Columbia River Project Water Use Plan

Revelstoke Flow Management Plan

Middle Columbia River Fish Population Indexing Surveys

Implementation Year 13

Reference: CLBMON-16

Technical Report

Study Period 2019

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CLBMON-16:
Middle Columbia River
Fish Population Indexing Surveys
2019 Technical Report

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July 2020

Executive Summary

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

1) Is there a change in abundance of adult fish using the MCR that corresponds with the implementation of a year-round minimum flow?
2) 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?
3) 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?
4) 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 prior to (2007 to 2010) and eight years after (2011 to 2019) the minimum flow release. In addition, data were collected from 2001 to 2006 as part of BC Hydro's Large River Fish Indexing Program, a similar program designed to monitor fish populations in the MCR.

The study area encompassed the 12 km portion of the Columbia River between Revelstoke Dam and the Illecillewaet River confluence. Fish were sampled by boat electroshocking at night within nearshore habitats. All captured fish were measured for length and weighed. Select species were implanted with a Passive Integrated Transponder (PIT) tag for individual identification. Between 2001 and 2019, each site was sampled three to five times per year in consecutive weeks as part of a mark-recapture study. Temporal and spatial variation in species richness, species evenness, abundance, spatial distribution, growth, and body condition were estimated using hierarchical Bayesian models (HBMs). Abundance was assessed using mark-recapture estimates of abundance for species with sufficient recapture data and using models of the total number caught and observed ('count density') for species with few recaptures.

There were increases in species richness and evenness between 2001 and 2008 that were attributed to increases in the abundance of several less common species. The density and/or probability of occupancy of Burbot (*Lota lota*), Lake Whitefish (*Coregonus clupeaformis*), Northern Pikeminnow (*Ptychocheilus oregonensis*), Rainbow Trout (*Oncorhynchus mykiss*), Redside Shiner (*Richardsonius balteatus*) and sculpin species (*Cottidae* spp.) all increased, while densities of more common species such as Bull Trout (*Salvelinus confluentus*) and Mountain Whitefish (*Prosopium williamsoni*) remained relatively stable during this time period. A second change in the fish community occurred beginning in 2012, with declining richness and occupancy of most less common species, including Burbot, Northern Pikeminnow, Rainbow Trout, and sculpin species. Species evenness was relatively constant in years following the flow regime change.

In count density models, there was a statistically significant negative effect of the flow regime on the rate of population growth for Burbot (-33%), Northern Pikeminnow (-46%), and Rainbow Trout (-29%). However, these species had large increases in density between 2001 and 2008 (i.e., before the flow regime change), which makes it difficult to relate changes to the flow regime. In contrast, densities of sucker species increased three-fold (from 14 to 42 fish/km) in the first five years after the flow regime change (2011 to 2015), but decreased in 2016 to 2019 (5–14 fish/km). Therefore, it is unclear whether the flow regime was a contributing factor to these changes.

The estimated abundances of Bull Trout and Mountain Whitefish suggested healthy populations in recent years, and no significant changes after the new flow regime. Adult Bull Trout abundance estimates were relatively stable in the first six years after the flow regime change (1,500–1,800 individuals in 2011 to 2016) and greater than average in 2017 to 2019 (1,900 to 2,400 individuals). Estimated abundance of adult Mountain Whitefish was greater in 2018 and 2019 (23,000 and 26,000 individuals) than all previous years (14,000–22,000 individuals).

Body condition estimates declined in consecutive years after the flow regime change for Bull Trout (~10%–15% decrease) and adult Largescale Sucker (*Catostomus macrocheilus*; 23% decrease). The low body condition of Bull Trout coincided with declines in the abundance of Kokanee (*Oncorhynchus nerka*), which are an important Bull Trout prey. The decline in adult Largescale Sucker body condition between 2010 and 2015 coincided with a large increase in density estimates of sucker species and abundance of Largescale Sucker, which suggests competition for resources and density-dependent growth. Similar declines in body condition of Bull Trout and Largescale Sucker, as well as a reduction in Kokanee abundance in Arrow Lakes Reservoir, suggest a broad-scale decline in growing conditions from 2010 to 2016. In recent years, body condition increased, including high body condition for Largescale Sucker in 2017 and 2018, and high body condition for Bull Trout in 2017 that was associated with high abundance of Kokanee.

There was an upstream shift in the distribution of some species in the years following the flow regime change. The difference was statistically significant for Rainbow Trout (5% effect size; credible interval [CRI] >0% to 11%) but not for Bull Trout (2%; CRI 0% to 5%) or sucker species (3%; CRI -2% to 7%). The minimum flow may result in habitat more suitable or attractive to some fish species in the upstream portion of the study area.

2019 was the final year of the monitoring program planned as part of BC Hydro's Water Use Plan. Data collected from 2001 to 2019 suggested some changes that coincided with the change in flow regime, including lower body condition of Bull Trout and suckers, increased abundance of suckers, and an upstream shift in the distribution of several species. However, the observational study design makes it difficult to conclude whether the flow regime was the cause of these changes, or merely happened at the same time. Regarding the effectiveness of the minimum flow in increasing the abundance and diversity of fishes in the MCR, there was no evidence of increased abundance of fishes in the MCR after the flow regime, with the exception of the increase in sucker density from 2011 to 2015. Estimates of species richness and evenness were either stable or decreased after the flow regime change, which does not suggest increased diversity of fish due to the new flow regime. The upstream shift in distribution in years after the flow regime may indicate increased abundance and diversity of fishes in the part of the MCR closest to Revelstoke Dam, but it remains uncertain if this change was caused by the change in flow regime or other factors. This uncertainty could be reduced by a eliminating the minimum flow in random years.

Keywords: Columbia River, Revelstoke Dam, Abundance Estimation, Hierarchical Bayesian Analysis, flow regime change, species diversity, fish condition, spatial distribution

Table E1: Status of management questions and hypotheses after Year 13 of the Middle Columbia River Fish Population Indexing Survey (CLBMON-16).

Management Questions	Management Hypotheses	Year 13 (2019) Status
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.	Bull Trout and Mountain Whitefish abundance estimates did not change significantly after the flow regime change. Density (abundance) estimates of sucker species initially increased after the flow regime change (2011 to 2015) but decreased to lower levels in 2016 to 2019. Rates of population growth of Burbot, Northern Pikeminnow, and Rainbow Trout were significantly lower after the flow regime change than before. There were also decreases in the probability of occupancy of Burbot, Northern Pikeminnow, and sculpin species that coincided with the timing of the new flow regime. Species evenness generally increased before the flow regime change (2001 to 2009) and fluctuated with no sustained trend after flow regime change (2010 to 2019). Species richness increased before the flow regime change and decreased after the flow regime change. It is unknown whether the flow regime change caused any of these changes. Hypothesis cannot be rejected.
Is there a change in growth rate of adult life stages of the most common fish species using the MCR that corresponds with the implementation of a year-round minimum flow?	**Ho$_2$:** The implementation of a 142 m^3/s minimum flow release from Revelstoke Dam will not significantly affect the mean growth rate of adult fish present in the MCR during index surveys.	Estimates of the von Bertalanffy growth coefficient for Bull Trout initially declined after the flow regime change but were within the range of values recorded before the flow regime change. The decrease was likely related to concurrent decreases in Kokanee abundance. Growth coefficients of Mountain Whitefish did not indicate any change associated with the flow regime. Growth of adult Largescale Sucker suggested very low growth during 2013 to 2016 but greater growth in 2017 to 2019. Growth of all other species could not be estimated because of small numbers of recaptured fish. Hypothesis cannot be rejected.
Is there a change in body condition (measured as a function of relative length to weight) of adult life stages of fish using the MCR that corresponds with the implementation of a year-round minimum flow?	**Ho$_3$:** The implementation of a 142 m^3/s minimum flow release from Revelstoke Dam will not significantly affect the body condition of adult fish present in the MCR during index surveys.	Estimates of body condition decreased in years after the flow regime change for Bull Trout (~10% to 15%) and Largescale Sucker (23%). The decrease in Bull Trout body condition coincided with a decrease in the abundance of Kokanee, which are an important prey item. The decrease in Largescale Sucker body condition from 2010 to 2015 coincided with an increase in the density of sucker species and abundance estimates of Largescale Sucker, suggesting competition for resources. It is not possible to conclude whether the flow regime change caused these changes in body condition. Hypothesis cannot be rejected.

Management Questions	Management Hypotheses	Year 13 (2019) Status
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?	H_{O4}: The implementation of a 142 m^3/s minimum flow release from Revelstoke Dam will not significantly alter the distribution of fish present in the MCR during index surveys.	Hypothesis is rejected. There was an upstream shift in the distribution of some species in the years following the flow regime change. The difference was statistically significant for Rainbow Trout (5% effect size) but not for Bull Trout (2%) or sucker species (3%).

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Evan Amies-Galonski	Computational Technician

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

The MCR includes the approximately 48 km long portion of the Columbia River from the outlet of REV downstream to Arrow Lakes Reservoir. 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). Projects within the RFMP 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 2011), these data provide 10 years of baseline information that will be used to understand the effect of the flow regime change on adult fish in the MCR (Table 1). Nine years of monitoring have been completed after the implementation of the minimum flow release (i.e., 2011–2019). The current study year (2019) is the ninth and final year of planned monitoring after the flow regime change. This report presents the results from 2019 compared to all previous years of monitoring since 2001. In addition to this technical report, a summary report provides an overview of key results and conclusions regarding the effect of the flow regime change on fish in the MCR (Golder et al. 2020).

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

Study Year	Associated BC Hydro Programs	Flow Regime	Seasons Sampled
2001	LRFIP[a]	Before Minimum Flow and REV5	Fall
2002	LRFIP[a]	Before Minimum Flow and REV5	Fall
2003	LRFIP[a]	Before Minimum Flow and REV5	Fall
2004	LRFIP[a]	Before Minimum Flow and REV5	Fall
2005	LRFIP[a]	Before Minimum Flow and REV5	Fall
2006	LRFIP[a]	Before Minimum Flow and REV5	Fall
2007	RFMP[b]	Before Minimum Flow and REV5	Fall
2008	RFMP[b] and WUP[c]	Before Minimum Flow and REV5	Fall
2009	RFMP[b] and WUP[c]	Before Minimum Flow and REV5	Fall
2010	RFMP[b] and WUP[c]	Before Minimum Flow and REV5	Fall
2011	RFMP[b] and WUP[c]	After Minimum Flow and REV5	Spring and Fall
2012	RFMP[b] and WUP[c]	After Minimum Flow and REV5	Spring and Fall
2013	RFMP[b] and WUP[c]	After Minimum Flow and REV5	Spring
2014	RFMP[b] and WUP[c]	After Minimum Flow and REV5	Fall
2015	RFMP[b] and WUP[c]	After Minimum Flow and REV5	Spring and Fall
2016	RFMP[b] and WUP[c]	After Minimum Flow and REV5	Spring (visual survey only) and Fall
2017	RFMP[b] and WUP[c]	After Minimum Flow and REV5	Fall
2018	RFMP[b] and WUP[c]	After Minimum Flow and REV5	Fall
2019	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 quantitatively assess changes in abundance, growth, diversity, and spatial distribution of fish in the MCR.

Specific secondary objectives are as follows:

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

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

1.2 Key Management Questions

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

1) 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?
2) 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?
3) 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?
4) 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 in the study area:

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

REV is located on the Columbia River approximately 8 km upstream from the Trans-Canada Highway bridge, which crosses the Columbia River in the City of Revelstoke (Figure 1). The dam was constructed with the primary objective of power generation and uses the combined storage capacity of Revelstoke Reservoir (impounded by REV) and Kinbasket Reservoir (impounded by Mica Dam). REV is not one of the CRT dams (i.e., Mica, Hugh L. Keenleyside [HLK], Duncan, and Libby dams); however, the operation of REV is affected by treaty and operational considerations at other dams upstream and downstream in the Columbia River basin. REV is the second largest power plant operating within BC Hydro's hydroelectric grid. REV has five generating units with a plan to add a sixth unit. Together these units provide approximately 21% of BC Hydro's total system capacity[1].

Typically, REV is operated as a daily peaking plant, where flow releases are high during daylight hours when energy demands are higher (BC Hydro 1999). Overnight, when energy demands are usually lower, water releases are reduced, but since the new flow regime was implemented, flows 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

[1] https://www.bchydro.com/content/dam/BCHydro/customer-portal/documents/corporate/accountability-reports/financial-reports/annual-reports/bchydro-quick-facts-june-2017.pdf

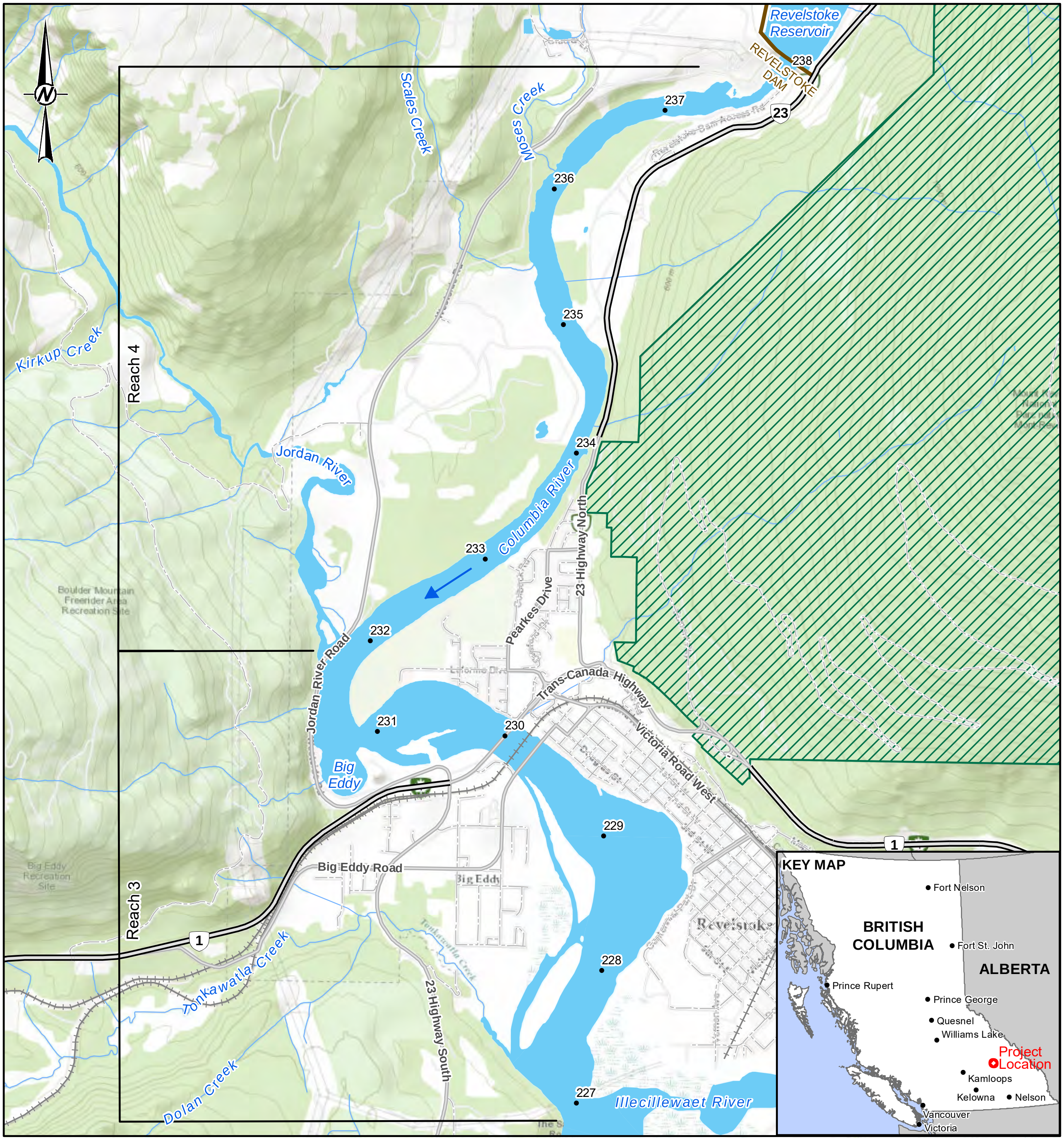
is not typically reached and the lowest flows are between 142 and 300 m^3/s (BC Hydro, personal communication). Periods of minimum flow release can occur at any time, but are more common at night during the spring (March to May) and fall (September to November) when electricity demands are low due to milder weather. Prior to the flow regime change, total 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. In some years, when ALR reaches full pool (mean surface elevation above sea level [masl] of 440 m), the river-reservoir interface zone can be at the base of REV. The river-reservoir interface zone typically moves downstream from the full pool operational policy in early July to a target low pool elevation in March and April each year. Reservoir elevations vary over time and depend on annual climatic conditions, CRT obligations, and operational needs. At ALR's minimum reservoir elevation (420 masl), approximately 48 km of the MCR downstream of REV is riverine.

