Columbia River Project Water Use Plan

Revelstoke Flow Management Plan

Middle Columbia River Fish Population Indexing Program

Implementation Year 8

Reference: CLBMON-16

Final Technical Report

Study Period: 2014

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CLBMON-16:
Middle Columbia River
Fish Population Indexing Survey

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Executive Summary

A year-round 142 m³/s minimum flow release from Revelstoke Dam (REV) was implemented in December 2010 as part of BC Hydro's Water Use Plan for the Columbia River. The implementation of the minimum flow coincided with the commissioning of an additional generation unit at Revelstoke Dam (REV5) that increased the maximum generation discharge capacity of the dam from 1700 m³/s to 2124 m³/s. The combined effects of these changes in dam operations are referred to as a flow regime change. The key environmental objective of the minimum flow release is to increase the abundance and diversity of fish populations in the middle Columbia River (MCR). The MCR Fish Population Indexing Program addresses four key management questions:

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

Another objective of the program, although not specifically identified as a key management hypothesis, is to investigate and document changes in species richness or species diversity in the MCR in response to the minimum flow release. Data were collected for the MCR Fish Population Indexing Program during four years (2007 to 2010) prior to and four years after (2011 to 2014) the minimum flow release. In addition, data were collected from 2001 to 2006 as part of BC Hydro's Large River Fish Indexing Program, a similar program designed to monitor fish populations in the MCR. Sampling was conducted in the fall from 2001 to 2010, the spring and fall from 2011 to 2012, the spring only in 2013, and the fall only in 2014.

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 individual identification. Between 2001 and 2014, each site was sampled three to five times per year in consecutive weeks as part of the mark-recapture study. Temporal and spatial variations in species richness, species evenness, abundance, spatial distribution, growth, and body condition were estimated using hierarchical Bayesian models (HBMs).

There was an increase in species richness and evenness between 2001 and 2008 which was attributed to substantial increases in the abundance of several less common species. The density and/or probability of occupancy of Burbot (*Lota lota*), Lake Whitefish (*Coregonus clupeaformis*), Northern Pikeminnow (*Ptychocheilus oregonensis*), Rainbow Trout (*Oncorhynchus mykiss*), Redside Shiner (*Richardsonius balteatus*) and Sculpin species (*Cottidae* spp.) all increased, while densities of more common species

such as Bull Trout (*Salvelinus confluentus*) and Mountain Whitefish (*Prosopium williamsoni*) remained relatively stable during this time period. 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 strongly correlated with discharge or reservoir elevation.

There was some evidence to suggest that body condition or growth of fishes in the MCR may have declined in the four years following the flow regime change. The growth and body condition of Bull Trout, and the body condition of adult Mountain Whitefish and Rainbow Trout all declined to low levels following the flow regime change. Multivariate analyses suggested that these trends in body condition were correlated with long-term trends in the Pacific Decadal Oscillation, an index of climate, and Kokanee in Arrow Lakes, which are an important prey for Bull Trout. Although body condition decreased substantially following the flow regime change, the observational study design makes it difficult to discern whether the low body condition was caused by the flow regime, or simply coincided with the new flow regime but was caused by other environmental changes and large-scale climatic variability.

Based on the data collected to date, there were no significant changes in the distribution of fishes in the MCR associated with the flow regime change. Species distribution varied little over time for most species except for Rainbow Trout and Sucker species, whose distribution may have shifted upstream between 2007 and 2014, although the magnitude of the change was small. This trend in distribution was correlated with a similar trend in 10th percentile discharge during fall, winter, and spring, mean discharge in winter, and discharge variability in the fall, suggesting a potential link between hydrological conditions and the distribution of these species.

In 2014, a new method, referred to as a geo-referenced visual enumeration survey, was trialed as a complementary technique to the mark-recapture surveys to monitor fish abundance. The survey consisted of a boat electroshocking pass during which fish were identified to species, counted, and their fork lengths estimated; the fish were not captured. The location of each observed fish was recorded using a hand-held GPS (Global Positioning System) unit. The results showed a positive relationship between visual survey counts and predicted catch from the mark-recapture model, suggesting these two metrics may show similar trends among sites. Additional years of data are required to assess whether visual counts provide a reliable and comparable index of abundance over time. If so, it may be possible to reduce the number of mark-recapture sessions, which would reduce potential impacts associated with repeatedly electroshocking and handling fishes.

Recommendations for future years of study include: 1) continuing mark-recapture sampling during the fall with at least two sessions to gather data comparable to years prior to the flow regime change; 2) conduct additional years of data collection using the geo-referenced visual survey to assess the effectiveness of this method; 3) decrease the number of mark-recapture sessions to two to reduce potential sampling effects on fish populations; and, 4) conduct preliminary analyses of scale-aging bias and precision as a way to improve assessment of fish age and growth.

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

Table E1: Status of management questions and hypotheses after Year 8 of the Middle Columbia River Fish Population Indexing Survey (CLBMON-16).

Objectives	Management Questions	Management Hypotheses	Year 8 (2014) 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. Abundance estimates of common species, such as Bull Trout and Mountain Whitefish, do not suggest any substantial changes during the monitoring period. The results suggested increases in several less common species, including Burbot, Northern Pikeminnow, Rainbow Trout, and Sculpin species, but these changes occurred prior to the flow regime change and do not suggest an effect of the minimum flow release on abundance.
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. Growth of Bull Trout based on recaptured fish declined in years following the flow regime change but remained within the range of values observed in previous years of the study. Growth of Mountain Whitefish and Rainbow Trout did not indicate any change following the flow regime change. Growth of all other species could not be estimated because of small numbers of recaptured fishes.
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.	The results suggested that body condition declined substantially following the flow regime change for Bull Trout, Rainbow Trout, and Mountain Whitefish. Because of the observational study design it is not possible to conclude whether the low body condition was caused by the flow regime, or simply coincided with the new flow regime but was caused by other environmental changes and large-scale climatic variability. There is some evidence to support the rejection of this hypothesis but additional years of data collection and/or a more experimental study design are required for strong conclusions.

Objectives	**Management Questions**	**Management Hypotheses**	**Year 8 (2014) 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.	The model results suggested no changes in the distribution of fishes in the MCR associated with the flow regime change. The distribution of Rainbow Trout and Sucker species may have shifted upstream between 2007 and 2014 but the change began several years before the implementation of minimum flows and therefore does not suggest an effect of the flow regime change.

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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 (2014) describes the fourth year of monitoring after an additional (i.e., fifth) generating unit was added to REV (REV5), and after the minimum flow release was established.

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

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

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 than 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 23% of BC Hydro's total systems capacity (http://www.bchydro.com/energy-in-bc/projects/revelstoke-unit-6.html).

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

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

1.5 Study Area

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

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

In 2014, the sample sites covered the entire shoreline of Reaches 3 and 4 (similar to monitoring in 2007 to 2013). Between 2001 and 2006 (i.e., prior to the WUP), sampling was limited to Reach 4 and the Big Eddy portion of Reach 3 (Figure 1); the portion of Reach 3 downstream of Big Eddy was not sampled during these years. Each site was a section of river between 519 and 2270 m in length along either the left or right bank.

The locations of the eight sites sampled in Reach 4 and the seven sites sampled in Reach 3 in 2014 are illustrated in Appendix A, Figures A1 and A2. Site descriptions and UTM locations for all sites are listed in Appendix A, Table A1. In 2014, each site was sampled three times (i.e., three sessions) between October 16 and 30 for the mark-recapture survey (fall; Table 2). In addition to mark-recapture surveys, visual enumeration boat electroshocking surveys were conducted in the MCR for the first time in 2014. These visual surveys are described in Section 2.1.5. The timing of the 2014 fall surveys corresponded to fall sample sessions that were conducted between 2001 and 2012.

Table 2: Annual study periods for mark-recapture boat electroshocking surveys conducted in the middle Columbia River, 2001 to 2014.

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

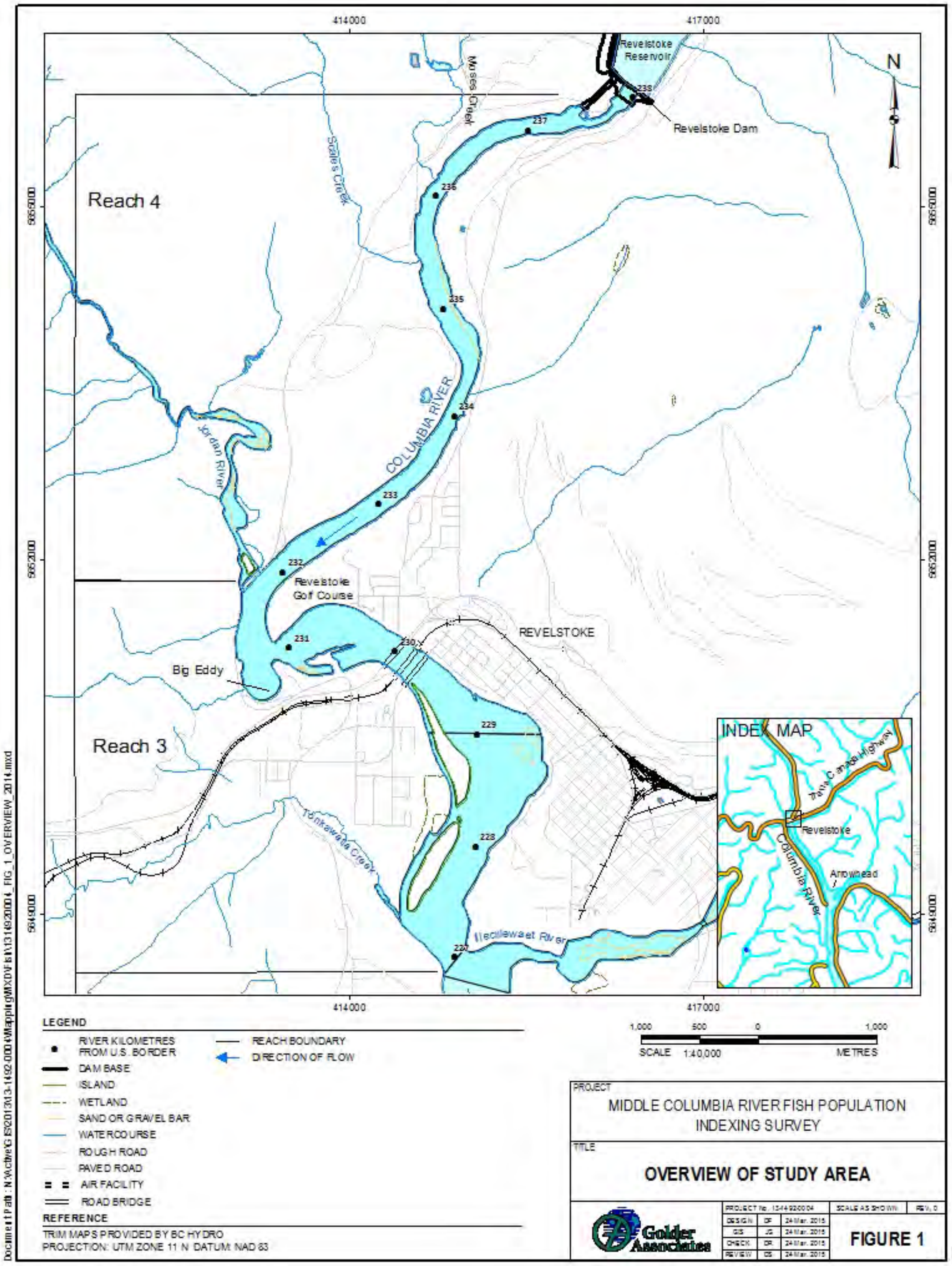

Figure 1: Overview of the middle Columbia River study area, 2014.

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 2014 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 2014 were obtained from BC Hydro's Columbia-Kootenay River Temperature and Discharge Database. Water elevations throughout this report are presented as metres above sea level (masl).

2.1.3 Water Temperature

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

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

2.1.4 Habitat Conditions

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

The type and amount of instream cover for fish was visually estimated at all sites. Water velocities were visually estimated and categorized at each site as low (less than 0.5 m/s), medium (0.5 to 1.0 m/s), or high (greater than 1.0 m/s). Water clarity was visually estimated and categorized at each site as low (less than 1.0 m depth), medium (1.0 to 3.0 m depth), or high (greater than 3.0 m depth). Mean and maximum depths were estimated by the boat operator based on the boat's sonar depth display.

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

Table 3: List and description of habitat variables recorded at each sample site in the middle Columbia River, 2014.

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 measured near the mid-point of the site after sampling (to the nearest 10 µS)
Cloud Cover	A categorical ranking of cloud cover (clear - 0-10% cloud cover; partly cloudy - 10-50% cloud cover; mostly cloudy - 50-90% cloud cover; overcast - 90-100% cloud cover)
Weather	A general description of the weather at the time of sampling (e.g., comments regarding wind, rain, or fog)
Water Surface Visibility	A categorical ranking of water surface visibility (low - waves; medium - small ripples; high - flat surface)
Boat Model	The model of boat used during sampling
Range	The range of voltage used during sampling (high or low)
Percent	The estimated duty cycle (as a percent) used during sampling
Amperes	The average electrical current used during sampling
Mode	The mode (AC or DC) and frequency (in Hz) of current used during sampling
Length Sampled	The length of shoreline sampled (to the nearest 1 m)
Time Sampled	The duration of electroshocker operation (to the nearest 1 second)
Mean Depth	The mean water column depth recorded during sampling (to the nearest 0.1 m)
Maximum Depth	The maximum water column depth recorded during sampling (to the nearest 0.1 m)
Water Clarity	A categorical ranking of water clarity (high - greater than 3.0 m visibility; medium - 1.0 to 3.0 m visibility; low - less than 1.0 m visibility)
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 Geo-referenced Visual Enumeration Survey

In 2014, a new method, referred to as the geo-referenced visual enumeration survey, was trialed as complementary technique to the mark-recapture surveys for monitoring fish abundance in the MCR. The geo-referenced visual enumeration survey was conducted October 8-10, 2014 at each of the mark-recapture index sites. The survey consisted of a boat electroshocking pass using the same methods as the mark-recapture survey (Section 2.1.6), except that fish were only counted and not captured with nets. Two observers were positioned in the same location as they would have been for netting, where they identified, enumerated, and estimated the length of observed fish. Two other individuals recorded all the observation data dictated by the observers, and recorded the geographical location of each observation using a hand-held GPS (Global Positioning System) unit. Species counted during the surveys were the same as those captured and tagged during the mark-recapture surveys (i.e., all fish species except for Kokanee [*Oncorhyncus nerka*], Redside Shiner [*Richardsonius balteatus*], and Sculpin species [*Cottidae*]).

The rationale behind these geo-referenced visual enumeration surveys was to avoid potential missed observations of fish that may occur when netters turn to put captured fish in the livewell during mark-recapture surveys. Geo-referenced visual enumeration surveys allow for continuous direct counts of observed fish that are likely more accurate than counts of fish made by netters during mark-recapture surveys. In addition, the visual surveys provide fine-scale distribution data, which could be used to understand mesohabitat use by fishes in the MCR and better address management questions regarding spatial distribution. If counts during the visual surveys provide a reliable index of abundance, compared to the mark-recapture estimates, it may be possible to reduce the number of mark-recapture sessions, which would reduce potential impacts of repeated electroshocking and handling of fishes.

During the visual surveys, observers were instructed to estimate the fork lengths of observed fish. However, given that observers often could not see the actual fork in the tail of the fish (due to the fish position or distance) observers may have been more likely to base their estimates on total length (i.e., the measurement from the tip of the caudal fin rather than the fork). Length estimates were also likely affected by magnification by water, as objects appear larger in water than in air because of the greater refractive index of water (Luria et al. 1967). Potential biases in length estimation were assessed and corrected in the length bias model (Sections 2.2.9 and 3.6.10)

2.1.6 Fish Capture

In 2014, fishes were captured between October 16 and October 30 (i.e., the fall 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 150 HP outboard jet-drive riverboat by a three-person crew. The electroshocking procedure consisted of maneuvering the boat downstream along the shoreline of each sample site. Two crew members positioned on a netting platform at the bow of the boat netted stunned fish, while a third individual operated the boat and electroshocking unit. The two netters attempted to capture all fish stunned by the electrical field. Captured fish were immediately sorted by the Bank Habitat Type 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, and Sculpin species were excluded from the mark-recapture component of the program. The abundance of Kokanee in the study area is highly variable and determined by recruitment processes outside of the study area and entrainment rates through REV. The distribution of Redside Shiner is generally limited to Big Eddy 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, up to 50 Kokanee, 50 Redside Shiner, and 50 Sculpin species were captured and processed for life history data; subsequently, these species were enumerated by the netters and recorded as "observed".

Boat electroshocking sites varied between 519 m and 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.

Voltage was adjusted as needed to achieve an amperage output of ~1.9 A (based on boat electroshocker's current meter), at a frequency of 30 Hz direct current. These settings have been shown to result in 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 settings proven to reduce injury rates, field crews took additional measures to reduce the likelihood of impacting fish stocks. These measures included:

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

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

2.1.7 Safety Communications

The operation of REV as a daily peaking plant can result in rapid and unpredictable changes in dam discharges. Real-time dam discharge rate changes were monitored by field crews via text messages automatically sent from the BC Hydro flow operations monitoring computer to the field crew's cell phone. These messages were sent when dam discharge either increased or decreased by 200 m^3/s 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.

2.1.8 Fish Processing

A site form was completed at the end of each sampled site. Site habitat conditions and observed fish were recorded before processing captured 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, 2014.

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 2.1.6) 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 2014, with major changes to the study identified in Table 5. Minor changes to the study's design between 2001 and 2014 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 2014.

Methodology Change	Years	Description
Number of sampling sessions	2002-2006, 2010-2014	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
	2009-2014	Reaches 3 and 4 were sampled
Fish tag type	2001-2004	T-bar anchor tags exclusively
	2005	T-bar anchor tags and PIT tags
	2006-2014	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
	2010-2014	All species except Kokanee, Redside Shiner, and Sculpin species
Electroshocking specifications and settings	2001-2004	Frequency was 60 Hz; boat hull used as the cathode
	2005-2014	Frequency was 30 Hz; array curtain was used as the cathode
Seasons sampled	2001-2010, 2014	Fall only
	2011-2012	Spring and Fall
	2013	Spring only
Geo-referenced visual enumeration survey	2014	Trial of new method consisting of visual counts during boat electroshocking without netting fish

2.2 Data Analyses

2.2.1 Data Compilation and Validation

Data were entered directly into the Middle Columbia River Fish Indexing Database (Attachment A) using Microsoft® Access 2010 software. The database has several integrated features to ensure data are entered correctly, consistently, and completely.

Various input validation rules programmed into the database checked each entry to verify that the data met specific criteria for that particular field. For example, all species codes were automatically checked upon entry against a list of accepted species codes that were saved as a reference table in the database. This feature forced the user to enter the correct species code for each species (e.g., Rainbow Trout had to be entered as “RB”; the database would not accept “RT” or “rb”). Combo boxes were used to restrict data entry to a limited list of choices, which kept data consistent and decreased data entry time. For example, a combo box limited the choices for Cloud Cover to: Clear; Partly Cloudy; Mostly Cloudy; or Overcast. The user had to select one of those choices, which decreased data entry time (e.g., by eliminating the need to type out “Partly Cloudy”) and ensured consistency in the data (e.g., by forcing the user to select “Partly Cloudy” instead of typing “Part Cloud” or “P.C.”). The database contained input masks that required the user to enter data in a pre-determined manner. For example, an input mask required the user to enter the Sample Time in 24-hour short-time format (i.e., HH:mm:ss). Event procedures ensured that data conformed to the underlying data in the database. For example, after the user entered the life history information for a particular fish, the database automatically calculated the body condition of that fish. If the body condition was outside a previously determined range for that species (based on the measurements of other fish in the database), a message box would appear on the screen informing the user of a possible data entry error. This allowed the user to double-check the species, length, and weight of the fish before it was released. The database also allowed a direct connection between the PIT tag reader (AVID PowerTracker VIII) and the data entry form, which eliminated transcription errors associated with manually recording a 15-digit PIT tag number.

2.2.2 Life Stage Assignment

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

Table 6: Fork length (in mm) based life stage classifications used in hierarchical Bayesian analyses for fish captured in the middle Columbia River, 2001 to 2014.

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

2.2.3 Hierarchical Bayesian Analysis

The temporal and spatial variation in species richness and evenness, abundance, growth, and body condition were analyzed using hierarchical Bayesian models using data from 2001 to 2014. The book ‘Bayesian Population Analysis using WinBUGS: A hierarchical perspective’ by Kery and Schaub (2011) provides an excellent reference for hierarchical Bayesian methods and is considered the companion text for the following analyses. A Bayesian approach was chosen over a frequentist approach to fitting models for the MCR data for several reasons. Firstly, a Bayesian approach allows more realistic, system-specific models to be fitted (Kuparinen et al 2012). Secondly, a Bayesian approach allows derived values, such as species richness, to be readily calculated with credible intervals (Kery and Schaub 2011 p.41). A Bayesian approach also readily handles missing values which are common in ecological studies such as the MCR and provides directly interpretable parameter estimates whose reliability does not depend on the sample size, which is important when recapture rates are low. The only disadvantage is the additional computational time required to fit models using a Bayesian as compared to a frequentist approach.

Hierarchical Bayesian models were fitted to the fish indexing data for the MCR using R version 3.1.2 (R Core Team 2013) and JAGS 3.4.0 (Plummer 2012) which interfaced with each other via jaggernaut 2.2.10 (Thorley 2013). For additional information on hierarchical Bayesian modelling in the BUGS (Bayesian analysis Using Gibbs Sampling) language, of which JAGS uses a dialect, the reader is referred to Kery and Schaub (2011) pages 41-44. The technical aspects of the analyses, including the general approach and model definitions in the JAGS (Just Another Gibbs Sampler; Plummer 2003) dialect of the BUGS language, are provided in Appendix F. The resultant parameter estimates are tabulated in Appendix G. In addition, the model definitions, parameter estimates and source code are all available online at http://www.poissonconsulting.ca/f/1446318417 (Thorley and Beliveau 2015).

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 six species: Burbot (*Lota lota*), Lake Whitefish, Northern Pikeminnow, Rainbow Trout, Redside Shiner, and Sculpin species.

Key assumptions of the occupancy model included:

- occupancy (the probability of presence) was described by a generalized linear mixed model with a logit link;
- occupancy varied with flow regime (period) and season;
- occupancy varied randomly with 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 2.2.6); and,
- observed presence was described by a Bernoulli distribution, given occupancy.

Species richness was estimated by summing the estimated occupancies for all species that had estimates of occupancy. In contrast to the traditional calculation of species richness that simply counts the number of species observed, this method excluded species that were very infrequently encountered, or nearly always encountered as they provide no information on inter-annual variation in species presence due to dam operations and in the case of very rarely encountered species add additional uncertainty.

Mountain Whitefish, Bull Trout, and Sucker species were not included because they were nearly always encountered. Very rarely encountered species, such as Cutthroat Trout and White Sturgeon, were not included in estimates of richness based on the assumption that these species were always present at some unknown low density, and whether or not they were detected in a given year was due to chance, and not reflective of true presence or absence in the study area.

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

2.2.5 Count Density, Species Diversity, and Evenness

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

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

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

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

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

Shannon's diversity depends on the total number of species, as well as the evenness in the proportional abundances. By dividing Shannon's diversity by the natural logarithm of the number of species, evenness is a measure of how evenly fish are distributed among species. In this study, 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 Site Fidelity

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

Key assumptions of the site fidelity model included:

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

2.2.7 Abundance

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

Key assumptions of the abundance model included:

- density (fish/km) varied with flow regime (period), season, and river kilometre;
- density 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 by season and method (captured or observed);
- efficiency 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;
- there was no migration into or out of the study area (supersite) among sessions; and,
- the number of fish captured was described by a Poisson-gamma distribution.

2.2.8 Geo-referenced Visual Enumeration Survey

The counts of observed fish during geo-referenced visual surveys were plotted against the predicted catches from the abundance model to assess how these two abundance indices from the two methods compared. The regression line and confidence bands on these plots represents the linear effect of the model parameter labelled “bType[2]” (Appendix G), which was the multiplier based on the ratio of observed to captured fish in the abundance model.

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

2.2.9 Length Bias Model

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

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Key assumptions of the observer length correction model include:

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

2.2.10 Growth

Annual growth was estimated from inter-annual recaptured fish using the Fabens (1965) method for estimating the von Bertalanffy (1938) growth curve. There were enough inter-annual recapture data to estimate growth using this method for Bull Trout, Mountain Whitefish, and Rainbow Trout. Growth was based on the change in length between fall seasons. 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, a 250 mm FL Mountain Whitefish, or a 300 mm FL Rainbow Trout. These fork lengths were selected as representative examples to illustrate changes in fork length over time for a standard size fish.

2.2.11 Body Condition

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

Key assumptions of the condition model included:

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

2.2.12 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 regarding 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, the following descriptive statistics were calculated:

- mean of hourly discharge (QMu);
- mean of the hourly absolute difference in discharge (QDlt), as a measure of hour-to-hour variability;
- 10th percentile of hourly discharge (Q10);
- 90th percentile of hourly discharge (Q90); and,
- mean reservoir elevation (Ele).

The October to December discharge and temperature time series were lagged by one year such that fish data in a given year were correlated with discharge or temperature data from the year prior to fish sampling. This was done because although November and December occur after the fall surveys were completed, habitat conditions during these months could affect the fish populations sampled in the fall of the following year.

Other environmental variables assessed were the mean values of chlorophyll *a* concentration (ChlA) and invertebrate biomass (Inv) from MCR Ecological Productivity Monitoring (2007-2013; Schleppe et al. 2014), Kokanee abundance estimates in upper Arrow Lakes Reservoir from hydro-acoustic surveys (M. Bassett, MFLNRO; personal communication), and annual means of monthly values of the Pacific Decadal Oscillation Index (PDO; Mantua et al. 2015). All time series variables were standardized by subtracting the mean and dividing by the standard deviation, prior to analysis.

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

Key assumptions of the dynamic factor analysis model include:

- the random walk processes in the trends were normally distributed; and,
- the residual variation in the standardized variables was normally distributed.

Preliminary analyses indicated that three common trends provided a reasonable model fit without apparent over-fitting. A limitation of dynamic factor analysis as currently implemented in a Bayesian framework is that it is not possible to be sure of the sign (positive or negative) of the common trends and the variable weightings, which has been referred to as the rotation problem (Abmann et al. 2014). For instance, the results could suggest a fish metric and an environmental variable were both correlated with a common trend but the direction of the relationship would not be certain. A simple solution was to examine the plots of standardized environmental variables to see if variables that were associated had the same or opposite increasing or decreasing trends. To visualize the relationships among fish metrics and environmental variables, non-metric multidimensional scaling (NMDS) was used to indicate the clustering of time series based on the absolute values of the dynamic factor analysis trend weightings. The more similar two time series, the closer they will tend to be on the resultant NMDS plot. Goodness of the fit of the NMDS was assessed by the stress values, where values <20% were considered an acceptable representation, and values >20% were considered unsatisfactory (Kruskal 1964).

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

3.0 RESULTS

3.1 Discharge

In 2014, mean daily discharge in the MCR was near average for most of the year (Appendix C, Figure C1) except in February to March when discharge was greater than the average from 2001 to 2013. Discharge during sampling in late October was lower than the long-term average (Figure 2).

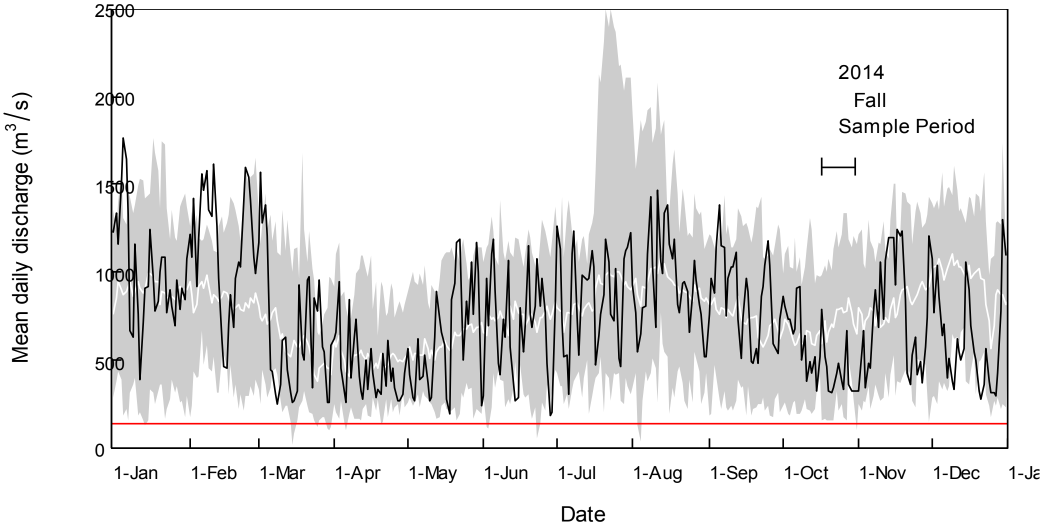

Figure 2: Mean daily discharge (m³/s) for the Columbia River at Revelstoke Dam, 2014. The shaded area represents minimum and maximum mean daily discharge values recorded at the dam from 2001 to 2013. The white line represents average mean daily discharge values over that same time period. The red line represents the minimum flow release of 142 m^3/s.

Similar to previous study years, discharge in 2014 exhibited large hourly fluctuations, a reflection of the primary use of the facility for daily peaking operations (Appendix C, Figure C2). Daily fluctuations were smaller in 2014 than in previous years, with daily maximums of less than 500 m³/s most days (Appendix C, Figure C2), compared to the increases during sampling in other years when discharges were often between 1000 and 1500 m³/s during daily power demand periods (ONA, Golder and Poisson 2014). In 2014, the greatest daily fluctuations were observed during Session 1 with smaller fluctuations during Sessions 2 and 3. Since the implementation of the minimum flow release, discharge from REV rarely declines to 142 m³/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 m³/s. Peak daily flows during the fall sample period ranged between approximately 350 and 1200 m^3/s (Appendix C, Figure C2).

3.2 Water Elevation

In 2014, mean daily water elevations in ALR were near the long-term average (2001-2013) throughout the year (Appendix C, Figure C3). There was slight increase above the long-term average elevation from mid-May to mid-July, followed by a slight decrease below long-term average elevations from mid-July to mid-September. During the 2014 study period, mean daily water elevation in ALR was approximately 433 m and consistent with the long-term average. Historically, 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 2014, mean daily water temperature was colder than average, and colder than the previous minimum from 2007 to 2013 for most of the year (Figure 3; Appendix C, Figure C4). Water temperature at the monitoring station used in 2014 (Station 2AS) was thought to be within 0.2°C of the station used in 2007 to 2013 (Station 2; ONA and LGL Ltd., personal communication, March 22, 2015). However, data from the same station should be used for all years in future years of the study. Spot temperature readings taken at the time of sampling ranged between 8.2 and 9.7°C (Attachment A).

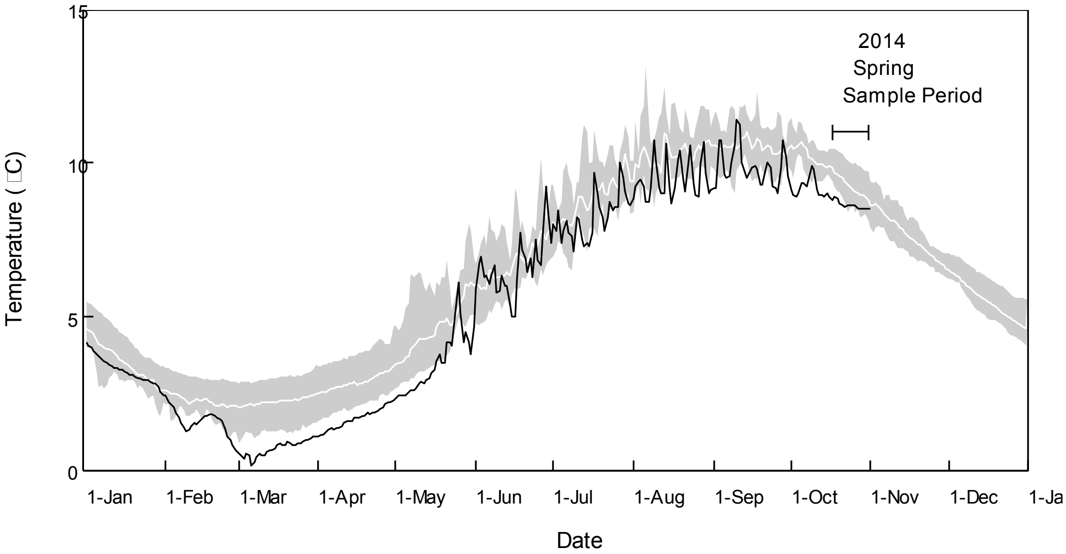

Figure 3: **Mean daily water temperature (°C) for the Columbia River at Station 2AS of the Physical Habitat Monitoring Program (CLBMON-15a), 2014. The shaded area represents minimum and maximum mean daily water temperature values recorded at Station 2 from 2007 to 2012. The white line represents average mean daily water temperature values over that same time period.**

3.4 Catch

In total, 8840 fishes, comprising 10 taxa, were captured or observed and recorded in the MCR during the fall sampling period (Appendix D, Table D1). The total number of fish captured and observed during spring study periods from 2011 to 2013 is compared in Appendix D, Table D2. The total numbers of fish captured and observed during fall study periods from 2001 to 2014 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 species count data by site and bank habitat type during the fall sampling period (Appendix B, Table B4);
- catch-per-unit-effort for all sportfish and non-sportfish during the fall 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 fall 2014 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 2014, and for Rainbow Trout from 2007 to 2014 (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 2014 (where applicable);
- length-weight relationships for Bull Trout (Appendix E, Figure E10) and Mountain Whitefish (Appendix E, Figure E11) from 2002 to 2014, and for Rainbow Trout from 2007 to 2014 (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 (*Perca flavescens*; Appendix E, Figure E19) for 2010 to 2014 (where applicable).

All data collected as part of the program between 2001 and 2014 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 are used to detect changes in species presence at a typical site and do not indicate the total number of species present (Figure 4). Species richness increased from 2001 to 2005, due to increasing occupancy of several species, including Burbot, Lake Whitefish, Northern Pikeminnow, Rainbow Trout, Redside Shiner, and Sculpin species (Appendix H, Figures H1-H6). In recent years, estimates of species richness have varied, with greater richness in 2008, 2010 and 2011, and lower richness in 2009, 2012, and 2014. 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.

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

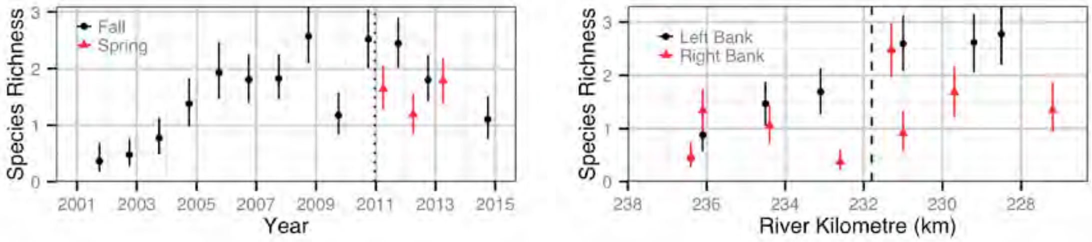

Figure 4: Species richness estimates (with 95% credible intervals) by year and season (left panel) and site (right panel) for the middle Columbia River study area, 2001 to 2014. The dotted line (left panel) represents the implementation of the minimum flow release and REV5 operations. The dashed line (right panel) represents the divide between Reaches 3 and 4 at the Jordan River confluence.

Species evenness increased gradually from 19% in 2001 to 27% in 2007, although credible intervals overlapped for all years (Figure 5). Spring estimates of evenness were greater than fall estimates from 2011 to 2013. In Reach 3, species evenness increased with proximity to Arrow Lakes Reservoir (decreasing river kilometre). Site 233.1-L (along the Revelstoke Golf Course) had particularly high evenness relative to adjacent sites (Figure 5). This pattern of greater evenness at Site 233.1-L is likely due to lower Mountain Whitefish densities in this site when compared to neighbouring sites (see Section 3.6.4).

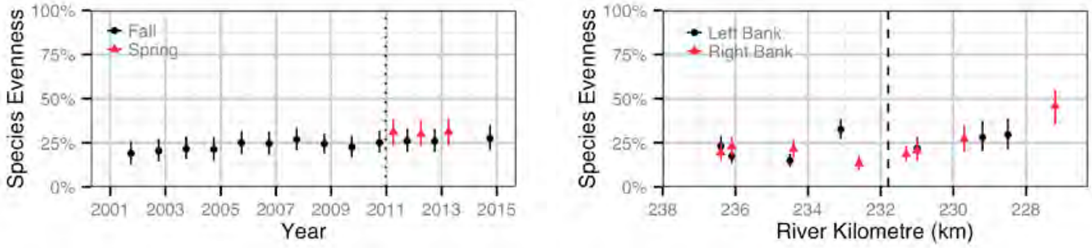

Figure 5: Species evenness estimates (with 95% credible intervals) by year and season (left panel) and site (right panel) for the middle Columbia River study area, 2001 to 2014. The dotted line (left panel) represents the implementation of the minimum flow release and REV5 operations. The dashed line (right panel) represents the divide between Reaches 3 and 4 at the Jordan River confluence.

3.6 Spatial Distribution and Abundance

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

1) count density estimates from a HBM using count data (i.e., the number of fish caught and observed per river kilometre) as an indicator of relative lineal density; and,
2) abundance estimates from a HBM of mark-recapture data as indicator of overall abundance in the study area.

Estimates of abundance were only possible for Bull Trout, Mountain Whitefish, Largescale Sucker, and Rainbow Trout. Count density was estimated for Burbot, Northern Pikeminnow, Rainbow Trout, 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.

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

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

3.6.1 Bull Trout

Juvenile Bull Trout abundance estimates generally increased from 2001 to 2006, and decreased from 2007 to 2014 (Figure 6). There were sites of relatively high and low abundance of juveniles in Reaches 3 and 4 with no obvious trend between abundance and river kilometre (right panel; Figure 6). The abundance of juvenile Bull Trout did not differ significantly by season (P=0.2) or flow regime (P=0.3).

Abundance estimates for adult Bull Trout increased from 2001 to 2003 and fluctuated with no long-term directional trend from 2004 to 2014 (Figure 7). Credible intervals for adult Bull Trout abundance estimates overlapped in all years of the study. Mean estimates of abundance of adult Bull Trout were greater in fall (~1500-1700 adults) than in spring (~1300-1400) in the two years when sampling was conducted in both seasons

(2010 and 2011) but the difference was not significant (*P*=0.3). Bull Trout abundance in a typical year was greatest immediately downstream of REV (between RKm 236 and 237) and downstream of the Jordan River confluence (between RKm 231 and 232). Adult Bull Trout abundance did not differ between flow regimes (*P*=0.3).

The distribution of juvenile Bull Trout by river kilometre was similar in all years of the study. Two exceptions were a downstream shift in distribution in 2001 and 2006, and slight upstream shift in distribution in 2014, although all credible intervals overlapped (left panel; Figure 8). The distribution of juvenile Bull Trout was similar in all fall sampling seasons (left panel; Figure 8). However, adult Bull Trout were distributed further upstream in the spring than in the fall, as indicated by larger positive values of the distribution coefficient (right panel; Figure 8), and a significant interaction between river kilometre (distribution) and season (*P*=0.001). The interaction between river kilometre (distribution) and flow regime was not significant for juvenile (*P* = 0.99) or adult (*P* = 0.7) Bull Trout, indicating that the effect of river kilometre on abundance did not differ by flow regime.

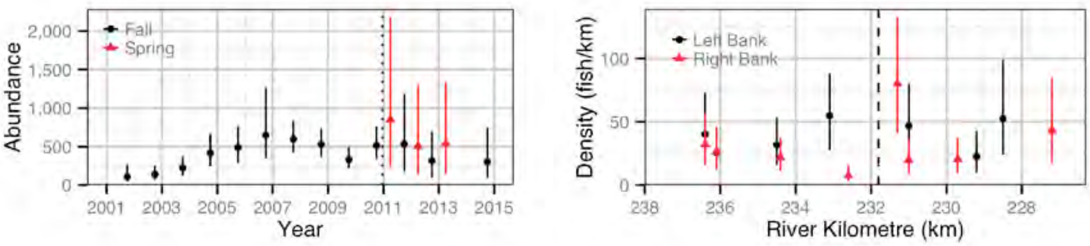

Figure 6: **Abundance estimates (with 95% credible intervals) by year and season (left panel) and site (right panel) for juvenile Bull Trout in the middle Columbia River study area, 2001 to 2014. The dotted line (left panel) represents the implementation of the minimum flow release and REV5 operations. The dashed line (right panel) represents the divide between Reaches 3 and 4 at the Jordan River confluence.**

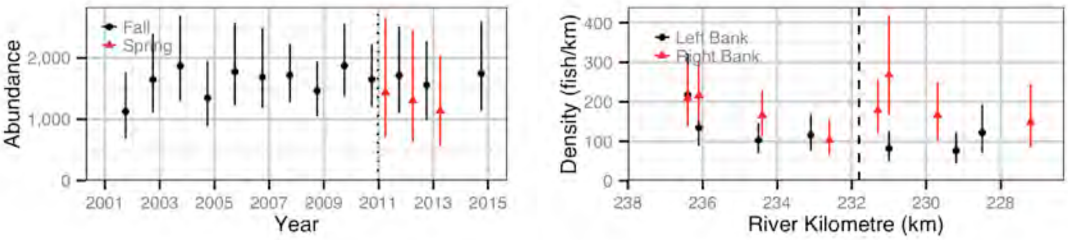

Figure 7: **Abundance estimates (with 95% credible intervals) by year and season (left panel) and site (right panel) for adult Bull Trout in the middle Columbia River study area, 2001 to 2014. The dotted line (left panel) represents the implementation of the minimum flow release and REV5 operations. The dashed line (right panel) represents the divide between Reaches 3 and 4 at the Jordan River confluence.**

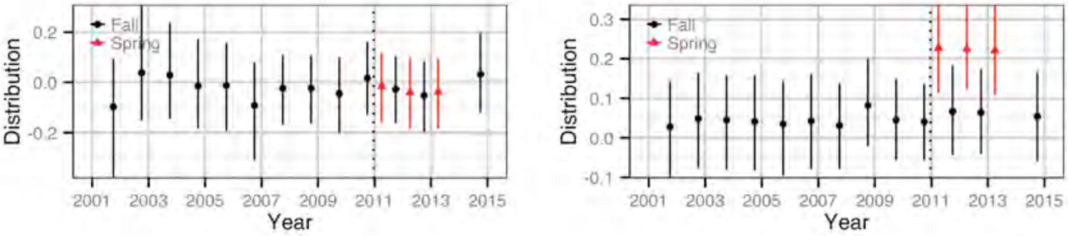

Figure 8: **Effect of year on the distribution (with 95% credible intervals) of juvenile (left panel) and adult (right panel) Bull Trout densities by year in the middle Columbia River study area, 2001 to 2014. Positive values indicate an upstream shift in distribution and negative values indicate a downstream shift. The dotted line represents the implementation of the minimum flow release and REV5 operations.**

3.6.2 Burbot

Overall, count densities for Burbot 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 9). Count density varied significantly by season (*P* = 0.006) with higher densities in the fall than in the spring. Burbot density was greatest near the Revelstoke Golf Course (233.1-L), downstream of Big Eddy (231.0-L), and near the Centennial Park Boat Launch (228.5-L). Burbot density did not vary significantly with flow regime (*P* = 0.4).

The distribution of Burbot was similar among all years (Figure 10). The estimates of the distribution effect declined from 2011 to 2013, suggesting a downstream shift in distribution, although the magnitude of the change was small. The interaction between river kilometre (distribution) and flow regime was not significant (*P* = 0.6), indicating that the relationship between river kilometre and count density did not differ by flow regime. The effect of river kilometre on count density did not vary by season (*P* = 0.7).

