

sDistributionYear	0.15358	0.01124	0.54801	0.13879	175	0.0000
tAbundance	0.79642	-1.47291	2.69679	0.94959	262	0.3005
tDistribution	0.06797	-0.34436	0.44484	0.18312	581	0.5891

	Rhat	Iterations
	1.08	2e+05

Site Fidelity - Juvenile Bull Trout

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bMoved	-0.3666	-0.8919	0.1367	0.2549	140	0.1373
bMovedSeason[2]	-0.2816	-1.4484	0.8074	0.5836	400	0.6440

Rhat	Iterations
1.03	1000

Site Fidelity - Juvenile Mountain Whitefish

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bMoved	1.0002	-0.6411	2.943	0.9167	179	0.2480
bMovedSeason[2]	0.1488	-2.2370	2.673	1.2608	1650	0.8907

Rhat	Iterations
1.02	1000

Site Fidelity - Adult Bull Trout

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bMoved	0.6329	0.2214	1.080	0.2153	68	0.0027
bMovedSeason[2]	1.6167	0.1320	3.456	0.8519	103	0.0373

Rhat	Iterations
1.01	1000

Site Fidelity - Adult Mountain Whitefish

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bMoved	0.03725	-0.1455	0.2122	0.09477	480	0.664
bMovedSeason[2]	-1.23878	-1.5866	-0.9104	0.17062	27	0.000

Rhat	Iterations
1.02	1000

Site Fidelity - Adult Rainbow Trout

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bMoved	-0.412	-1.654	0.6798	0.6029	283	0.5053
bMovedSeason[2]	-1.522	-4.689	1.0500	1.4011	188	0.2573

Rhat	Iterations
1.02	1000

Site Fidelity - Adult Sucker (Largescale)

Parameter	Estimate	Lower	Upper	SD	Error	Significance

bMoved	-0.3889	-1.005	0.1484	0.2928	148	0.1787
bMovedSeason[2]	-0.4122	-2.394	1.4496	0.9652	466	0.6853

Rhat	Iterations
1.02	1000

Abundance - Juvenile Mountain Whitefish

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bDensity	5.90978	4.626464	7.19876	0.63866	22	0.0000
bDensityRegime[2]	-0.48239	-1.786131	0.88208	0.68033	277	0.4199
bDensitySeason[2]	0.27648	-0.794851	1.41687	0.54572	400	0.6129
bDistribution	0.08705	-0.119295	0.30528	0.10663	244	0.3900
bDistributionRegime[2]	0.02051	-0.194031	0.26127	0.12256	1110	0.8279
bDistributionSeason[2]	-0.08247	-0.137233	-0.02828	0.02876	66	0.0080
bEfficiency	-5.80413	-6.623554	-5.00042	0.41590	14	0.0000
bEfficiencySeason[2]	0.68501	-0.422483	1.74098	0.55216	158	0.2030
sDensitySite	0.91820	0.567997	1.46611	0.23071	49	0.0000
sDensitySiteYear	0.54555	0.424362	0.69262	0.07128	25	0.0000
sDensityYear	0.83364	0.396244	1.78407	0.34205	83	0.0000
sDistributionYear	0.10433	0.009736	0.29296	0.07384	136	0.0000
sEfficiencySessionSeasonYear	0.28712	0.194558	0.41464	0.05631	38	0.0000
tAbundance	-0.48239	-1.786131	0.88208	0.68033	277	0.4199
tDistribution	0.02051	-0.194031	0.26127	0.12256	1110	0.8279

Rhat	Iterations
1.04	2e+05

Abundance - Adult Bull Trout

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bDensity	4.20835	3.821262	4.56973	0.19401	9	0.0000
bDensityRegime[2]	-0.21596	-0.651413	0.21110	0.21768	200	0.3114
bDensitySeason[2]	-0.31832	-0.901175	0.27665	0.29307	185	0.2615
bDistribution	0.04286	-0.056668	0.14114	0.05116	231	0.3952
bDistributionRegime[2]	0.02290	-0.075820	0.12272	0.05129	433	0.6707
bDistributionSeason[2]	0.17070	0.109112	0.23041	0.03079	36	0.0000
bEfficiency	-3.44160	-3.657811	-3.23149	0.10937	6	0.0000
bEfficiencySeason[2]	0.05735	-0.490728	0.59937	0.28234	950	0.8204
sDensitySite	0.48441	0.289877	0.80582	0.12856	53	0.0000
sDensitySiteYear	0.45317	0.377749	0.53767	0.04308	18	0.0000
sDensityYear	0.20907	0.020809	0.46557	0.11601	106	0.0000
sDistributionYear	0.03979	0.001965	0.09882	0.02755	122	0.0000
sEfficiencySessionSeasonYear	0.28829	0.210698	0.38018	0.04264	29	0.0000
tAbundance	-0.21596	-0.651413	0.21110	0.21768	200	0.3114
tDistribution	0.02290	-0.075820	0.12272	0.05129	433	0.6707