1.5 Study Area

The CLBMON-16 study area is 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 (river kilometre [RKm] 238.0 as measured from HLK) to the confluence with the Jordan River (RKm 231.8). Reach 3 extends from the mouth of the Jordan River downstream to the mouth of the Illecillewaet River confluence (RKm 226.3).

Reach 2, located between the Illecillewaet River confluence and 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 flow regime change. Sampling in Reach 2 was removed from the Terms of Reference in 2010. Reach 1 (the Akolkolex River confluence downstream to Beaton Flats [RKm 190.0]) was not sampled as part of CLBMON-16 during any study year and also was removed from the Terms of Reference in 2010 (BC Hydro 2010a).



LEGEND

- RIVER KMS FROM HLK DAM
- REACH BOUNDARY
- DAM BASE
- HIGHWAY
- MAJOR ROAD
- LOCAL ROAD
- RAILWAY
- WATERCOURSE
- NATIONAL PARK
- WATERBODY

0 800 1,600

1:40,000 METRES

REFERENCES

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

CLIENT
BC HYDRO

PROJECT
MIDDLE COLUMBIA RIVER FISH POPULATION INDEXING STUDY

TITLE
OVERVIEW OF STUDY AREA

CONSULTANT

GOLDER

YYYY-MM-DD	2020-03-31
DESIGNED	DR
PREPARED	GS
REVIEWED	DR
APPROVED	SR

PROJECT NO.	PHASE	REV.	FIGURE
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The 2019 study area was the same as from 2007 to 2018. The sample sites covered the entire shoreline of Reaches 3 and 4, with the exception of the first 1 km downstream of the face of REV, which cannot be sampled due to safety reasons and BC Hydro policy. Between 2001 and 2006 (i.e., prior to the implementation of 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 prior to 2007. In 2001 and 2002, sampling was allowed up to the face of the dam whereas from 2003 onwards, sampling began 1 km downstream from REV due to BC Hydro policy.

The locations of the eight sites sampled in Reach 4 and the seven sites sampled in Reach 3 in 2019 are illustrated in Appendix A, Figures A1 and A2, respectively. Each site was a section of river between 519 and 2,270 m in length along either the left or right bank. Site descriptions and UTM locations for all sites are listed in Appendix A, Table A1. In 2019, each site was sampled three times (i.e., three sessions) in the fall (15 October to 6 November) for the mark-recapture survey (Table 2). In addition to mark-recapture surveys, a geo-referenced visual enumeration boat electroshocking survey was conducted in the fall in 2019. Methods employed during visual surveys are described in Section 2.1.5.

Table 2: Annual study periods for mark-recapture and visual boat electroshocking surveys conducted in the middle Columbia River, 2001 to 2019.

Year	Season	Start Date	End Date	Number of Mark-Recapture Sessions	Mark-Recapture Sampling Duration (in days)	Visual Survey Dates
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	8–10 October
2015	Spring	2 June	12 June	2	11	16–17 June
2015	Fall	13 October	29 October	3	17	8 October
2016	Spring	-	-	0	0	14–15 June
2016	Fall	11 October	27 October	3	17	5–6 October
2017	Fall	10 October	26 October	3	17	4–5 October
2018	Fall	15 October	1 November	3	18	11–12 October
2019	Fall	15 October	6 November	3	22	7–8 October

2 METHODS

2.1 Data Collection

2.1.1 Discharge

Hourly average discharge data for the mainstem Columbia River (discharge through REV) from 2001 to 2019 were obtained from BC Hydro's Columbia Basin Hydrological 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 2018 were obtained from BC Hydro's Columbia Basin Hydrological 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 2018 were obtained from BC Hydro's MCR Physical Habitat Monitoring Program (CLBMON-15a). Data from 2007 to 2013 and 2015 to 2018 were from Station 2 and data from 2014 were from Station 2AS because data from Station 2 were not available in 2014. 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 of each other (Elmar Plate, LGL Ltd., pers. comm., 22 March 2015). In 2018, water temperature is only available for January 1 to April 30 because the CLBMON-15a monitoring stations were removed from the river on May 1, 2018 and water temperature is no longer monitored by that program. A water temperature logger was installed at Station 2 on 23 May 2019 and downloaded on 31 October 2019, which provided water temperature for part of the year in 2019. Water temperature data throughout this report are presented as daily mean values.

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

2.1.4 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 and GPS coordinates of habitat type delineations recorded during surveys (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 to 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, 2019.

Variable	Description
Date	The date the site was sampled
Time	The time the site was sampled
Estimated Flow Category	A categorical ranking of Revelstoke Dam discharge (high; low; transitional) based on crew observations of channel fullness
Air Temperature	Air temperature at the time of sampling (to the nearest 1°C)
Water Temperature	Water temperature at the time of sampling (to the nearest 1°C)
Water Conductivity	Water conductivity measured near the mid-point of the site after sampling (to the nearest 10 µS/cm)
Cloud Cover	A categorical ranking of cloud cover (clear - 0-10% cloud cover; partly cloudy - 10-50% cloud cover; mostly cloudy - 50-90% cloud cover; overcast – 90-100% cloud cover)
Weather	A general description of the weather at the time of sampling (e.g., comments regarding wind, rain, or fog)
Water Surface Visibility	A categorical ranking of water surface visibility (low - waves; medium - small ripples; high - flat surface)
Boat Model	The model of boat used during sampling
Range	The range of voltage used during sampling (high or low)
Percent	The setting on the “Percent of Range” dial, which affects voltage and duty cycle
Amperes	The average electrical current used during sampling
Mode	The mode (AC or DC) and frequency (in Hz) of current used during sampling
Length Sampled	The length of shoreline sampled (to the nearest 1 m)
Time Sampled	The duration of electroshocker operation (to the nearest 1 second)
Mean Depth	The mean water column depth recorded during sampling (to the nearest 0.1 m)
Maximum Depth	The maximum water column depth recorded during sampling (to the nearest 0.1 m)
Water Clarity	A categorical ranking of water clarity (high - greater than 3.0 m visibility; medium - 1.0 to 3.0 m visibility; low - less than 1.0 m visibility) based on visual estimates
Instream Velocity	A categorical ranking of water velocity (high - greater than 1.0 m/s; medium - 0.5 to 1.0 m/s; low - less than 0.5 m/s) based on visual estimates
Instream Cover	The type (i.e., interstices; woody debris; cutbank; turbulence; flooded terrestrial vegetation; aquatic vegetation; shallow water; deep water) and amount (as a percent) of available instream cover
Crew	The field crew that conducted the sample
Sample Comments	Any additional comments regarding the sample

2.1.5 Geo-referenced Visual Enumeration Survey

From 2014 to 2019, a geo-referenced visual enumeration survey was conducted as a complementary technique to the mark-recapture surveys for monitoring fish abundance in the MCR. 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 meso-habitat use by fish in the MCR and better address management questions regarding fine-scale spatial distribution.

In 2014 to 2019, geo-referenced visual enumeration surveys were conducted during the first week of the fall sampling program at each of the mark-recapture index sites. In 2016, the geo-referenced visual enumeration survey was also conducted in the spring. 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, as well as the geographical location of each individual or group of fish observed using a hand-held GPS unit. Species included in the count data during the surveys were the same as the mark-recapture surveys (i.e., all fish species except Kokanee [*Oncorhynchus nerka*], Redside Shiner [*Richardsonius balteatus*], and sculpin species [*Cottidae*]).

2.1.6 Fish Capture

In 2019, fish were captured during the fall (15 October – 6 November) sampling session using methods similar to previous years of the project (Golder 2002, 2003, 2004a, 2005a, 2006, 2007, 2008, 2009, 2010; Ford and Thorley 2011, 2012; Golder and Poisson 2013; ONA et al. 2014; Golder et al. 2015, 2016, 2017, 2018a, 2019).

Boat electroshocking was conducted in Reaches 3 and 4 of the study area to capture fish within nearshore habitats along the channel margins. Boat electroshocking employed a Smith-Root Inc. high-output Generator Powered Pulsator (GPP 5.0) electroshocker operated out of an outboard jet-drive riverboat by a three-person crew. The electroshocking procedure consisted of manoeuvring the boat downstream along the shoreline of each sample site. Two crew members positioned on a netting platform at the bow of the boat netted stunned fish, while a third individual operated the boat and electroshocking unit. The two netters attempted to capture all fish stunned by the electrical field. Captured fish were immediately sorted by the Bank Habitat Type (Appendix B, Table B1) according to where they were captured by placing them into separate partitions in an onboard live-well. Fish that could be positively identified but avoided capture were enumerated by Bank Habitat Type and recorded as “observed”. Both time sampled (seconds of electroshocker operation) and length of shoreline sampled (in kilometres) were recorded for each sample site.

Kokanee, Redside Shiner, and sculpin species were excluded from the mark-recapture component of the program. The abundance of Kokanee in the study area is highly variable, depends partly on entrainment through REV, and the majority of their life-cycle occurs outside of the study area. The distribution of Redside Shiner is generally limited to Big Eddy (RKm 231) and the Centennial Park Boat Launch areas of Reach 3 (RKm 228; Figure 1). The limited distribution and high variability in catch rates limited recapture success of Redside Shiner, thus limiting the effectiveness of a mark-recapture program for this species. Sculpin species are relatively common throughout the study area; however, they are difficult to capture during boat electroshocking operations and are better sampled by shallow water sampling techniques. Sculpin species and Redside Shiner were studied as part of BC Hydro’s Middle Columbia

River Juvenile Habitat Use Program (CLBMON-17; Triton 2014). During the CLBMON-16 sampling program, up to 50 Kokanee, 50 Redside Shiner, and 50 sculpin were captured and measured each year. After collecting these samples, Kokanee, Redside Shiner, and sculpin were enumerated by the netters and recorded as "observed".

Boat electroshocking sites varied between 519 and 2,270 m in length. If, due to logistical reasons, a site could not be fully sampled (e.g., public too close to shore, water too shallow, swimming wildlife, other research activities in the area), 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 to the minimum amperage output required to achieve the desired effect on fish, i.e., forced swimming towards the anode (known as electrotaxis or galvanotaxis), or narcosis, which is when fish become immobilized by the electric field. This corresponded to an amperage output of 3 to 4 A on the new models of electroshocker and ~1.9 A on the older models (new and old GPP models appear to measure a different component of the electrical waveform but we have been unable to confirm the reason for the difference with the manufacturer). A pulsed direct current with a frequency of 30 Hz was used. These settings have been shown to result in lower electroshocking-induced injury rates for Rainbow Trout (*Oncorhynchus mykiss*) than when using greater frequencies (60 or 120 Hz) and amperages (1.5 to 3.3. A; Golder 2004b, 2005b). Although electrical output was variable (i.e., depending on water conductivity, water depth, water temperature, and changes in water quality of tributary inputs), 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 were observed (e.g., White Sturgeon [*Acipenser transmontanus*] and large Bull Trout remaining in the electrical field too long);
- netting fish as quickly as possible to limit the amount of time they were 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 re-entering the electrical field after they had already been removed from the water (i.e., crew members would not net a second fish if they already had 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 changes were monitored by field crews via emails 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 more than 200 m^3/s. This real-time discharge information was essential for logistical planning and allowed the crew to maximize sampling effort during the period when discharge was sufficient to allow effective sampling. To prevent the boat and crew from being stranded in shallow water during periods of low flow, sampling efforts were typically limited to Reach 3 upon notification of a flow reduction to a level below 200 m^3/s.

2.1.8 Fish Processing

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

All fish (with the exception of Kokanee, Redside Shiner, and sculpin species as detailed in Section 2.1.6) that were 120 mm or larger in FL and were in good condition were marked with a Passive Integrated Transponder (PIT) tag (Datamars, FDX-B, food safe polymer, 11.4 x 2.18 mm). Fish between 120 and 170 mm FL had a tag implanted into the abdominal cavity just off the mid-line and anterior to the pelvic girdle using a single shot applicator (model MK7, Biomark Inc., Boise, Idaho, USA) or a No. 11 surgical scalpel (depending on the size of the fish). Fish ≥170 mm FL had tags implanted with a Hallprint-brand single shot 12 mm polymer PIT tag applicator gun into the dorsal musculature on the left side below the dorsal fin near the pterygiophores. All tags and tag injectors were immersed in an antiseptic (Super Germiphene™) and rinsed with distilled water prior to insertion. Tags were checked to ensure they were inserted securely and the tag number was recorded in the Middle Columbia River Fish Indexing Database.

Table 4: List and description of variables recorded for each fish captured in the middle Columbia River, 2019.

Variable	Description
Species	The species of fish recorded
Size Class	A general size class for observed fish (YOY for age-0 fish, Immature for fish <250 mm FL, Adult for fish >250 mm FL)
Length	The fork length (FL) or total length (TL) of the fish to the nearest 1 mm
Weight	The wet weight of the fish to the nearest 1 g
Sex and Maturity	The sex and maturity of a fish (determine where possible through external examination)
Scale	Whether or not a scale sample was collected for ageing purposes
Tag Colour/Type	The type (i.e., T-bar anchor, PIT, or PIP tag) and colour (for T-bar anchor tags only) of tag applied
Tag Number	The number of the applied tag
Tag Scar	The presence of a scar from a previous tag application
Condition	The general condition of the fish (e.g., alive, dead, unhealthy, etc.)
Preserve	Details regarding sample collection (e.g., stomach contents, DNA, whole fish, etc.)
Habitat Type	The bank habitat type where the fish was recorded
Comments	Any additional comments regarding the fish

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

Overall, sampling methods were very similar between 2001 and 2019, with major changes to the study identified in Table 5. Minor changes to the study design between 2001 and 2019 that have little effect on 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 2019.