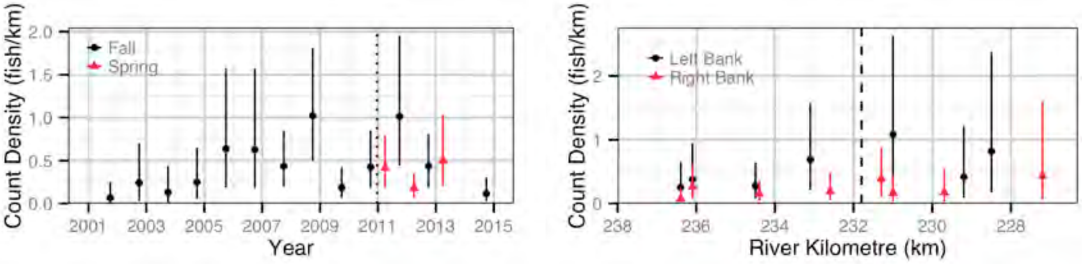

Figure 9: **Count density estimates (with 95% credible intervals) by year and season (left panel) and site (right panel) for Burbot in the middle Columbia River study area, 2001 to 2014. The dotted line (left panel) represents the implementation of the minimum flow release and REV5 operations. The dashed line (right panel) represents the divide between Reaches 3 and 4 at the Jordan River confluence.**

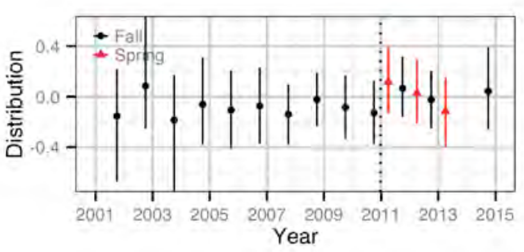

Figure 10: Effect of year on the distribution (with 95% credible intervals) of Burbot densities by year in the middle Columbia River study area, 2001 to 2014. Positive values indicate an upstream shift in distribution and negative values indicate a downstream shift. The dotted line represents the implementation of the minimum flow release and REV5 operations.

3.6.3 Kokanee

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

3.6.4 Mountain Whitefish

The estimated abundance of juvenile Mountain Whitefish decreased following the flow regime change in 2010, followed by a slight increase in 2014 compared to the two previous sampling years (Figure 11). Juvenile Mountain Whitefish abundance was greater in spring than in fall in 2011 and 2012 but the difference was not significant (P = 0.5). The estimated abundance of adult Mountain Whitefish in the fall indicated no long-term directional trend between 2001 and 2014 (Figure 12). Abundance of adults in the spring was lower than in the fall (P = 0.001) and decreased in subsequent spring sampling sessions following the flow regime change. The abundance of juvenile and adult Mountain Whitefish did not differ significantly among flow regimes (P = 0.4 and P = 0.5, respectively).

The abundance of Mountain Whitefish was greatest along the right bank 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 for both juveniles and adults (right panels; Figures 11 and 12). The estimated effect of distribution (river kilometre) on density varied among years but did not indicate any sustained changes in distribution (Figure 13). The results suggested that Mountain Whitefish were distributed further downstream in spring than in fall, as indicated by lower values of the distribution effect estimate, for both juveniles and adults (Figure 13). The significant interaction between river kilometre and season also supported seasonal differences in distribution for juvenile (P = 0.01) and adult (P = 0.02) Mountain Whitefish. The interaction between river kilometre (distribution) and flow regime was not significant for juvenile (P = 0.7) or adult (P = 0.8) Mountain Whitefish, indicating that the effect of river kilometre on abundance did not differ by flow regime.

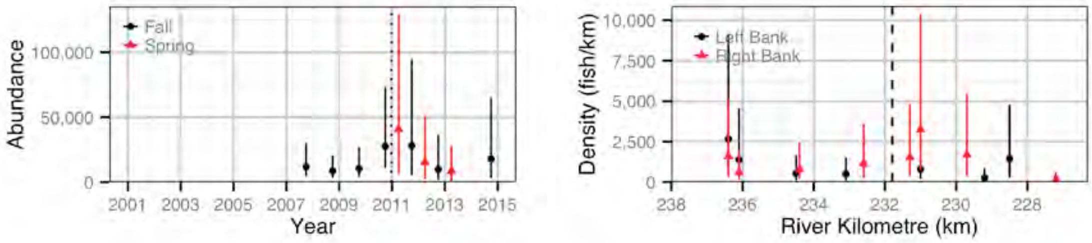

Figure 11: Abundance estimates (with 95% credible intervals) by year and season (left panel) and site (right panel) for juvenile Mountain Whitefish in the middle Columbia River study area, 2007 to 2014. The dotted line (left panel) represents the implementation of the minimum flow release and REV5 operations. The dashed line (right panel) represents the divide between Reaches 3 and 4 at the Jordan River confluence.

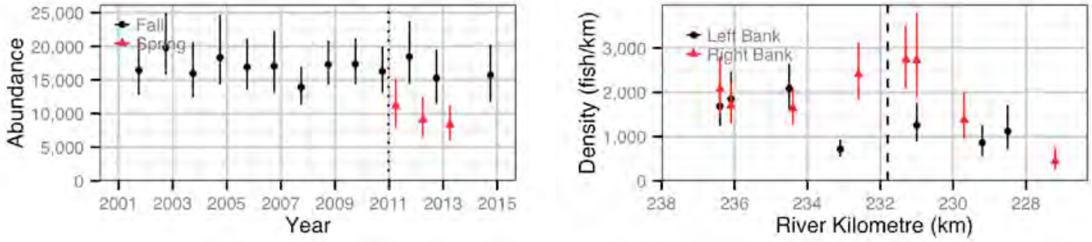

Figure 12: Abundance estimates (with 95% credible intervals) by year and season (left panel) and site (right panel) for adult Mountain Whitefish in the middle Columbia River study area, 2001 to 2014. The dotted line (left panel) represents the implementation of the minimum flow release and REV5 operations. The dashed line (right panel) represents the divide between Reaches 3 and 4 at the Jordan River confluence.

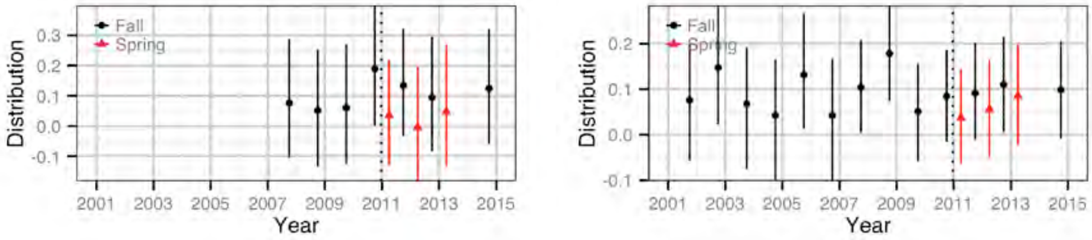

Figure 13: Effect year on the distribution (with 95% credible intervals) of juvenile (left panel) and adult (right panel) Mountain Whitefish densities by year in the middle Columbia River study area, 2001 to 2014. Positive values indicate an upstream shift in distribution and negative values indicate a downstream shift. The dotted line represents the implementation of the minimum flow release and REV5 operations.

3.6.5 Rainbow Trout

Rainbow Trout count density (all life-stages) estimates suggested a gradual increase between 2001 and 2008 (Figure 14). Count density of Rainbow Trout was low in 2009, increased in 2010 and 2011, and declined in 2012 and 2014 (Figure 14). Abundance estimates for adult Rainbow Trout also suggested a decrease in abundance in 2014 (Figure 15). Estimates of abundance (P = 0.8) and count density (P = 0.8) did not differ among seasons. The count density and abundance of Rainbow Trout did not differ significantly among flow regimes (P = 0.2 and P = 0.1, respectively).

Rainbow Trout densities were greater in Reach 3 than in Reach 4, and were greatest at sites on the left bank that had predominantly rip-rap substrate (Appendix A, Figure A2). Estimates of the effect of distribution (river kilometre) on Rainbow Trout count density and abundance increased between 2007 and 2014, which suggests an upstream shift in the distribution of Rainbow Trout during this period (Figure 16). The negative values of the slope coefficient in 2008 indicate an inverse relationship between river kilometre and density, but the estimates increased to close to zero in 2014, which would suggest no relationship between river kilometre and density. The slope of the river kilometre versus density relationship did not differ by season for count density (P = 0.7) or abundance (P = 0.8). The interaction between river kilometre (distribution) and flow regime was marginally significant for the count density (P = 0.048) and abundance (P = 0.07) of Rainbow Trout, suggesting that the effect of river kilometre on abundance may differ by flow regime.

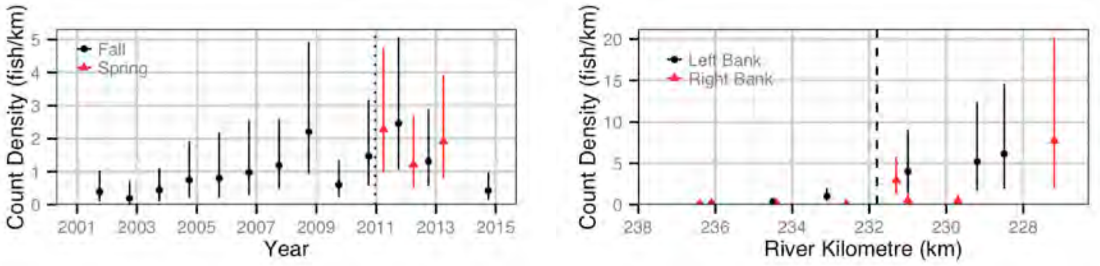

Figure 14: Count density estimates (with 95% credible intervals) by year and season (left panel) and site (right panel) for Rainbow Trout (all life-stages) in the middle Columbia River study area, 2001 to 2014. The dotted line (left panel) represents the implementation of the minimum flow release and REV5 operations. The dashed line (right panel) represents the divide between Reaches 3 and 4 at the Jordan River confluence.

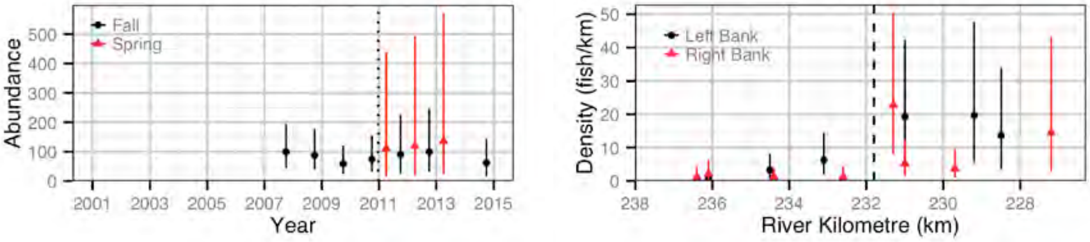

Figure 15: **Abundance estimates (with 95% credible intervals) by year and season (left panel) and site (right panel) for adult Rainbow Trout in the middle Columbia River study area, 2007 to 2014. The dotted line (left panel) represents the implementation of the minimum flow release and REV5 operations. The dashed line (right panel) represents the divide between Reaches 3 and 4 at the Jordan River confluence.**

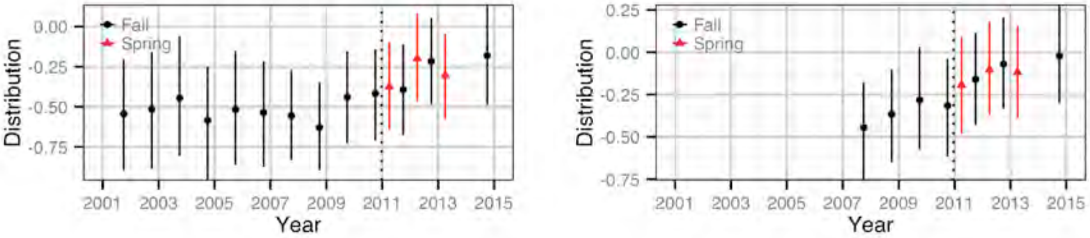

Figure 16: **Effect of year on the distribution (with 95% credible intervals) of Rainbow Trout count densities (left panel) and abundance estimates (right panel) by year in the middle Columbia River study area, 2001 to 2014. Positive values indicate an upstream shift in distribution and negative values indicate a downstream shift. The dotted line represents the implementation of the minimum flow release and REV5 operations.**

3.6.6. Sucker Species

In 2001 and from 2010 to 2014, 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 97% of the Sucker species catch; the remaining 3% 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.

Count density for all Sucker species combined was estimated from 2001 to 2014 and indicated increasing density from 2009 to 2014 (Figure 17). Abundance estimates of Largescale Sucker did not show this same increase from 2010 to 2014 (Figure 18). The density of Sucker species was greater in fall than in spring (*P* = 0.001). The abundance of Largescale Sucker was also greater in fall than in spring but the difference was not significant (*P* = 0.1).

Sucker species densities were generally lowest immediately downstream of REV and highest in Reach 3 (right panels; Figures 17 and 18). The greater values of the distribution effect after 2010 than before suggested an upstream shift in distribution following the flow regime change (Figure 19). However, the interaction between river kilometre (distribution) and flow regime was not significant for count density of Sucker species (*P* = 0.08) or abundance of Large Scale Sucker (*P* = 0.4), suggesting the distribution was not different between flow regimes. The interaction between river kilometre and season indicated that distribution differed by season with a distribution further downstream in the spring than in the fall for both Sucker species (*P* = 0.001) and Largescale Sucker (*P* = 0.001).

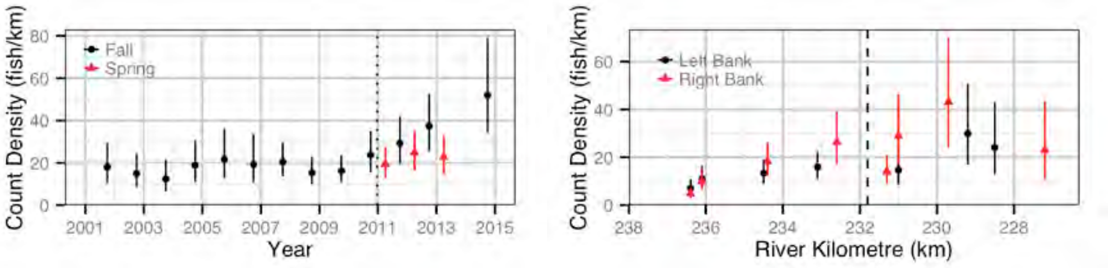

Figure 17: Count density estimates (with 95% credible intervals) by year and season (left panel) and site (right panel) for Sucker species in the middle Columbia River study area, 2001 to 2014. The dotted line (left panel) represents the implementation of the minimum flow release and REV5 operations. The dashed line (right panel) represents the divide between Reaches 3 and 4 at the Jordan River confluence.

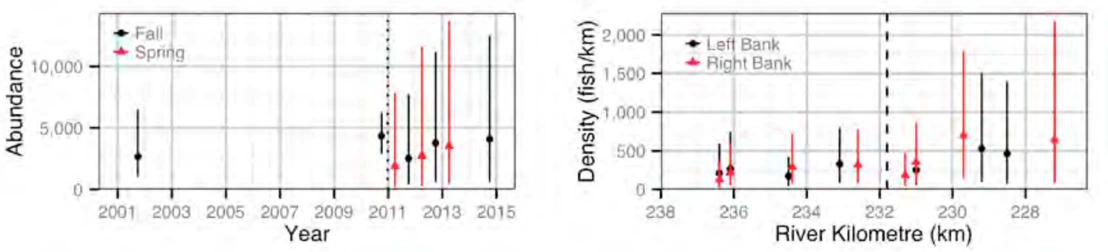

Figure 18: Abundance estimates (with 95% credible intervals) by year and season (left panel) and site (right panel) for Largescale Sucker in the middle Columbia River study area, 2001, and 2010 to 2014. The dotted line (left panel) represents the implementation of the minimum flow release and REV5 operations. The dashed line (right panel) represents the divide between Reaches 3 and 4 at the Jordan River confluence.

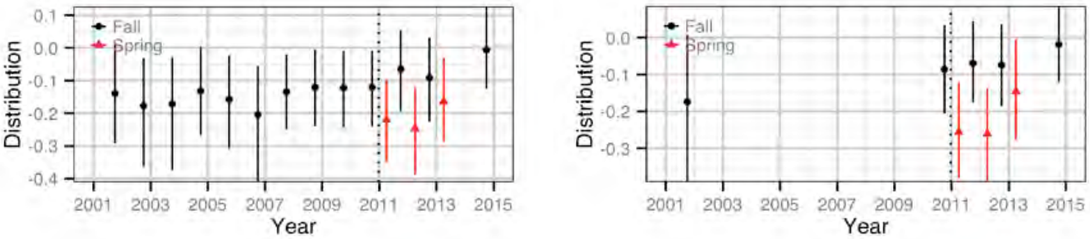

Figure 19: **Effect of year on the distribution (with 95% credible intervals) of Sucker species count densities (left panel) and Largescale Sucker abundance estimates (right panel) by year in the middle Columbia River study area, 2001 to 2014. Positive values indicate an upstream shift in distribution and negative values indicate a downstream shift. The dotted line represents the implementation of the minimum flow release and REV5 operations.**

3.6.7 Northern Pikeminnow

Northern Pikeminnow densities in the MCR increased substantially from 2001 to 2010, declined from 2010 to 2013 and remained low in 2014 (Figure 20). Season was a significant predictor of Northern Pikeminnow density (*P* = 0.01), with fall densities approximately 9 times greater than spring densities. Northern Pikeminnow density did not differ significantly between flow regimes (*P* > 0.9).

Northern Pikeminnow density was greater in Reach 3 than in Reach 4, and increased with decreasing river kilometre, which represents increasing proximity to Arrow Lakes Reservoir (Figure 20). The interaction between river kilometre (distribution) and flow regime was not significant (*P* = 0.9), indicating that the relationship between river kilometre and count density did not differ by flow regime. The interaction of season and river kilometre was not significant (*P* = 0.9), suggesting that the distribution of Northern Pikeminnow did not differ between spring and fall sampling seasons (Figure 21).

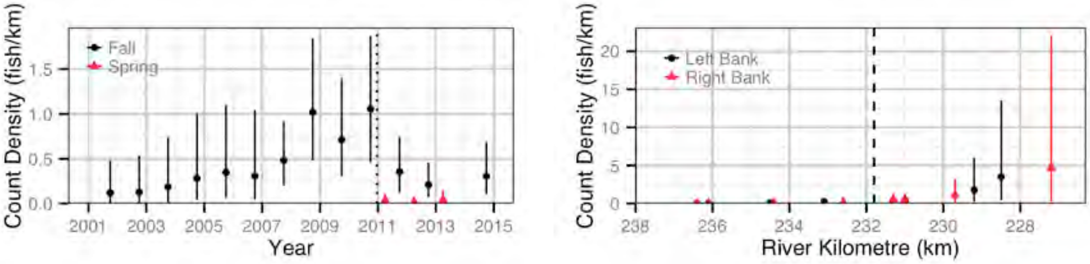

Figure 20: **Count density estimates (with 95% credible intervals) by year and season (left panel) and site (right panel) for Northern Pikeminnow in the middle Columbia River study area, from 2001 to 2014. The dotted line (left panel) represents the implementation of the minimum flow release and REV5 operations. The dashed line (right panel) represents the divide between Reaches 3 and 4 at the Jordan River confluence.**

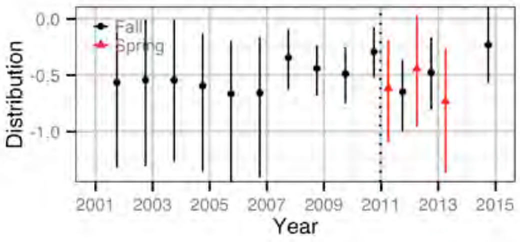

Figure 21: Effect of year on the distribution (with 95% credible intervals) of Northern Pikeminnow densities in the middle Columbia River study area, from 2001 to 2014. Positive values indicate an upstream shift in distribution and negative values indicate a downstream shift. The dotted line represents the implementation of the minimum flow release and REV5 operations.

3.6.8 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 2.8 to 6.9% across all sessions and years for juveniles and 2.0 to 4.5% for adults (Appendix H, Figures H7-H8).

Capture efficiency was lower for juvenile Mountain Whitefish (<1%), but stable across sampling sessions and years (Appendix H, Figure H9). For adult Mountain Whitefish (age-2 and older), capture efficiency was similar across years and sessions but greater in the spring (~4-6%) than in the fall (~2-3%) in both 2011 and 2012 (Appendix H, Figure H10). This may indicate that adult Mountain Whitefish were more likely to leave the study area after marking during the fall than they were during the spring.

Capture efficiency of Rainbow Trout ranged from 5.0 to 7.1% in the fall and 4.2 to 6.0% in the spring (Appendix H, Figure H11). Capture efficiency of Largescale Sucker was similar among years but was lower in spring (0.8-1.4%) than in the fall (1.1-3.0%; 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.

The abundance model used data for captured fish during the mark-recapture surveys and counted fish during the geo-referenced visual surveys. Capture efficiency was calculated based on the marked and recaptured fish, whereas the relative efficiency was calculated as the ratio of fish counted to fish captured. Relative efficiencies of 200-300% for adult Bull Trout, Mountain Whitefish, and Largescale Sucker suggested that two to three times as many fish of these species are observed and counted than are captured by netters, with similar relative efficiency among species (Appendix H, Figure H13). For juvenile fishes, the relative efficiency of counted to captured was 150% for Mountain Whitefish and 64% for Bull Trout. Relative efficiency was not calculated for Rainbow Trout because only two were observed during the geo-referenced visual survey.

3.6.9 Site Fidelity

Site fidelity, defined as the probability of a fish that was 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 H17). Site fidelity of Bull Trout was greater in fall than in spring, and declined with increasing body size (fork length) from ~70% for a 200 mm fish to ~25% for a 600 mm fish during the fall season (Appendix H, Figure H14). Site fidelity of Largescale Sucker increased with increasing body size from ~20% for a 300 mm fish to ~75% for a 500 mm fish during the fall season (Appendix H, Figure H15). For Mountain Whitefish, site fidelity did not vary by body length during the fall, with site fidelity estimates of ~50% (Appendix H, Figure H16). During spring sampling, Mountain Whitefish site fidelity increased between body sizes of 150 to 300 mm and was close to 100% for fish larger than 300 mm. Site fidelity of Rainbow Trout decreased with increasing body size from ~75% for a 200 mm fish to ~50% for a 400 mm fish (Appendix H, Figure H17). Credible intervals for site fidelity estimates were large (often >50% range), especially for spring sampling and species with fewer recaptures such as Rainbow Trout, indicating high uncertainty in the probability of being recaptured at the same site for a given season and body size.

3.6.10 Geo-referenced visual enumeration surveys

Two of the objectives of the geo-referenced visual enumeration surveys were to assess its effectiveness as an index of abundance and to provide fine-scale data regarding fish distribution in the MCR. The results show positive relationships between counts of fish during the visual surveys and predicted catches from the mark-recapture model for the same sites (Figure 25). There appeared to be more variability, indicating a less consistent relationship between count and catch, at higher abundance for all species and life stages. The relationship between visual survey counts and predicted catch was the weakest for juvenile Bull Trout, likely because of low and variable abundance among sites. Overall, the results suggest that mark-recapture estimates and visual survey counts are comparable and may show similar trends over time and space, although additional data and analyses are required to confirm the relationship. The maps of fish densities during the surveys (Appendix I) can be used to identify important fish habitats, and compared to future years to assess the effects of variations in river discharge on fish distribution and habitat usage.

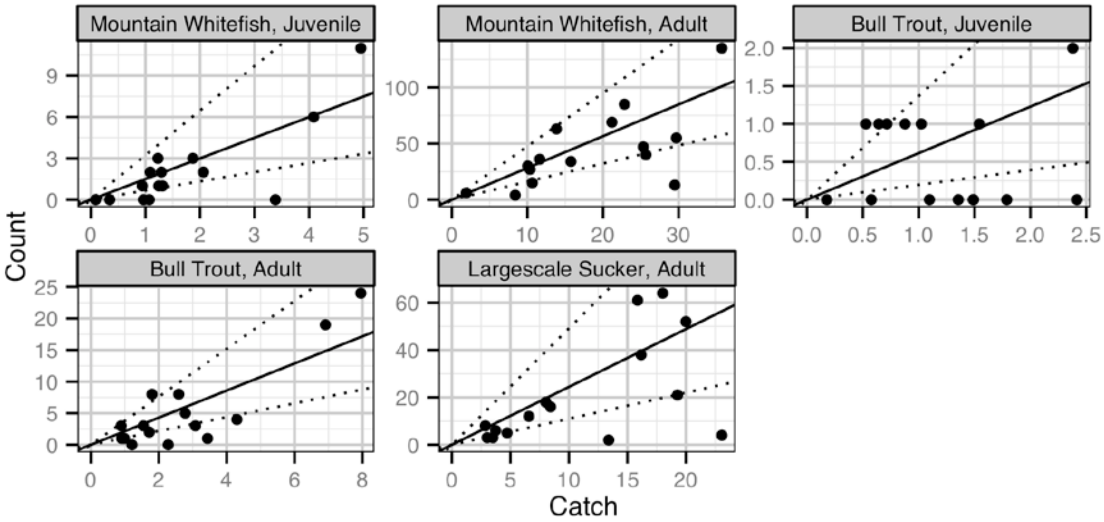

Figure 22: Comparison of fish counts during visual surveys to predicted catch from mark-recapture models for the middle Columbia River, 2014. Each point represents the count and predicted catch from one sample site. The solid line is the parameter in the abundance model that represents the count:catch efficiency and the dotted lines are its 95% CRIs.

3.6.11 *Observer Length Bias*

The length bias model used the length-frequency distribution of captured fish to estimate the bias in the estimated lengths of fish counted in the geo-referenced visual survey. The results suggested that both observers underestimated lengths (Figure 23), with the bias greater for Observer 1 than for Observer 2. The bias depended on species with underestimates up to ~30% for Mountain Whitefish and Sucker species, and up to ~20% for Bull Trout (Figure 24). Estimates of observer bias were used to correct estimated fork lengths of fish observed during the visual survey.

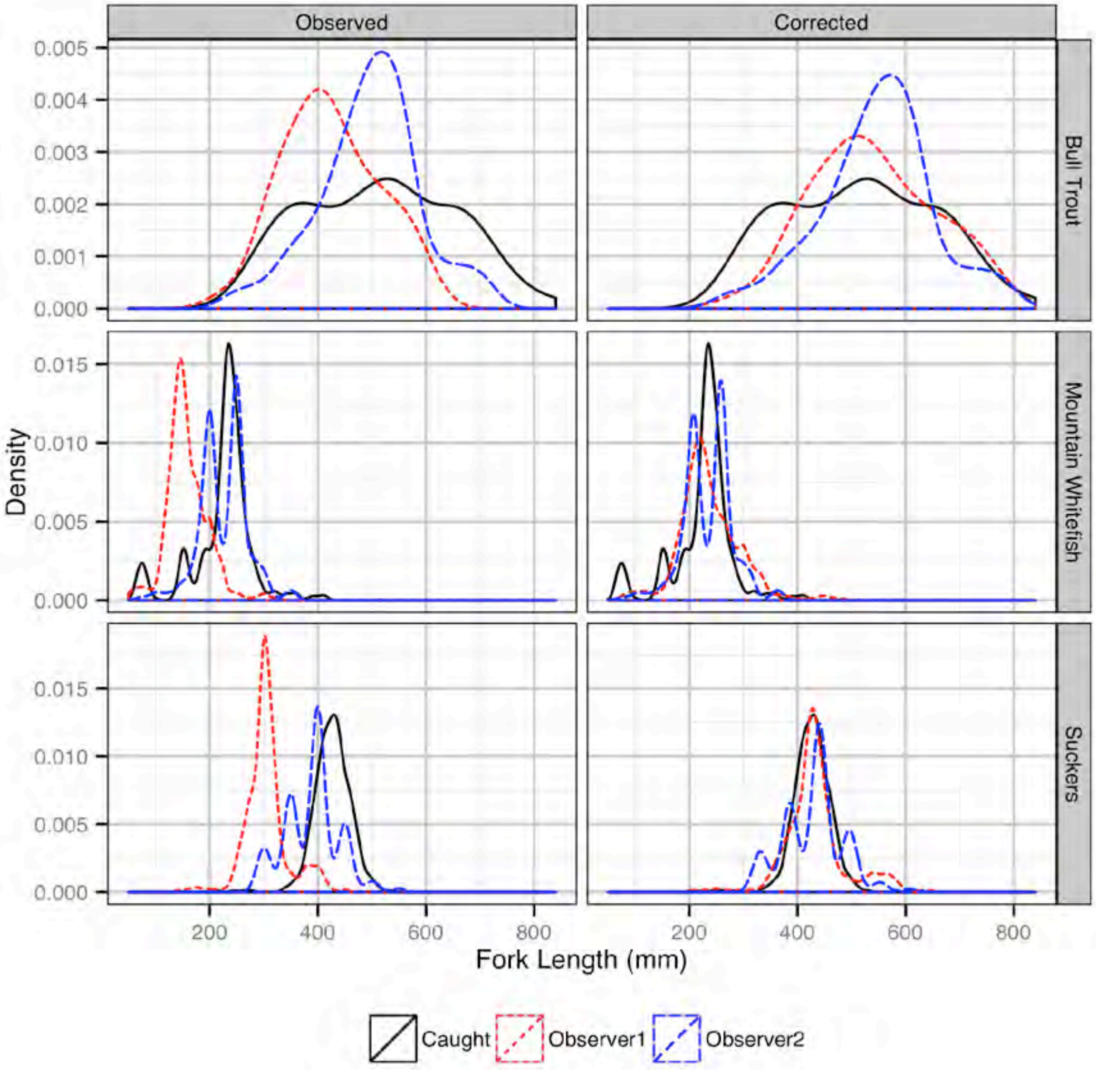

Figure 23: Fork length-density plots for measured and estimated fork lengths of fish caught or observed in the middle Columbia River study area, 2014.

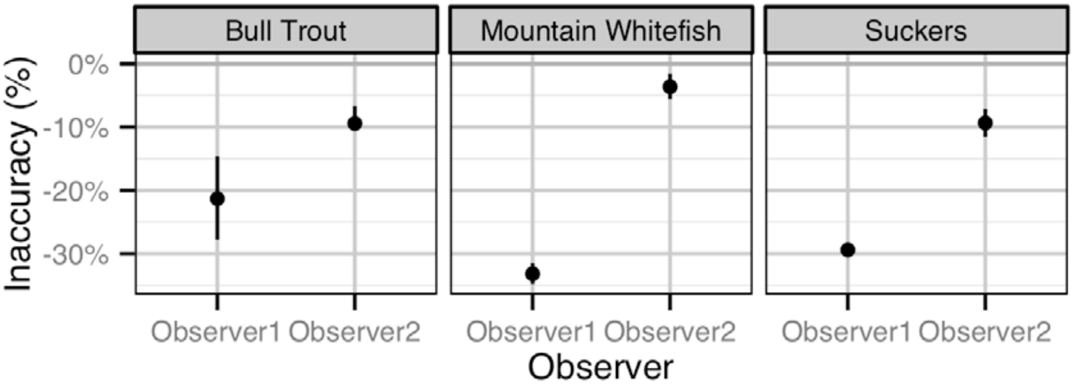

Figure 24: **Inaccuracy (bias) in observer estimated fork lengths of fish based on length bias model of captured (mark-recapture surveys) and estimated (geo-referenced visual surveys) length-frequency distributions from the middle Columbia River study area, 2014.**

3.7 Growth Rate

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

3.7.1 Bull Trout

Based on the HBM of annual growth of recaptured individuals, there was a substantial decline in Bull Trout growth rates between 2007 and 2008, followed by an increase from 2008 to 2010 (Figure 25). For a Bull Trout with a fork length of 500 mm, mean annual growth increased from approximately 41 mm in 2008 to approximately 72 mm in 2010 (Figure 25). In 2014 there was a decline in growth rate from the previous two years. The relationship between Bull Trout annual growth rate and flow regime was not significant (*P* = 0.9).

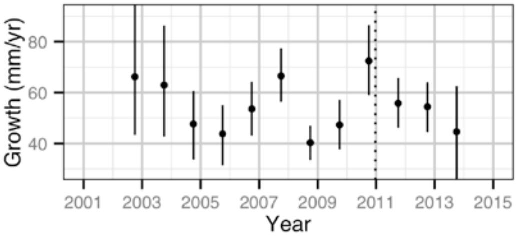

Figure 25: **Annual growth estimates (with 95% credible intervals) by year for a 500 mm FL Bull Trout in the middle Columbia River study area, 2001 to 2014. The dotted line represents the implementation of the minimum flow release and REV5 operations.**

3.7.2 *Mountain Whitefish*

Annual growth of recaptured Mountain Whitefish was lower between 2002 to 2005 than during most years since 2005 (Figure 26). Growth of adult-sized Mountain Whitefish (250 mm) was near 1cm/year during all years, indicating slow growth of this species in the MCR. There was no significant difference in growth before and after the flow regime change (*P* = 0.3).

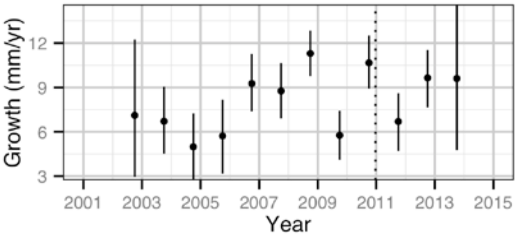

Figure 26: Annual growth estimates (with 95% credible intervals) by year for a 250 mm FL Mountain Whitefish in the middle Columbia River study area, 2001 to 2014. The dotted line represents the implementation of the minimum flow release and REV5 operations.

3.7.3 *Rainbow Trout*

From 2006 to 2014 the growth of recaptured Rainbow Trout was similar with mean annual growth rates ranging from 32 to 50 mm. There was no significant difference in annual growth before and after the flow regime change (*P* = 0. 5).

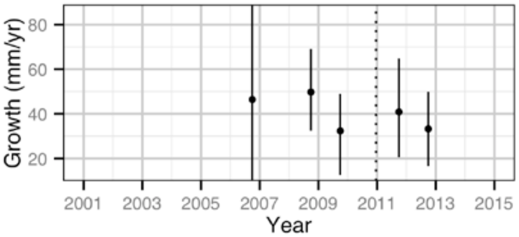

Figure 27: Annual growth estimates (with 95% credible intervals) by year for a 300 mm FL Rainbow Trout in the middle Columbia River study area, 2006 to 2014. The dotted line represents the implementation of the minimum flow release and REV5 operations

3.8 *Body Condition*

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

3.8.1 Bull Trout

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

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 2014 (Figure 28). 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 29). In 2014, body condition for adult Bull Trout remained low with an effect size of ~10% lower than a typical year.

The slope of the weight-length relationship did not differ by flow regime (*P* = 0.5) but the intercept did differ by flow regime (*P* = 0.01), indicating significantly lower body condition for Bull Trout after the flow regime change than before. There was no effect of season on the slope (*P* = 0.5) or intercept (*P* = 0.8) of the weight-length relationships, suggesting no significant difference in Bull Trout body condition between spring and fall.

For both juvenile and adult Bull Trout, there was little variation in condition among sample sites (Figures 28 and 29, respectively).

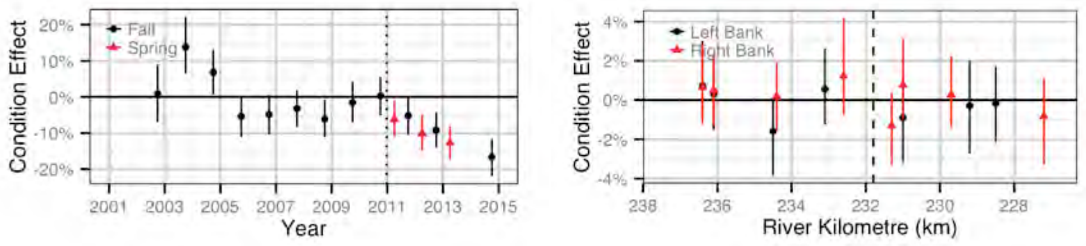

Figure 28: Body condition effect size estimates (with 95% credible intervals) by year and season (left panel) and site (right panel) for a 300 mm FL juvenile Bull Trout in the middle Columbia River study area, 2002 to 2014. The dotted line (left panel) represents the implementation of the minimum flow release and REV5 operations. The dashed line (right panel) represents the divide between Reaches 3 and 4 at the Jordan River confluence.

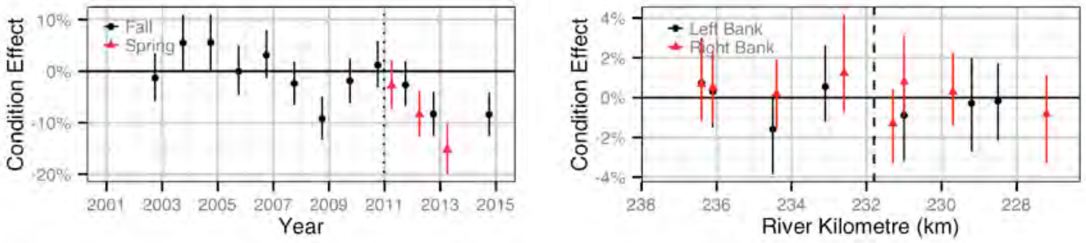

Figure 29: Body condition effect size estimates (with 95% credible intervals) by year and season (left panel) and site (right panel) for a 500 mm FL adult Bull Trout in the middle Columbia River study area, 2002 to 2014. The dotted line (left panel) represents the implementation of the minimum flow release 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.

Body condition of juvenile Mountain Whitefish showed a general decline from 2003 to 2011, and then increased from 2012 to 2013 (Figure 30). A decline in body condition was observed in 2014. Body condition of adult Mountain Whitefish showed a steady decline from 2003 to 2009 (Figure 31). From 2011 to 2014 the body condition of adult Mountain Whitefish had effect sizes between -3 and -5% (fall season), indicating slightly lower than average body condition.

Flow regime did not have an effect on the slope of the length-weight relationship ($P = 0.2$) but did have an effect on the intercept ($P = 0.008$). This suggests that Mountain Whitefish body condition was significantly greater before the flow regime change than after. There was a difference in the slope ($P = 0.001$) and intercept ($P = 0.001$) of the length-weight relationship by season. Mountain Whitefish had significantly greater body condition in the fall than in the spring.

For all study years combined, adult Mountain Whitefish body condition was lower in Reach 4 and higher in Reach 3 (Figure 31).

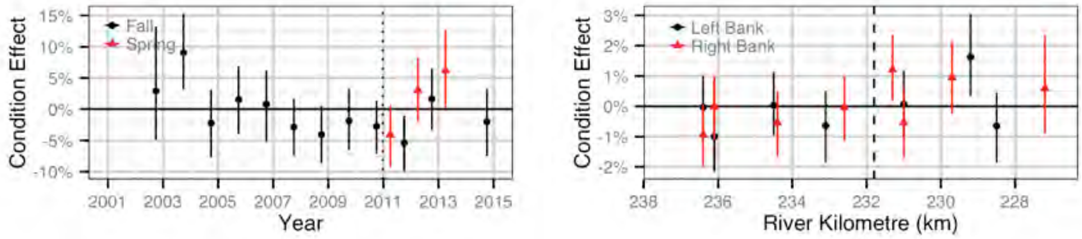

Figure 30: Body condition effect size estimates (with 95% credible intervals) by year and season (left panel) and site (right panel) for a 100 mm FL juvenile Mountain Whitefish in the middle Columbia River study area, 2002 to 2014. The dotted line (left panel) represents the implementation of the minimum flow release and REV5 operations. The dashed line (right panel) represents the divide between Reaches 3 and 4 at the Jordan River confluence.

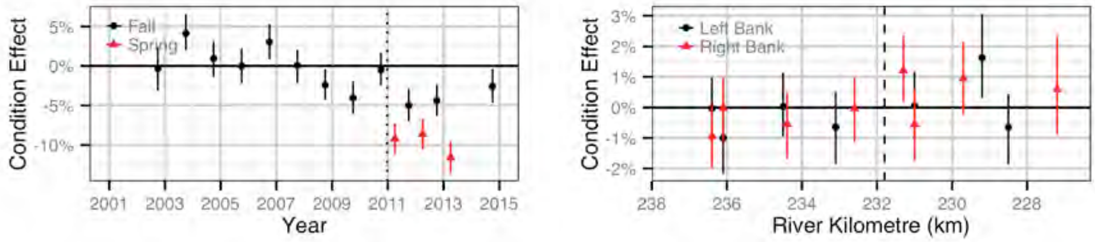

Figure 31: Body condition effect size estimates (with 95% credible intervals) by year and season (left panel) and site (right panel) for a 250 mm FL adult Mountain Whitefish in the middle Columbia River study area, 2002 to 2014. The dotted line (left panel) represents the implementation of the minimum flow release and REV5 operations. The dashed line (right panel) represents the divide between Reaches 3 and 4 at the Jordan River confluence.

3.8.3 Rainbow Trout

Body condition varied little among study years and credible intervals overlapped for all estimates (Figures 32 and 33). For adult Rainbow Trout, body condition in the fall decreased from 2009 to 2014 (Figure 33). Estimates of body condition could not be calculated for Rainbow Trout prior to 2003 because weights were not recorded in 2001 and Rainbow Trout were not encountered in 2002. Body condition could not be estimated for Rainbow Trout at Site 232.6-R because this species has never been captured at that site.

There was no difference between the slope (*P* = 0.4) or intercept (*P* = 0.9) of Rainbow Trout weight-length relationships before and after the flow regime change, suggesting no effect of the flow regime on Rainbow Trout body condition. The slope of the weight-length relationship did not differ by season (*P* = 0.7) but the intercept did differ by season (*P* = 0.001), indicating a significantly lower body condition in the spring than the fall.

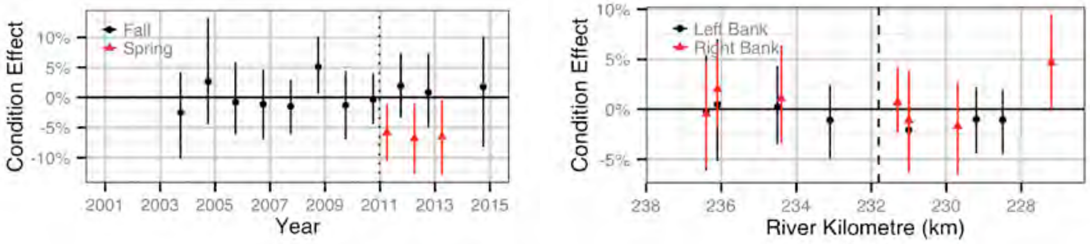

Figure 32: **Body condition effect size estimates (with 95% credible intervals) by year and season (left panel) and site (right panel) for a 150 mm FL juvenile Rainbow Trout in the middle Columbia River study area, 2003 to 2014. The dotted line (left panel) represents the implementation of the minimum flow release and REV5 operations. The dashed line (right panel) represents the divide between Reaches 3 and 4 at the Jordan River confluence.**

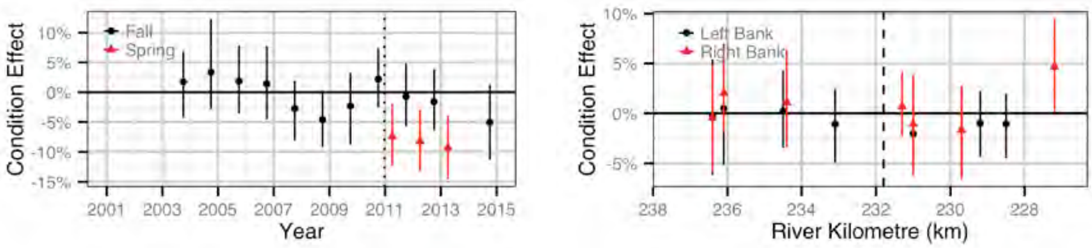

Figure 33: **Body condition effect size estimates (with 95% credible intervals) by year and season (left panel) and site (right panel) for a 300 mm FL adult Rainbow Trout in the middle Columbia River study area, 2003 to 2014. The dotted line (left panel) represents the implementation of the minimum flow 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 2014. 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 Environmental Variables

To investigate associations between environmental variables and fish populations, multivariate analyses were conducted to assess long-term trends and short-term correlations in the data. Dynamic factor analysis was used to identify common long-term trends in environmental and fish variables (Figure 34). NMDS was used to graphically assess variables that had the most similar trends over time, as indicated by proximity on the NMDS plot (Figure 35). The stress value for the NMDS of long-term trends was 15%, indicating an acceptable representation of the trends by the NMDS analysis. The results suggested that the body conditions of adult Rainbow Trout, adult Mountain Whitefish, and juvenile and adult Bull Trout were associated with the abundance of Kokanee in Arrow Lakes and the PDO index (Figure 35). All of these variables generally declined during the study period (2001-2014), with many of the variables showing a small and temporary increase in 2008 to 2010 (Figure 34). The distribution of Northern Pikeminnow was associated with reservoir elevation in October to December. The distribution and abundance of Rainbow Trout and the abundance of Sucker species was associated with Q10 discharge during fall, winter, and spring, mean discharge in winter, and discharge variability in the fall (upper left of Figure 34), all of which generally increased following the flow regime change in 2010. The count density of Rainbow Trout was positively associated with mean discharge during spring, and reservoir elevation during spring and summer (bottom left of Figure 34). Invertebrate biomass was associated with the body condition of juvenile Rainbow Trout.