	Rhat	Iterations
	1.02	1e+05

Abundance - Adult Mountain Whitefish

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bDensity	6.59232	6.165380	6.92823	0.18858	6	0.0000
bDensityRegime[2]	-0.06525	-0.393118	0.24133	0.15677	486	0.6806
bDensitySeason[2]	-0.54611	-0.771560	-0.33029	0.11430	40	0.0000
bDistribution	0.08668	-0.014721	0.19071	0.05271	118	0.0998
bDistributionRegime[2]	0.03421	-0.075782	0.13989	0.05447	315	0.5010
bDistributionSeason[2]	-0.06937	-0.089339	-0.04591	0.01097	31	0.0000
bEfficiency	-3.91010	-4.036179	-3.78523	0.06366	3	0.0000
bEfficiencySeason[2]	0.88554	0.647967	1.10707	0.12039	26	0.0000
sDensitySite	0.54654	0.344551	0.91054	0.14730	52	0.0000
sDensitySiteYear	0.42053	0.369420	0.48258	0.03015	13	0.0000
sDensityYear	0.11325	0.009933	0.27993	0.07255	119	0.0000
sDistributionYear	0.06342	0.010889	0.13389	0.03010	97	0.0000
sEfficiencySessionSeasonYear	0.26836	0.218023	0.32712	0.02823	20	0.0000
tAbundance	-0.06525	-0.393118	0.24133	0.15677	486	0.6806
tDistribution	0.03421	-0.075782	0.13989	0.05447	315	0.5010

	Rhat	Iterations
	1.09	1e+05

Abundance - Adult Sucker (Largescale)

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bDensity	4.7654	3.37994	6.093932	0.66594	28	0.0000
bDensityRegime[2]	0.8763	-0.83660	2.535281	0.81215	192	0.2282
bDensitySeason[2]	-0.9872	-1.85660	-0.020303	0.45862	93	0.0476
bDistribution	-0.1368	-0.52594	0.177661	0.18025	257	0.3452
bDistributionRegime[2]	0.1175	-0.32821	0.716513	0.23558	444	0.5159
bDistributionSeason[2]	-0.2217	-0.29178	-0.155417	0.03443	31	0.0000
bEfficiency	-3.7923	-4.12324	-3.470488	0.16789	9	0.0000
bEfficiencySeason[2]	-0.9270	-1.91299	-0.004846	0.46478	103	0.0516
sDensitySite	0.4030	0.15509	0.715174	0.13647	69	0.0000
sDensitySiteYear	0.4896	0.35508	0.656606	0.07685	31	0.0000
sDensityYear	0.7971	0.21464	1.831250	0.41390	101	0.0000
sDistributionYear	0.1868	0.02085	0.634588	0.16930	164	0.0000
sEfficiencySessionSeasonYear	0.3684	0.25294	0.532247	0.07165	38	0.0000
tAbundance	0.8763	-0.83660	2.535281	0.81215	192	0.2282
tDistribution	0.1175	-0.32821	0.716513	0.23558	444	0.5159

	Rhat	Iterations
	1.03	4e+05

Capture Efficiency - Juvenile Bull Trout

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bEfficiency	-3.0780	-3.4822	-2.7502	0.1916	12	0.0000
bEfficiencySeason[2]	-0.3587	-1.0863	0.4153	0.3878	209	0.3573
sEfficiencySessionSeasonYear	0.5802	0.1161	1.0220	0.2216	78	0.0000

Rhat	Iterations
1.04	10000

Capture Efficiency - Juvenile Mountain Whitefish

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bEfficiency	-5.9845	-7.200744	-5.081	0.5538	18	0.0000
bEfficiencySeason[2]	0.8390	-0.640380	2.294	0.7142	175	0.2136
sEfficiencySessionSeasonYear	0.6398	0.007024	1.884	0.5057	147	0.0000

Rhat	Iterations
1.05	10000

Capture Efficiency - Adult Bull Trout

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bEfficiency	-3.5116	-3.8080	-3.2567	0.1388	8	0.000
bEfficiencySeason[2]	0.2349	-0.3585	0.8615	0.3315	260	0.501
sEfficiencySessionSeasonYear	0.4639	0.1393	0.8035	0.1690	72	0.000

Rhat	Iterations
1.03	10000

Capture Efficiency - Adult Mountain Whitefish

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bEfficiency	-3.7867	-3.9458	-3.6476	0.07355	4	0
bEfficiencySeason[2]	0.7650	0.4848	1.0510	0.14681	37	0
sEfficiencySessionSeasonYear	0.3148	0.1928	0.4749	0.06982	45	0

Rhat	Iterations
1.02	10000

Capture Efficiency - Adult Rainbow Trout

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bEfficiency	-3.0347	-3.75934	-2.367	0.3660	23	0.000
bEfficiencySeason[2]	0.3818	-0.80690	1.601	0.6098	315	0.523
sEfficiencySessionSeasonYear	0.5147	0.04226	1.337	0.3395	126	0.000

Rhat	Iterations
1.04	10000

Capture Efficiency - Adult Sucker (Largescale)

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bEfficiency	-3.8896	-4.33522	-3.5500	0.2038	10	0.0000

bEfficiencySeason[2]	-0.5687	-1.51340	0.3157	0.4809	161	0.2196
sEfficiencySessionSeasonYear	0.3879	0.05404	0.9453	0.2347	115	0.0000

Rhat	Iterations
1.06	10000

Growth - Bull Trout

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bK	-1.7666	-2.0179	-1.5165	0.1326	14	0.0000
bKRegime[2]	0.0338	-0.4980	0.5531	0.2547	1555	0.8802
bLinf	849.2730	798.1868	912.9158	29.5070	7	0.0000
sGrowth	31.6647	28.9252	34.9028	1.5398	9	0.0000
sKYear	0.2958	0.1398	0.5902	0.1136	76	0.0000
tGrowth	0.0338	-0.4980	0.5531	0.2547	1555	0.8802

Rhat	Iterations
1.02	10000

Growth - Mountain Whitefish

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bK	-2.68292	-3.0977	-2.3186	0.1961	15	0.0000
bKRegime[2]	0.03225	-0.7417	0.7602	0.3759	2329	0.9507
bLinf	362.43462	343.4124	383.7954	10.4440	6	0.0000
sGrowth	10.73578	10.2272	11.2958	0.2761	5	0.0000
sKYear	0.42473	0.2098	0.8103	0.1561	71	0.0000
tGrowth	0.03225	-0.7417	0.7602	0.3759	2329	0.9507