Methodology Change	Years	Description
Number of sampling sessions (fall season)	2014–2019	Three sampling sessions
	2002–2006, 2010–2012	Four sampling sessions
	2001, 2007–2009	Five sampling sessions
Sampling locations	2001–2007	Reach 4 and the Big Eddy portion of Reach 3 were sampled
	2007–2009	Reaches 2, 3 and 4 were sampled
	2009–2019	Reaches 3 and 4 were sampled
Fish tag type	2001–2004	T-bar anchor tags exclusively
	2005	T-bar anchor tags and PIT tags
	2006–2019	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
	2010–2019	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
	2005–2019	Frequency was 30 Hz; array curtain was used as the cathode
Seasons sampled	2001–2010, 2014, 2017–2019	Fall only
	2011–2012, 2015–2016	Spring and Fall
	2013	Spring only
Geo-referenced visual enumeration survey	2014–2019	Visual counts during boat electroshocking without netting fish

2.2 Data Analyses

2.2.1 Data Compilation and Validation

Data were entered directly into the Middle Columbia River Fish Indexing Database using Microsoft® Access 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 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, Largescale Sucker, Mountain Whitefish, and Rainbow Trout were assigned a life stage (i.e., fry, juvenile, or adult) based on the fork length values provided in Table 6. These values were based on length-frequency distributions and professional judgment. Fry were excluded from all statistical models 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 2019.

Species	Fry (age-0)	Juvenile	Adult
Bull Trout	<120	120 to 399	≥400
Largescale Sucker	<120	120 to 349	≥350
Mountain Whitefish	<120	120 to 174	≥175
Rainbow Trout	<120	120 to 249	≥250

2.2.3 Statistical Analysis

The temporal and spatial variation in species richness and evenness, abundance, growth, and body condition were analyzed using hierarchical Bayesian models (HBMs) and data from 2001 to 2019. 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 estimates of uncertainty (Kéry and Schaub 2011). 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.

The Bayesian estimates were produced using JAGS (Plummer 2015) and STAN (Carpenter et al. 2017) software. For additional information on Bayesian estimation the reader is referred to Kéry and Schaub (2011) and McElreath (2016). The analyses were implemented using R version 3.6.2 (R Core Team 2019) and the mbr family of packages.

The parameters were summarised in terms of the point estimate, standard deviation (sd), z-score, lower and upper 95% credible limits (CLs), and the p-value (Kéry and Schaub 2011). Credible limits are the Bayesian equivalent of confidence limits and the range from the lower CL to the upper CL is referred to as a credible interval (CRI). For Bayesian models, the point estimate was the median (50^{th} percentile) of the Markov Chain Monte Carlo (MCMC) samples, the z-score was mean/sd and the 95% CLs were the 2.5^{th} and 97.5^{th} percentiles. The z-scores were used to calculate p-values for each of the parameter estimates. A p-value of 0.05 or greater indicates that the lower or upper 95% CL is 0. Where relevant, model adequacy was confirmed by examination of residual plots.

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

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

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

In HBM plots, the point estimates of the response variable with 95% CRIs are shown while the remaining variables were held constant. Continuous and discrete fixed variables were held constant at their mean and first level values, respectively, while random variables were held constant at their typical values (i.e., the expected values of the underlying hyperdistributions; Kéry and Schaub 2011). Plots of response variables by site had the year constant at 2010 (the reference level), which was chosen because it was the last year before the flow regime change. 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).

The technical aspects of the analyses, including the general approach and model definitions 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 *https://www.poissonconsulting.ca/f/1050384286* (Thorley and Amies-Galonski 2020).

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 (Kéry and Schaub 2011), 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 that had sufficient variation in their frequency of encounter to provide information on changes through time, which 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 the following:

- occupancy (the probability of presence) was described by a generalized linear mixed model with a logit link;
- occupancy varied with season;
- occupancy varied randomly with site and site within year;
- the effect of year on occupancy was autoregressive with a lag of one year and varied with flow regime;
- sites were closed (i.e., the species is present or absent at a site for all sessions within a particular season of a year), which was assessed through estimates of site fidelity (Section 2.2.7); 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 (*Oncorhynchus clarkii*) and White Sturgeon, were also not included in estimates of richness as the data provided little to no information on changes in their occupancy through time.

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 (Kéry 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 (Kéry and Schaub 2011). Unlike Kéry 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 not systematic in order to interpret estimates as relative abundance. The model estimated the number of fish expected to be captured or observed at each site per river kilometre based on the sampling data, the influence of other variables in the model, and the prior distributions of model parameters. These estimates were used as an indicator of relative density and are referred to in this report as count density, in fish counted per kilometre (count/km).

Key assumptions of the count model included the following:

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

The autoregressive effect of year was used to account for temporal autocorrelation in the abundance of fish between consecutive years. For sucker species, the model including the autoregressive effect of year would not converge so a simpler model was used. The model had the same assumptions as above, except that it had no autoregressive year effect, and it assumed that count density varied with flow regime.

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 following formula (Pielou 1966):

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

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

In the MCR, the total number of species present in the study area likely does not vary from year to year, although uncommon species may or may not be detected in a given site or year. For the count density model, 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 reliable and robust way 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 Diversity Profiles

In addition to the measures of species richness and evenness described above, diversity profiles were used to address the management question regarding diversity in the MCR. Traditional indices of diversity, such as species richness, Shannon's index, or Simpson's index differ in how the relative abundance of species affects the index, which affects the degree to which rare versus common species are represented. A diversity profile is a method that plots the relationship between diversity and the weighting given to rare versus common species (Leinster and Cobbold 2012). The response variable in a diversity profile is the "effective number of species", which is the number of equally common species required to get a particular value of an index (Jost 2006). Effective numbers are recommended for comparisons of diversity because they allow intuitive and straightforward comparison of the number of species, instead of individual indices, which are more difficult to interpret and can be misleading due to non-linearity (Jost 2006; Chao et al. 2014). For instance, a community of eight equally common species has a Shannon index of 2.1 (calculated using natural log) and 8 effective species, whereas a community of 16 equally common species has a Shannon index of 2.8 and 16 effective species. The second community is twice as diverse as the first but appears only 33% more diverse using the Shannon index (2.8 vs. 2.1).

Diversity profiles also can take into account similarity between species when calculating diversity. Most measures of diversity do not take into account similarity between species, such that the diversity of a community of three trout species is equal to that of a community with a sculpin species, a trout species, and Burbot. However, most people would intuitively consider the latter community more diverse. Diversity profiles can account for diversity among species by assigning a similarity value between 0 and 1 for each pair of species, where a value of 1 indicates an equivalent species and a value of 0 indicates no similarity (Leinster and Cobbold 2012). Similarity values could be assigned based on any biologically criteria desired, such as genetic or functional similarity.

Diversity profiles were calculated using the following equation:

$$^{q}D^{\mathbf{Z}}(\mathrm{p}) = \left(\sum p_i \,(\mathrm{Zp})_i^{q-1}\right)^{1/(1-q)}$$

where D is the effective number of species, p is the relative abundance of the species present, q is the parameter representing the relative contribution of relative abundance data, and Z is the similarity matrix among species (Leinster and Cobbold 2012). A value of q = 0 represents no importance of relative abundance and is equivalent to a count of the number of species, often referred to as species richness. A value of q = 1 is equivalent to the Shannon index and q = 2 is equivalent to Simpson's index (Simpson 1949). Values less than one give greater weight to rare species and values greater than one give greater weight to common species. The shape of diversity profiles can be used to interpret the community composition and make comparisons between data sets. For instance, a flat profile indicates near equal abundance among species, whereas a steeper profile indicates more unequal abundance among species. Diversity profiles allow comparison of the number of effective species across the entire range of importance of rare/common species, instead of requiring the assumptions of a single diversity index.

For the present analysis, estimates of count densities of Rainbow Trout, sucker species, Burbot, and Northern Pikeminnow were combined with the equivalent count estimates for adult Bull Trout and adult Mountain Whitefish from the abundance model to calculate diversity profiles. Other species were not included in the model. All pairs of species were assigned a similarity value of zero, meaning that all species were considered equally and totally different from each other. Yearly values for the diversity profiles were calculated from predicted counts for a typical site. Diversity profiles by site were calculated from predicted counts for a typical year. In both cases, diversity profiles were calculated for each of the 1500 MCMC samples from the Bayesian models. Mean values with 95% CRIs were calculated from these 1500 samples for each year and site. Estimates of the effective number of species were plotted by year and by site for q = 0.01, which is an approximation of species richness, and q = 1.01, which is similar to Shannon's index. Because only six species were used to calculate diversity profiles, the effective number of species when q = 0 was always six. For this reason, q = 0.01 was used to assess annual differences in effective number of species while giving strong representation to rare species, and is therefore considered an approximation of species richness.

2.2.7 Site Fidelity

Site fidelity was the estimated probability of a recaptured fish being caught at the same site at which it was previously encountered during the same year. 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 (Kéry 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. Age-0 fish were excluded from the site fidelity model.

Key assumptions of the site fidelity model included the following:

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

2.2.8 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-gamma model. The model used estimates of capture efficiency from 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 (mark-recapture sessions) fish. 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 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 autoregressive generalized linear mixed model with a logit link for capture efficiency and a natural logarithm link for abundance.

Key assumptions of the abundance model included the following:

- density (fish/km) varied with season;
- density varied randomly with site, year, and site within year;
- the effect of year on lineal density (fish/km) was autoregressive with a lag of one year;
- the change in the annual density (rate of population growth) varied by flow regime;

- efficiency (the probability of capture) varied by season and method (captured or observed);
- efficiency varied randomly by session within season within year;
- marked and unmarked fish had the same probability of capture;
- there was no tag loss, mortality, or misidentification of fish;
- there was no migration into or out of the study area (supersite) among sessions;
- the number of fish captured was described by a Poisson-gamma distribution; and
- the overdispersion varied by encounter type (captured or observed).

Adult Largescale Sucker were analyzed using a simpler model because the full model did not converge, likely because of the shorter time-series (2010–2019) and/or smaller sample sizes for this species. The model had the same assumptions as above, except that it had no autoregressive year effect, and it assumed that density varied with flow regime.

2.2.9 Geo-referenced Visual Enumeration Survey

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

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

2.2.9 Distribution Model

To assess annual differences in the distribution of fish, the site within year random effects from the count and abundance models were analysed using a linear mixed model.

Key assumptions of the linear mixed model included the following:

- the distribution effect varied by river kilometer;
- the distribution effect of river kilometer varied by flow regime;
- the distribution effect of river kilometer varied randomly by year; and
- the distribution effect was normally distributed.

The response variable, which is referred to as the distribution, was the yearly variation in the density at the individual sites after accounting for site and year effects. An increase in the distribution represents an increase in the relative density of fish closer to Revelstoke Dam. A positive distribution does not however necessarily indicate that the density of fish is higher closer to Revelstoke Dam.

2.2.10 Length Bias Model

The bias (inaccuracy) and error (imprecision) in each observer's fish length estimates during the geo-referenced visual surveys were quantified from the divergence from the length distribution of the fish measured during mark-recapture surveys. The percent length correction that minimised the Jensen-Shannon divergence (Lin 1991) between the two distributions provided a measure of the inaccuracy while the minimum divergence provided a measure of the imprecision. The Jensen-Shannon divergence was calculated with log to base 2 which means it lies between 0 and 1. The observed fish lengths were corrected for the estimated length biases.

2.2.11 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, Largescale Sucker, and Mountain Whitefish. Growth was based on the change in length between fall seasons.

Key assumptions of the growth model included the following:

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

Plots of annual growth show the mean estimate of the growth coefficient, k, which represents the rate at which fish approach the asymptotic size. In addition to plots of the growth coefficient, the maximum growth in mm per year was calculated by multiplying the growth coefficient by the asymptotic length and plotted for each year. The maximum growth rate can be interpreted as the maximum growth during early life and can be used to compare between populations or years (Gallucci and Quinn 1979; Shuter et al. 1998).

When reviewing the data and model results for Mountain Whitefish, it was observed that the majority of individuals appeared to stop growing at approximately 275 mm in FL, which suggested an asymptotic size of approximately 300 mm. However, numerous larger individuals between 300 and 425 mm showed considerable growth (5–25 mm per year) between recaptures, which caused issues with model fit and biased values of the growth coefficient. The reason for the differences in body size at which growth attenuated could have been that there were two sub-populations of Mountain Whitefish in the study area, which is discussed further in Section 4.4.2. To address this problem, the growth model for Mountain Whitefish did not include fish with fork lengths >250 mm. The growth analysis of fish ≤250 mm showed the same trends as the analysis that included all Mountain Whitefish (not shown), but had more realistic values of the growth coefficient. The analysis presented is a more reliable way to assess the inter-annual differences in growth of Mountain Whitefish in the MCR but does not reflect growth of large (>250 mm) adult fish.

For Largescale Sucker, sensitivity analyses (see methods in Appendix F) indicated that the estimates of growth parameters were sensitive to the choice of prior distributions in the model (Table 11 of Appendix G). This was likely because nearly all the individuals captured were adults and therefore there was insufficient information about growth to overwhelm the prior information.

The von Bertalanffy growth curve could not be estimated for Rainbow Trout because the number of recaptures was too small to reliably calculate the growth curve and compare the coefficients between flow regimes. For Rainbow Trout, data from recaptured individuals was used to plot the annual growth in mm/yr versus the length at initial capture, as a visual assessment of growth.

2.2.12 Body Condition

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

Key assumptions of the condition model included the following:

- 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;
- 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 normally distributed.

Site was not included as an effect in the model because analysis in previous years showed little variation between sites (Golder et al. 2018a). The effect of flow regime was not included in the body condition model for Largescale Sucker because only one year of data was available prior to the flow regime change. Age-0 fish, based on length, were not included in the condition analysis. The percent difference (effect size) in body condition between flow regimes was calculated for a representative sized juvenile and adult for Bull Trout (300 or 500 mm), Largescale Sucker (500 mm; adults only), Mountain Whitefish (100 or 250 mm), and Rainbow Trout (150 or 300 mm). Using these representative fork lengths, the statistical significance and effect size of the difference in predicted weight-at-length between flow regimes was assessed.

For Largescale Sucker, the small number of juvenile fish (<350 mm) resulted in greater uncertainty in the weight-length parameters, and model-checking indicated that the parameters were sensitive to the choice of prior distributions (Table 24 of Appendix G). For this reason, predicted condition (i.e., weight-at-length) was not presented for juvenile Largescale Sucker.

3 RESULTS

3.1 Discharge

In 2019, mean daily discharge in the MCR was lower than average for most of March through September. During sampling October of 2019, mean daily discharge was highly variable, ranging from 300 to 1000 m³/s but was within the range of values observed during other years of sampling after the flow regime change (2011 to 2018). Minimum values of mean daily discharge were generally lower before the flow regime change (2001 to 2010) than after the flow regime change (2011 to 2018; Figure 2). Mean daily discharges from 2001 to 2019 are provided in Appendix C, Figure C1.