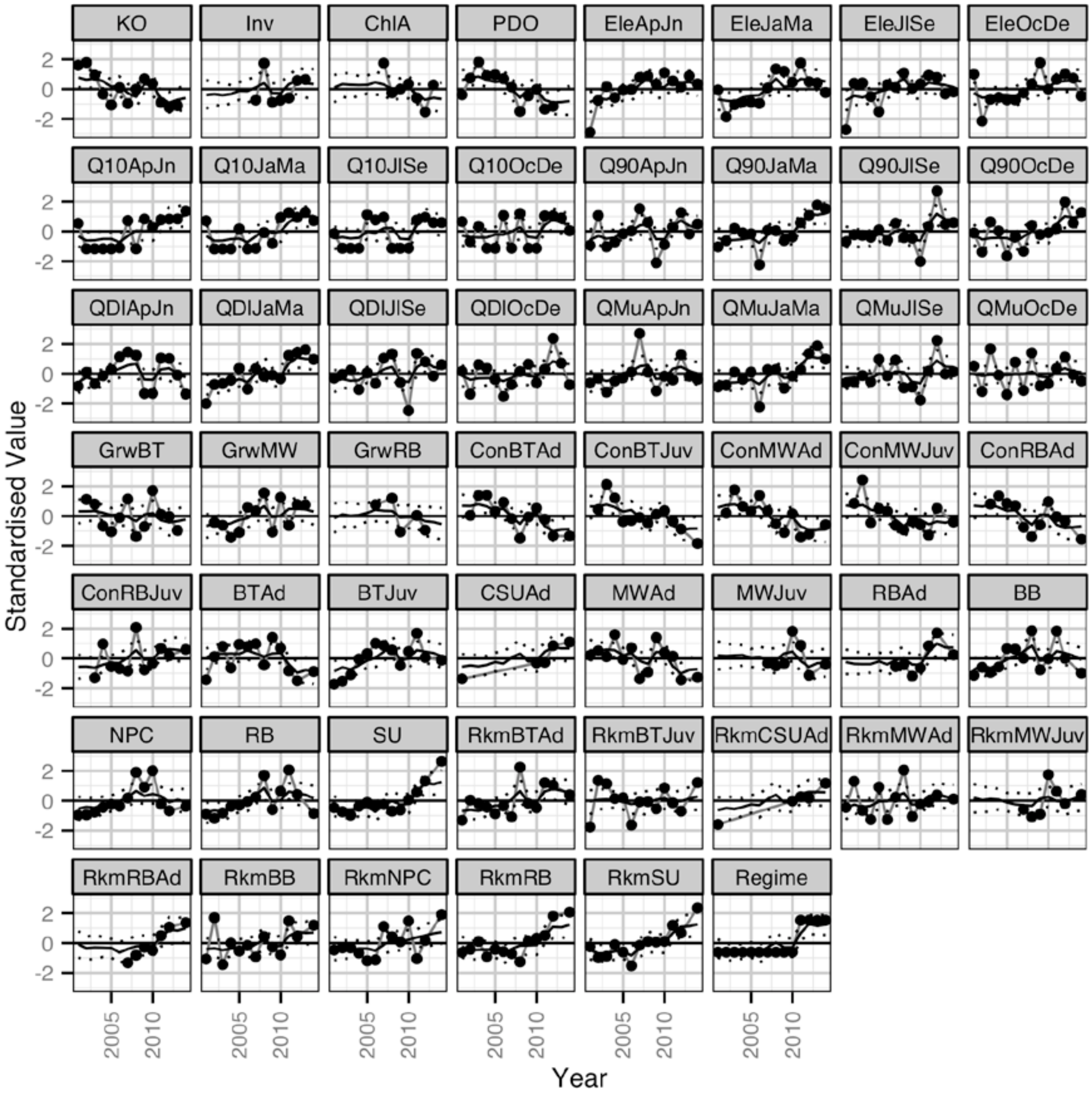

Figure 34: **Standardized values of the environmental variables by year with the predicted values from Dynamic Factor Analysis as black lines and 95% credible intervals as dotted lines.**

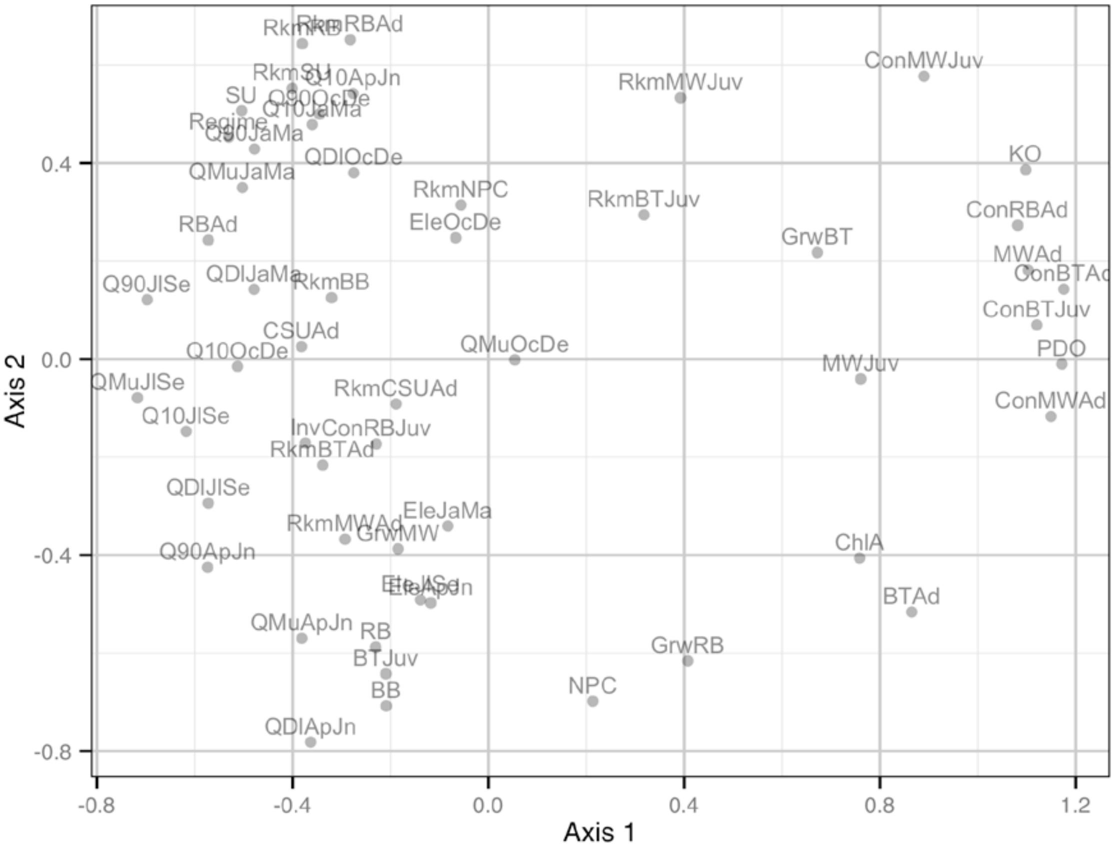

Figure 35: **Non-metric multidimensional scaling (NMDS) plot showing clustering of standardized variables by trend weightings from the dynamic factor analysis used to assess common long-term trends in the environmental and fish variables.**

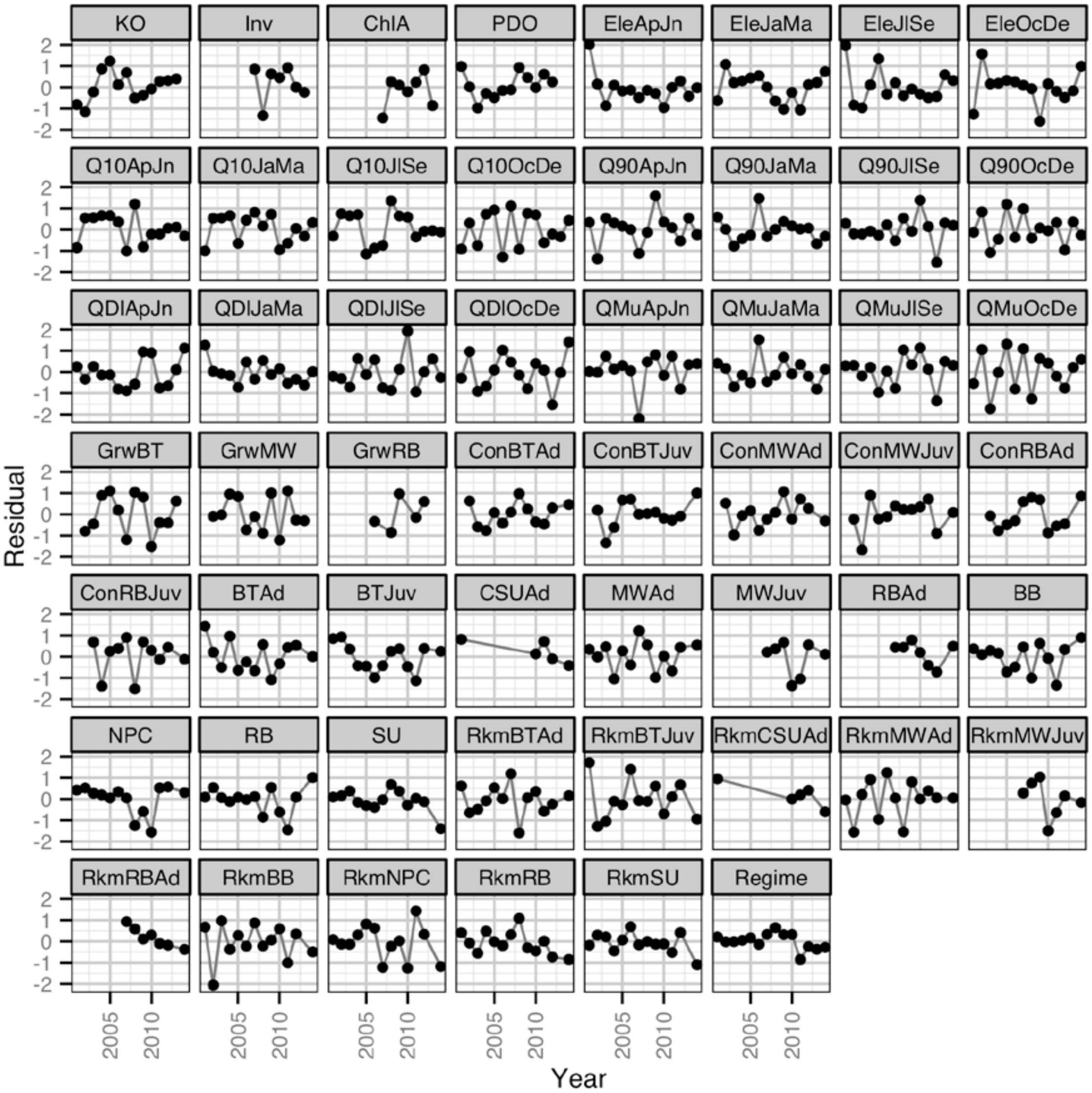

Figure 36: Residuals of standardized variables from dynamic factor analysis of environmental and fish variables. The plots represent short-term variability that was not explained by the long-term common trends.

Correlations between the residuals of the dynamic factor analysis model were calculated to assess short-term inter-annual associations among variables, after removing the effect of long-term trends (Figure 36). The analysis did not suggest a large number of short-term associations, as indicated by relatively spread-out points on the NMDS plot (Figure 37). The stress value for the short-term correlation NMDS was 36%, suggesting a poor representation of the relationships by the two dimensional NMDS analysis. Although there were no large groupings of variables, there were some fish metrics with variability that was associated with environmental variables. For instance, the body condition of juvenile Bull Trout was associated with reservoir elevation in fall and winter and discharge variability in the fall (Figure 37). Overall, the analysis did not suggest any strong short-term associations in the data.

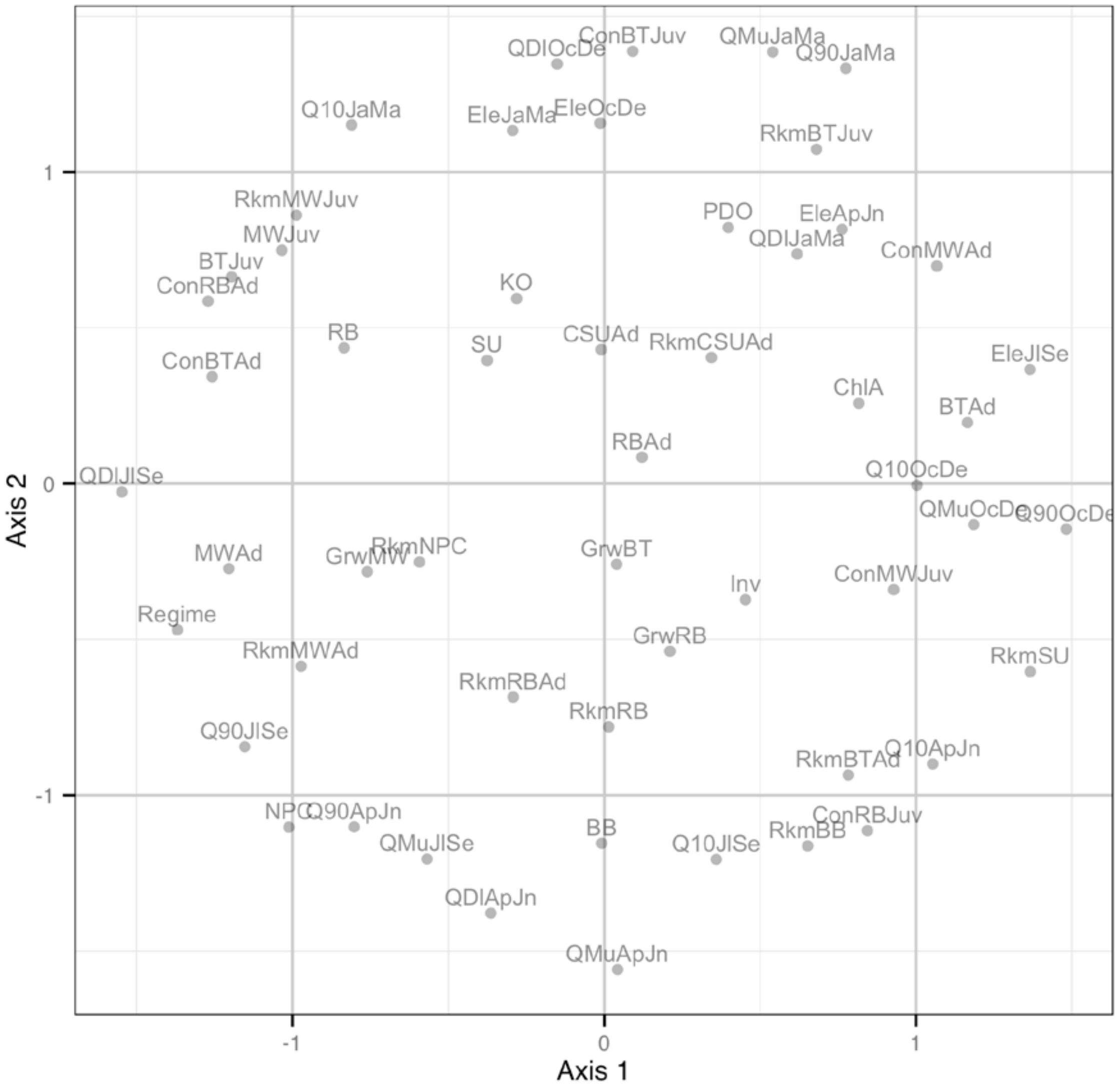

Figure 37: Non-metric multidimensional scaling (NMDS) plot showing clustering of variables by absolute correlations of short-term variation in environmental and fish variables.

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, whereas discharge was near average in 2013 and 2014. Both natural inter-annual variability and the flow regime change have the potential to influence fish populations in the MCR.

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. During years when species richness increased, electroshocking protocols (Section 2.1.6) and capture efficiencies of tagged species (Section 3.6.8) were similar. Therefore, the observed increases in the probability of occupancy likely reflect real changes in abundance and not sampling biases, such as increased netting efficiency over time.

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 2007. 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. Species richness was lower in the spring than in the fall, which was related to lower probability of occupancy of Burbot, Northern Pikeminnow, Lake Whitefish, and Redside Shiner. Species evenness was higher in spring than fall, likely because of lower densities of the most common species, Mountain Whitefish and Bull Trout.

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 2014 when the flow regime change occurred.

4.3 Management Question #1 – Abundance

4.3.1 Bull Trout

The abundance of adult Bull Trout did not suggest any significant changes over time or related to the flow regime change. The abundance of juvenile Bull Trout increased from 2001 to 2007 and mostly decreased from 2007 to 2014. The period of increasing juvenile 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 in most years. However, based on the environmental analyses, there were no strong associations between juvenile Bull Trout abundance and discharge or reservoir elevation, indicating that there was not a consistent relationship between these variables.

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

Site fidelity of Bull Trout was approximately 15-20% greater in the fall than in the spring, depending on body size, with larger fish more likely to be recaptured at different sites than smaller fish (Appendix H, Figure H14). The lower site fidelity of large adult Bull Trout during the fall could reflect pre-spawning movements or larger home ranges compared to smaller fish. The distribution of adult Bull Trout was further upstream in the spring than in the fall (Figure 8) but it is not clear whether this trend may be related to seasonal changes in prey distribution, pre-spawning movements, or other factors.

4.3.2 Burbot

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 2011 with no obvious trend. Densities in the fall decreased in subsequent years since 2011 but it is unknown whether these changes in Burbot density were related to the flow regime change or other factors.

4.3.3. Kokanee

Density and probability of occupancy of Kokanee were not estimated because the extremely variable counts of this species resulted in modelling difficulties and unreliable estimates. Sockeye salmon, including the land-locked Kokanee form, often have large inter-annual variation and cyclical patterns of low and high abundance (Quinn 2005), which may partly explain the variability in site occupancy and density. Kokanee migrate into the MCR during the fall season to spawn in adjoining tributaries, but this species generally rears and feeds in large lakes (e.g., ALR; Scott and Crossman 1973). Because the study area is primarily used as a migratory corridor during the fall, it is unlikely that abundance of this species in the MCR will be influenced by the flow regime change. Other dam-related factors, such as entrainment rates through REV, could potentially have a larger impact on the abundance of Kokanee in the MCR. Boat electroshocking in the MCR is not intended nor is it effective for enumerating Kokanee populations in the MCR and ALR. Kokanee abundance is more effectively assessed through spawning ground enumeration and hydro-acoustic surveys in the reservoir, both of which are already being conducted.

4.3.4 Mountain Whitefish

Densities of adult Mountain Whitefish indicated stable abundance between 2001 and 2014. There were relatively higher densities of juvenile Mountain Whitefish in 2010 and 2011 compared to other study years, which were likely the result of large numbers of age-0 fish in 2009 and 2010 (Appendix E, Figure E2). These two cohorts represent spawning that occurred during the winters of 2008/2009 and 2009/2010, time periods that were characterized by water temperatures and river discharges comparable to other study years, but higher than average water elevation during winter in ALR, especially in 2008/2009 (Appendix C, Figure C3).

The abundance of juvenile Mountain Whitefish was greater in the spring compared to the subsequent fall in 2011 and 2012. Although the difference was small, this seasonal change in abundance suggests that many juvenile Mountain Whitefish may migrate into the MCR from ALR or tributaries during the spring and leave the MCR in the fall. Adult Mountain Whitefish abundance was greater in the fall than in the spring. As Mountain Whitefish spawn in the late fall and winter (McPhail 2007), the greater abundance in the fall could indicate adults moving upstream from ALR to potential spawning areas either in the MCR or its tributaries.

Abundance of juvenile Mountain Whitefish decreased from 2011 to 2013. 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 spring of 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) 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.

Recapture rates of adult Mountain Whitefish were higher in the spring (~4-6%) than in the fall (~2-3%; Appendix H, Figure H10). Reasons for the large increase in capture efficiency in the spring are unknown but could be related to greater likelihood of adult Mountain Whitefish leaving the study area in the fall, as estimates of site fidelity indicated greater movement among sites in the fall than in the spring (Appendix H, Figure H16). This degree of seasonal difference in capture efficiency was not noted for any other species or life stages, which indicates that the increase was not due to a sampling bias (e.g., equipment error, selective netting by the field crew, differences in water conductivity, etc.) but more likely related to seasonal changes in behaviour of adult Mountain Whitefish. Mountain Whitefish spawn between November and February in the Lower Columbia River (LCR) downstream of HLK (Golder 2012), so some adult fish may migrate out of the MCR during the fall and into tributaries for spawning. However, capture efficiency did not decline in subsequent sessions of the fall season in most years, which would be expected if the number of Mountain Whitefish leaving the study area increased during the fall sampling season. Without mark-recapture data, seasonal differences in sampling efficiency would not have been detected and abundance would have been overestimated.

4.3.5 Rainbow Trout

Count density estimates for Rainbow Trout gradually increased from 2001 to 2008 and decreased from 2011 to 2014 (fall seasons), whereas abundance estimates were relatively consistently for all years mark-recapture data were available (2007-2014). Low catches of this species resulted in high uncertainty in density and abundance estimates. Although there was a decrease in count density during fall following the flow regime change, the abundance and spring count density estimates do not support an effect of the flow regime on the Rainbow Trout abundance in the MCR.

There were no differences in Rainbow Trout abundance between spring and fall seasons. However, the abundance of Rainbow Trout increased with proximity to ALR, with the greatest abundance in sites in the transition zone between ALR and the MCR. The results also suggested an upstream shift in the distribution of both juveniles and adults between 2007 and 2014. These changes could be related to changes in the spatial extent of reservoir backwatering on MCR habitat because many of the years between 2007 and 2014, with the exception of 2013 and 2014, had higher than average reservoir levels. It could be that high reservoir levels extend the transitional area preferred by Rainbow Trout a greater distance upstream from ALR and result in greater densities and a distribution further upstream, compared to years with lower reservoir levels. This influence of high reservoir was also supported by the analysis of long-term environmental trends, which suggested that the count density of adult Rainbow Trout was positively associated with several hydrological variables including mean discharge during spring, and reservoir elevation (spring and summer).

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

Count density of Sucker species was stable from 2001 to 2008 but steadily increased from 2009 to 2014, more than tripling from 16 to 52 fish per kilometre during this period (Figure 17). The estimated abundance of Largescale Sucker also increased during this period, though not as dramatically, from ~2500 in 2011 to 4090 in 2014 (fall sampling). Although the increase in Sucker species started in 2009 before the flow regime change, it is possible that minimum flows contributed to the increase after 2010. One of the predicted and desired effects of the minimum flow was to increase permanently wetted area and primary productivity, including algae (Perrin et al. 2004). As Sucker species feed primarily on periphyton and aquatic invertebrates (Dauble 1986), Sucker species are expected to respond to changes in productivity caused by flow regime sooner that fishes at higher trophic levels.

On the other hand, 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. If populations of mature adult Sucker did increase in the study area following the flow regime change, it would likely represent increased usage of the MCR by fish originating from ALR. However, 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. It is possible that in survey years prior to 2011, the netters underestimated numbers observed. Sucker species tend to aggregate in large groups and when the electroshocking 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 and remained low in 2014. The period of increasing density coincided with higher than average reservoir elevation in ALR from 2007 to 2010. The analysis of long-term environmental trends suggested that the distribution of Northern Pikeminnow was associated with reservoir elevation during the fall (October to December). The decrease in the density of Northern Pikeminnow in 2011 coincided with the implementation of the flow regime 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 at sites in streams with water velocity less than 0.4 m/s but occasionally in lakes (McPhail 2007). Little is known about spawning behaviour of Northern Pikeminnow in the MCR, so it is unclear if the very low densities observed in the spring are due to spawning migration out of the area or other factors.

4.3.8 Sculpin Species

The probability of occupancy of Sculpin species at a typical site increased from 4% in 2001 to >80% in 2006 to 2008. Occupancy declined in successive fall sampling following the flow regime change from 82% in 2011 to 41% in 2014. 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 declined starting after 2011 but it is not known if this was caused by the flow regime change. The large increase in occupancy between 2001 and 2008 occurred during the same general flow regime at Revelstoke Dam. Given their small body size and the associated inefficiency of the selected sampling method at capturing Sculpin species, it is unlikely that the program, in its current form, will generate reliable estimates to answer the management questions for these species. Sculpin species were routinely captured as part of BC Hydro's MCR Juvenile Fish Habitat Use Program (CLBMON-17; Triton 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 Bull Trout, Mountain Whitefish and Rainbow Trout.

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

4.4.1 Bull Trout

The growth rate of Bull Trout declined in the years following the flow regime change although the growth rates following the change were within the range previously observed. The difference in growth rate before and after the flow regime change was not statistically significant. Bull Trout growth was not strongly associated with long-term trends in other variables but based on the NMDS plot was most associated with the trends in Bull Trout body condition, Kokanee abundance, and PDO (Figure 35), as discussed in Section 4.5.1. 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).

4.4.2 Mountain Whitefish

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

Growth rate, modelled as the annual increase in fork length using the von Bertalanffy equation, did not indicate any decrease following the flow regime change. Grow rate increased from 6 to 12 mm between 2004 and 2008 and has fluctuated within this range since 2009. Contrary to the length-at-age analyses from previous years, the growth rate results based on recaptured fish do not suggest an effect of the flow regime on Mountain Whitefish growth. Multivariate analyses suggest similar long-term trends in the growth of Mountain Whitefish and reservoir elevation during winter, spring and summer (Figure 35), all of which generally increased during the mid-2000s (Figure 34). In the Skeena River, another large river in British Columbia, food abundance was the main factor limiting growth and abundance for Mountain Whitefish (Godfrey 1955 as cited by Ford et al. 1995). Invertebrate abundance measured in the MCR by the Ecological Productivity Monitoring study was not correlated with Mountain Whitefish growth or body condition, although invertebrate data were only available for 2007 to 2013.

4.4.3 Rainbow Trout

Rainbow Trout growth rate had wide credibility intervals but the mean values varied little before and after the change in flow regime. Based on the multivariate analysis there were no correlations between Rainbow Trout growth and the environmental variables assessed. The results do not suggest any change in the growth of Rainbow Trout associated with the flow regime change but there is relatively large uncertainty with this conclusion because of few years of data before and after the flow regime change and small sample sizes each year.

4.5 Management Question #3 – Body Condition

Body condition was analyzed using a HBM for Lake Whitefish, Largescale Sucker, Northern Pikeminnow, Prickly Sculpin, and Redside Shiner (in addition to Bull Trout, Mountain Whitefish, and Rainbow Trout; see below); however, limited data for these species resulted in wide credible intervals surrounding all estimates. Temporal or spatial trends in body condition were not observed for any of the above species. Life history data were collected for these species from 2010 to 2014 only, and due to the small sample sizes, credible intervals surrounding body condition estimates were wide. Uncertainties surrounding these estimates will likely decrease over time as more data are collected. 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 2014 following the flow regime change. The recent decline in Bull Trout body condition (2011-2014) was observed for both juvenile (17% decrease) and adult (8% decrease) life stages. Multivariate analyses suggested that the long-term trends in Bull Trout body condition were associated with the abundance of Kokanee in Arrow Lakes and the PDO index. Kokanee are known to be one of the primary prey items of Bull Trout in the fall in the MCR and elsewhere (McPhail and Baxter 1996). The PDO is a climate index that is associated with the survival and abundance of Pacific salmon in the marine environment (Mantua et al. 1997) but has also been linked to water temperature and zooplankton productivity in freshwater lakes (Schindler et al. 2005). In southern BC, the warm phase of the PDO, which is indicated by positive values of the index, is generally associated with warmer air temperature from October to April, less precipitation, lower snowpack, negative mass balance of glaciers (i.e. melting rather than accumulating), and lower streamflow in the Columbia River (McCabe and Dettinger 2002, Whitfield et al. 2010). Therefore, the declining PDO values observed during most of the study period (Figure 34) would be expected to be associated with cooler temperatures and increased streamflow, both of which could potentially negatively affect zooplankton (Schindler et al. 2005), which are the main food source for Kokanee. The multivariate analyses and supporting literature suggest possible associations among large-scale multi-year climate variability (indexed by the PDO), physical habitat conditions, zooplankton productivity, Kokanee abundance, and Bull Trout body condition, but additional data and analyses would be required to test this hypothesis. If the correlation between PDO and fish populations represents a real effect and not a spurious correlation, any effect would have to be manifest through influences on local conditions (e.g. temperature). Which local environmental variable(s) might explain the relationship is unknown as discharge variables were not correlated with PDO in the analysis, and water temperature was not included because data were only available since 2008.

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. However, because of the observational study design it is not possible to determine whether the low body condition was caused by the flow regime, or simply coincided with the change but was caused by other environmental changes and large-scale climatic variability.

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.

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 Mountain Whitefish body condition corresponded with a large decline in Bull Trout body condition that started in 2011. 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 body condition.

The body condition of Mountain Whitefish adults was associated with the PDO index, based on the multivariate analyses. It is possible that climatic variability and its effects on water temperature and discharge, as discussed in Section 4.5.1, could have influenced invertebrate prey abundance or other factors that affected Mountain Whitefish body condition. However, a possible causal mechanism of the association and literature supporting the relationship are lacking.

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

The body condition of Mountain Whitefish was higher in Reach 3 than in Reach 4. This result may be due to additional nutrients flowing into the MCR from the Jordan River (i.e., the divide line between the two reaches) resulting in higher productivity downstream of the confluence. As recommended in the CLBMON 15b study by Schleppe et al. (2011), monitoring the benthos upstream and downstream of the confluence would provide valuable 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. Abundance and biomass of benthic invertebrates was greater in the fall than in the spring season in the MCR (Schleppe et al. 2014).

4.5.3 Rainbow Trout

The body condition of adult Rainbow Trout decreased following the flow regime change, as was observed for Bull Trout and Mountain Whitefish. For Rainbow Trout, the effect size of the decrease in body condition was 7% between 2010 and 2014. The decrease in body condition was not correlated with long term trends in discharge metrics but was correlated with trends in body condition of Bull Trout and Mountain Whitefish, suggesting that similar climatic influences could have played a role in the decreases (as discussed in Section 4.5.1.). As was observed for Mountain Whitefish, body condition of Rainbow Trout was much lower in the spring than in the fall, likely because of less food availability in winter than in summer.

Body condition of Rainbow Trout was greatest at the site further downstream and closest to ALR (227.2-R). Boat electroshocking surveys were conducted in Reach 2 in 2008 and 2009. During those surveys, 42 Rainbow Trout were measured for length and weight (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 effect of the flow regime change on the spatial distribution of fish in the MCR was evaluated by testing whether the linear relationship between abundance and river kilometre varied by flow regime. In the models estimating count density and abundance, if the interaction (slope) between river kilometre (distribution) and flow regime was significant, the interpretation was that the flow regime had a significant effect on the spatial distribution of fish in the MCR. The interaction between river kilometre and flow regime was not significant for most 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. Two exceptions were the models for Rainbow Trout and Sucker species, which suggested a small upstream shift in distribution after the flow regime change (Sections 3.6.5-3.6.6). 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 analysis suggested seasonal differences in the distribution of many fish species in the MCR. The spatial distribution in the MCR, including seasonal and temporal trends, 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 increasing distance downstream from REV. Similarly, in Reach 3, Bull Trout densities were highest near the Jordan River confluence (RKm 231.6) and tended to decrease with distance downstream from the confluence. Both Moses Creek and the Jordan River are known spawning areas for Kokanee. The pattern of decreasing Bull Trout densities with increased distance downstream of both tributaries suggests that Bull Trout may be aggregating to feed on pre-spawning Kokanee entering these systems or on spent Kokanee exiting these systems. However, densities of Bull Trout also were high at these locations during the spring, which suggests that availability of Kokanee spawners as prey is not the only factor leading to high Bull Trout densities near the tributaries.

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

4.6.2 Burbot

Similar to results reported in previous years (e.g. Ford and Thorley 2012, Golder and Poisson 2013), density was greatest at Site 231.0-L, which is along the left bank between the Revelstoke Golf Course and the Rock Groyne. This site contains rip-rap substrate, steep banks, and high water velocities. Higher catch-rates of Burbot were recorded in similar habitats downstream of HLK as part of BC Hydro's LCR Fish Population Indexing Program (CLBMON-45; Ford and Thorley 2011b). The results suggested no differences in Burbot distribution by flow regime or season.

4.6.3 Kokanee

Spatial distribution was assessed using catch data (Appendix D, Table 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, distribution was patchy, with large numbers of fish observed in small areas, reflecting schooling behavior of pre-spawning Kokanee.

4.6.4 Mountain Whitefish

Adult Mountain Whitefish were most common from Site 232.6-R (upstream of the Jordan River confluence) to Big Eddy Bridge (Site 227.2-R). Habitat in this portion of the study area is dominated by shallow water depths, high water velocities, and small substrate (i.e., gravel and cobble) and may serve as a holding area for this species prior to spawning. Mountain Whitefish spawning has not been documented in the MCR; however, field crews have noted both gravid and ripe Mountain Whitefish during surveys. Mountain Whitefish densities were noticeably lower on the left bank (i.e., between the Revelstoke Golf Course and the Rock Groyne). Habitat in this area is typified by high water velocities, high water depths, and rip-rap or large substrate banks. Site 227.2-R (Salmon Rocks) has similar habitat characteristics and also had low adult Mountain Whitefish densities. Habitat preferences inferred from these observations generally agree with studies from other areas in western Canada, as Mountain Whitefish are typically found in areas with moderate to high flows, large gravels or cobbles, and shallow depths (Ford et al. 1995, McPhail 2007, Golder 2012).

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

Analysis suggested small inter-annual fluctuations in the distribution of juvenile and adult Mountain Whitefish but no effect of the flow regime. The model results suggested a more downstream distribution of Mountain Whitefish in the spring than the fall for both juveniles and adults but this seasonal difference was small.

4.6.5 Rainbow Trout

Between 2001 and 2014, 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, four were recorded in during sampling in the spring of 2013, and two were recorded in the fall of 2014. Increases in Rainbow Trout abundance in 2010 and 2011 suggested that the bank stabilization adjacent to Site 233.1-L made the area more suitable for Rainbow Trout. However, few Rainbow Trout were recorded at this site in 2012 to 2014, with similar numbers caught or observed as before the habitat enhancement. These fluctuations in Rainbow Trout abundance make it difficult to conclude whether the initial increase and subsequent decrease were related to changes in shoreline habitat, or overall abundance in the study area.

The results suggested a gradual shift to a more upstream distribution between 2007 and 2014. The increase in the model coefficient representing distribution suggested that in earlier years, density decreased with river kilometre, as indicated by a negative coefficient values, whereas in recent years the estimates were close to zero, suggesting no effect of river kilometre on density. Reasons for the temporal change in distribution are unknown but may be related to environmental conditions, as the distribution and abundance of adult Rainbow Trout were associated with Q10 discharge during fall, winter, and spring, mean discharge in winter, and discharge variability in the fall. As the gradual change in distribution started in 2008, this change was unlikely to be related to the flow regime change.

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. The seasonal difference, with further downstream distribution in spring, may also reflect habitat preference for slower moving water because the transition zone between ALR and the MCR is further downstream in the spring when reservoir levels are lower than in the fall.

As was observed for Rainbow Trout, there was a small upstream shift in distribution in the most recent years of the study for Sucker species and Largescale Sucker. Based on proximity on the NMDS plot, the distribution of Sucker species was associated Q10 discharge during fall, winter, and spring, mean discharge in winter, and discharge variability in the fall. The association between the distribution of Rainbow Trout and Sucker species and these hydrological variables suggests that inter-annual variability in discharge may influence the distribution of these species in the MCR.

4.6.7 Northern Pikeminnow

Northern Pikeminnow densities were higher in Reach 3 than in Reach 4 and density increased with proximity to ALR. Credible intervals overlapped for all estimates, but densities for this species were generally higher in sites that contained backwater habitat areas or had lower water velocities, such as Site 228.5-L (upstream of the Illecillewaet River confluence), Site 231.3-L (Big Eddy), Site 227.2-R (Salmon Rocks), and Site

229.2-L (between the Rock Groyne and the Centennial Park Boat Launch). This distribution reflects this species preference for low velocity habitats (Scott and Crossman 1973).

Northern Pikeminnow were more abundant in the MCR during the fall than during the spring but their distribution did not vary seasonally. Given the large size of the Northern Pikeminnow present during the fall season, it is possible that these fish were in the study area to feed on spawning Kokanee, as was reported in Pend d'Oreille Lake, Washington (Clarke et al. 2005).

4.6.8 Sculpin Species

Catches of Sculpin species were highest in Big Eddy and along the rip-rap on the left bank of Reach 3. Of the Sculpin species captured since 2010, 94% were Prickly Sculpin (*n* = 231) and 6% were Slimy Sculpin (*Cottus cognatus*) (*n* = 15). 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 4 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. Overall, trends in most fish population variables did not appear to be linked to the flow regime change, although there were some variables, such as body condition for several species, with trends that coincided with the flow regime change.

There was an increase in species richness and evenness between 2001 and 2008 that was attributed to significant increases in the occupancy and/or density of several less common species. The probability of occupancy of Burbot, Lake Whitefish, Northern Pikeminnow, Rainbow Trout, Redside Shiner, and Sculpin species all increased between 2001 and 2005-2008, depending on the species. The abundance of more common species, such as Bull Trout and Mountain Whitefish remained relatively stable during this time period. Although the results suggest a substantial change in the fish community between 2001 and 2008, reasons for the change are unknown. Multivariate analyses suggested correlations between the density of Northern Pikeminnow and reservoir elevation, and between Rainbow Trout density and several measures of discharge, suggesting that the increasing densities of some of the less common species may have been associated with variability in hydrological conditions.

There was some evidence to suggest that body condition or growth of fish in the MCR may have declined in the four years following the flow regime change. The growth and body condition of Bull Trout, and the body condition of adult Mountain Whitefish and Rainbow Trout all declined to low levels following the flow regime change. Multivariate analyses suggested that these trends in body condition were correlated with long-term trends in the PDO, an index of climate, and Kokanee in Arrow Lakes, which are an important prey for Bull Trout.

Based on the data collected to date, there were no significant changes in the distribution of fishes in the MCR associated with the flow regime change. Species distribution varied little over time for most species except for Rainbow Trout and Sucker species, whose distribution may have shifted upstream between 2007 and 2014, although the magnitude of the change was small. This trend in distribution was correlated with a similar trend in Q10 discharge during fall, winter, and spring, mean discharge in winter, and discharge variability in the fall, suggesting a potential link between hydrological conditions and the distribution of these species.

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.

Geo-referenced visual enumeration surveys were conducted for the first time in 2014 and preliminary analysis suggested that data from these surveys show comparable trends among sites as the mark-recapture abundance estimates. However, additional years of data are required to assess whether geo-referenced visual counts provide a reliable and comparable index of abundance over time. Maps of fish densities from the geo-referenced surveys can be used to identify important fish habitats, and compared to future years to assess the effects of flow regime variations on fish distribution and habitat usage.

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 Revelstoke Dam under an experimental flow regime including REV5 operation but 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.

- Geo-referenced visual enumeration surveys should continue, which will 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 be possible to calibrate the efficiency of the method and reduce the number of mark-recapture passes needed during each sample season. Continuing mark-recapture surveys with at least two sessions is recommended for 2015 and 2016 to ensure data are comparable to previous years of the study to address the management questions regarding growth. Reducing the number of mark-recapture session from 4 or 5 (2001-2013) to two will reduce potential impacts of repeated electroshocking and handling of fishes.

- Ageing of fish using scales is not currently conducted in the monitoring program. Previous analyses indicated that age-0 and age-1 Mountain Whitefish can be aged based on length-frequency distributions making scale-ageing unnecessary. Estimated ages from scale analysis for older Mountain Whitefish and most other species were thought to be unreliable. However, using age assignments from recaptured fish of known age, it may be possible to quantify uncertainty and bias in scale-based ages, and correct predicted ages of fish of unknown age based on the model. Assessment of growth and/or age by quantifying inter-circuli distances may also be possible. A preliminary analysis of these alternative methods for assessment of age and growth of fish in the MCR is recommended. This would be particularly important to continue to address the management question regarding growth if the number of mark-recapture sessions is reduced in future years of study.

- It is unknown if and where Mountain Whitefish and Rainbow Trout spawn in the mainstem of the MCR. Spawning assessments for these species would be required to understand how minimum flows or other dam operations influence spawning and early-life history.

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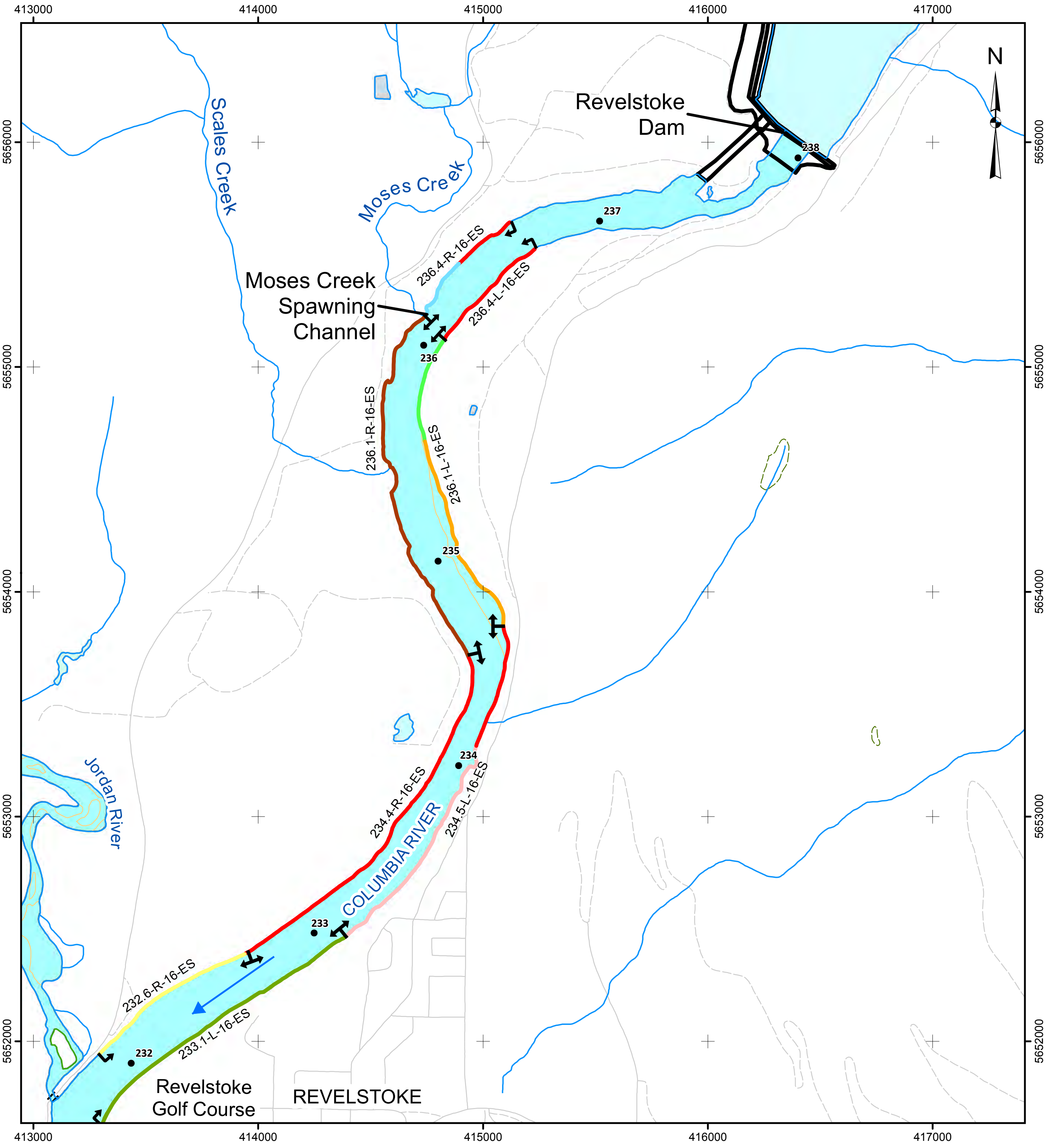
Appendix A - Maps



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

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 4

PROJECT No. 13-1492-0004			SCALE AS SHOWN	REV. 0
DESIGN	DF	24 Mar. 2015	FIGURE A1	
GIS	AL	24 Mar. 2015		
CHECK	DR	24 Mar. 2015		
REVIEW	DS	24 Mar. 2015		

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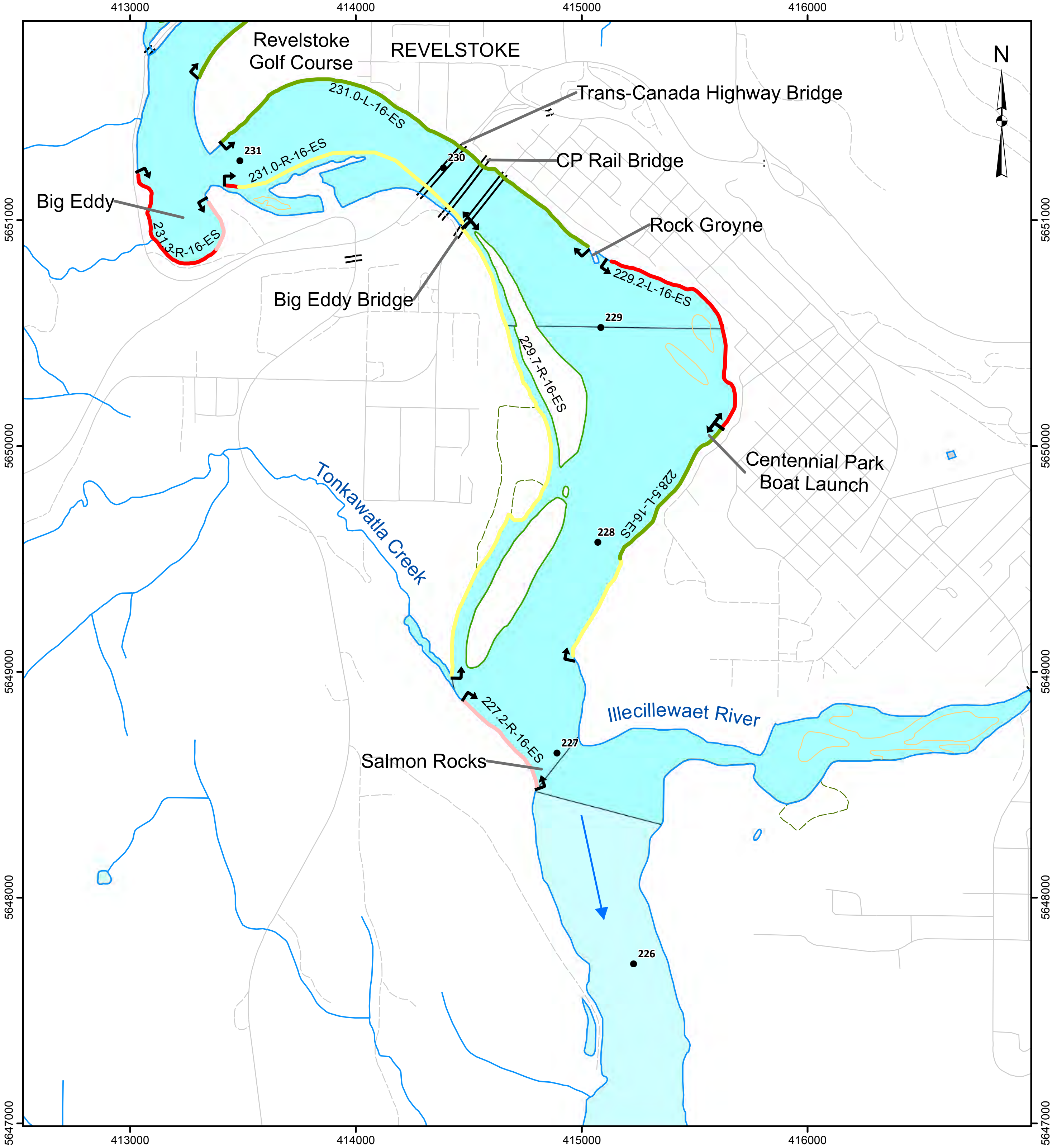

LEGEND

- ● 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	24 Mar. 2015	FIGURE A2	
GIS	AL	24 Mar. 2015		
CHECK	DR	24 Mar. 2015		
REVIEW	DS	24 Mar. 2015		

Document Path: N:\Active\GIS\2013\13-1492-0004\Mapping\MXD\Fish\1314920004_FIG_A2_INDEXING_2014.mxd

Table A1 Locations and distances from Revelstoke Dam of boat electroshocking sites in the Middle Columbia River, 2014.