Rhat	Iterations
1.03	20000

Condition - Juvenile Bull Trout

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bWeight	5.51577	5.472969	5.56097	0.022088	1	0.0000
bWeightLength	3.09918	3.070663	3.12740	0.014678	1	0.0000
bWeightRegime[2]	-0.06585	-0.147559	0.02538	0.043816	131	0.1140
bWeightSeason[2]	-0.01355	-0.034853	0.00768	0.010913	157	0.2127
sWeight	0.10405	0.099267	0.10885	0.002481	5	0.0000
sWeightSite	0.01530	0.003232	0.03056	0.007003	89	0.0000
sWeightSiteYear	0.01092	0.001207	0.02512	0.006562	109	0.0000
sWeightYear	0.05737	0.031146	0.09996	0.018806	60	0.0000
tCondition	-0.06585	-0.147559	0.02538	0.043816	131	0.1140

Rhat	Iterations
1.04	40000

Condition - Juvenile Mountain Whitefish

Parameter	Estimate	Lower	Upper	SD	Error	Significance

bWeight	3.5604707	3.5419949	3.57926	0.009583	1	0.0000
bWeightLength	2.9480321	2.8633107	3.03211	0.042966	3	0.0000
bWeightRegime[2]	-0.0164309	-0.0519889	0.02120	0.018460	223	0.3772
bWeightSeason[2]	0.0001869	-0.0181120	0.01736	0.008920	9490	0.9800
sWeight	0.1075213	0.1036648	0.11151	0.001978	4	0.0000
sWeightSite	0.0080554	0.0003498	0.02137	0.005733	130	0.0000
sWeightSiteYear	0.0221623	0.0097315	0.03285	0.005753	52	0.0000
sWeightYear	0.0213545	0.0080408	0.04229	0.008759	80	0.0000
tCondition	-0.0164309	-0.0519889	0.02120	0.018460	223	0.3772

Rhat	Iterations
1.02	10000

Condition - Adult Bull Trout

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bWeight	7.570905	7.5268284	7.616426	0.023215	1	0.0000
bWeightLength	3.043657	3.0026155	3.088092	0.022015	1	0.0000
bWeightRegime[2]	-0.098010	-0.1844099	-0.002311	0.045849	93	0.0444
bWeightSeason[2]	-0.005243	-0.0384774	0.026434	0.016585	619	0.7459
sWeight	0.159374	0.1539146	0.165422	0.002901	4	0.0000
sWeightSite	0.014131	0.0009545	0.033180	0.008411	114	0.0000
sWeightSiteYear	0.027094	0.0116366	0.041598	0.007510	55	0.0000
sWeightYear	0.065032	0.0378199	0.112969	0.019071	58	0.0000
tCondition	-0.098010	-0.1844099	-0.002311	0.045849	93	0.0444

Rhat	Iterations
1.03	20000

Condition - Adult Mountain Whitefish

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bWeight	4.95081	4.932520	4.96848	0.0089447	0	0
bWeightLength	3.17967	3.168084	3.19180	0.0060579	0	0
bWeightRegime[2]	-0.05747	-0.086057	-0.02757	0.0149570	51	0
bWeightSeason[2]	-0.03719	-0.042511	-0.03186	0.0028525	14	0
sWeight	0.09210	0.091005	0.09323	0.0005731	1	0
sWeightSite	0.00932	0.003791	0.01603	0.0032253	66	0
sWeightSiteYear	0.01652	0.013224	0.02026	0.0017949	21	0
sWeightYear	0.02498	0.015077	0.04013	0.0066885	50	0
tCondition	-0.05747	-0.086057	-0.02757	0.0149570	51	0

Rhat	Iterations
1.03	20000

Condition - Adult Rainbow Trout

Parameter	Estimate	Lower	Upper	SD	Error	Significance

bWeight	6.08831	6.0465283	6.1392945	0.023214	1	0.0000
bWeightLength	3.05947	2.9767795	3.1402146	0.041085	3	0.0000
bWeightRegime[2]	-0.01781	-0.1024085	0.0558622	0.040135	444	0.6647
bWeightSeason[2]	-0.05670	-0.1115305	-0.0009062	0.027670	98	0.0479
sWeight	0.09705	0.0844802	0.1105521	0.006745	13	0.0000
sWeightSite	0.01873	0.0006613	0.0532621	0.014162	140	0.0000
sWeightSiteYear	0.02132	0.0013503	0.0544168	0.014839	124	0.0000
sWeightYear	0.04241	0.0071652	0.0920718	0.022475	100	0.0000
tCondition	-0.01781	-0.1024085	0.0558622	0.040135	444	0.6647

Rhat	Iterations
1.04	10000

Length - Juvenile Bull Trout

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bLength	5.72996	5.666876	5.79228	0.030834	1	0.0000
bLengthRegime[2]	-0.03411	-0.101135	0.02221	0.031239	181	0.2515
bLengthSeason[2]	-0.09342	-0.141262	-0.04458	0.024248	52	0.0000
sLength	0.22462	0.214459	0.23563	0.005537	5	0.0000
sLengthSite	0.09459	0.059296	0.14945	0.023731	48	0.0000
sLengthSiteYear	0.04641	0.012123	0.07137	0.013963	64	0.0000
sLengthYear	0.02496	0.002694	0.05352	0.014497	102	0.0000