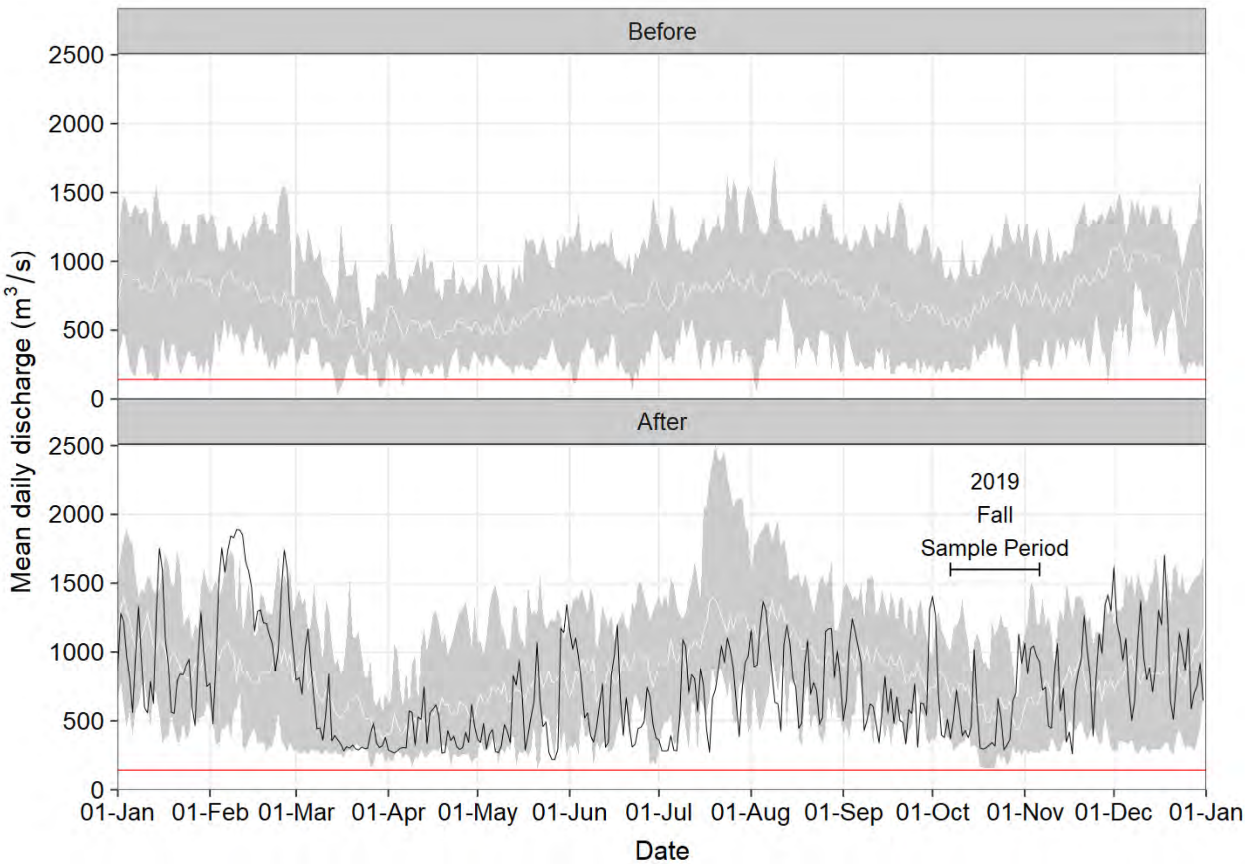

Figure 2: Mean daily discharge (m³/s) for the Columbia River at Revelstoke Dam in 2019 (black line) compared to historical discharge before and after the flow regime change. The shaded area represents minimum and maximum mean daily discharge values recorded at the dam from before (2001 to 2010) and after (2011 to 2019) the flow regime change. The white line represents average mean daily discharge values over those time periods. The red line represents the minimum flow release of 142 m³/s.

Similar to previous study years, hourly discharge in 2019 exhibited large fluctuations, a reflection of the primary use of the facility for daily peaking operations. Hourly discharge ranged between approximately 300 and 1,500 m³/s during all three sampling sessions in 2019 (Appendix C, Figure C2). Hourly discharge was low (300 to 400 m³/s) and stable during some days of the sampling period (e.g., 17–18, 21-22 October), but exhibited large within-day variation between 300 and 1500 m³/s on other days (e.g., 28–31 October). Since the implementation of the minimum flow release, discharge from REV rarely declined to 142 m³/s due to operational considerations (Karen Bray, BC Hydro, pers. comm.). In years since the flow regime change, the lowest discharges recorded during any day over the year have typically been between 142 and 160 m³/s.

3.2 Water Elevation

In 2019, mean daily water elevation in ALR was approximately 2 to 3 m greater than average from April through May. During fall sampling in 2019, ALR elevation ranged from 436 to 437 m, which was 3.5 to 4.5 m greater than the average value recorded between 2001 and 2018 for that time of year. During other parts of the year, including January to February and July to September, ALR elevation was near average. Historically, water elevations in ALR were lower than average from 2001 to 2006 and 2015 to 2016, greater than average from 2007 to 2012 and 2017 to 2018, and near the long-term average in 2013 and 2014 (Appendix C, Figure C3).

3.3 Water Temperature

Water temperature data from 2019 were available from late May to the end of October. Daily mean water temperature was below average during June, July, and October, with differences up to 2°C in June and July, but less than 1°C in October (Figure 3; Appendix C, Figure C4). During August to September of 2019, daily mean water temperature was near the average from 2007 to 2018. Water temperature data are not available for the MCR prior to 2007.

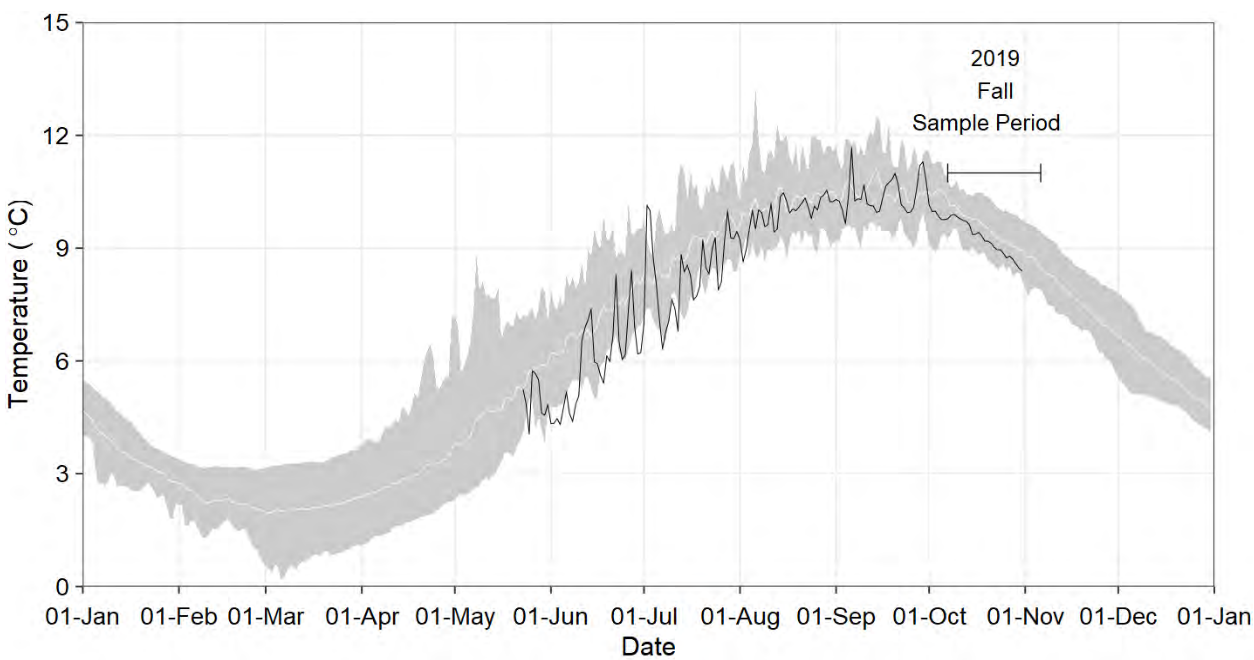

Figure 3: Mean daily water temperature in the middle Columbia River study area, 2019 (black line). The shaded area represents minimum and maximum mean daily water temperature values recorded by BC Hydro's Physical Habitat Monitoring Program (CLBMON-15a) from 2007 to 2018.

3.4 Catch

In total, 7,588 fish, comprising 13 species, were captured or observed and recorded in the MCR during the 2019 sampling period (Appendix D, Table D1). The number of fish caught and observed by species during fall study periods from 2001 to 2019 are shown in Appendix D, Table D1. Various metrics were used to provide background information on fish populations, and to help set initial parameter value estimates. Although these general summaries are important, they are not discussed in specific detail in this report. The location in the appendices of life history and catch metrics are shown in Table 7.

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

Metric	Appendix Location
captured and observed species count data by site and bank habitat type in 2019	Appendix B, Table B4
catch-per-unit-effort for all sportfish and non-sportfish in 2019	Appendix D, Tables D2–D3
inter-site movement summaries for Bull Trout, Largescale Sucker, Mountain Whitefish, and Rainbow Trout, for all years combined	Appendix D, Figures D1–D4
catch and recapture summaries by species in 2019	Appendix D, Table D4
length-frequency histograms by species for all years between 2001 to 2019 when sufficient data were available	Appendix E, Figures E1–E10
weight-length relationships by species for all years between 2001 and 2019 when sufficient data were available	Appendix E, Figures E11–E20

All data collected as part of the program between 2001 and 2019 are included in the Middle Columbia River Fish Indexing Database (database provided to BC Hydro).

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

3.5 Species Richness and Diversity

Annual estimates of species richness were used to detect changes in species presence at a typical site and do not indicate the total number of species present (Figure 4). Species richness increased from 0.2 species in a typical site in 2001 to 2.5 species per site in 2008, which was attributed to increasing occupancy of several species, including Burbot, Lake Whitefish, Northern Pikeminnow, Rainbow Trout, Redside Shiner, and sculpin species (Appendix H, Figures H1–H6). Species richness peaked in 2008 to 2011 (2.5 species per site), except with lower richness in 2009. After the flow regime change, estimates of species richness declined from 2011 to 2014, and changed little from 2015 to 2019. The small increase from 1.4 in 2018 to 1.8 species per site in 2019 was related to greater probability of occupancy of sculpin species (Appendix H, Figure H6). For years when surveys were conducted in both the spring and the fall, species richness was lower in the spring (2011, 2012 and 2015), which was associated with lower probability of occupancy by Burbot, Lake Whitefish, Northern Pikeminnow, and Redside Shiner.

Site estimates of species richness by river kilometre (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.

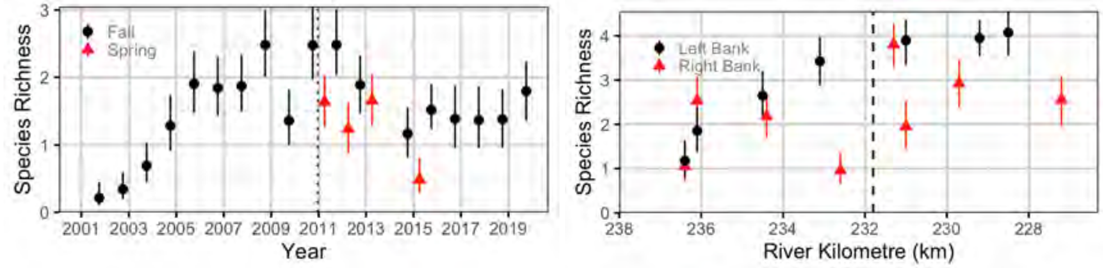

Figure 4: Species richness estimates (with 95% credible intervals) by year and season (left panel) and site (right panel) for the middle Columbia River study area, 2001 to 2019. The dotted line (left panel) represents the implementation of the minimum flow release and REV5 operations. The dashed line (right panel) represents the divide between Reaches 3 and 4 at the Jordan River confluence. Revelstoke dam is located at RKm 238.

Species evenness increased from 17% in 2001 to 29% in 2007 and fluctuated between 23% and 28% between 2008 and 2019 (Figure 5). Spring estimates of evenness were greater than fall estimates from 2011 to 2013 and 2015. Greater evenness in the spring than fall was related to lower densities of Mountain Whitefish and Bull Trout. In Reach 3, species evenness increased with proximity to Arrow Lakes Reservoir (decreasing river kilometre). Site 233.1-L (along the Revelstoke Golf Course) had particularly high evenness relative to adjacent sites (Figure 5). This pattern of greater evenness at Site 233.1-L was likely due to lower Mountain Whitefish densities in this site when compared to neighbouring sites (see Section 3.6.4).

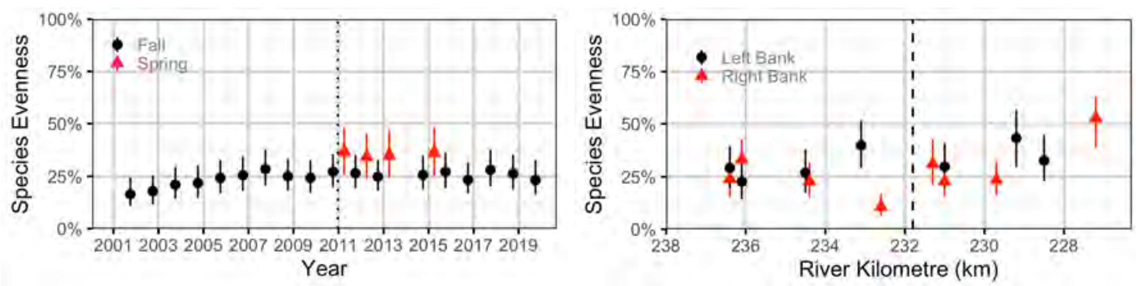

Figure 5: Species evenness estimates (with 95% credible intervals) by year and season (left panel) and site (right panel) for the middle Columbia River study area, 2001 to 2019. The dotted line (left panel) represents the implementation of the minimum flow release and REV5 operations. The dashed line (right panel) represents the divide between Reaches 3 and 4 at the Jordan River confluence. Revelstoke dam is located at RKm 238.

Diversity profiles calculated using the count density estimates from six species were similar in all years from 2001 to 2019 (left panel; Figure 6). The effective number of species was 6 when the sensitivity parameter, q, was 0, which is equivalent to species richness. When q = 1, which is equivalent to Shannon's index, the effective number of species ranged from 1.3 to 1.5 among years. When q =2, which is equivalent to Simpson's index, the number of effective species ranged from 1.2 to 1.3. These low values of the effective number of species reflect that catches of fish at most sites in the MCR are dominated a few species, specifically Mountain Whitefish, Bull Trout, and sucker species, with very low numbers of all other species. The effective number of species varied more between sites with values between 1.2 and 2.2 when q = 1 (right panel; Figure 6).

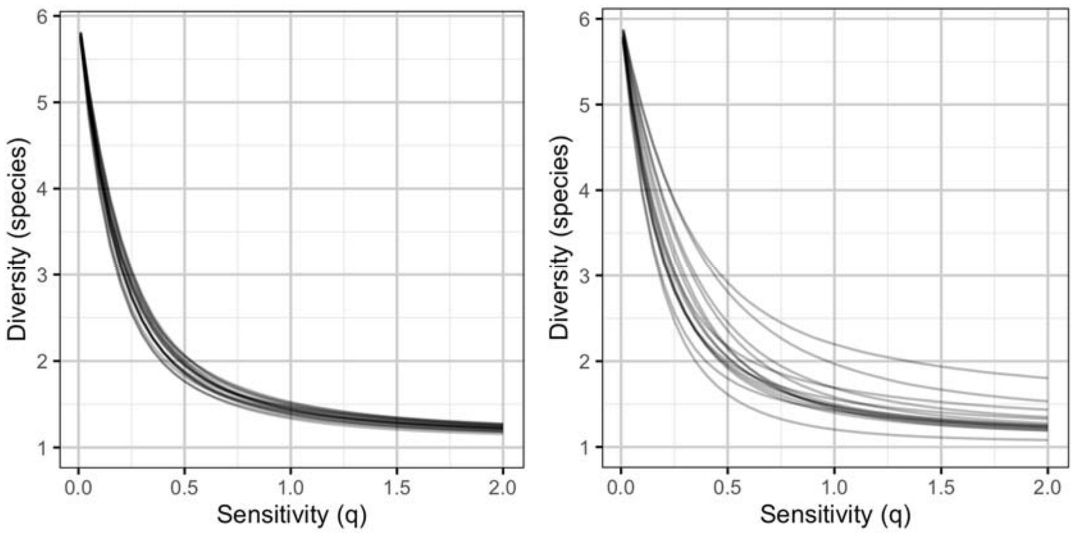

Figure 6: Species diversity profiles show the effective number of species (vertical axis) versus the sensitivity parameter that determines to degree to which rare species are considered (horizontal axis). Left panel shows a different line for each year and right panel shows a different line for each site.