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

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

[b] River kilometres measured upstream from the Canada-U.S. border.

[c] Bank location as viewed facing downstream.

Appendix B – Habitat Summary Information

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

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

Continued.

Table B1 Concluded.

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

Velocity Classifications:

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

Table B2 Lengths of bank habitat types within boat electroshocking sites in the Middle Columbia River, 2014.

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, 8 October to 30 October 2014

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-R-16-ES	2	9	9.6	150	Partly cloudy	High	High	High	85	0	5	0	0	10	0
4	236.4-R-16-ES	3	10	9.4	160	Mostly cloudy	High	High	High	97	0	3	0	0	0	0
4	236.4-R-16-ES	4	4	9	150	Overcast	Medium	Medium	High	100	0	0	0	0	0	0
4	236.4-L-16-ES	2	10	9.6	150	Partly cloudy	High	Medium	High	100	0	0	0	0	0	0
4	236.4-L-16-ES	3	11	9.4	160	Mostly cloudy	High	Medium	High	100	0	0	0	0	0	0
4	236.4-L-16-ES	4	4	9	150	Overcast	Medium	Medium	High	100	0	0	0	0	0	0
4	236.1-L-16-ES	2	8	9.3	160	Partly cloudy	High	High	Medium	70	0	0	0	0	30	0
4	236.1-L-16-ES	3	10	9.3	160	Overcast	High	Medium	High	90	0	0	0	0	10	0
4	236.1-L-16-ES	4	4	9	150	Overcast	Medium	Medium	High	95	2	0	0	0	3	0
4	236.1-R-16-ES	2	9	9.3	160	Partly cloudy	High	Medium	Medium	90	0	0	0	0	10	0
4	236.1-R-16-ES	3	10	9.4	160	Partly cloudy	High	Medium	High	99	0	1	0	0	0	0
4	236.1-R-16-ES	4	3	9	150	Overcast	Medium	High	High	90	0	10	0	0	0	0
4	234.4-R-16-ES	2	8	9.3	160	Mostly cloudy	High	Medium	High	92	3	0	0	5	0	0
4	234.4-R-16-ES	3	10	9.3	160	Overcast	High	High	High	95	5	0	0	0	0	0
4	234.4-R-16-ES	4	6	9	140	Partly cloudy	High	High	High	65	20	0	10		5	0
4	234.5-L-16-ES	2	10	9.7	150	Overcast	High	High	High	78	2	10	0	0	10	0
4	234.5-L-16-ES	3	9	9.3	-	Mostly cloudy	High	High	High	83	2	5	0	5	5	0
4	234.5-L-16-ES	4	6	9	140	Mostly cloudy	High	High	High	20	0	30	0	0	50	0
4	233.1-L-16-ES	2	9	9.7	150	Overcast	High	High	High	78	2	0	0	0	20	0
4	233.1-L-16-ES	3	9	9.3	160	Overcast	High	Medium	High	85	5	0	0	10	0	0
4	233.1-L-16-ES	4	4	9	140	Clear	High	High	High	88	2	5	0	0	5	0
4	232.6-R-16-ES	2	9	9.6	150	Overcast	High	Medium	High	70	0	0	0	30	0	0
4	232.6-R-16-ES	3	9	9.3	160	Overcast	High	Medium	High	50	0	0	0	50	0	0
4	232.6-R-16-ES	4	5	9	140	Clear	High	Medium	High	50	2	0	0	48	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
3	231.3-R-16-ES	2	9	-	-	Overcast	High	Medium	Medium	65	5	0	0	0	30	0
3	231.3-R-16-ES	3	10	9.1	-	Mostly cloudy	High	Low	High	55	20	5	0	0	20	0
3	231.3-R-16-ES	4	6	8.2	130	Overcast	High	Medium	High	55	10	5	0	0	30	0
3	231.0-L-16-ES	2	8	9.6	150	Overcast	High	High	Medium	98	2	0	0	0	0	0
3	231.0-L-16-ES	3	9	9.2	-	Overcast	High	High	High	95	3	0	0	2	0	0
3	231.0-L-16-ES	4	6	8.6	140	Overcast	High	High	High	90	5	3	0	2	0	0
3	231.0-R-16-ES	2	10	9.7	150	Mostly cloudy	High	High	High	90	5	0	0	0	5	0
3	231.0-R-16-ES	3	9	9.2	-	Overcast	High	High	High	52	3	0	0	40	5	0
3	231.0-R-16-ES	4	6	8.3	140	Overcast	High	Medium	High	60	0	0	0	30	10	0
3	229.2-L-16-ES	2	8	9.5	150	Mostly cloudy	High	Medium	Medium	95	5	0	0	0	0	0
3	229.2-L-16-ES	3	9	9.3	-	Clear	High	Low	High	80	2	0	0	18	0	0
3	229.2-L-16-ES	4	7	8.3	150	Overcast	Medium	Medium	Medium	79	1	0	0	20	0	0
3	228.5-L-16-ES	2	8	9.5	150	Mostly cloudy	High	High	High	45	5	25	0	0	25	0
3	228.5-L-16-ES	3	9	9.3	-	Clear	High	High	High	60	5	5	0	15	5	10
3	228.5-L-16-ES	4	7	8.3	150	Overcast	Medium	Medium	High	50	5	5	0	15	15	10
3	227.2-R-16-ES	2	8	9.5	150	Mostly cloudy	High	High	High	5	0	45	0	0	50	0
3	227.2-R-16-ES	3	9	9.3	-	Clear	Medium	Medium	Medium	5	0	10	0	0	85	0
3	227.2-R-16-ES	4	7	8.3	150	Overcast	High	High	High	0	0	5	0	0	95	0
3	229.7-R-16-ES	2	9	9.7	160	Mostly cloudy	High	Medium	Medium	75	5	0	0	20	0	0
3	229.7-R-16-ES	3	9	9.3	-	Clear	High	Medium	High	25	5	0	0	70	0	0
3	229.7-R-16-ES	4	7	8.8	150	Overcast	High	Medium	High	70	10	0	0	20	0	0

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

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

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

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

Table B4 Summary of species counts adjacent to bank habitat types in the Middle Columbia River, 16 October to 30 October 2014.

Reach	Site[a]	Species	Size Class	Bank Habitat Type[a]								Total
				A1	A3	A4	A5	A6	A1+A2	D1	D2	
4	232.6-R-16-ES	Bull Trout	Adult							2		**2**
	232.6-R-16-ES	Kokanee	Adult							6		**6**
	232.6-R-16-ES	Lake Whitefish	Adult							1		**1**
	232.6-R-16-ES	Largescale Sucker	Adult							6		**6**
	232.6-R-16-ES	Mountain Whitefish	Adult							49		**49**
	232.6-R-16-ES	Mountain Whitefish	Immature							58		**58**
	232.6-R-16-ES	Mountain Whitefish	YOY							8		**8**
	232.6-R-16-ES	Sucker Spp.	Adult							12		**12**
	Site 232.6-R-16-ES Total			**0**	**0**	**0**	**0**	**0**	**0**	**142**	**0**	**142**
	233.1-L-16-ES	Bull Trout	Adult	7				52				**59**
	233.1-L-16-ES	Burbot	Adult					1				**1**
	233.1-L-16-ES	Kokanee	Adult					143				**143**
	233.1-L-16-ES	Lake Whitefish	Adult					2				**2**
	233.1-L-16-ES	Largescale Sucker	Adult	26				50				**76**
	233.1-L-16-ES	Longnose Sucker	Adult	1								**1**
	233.1-L-16-ES	Mountain Whitefish	Adult	2				85				**87**
	233.1-L-16-ES	Mountain Whitefish	Immature	22				34				**56**
	233.1-L-16-ES	Mountain Whitefish	YOY					5				**5**
	233.1-L-16-ES	Prickly Sculpin	All	1								**1**
	233.1-L-16-ES	Rainbow Trout	Adult					1				**1**
	233.1-L-16-ES	Sculpin Spp.	All					1				**1**
	233.1-L-16-ES	Sucker Spp.	Adult					145				**145**
	Site 233.1-L-16-ES Total			**59**	**0**	**0**	**0**	**519**	**0**	**0**	**0**	**578**
	234.4-R-16-ES	Bull Trout	Adult	97								**97**
	234.4-R-16-ES	Bull Trout	Immature	1								**1**
	234.4-R-16-ES	Kokanee	Adult	1517								**1517**
	234.4-R-16-ES	Lake Whitefish	Adult	7								**7**
	234.4-R-16-ES	Largescale Sucker	Adult	78								**78**
	234.4-R-16-ES	Mountain Whitefish	Adult	364								**364**
	234.4-R-16-ES	Mountain Whitefish	Immature	114								**114**
	234.4-R-16-ES	Northern Pikeminnow	Adult	1								**1**
	234.4-R-16-ES	Rainbow Trout	Adult	2								**2**
	234.4-R-16-ES	Sucker Spp.	Adult	199								**199**
	Site 234.4-R-16-ES Total			**2380**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**2380**
	234.5-L-16-ES	Bull Trout	Adult	2			25					**27**
	234.5-L-16-ES	Kokanee	Adult	5			207					**212**
	234.5-L-16-ES	Lake Whitefish	Adult	1			1					**2**
	234.5-L-16-ES	Largescale Sucker	Adult	4			13					**17**
	234.5-L-16-ES	Longnose Sucker	Immature	1								**1**
	234.5-L-16-ES	Mountain Whitefish	Adult	26			159					**185**
	234.5-L-16-ES	Mountain Whitefish	Immature	12			63					**75**
	234.5-L-16-ES	Rainbow Trout	Adult				1					**1**
	234.5-L-16-ES	Sculpin Spp.	All	1								**1**
	234.5-L-16-ES	Sucker Spp.	Adult	13			50					**63**
	Site 234.5-L-16-ES Total			**65**	**0**	**0**	**519**	**0**	**0**	**0**	**0**	**584**
	236.1-L-16-ES	Bull Trout	Adult		2						10	**12**
	236.1-L-16-ES	Kokanee	Adult		3						6	**9**
	236.1-L-16-ES	Largescale Sucker	Adult	3	8						12	**23**
	236.1-L-16-ES	Mountain Whitefish	Adult		15						73	**88**
	236.1-L-16-ES	Mountain Whitefish	Immature	5	11						75	**91**
	236.1-L-16-ES	Mountain Whitefish	YOY	1	3						4	**8**
	236.1-L-16-ES	Prickly Sculpin	All	1								**1**
	236.1-L-16-ES	Sculpin Spp.	All								3	**3**
	236.1-L-16-ES	Sucker Spp.	Adult		21						26	**47**
	Site 236.1-L-16-ES Total			**10**	**63**	**0**	**0**	**0**	**0**	**0**	**209**	**282**

[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[a]								Total
				A1	A3	A4	A5	A6	A1+A2	D1	D2	
	236.1-R-16-ES	Bull Trout	Adult						30			**30**
	236.1-R-16-ES	Burbot	Adult						1			**1**
	236.1-R-16-ES	Kokanee	Adult						94			**94**
	236.1-R-16-ES	Largescale Sucker	Adult						90			**90**
	236.1-R-16-ES	Mountain Whitefish	Adult						331			**331**
	236.1-R-16-ES	Mountain Whitefish	Immature						118			**118**
	236.1-R-16-ES	Mountain Whitefish	YOY						2			**2**
	236.1-R-16-ES	Northern Pikeminnow	Adult						4			**4**
	236.1-R-16-ES	Rainbow Trout	Adult						1			**1**
	236.1-R-16-ES	Sculpin Spp.	All						1			**1**
	236.1-R-16-ES	Sucker Spp.	Adult						204			**204**
	Site 236.1-R-16-ES Total			**0**	**0**	**0**	**0**	**0**	**876**	**0**	**0**	**876**
	236.4-L-16-ES	Bull Trout	Adult	15								**15**
	236.4-L-16-ES	Lake Whitefish	Adult	2								**2**
	236.4-L-16-ES	Largescale Sucker	Adult	20								**20**
	236.4-L-16-ES	Longnose Sucker	Adult	1								**1**
	236.4-L-16-ES	Mountain Whitefish	Adult	83								**83**
	236.4-L-16-ES	Mountain Whitefish	Immature	86								**86**
	236.4-L-16-ES	Sucker Spp.	Adult	25								**25**
	236.4-L-16-ES	Sucker Spp.	Immature	8								**8**
	Site 236.4-L-16-ES Total			**240**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**240**
	236.4-R-16-ES	Bull Trout	Adult	6		1						**7**
	236.4-R-16-ES	Kokanee	Adult	6		2						**8**
	236.4-R-16-ES	Largescale Sucker	Adult	12		1						**13**
	236.4-R-16-ES	Mountain Whitefish	Adult	33		22						**55**
	236.4-R-16-ES	Mountain Whitefish	Immature	15		28						**43**
	236.4-R-16-ES	Sucker Spp.	Adult	20		10						**30**
	Site 236.4-R-16-ES Total			**92**	**0**	**64**	**0**	**0**	**0**	**0**	**0**	**156**
Reach 4 Total				**2846**	**63**	**64**	**519**	**519**	**876**	**142**	**209**	**5238**
3	227.2-R-16-ES	Northern Pikeminnow	Adult				1					**1**
	227.2-R-16-ES	Prickly Sculpin	All				2					**2**
	227.2-R-16-ES	Mountain Whitefish	Immature				5					**5**
	227.2-R-16-ES	Bull Trout	Adult				7					**7**
	227.2-R-16-ES	Kokanee	Adult				12					**12**
	227.2-R-16-ES	Largescale Sucker	Adult				12					**12**
	227.2-R-16-ES	Sculpin Spp.	All				12					**12**
	227.2-R-16-ES	Sucker Spp.	Adult				16					**16**
	227.2-R-16-ES	Mountain Whitefish	Adult				18					**18**
	Site 227.2-R-16-ES Total			**0**	**0**	**0**	**85**	**0**	**0**	**0**	**0**	**85**
	228.5-L-16-ES	Bull Trout	Adult					15		6		**21**
	228.5-L-16-ES	Kokanee	Adult					8		3		**11**
	228.5-L-16-ES	Lake Whitefish	Adult					1		1		**2**
	228.5-L-16-ES	Largescale Sucker	Adult					8		59		**67**
	228.5-L-16-ES	Mountain Whitefish	Adult					12		82		**94**
	228.5-L-16-ES	Mountain Whitefish	Immature							45		**45**
	228.5-L-16-ES	Mountain Whitefish	YOY							24		**24**
	228.5-L-16-ES	Northern Pikeminnow	Adult							1		**1**
	228.5-L-16-ES	Prickly Sculpin	All					2				**2**
	228.5-L-16-ES	Rainbow Trout	Adult					1				**1**
	228.5-L-16-ES	Sculpin Spp.	All					6		13		**19**
	228.5-L-16-ES	Sucker Spp.	Adult					8		112		**120**
	Site 228.5-L-16-ES Total			**0**	**0**	**0**	**0**	**61**	**0**	**346**	**0**	**407**

[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[a]								Total
				A1	A3	A4	A5	A6	A1+A2	D1	D2	
	229.2-L-16-ES	Bull Trout	Adult	22								**22**
	229.2-L-16-ES	Kokanee	Adult	139								**139**
	229.2-L-16-ES	Largescale Sucker	Adult	48								**48**
	229.2-L-16-ES	Mountain Whitefish	Adult	177								**177**
	229.2-L-16-ES	Mountain Whitefish	Immature	42								**42**
	229.2-L-16-ES	Mountain Whitefish	YOY	2								**2**
	229.2-L-16-ES	Northern Pikeminnow	Adult	1								**1**
	229.2-L-16-ES	Prickly Sculpin	All	4								**4**
	229.2-L-16-ES	Rainbow Trout	Adult	1								**1**
	229.2-L-16-ES	Rainbow Trout	Immature	1								**1**
	229.2-L-16-ES	Sculpin Spp.	All	17								**17**
	229.2-L-16-ES	Sucker Spp.	Adult	107								**107**
	Site 229.2-L-16-ES Total			**561**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**561**
	229.7-R-16-ES	Bull Trout	Adult							25		**25**
	229.7-R-16-ES	Kokanee	Adult							13		**13**
	229.7-R-16-ES	Lake Whitefish	Adult							11		**11**
	229.7-R-16-ES	Largescale Sucker	Adult							69		**69**
	229.7-R-16-ES	Mountain Whitefish	Adult							126		**126**
	229.7-R-16-ES	Mountain Whitefish	Immature							100		**100**
	229.7-R-16-ES	Mountain Whitefish	YOY							85		**85**
	229.7-R-16-ES	Prickly Sculpin	All							2		**2**
	229.7-R-16-ES	Sculpin Spp.	All							5		**5**
	229.7-R-16-ES	Sucker Spp.	Adult							62		**62**
	Site 229.7-R-16-ES Total			**0**	**0**	**0**	**0**	**0**	**0**	**498**	**0**	**498**
	231.0-L-16-ES	Bull Trout	Adult					35				**35**
	231.0-L-16-ES	Bull Trout	Immature					1				**1**
	231.0-L-16-ES	Burbot	Adult					1				**1**
	231.0-L-16-ES	Kokanee	Adult					410				**410**
	231.0-L-16-ES	Lake Whitefish	Adult					2				**2**
	231.0-L-16-ES	Largescale Sucker	Adult					19				**19**
	231.0-L-16-ES	Mountain Whitefish	Adult					126				**126**
	231.0-L-16-ES	Mountain Whitefish	Immature					31				**31**
	231.0-L-16-ES	Prickly Sculpin	All					3				**3**
	231.0-L-16-ES	Rainbow Trout	Adult					3				**3**
	231.0-L-16-ES	Rainbow Trout	Immature					2				**2**
	231.0-L-16-ES	Sculpin Spp.	All					6				**6**
	231.0-L-16-ES	Sucker Spp.	Adult					40				**40**
	Site 231.0-L-16-ES Total			**0**	**0**	**0**	**0**	**679**	**0**	**0**	**0**	**679**
	231.0-R-16-ES	Bull Trout	Adult	8						62		**70**
	231.0-R-16-ES	Kokanee	Adult	81						290		**371**
	231.0-R-16-ES	Largescale Sucker	Adult							26		**26**
	231.0-R-16-ES	Mountain Whitefish	Adult							259		**259**
	231.0-R-16-ES	Mountain Whitefish	Immature							191		**191**
	231.0-R-16-ES	Mountain Whitefish	YOY	1						19		**20**
	231.0-R-16-ES	Northern Pikeminnow	Adult							1		**1**
	231.0-R-16-ES	Sucker Spp.	Adult	3						40		**43**
	Site 231.0-R-16-ES Total			**93**	**0**	**0**	**0**	**0**	**0**	**888**	**0**	**981**

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

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

Continued...

Table B4 Concluded.

Reach	Site[a]	Species	Size Class	Bank Habitat Type[a]								Total
				A1	A3	A4	A5	A6	A1+A2	D1	D2	
	231.3-R-16-ES	Bull Trout	Adult	10			1					**11**
	231.3-R-16-ES	Kokanee	Adult	52			1					**53**
	231.3-R-16-ES	Kokanee	YOY	1								**1**
	231.3-R-16-ES	Largescale Sucker	Adult	6								**6**
	231.3-R-16-ES	Longnose Sucker	Adult	1								**1**
	231.3-R-16-ES	Longnose Sucker	Immature	1								**1**
	231.3-R-16-ES	Mountain Whitefish	Adult	195								**195**
	231.3-R-16-ES	Mountain Whitefish	Immature	83								**83**
	231.3-R-16-ES	Northern Pikeminnow	Adult	1								**1**
	231.3-R-16-ES	Prickly Sculpin	All	1								**1**
	231.3-R-16-ES	Rainbow Trout	Adult	1			1					**2**
	231.3-R-16-ES	Redside Shiner	All	1								**1**
	231.3-R-16-ES	Sculpin Spp.	All	26								**26**
	231.3-R-16-ES	Sucker Spp.	Adult	9								**9**
	Site 231.3-R-16-ES Total			**388**	**0**	**0**	**3**	**0**	**0**	**0**	**0**	**391**
Reach 3 Total				**1042**	**0**	**0**	**88**	**740**	**0**	**1732**	**0**	**3602**
Grand Total				**3888**	**63**	**64**	**607**	**1259**	**876**	**1874**	**209**	**8840**

[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

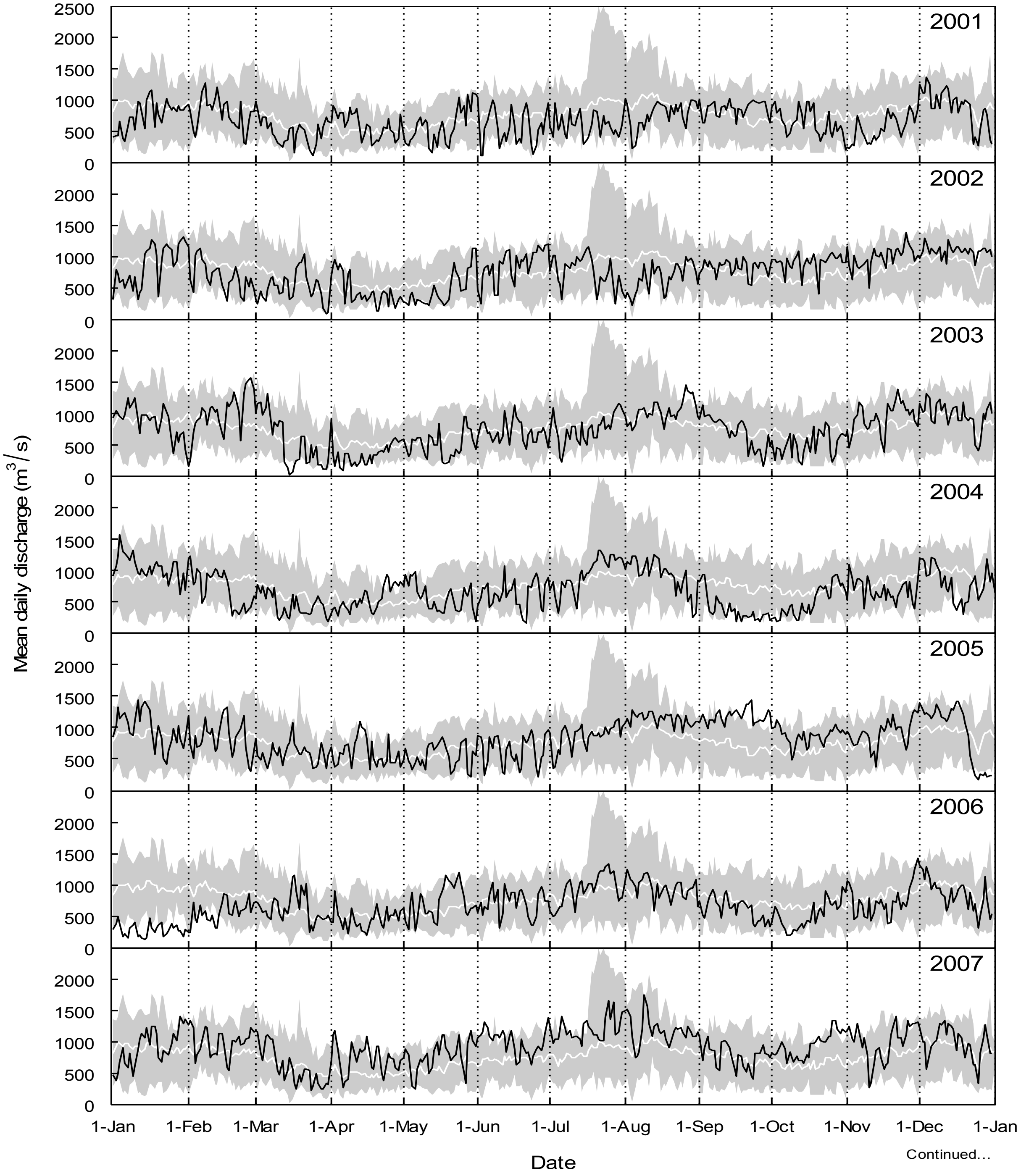

Figure C1 Mean daily discharge (m³/s) for the Columbia River at Revelstoke Dam, 2001 to 2014. The shaded area represents minimum and maximum mean daily discharge values recorded at Revelstoke Dam during other study years (between 2001 and 2014). The white line represents average mean daily discharge values over the same time period.

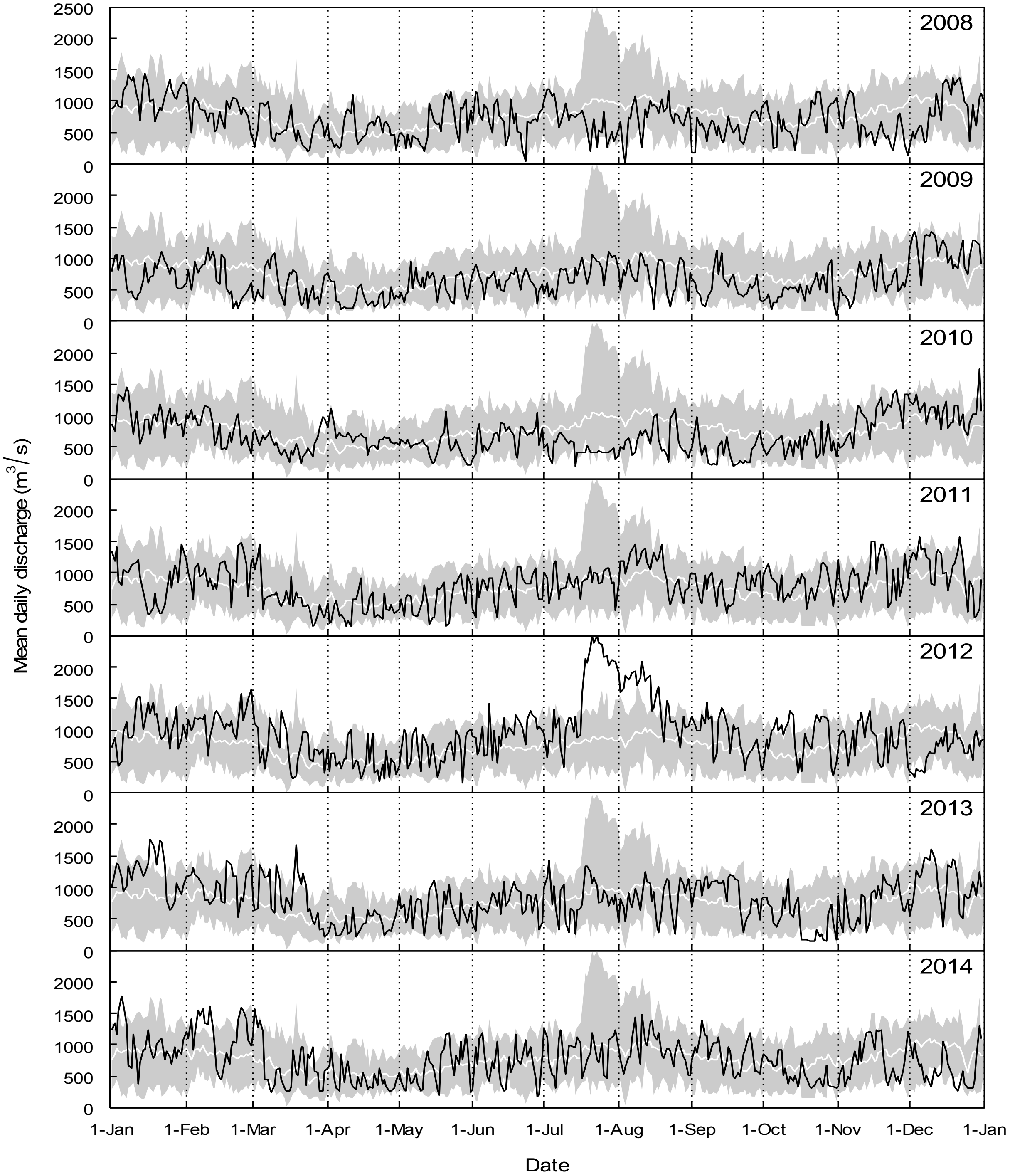

Figure C1 Concluded.

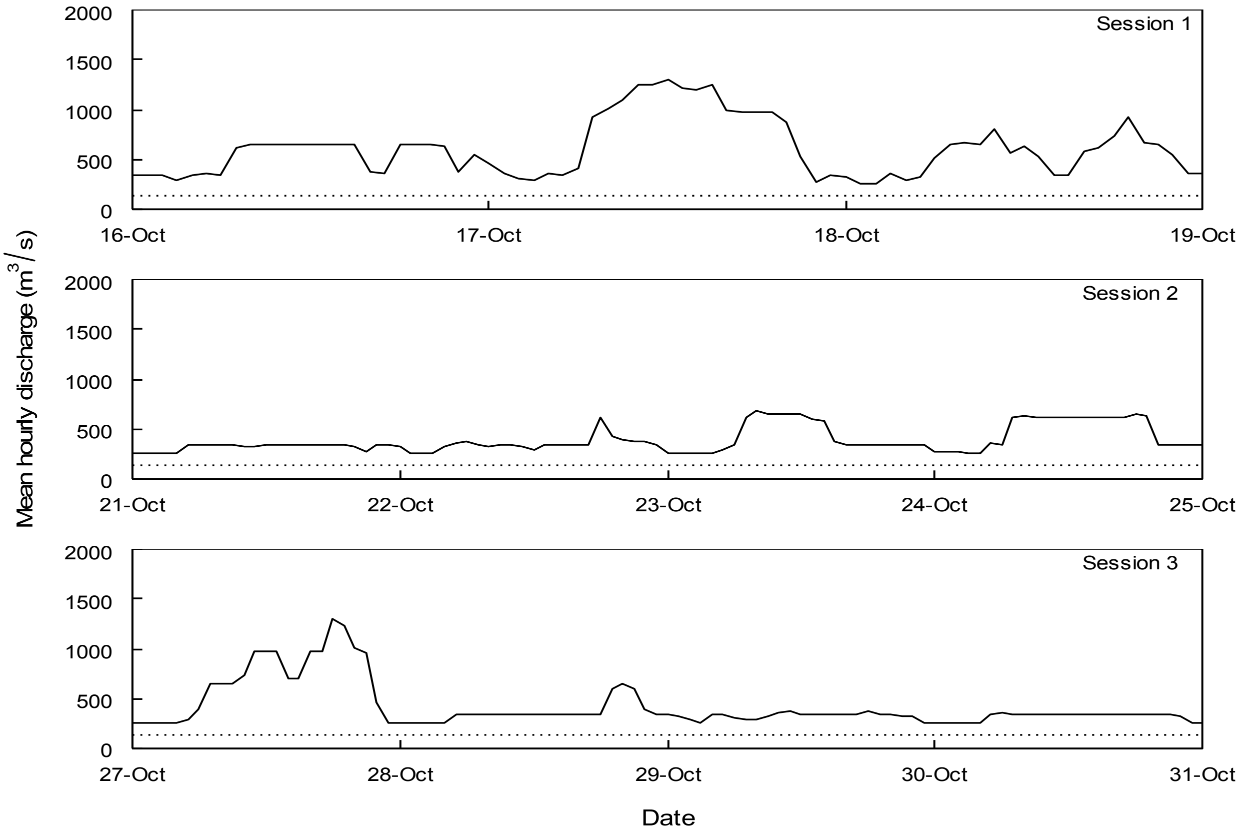

Figure C2 Mean hourly discharge (m³/s) for the Columbia River at Revelstoke Dam by sample session, October 16 to October 31, 2014. The dotted line denotes the 142 m³/s minimum flow release.

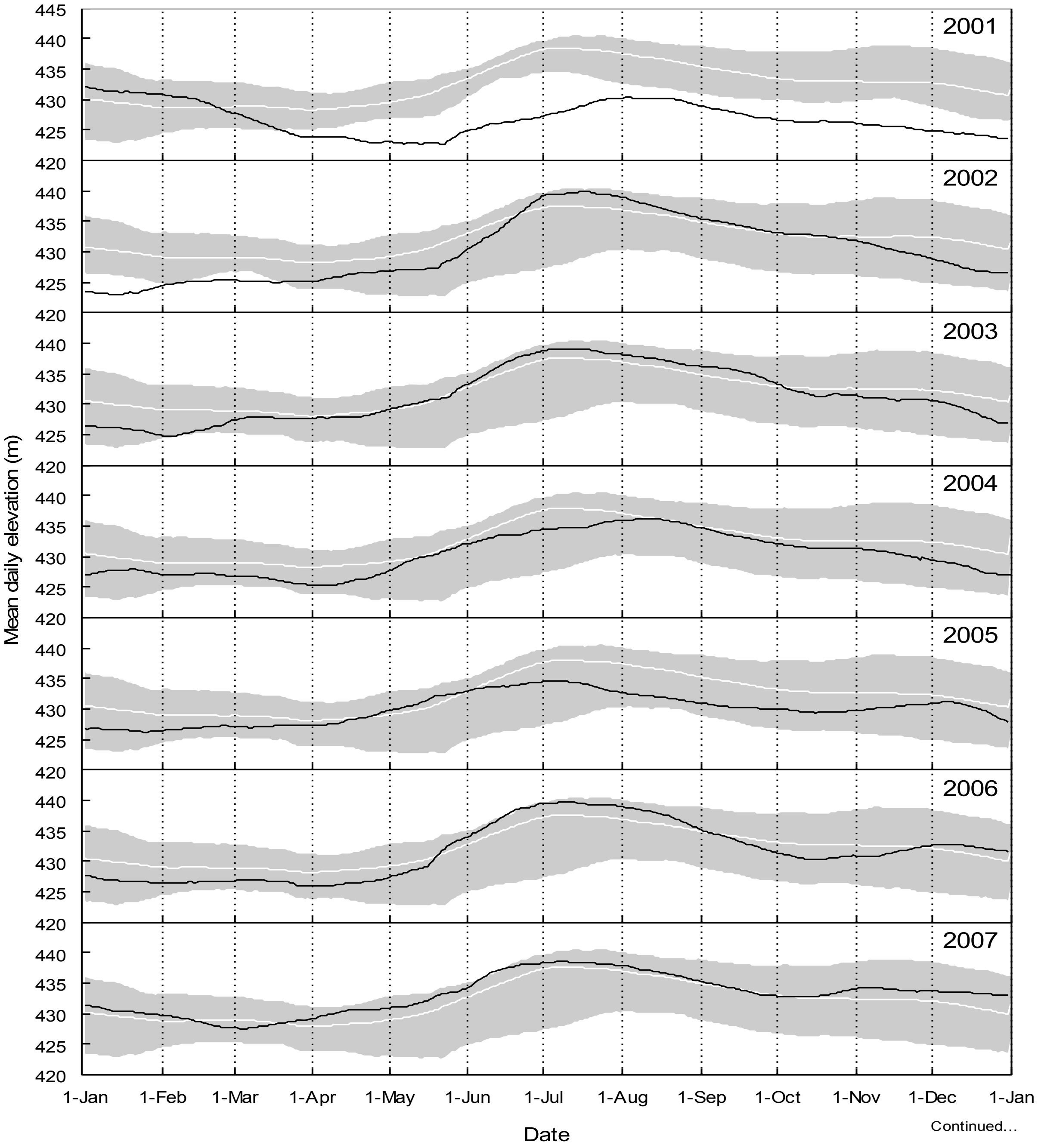

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Figure C3 Mean daily water level elevation (in metres above sea level) for the Columbia River at Nakusp, 2001 to 2014. The shaded area represents minimum and maximum mean daily water elevations recorded at Nakusp during other study years (between 2001 and 2013). The white line represents average mean daily water elevation over the same time period.

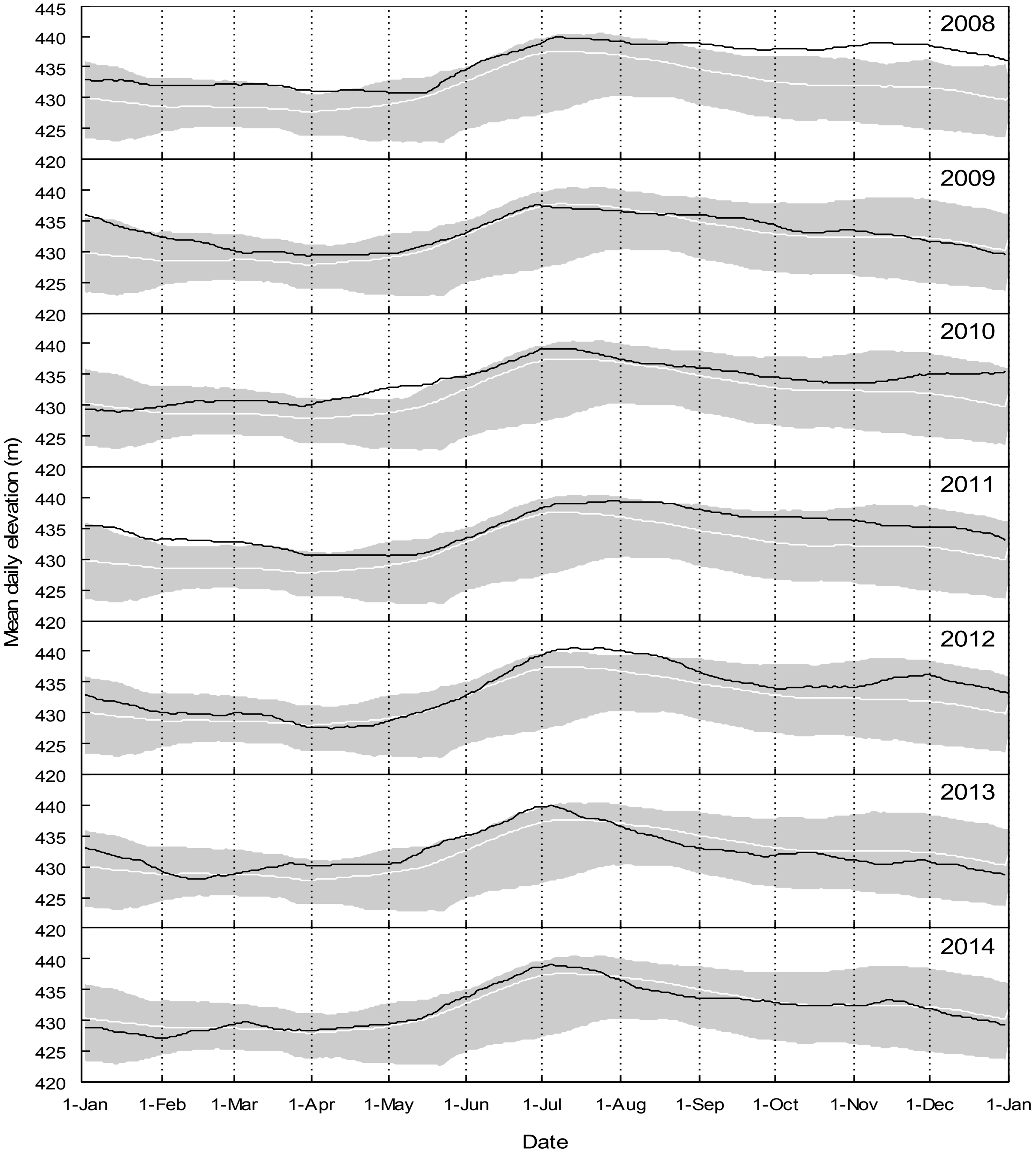

Figure C3 Concluded.