Rhat	Iterations
1.07	10000

Length - Juvenile Mountain Whitefish

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bLength	5.031096	5.017517	5.045676	0.006890	0	0.00
bLengthRegime[2]	-0.030737	-0.055184	-0.008117	0.011552	77	0.01
bLengthSeason[2]	0.069682	0.060453	0.079195	0.004897	13	0.00
sLength	0.062730	0.060460	0.064986	0.001130	4	0.00
sLengthSite	0.011718	0.005767	0.020016	0.003797	61	0.00
sLengthSiteYear	0.007552	0.001896	0.012831	0.002744	72	0.00
sLengthYear	0.014119	0.007248	0.025400	0.004771	64	0.00

Rhat	Iterations
1.04	10000

Length - Adult Bull Trout

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bLength	6.31237	6.274086	6.35021	0.019502	1	0.0000
bLengthRegime[2]	-0.03744	-0.094524	0.02297	0.029616	157	0.2053
bLengthSeason[2]	0.01916	-0.017943	0.05331	0.018530	186	0.3051
sLength	0.18176	0.175810	0.18817	0.003132	3	0.0000

sLengthSite	0.05599	0.035750	0.08868	0.013542	47	0.0000
sLengthSiteYear	0.01889	0.001564	0.03685	0.009515	93	0.0000
sLengthYear	0.03375	0.014809	0.06153	0.011823	69	0.0000

Rhat	Iterations
1.04	80000

Length - Adult Mountain Whitefish

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bLength	5.48669	5.45668	5.51324	0.0147550	1	0.0000
bLengthRegime[2]	-0.03665	-0.09747	0.01260	0.0272310	150	0.1557
bLengthSeason[2]	-0.02503	-0.03259	-0.01674	0.0041721	32	0.0000
sLength	0.13994	0.13844	0.14145	0.0007813	1	0.0000
sLengthSite	0.03247	0.02058	0.04995	0.0077833	45	0.0000
sLengthSiteYear	0.02351	0.01965	0.02802	0.0021776	18	0.0000
sLengthYear	0.03824	0.02355	0.06395	0.0101290	53	0.0000

Rhat	Iterations
1.08	40000

Length - Adult Rainbow Trout

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bLength	5.86147	5.753889	5.97072	0.05609	2	0.0000
bLengthRegime[2]	-0.04416	-0.188676	0.09999	0.07169	327	0.4748
bLengthSeason[2]	0.04535	-0.056329	0.15494	0.05317	233	0.4122
sLength	0.18965	0.168068	0.21685	0.01261	13	0.0000
sLengthSite	0.14707	0.073783	0.25242	0.04582	61	0.0000
sLengthSiteYear	0.03295	0.001001	0.08619	0.02295	129	0.0000
sLengthYear	0.06814	0.003175	0.17548	0.04721	126	0.0000

Rhat	Iterations
1.05	40000

Length - Adult Sucker (Largescale)

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bLength	6.05062	5.947679	6.10140	0.034319	1	0.000
bLengthRegime[2]	0.03445	-0.031591	0.13290	0.038724	239	0.258
bLengthSeason[2]	-0.03244	-0.044380	-0.02093	0.006127	36	0.000
sLength	0.07415	0.071669	0.07673	0.001293	3	0.000
sLengthSite	0.01454	0.005480	0.02644	0.005181	72	0.000
sLengthSiteYear	0.01180	0.003967	0.01943	0.003912	66	0.000
sLengthYear	0.03429	0.007222	0.11049	0.032254	151	0.000

Rhat	Iterations
1.14	80000

Multivariate Analysis - Environmental

Parameter	Estimate	Lower	Upper	SD	Error	Significance
sValue	0.7031	0.6080	0.812	0.05315	15	0
sWeight[1]	1.8070	1.0478	2.948	0.48500	53	0
sWeight[2]	0.8926	0.2040	1.723	0.37029	85	0
sWeight[3]	0.7793	0.1167	1.518	0.35490	90	0
sWeight[4]	0.8787	0.2163	1.674	0.37193	83	0
sWeight[5]	1.3199	0.6853	2.234	0.40753	59	0

Rhat	Iterations
1.02	10000

Multivariate Analysis - Indexing

Parameter	Estimate	Lower	Upper	SD	Error	Significance
sValue	0.8144	0.73454	0.9015	0.04201	10	0
sWeight[1]	1.4652	0.88325	2.2488	0.34749	47	0
sWeight[2]	0.4808	0.03215	1.0852	0.29986	110	0
sWeight[3]	0.4277	0.01620	0.9354	0.24915	107	0
sWeight[4]	0.8071	0.15416	1.4737	0.33987	82	0
sWeight[5]	0.8335	0.25003	1.4688	0.29258	73	0

Rhat	Iterations
1.07	10000

Significance

The following table summarises the significance levels for the management hypotheses tested in the analyses.

Parameter	Analysis	Species	Stage	Significance	Direction
Growth	Growth	Bull Trout	All	0.8802	
Growth	Growth	Mountain Whitefish	All	0.9507	
Condition	Condition	Bull Trout	Juvenile	0.1140	
Condition	Condition	Bull Trout	Adult	0.0444	-
Condition	Condition	Mountain Whitefish	Juvenile	0.3772	
Condition	Condition	Mountain Whitefish	Adult	0.0000	-
Condition	Condition	Rainbow Trout	Adult	0.6647	
Abundance	Count	Bull Trout	All	0.2914	
Abundance	Abundance	Bull Trout	Adult	0.3114	
Abundance	Count	Mountain Whitefish	All	0.7063	
Abundance	Abundance	Mountain Whitefish	Juvenile	0.4199	
Abundance	Abundance	Mountain Whitefish	Adult	0.6806	
Abundance	Count	Rainbow Trout	All	0.0279	+
Abundance	Count	Burbot	All	0.1058	
Abundance	Count	Northern Pikeminnow	All	0.6707	
Abundance	Abundance	Sucker (Largescale)	Adult	0.2282	
Abundance	Count	Sucker	All	0.0060	+