The effective number of species was compared among years using sensitivity values of q = 0.01, which is similar to species richness, and q = 1.01, which is similar to Shannon's index. Annual values of the number of effective species when q = 0.01 increased from 2001 to 2008 and declined during 2011 to 2017 (left panel; Figure 7). However, the differences in the effective number of species, ranging from 5.7 to 5.8, were small. When q = 1.01, the effective number of species increased from 1.3 in 2011 to 1.5 in 2007 and fluctuated between 1.4 and 1.5 from 2008 to 2019 (right panel; Figure 7). Annual trends from diversity profiles (Figure 7) were similar to those shown by the other measures of richness and species evenness (Figures 4 and 5).

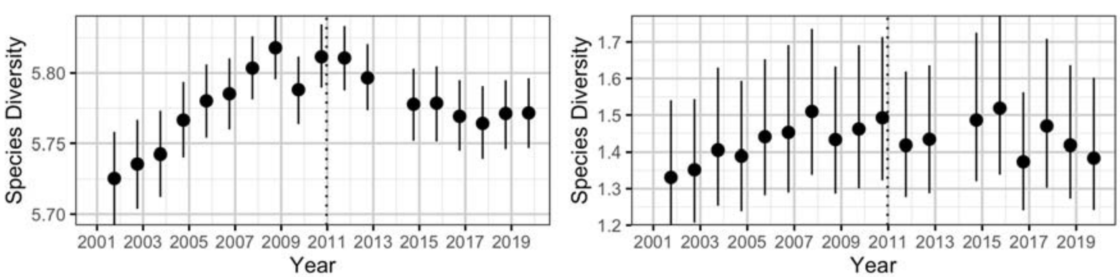

Figure 7: Effective number of species with 95% CRIs where q = 0.01 (left panel, equal to species richness) and q = 1.01 (right panel, equal to Shannon's index of diversity).

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 for fish species that abundance estimates could not be calculated; and,

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

Estimates of abundance were only possible for Bull Trout, Largescale Sucker, Mountain Whitefish, and Rainbow Trout due to low recapture rates of other species. Count density was estimated for Burbot, Northern Pikeminnow, Rainbow Trout, and sucker species. Both count density and abundance were estimated for Rainbow Trout because abundance estimates were only possible for years since 2007 due to low sample sizes. Count density estimates were produced for Rainbow Trout to assess trends across the entire monitoring period (2001–2019). Extremely low and/or variable count data for Brook Trout (*Salvelinus fontinalis*), Cutthroat Trout, Kokanee, Lake Whitefish, Peamouth, Pygmy Whitefish (*Prosopium coulteri*), Redside Shiner, White Sturgeon, and Yellow Perch resulted in unreliable estimates of density for these species; consequently, these estimates are not reported.

To assess changes in the spatial distribution of fish in the MCR, a distribution model was used, where the response variable was the yearly variation in the density at the individual sites after accounting for site and annual effects. In the model, an increase in the distribution represents an increase in the relative density (fish/km) of fish closer to Revelstoke Dam (i.e., an upstream shift in distribution). Changes in distribution are shown as an effect size (percentage change) in the relative density per upstream kilometre. If the interaction between river kilometre and flow regime was significant, this was interpreted as a significant effect of the flow regime on spatial distribution.

The count density and abundance models included an autoregressive effect of year on abundance to account for temporal autocorrelation. The estimates of the autoregressive effect of year on abundance represent the rate of population growth, where positive rates indicate increasing abundance and negative rates indicate decreasing abundance. The rate was allowed to vary with flow regime, where a statistically significant effect was interpreted as a significant difference in population growth rate between flow regimes.

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

3.6.1 Bull Trout

Juvenile Bull Trout abundance estimates increased from 2001 to 2007 (97 to 683 individuals), and varied between 390 and 928 individuals between 2008 and 2019 (Figure 8). 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 8). The abundance of juvenile Bull Trout did not differ significantly by season ($P = 0.5$). The rate of population growth of juvenile Bull Trout was lower after the flow regime change than before (effect size: -14%, CRI: -27% to 1%) but the difference was not statistically significant ($P = 0.06$).

Abundance estimates for adult Bull Trout increased from ~1,050 in 2001 to ~2,050 in 2009, but subsequently decreased, with estimates varying between ~1,500 and 1,800 between 2010 and 2016 (Figure 9). Estimated abundance of Bull Trout was greater than average (~1,900 to 2,400) in 2017 to 2019. Credible intervals for adult Bull Trout abundance estimates overlapped in all years of the study except for between 2001 and 2017–2018. Mean estimates of abundance of adult Bull Trout were greater in fall (~1,500-1,700 adults) than in spring (~1,200–1,400) in years when sampling was conducted in both seasons but the difference was not significant ($P = 0.5$). The rate of population growth for adult Bull Trout did not differ between flow regimes ($P = 0.96$; effect size: -1%, CRI: -10% to 10%). Bull Trout abundance in a typical year was greatest immediately downstream of REV (between RKm 236 and 237) and downstream of the Jordan River confluence (between RKm 231 and 232).

The distribution of juvenile Bull Trout by river kilometre was similar from 2001 to 2019 with overlapping credible intervals in all years (left panel; Figure 10). After the flow regime change (2011 to 2019), juvenile Bull Trout distribution shifted upstream (increase in values) but the difference was small (effect size: 0%, CRI: -1% to 1%), and the effect of flow regime on distribution was not significant (*P* = 0.4). The distribution of adult Bull Trout was similar in all years prior to the flow regime change (right panel; Figure 10). After the flow change, adult Bull Trout distribution was further upstream in 2011 to 2017, but returned to effect sizes near 0% in 2018 to 2019. The estimated effect size of flow regime on distribution of adult Bull Trout was a 2% increase in density per kilometre upstream (CRI: 0% to 5%) but the effect was not statistically significant (*P* = 0.1).

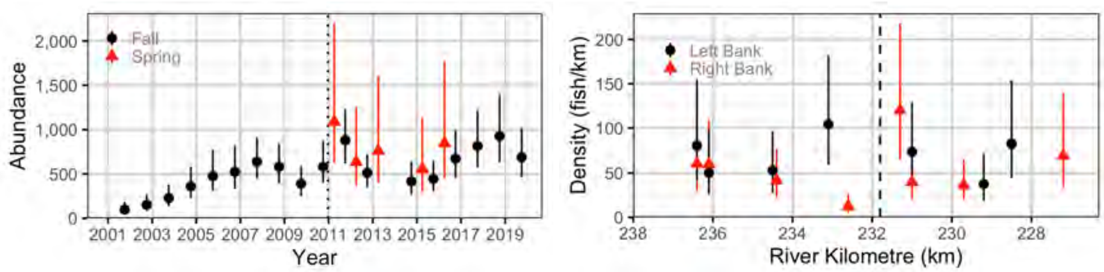

Figure 8: Abundance estimates (with 95% credible intervals) by year and season (left panel) and site (right panel) for juvenile Bull Trout in the middle Columbia River study area, 2001 to 2019. The dotted line (left panel) represents the implementation of the minimum flow release and REV5 operations. The dashed line (right panel) represents the divide between Reaches 3 and 4 at the Jordan River confluence. Revelstoke Dam is located at RKm 238.

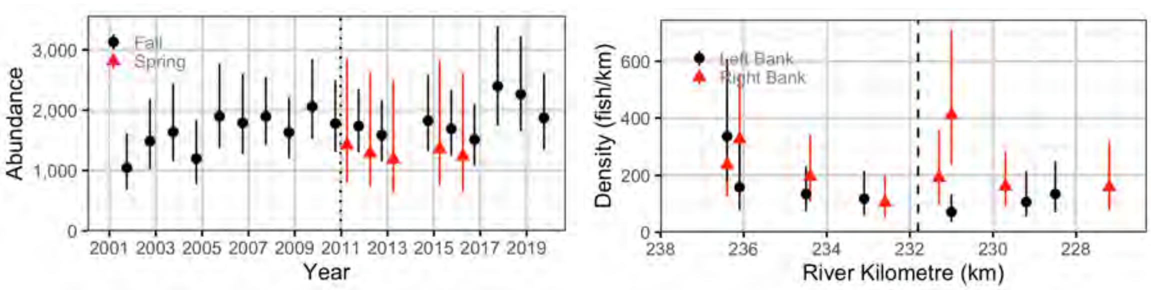

Figure 9: Abundance estimates (with 95% credible intervals) by year and season (left panel) and site (right panel) for adult Bull Trout in the middle Columbia River study area, 2001 to 2019. The dotted line (left panel) represents the implementation of the minimum flow release and REV5 operations. The dashed line (right panel) represents the divide between Reaches 3 and 4 at the Jordan River confluence. Revelstoke Dam is located at RKm 238.

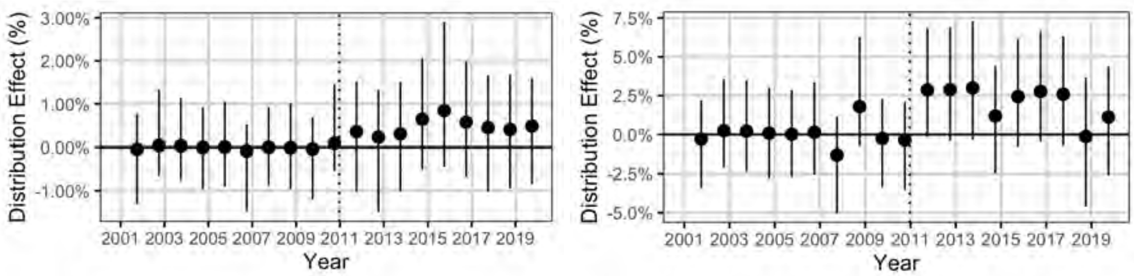

Figure 10: Effect of year on the distribution (with 95% credible intervals) of juvenile (left panel) and adult (right panel) Bull Trout densities by year in the middle Columbia River study area, 2001 to 2019. Positive values indicate an upstream shift in distribution and negative values indicate a downstream shift. The dotted line represents the implementation of the minimum flow release and REV5 operations.

3.6.2 Sucker Species

In 2001, and from 2010 to 2019, suckers that were captured were identified to the species level; suckers were not identified to the species level during 2002 to 2009. During years when sucker species were recorded, Largescale Sucker accounted for approximately 97% of the sucker species catch and the remaining 3% were Longnose Sucker (*Catostomus catostomus*) during the fall sample periods. During the spring sample periods (2011 to 2013 and 2015), 68% of the sucker catch was Largescale Sucker and 32% was Longnose Sucker.

Sucker species count densities increased three-fold from 2011 to 2015 with most of the increase occurring between 2013 and 2015 (Figure 11). Count densities of sucker species decreased in 2016 to 2019. Abundance estimates of Largescale Sucker showed a similar trend, with increasing estimates from 2011 to 2015, and lower estimates in 2016 to 2019 (Figure 12). Density of sucker species based on count estimates varied by season ($P = 0.0007$) with greater density in fall than spring. However, abundance estimates of Largescale Sucker did not differ by season ($P > 0.9$).

To assess the effect of flow regime, the count density model included an effect of flow regime on density, because the model would not converge with an effect of flow regime on population growth rate like was done for other species. The effect of flow regime was significant ($P = 0.02$; effect size: 78%, CRI: 7% to 198%), with greater density after the flow regime change than before. The positive value of the mean effect size (78%) was attributed to two years (2015 and 2016) with high density, whereas other years after the flow regime change had densities similar to before the flow regime change. The effect of flow regime on abundance of Largescale Sucker was not modelled because data were only available for one year before the flow regime change.

Sucker species densities were generally lowest immediately downstream of REV and highest on the right bank downstream of the Trans-Canada Highway bridge (RKm 230; Figure 11). Distribution varied minimally between 2001 and 2010, but was further downstream in 2011 and 2012 (Figure 13). In 2013 to 2019, estimates of the distribution of sucker species during the fall were greater than previous years. However, the effect of flow regime on distribution was not statistically significant ($P = 0.3$; effect size: 3%, CRI: -2% to 7%).

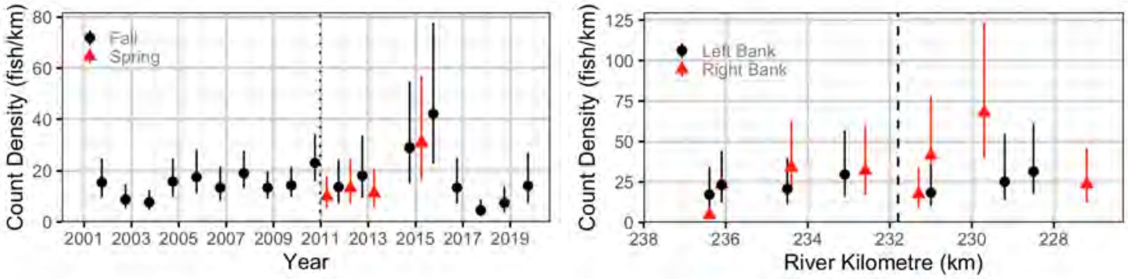

Figure 11: Count density estimates (with 95% credible intervals) by year and season (left panel) and site (right panel) for sucker species in the middle Columbia River study area, 2001 to 2019. The dotted line (left panel) represents the implementation of the minimum flow release and REV5 operations. The dashed line (right panel) represents the divide between Reaches 3 and 4 at the Jordan River confluence. Revelstoke Dam is located at RKm 238.

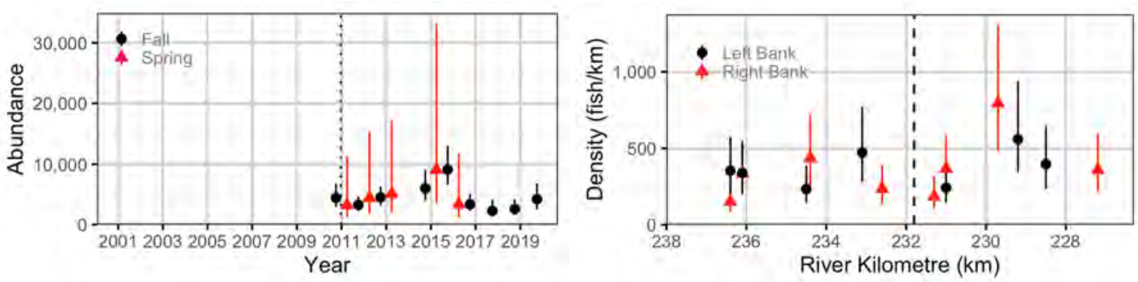

Figure 12: Abundance estimates (with 95% credible intervals) by year and season (left panel) and site (right panel) for adult Largescale Sucker in the middle Columbia River study area, 2001 to 2019. The dotted line (left panel) represents the implementation of the minimum flow release and REV5 operations. The dashed line (right panel) represents the divide between Reaches 3 and 4 at the Jordan River confluence. Revelstoke Dam is located at RKm 238.