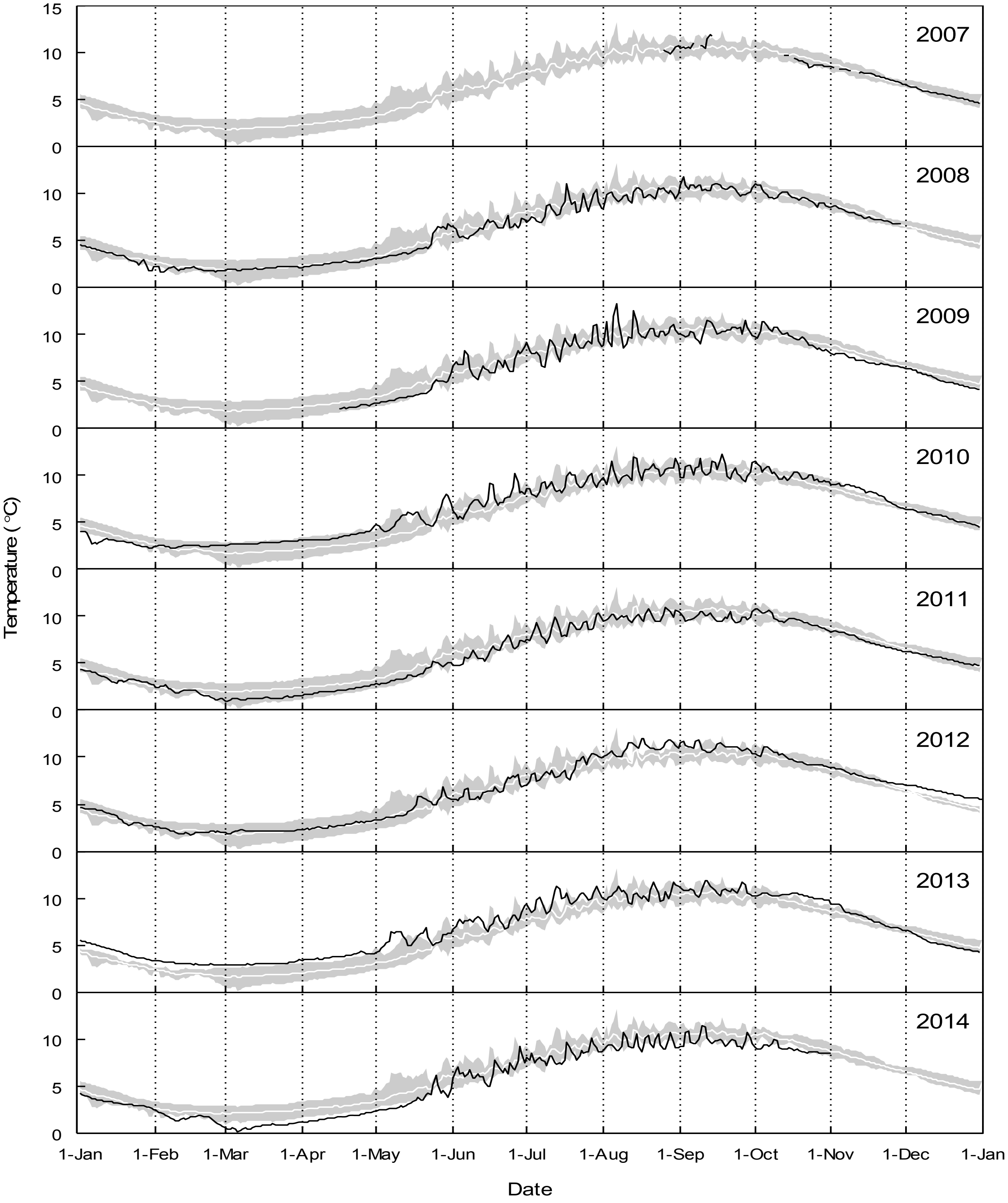

Figure C4 Mean daily water temperature (°C) for the Columbia River at Revelstoke Dam, 2007 to 2014. The shaded area represents minimum and maximum mean daily water temperatures recorded at Revelstoke Dam during other study years (between 2007 and 2014). The white line represents average mean daily water 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

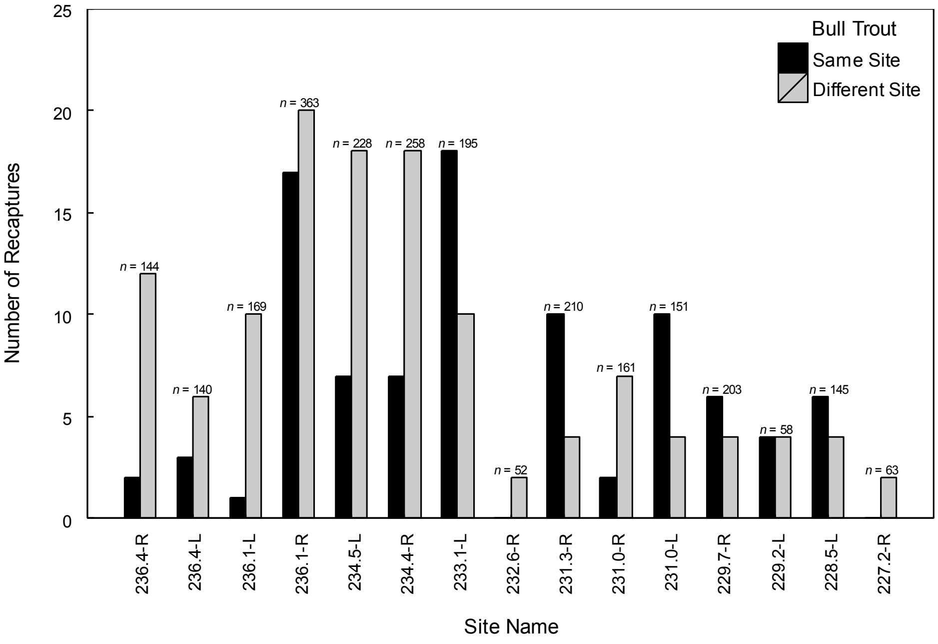

Figure D1 Inter-site movement summary for Bull Trout in the Middle Columbia River from 2001 to 2014. "n" represents total number caught per site from 2001 to 2014. Grey bar indicates number of recaptures tagged at a different site. Black bar indicates number of recaptures tagged at same site.

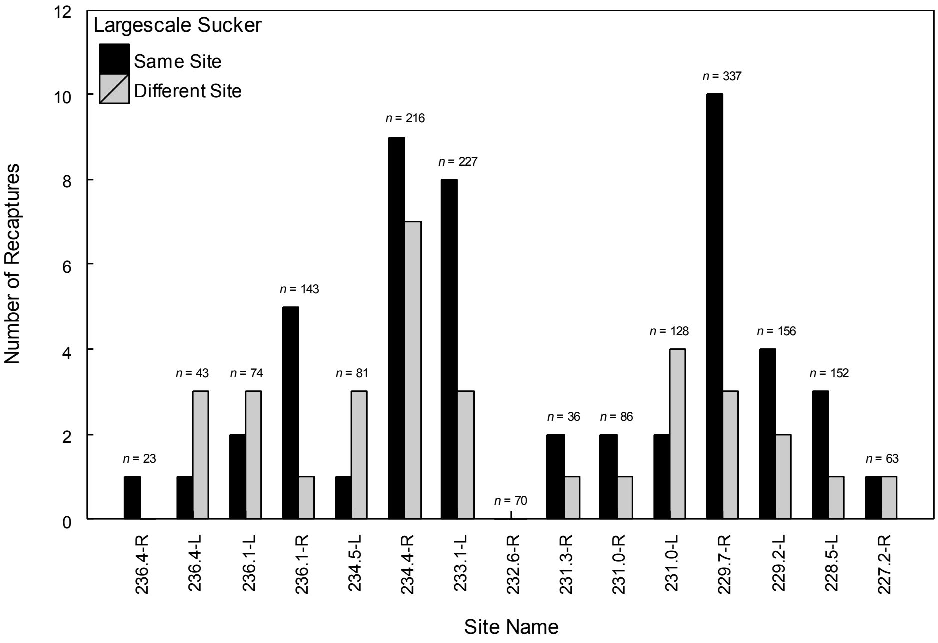

Figure D2 Inter-site movement summary for Largescale Sucker in the Middle Columbia River from 2001 to 2014. "n" represents total number caught per site from 2001 to 2014. Grey bar indicates number of recaptures tagged at a different site. Black bar indicates number of recaptures tagged at same site.

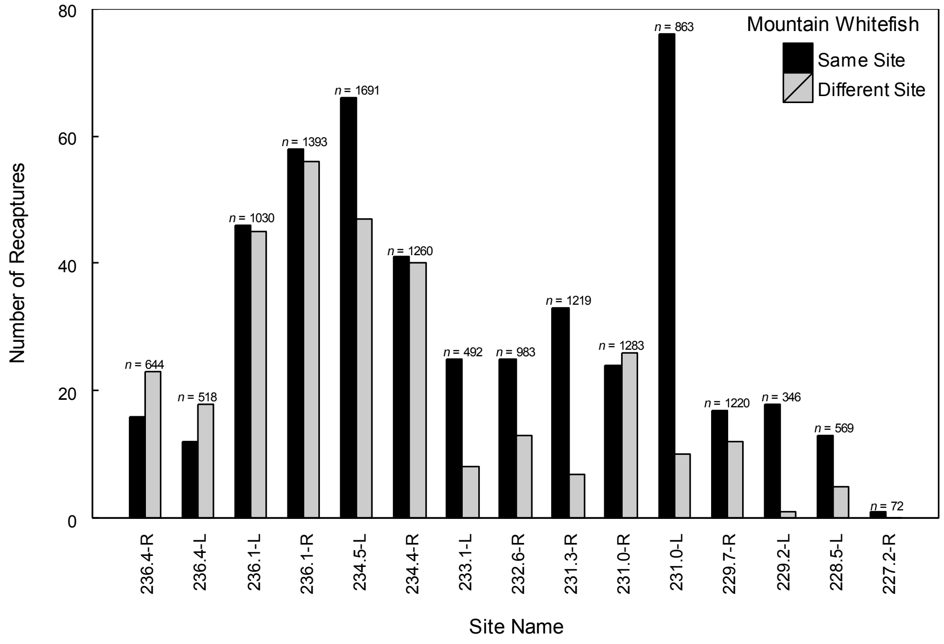

Figure D3 Inter-site movement summary for Mountain Whitefish in the Middle Columbia River from 2001 to 2014. “n” represents total number caught per site from 2001 to 2014. Grey bar indicates number of recaptures tagged at a different site. Black bar indicates number of recaptures tagged at same site.

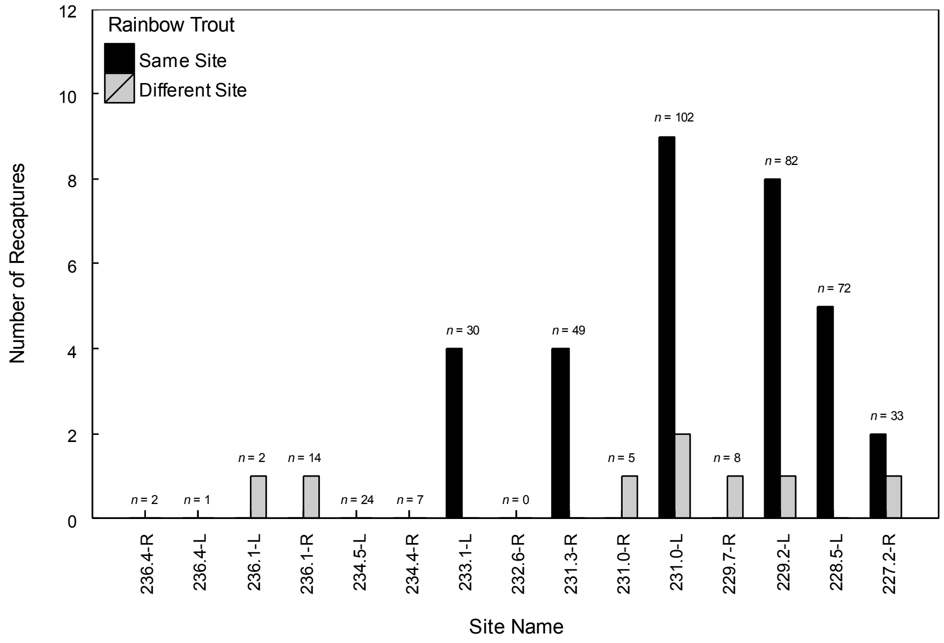

Figure D4 Inter-site movement summary for Rainbow Trout in the Middle Columbia River from 2001 to 2014. “n” represents total number caught per site from 2001 to 2014. Grey bar indicates number of recaptures tagged at a different site. Black bar indicates number of recaptures tagged at same site.

Table D5 Summary of the number (N) of fish captured and recaptured in sampled sections of the Middle Columbia River during the spring season, 16 October to 30 October 2014.

Species	Size-class	Session	N Captured	N Marked	N Recaptured (within year)	N Recaptured (between years)
Bull Trout	All	1	66	60	-	6
		2	52	46	3	3
		3	70	61	5	4
Bull Trout Total			188	167	8	13
Lake Whitefish	All	1	1	1	-	0
		2	5	5	0	0
		3	13	13	0	0
Lake Whitefish Total			19	19	0	0
Mountain Whitefish	All	1	238	199	-	39
		2	311	258	6	47
		3	321	255	13	53
Mountain Whitefish Total			870	712	19	139
Northern Pikeminnow	All	1	2	2	-	0
		2	6	5	0	1
		3	1	1	0	0
Northern Pikeminnow Total			9	8	0	1
Rainbow Trout	All	1	1	1	-	0
		2	5	5	0	0
		3	5	5	0	0
Rainbow Trout Total			11	11	0	0
Sucker spp.	All	1	192	169	-	23
		2	205	182	7	16
		3	178	150	16	12
Sucker spp. Total			575	501	23	51

Appendix E – Life History

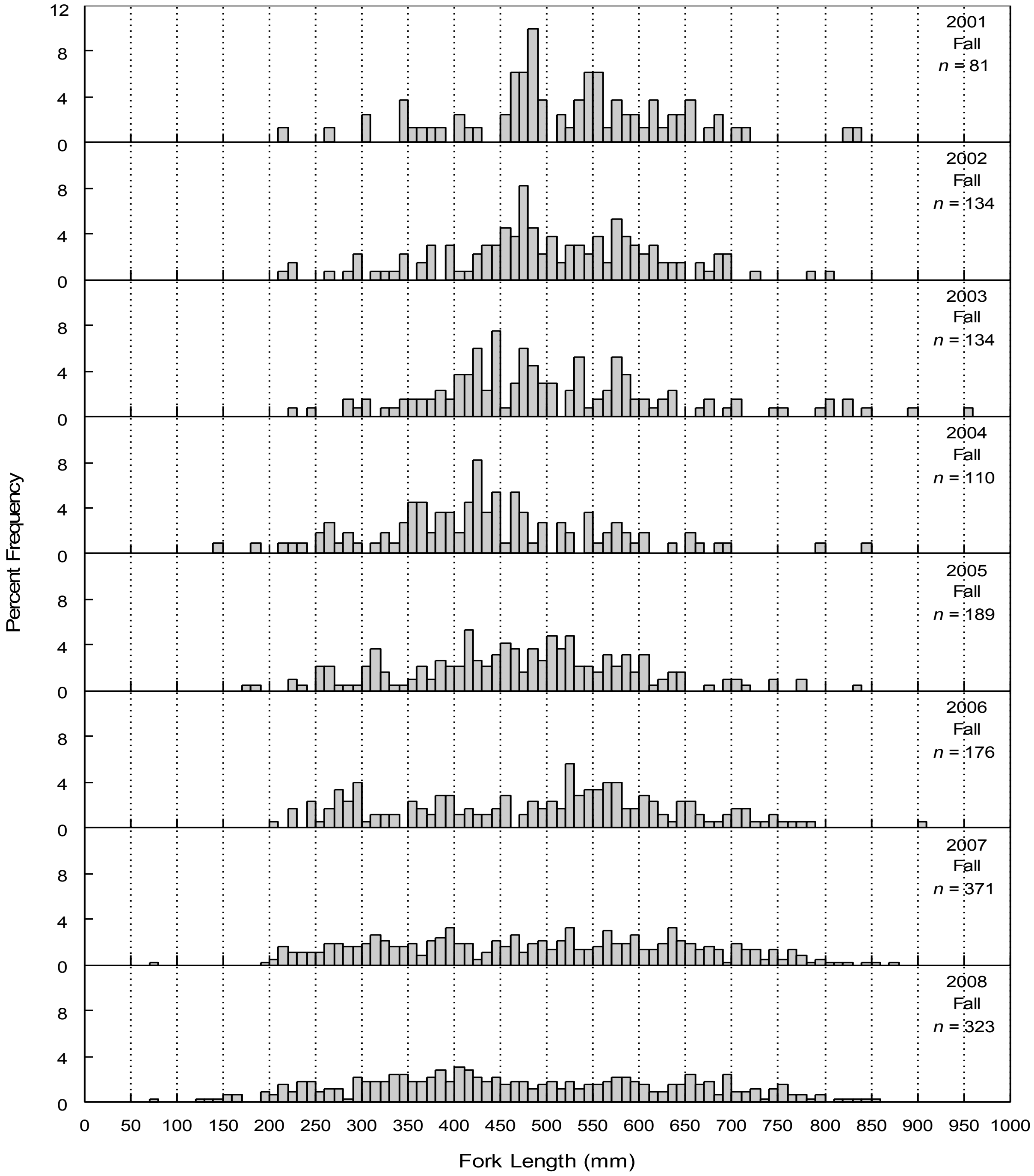

Figure E1 Length-frequency distributions for Bull Trout captured by boat electroshocking in Reaches 3 and 4 of the Middle Columbia River, 2001 to 2014. Bull Trout that were initially marked during an earlier year of the program were excluded from the analysis due to potential tagging effects on growth. Boat electroshocking surveys were not conducted downstream of Big Eddy for all years prior to 2007.

Continued…

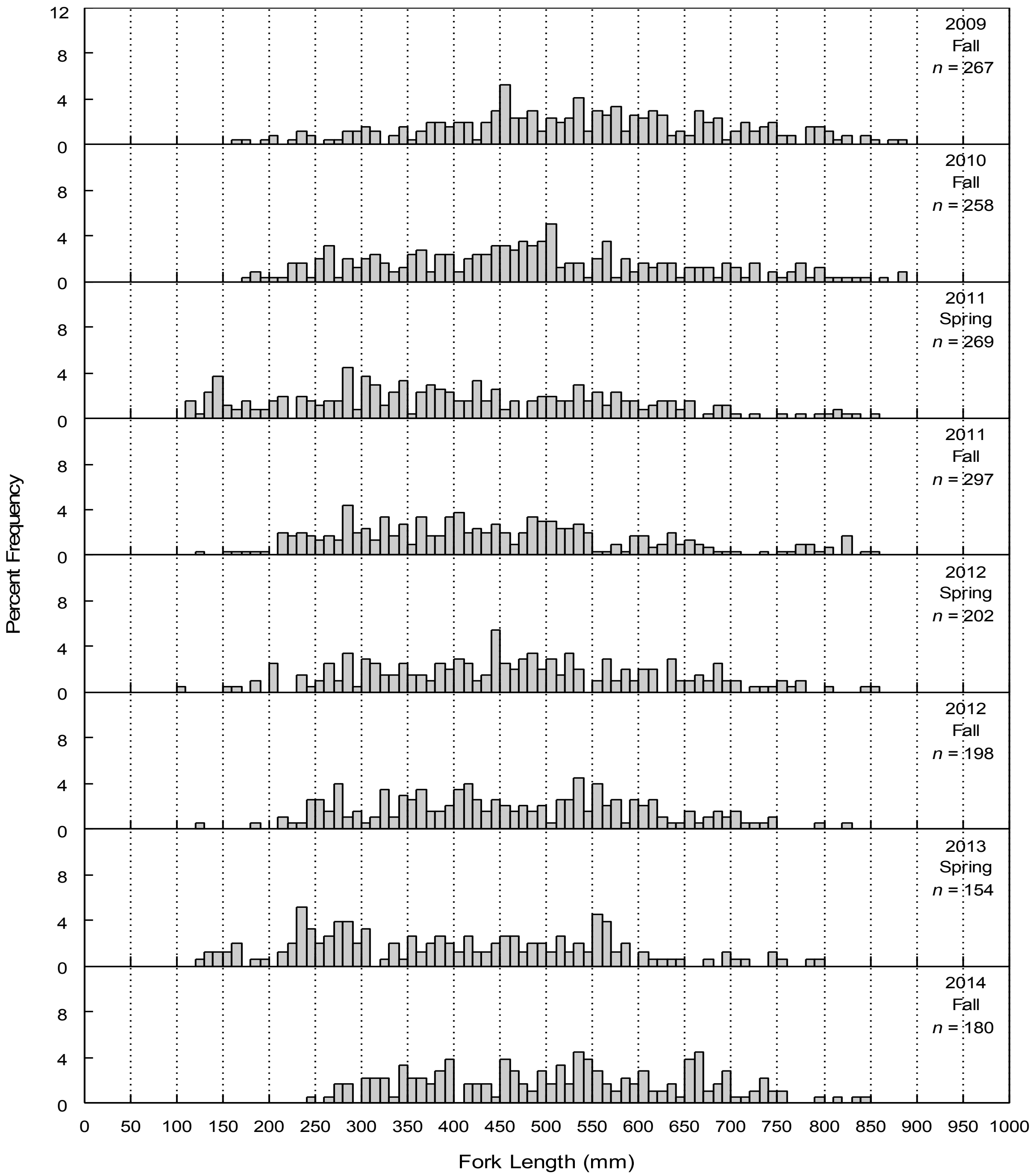

Figure E1 Concluded.

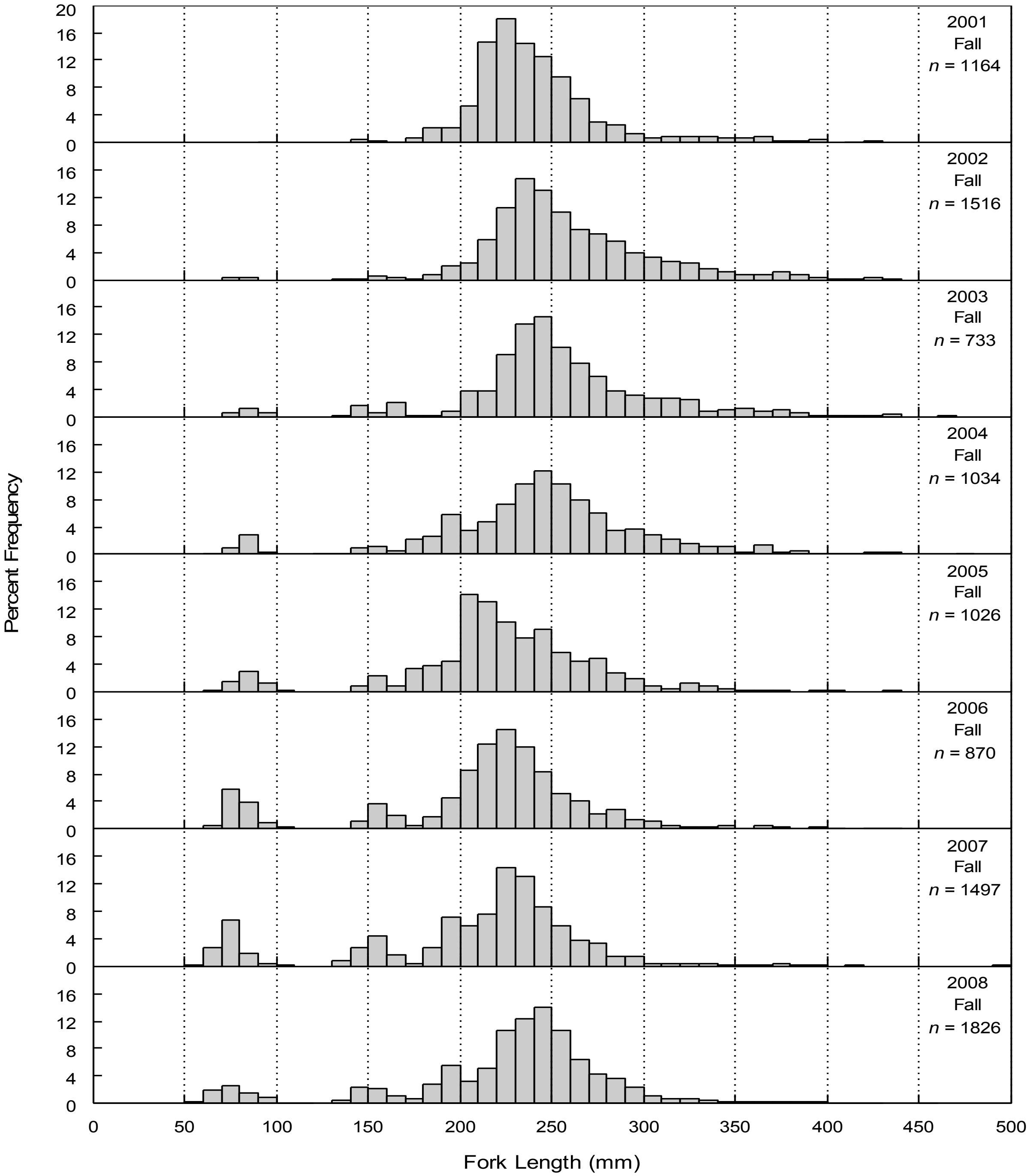

Figure E2 Length-frequency distributions for Mountain Whitefish captured by boat electroshocking in Reaches 3 and 4 of the Middle Columbia River, 2001 to 2014. Mountain Whitefish that were initially marked during an earlier year of the program were excluded from the analysis due to potential tagging effects on growth. Boat electroshocking surveys were not conducted downstream of Big Eddy for all years prior to 2007.

Continued…

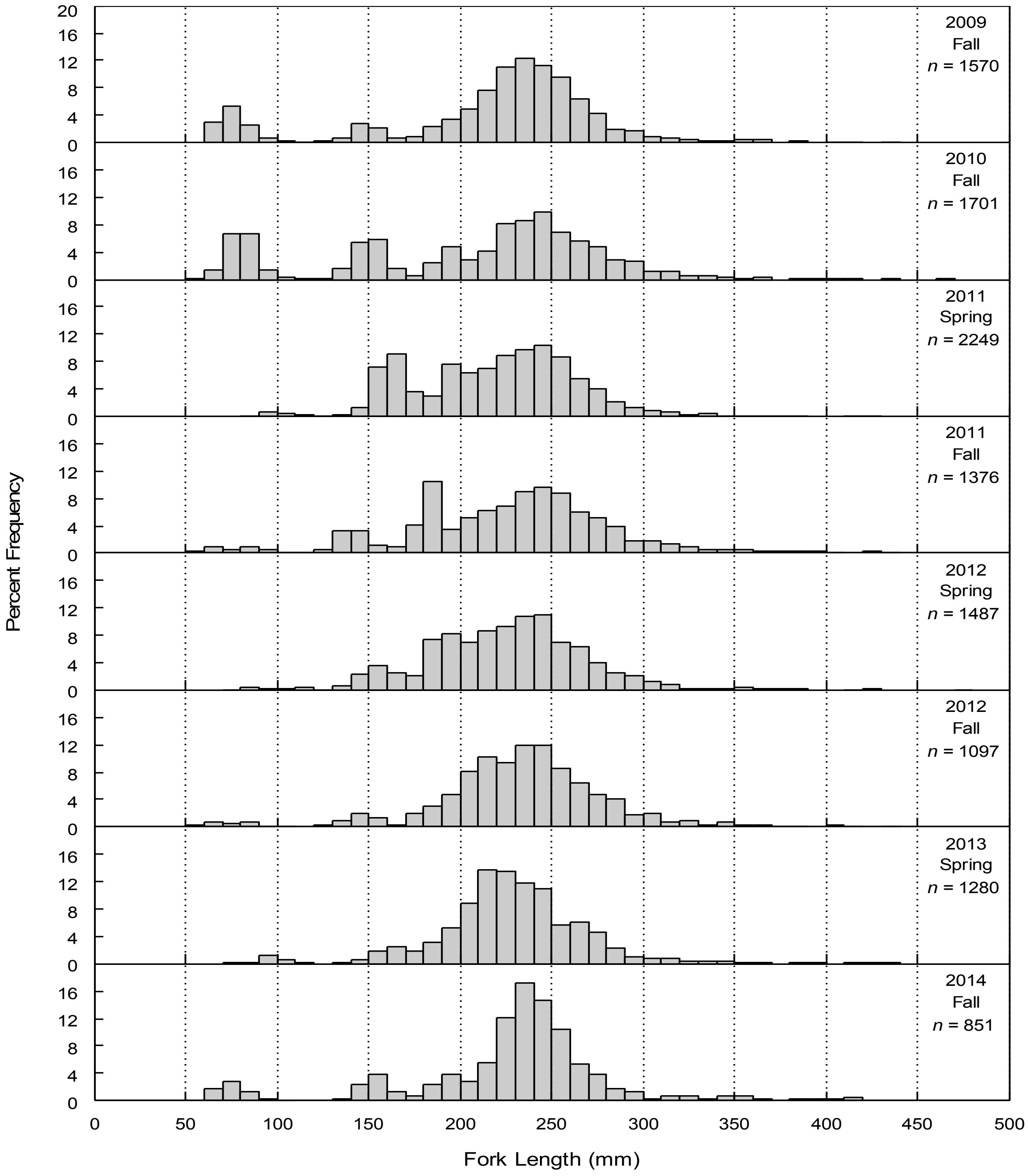

Figure E2 Concluded.

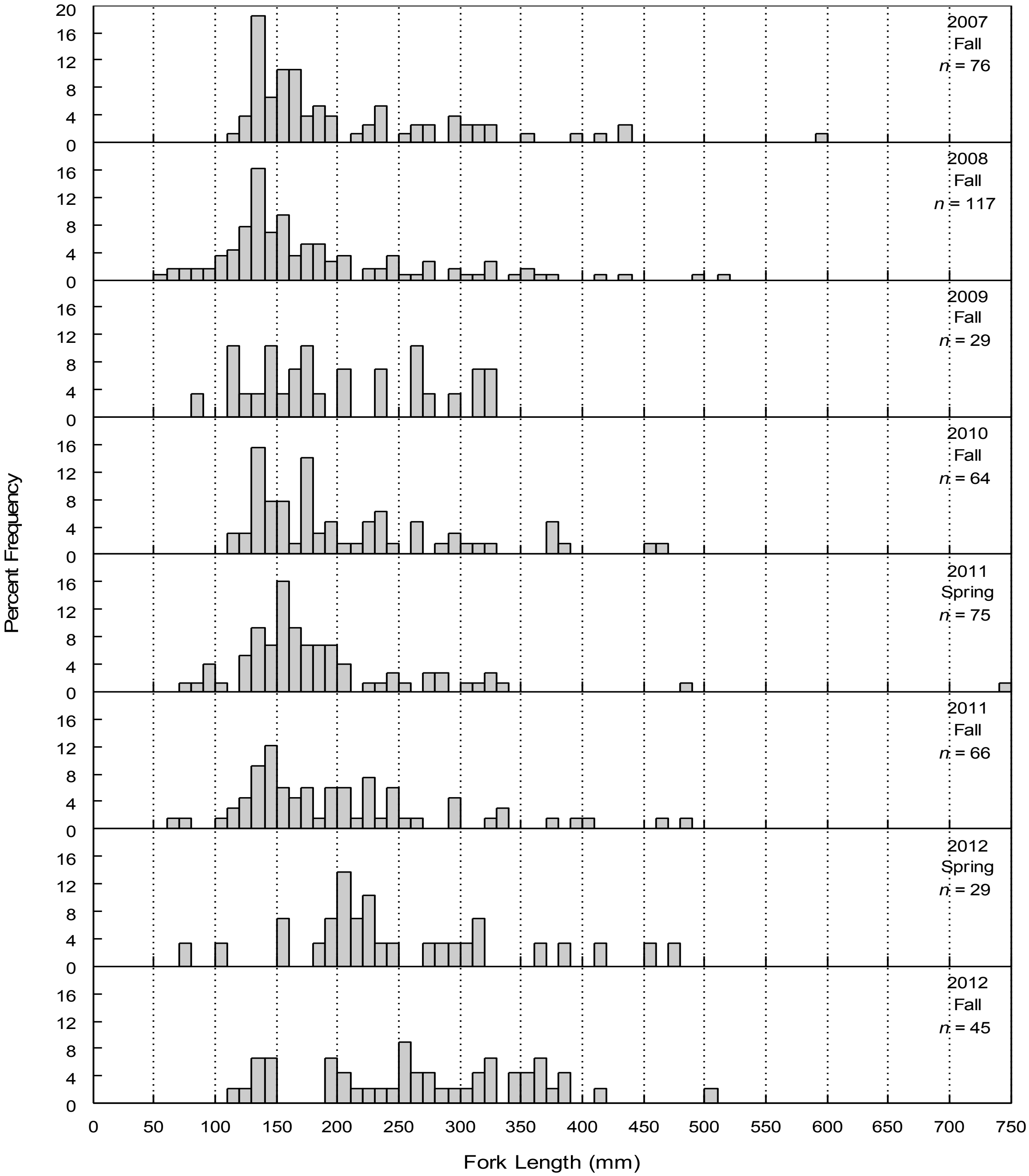

Figure E3 Length-frequency distributions for Rainbow Trout captured by boat electroshocking in Reaches 3 and 4 of the Middle Columbia River, 2007 to 2014. Rainbow Trout that were initially marked during an earlier year of the program were excluded from the analysis due to potential tagging effects on growth. Boat electroshocking surveys were not conducted downstream of Big Eddy for all years prior to 2007.

Continued..

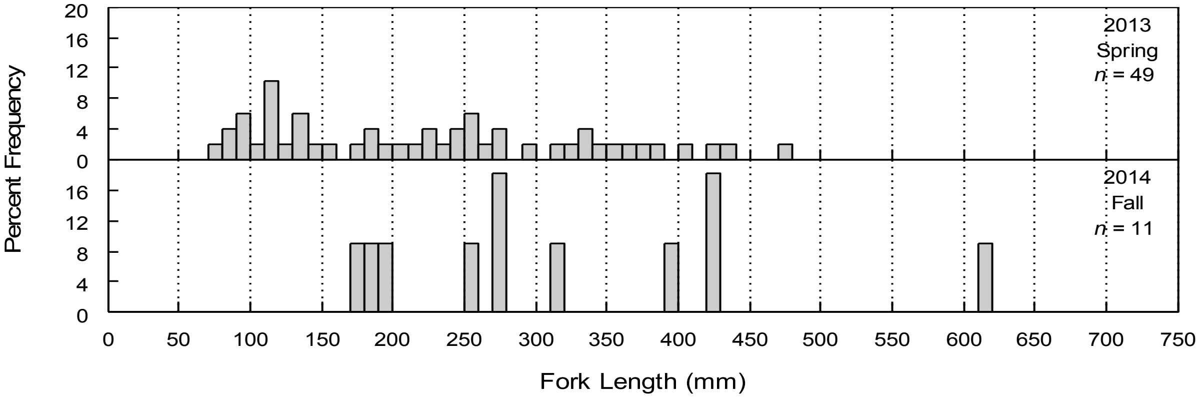

Figure E3 Concluded.

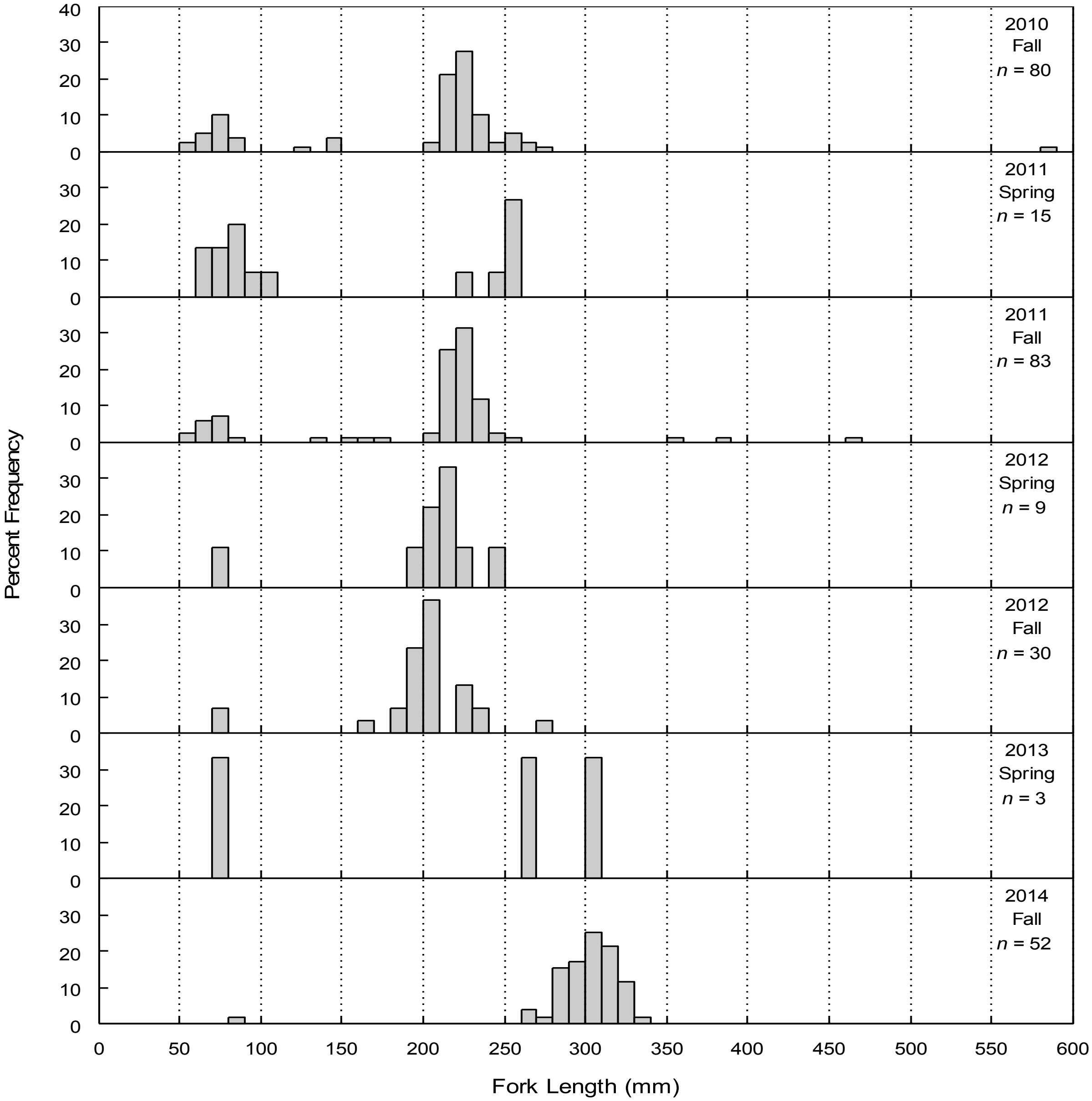

Figure E4 Length-frequency distributions for Kokanee captured by boat electroshocking in Reaches 3 and 4 of the Middle Columbia River, 2010 to 2014.

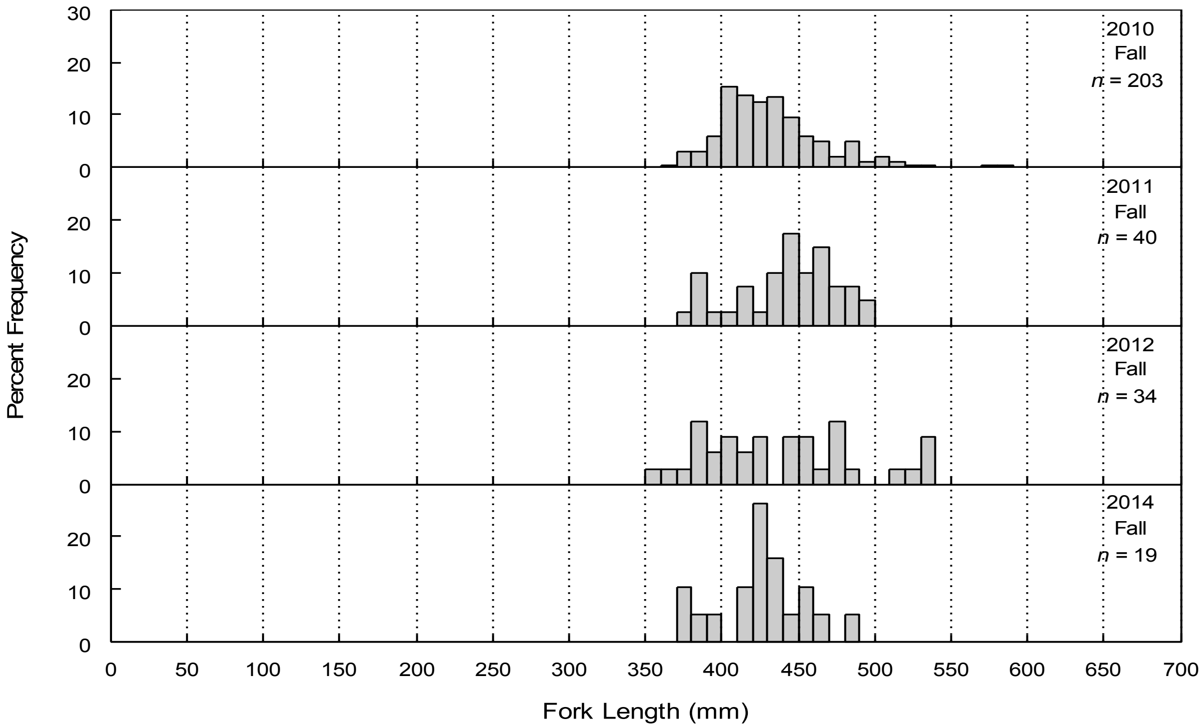

Figure E5 Length-frequency distributions for Lake Whitefish captured by boat electroshocking in Reaches 3 and 4 of the Middle Columbia River, 2010 to 2014. Lake Whitefish that were initially marked during an earlier year of the program were excluded from the analysis due to potential tagging effects on growth. Lake Whitefish were not captured during the spring of 2013.

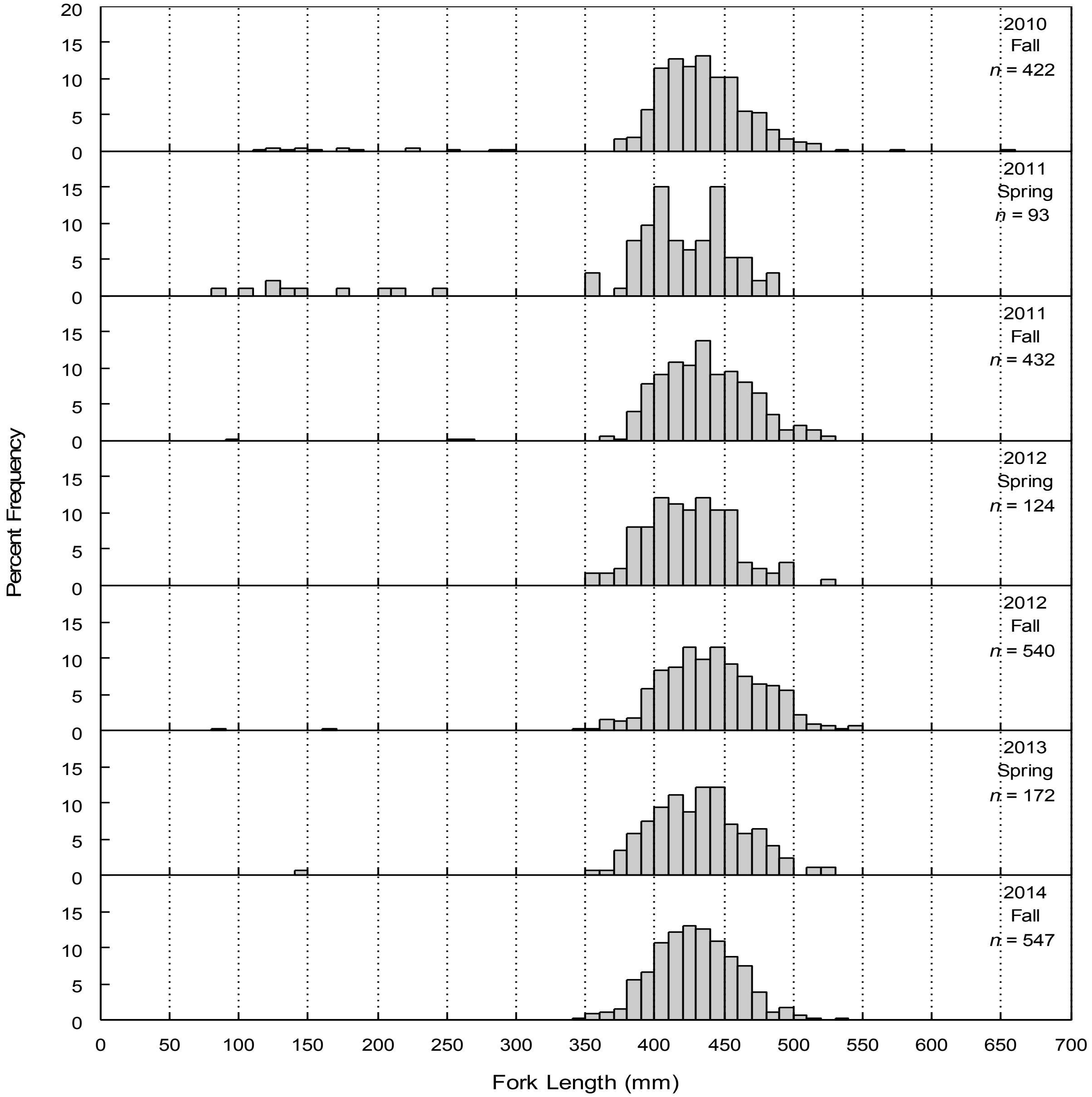

Figure E6 Length-frequency distributions for Largescale Sucker captured by boat electroshocking in Reaches 3 and 4 of the Middle Columbia River, 2010 to 2014. Largescale Sucker that were initially marked during an earlier year of the program were excluded from the analysis due to potential tagging effects on growth.