Distribution	Count	Bull Trout	All	0.5788
Distribution	Abundance	Bull Trout	Adult	0.6707
Distribution	Count	Mountain Whitefish	All	0.8373
Distribution	Abundance	Mountain Whitefish	Juvenile	0.8279
Distribution	Abundance	Mountain Whitefish	Adult	0.5010
Distribution	Count	Rainbow Trout	All	0.1018
Distribution	Count	Burbot	All	0.8283
Distribution	Count	Northern Pikeminnow	All	0.1277
Distribution	Abundance	Sucker (Largescale)	Adult	0.5159
Distribution	Count	Sucker	All	0.3752

Appendix H – Additional Results

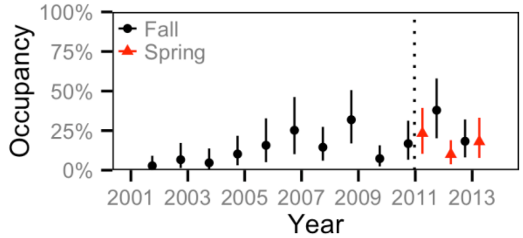

Figure H1. Occupancy estimates (with 95% credible intervals) by year and season for Burbot in the Middle Columbia River study area, 2001 to 2013. The dotted line represents the implementation of the minimum flow release and REV5 operations.

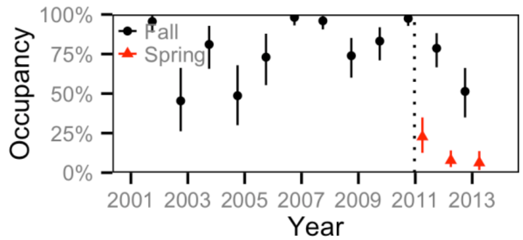

Figure H2. Occupancy estimates (with 95% credible intervals) by year and season for Kokanee in the Middle Columbia River study area, 2001 to 2013. The dotted line represents the implementation of the minimum flow release and REV5 operations.

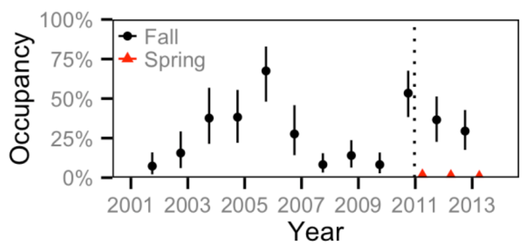

Figure H3. Occupancy estimates (with 95% credible intervals) by year and season for Lake Whitefish in the Middle Columbia River study area, 2001 to 2013. The dotted line represents the implementation of the minimum flow release and REV5 operations.

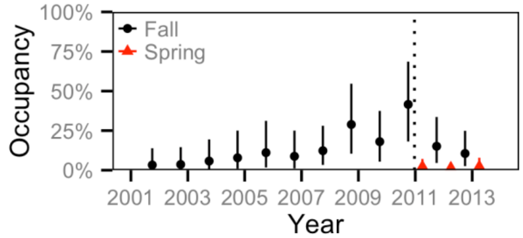

Figure H4: Occupancy estimates (with 95% credible intervals) by year and season for Northern Pikeminnow in the Middle Columbia River study area, 2001 to 2013. The dotted line represents the implementation of the minimum flow release and REV5 operations.

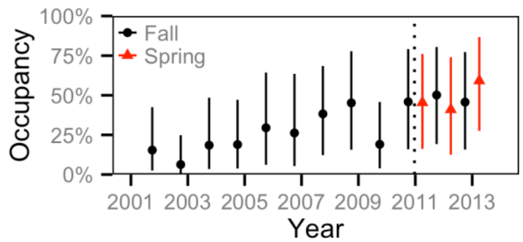

Figure H5. Occupancy estimates (with 95% credible intervals) by year and season for Rainbow Trout in the Middle Columbia River study area, 2001 to 2013. The dotted line represents the implementation of the minimum flow release and REV5 operations.

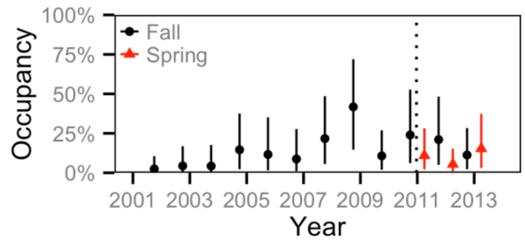

Figure H6. Occupancy estimates (with 95% credible intervals) by year and season for Redside Shiner in the Middle Columbia River study area, 2001 to 2013. The dotted line represents the implementation of the minimum flow release and REV5 operations.

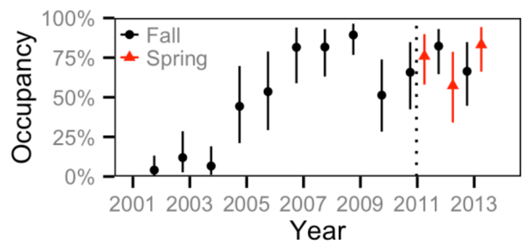

Figure H7. Occupancy estimates (with 95% credible intervals) by year and season for Sculpin species in the Middle Columbia River study area, 2001 to 2013. The dotted line represents the implementation of the minimum flow release and REV5 operations.