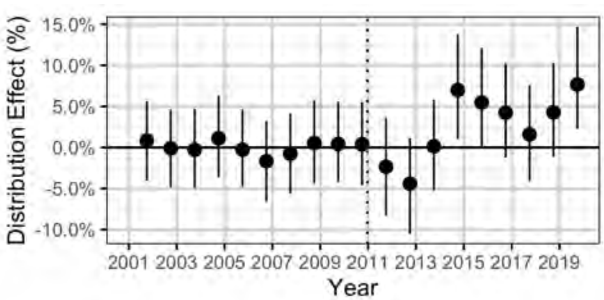

Figure 13: Effect of year on the distribution (with 95% credible intervals) of sucker species densities by year in the middle Columbia River study area, 2001 to 2019. Positive values indicate an upstream shift in distribution and negative values indicate a downstream shift. The dotted line represents the implementation of the minimum flow release and REV5 operations.

3.6.3 Mountain Whitefish

The estimated abundance of juvenile Mountain Whitefish was greatest in the fall of 2010 (~20,000) and the spring of 2011 (~25,000) and lower in all other years (~5,000–17,000; Figure 14). Juvenile Mountain Whitefish abundance estimates were lowest in 2018 (~5,200) and near average in 2019 (9,500). Juvenile Mountain Whitefish abundance did not differ between seasons (P = 0.5). The estimated density of juvenile Mountain Whitefish was greatest along the right bank upstream of the Jordan River confluence

(RKm 232) to the rail bridge (RKm 230) and along the left bank upstream of the Moses Creek Spawning Channel (RKm 236; right panel; Figure 14). The rate of population growth did not differ significantly between flow regimes for juvenile Mountain Whitefish (*P* = 0.4; effect size: -15%, CRI: -44% to 21%).

The estimated abundance of adult Mountain Whitefish in the fall fluctuated between ~14,000 and ~26,000 individuals from 2001 to 2019 with no consistent long-term changes (Figure 15). The adult abundance estimates in 2018 (23,000) and 2019 (26,000) were greater than all previous years (14,000–22,000) although credible intervals overlapped for all estimates. Estimated abundance of adult Mountain Whitefish in the fall was nearly double the abundance during spring (*P* = 0.0007). The rate of population growth did not differ significantly between flow regimes for adult Mountain Whitefish (*P* = 0.5; effect size: 2%, CRI: -5% to 9%). For adult Mountain Whitefish, the estimated density was highest along the right bank from RKm 234.5 downstream to the railway bridge (RKm 229.5; right panel; Figure 15).

The estimated distribution effect suggested similar distribution between most study years, but an upstream shift in distribution in 2016 to 2019 (Figure 16). The interaction between river kilometre and flow regime was not significant for adult Mountain Whitefish (*P* = 0.3; effect size: 2%, CRI: -2% to 5%), suggesting that distribution did not differ by flow regime.

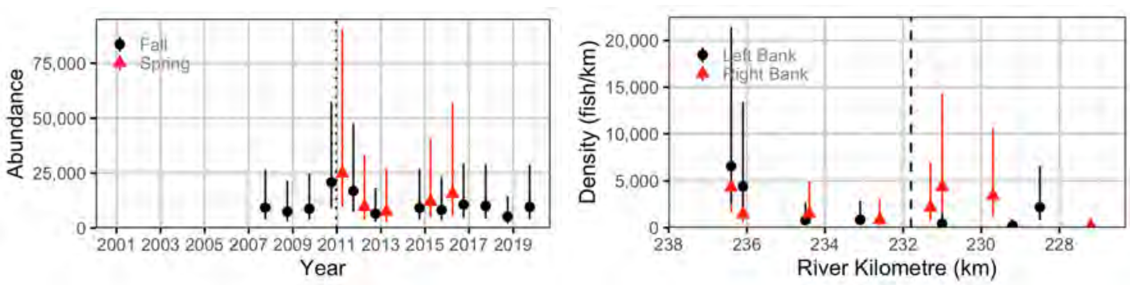

Figure 14: Abundance estimates (with 95% credible intervals) by year and season (left panel) and site (right panel) for juvenile Mountain Whitefish in the middle Columbia River study area, 2007 to 2019. The dotted line (left panel) represents the implementation of the minimum flow release and REV5 operations. The dashed line (right panel) represents the divide between Reaches 3 and 4 at the Jordan River confluence. Revelstoke Dam is located at RKm 238.

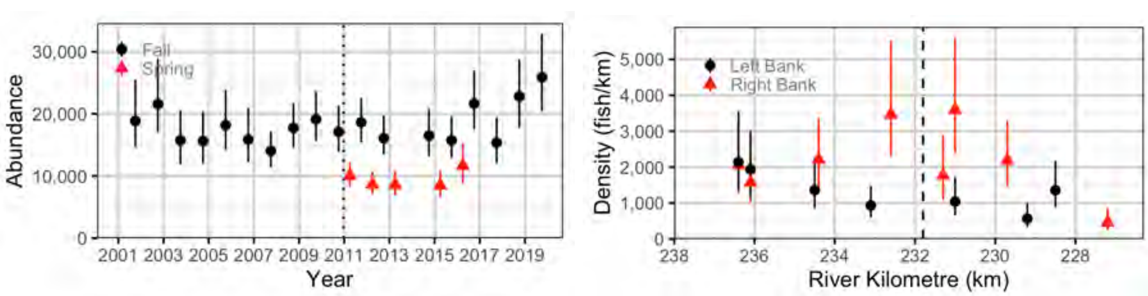

Figure 15: Abundance estimates (with 95% credible intervals) by year and season (left panel) and site (right panel) for adult Mountain Whitefish in the middle Columbia River study area, 2001 to 2019. The dotted line (left panel) represents the implementation of the minimum flow release and REV5 operations. The dashed line (right panel) represents the divide between Reaches 3 and 4 at the Jordan River confluence. Revelstoke Dam is located at RKm 238.

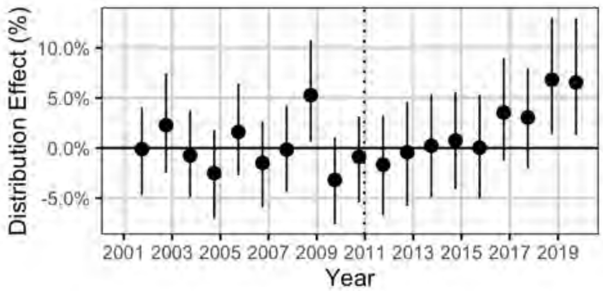

Figure 16: Effect year on the distribution (with 95% credible intervals) of adult Mountain Whitefish density by year in the middle Columbia River study area, 2001 to 2019. Positive values indicate an upstream shift in distribution and negative values indicate a downstream shift. The dotted line represents the implementation of the minimum flow release and REV5 operations.

3.6.4 Rainbow Trout

Rainbow Trout count density estimates (all life stages) increased from 0.1 fish/km in 2001 to 1.9 fish/km in 2008 (Figure 17). Count density of Rainbow Trout decreased from 1.9 fish/km in 2011 to 0.4 fish/km in 2015 but increased to 1.0 fish/km in 2019.

Abundance estimates for adult Rainbow Trout had no long-term trend but were greater in 2017 and 2018 than previous years (Figure 18). Estimates of abundance (P = 0.8) and count density (P = 0.5) did not differ among seasons. The rate of population growth based on change in count density of Rainbow Trout was significantly different between flow regimes (P = 0.01), with a negative growth rate after the change in flow regime (effect size: -29, CRI: -46% to -11%). The rate of population growth based on the abundance model did not differ between flow regimes (P = 0.6; effect size: 9%, CRI: -25% to 56%).

Estimates of Rainbow Trout density were greater in Reach 3 than in Reach 4 (Figures 17 and 18) and were greatest at sites on the left bank that had predominantly rip-rap substrate (Appendix A, Figure A2). In the distribution model for Rainbow Trout (based on count densities), the effect of flow regime on river kilometre was significant (P = 0.04; effect size: 5%, CRI: 0% to 11%), suggesting further upstream distribution after the flow regime change. Distribution was furthest downstream in 2007 and 2008 (Figure 19).

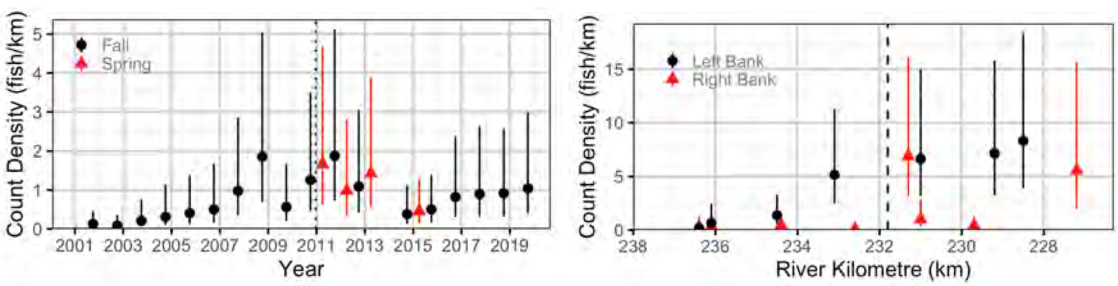

Figure 17: Count density estimates (with 95% credible intervals) by year and season (left panel) and site (right panel) for Rainbow Trout (all life stages) in the middle Columbia River study area, 2001 to 2019. The dotted line (left panel) represents the implementation of the minimum flow release and REV5 operations. The dashed line (right panel) represents the divide between Reaches 3 and 4 at the Jordan River confluence. Revelstoke Dam is located at RKm 238.

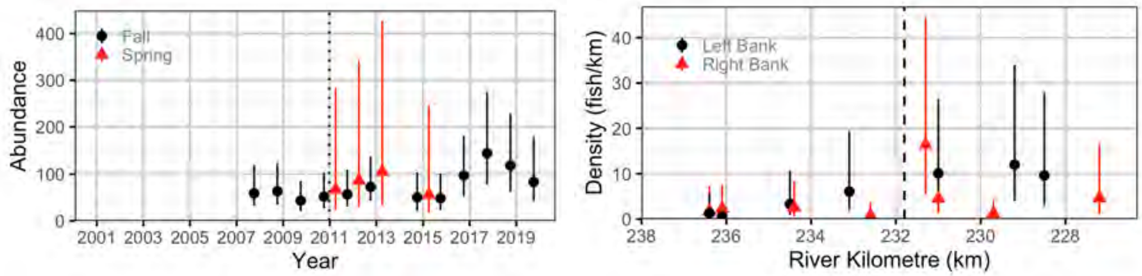

Figure 18: Abundance estimates (with 95% credible intervals) by year and season (left panel) and site (right panel) for adult Rainbow Trout in the middle Columbia River study area, 2007 to 2019. The dotted line (left panel) represents the implementation of the minimum flow release and REV5 operations. The dashed line (right panel) represents the divide between Reaches 3 and 4 at the Jordan River confluence. Revelstoke Dam is located at RKm 238.

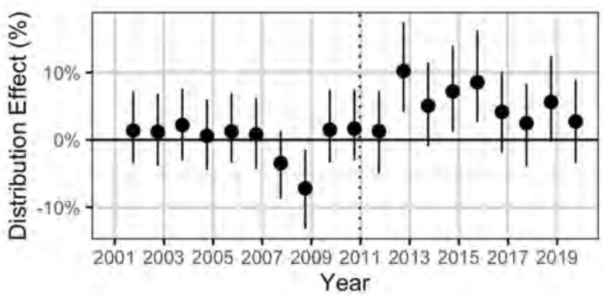

Figure 19: Effect of year on the distribution (with 95% credible intervals) of Rainbow Trout densities by year in the middle Columbia River study area, 2001 to 2019. Positive values indicate an upstream shift in distribution and negative values indicate a downstream shift. The dotted line represents the implementation of the minimum flow release and REV5 operations.

3.6.5 Burbot

Count densities for Burbot (≤1.0 fish/km) were low compared to count densities of most other species caught during all study years. Both adult and juvenile life stages of Burbot were captured and observed during the monitoring period although the majority of individuals (94%) were considered adults (≥250 mm TL). Count density estimates of Burbot were higher in 2008 and 2011 (1.0 fish/km) than in other study years and were less than 0.5 fish/km in years after 2011 (Figure 20). Count density of Burbot was very low in 2014 to 2016 (<0.1 fish/km) but slightly higher in 2017 to 2018 (0.2 to 0.4 fish/km). Count density differed significantly by season ($P = 0.005$) with higher densities in the fall than in the spring. Burbot density was greatest near the Revelstoke Golf Course (Site 233.1-L), downstream of Big Eddy (Site 231.0-L), and near the Centennial Park Boat Launch (Site 228.5-L). The rate of population growth of Burbot was lower after the flow regime than before (effect size: -33%, CRI: -57% to 3%) but the difference was not statistically significant ($P = 0.06$). The distribution of Burbot by river kilometre was similar in all years of the study. Exceptions were an upstream shift in distribution in 2011 and a downstream shift in 2018 (Figure 21). Distribution of Burbot did not differ significantly between flow regimes ($P > 0.9$; effect size: 0%, CRI: -1% to 1%).

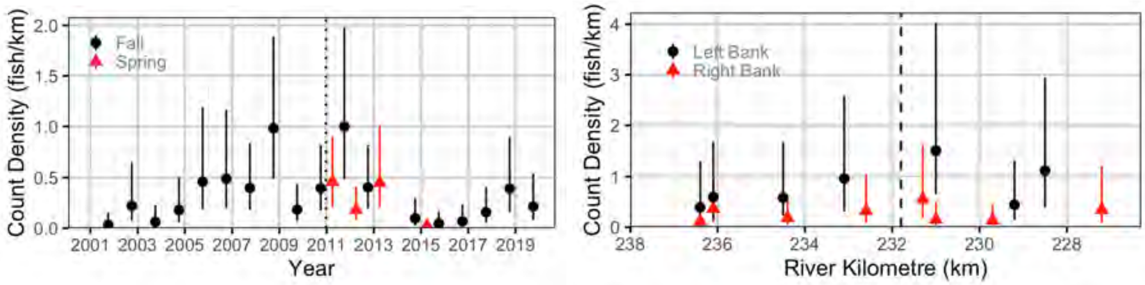

Figure 20: Count density estimates (with 95% credible intervals) by year and season (left panel) and site (right panel) for Burbot in the middle Columbia River study area, 2001 to 2019. The dotted line (left panel) represents the implementation of the minimum flow release and REV5 operations. The dashed line (right panel) represents the divide between Reaches 3 and 4 at the Jordan River confluence. Revelstoke Dam is located at RKm 238.

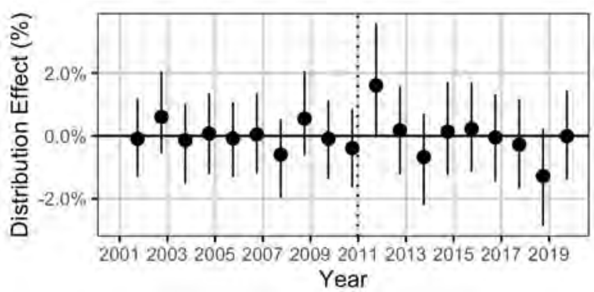

Figure 21: Effect of year on the distribution (with 95% credible intervals) of Burbot densities by year in the middle Columbia River study area, 2001 to 2019. Positive values indicate an upstream shift in distribution and negative values indicate a downstream shift. The dotted line represents the implementation of the minimum flow release and REV5 operations.