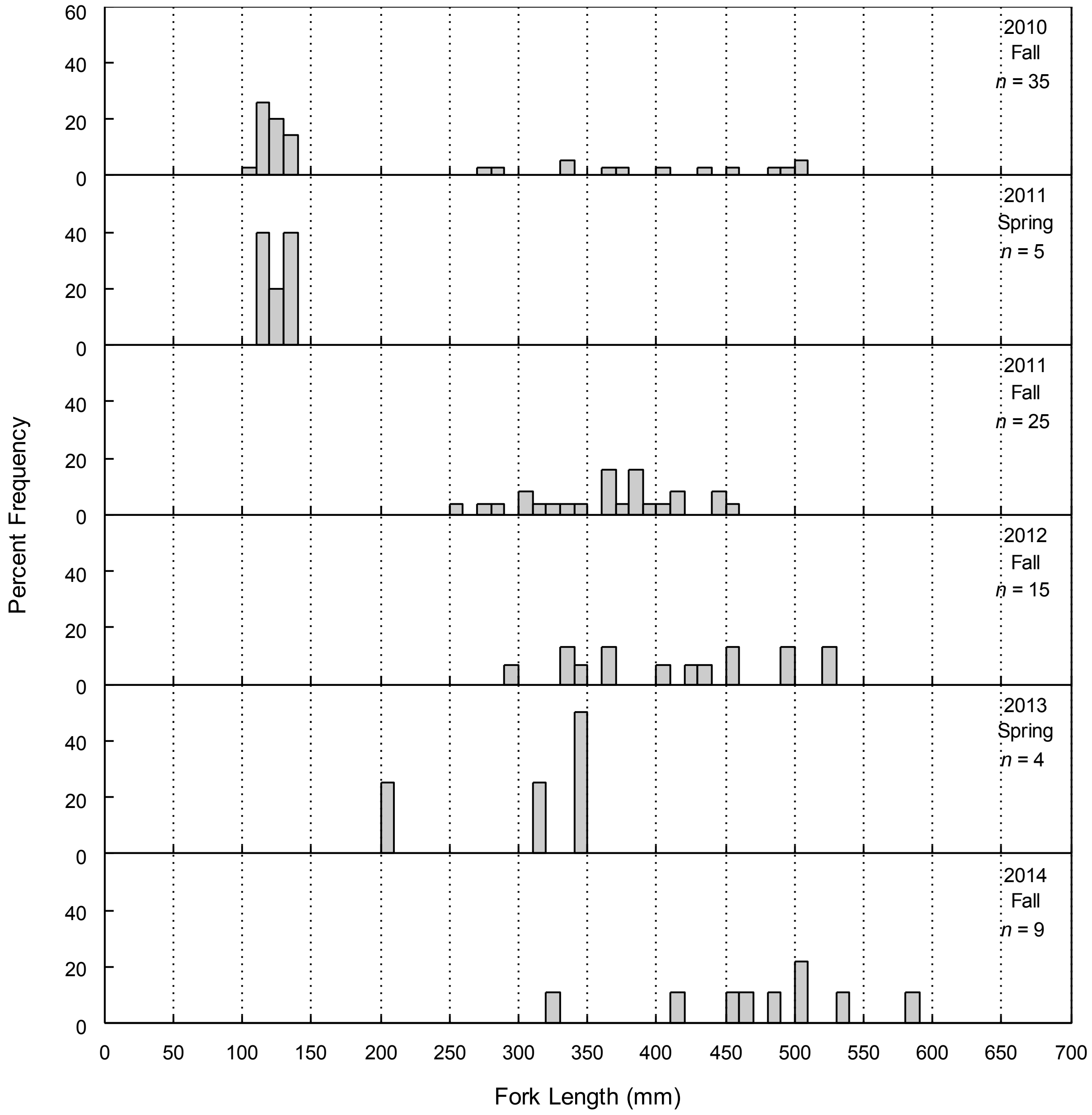

Figure E7 Length-frequency distributions for Northern Pikeminnow captured by boat electroshocking in Reaches 3 and 4 of the Middle Columbia River, 2010 to 2014. Northern Pikeminnow that were initially marked during an earlier year of the program were excluded from the analysis due to potential tagging effects on growth.

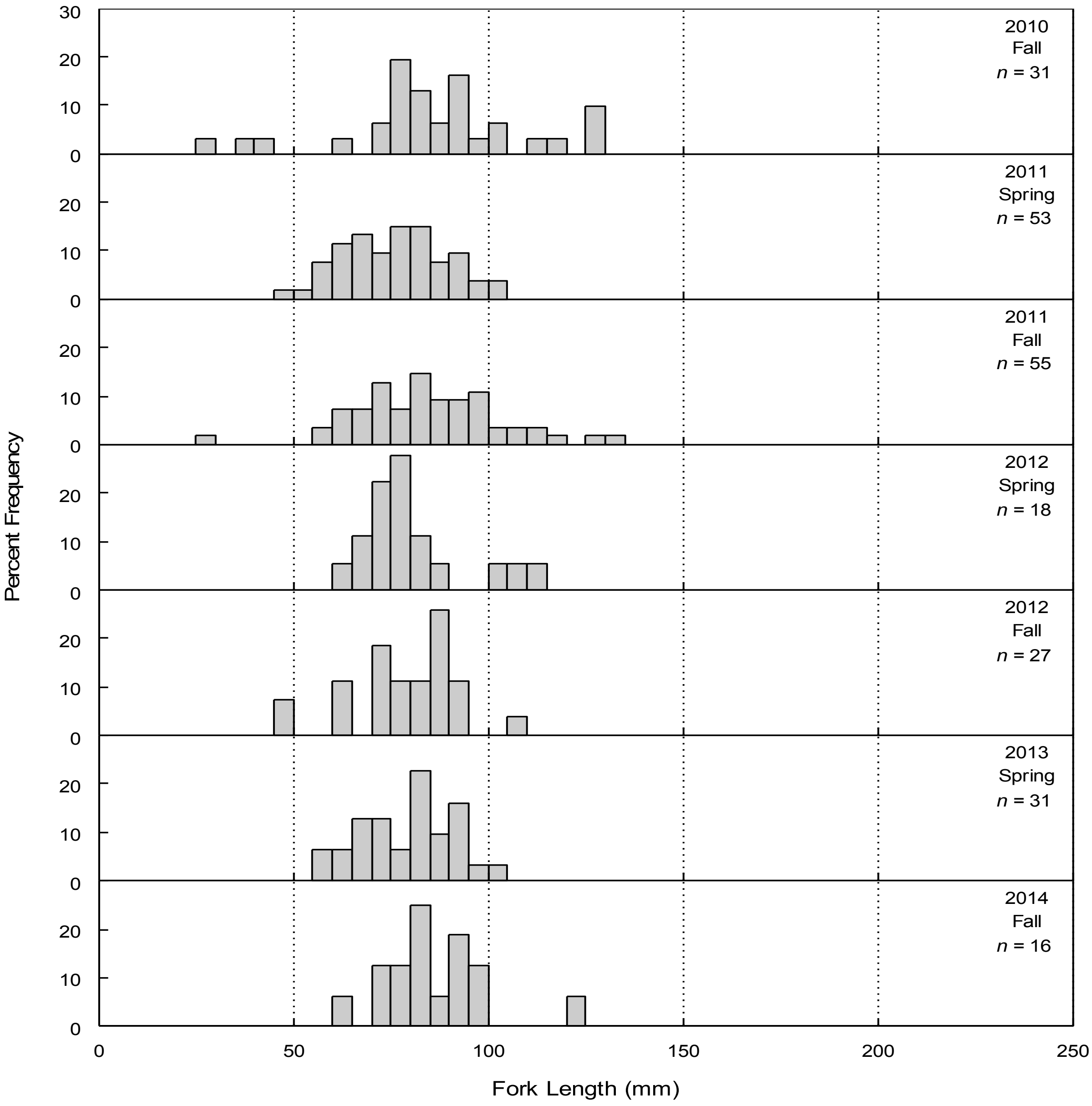

Figure E8 Length-frequency distributions for Prickly Sculpin captured by boat electroshocking in Reaches 3 and 4 of the Middle Columbia River, 2010 to 2014.

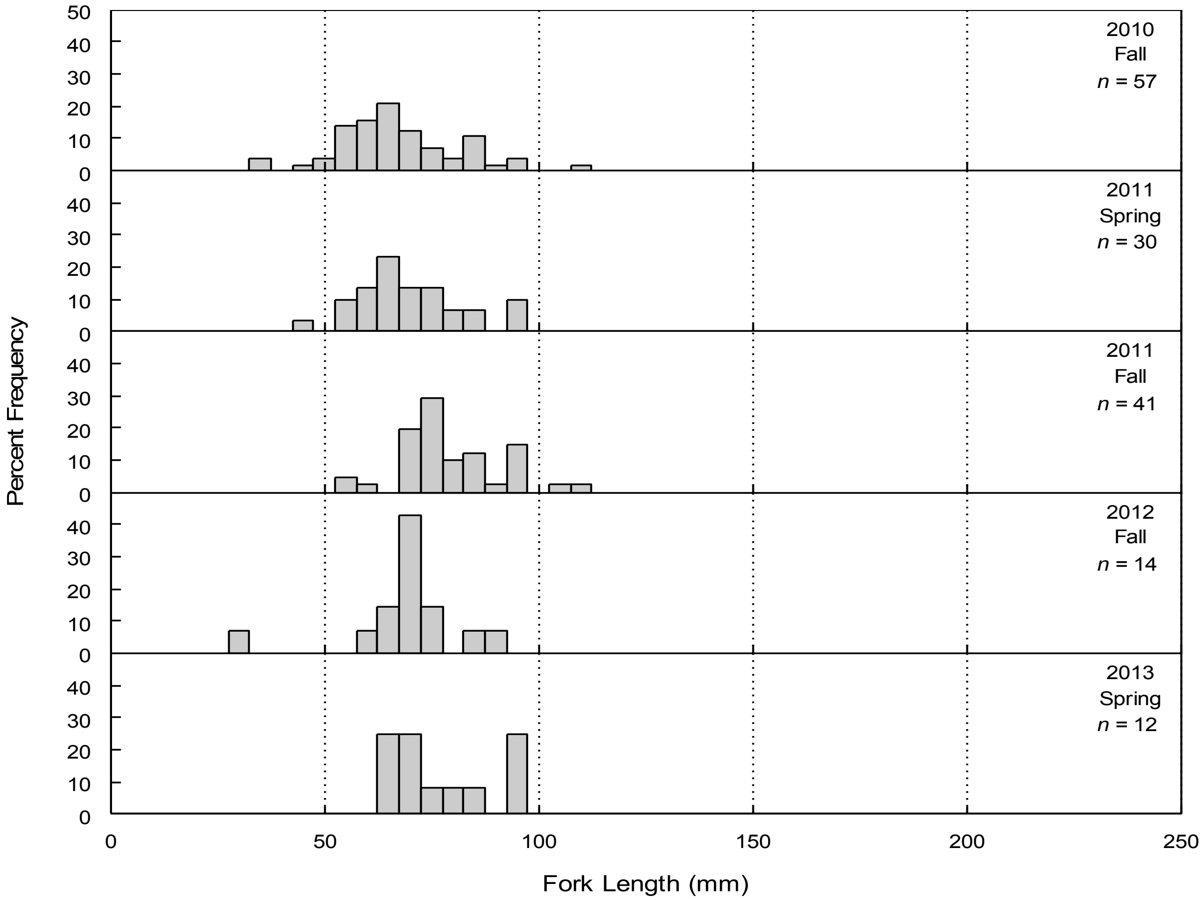

Figure E9 Length-frequency distributions for Redside Shiner captured by boat electroshocking in Reaches 3 and 4 of the Middle Columbia River, 2010 to 2013. Only one Redside Shiner was caught in 2014.

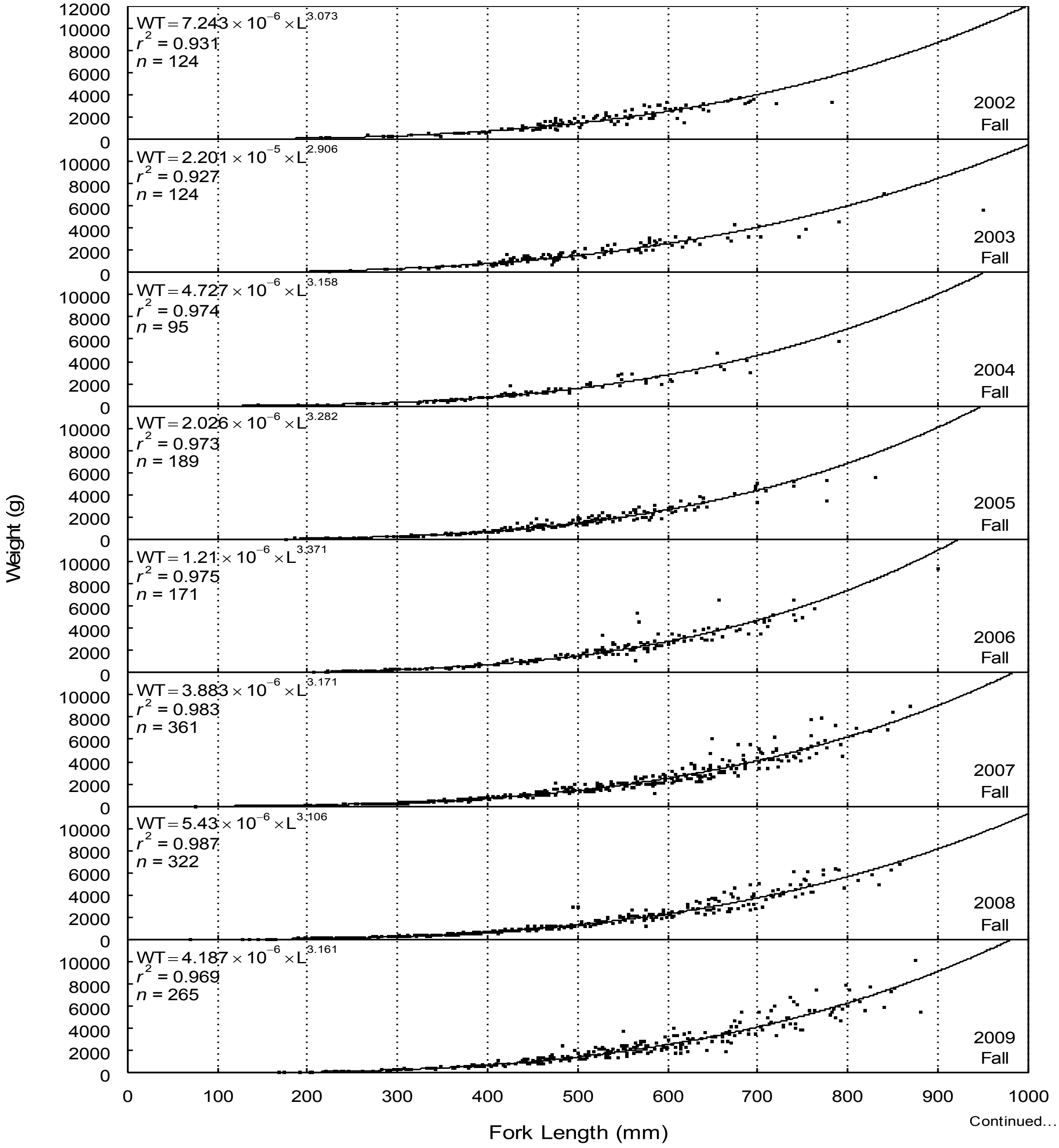

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Figure E10 Length-weight regression for Bull Trout captured by boat electroshocking in Reaches 3 and 4 of the Middle Columbia River, 2001 to 2014. Bull Trout that were initially marked during an earlier year of the program were excluded from the analysis due to potential tagging effects on growth. Boat electroshocking surveys were not conducted downstream of Big Eddy for all years prior to 2007.

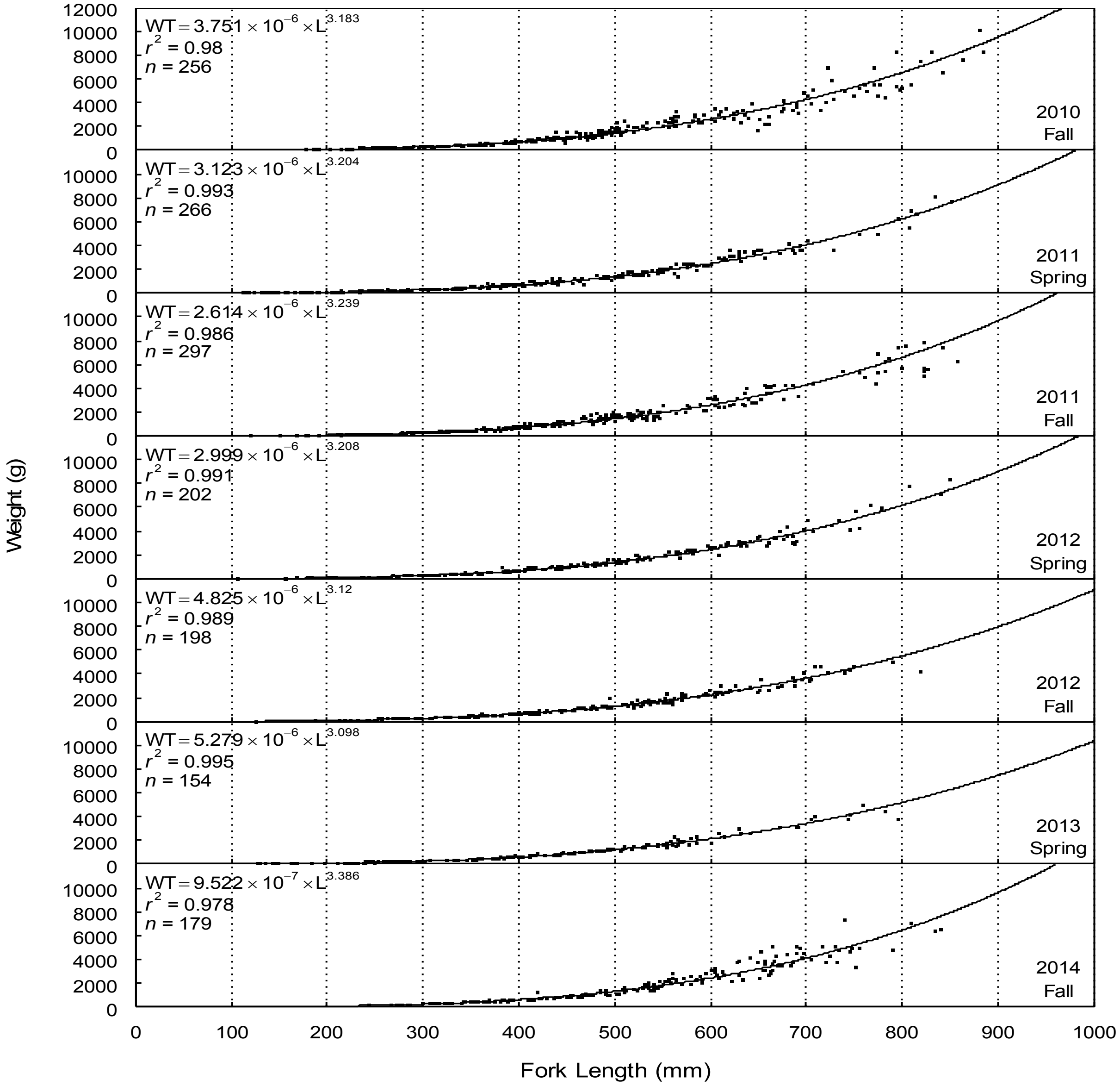

Figure E10 Concluded.

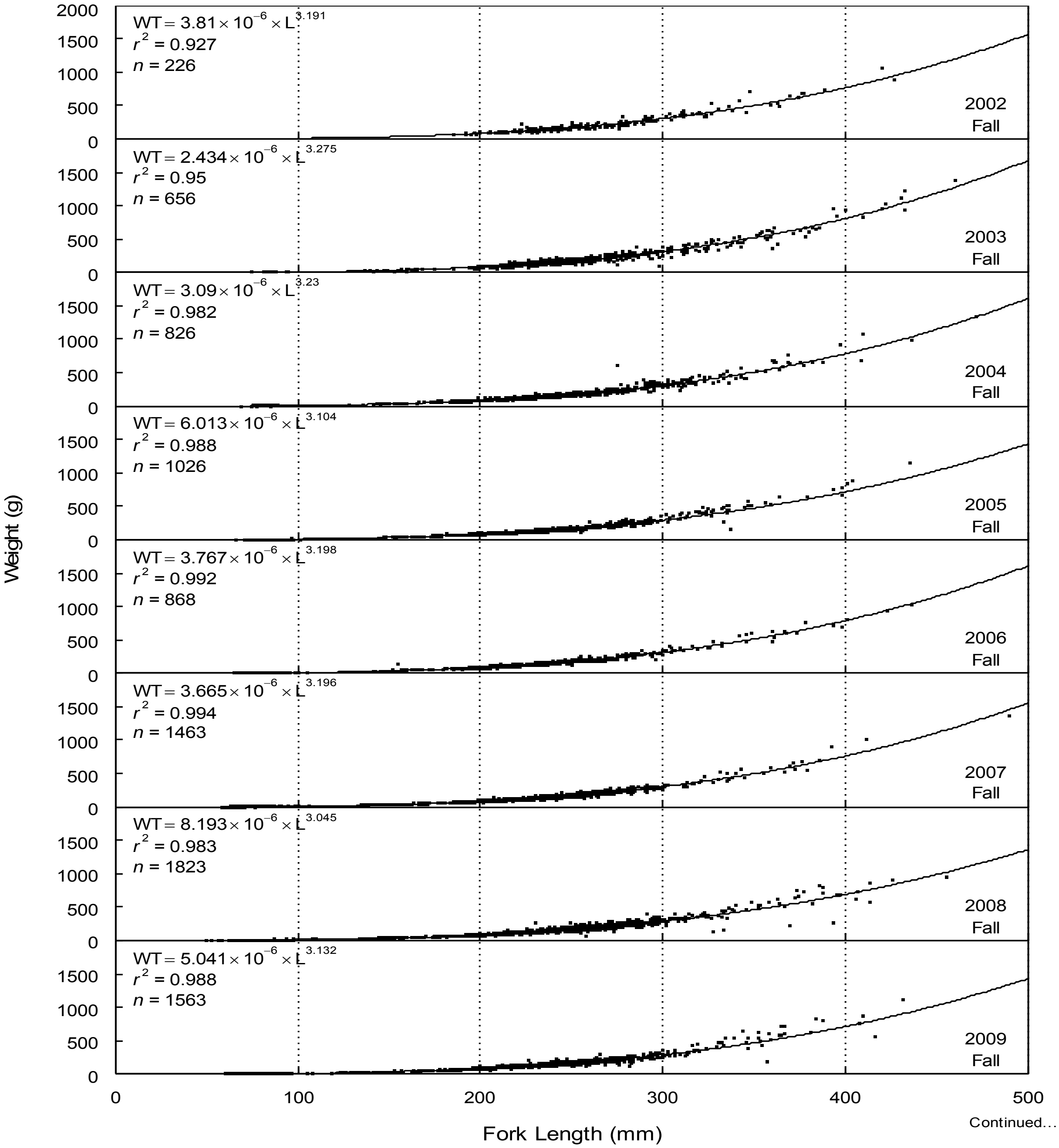

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Figure E11 Length-weight regression for Mountain Whitefish captured by boat electroshocking in Reaches 3 and 4 of the Middle Columbia River, 2001 to 2014. Mountain Whitefish that were initially marked during an earlier year of the program were excluded 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.

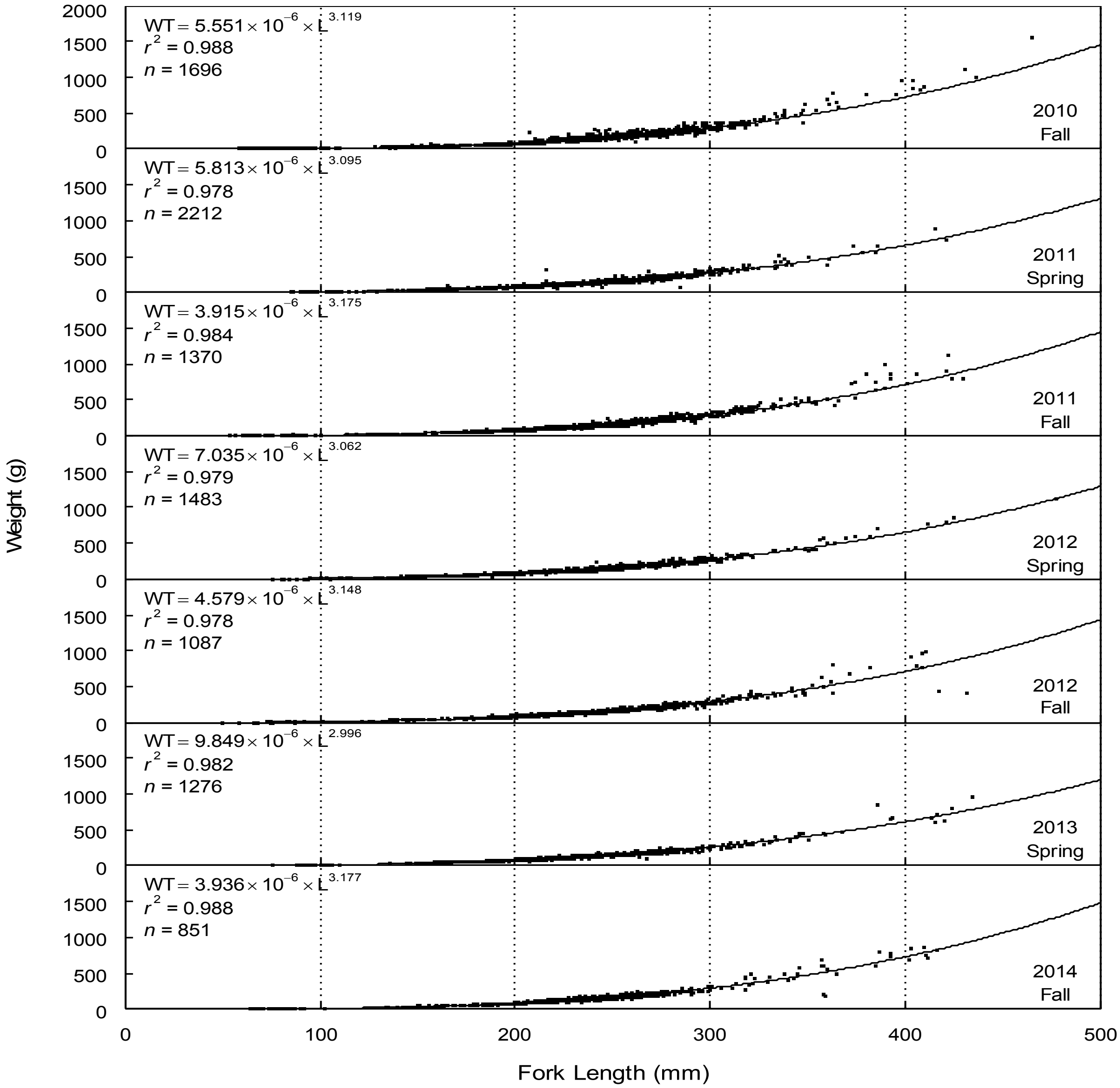

Figure E11 Concluded.

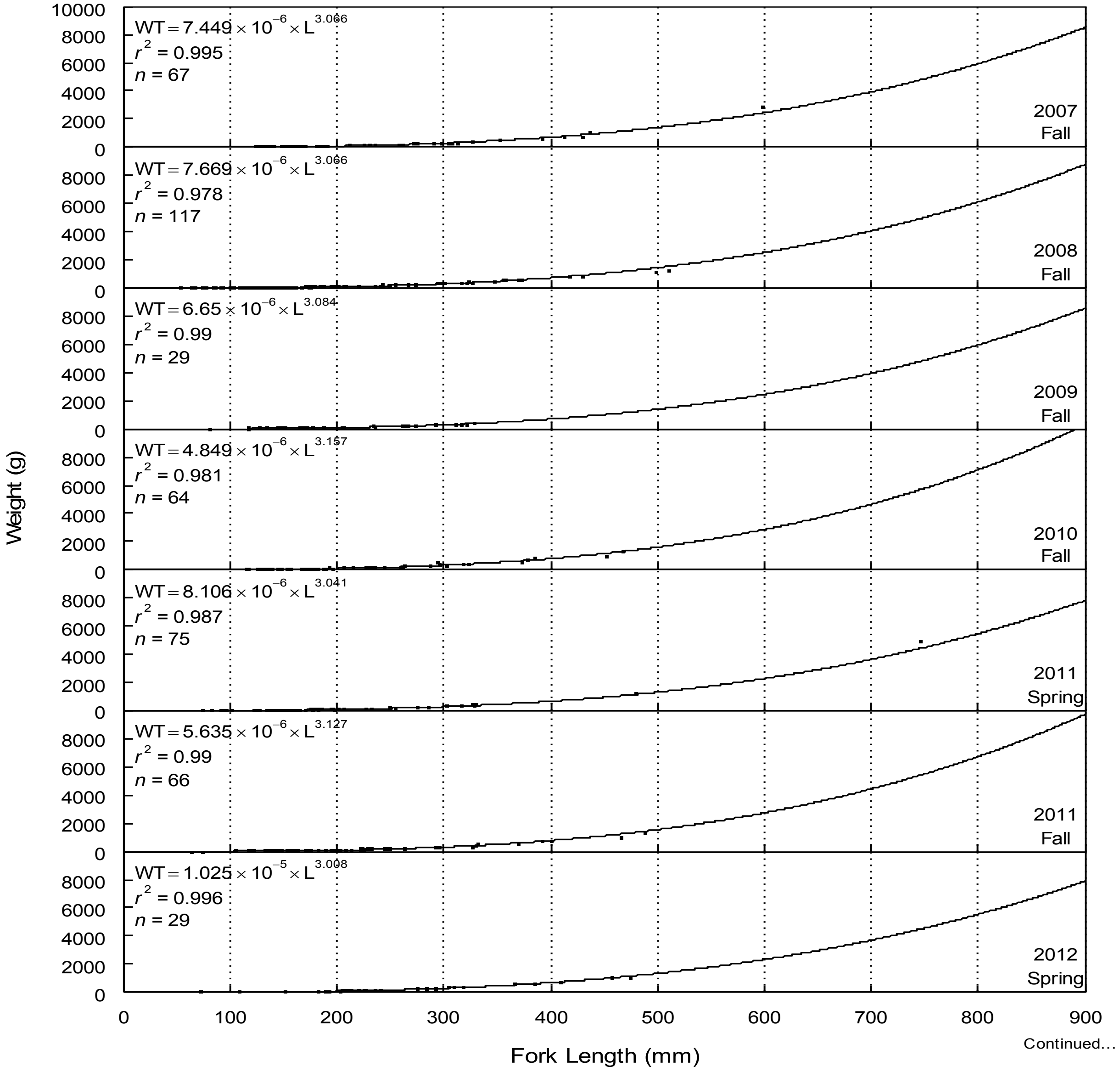

Figure E12 Length-weight regression for Rainbow Trout captured by boat electroshocking in Reaches 3 and 4 of the Middle Columbia River, 2010 to 2014. Rainbow Trout that were initially marked during an earlier year of the program were excluded from the analysis due to potential tagging effects on growth. Boat electroshocking surveys were not conducted downstream of Big Eddy for all years prior to 2007.

Continued..

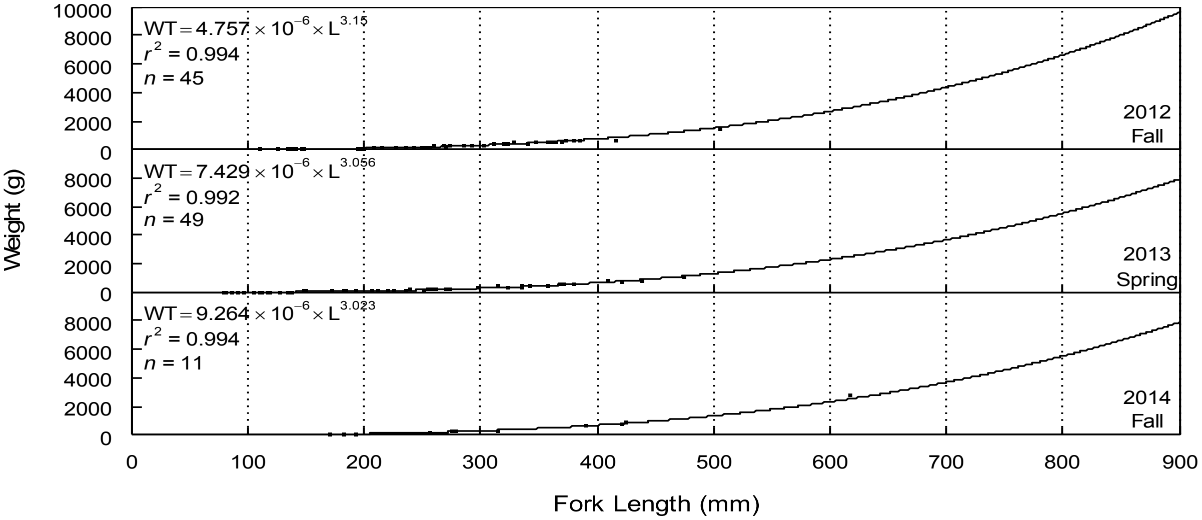

Figure E12 Concluded.

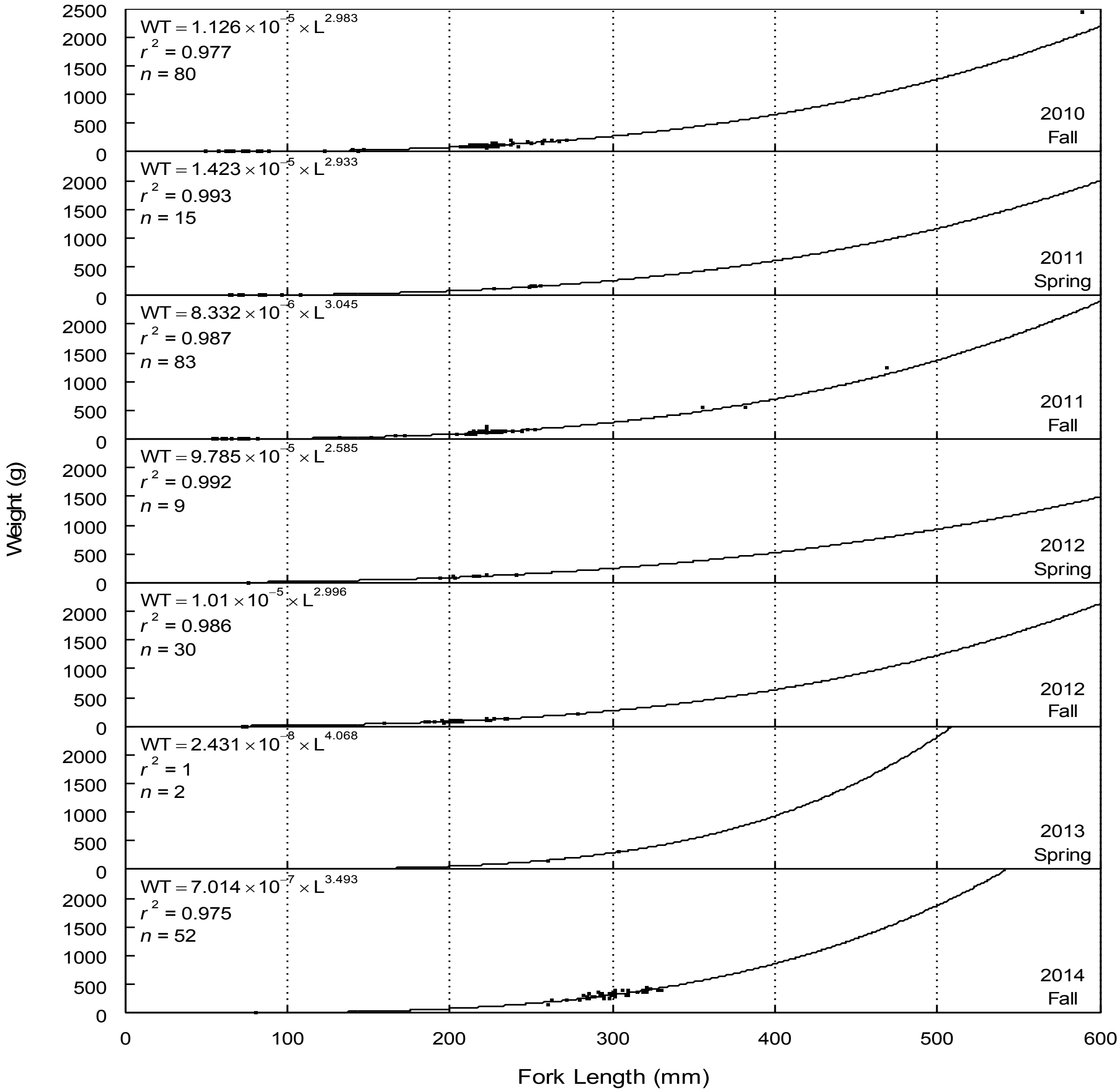

Figure E13 Length-weight regression for Kokanee captured by boat electroshocking in Reaches 3 and 4 of the Middle Columbia River, 2010 to 2014.

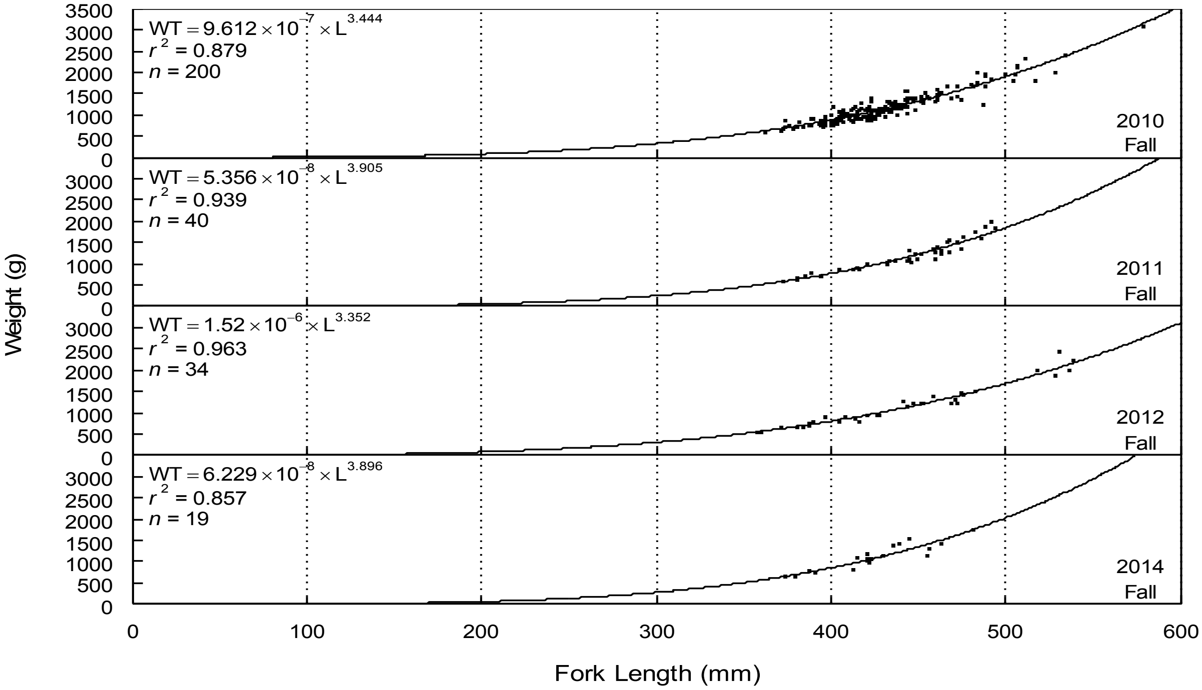

Figure E14 Length-weight regression for Lake Whitefish captured by boat electroshocking in Reaches 3 and 4 of the Middle Columbia River, 2010 to 2014. Lake Whitefish that were initially marked during an earlier year of the program were excluded from the analysis due to potential tagging effects on growth. Lake Whitefish were not captured during the spring of 2013.

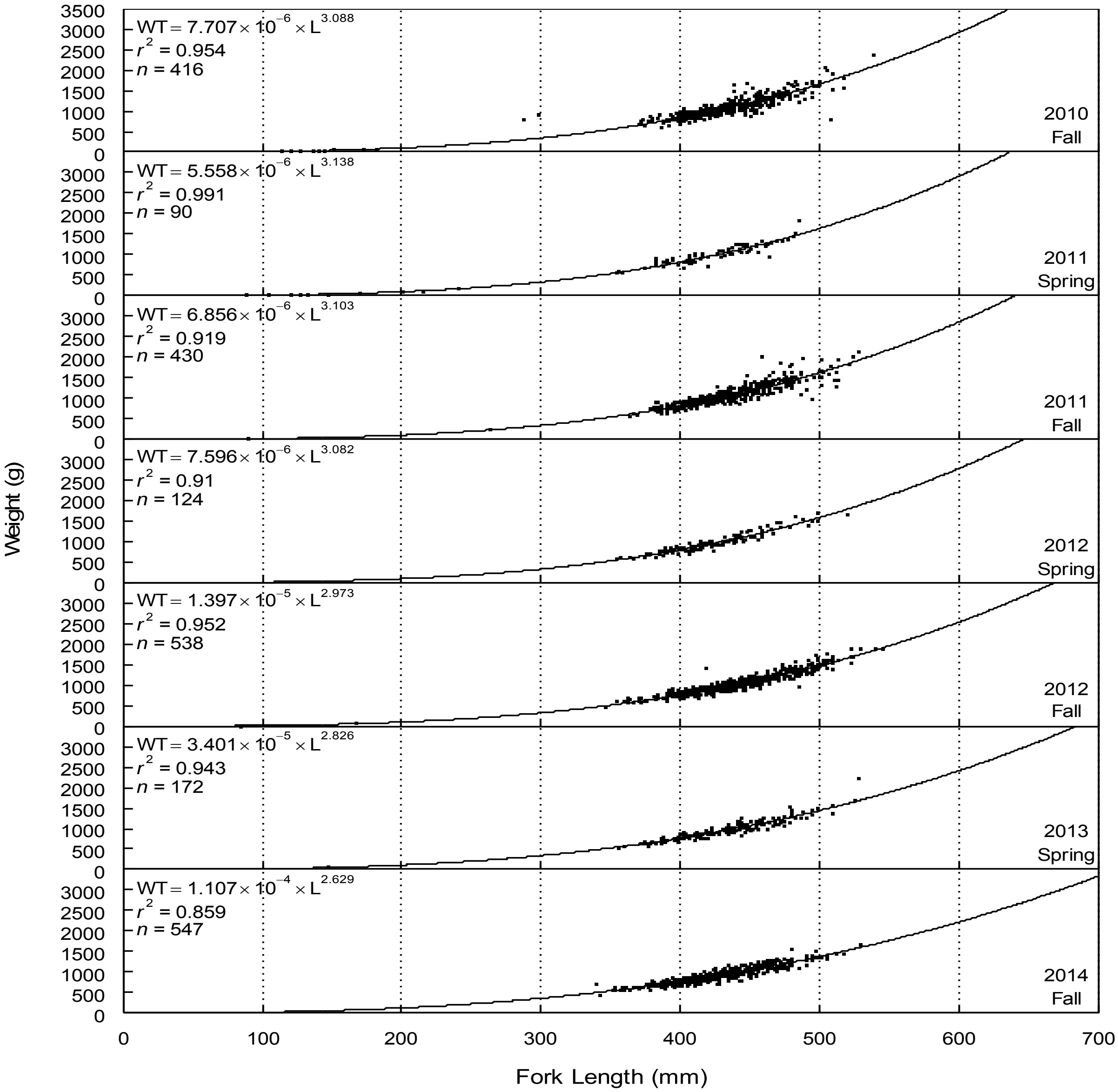

Figure E15 Length-weight regression for Largescale Sucker captured by boat electroshocking in Reaches 3 and 4 of the Middle Columbia River, 2010 to 2014. Largescale Sucker that were initially marked during an earlier year of the program were excluded from the analysis due to potential tagging effects on growth.