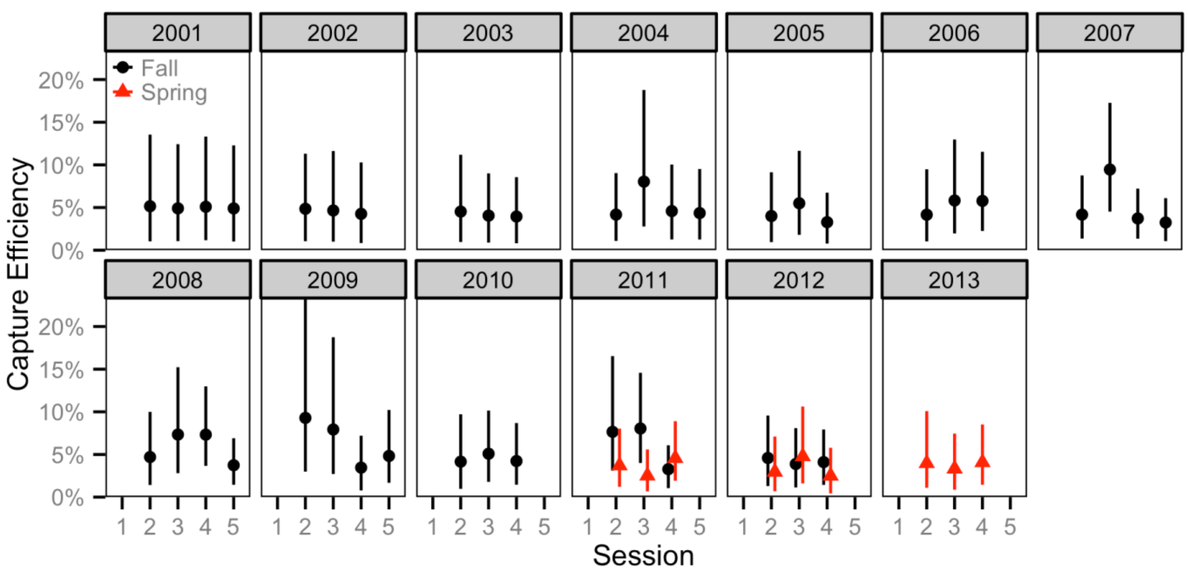

Figure H8. Capture efficiency estimates (with 95% credible intervals) by year, season, and session for juvenile Bull Trout in the Middle Columbia River study area, 2001 to 2013. Efficiency was calculated in the hierarchical Bayesian model estimating absolute abundance using mark-recapture data.

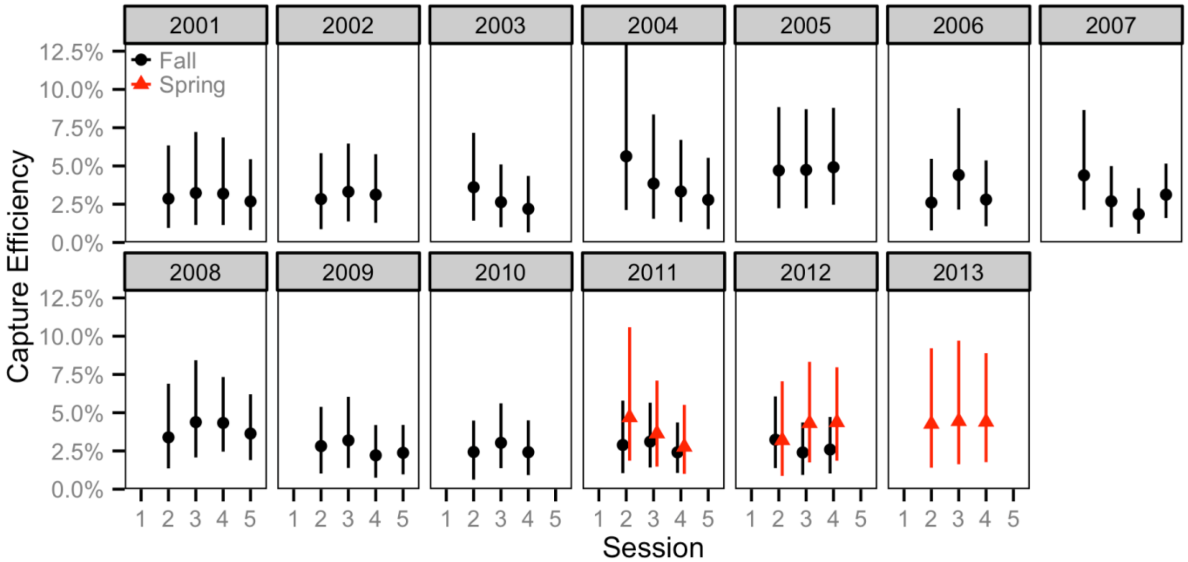

Figure H9. Capture efficiency estimates (with 95% credible intervals) by year, season, and session for adult Bull Trout in the Middle Columbia River study area, 2001 to 2013. Efficiency was calculated in the hierarchical Bayesian model estimating absolute abundance using mark-recapture data.