3.6.6 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.

3.6.7 Northern Pikeminnow

Density estimates for Northern Pikeminnow in the MCR increased from <0.1 fish/km in 2001 to 0.8 fish/km in 2010, ranged from 0.3 to 0.5 fish/km between 2011 and 2016, and decreased to 0.1 fish/km in 2017 to 2019 (Figure 22). The count density of Northern Pikeminnow density differed significantly between seasons (P = 0.0007), with fall densities (0.3 to 0.5 fish/km) nearly 10 times greater than spring densities (<0.05 fish/km). The annual rate of population growth of Northern Pikeminnow differed significantly between flow regimes (P = 0.002; effect size: -46%, CRI: -63% to -28%), with a decreasing population growth rate after the flow regime change. Abundance and capture efficiency were not estimated for Northern Pikeminnow because of small samples sizes. However, 3 of 5 captures in 2017 and 2 of 3 captures in 2018 were recaptures (including between and within year recaptures), which suggests a high recapture rate for this species in the study area.

Estimates of Northern Pikeminnow density were greater in Reach 3 than in Reach 4, and increased with decreasing river kilometre, which represents increasing proximity to Arrow Lakes Reservoir (Figure 22). Northern Pikeminnow distribution was slightly further upstream in 2014 and 2015 than other years but overall there was little difference in distribution among years (Figure 23). The effect of the flow regime on distribution of Northern Pikeminnow was not significant (*P* = 0.7; effect size: 0%, CRI: -2% to 3%).

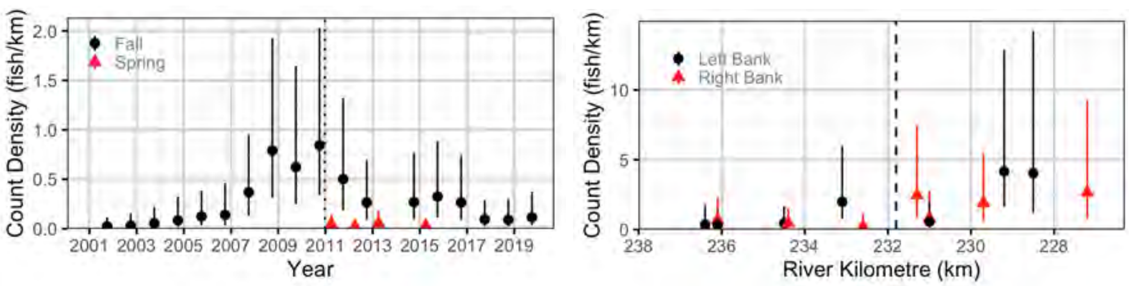

Figure 22: Count density estimates (with 95% credible intervals) by year and season (left panel) and site (right panel) for Northern Pikeminnow in the middle Columbia River study area, from 2001 to 2019. The dotted line (left panel) represents the implementation of the minimum flow release and REV5 operations. The dashed line (right panel) represents the divide between Reaches 3 and 4 at the Jordan River confluence. Revelstoke Dam is located at RKm 238.

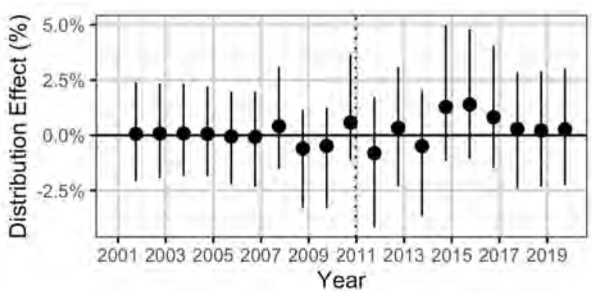

Figure 23: Effect of year on the distribution (with 95% credible intervals) of Northern Pikeminnow densities by year in the middle Columbia River study area, 2001 to 2019. Positive values indicate an upstream shift in distribution and negative values indicate a downstream shift. The dotted line represents the implementation of the minimum flow release and REV5 operations.

3.6.8 Capture Efficiencies

Capture efficiency was calculated as part of the abundance model using mark-recapture data. Mean estimates of capture efficiency for Bull Trout were consistent over time, ranging from 3% to 6% across all sessions and years for juveniles and 2% to 3% for adults (Appendix H, Figures H7-H8).

Capture efficiency of Largescale Sucker in 2019 ranged from 2% to 3%, which was within the range of previous years of the study (1% to 6% in fall; Appendix H, Figure H9). Capture efficiency of Largescale Sucker was greater in 2016 than other years, with estimates of 5% to 6% in capture sessions 1 to 3. Capture efficiency of Largescale Sucker was lower during the spring than fall, with values typically less than 2%.

Capture efficiency was low for juvenile Mountain Whitefish (<1%), but stable across sampling sessions and years (Appendix H, Figure H10). For adult Mountain Whitefish (age-2 and older), capture efficiency was similar across years and sessions but greater in the spring (3% to 5%) than in the fall (1% to 3%; Appendix H, Figure H11). This may indicate that adult Mountain Whitefish were more likely to leave the study area after marking during the fall than during the spring.

Capture efficiency of Rainbow Trout ranged from 6% to 10% in the fall and 3% to 6% in the spring (Appendix H, Figure H12).

Although there were small differences in capture efficiency among species and life stages, there were no long-term trends in capture efficiency over time or sessions. Inter-session variation in capture efficiency did not appear to co-vary substantially among species. This indicates that field crews maintained similar capture efficiency within and among sample sessions.

The abundance model used data for captured fish during the mark-recapture surveys and counted fish during the geo-referenced visual surveys. Capture efficiency was calculated based on the marked and recaptured fish. The relative efficiency was calculated as the percent difference between counted and captured fish, relative to the number of captured fish. Relative efficiency of 84% for adult Bull Trout suggested that 84% more fish were observed and counted than were captured by netters (Appendix H, Figure H13). The relative efficiency for adult Mountain Whitefish was 130% and for Largescale Suckers was 89%. For juvenile fish, the relative efficiency of counted to captured fish was 145% for Mountain Whitefish and 64% for Bull Trout.

The relative error, which is a measure of the variability (overdispersion) in the number of fish counted versus captured, was 54% for adult Mountain Whitefish, 50% for adult Bull Trout, and 50% for Largescale Suckers, which indicates greater variability in the georeferenced counts than in the catches during mark-recapture (Appendix H, Figure H14).

3.6.9 Site Fidelity

Site fidelity was defined as the probability that a fish recaptured within the same season in a particular year was encountered at the same site as the previous capture (Appendix H, Figures H15 to H18). Site fidelity was used to evaluate the extent to which sites are closed within a sampling season. Site fidelity of Bull Trout was greater in fall than in spring, and declined with increasing body size (fork length) from ~75% for a 200 mm fish to ~25% for a 600 mm fish during the fall season (Appendix H, Figure H15). Site fidelity of Largescale Sucker increased with increasing body size from ~25% for a 300 mm fish to ~70% for a 500 mm fish during the fall season (Appendix H, Figure H16). For Mountain Whitefish, site fidelity varied little by body length during the fall, with site fidelity estimates of 46% to 58% (Appendix H, Figure H17). During spring sampling, Mountain Whitefish site fidelity increased between body sizes of 150 to 350 mm and was close to 100% for fish larger than 350 mm. Site fidelity of Rainbow Trout decreased with increasing body size from 79% for a 200 mm fish to 26% for a 400 mm fish during the fall season (Appendix H, Figure H18). Credible intervals for site fidelity estimates were large (often >50% range), especially for spring sampling and species with fewer recaptures, such as Rainbow Trout, indicating high uncertainty in the probability of being recaptured at the same site for a given season and body size.

3.6.10 Observer Length Bias

The length bias model used the length-frequency distribution of captured fish to estimate the bias in the estimated lengths of fish counted in the geo-referenced visual survey (Figure 24). Bull Trout tended to be overestimated in length, while Mountain Whitefish and sucker species were typically underestimated, although there was variation between observers (Figure 25). The amount of inaccuracy (bias) varied by species with underestimates up to 36% for Mountain Whitefish and 28% for sucker species (Figure 25). Inaccuracy ranged from overestimates of 19% to underestimates of 28% for Bull Trout, depending on the observer. Estimates of observer bias were used to correct estimated fork lengths of fish observed during the visual survey.

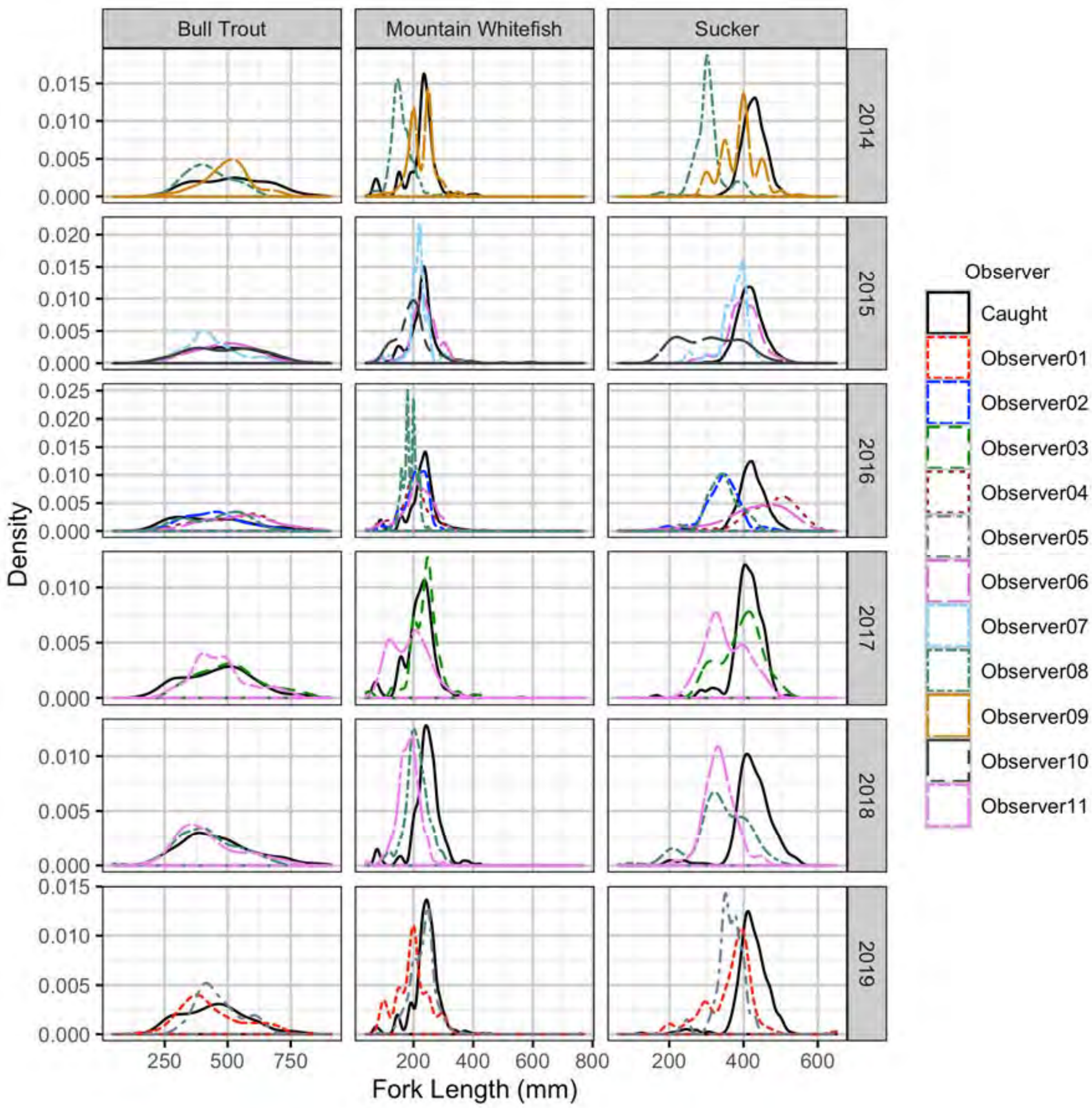

Figure 24: Fork length-density plots for measured and estimated fork lengths of Bull Trout, Mountain Whitefish, and sucker species caught or observed in the middle Columbia River study area, 2014–2019.

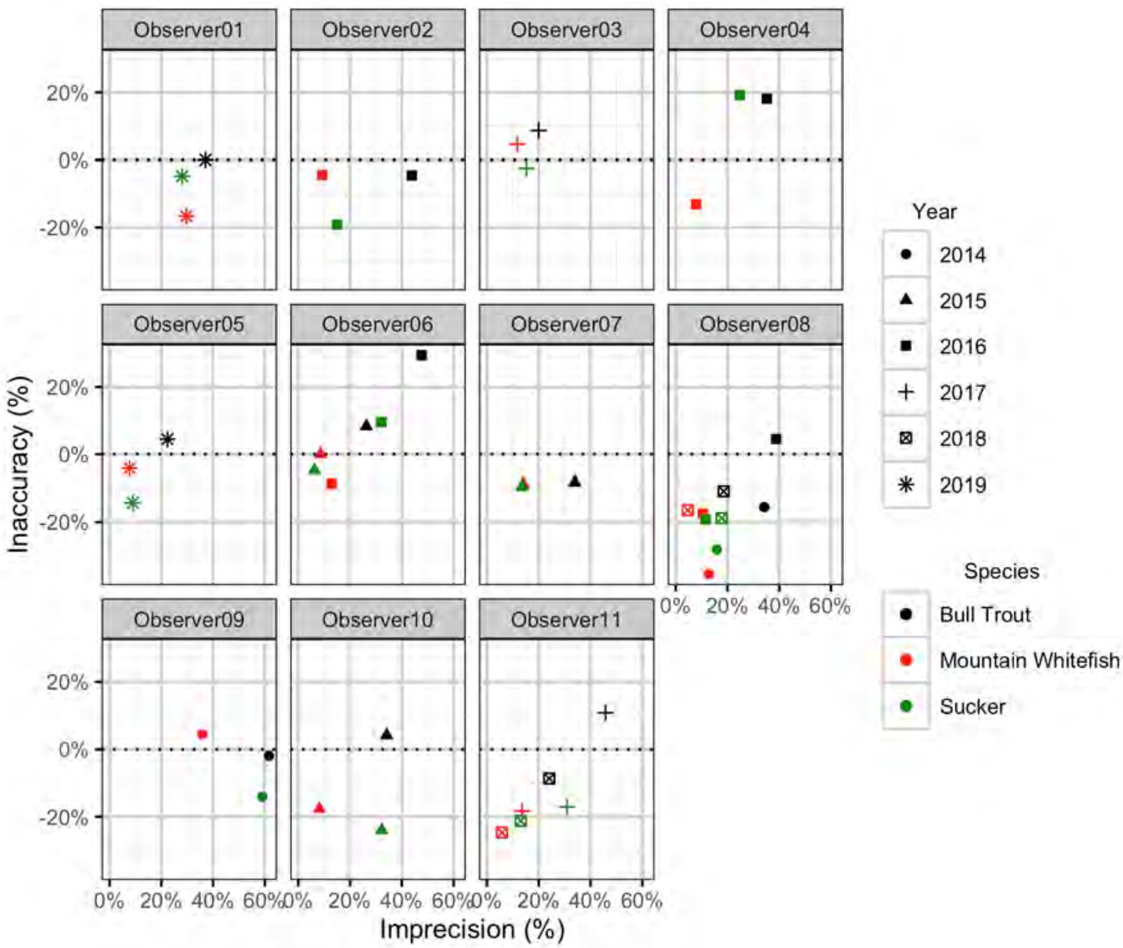

Figure 25: Fish length inaccuracy (bias) and imprecision by observer, year of observation, and species. Observations use the length bias model of captured (mark-recapture surveys) compared to estimated (geo-referenced visual surveys) length-frequency distributions from the middle Columbia River study area, 2014–2019.