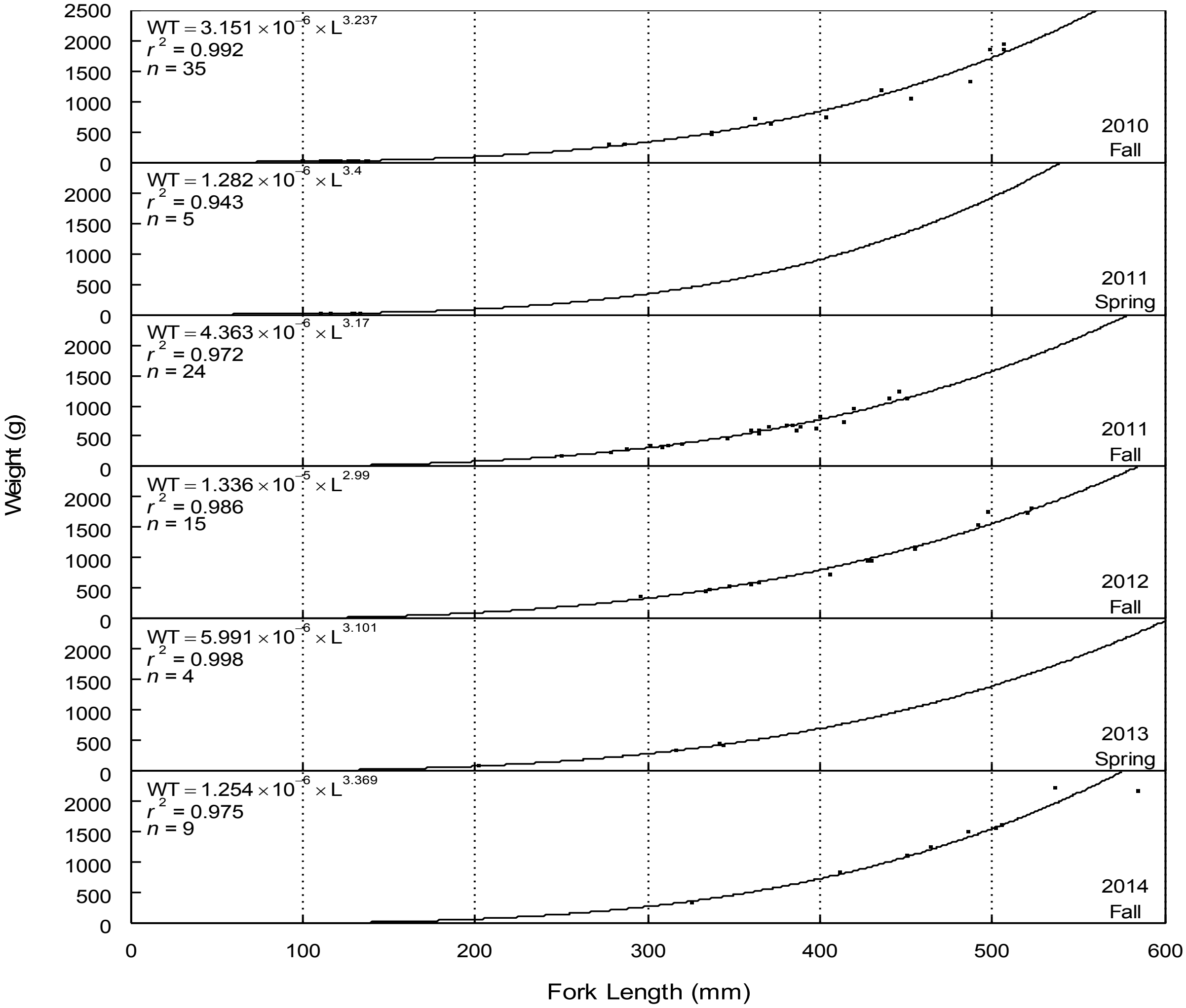

Figure E16 Length-weight regression for Northern Pikeminnow captured by boat electroshocking in Reaches 3 and 4 of the Middle Columbia River, 2010 to 2014. Northern Pikeminnow that were initially marked during an earlier year of the program were excluded from the analysis due to potential tagging effects on growth.

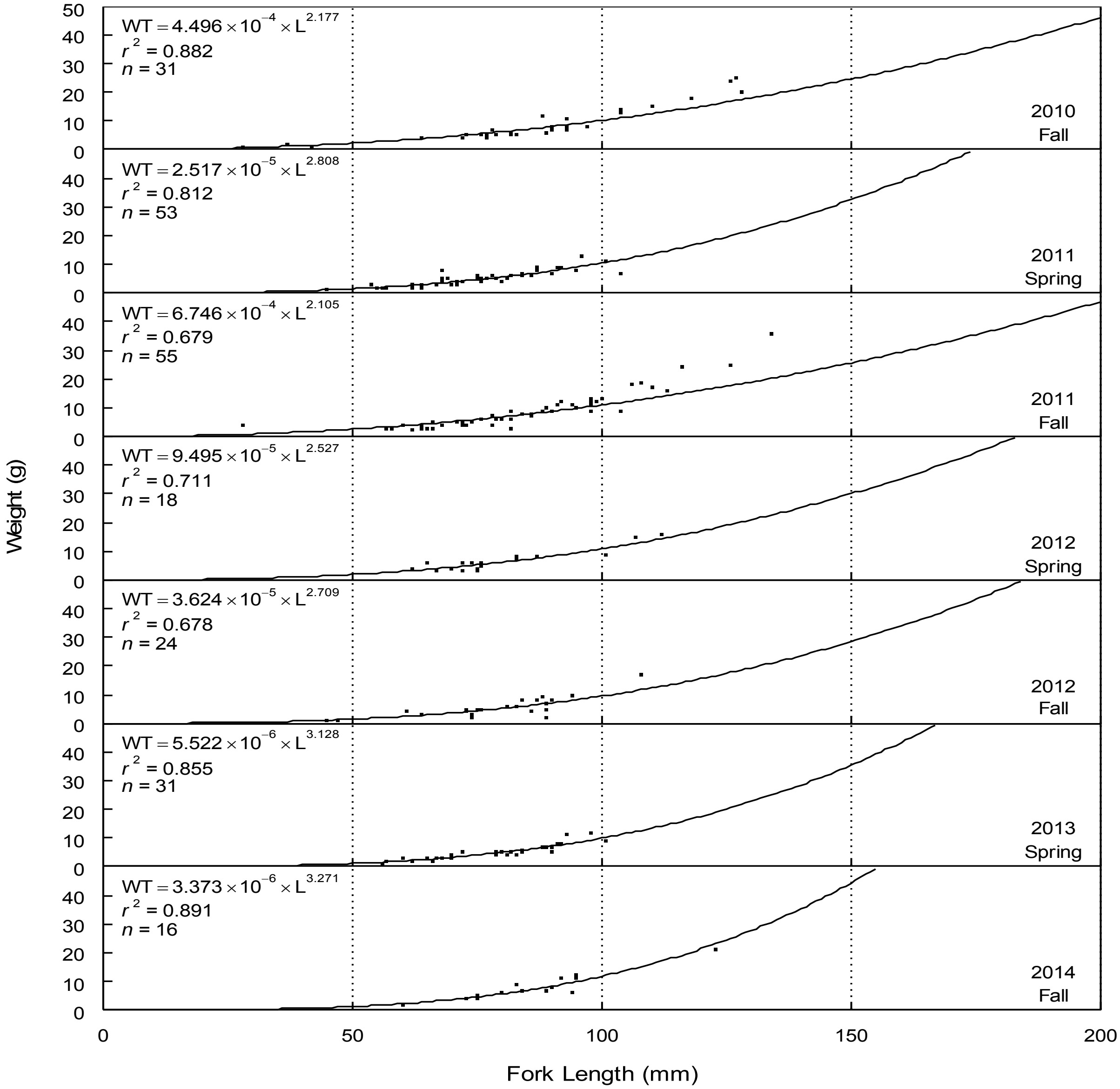

Figure E17 Length-weight regression for Prickly Sculpin captured by boat electroshocking in Reaches 3 and 4 of the Middle Columbia River, 2010 to 2014.

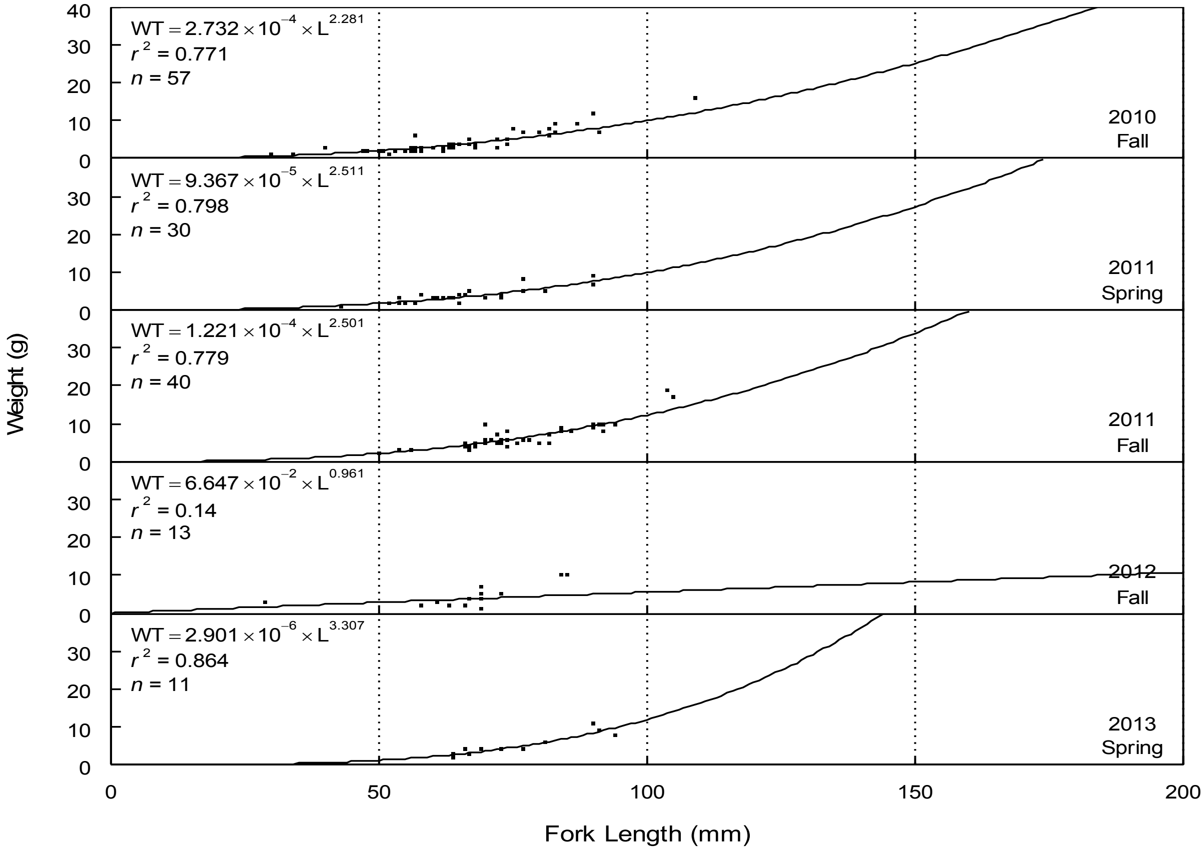

Figure E18 Length-weight regression for Redside Shiner captured by boat electroshocking in Reaches 3 and 4 of the Middle Columbia River, 2010 to 2013. Only one Redside Shiner was caught in 2014.

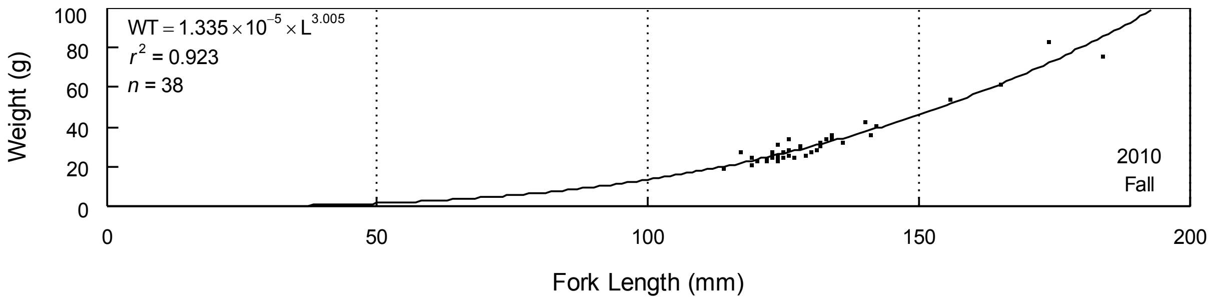

Figure E19 Length-weight regression for Yellow Perch captured by boat electroshocking in Reaches 3 and 4 of the Middle Columbia River, 2010. Yellow Perch that were initially marked during an earlier year of the program were excluded from the analysis due to potential tagging effects on growth.

Appendix F – HBA Methods

Hierarchical Bayesian Analyses 2014 – Methods

Suggested Citation: Thorley, J.L. and Beliveau, A. (2015) Middle Columbia River Fish Indexing Analysis 2014. URL: http://www.poissonconsulting.ca/f/1446318417.

The source code is available on GitHub.

Methods

Data Preparation

The data were provided by Golder Associates.

Life-Stage

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

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

Statistical Analysis

Hierarchical Bayesian models were fitted to the count data using R version 3.1.2 (Team 2013) and JAGS 3.4.0 (Plummer 2012) which interfaced with each other via jaggernaut 2.2.10 (Thorley 2013). For additional information on hierarchical Bayesian modelling in the BUGS language, of which JAGS uses a dialect, the reader is referred to Kery and Schaub (2011, 41–44).

Unless specified, the models assumed vague (low information) prior distributions (Kery and Schaub 2011, 36). The posterior distributions were estimated from a minimum of 1,000 Markov Chain Monte Carlo (MCMC) samples thinned from the second halves of three chains of at least 10,000 iterations in length (Kery and Schaub 2011, 38–40). Model convergence was confirmed by ensuring that Rhat (Kery and Schaub 2011, 40) was less than 1.1 for each of the parameters in the model (Kery and Schaub 2011, 61). Model adequacy was confirmed by examination of residual plots.

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

Variable selection was achieved by dropping *insignificant* (Kery and Schaub 2011, 37, 42) fixed (Kery and Schaub 2011, 77–82) variables and *uninformative* random variables. A fixed variables was considered to be insignificant if its significance was ≥ 0.05 while a random variable was considered to be uninformative if its percent relative error was ≥ 80%.

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

Growth

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

$$\frac{\mathrm{dl}}{\mathrm{dt}} = \mathrm{k}(\mathrm{L}_\infty - \mathrm{l})$$

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

Integrating the above equation gives

$$\mathrm{l}_\mathrm{t} = \mathrm{L}_\infty(1 - \mathrm{e}^{-\mathrm{k}(\mathrm{t}-\mathrm{t}0)})$$

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

The Fabens form allows

$$\mathrm{l}_\mathrm{r} = \mathrm{L}_\mathrm{c} + (\mathrm{L}_\infty - \mathrm{L}_\mathrm{c})(1 - \mathrm{e}^{-\mathrm{kT}})$$

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

Key assumptions of the growth model include:

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

Condition

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

More specifically the model was based on the allometric relationship

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

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

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

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

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

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

Key assumptions of the final condition model include:

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

Occupancy

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

Key assumptions of the occupancy model include:

- Occupancy (probability of presence) is described by a generalized linear mixed model with a logit link.
- Occupancy varies with discharge regime and season.
- Occupancy varies randomly with 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, given occupancy.

Species Richness

The estimated probabilities of presence for the six species considered in the occupany analyses were summed to give the expected species richnesses at a given (or typical) site in a given (or typical) year.

Count

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

Key assumptions of the abundance model include:

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

Movement

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

Key assumptions of the site fidelity model include:

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

Observer Length Correction

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

Key assumptions of the observer length correction model include:

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

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

Abundance

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

Key assumptions of the 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 by season and method (capture versus count).
- Efficiency varies randomly by session within season within year.
- Marked and unmarked fish have the same probability of capture.
- There is no tag loss, migration (at the supersite level), mortality or misidentification of fish.
- The number of fish caught is gamma-Poisson distributed.

Species Evenness

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

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

Long-Term Trends

The long-term congruence between the yearly fall fish metrics (Grw = Growth, Con = Condition, Blank = Abundance, Rkm = Distribution) by life stage (Juv = Juvenile, AD = Adult) and a range of environmental variables including the tri-monthly (JaMa = January - March, ApJn = April - June, JlSe = July - September, OcDe = October - December) discharge from Revelstoke Dam (Q10, QMu = Mean, Q90, QDlt = Mean absolute difference) and the elevation (Ele), the Pacific Decadal Oscillation (PDO), the chlorophyll-a (ChlA) and invertebrate production (Inv) and the kokanee abundance (KO) was examined using Dynamic Factor Analysis (Zuur, Tuck, and Bailey 2003). Due to the *rotation problem* the underlying trends were indeterminate (Abmann, Boysen-Hogrefe, and Pape 2014). The October to December discharge and elevation values were lead (opposite of lagged) by one year to account for the fact that they occurred after sampling.

Key assumptions of the Dynamic Factor Analysis (DFA) model include:

- The time series are described by three underlying trends.
- The random walk processes in the trends are normally distributed.
- The residual variation in the standardised variables is normally distributed.

The similarities were represented visually by using non-metric multidimensional scaling (NMDS) to map the distances onto two-dimensional space. The more similar two time series are they closer they will tend to be in the resultant NMDS plot.

Short-Term Correlations

To assess the short-term congruence between the yearly fish metrics and the environmental variables, the pair-wise distances between the residuals from the DFA model were calculated as $1 - \text{abs}(\text{cor}(x, y))$ where cor is the Pearson correlation, abs the absolute value and x and y are the two time series being compared.

The short-term similarities were represented visually by using NMDS to map the distances onto two-dimensional space.

Model Code

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

Growth

Variable/Parameter	Description
`bKIntercept`	Intercept for `log(bK)`
`bKRegime[i]`	Effect of `i`th regime on `bKIntercept`
`bKYear[i]`	Random effect of `i`th `Year` on `bKIntercept`
`bLinf`	Mean maximum length
`eGrowth[i]`	Expected `Growth` of the `i`th recapture
`Growth[i]`	Change in length of the `i`th fish between release and recapture
`LengthAtRelease[i]`	Length of the `i`th recapture when released
`nRegime[i]`	Number of regimes
`sGrowth`	SD of residual variation in `Growth`
`sKYear[i]`	SD of effect of `Year` on `bKIntercept`
`Threshold`	Last year of the first regime
`Year[i]`	Year the `i`th recapture was released
`Years[i]`	Number of years between release and recapture for the `i`th recapture

Growth - Model1

```
model {

  bKIntercept ~ dnorm (0, 5^-2)

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

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

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

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

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

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

```
  tGrowth <- bKRegime[2]
}
```

Condition

Variable/Parameter	Description
`bWeightIntercept`	Intercept for `eWeightIntercept`
`bWeightRegimeIntercept[i]`	Effect of `i`th regime on `bWeightIntercept`
`bWeightRegimeSlope[i]`	Effect of `i`th regime on `bWeightSlope`
`bWeightSeasonIntercept[i]`	Effect of `i`th season on `bWeightIntercept`
`bWeightSeasonSlope[i]`	Effect of `i`th season on `bWeightSlope`
`bWeightSiteIntercept[i]`	Random effect of `i`th site on `bWeightIntercept`
`bWeightSiteYearIntercept[i,j]`	Random effect of `i`th site in `j`th year on `bWeightIntercept`
`bWeightSlope`	Intercept for `eWeightSlope`
`bWeightYearIntercept[i]`	Random effect of `i`th year on `bWeightIntercept`
`bWeightYearSlope[i]`	Random effect of `i`th year on `bWeightSlope`
`eWeight[i]`	Expected weight of the `i`th fish
`eWeightIntercept[i]`	Intercept for `log(eWeight[i])`
`eWeightSlope[i]`	Slope for `log(eWeight[i])`
`Length[i]`	Length of `i`th fish
`sWeight`	Residual SD of `Weight`
`sWeightSiteIntercept`	SD for the effect of site on `bWeightIntercept`
`sWeightSiteYearIntercept`	SD for the effect of the combination of site and year on `eWeightIntercept`
`sWeightYearIntercept`	SD of the effect of year on `bWeightIntercept`
`sWeightYearSlope`	SD for the random effect of year on `eWeightSlope`
`Weight[i]`	Weight of `i`th fish

Condition - Model1

```
model {

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

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

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

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

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

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

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

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

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

    log(eWeight[i]) <- eWeightIntercept[i] + eWeightSlope[i] * Length[i]
    Weight[i] ~ dlnorm(log(eWeight[i]) , sWeight^-2)
  }
  tCondition1 <- bWeightRegimeIntercept[2]
  tCondition2 <- bWeightRegimeSlope[2]
}
```

Occupancy

Variable/Parameter	Description

`bOccupancy`	Intercept of `logit(eOccupancy)`
`bOccupancyRegime[i]`	Effect of i^{th} regime on `logit(eOccupancy)`
`bOccupancySeason[i]`	Effect of i^{th} season on `logit(eOccupancy)`
`bOccupancySite[i]`	Effect of i^{th} site on `logit(eOccupancy)`
`bOccupancyYear[i]`	Effect of i^{th} year on `logit(eOccupancy)`
`eObserved[i]`	Probability of observing species on i^{th} site visit
`eOccupancy[i]`	Predicted occupancy (species presence versus absence) on i^{th} site visit
`nRegime`	Number of regimes in the dataset (2)
`nSeason`	Number of seasons in the dataset (2)
`nSite`	Number of sites in the dataset
`nYear`	Number of years of data
`Observed[i]`	Whether the species was observed on i^{th} site visit (0 or 1)
`Regime[i]`	Regime ofi^{th} site visit
`Season[i]`	Season of i^{th} site visit
`Site[i]`	Site of i^{th} site visit
`sOccupancySite`	SD parameter for the distribution of `bOccupancySite[i]`
`sOccupancyYear`	SD parameter for the distribution of `bOccupancyYear[i]`
`Year[i]`	Year of i^{th} site visit

Occupancy - Model1

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

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

Count

Variable/Parameter	Description
`bDensity`	Intercept of `log(eDensity)`
`bDensityRegime[i]`	Effect of i^{th} regime on `log(eDensity)`
`bDensitySeason[i]`	Effect of i^{th} season on `log(eDensity)`
`bDensitySite[i]`	Effect of i^{th} site on `log(eDensity)`
`bDensitySiteYear[i, j]`	Effect of i^{th} site in j^{th} year on `log(eDensity)`
`bDensityYear[i]`	Effect of i^{th} year on `log(eDensity)`
`bDistribution`	Intercept of `eDistribution`
`bDistributionRegime[i]`	Effect of i^{th} regime on `eDistribution`
`bDistributionSeason[i]`	Effect of i^{th} season on `eDistribution`
`bDistributionYear[i]`	Effect of i^{th} year on `eDistribution`
`Count[i]`	Count on i^{th} site visit
`eCount[i]`	Expected count on i^{th} site visit
`eDensity[i]`	Lineal density on i^{th} site visit
`eDispersion[i]`	Overdispersion factor on i^{th} site visit
`eDistribution[i]`	Effect of centred river kilometre on i^{th} site visit on `log(eDensity)`
`ProportionSampled[i]`	Proportion of i^{th} site that was sampled
`sDispersion[i]`	SD of the overdispersion factor distribution
`SiteLength[i]`	Length of i^{th} site

Count - Model1

```
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)
    }
  }

  sDispersion ~ dunif(0, 5)
  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(1 / sDispersion^2, 1 / sDispersion^2)
    Count[i] ~ dpois(eCount[i] * eDispersion[i])
  }
  tAbundance <- bDensityRegime[2]
  tDistribution <- bDistributionRegime[2]
}
```

Movement

Variable/Parameter	Description
`bLength`	Coefficient for the effect of `Length` on `logit(eMoved)`
`bLengthSeason[i]`	Coefficient for the effect of the interaction between `Length` and `Season` on `logit(eMoved)`
`bMoved`	Intercept for `logit(eMoved)`
`bMovedSeason[i]`	Effect of `i`th season on `logit(eMoved)`
`eMoved[i]`	Probability of different site from previous encounter for `i`th recapture
`Length[i]`	Length of `i`th recaptured fish
`Moved[i]`	Indicates whether `i`th recapture is recorded at a different site from previous encounter
`nSeason`	Number of seasons in the study (2)
`Season[i]`	Season of `i`th recapture

Movement - Model1

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

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

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

Observer Length Correction

Variable/Parameter	Description
`bLength[i]`	Relative inaccuracy of the`i`th `Observer`
`ClassLength`	Mean `Length` of fish belonging to the `i`th class
`dClass[i]`	Prior value for the relative proportion of fish in the `i`th class
`eClass[i]`	Expected class of the `i`th fish
`eLength[i]`	Expected `Length` of the `i`th fish
`eSLength[i]`	Expected SD of the residual variation in `Length` for the `i`th

`Length[i]`	Observed fork length of the i^{th} fish
`Observer[i]`	Observer of the i^{th} fish where the first observer used a length board
`pClass[i]`	Proportion of fish in the i^{th} class
`sLength[i]`	Relative imprecision of the i^{th} `Observer`

Observer Length Correction - Model1

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

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

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

Abundance

Variable/Parameter	Description
`bDensity`	Intercept for `log(eDensity)`
`bDensityRegime[i]`	Effect of i^{th} `Regime` on `bDensity`
`bDensitySeason[i]`	Effect of i^{th} `Season` on `bDensity`
`bDensitySite[i]`	Random effect of i^{th} `Site` on `bDensity`
`bDensitySiteYear[i, j]`	Effect of i^{th} `Site` in j^{th} year on `bDensity`
`bDensityYear[i]`	Random effect of i^{th} `Year` on `bDensity`
`bDistribution`	Intercept for `eDistribution`
`bDistributionRegime[i]`	Effect of i^{th} `Regime` on `bDistribution`
`bDistributionSeason[i]`	Effect of i^{th} `Season` on `bDistribution`
`bDistributionYear[i]`	Random effect of i^{th} `Year` on `bDistribution`
`bEfficiency`	`Intercept for logit(eEfficiency)`
`bEfficiencySessionSeasonYear[i, j, k]`	Effect of i^{th} `Session` in j^{th} `Season` of k^{th} `Year` on `bEfficiency`

`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 relationship between centred river kilometre and `i`th site visit on `bDensity`
`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 - Model1

```
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,
sEfficiencySessionSeasonYear^-2)
      }
    }
  }

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

  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]])
  }

  sDispersion ~ dunif(0, 5)
  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]]

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

```
eEfficiency[i] * bType[Type[i]]

    eDispersion[i] ~ dgamma(1 / sDispersion^2, 1 / sDispersion^2)

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

Long-Term Trends

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

Long-Term Trends - Model1

```
model{

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

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

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

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

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Appendix G – HBA Results

Hierarchical Bayesian Analyses 2014 - Results

Results

Model Parameters

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

Growth - Bull Trout

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bKIntercept	-1.8218	-2.1170	-1.5128	0.1458	17	0.0010
bKRegime[2]	0.0184	-0.4323	0.3983	0.2027	2300	0.8903
bLinf	851.2000	799.7000	919.0000	30.6000	7	0.0010
sGrowth	31.6850	28.7520	35.1080	1.6090	10	0.0010
sKYear	0.3004	0.1492	0.5388	0.1048	65	0.0010
tGrowth	0.0184	-0.4323	0.3983	0.2027	2300	0.8903

Convergence	Iterations
1.01	10000

Growth - Mountain Whitefish

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bKIntercept	-2.6984	-3.0438	-2.3537	0.1767	13	0.0010
bKRegime[2]	0.2167	-0.2672	0.6785	0.2326	220	0.3228
bLinf	360.8500	342.4600	381.4800	9.9300	5	0.0010
sGrowth	10.8910	10.4030	11.4250	0.2640	5	0.0010
sKYear	0.3738	0.2081	0.6564	0.1264	60	0.0010
tGrowth	0.2167	-0.2672	0.6785	0.2326	220	0.3228

Convergence	Iterations
1.01	20000

Growth - Rainbow Trout

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bKIntercept	-1.655	-2.805	-0.487	0.586	70	0.0120
bKRegime[2]	-0.304	-1.393	0.670	0.495	340	0.4492
bLinf	583.400	431.300	902.100	120.400	40	0.0010
sGrowth	26.260	17.230	41.080	6.260	45	0.0010
sKYear	0.392	0.010	1.475	0.398	190	0.0010
tGrowth	-0.304	-1.393	0.670	0.495	340	0.4492

Convergence	Iterations
1.04	10000

Condition - Bull Trout

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bWeightIntercept	6.83125	6.78961	6.86973	0.02032	1	0.0010
bWeightRegimeIntercept[2]	-0.09680	-0.16540	-0.02900	0.03560	70	0.0095
bWeightRegimeSlope[2]	0.04480	-0.09060	0.19340	0.07250	320	0.5161
bWeightSeasonIntercept[2]	-0.00320	-0.02488	0.01874	0.01113	680	0.7910
bWeightSeasonSlope[2]	0.01740	-0.03570	0.07300	0.02730	310	0.5236
bWeightSlope	3.15920	3.06850	3.23770	0.04090	3	0.0010
sWeight	0.14103	0.13699	0.14508	0.00201	3	0.0010
sWeightSiteIntercept	0.01308	0.00199	0.02552	0.00589	90	0.0010
sWeightSiteYearIntercept	0.01841	0.00571	0.02868	0.00574	62	0.0010
sWeightYearIntercept	0.05594	0.03527	0.08938	0.01409	48	0.0010
sWeightYearSlope	0.11530	0.06900	0.19080	0.03430	53	0.0010
tCondition1	-0.09680	-0.16540	-0.02900	0.03560	70	0.0095
tCondition2	0.04480	-0.09060	0.19340	0.07250	320	0.5161

Convergence	Iterations
1.02	80000

Condition - Mountain Whitefish

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bWeightIntercept	4.78875	4.76928	4.80754	0.00997	0	0.0010
bWeightRegimeIntercept[2]	-0.04307	-0.06920	-0.01494	0.01373	63	0.0078
bWeightRegimeSlope[2]	-0.05090	-0.12800	0.02540	0.03890	150	0.1778
bWeightSeasonIntercept[2]	-0.03843	-0.04735	-0.03053	0.00427	22	0.0010
bWeightSeasonSlope[2]	-0.06508	-0.10478	-0.02382	0.02025	62	0.0010
bWeightSlope	3.20633	3.15996	3.24697	0.02262	1	0.0010
sWeight	0.09692	0.09521	0.09863	0.00086	2	0.0010
sWeightSiteIntercept	0.01036	0.00546	0.01758	0.00299	59	0.0010
sWeightSiteYearIntercept	0.01093	0.00687	0.01516	0.00209	38	0.0010
sWeightYearIntercept	0.02712	0.01655	0.04399	0.00713	51	0.0010
sWeightYearSlope	0.05628	0.02991	0.10296	0.01890	65	0.0010
tCondition1	-0.04307	-0.06920	-0.01494	0.01373	63	0.0078
tCondition2	-0.05090	-0.12800	0.02540	0.03890	150	0.1778

Convergence	Iterations
1.02	20000

Condition - Rainbow Trout

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bWeightIntercept	4.56534	4.52899	4.60259	0.01794	1	0.0010
bWeightRegimeIntercept[2]	-0.00360	-0.05980	0.05100	0.02600	1600	0.9182
bWeightRegimeSlope[2]	-0.05310	-0.17980	0.07500	0.06540	240	0.4092
bWeightSeasonIntercept[2]	-0.07479	-0.10810	-0.04213	0.01679	44	0.0010
bWeightSeasonSlope[2]	0.01370	-0.07000	0.09940	0.04310	620	0.7346

bWeightSlope	3.09140	3.01810	3.17190	0.03840	2	0.0010
sWeight	0.11033	0.10350	0.11829	0.00381	7	0.0010
sWeightSiteIntercept	0.02911	0.00847	0.05630	0.01228	82	0.0010
sWeightSiteYearIntercept	0.01623	0.00071	0.03833	0.01054	120	0.0010
sWeightYearIntercept	0.02401	0.00105	0.06068	0.01533	120	0.0010
sWeightYearSlope	0.08460	0.03700	0.16050	0.03200	73	0.0010
tCondition1	-0.00360	-0.05980	0.05100	0.02600	1600	0.9182
tCondition2	-0.05310	-0.17980	0.07500	0.06540	240	0.4092

Convergence	Iterations
1.08	10000

Occupancy - Rainbow Trout

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bOccupancy	-1.230	-2.606	0.243	0.692	120	0.0819
bOccupancyRegime[2]	0.951	-0.492	2.513	0.746	160	0.1637
bOccupancySeason[2]	-0.111	-0.776	0.594	0.328	620	0.6947
sOccupancySite	2.173	1.430	3.252	0.483	42	0.0010
sOccupancyYear	1.139	0.627	1.925	0.353	57	0.0010

Convergence	Iterations
1.02	10000

Occupancy - Burbot

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bOccupancy	-2.181	-3.185	-1.216	0.496	45	0.0010
bOccupancyRegime[2]	0.674	-0.904	2.416	0.806	250	0.3913
bOccupancySeason[2]	-0.601	-1.249	0.050	0.334	110	0.0719
sOccupancySite	0.987	0.598	1.607	0.263	51	0.0010
sOccupancyYear	1.232	0.671	2.310	0.401	67	0.0010

Convergence	Iterations
1.03	10000

Occupancy - Lake Whitefish

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bOccupancy	-1.2720	-2.156	-0.3870	0.4410	70	0.0100
bOccupancyRegime[2]	0.2570	-1.535	1.8170	0.8250	650	0.7166
bOccupancySeason[2]	-3.9130	-5.879	-2.5030	0.8250	43	0.0010
sOccupancySite	0.5257	0.213	0.9202	0.1854	67	0.0010
sOccupancyYear	1.2540	0.722	2.1070	0.3490	55	0.0010

Convergence	Iterations
1.04	10000

Occupancy - Northern Pikeminnow

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bOccupancy	-2.282	-3.587	-0.976	0.637	57	0.0010

bOccupancyRegime[2]	0.335	-1.286	2.171	0.883	520	0.6927
bOccupancySeason[2]	-2.028	-3.074	-1.070	0.509	49	0.0010
sOccupancySite	1.641	0.976	2.741	0.448	54	0.0010
sOccupancyYear	1.237	0.630	2.327	0.451	69	0.0010

Convergence	Iterations
1.01	10000

Occupancy - Redside Shiner

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bOccupancy	-2.314	-3.875	-0.427	0.859	75	0.0240
bOccupancyRegime[2]	-0.056	-2.231	2.077	1.091	3900	0.9641
bOccupancySeason[2]	-0.756	-1.524	0.014	0.394	100	0.0559
sOccupancySite	2.276	1.375	3.794	0.606	53	0.0010
sOccupancyYear	1.719	0.937	2.903	0.534	57	0.0010

Convergence	Iterations
1.03	10000

Occupancy - Sculpins

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bOccupancy	-0.326	-1.850	1.063	0.723	450	0.6547
bOccupancyRegime[2]	1.509	-0.525	3.793	1.085	140	0.1637
bOccupancySeason[2]	-0.379	-1.020	0.251	0.321	170	0.2496
sOccupancySite	1.412	0.914	2.168	0.327	44	0.0010
sOccupancyYear	2.018	1.258	3.248	0.532	49	0.0010

Convergence	Iterations
1.02	10000

Count - Rainbow Trout

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bDensity	-1.6990	-2.6990	-0.7400	0.4960	58	0.0010
bDensityRegime[2]	0.8900	-0.3570	2.1380	0.6550	140	0.1682
bDensitySeason[2]	-0.0603	-0.4302	0.3274	0.1982	630	0.7556
bDistribution	-0.5130	-0.7795	-0.2516	0.1360	51	0.0010
bDistributionRegime[2]	0.2334	0.0079	0.4421	0.1106	93	0.0484
bDistributionSeason[2]	0.0176	-0.0871	0.1291	0.0567	610	0.7827
sDensitySite	1.2410	0.7710	2.0910	0.3230	53	0.0010
sDensitySiteYear	0.5237	0.3410	0.7221	0.0951	36	0.0010
sDensityYear	0.9490	0.4910	1.6010	0.2930	59	0.0010
sDispersion	0.8411	0.7329	0.9597	0.0597	13	0.0010
sDistributionYear	0.1349	0.0349	0.2778	0.0601	90	0.0010
tAbundance	0.8900	-0.3570	2.1380	0.6550	140	0.1682
tDistribution	0.2334	0.0079	0.4421	0.1106	93	0.0484

Convergence	Iterations

1.07	20000

Count - Burbot

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bDensity	-2.1160	-3.1210	-1.1920	0.4930	46	0.0010
bDensityRegime[2]	0.5580	-0.7300	2.0660	0.7230	250	0.4310
bDensitySeason[2]	-0.8420	-1.4070	-0.2600	0.2910	68	0.0058
bDistribution	-0.0930	-0.3294	0.1296	0.1217	250	0.4232
bDistributionRegime[2]	0.0741	-0.1960	0.3532	0.1400	370	0.5798
bDistributionSeason[2]	0.0520	-0.1489	0.2890	0.1112	420	0.6648
sDensitySite	0.8547	0.4812	1.4167	0.2371	55	0.0010
sDensitySiteYear	0.4091	0.0735	0.7864	0.1881	87	0.0010
sDensityYear	1.1740	0.6670	1.8430	0.3090	50	0.0010
sDispersion	1.2123	0.9288	1.4938	0.1413	23	0.0010
sDistributionYear	0.1545	0.0042	0.4699	0.1095	150	0.0010
tAbundance	0.5580	-0.7300	2.0660	0.7230	250	0.4310
tDistribution	0.0741	-0.1960	0.3532	0.1400	370	0.5798

Convergence	Iterations
1.08	20000

Count - Northern Pikeminnow

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bDensity	-2.5760	-3.6690	-1.7400	0.4910	37	0.0010
bDensityRegime[2]	0.0570	-1.5000	1.8730	0.8390	3000	0.9961
bDensitySeason[2]	-2.3860	-4.2830	-0.8380	0.8670	72	0.0020
bDistribution	-0.5311	-0.8974	-0.2505	0.1698	61	0.0010
bDistributionRegime[2]	0.0109	-0.3993	0.5896	0.2367	4500	0.9082
bDistributionSeason[2]	0.0306	-0.4633	0.4880	0.2428	1600	0.8663
sDensitySite	0.4197	0.0441	0.9846	0.2494	110	0.0010
sDensitySiteYear	0.6942	0.2967	1.1578	0.2223	62	0.0010
sDensityYear	1.1830	0.5540	1.9070	0.3630	57	0.0010
sDispersion	1.3930	1.1430	1.6588	0.1357	19	0.0010
sDistributionYear	0.2710	0.0341	0.6450	0.1535	110	0.0010
tAbundance	0.0570	-1.5000	1.8730	0.8390	3000	0.9961
tDistribution	0.0109	-0.3993	0.5896	0.2367	4500	0.9082

Convergence	Iterations
1.04	10000

Count - Suckers

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bDensity	1.9919	1.6230	2.3801	0.1878	19	0.0010
bDensityRegime[2]	0.8786	0.4453	1.3550	0.2333	52	0.0010
bDensitySeason[2]	-0.5730	-0.8155	-0.3187	0.1254	43	0.0010

bDistribution	-0.1463	-0.2546	-0.0399	0.0572	73	0.0132
bDistributionRegime[2]	0.0984	-0.0166	0.2240	0.0592	120	0.0829
bDistributionSeason[2]	-0.1547	-0.2366	-0.0748	0.0406	52	0.0010
sDensitySite	0.4630	0.2749	0.7650	0.1270	53	0.0010
sDensitySiteYear	0.4721	0.3624	0.5916	0.0594	24	0.0010
sDensityYear	0.3102	0.1454	0.5536	0.1073	66	0.0010
sDispersion	0.7922	0.7398	0.8459	0.0262	7	0.0010
sDistributionYear	0.0572	0.0046	0.1325	0.0361	110	0.0010
tAbundance	0.8786	0.4453	1.3550	0.2333	52	0.0010
tDistribution	0.0984	-0.0166	0.2240	0.0592	120	0.0829

Convergence	Iterations
1.1	80000

Movement - Bull Trout

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bLength	0.00455	0.00141	0.00782	0.00163	70	0.0040
bLengthSeason[2]	0.00155	-0.00872	0.01440	0.00576	740	0.7965
bMoved	-1.81500	-3.29300	-0.41300	0.71800	79	0.0140
bMovedSeason[2]	0.24000	-5.23000	4.96000	2.54000	2100	0.8563

Convergence	Iterations
1.01	10000

Movement - Mountain Whitefish

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bLength	-0.00006	-0.00642	0.00599	0.00317	11000	0.9961
bLengthSeason[2]	-0.02774	-0.04229	-0.01615	0.00667	47	0.0010
bMoved	-0.10900	-1.69000	1.50000	0.81700	1500	0.9022
bMovedSeason[2]	5.83000	2.94400	9.37000	1.59800	55	0.0010

Convergence	Iterations
1.07	10000

Movement - Rainbow Trout

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bLength	0.0076	-0.00618	0.02122	0.00697	180	0.2695
bLengthSeason[2]	0.2315	0.05600	0.50860	0.11170	98	0.0020
bMoved	-2.6020	-6.23100	0.63800	1.75200	130	0.1258
bMovedSeason[2]	-70.7000	-153.90000	-17.20000	33.70000	97	0.0020

Convergence	Iterations
1.05	10000

Movement - Largescale Sucker

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bLength	-0.0127	-0.02673	-0.00042	0.00677	100	0.0406
bLengthSeason[2]	-0.1508	-0.34480	-0.01020	0.08690	110	0.0136

bMoved	5.4100	-0.06000	11.58000	3.00000	110	0.0580
bMovedSeason[2]	65.2000	3.70000	149.00000	37.90000	110	0.0213

Convergence	Iterations
1.03	20000

Observer Length Correction - Bull Trout

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bLength[1]	1.00000	1.00000	1.00000	0.00000	0	0.001
bLength[2]	0.78680	0.72240	0.85420	0.03430	8	0.001
bLength[3]	0.90578	0.89742	0.93318	0.00738	2	0.001
sLength[1]	1.00000	1.00000	1.00000	0.00000	0	0.001
sLength[2]	4.51600	1.37100	9.65400	2.21800	92	0.001
sLength[3]	1.11810	1.00300	1.43850	0.14270	19	0.001

Convergence	Iterations
1.09	20000

Observer Length Correction - Mountain Whitefish

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bLength[1]	1.00000	1.00000	1.00000	0.00000	0	0.001
bLength[2]	0.66805	0.65234	0.68480	0.00810	2	0.001
bLength[3]	0.96368	0.94432	0.98423	0.01034	2	0.001
sLength[1]	1.00000	1.00000	1.00000	0.00000	0	0.001
sLength[2]	3.93900	3.38600	4.53600	0.29700	15	0.001
sLength[3]	4.60500	3.96700	5.34900	0.35000	15	0.001

Convergence	Iterations
1.01	10000

Observer Length Correction - Suckers

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bLength[1]	1.00000	1.00000	1.00000	0.00000	0	0.001
bLength[2]	0.70585	0.69649	0.71564	0.00492	1	0.001
bLength[3]	0.90656	0.88490	0.92860	0.01133	2	0.001
sLength[1]	1.00000	1.00000	1.00000	0.00000	0	0.001
sLength[2]	2.47600	1.84200	3.29000	0.35700	29	0.001
sLength[3]	6.57400	5.28100	8.11200	0.75600	22	0.001

Convergence	Iterations
1	10000

Abundance - Bull Trout - Adult

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bDensity	4.2687	3.90600	4.62950	0.18250	8	0.0010
bDensityRegime[2]	-0.1643	-0.52200	0.20230	0.18260	220	0.3274
bDensitySeason[2]	-0.2960	-0.88400	0.31100	0.30500	200	0.3274
bDistribution	0.0441	-0.05310	0.13620	0.04770	210	0.3354

bDistributionRegime[2]	0.0179	-0.07110	0.10990	0.04610	510	0.6747
bDistributionSeason[2]	0.1611	0.09460	0.23410	0.03640	43	0.0010
bEfficiency	-3.4853	-3.69240	-3.26470	0.10920	6	0.0010
bEfficiencySeason[2]	0.0170	-0.59500	0.60400	0.30100	3500	0.9422
bType[1]	1.0000	1.00000	1.00000	0.00000	0	0.0010
bType[2]	2.1460	1.09400	3.79900	0.71700	63	0.0010
sDensitySite	0.4391	0.26470	0.71190	0.11480	51	0.0010
sDensitySiteYear	0.4457	0.35560	0.54100	0.04850	21	0.0010
sDensityYear	0.1700	0.01310	0.38750	0.10130	110	0.0010
sDispersion	0.4171	0.33830	0.49460	0.03980	19	0.0010
sDistributionYear	0.0333	0.00119	0.08638	0.02348	130	0.0010
sEfficiencySessionSeasonYear	0.2488	0.15630	0.34780	0.04730	39	0.0010
tAbundance	-0.1643	-0.52200	0.20230	0.18260	220	0.3274
tDistribution	0.0179	-0.07110	0.10990	0.04610	510	0.6747