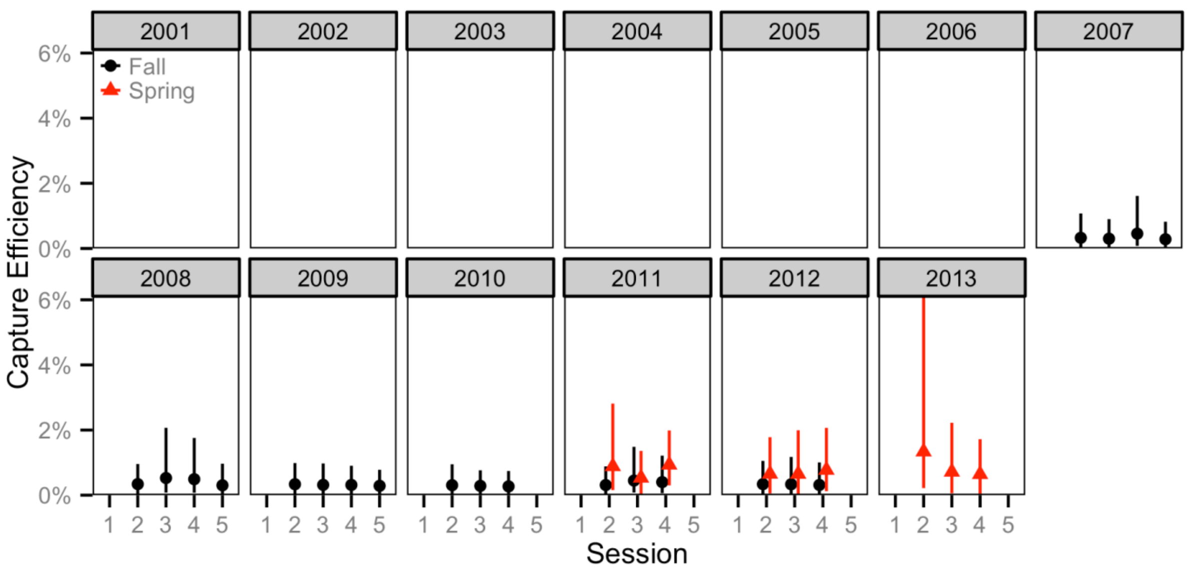

Figure H10. Capture efficiency estimates (with 95% credible intervals) by year, season, and session for juvenile Mountain Whitefish in the Middle Columbia River study area, 2001 to 2013. Efficiency was calculated in the hierarchical Bayesian model estimating absolute abundance using mark-recapture data.

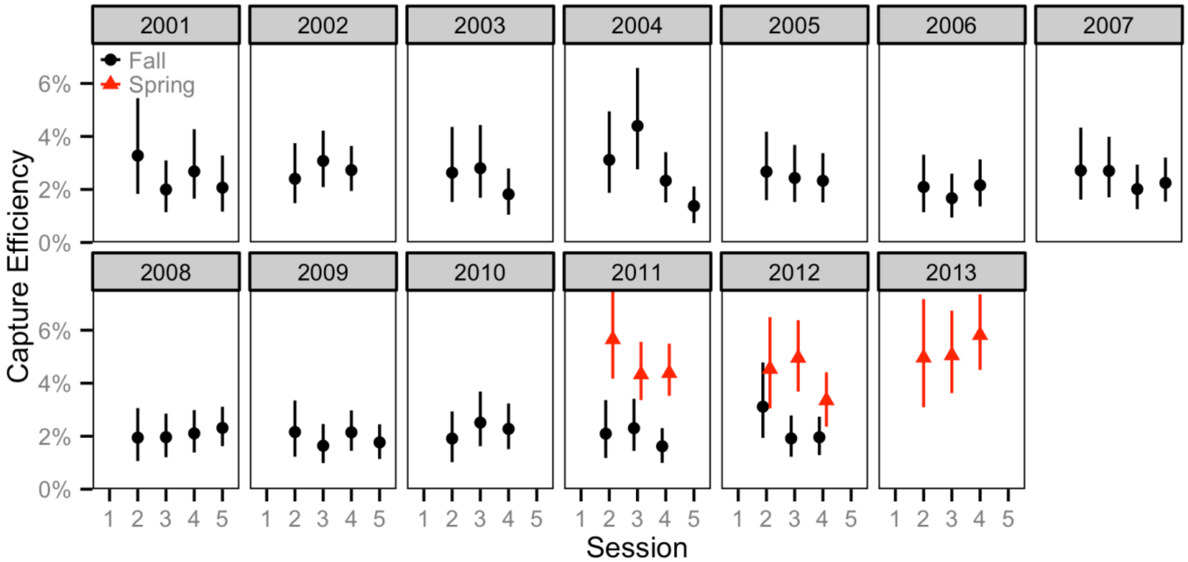

Figure H11. Capture efficiency estimates (with 95% credible intervals) by year, season, and session for adult Mountain Whitefish in the Middle Columbia River study area, 2001 to 2013. Efficiency was calculated in the hierarchical Bayesian model estimating absolute abundance using mark-recapture data.