Convergence	Iterations
1.02	1e+05

Abundance - Bull Trout - Juvenile

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bDensity	2.6560	1.9860	3.2710	0.3380	24	0.0010
bDensityRegime[2]	0.4230	-0.4520	1.4470	0.4780	220	0.3134
bDensitySeason[2]	0.4260	-0.1780	1.0940	0.3250	150	0.1797
bDistribution	-0.0214	-0.1586	0.1235	0.0723	660	0.7346
bDistributionRegime[2]	-0.0014	-0.1376	0.1372	0.0645	9800	0.9881
bDistributionSeason[2]	0.0110	-0.0623	0.0925	0.0380	700	0.7825
bEfficiency	-3.0141	-3.2602	-2.7443	0.1338	9	0.0010
bEfficiencySeason[2]	-0.3880	-1.0420	0.2340	0.3230	160	0.2216
bType[1]	1.0000	1.0000	1.0000	0.0000	0	0.0010
bType[2]	0.6140	0.1960	1.3680	0.3170	95	0.0010
sDensitySite	0.6765	0.4235	1.0614	0.1704	47	0.0010
sDensitySiteYear	0.1613	0.0195	0.3048	0.0770	88	0.0010
sDensityYear	0.7138	0.4196	1.2311	0.2127	57	0.0010
sDispersion	0.3809	0.2562	0.4934	0.0608	31	0.0010
sDistributionYear	0.0695	0.0041	0.1929	0.0496	140	0.0010
sEfficiencySessionSeasonYear	0.2636	0.1574	0.3864	0.0577	43	0.0010
tAbundance	0.4230	-0.4520	1.4470	0.4780	220	0.3134
tDistribution	-0.0014	-0.1376	0.1372	0.0645	9800	0.9881

Convergence	Iterations
1.07	1e+05

Abundance - Mountain Whitefish - Adult

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bDensity	6.65010	6.33150	6.92360	0.15360	4	0.0010

bDensityRegime[2]	-0.08270	-0.32640	0.18070	0.12740	310	0.4931
bDensitySeason[2]	-0.53220	-0.76530	-0.29620	0.12010	44	0.0010
bDistribution	0.09300	-0.00700	0.19240	0.05180	110	0.0819
bDistributionRegime[2]	0.01580	-0.08280	0.12640	0.05280	660	0.7705
bDistributionSeason[2]	-0.05378	-0.09752	-0.00928	0.02314	82	0.0220
bEfficiency	-3.91190	-4.02290	-3.79080	0.06040	3	0.0010
bEfficiencySeason[2]	0.89140	0.67840	1.11290	0.10920	24	0.0010
bType[1]	1.00000	1.00000	1.00000	0.00000	0	0.0010
bType[2]	2.82900	1.61000	4.75600	0.81000	56	0.0010
sDensitySite	0.51760	0.33120	0.77480	0.11800	43	0.0010
sDensitySiteYear	0.35290	0.29030	0.41610	0.03260	18	0.0010
sDensityYear	0.10200	0.00420	0.24690	0.06590	120	0.0010
sDispersion	0.45295	0.41916	0.48820	0.01764	8	0.0010
sDistributionYear	0.06320	0.01800	0.12400	0.02690	84	0.0010
sEfficiencySessionSeasonYear	0.21520	0.15660	0.28380	0.03250	30	0.0010
tAbundance	-0.08270	-0.32640	0.18070	0.12740	310	0.4931
tDistribution	0.01580	-0.08280	0.12640	0.05280	660	0.7705

Convergence	Iterations
1.05	1e+05

Abundance - Mountain Whitefish - Juvenile

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bDensity	5.9020	4.6740	7.2190	0.6500	22	0.0010
bDensityRegime[2]	-0.3590	-1.5100	0.9210	0.5970	340	0.4192
bDensitySeason[2]	0.3830	-0.9140	1.6290	0.6280	330	0.5110
bDistribution	0.0952	-0.0975	0.3167	0.1048	220	0.3474
bDistributionRegime[2]	0.0302	-0.1417	0.2128	0.0863	590	0.6967
bDistributionSeason[2]	-0.0984	-0.1725	-0.0254	0.0386	75	0.0100
bEfficiency	-5.7830	-6.8390	-5.0540	0.4520	15	0.0010
bEfficiencySeason[2]	0.5540	-0.6780	1.8200	0.6240	220	0.3693
bType[1]	1.0000	1.0000	1.0000	0.0000	0	0.0010
bType[2]	1.4990	0.6660	3.2350	0.6760	86	0.0010
sDensitySite	0.9191	0.5861	1.4381	0.2158	46	0.0010
sDensitySiteYear	0.4743	0.3299	0.6275	0.0766	31	0.0010
sDensityYear	0.7310	0.3500	1.4820	0.2840	77	0.0010
sDispersion	0.5012	0.3968	0.5977	0.0516	20	0.0010
sDistributionYear	0.0844	0.0076	0.2214	0.0537	130	0.0010
sEfficiencySessionSeasonYear	0.2400	0.1041	0.3780	0.0695	57	0.0010
tAbundance	-0.3590	-1.5100	0.9210	0.5970	340	0.4192
tDistribution	0.0302	-0.1417	0.2128	0.0863	590	0.6967

Convergence	Iterations
1.06	1e+05

Abundance - Rainbow Trout - Adult

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bDensity	0.4830	-0.5060	1.5060	0.5160	210	0.3453
bDensityRegime[2]	0.5840	-0.1510	1.3070	0.3820	120	0.1211
bDensitySeason[2]	-0.1260	-1.4350	1.4070	0.7230	1100	0.8135
bDistribution	-0.3486	-0.6618	-0.0678	0.1513	85	0.0298
bDistributionRegime[2]	0.2662	-0.0281	0.5557	0.1488	110	0.0655
bDistributionSeason[2]	-0.0335	-0.2166	0.1640	0.0963	570	0.6945
bEfficiency	-2.8650	-3.5730	-2.2690	0.3390	23	0.0010
bEfficiencySeason[2]	-0.2650	-1.8020	1.0260	0.7290	530	0.7600
bType[1]	1.0000	1.0000	1.0000	0.0000	0	0.0010
bType[2]	4.9460	0.2050	9.6860	2.9040	96	0.0010
sDensitySite	1.0340	0.5780	1.8000	0.3170	59	0.0010
sDensitySiteYear	0.4359	0.0552	0.8008	0.1900	86	0.0010
sDensityYear	0.2910	0.0140	0.8750	0.2352	150	0.0010
sDispersion	0.5192	0.0502	0.9077	0.2156	83	0.0010
sDistributionYear	0.1242	0.0053	0.3510	0.0973	140	0.0010
sEfficiencySessionSeasonYear	0.2475	0.0126	0.5690	0.1500	110	0.0010
tAbundance	0.5840	-0.1510	1.3070	0.3820	120	0.1211
tDistribution	0.2662	-0.0281	0.5557	0.1488	110	0.0655

Convergence	Iterations
1.05	4e+05

Abundance - Largescale Sucker - Adult

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bDensity	4.7830	3.6150	5.7510	0.5450	22	0.0010
bDensityRegime[2]	0.9140	-0.2680	2.4900	0.6560	150	0.1175
bDensitySeason[2]	-0.9230	-1.8540	0.1420	0.5100	110	0.0956
bDistribution	-0.1175	-0.3519	0.0884	0.1071	190	0.2209
bDistributionRegime[2]	0.0871	-0.1656	0.3376	0.1205	290	0.4180
bDistributionSeason[2]	-0.1860	-0.2736	-0.1036	0.0429	46	0.0010
bEfficiency	-3.7569	-4.0609	-3.4712	0.1500	8	0.0010
bEfficiencySeason[2]	-0.9210	-1.9540	-0.0460	0.5010	100	0.0379
bType[1]	1.0000	1.0000	1.0000	0.0000	0	0.0010
bType[2]	2.4430	1.1000	4.9160	1.0690	78	0.0010
sDensitySite	0.4052	0.2018	0.7014	0.1272	62	0.0010
sDensitySiteYear	0.4326	0.2913	0.6044	0.0776	36	0.0010
sDensityYear	0.6470	0.1950	1.5500	0.3460	100	0.0010
sDispersion	0.5141	0.4324	0.6038	0.0426	17	0.0010
sDistributionYear	0.1076	0.0086	0.3355	0.0818	150	0.0010
sEfficiencySessionSeasonYear	0.3206	0.1967	0.4790	0.0714	44	0.0010
tAbundance	0.9140	-0.2680	2.4900	0.6560	150	0.1175
tDistribution	0.0871	-0.1656	0.3376	0.1205	290	0.4180

	Convergence	Iterations
	1.03	2e+05

Long-Term Trends

Parameter	Estimate	Lower	Upper	SD	Error	Significance
sTrend	0.4722	0.3318	0.6403	0.0787	33	0.001
sValue	0.7557	0.7026	0.8112	0.0277	7	0.001

Convergence	Iterations
1.06	1e+05

Appendix H – Additional Results

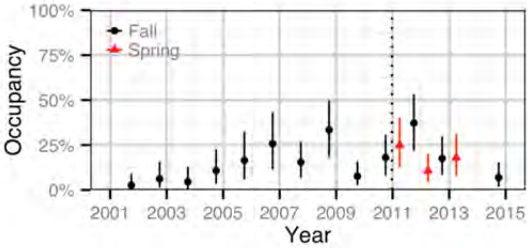


Figure H1. Occupancy estimates (with 95% credible intervals) by year and season for Burbot in the Middle Columbia River study area, 2001 to 2014. The dotted line represents the implementation of the minimum flow release and REV5 operations.

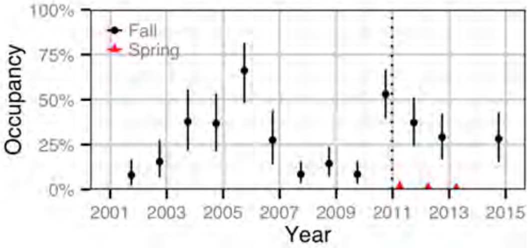


Figure H2. Occupancy estimates (with 95% credible intervals) by year and season for Lake Whitefish in the Middle Columbia River study area, 2001 to 2014. The dotted line represents the implementation of the minimum flow release and REV5 operations.

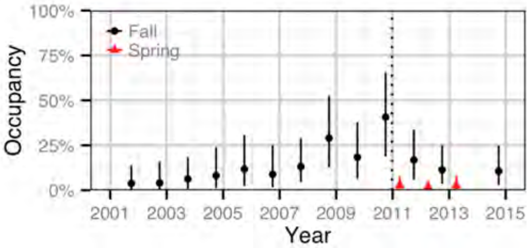


Figure H3. Occupancy estimates (with 95% credible intervals) by year and season for Northern Pikeminnow in the Middle Columbia River study area, 2001 to 2014. The dotted line represents the implementation of the minimum flow release and REV5 operations.

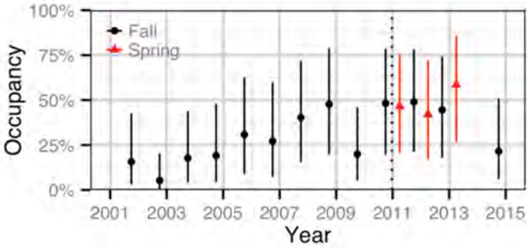


Figure H4. Occupancy estimates (with 95% credible intervals) by year and season for Rainbow Trout in the Middle Columbia River study area, 2001 to 2014. The dotted line represents the implementation of the minimum flow release and REV5 operations.

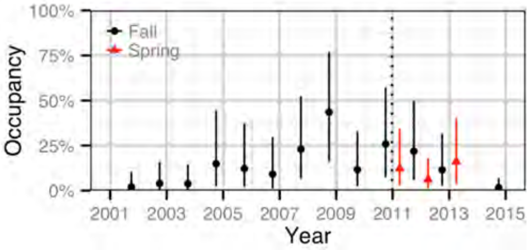


Figure H5. Occupancy estimates (with 95% credible intervals) by year and season for Redside Shiner in the Middle Columbia River study area, 2001 to 2014. The dotted line represents the implementation of the minimum flow release and REV5 operations.

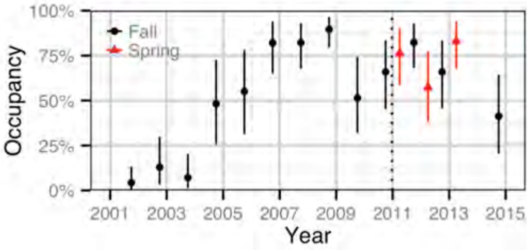


Figure H6. Occupancy estimates (with 95% credible intervals) by year and season for Sculpin species in the Middle Columbia River study area, 2001 to 2014. The dotted line represents the implementation of the minimum flow release and REV5 operations.

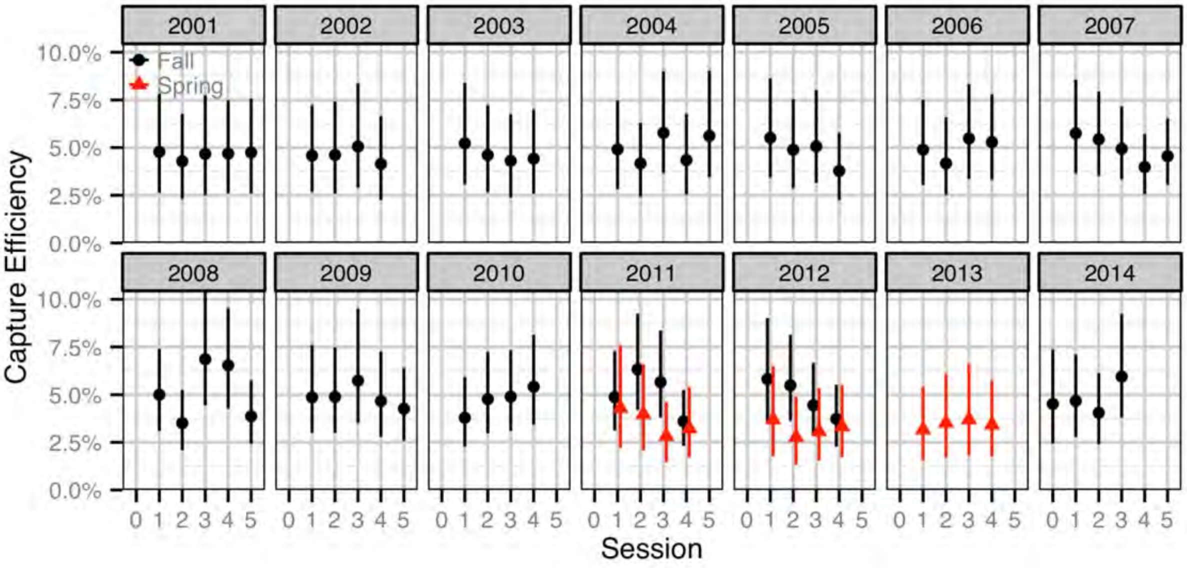


Figure H7. Capture efficiency estimates (with 95% credible intervals) by year, season, and session for juvenile Bull Trout in the Middle Columbia River study area, 2001 to 2014. Efficiency was calculated in the hierarchical Bayesian model estimating absolute abundance using mark-recapture data.

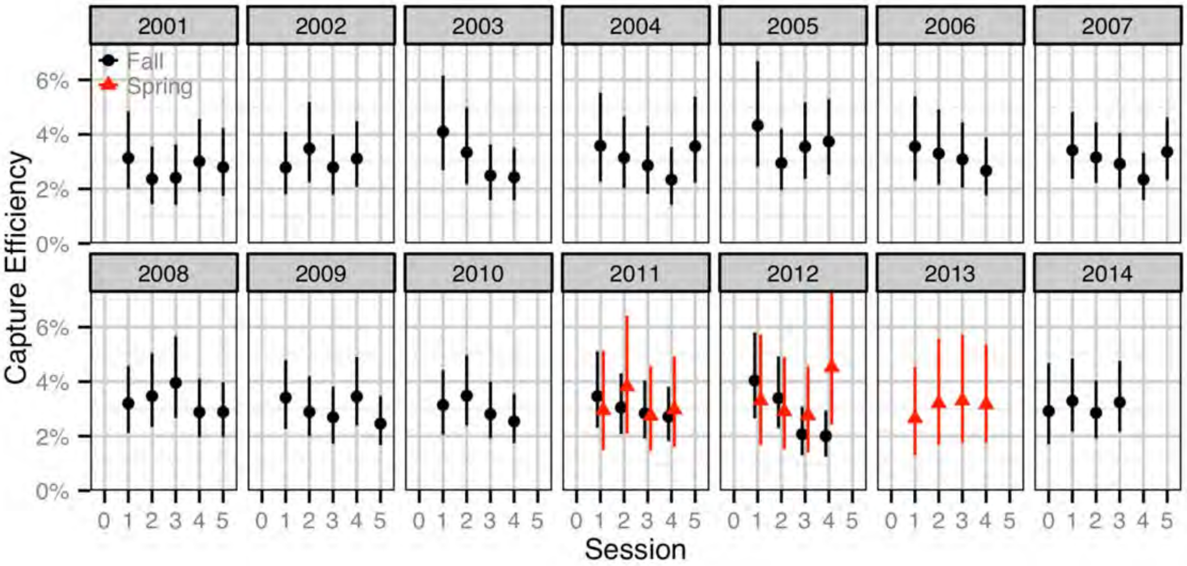


Figure H8. Capture efficiency estimates (with 95% credible intervals) by year, season, and session for adult Bull Trout in the Middle Columbia River study area, 2001 to 2014. Efficiency was calculated in the hierarchical Bayesian model estimating absolute abundance using mark-recapture data.

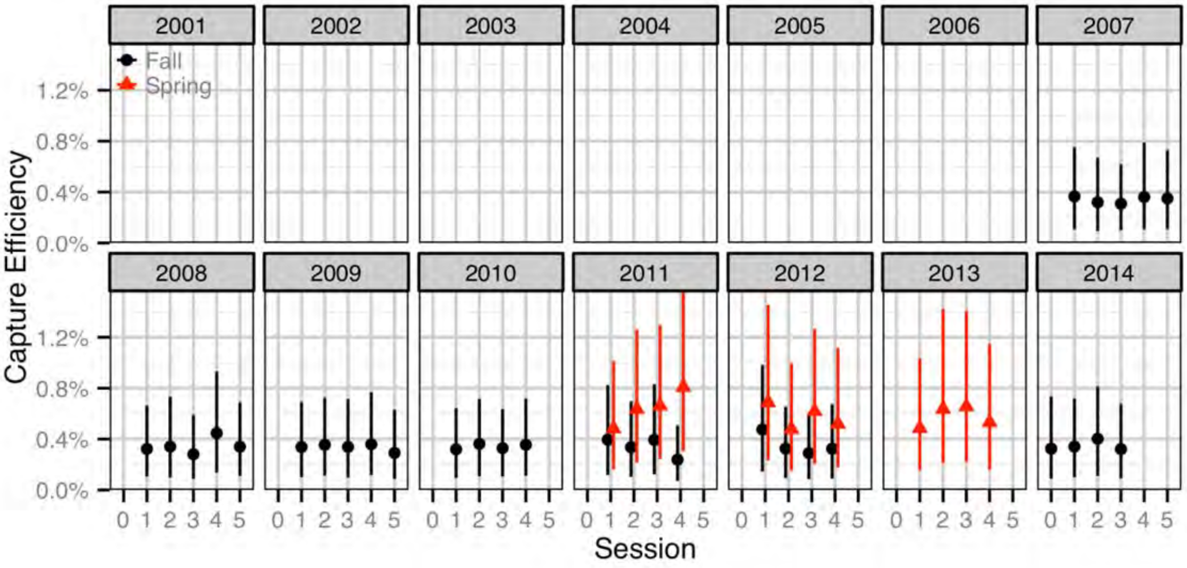


Figure H9. Capture efficiency estimates (with 95% credible intervals) by year, season, and session for juvenile Mountain Whitefish in the Middle Columbia River study area, 2001 to 2014. Efficiency was calculated in the hierarchical Bayesian model estimating absolute abundance using mark-recapture data.

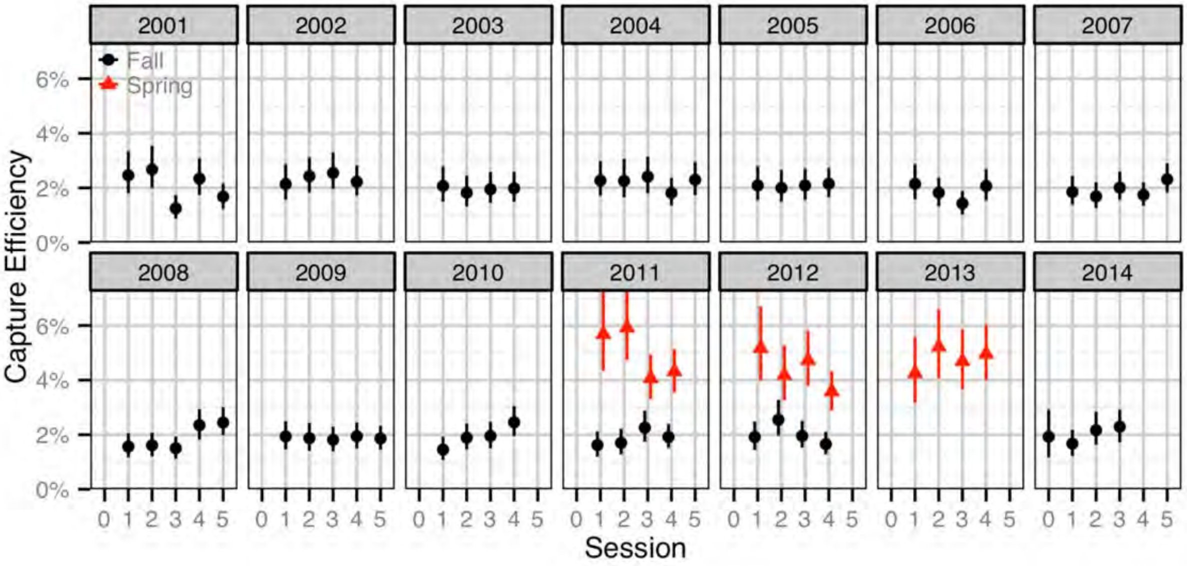


Figure H10. Capture efficiency estimates (with 95% credible intervals) by year, season, and session for adult Mountain Whitefish in the Middle Columbia River study area, 2001 to 2014. Efficiency was calculated in the hierarchical Bayesian model estimating absolute abundance using mark-recapture data.

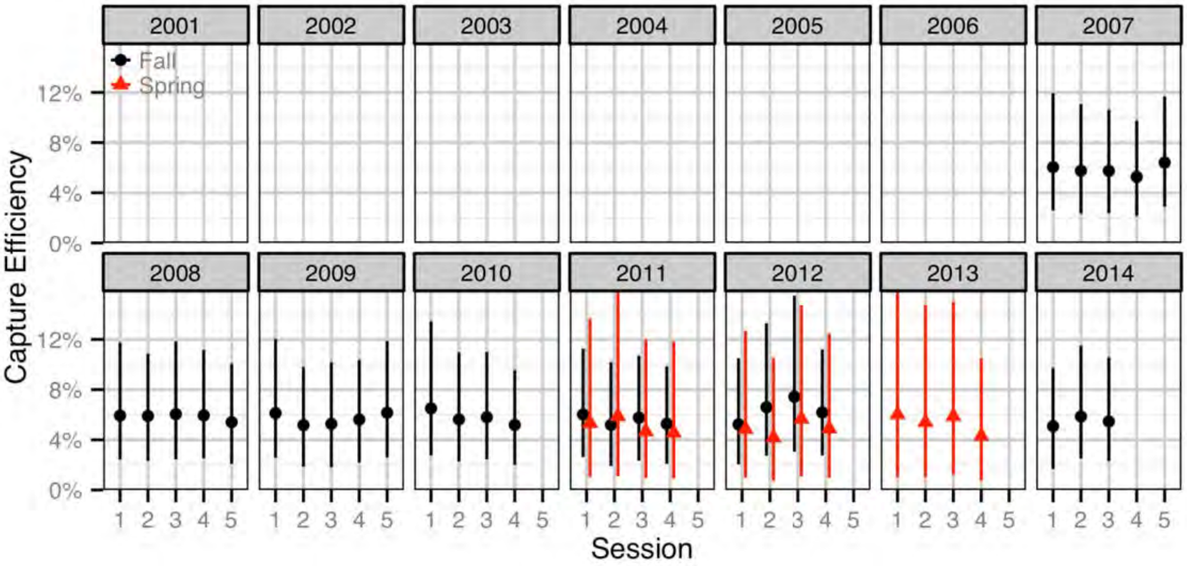


Figure H11. Capture efficiency estimates (with 95% credible intervals) by year, season, and session for adult Rainbow Trout in the Middle Columbia River study area, 2007 to 2014. Efficiency was calculated in the hierarchical Bayesian model estimating absolute abundance using mark-recapture data.

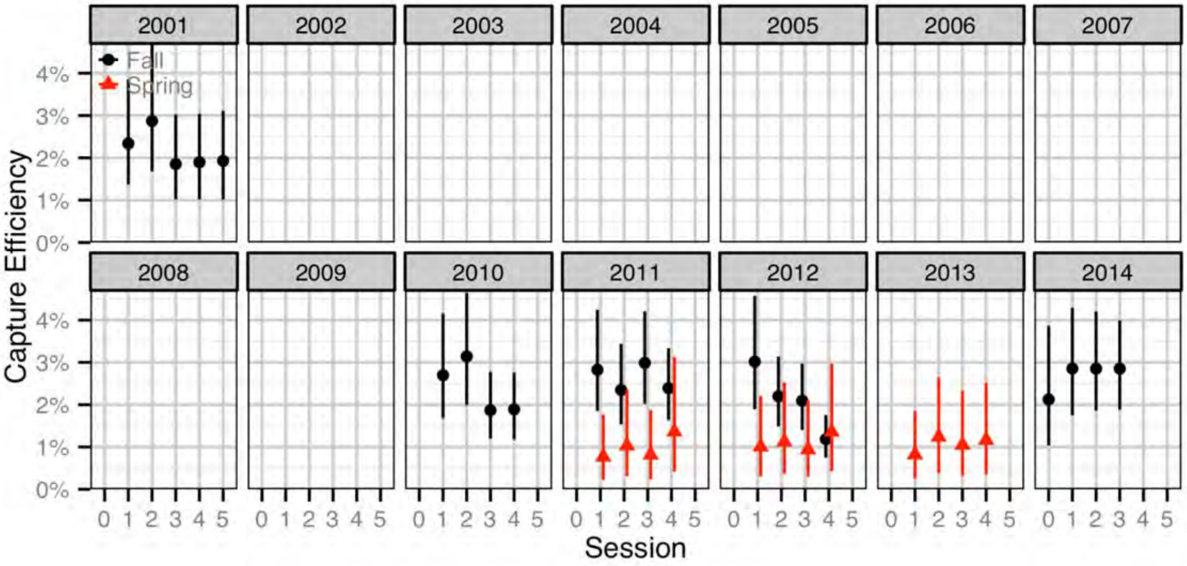


Figure H12. Capture efficiency estimates (with 95% credible intervals) by year, season, and session for Largescale Sucker in the Middle Columbia River study area, 2007 to 2014. Efficiency was calculated in the hierarchical Bayesian model estimating absolute abundance using mark-recapture data.

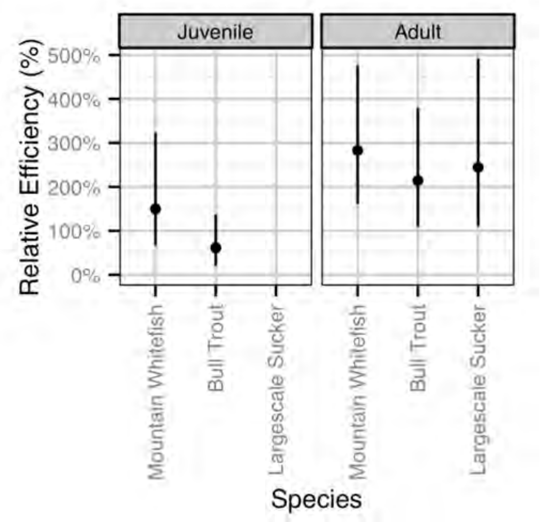


Figure H13. Relative efficiency estimates (with 95% credible intervals) for Mountain Whitefish, Bull Trout and Largescale Sucker based on life stage.

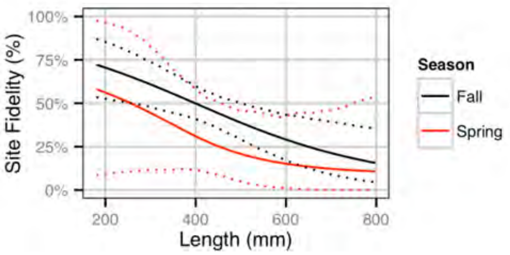


Figure H24. Site fidelity estimates (with 95% credible intervals) by season and fish length for intra-year recaptured Bull Trout in the Middle Columbia River study area, 2001-2014.

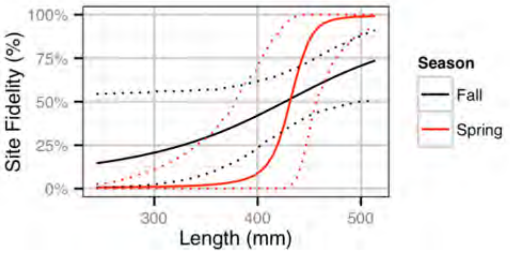


Figure H35. Site fidelity estimates (with 95% credible intervals) by season and fish length for intra-year recaptured Largescale Sucker in the Middle Columbia River study area, 2001-2014.

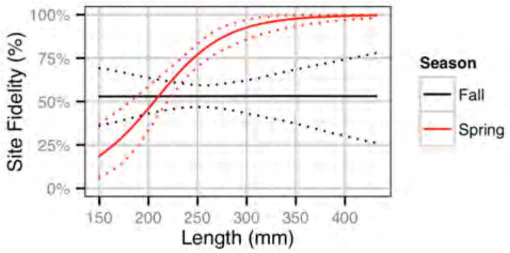


Figure H46. Site fidelity estimates (with 95% credible intervals) by season and fish length for intra-year recaptured Mountain Whitefish in the Middle Columbia River study area, 2001-2014.

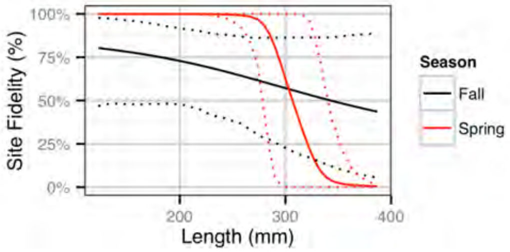
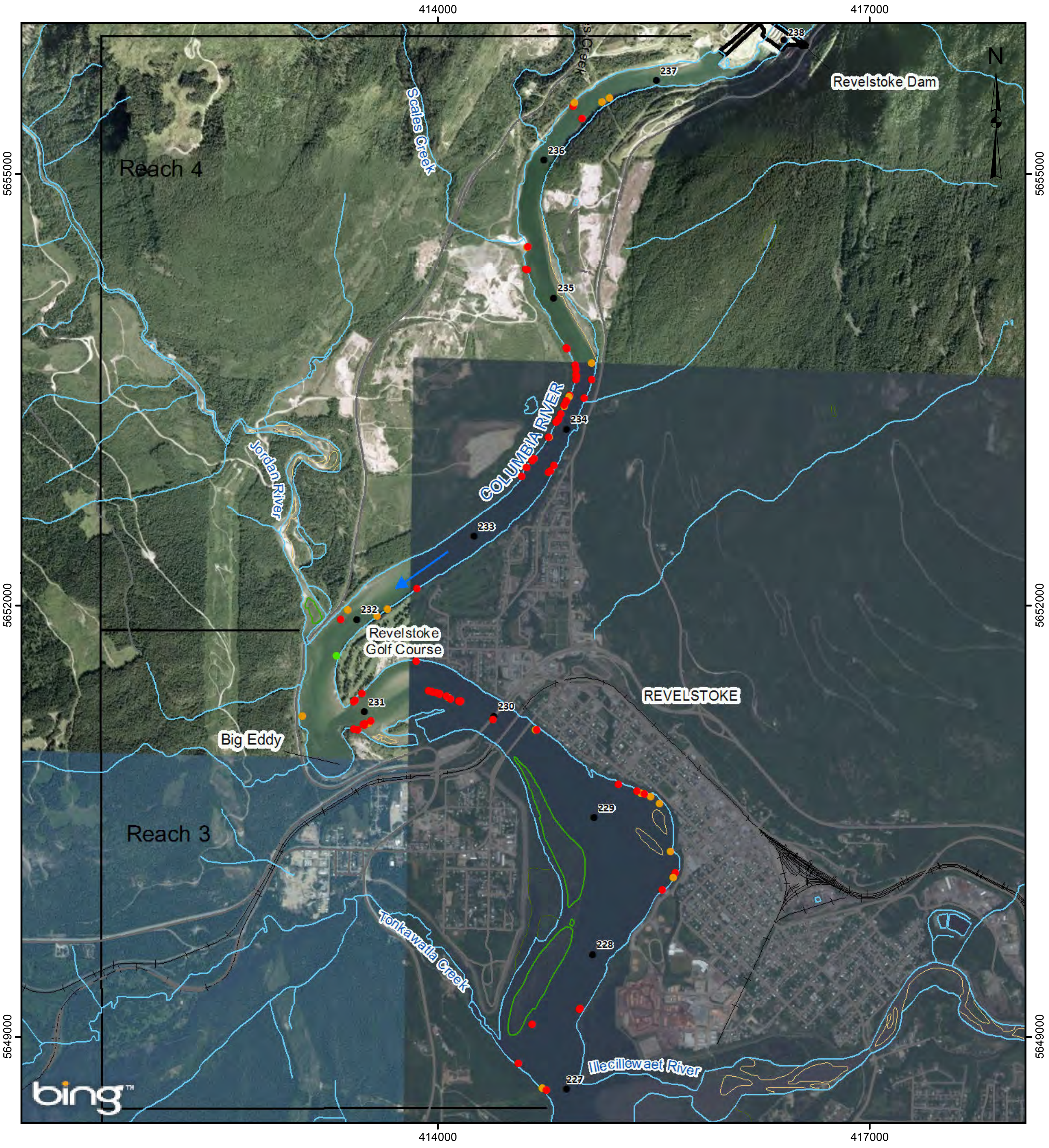


Figure H57. Site fidelity estimates (with 95% credible intervals) by season and fish length for intra-year recaptured Rainbow Trout in the Middle Columbia River study area, 2001-2014.

Appendix I – Spatial Distribution Maps



LEGEND

BULL TROUT

- ● FRY
- ● JUVENILE
- ● ADULT

- ● RIVER KILOMETRES FROM U.S. BORDER
- ━ DAM BASE
- ─ ISLAND
- – – WETLAND
- ─ SAND OR GRAVEL BAR
- ─ WATERCOURSE
- ─ ROAD
- ← DIRECTION OF FLOW

1,000 500 0 1,000

SCALE 1:37,500 METRES

REFERENCE

1. TRIM MAPS PROVIDED BY BC HYDRO
2. BASE IMAGERY OBTAINED FROM © HARRIS CORP, EARTHSTAR GEOGRAPHICS LLC EARTHSTAR GEOGRAPHICS SIO © 2015 MICROSOFT CORPORATION

PROJECTION: UTM ZONE 11N DATUM: NAD83

PROJECT

MIDDLE COLUMBIA RIVER FISH POPULATION INDEXING SURVEY

TITLE

BULL TROUT

Golder Associates

PROJECT No. 13-1492-0004			SCALE AS SHOWN	REV. 0
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GIS	CD	24 Mar. 2015		
CHECK	DR	24 Mar. 2015		
REVIEW	DS	24 Mar. 2015		

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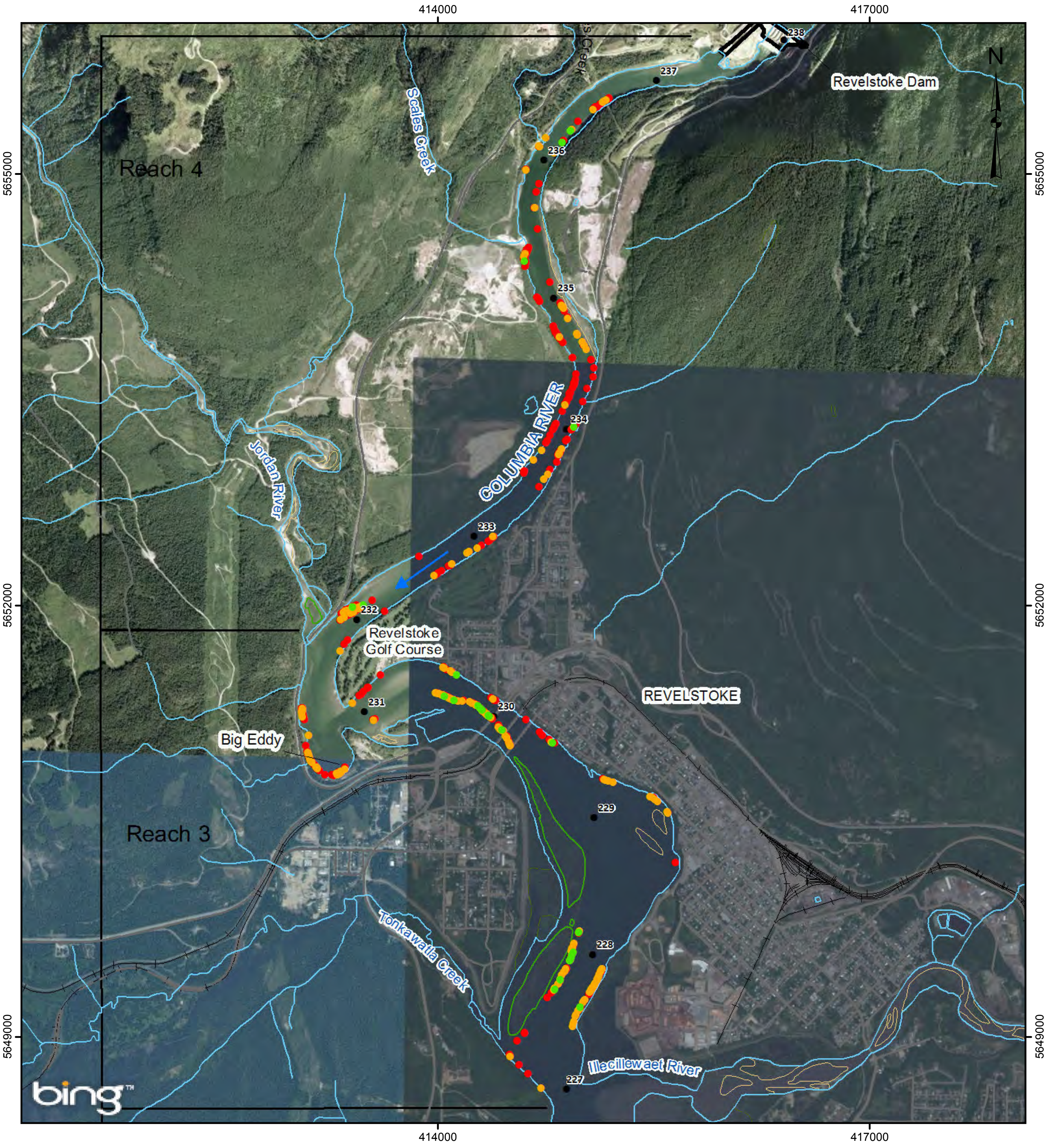

LEGEND

MOUNTAIN WHITEFISH

● FRY
● JUVENILE
● ADULT

● RIVER KILOMETRES FROM U.S. BORDER
— DAM BASE
— ISLAND
--- WETLAND
— SAND OR GRAVEL BAR
— WATERCOURSE
— ROAD
← DIRECTION OF FLOW

1,000 500 0 1,000

SCALE 1:37,500 METRES

REFERENCE

1. TRIM MAPS PROVIDED BY BC HYDRO
2. BASE IMAGERY OBTAINED FROM © HARRIS CORP, EARTHSTAR GEOGRAPHICS LLC EARTHSTAR GEOGRAPHICS SIO © 2015 MICROSOFT CORPORATION
PROJECTION: UTM ZONE 11N DATUM: NAD83

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PROJECT

MIDDLE COLUMBIA RIVER FISH POPULATION INDEXING SURVEY

TITLE

MOUNTAIN WHITEFISH

Golder Associates

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GIS	CD	24 Mar. 2015		
CHECK	DR	24 Mar. 2015		
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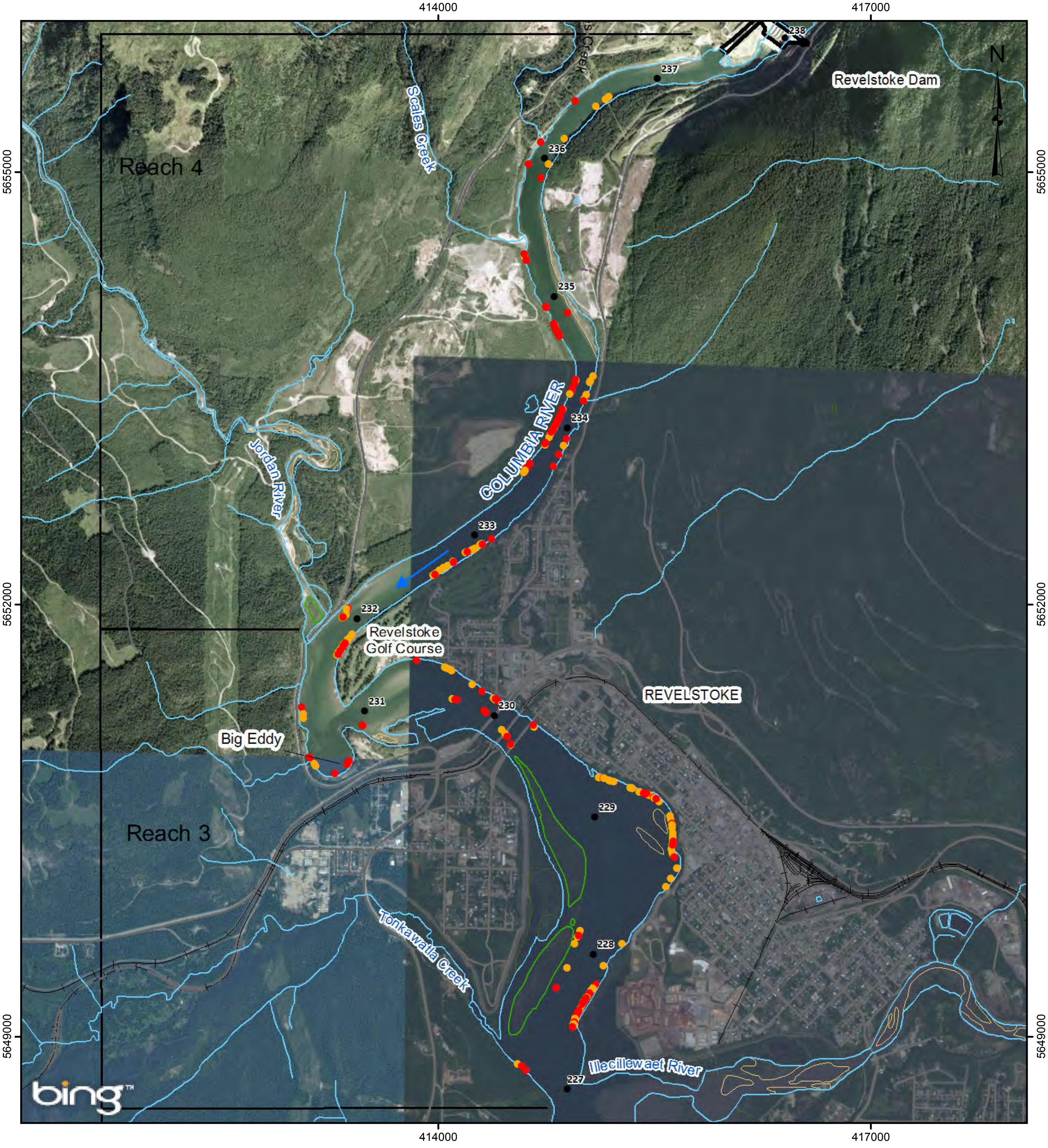

1,000 500 0 1,000

SCALE 1:37,500 METRES

LEGEND

SUCKER

● JUVENILE

● ADULT

● RIVER KILOMETRES FROM U.S. BORDER

— DAM BASE

— ISLAND

– – WETLAND

— SAND OR GRAVEL BAR

— WATERCOURSE

— ROAD

← DIRECTION OF FLOW

REFERENCE

1. TRIM MAPS PROVIDED BY BC HYDRO
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PROJECTION: UTM ZONE 11N DATUM: NAD83

PROJECT

MIDDLE COLUMBIA RIVER FISH POPULATION INDEXING SURVEY

TITLE

SUCKER SPECIES

Golder Associates

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