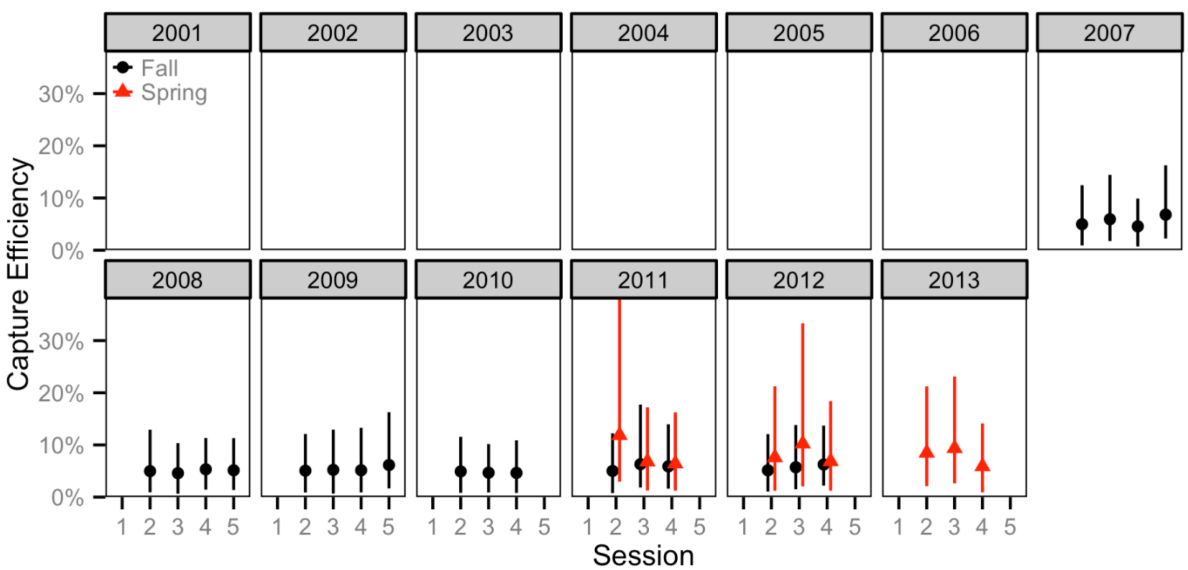

Figure H12. Capture efficiency estimates (with 95% credible intervals) by year, season, and session for adult Rainbow Trout in the Middle Columbia River study area, 2007 to 2013. Efficiency was calculated in the hierarchical Bayesian model estimating absolute abundance using mark-recapture data.

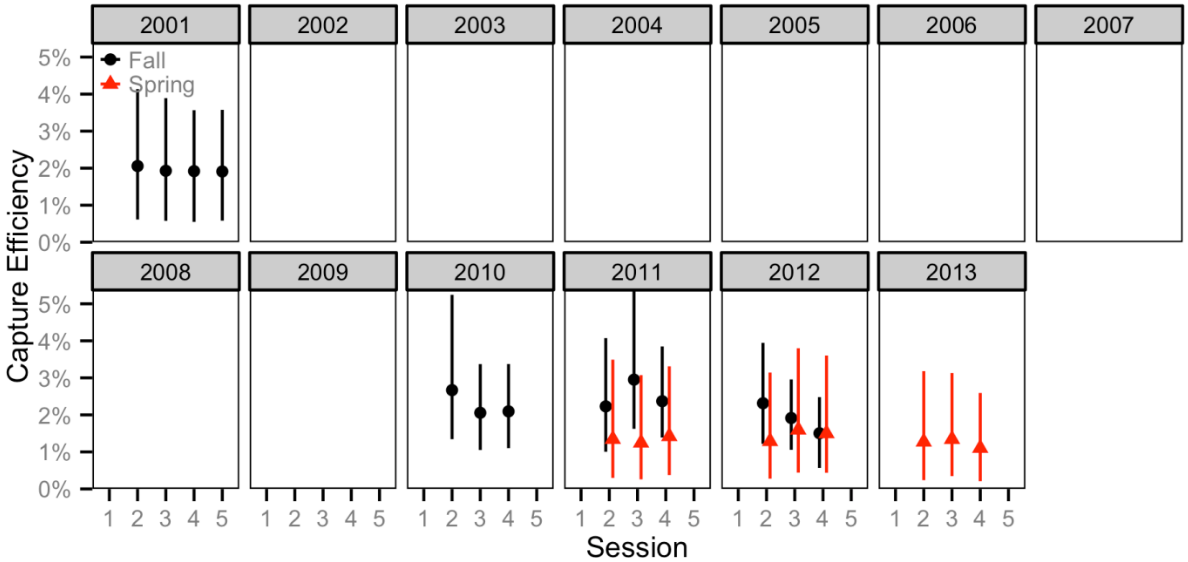

Figure H13. Capture efficiency estimates (with 95% credible intervals) by year, season, and session for Largescale Sucker in the Middle Columbia River study area, 2007 to 2013. Efficiency was calculated in the hierarchical Bayesian model estimating absolute abundance using mark-recapture data.

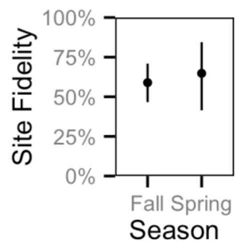

Figure H14. Site fidelity estimates (with 95% credible intervals) by season for intra-year recaptured juvenile Bull Trout in the Middle Columbia River study area, 2001-2013.

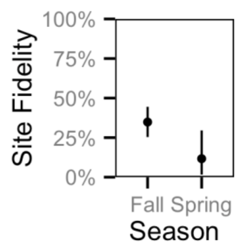

Figure H15. Site fidelity estimates (with 95% credible intervals) by season for intra-year recaptured Bull adult Trout in the Middle Columbia River study area, 2001-2013.

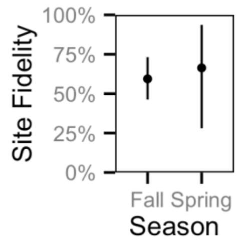

Figure H16. Site fidelity estimates (with 95% credible intervals) by season for intra-year recaptured adult Largescale Sucker in the Middle Columbia River study area, 2001-2013.

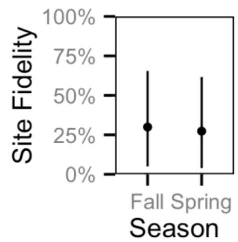

Figure H17. Site fidelity estimates (with 95% credible intervals) by season for intra-year recaptured juvenile Mountain Whitefish in the Middle Columbia River study area, 2001-2013.

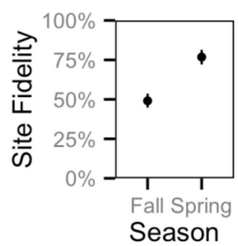

Figure H18. Site fidelity estimates (with 95% credible intervals) by season for intra-year recaptured adult Mountain Whitefish in the Middle Columbia River study area, 2001-2013.

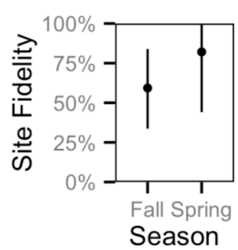

Figure H19. Site fidelity estimates (with 95% credible intervals) by season for intra-year recaptured adult Rainbow Trout in the Middle Columbia River study area, 2007-2013.