3.7 Growth Rate

Growth rates based on recaptured fish were estimated using von Bertalanffy models for Bull Trout, Largescale Sucker, and Mountain Whitefish (Figure 26). The growth model for Mountain Whitefish excluded all individuals larger than 250 mm in fork length, as explained in Section 3.7.2.

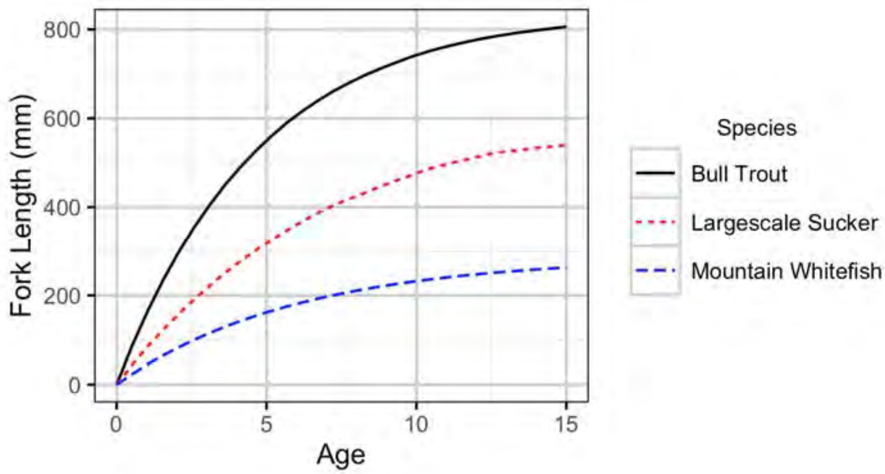

Figure 26: Predicted von Bertalanffy growth curve for inter-year recaptured Bull Trout, Largescale Sucker, and Mountain Whitefish in the middle Columbia River study area, 2001–2019.

3.7.1 Bull Trout

Based on the von Bertalanffy growth model of recaptured individuals, the estimated growth coefficient of Bull Trout ranged from 0.12 to 0.25 between 2001 and 2019 (left panel; Figure 27), with the greatest estimates in 2010 (0.24) and 2017 (0.25). The estimated growth coefficient decreased in years immediately following the flow regime change from 0.24 in 2010 to 0.14 in 2016. However, values of the growth coefficient (k) after the flow regime change (2011–2019) were within the range observed during the previous flow regime (2001–2010). There was no significant difference in the estimated growth coefficient before and after the flow regime change (*P* = 0.7; effect size: -7%, CRI: -31% to 24%). As the von Bertalanffy model is non-linear, the predicted annual growth (change in body length) depends on the size of fish. The maximum growth rate during early life was used to compare between years and ranged from 105 mm/yr in 2008 to 211 mm/yr in 2017 (right panel; Figure 27).

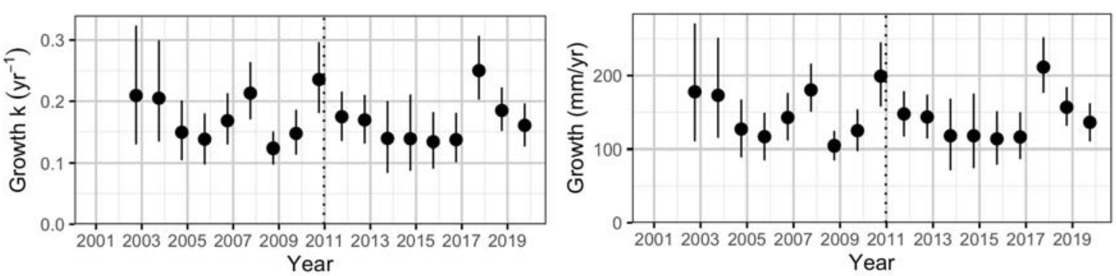

Figure 27: Annual estimates of the von Bertalanffy growth coefficient (left panel) and predicted maximum growth (right panel) with 95% credible intervals for Bull Trout in the middle Columbia River study area, 2001 to 2019. The dotted line represents the implementation of the minimum flow release and REV5 operations.

3.7.2 Largescale Sucker

Both the growth coefficient and the predicted maximum growth suggested slow growth of Largescale Sucker (Figure 28). This reflects the low growth rates of adult Largescale Sucker and the lack of recapture data for juvenile Largescale Sucker. The predicted maximum growth rate declined to close to 0 mm/yr from 2013 to 2016, suggesting very low growth during these years. Slower growth during 2013 to 2016 was also observed for Bull Trout, although the decrease was not as pronounced for Bull Trout as for Largescale Sucker. The predicted maximum growth rate of Largescale Sucker increased to values between 10 and 30 mm/yr in 2017 to 2019.

Recapture data showed that the annual growth (change in fork length) of adult Largescale Sucker was between 0 and 25 mm/yr for most individuals between 350 and 550 mm and did not decline with fork length at initial capture (Appendix H, Figure H19). The lack of declining growth with increasing body size, as is predicted by a von Bertalanffy model, combined with sparse data for juveniles, resulted in difficulties in fitting the von Bertalanffy curve to the data, and sensitivity of the results to the choice of priors. This resulted in greater uncertainty in the estimates of model parameters compared to Bull Trout. Despite this uncertainty, both the raw data from recaptures and the model estimates support a decrease in growth to nearly 0 mm/yr for adult Largescale Sucker in 2013 to 2016, followed by an increase in growth in 2017 to 2019.

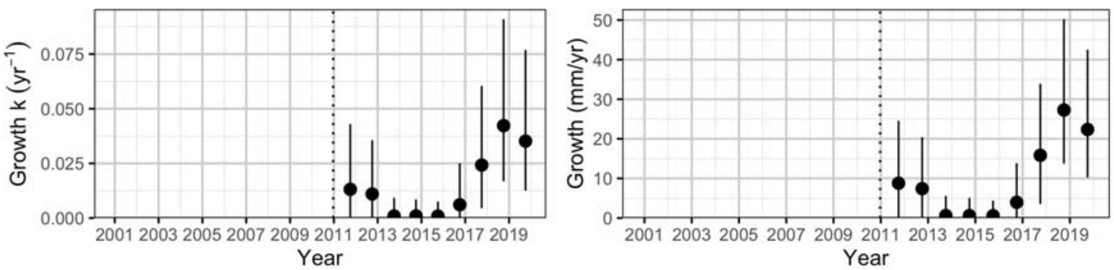

Figure 28: Annual estimates of the von Bertalanffy growth coefficient (left panel) and predicted maximum growth (right panel) with 95% credible intervals for Largescale Sucker in the middle Columbia River study area, 2011 to 2019. The dotted line represents the implementation of the minimum flow release and REV5 operations.

3.7.3 Mountain Whitefish

The majority of recaptured Mountain Whitefish had limited or no growth after reaching approximately 275 mm FL, suggesting an asymptote at this body size for the von Bertalanffy curve. However, some larger recaptured Mountain Whitefish between 300 and 400 mm had considerable annual growth between recaptures (5 to 25 mm per year; Appendix H; Figure H21). This suggested two different groups of Mountain Whitefish with different growth trajectories. As the two growth trajectories cannot be modeled using a single von Bertalanffy curve, only Mountain Whitefish 250 mm or smaller were included in the von Bertalanffy growth model, to provide better estimates of the growth coefficient. Therefore, the interpretation of trends in growth only apply to Mountain Whitefish smaller than 250 mm, which included the majority of the catch, but not to larger individuals.

Estimates of the annual growth coefficient of recaptured Mountain Whitefish ranged between 0.12 and 0.27 in all years except for 2018 when the estimated coefficient was much greater (0.42; left panel of Figure 29). Growth coefficient estimates were within the same range both before and after the flow regime change with the exception of 2018. There was no significant difference in the estimated growth coefficient before and after the flow regime change (P = 0.7; effect size: 8%, CRI: -30% to 64%). The predicted maximum growth rate during early life was 122 mm/hr in 2018, and ranged from 34 to 79 mm/hr in other years (right panel; Figure 29). For a Mountain Whitefish of ~180 mm in fork length, the observed growth was approximately 30 to 40 mm in 2018 compared to 15 to 30 mm in other years (data not shown).

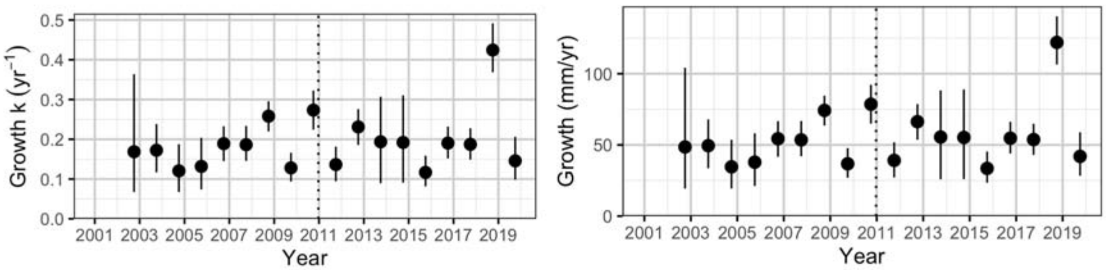

Figure 29: Annual estimates of the von Bertalanffy growth coefficient (left panel) and predicted maximum growth (right panel) with 95% credible intervals for Mountain Whitefish in the middle Columbia River study area, 2001 to 2019. The dotted line represents the implementation of the minimum flow release and REV5 operations.

3.7.4 Rainbow Trout

The von Bertalanffy growth curve could not be calculated for Rainbow Trout because of insufficient recapture data. As a visual assessment of the growth of Rainbow Trout, the annual growth (mm/yr) of recaptured fish was plotted versus the length at initial capture. The annual growth decreased with increasing fork length, as expected by a von Bertalanffy model, but the sample size was too small to estimate the curve for the periods before and after the flow regime change. Annual growth ranged from approximately 30 to 90 mm/yr for a 200 mm Rainbow Trout, and approximately 15 to 60 mm for a 350 mm Rainbow Trout (Appendix H, Figure H20). Although the sample sizes of inter-year recaptured Rainbow Trout were small, the annual growth data did not suggest any differences in growth before and after the flow regime change, based on this visual assessment.

3.8 Body Condition

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

3.8.1 Bull Trout

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

Trends in estimates of the body condition of Bull Trout in the MCR were similar for juveniles and adults (Figures 30 and 31). Body condition estimates were greatest in 2003 and 2004 and decreased after the flow regime change, with an effect size ranging between 11% to 16% lower than a typical year for juveniles and 8% to 11% lower than at typical year for adults from 2014 to 2016. Body condition increased by over 20% in 2017, with an effect size of 9% for juvenile and 10% for adult Bull Trout. In 2018 and 2019, body condition returned to below average values for juveniles (-10% to -11%) and adults (-9% to -10%).

The predicted condition (weight-at-length) was significantly lower after than before the flow regime change for both juvenile (300 mm; P = 0.02; effect size: -9%, CRI: -16% to -3%) and adult Bull Trout (500 mm; P = 0.03; effect size: -7%, CRI: -13% to -1%). There was no effect of season on the slope

(*P* = 0.7) or intercept (*P* = 0.9) of the weight-length relationship, suggesting no significant difference in Bull Trout body condition between spring and fall. Site was not included as an effect in the model because previous year's analyses showed very little variation in condition among sites.

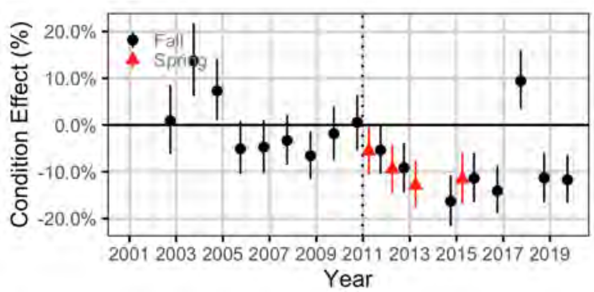

Figure 30: Body condition effect size estimates (with 95% credible intervals) by year for a 300 mm FL juvenile Bull Trout in the middle Columbia River study area, 2002 to 2019. The dotted line represents the implementation of the minimum flow release and REV5 operations.

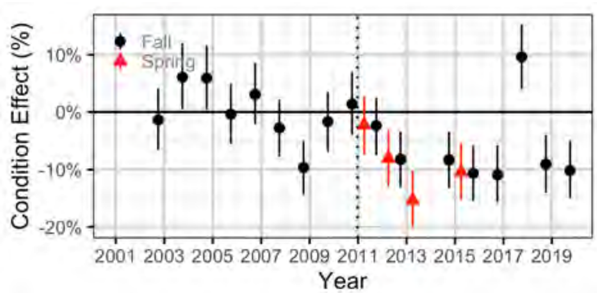

Figure 31: Body condition effect size estimates (with 95% credible intervals) by year for a 500 mm FL adult Bull Trout in the middle Columbia River study area, 2002 to 2019. The dotted line represents the implementation of the minimum flow release and REV5 operations.

3.8.2 Largescale Sucker

The estimated body condition of adult Largescale Sucker declined in years following the flow regime change from 12% in 2010 to -11% in 2015 (Figure 32), increased in 2017 (6%) and 2018 (8%) and remained higher than average in 2019 (4%). The effect of flow regime on the predicted weight-at-length of Largescale Sucker was not statistically tested because there was only one study season prior to the flow regime change. The slope and intercept of the weight-length relationship differed by season (both $P \leq 0.001$), with greater values in spring than in fall. The condition of juvenile Largescale Sucker was not estimated because very few individuals smaller than 320 mm were captured between 2010 and 2019.

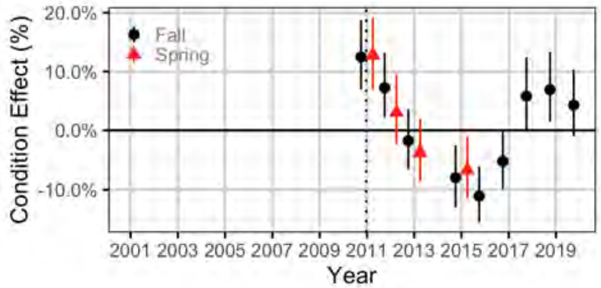

Figure 32: Body condition effect size estimates (with 95% credible intervals) by year for a 500 mm FL adult Largescale Sucker in the middle Columbia River study area, 2010 to 2019. The dotted line represents the implementation of the minimum flow release and REV5 operations.

3.8.3 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 2011, 2012). Analyses in this report only included previously untagged fish to avoid potential effects of tagging on body condition.

Body condition estimates of juvenile Mountain Whitefish showed a decline from a 9% effect size in 2003 to -7% in 2011 and remained fairly low (0% or lower effect size) in 2012 to 2016 (Figure 33). The body condition estimate of juveniles was larger in 2017 than all previous study years (11% effect size) but decreased to 2% in 2018 and -4% in 2019. Body condition estimates of adult Mountain Whitefish had a similar pattern to juveniles, with declining condition from 2003 to 2010, low values in 2011 to 2016, high body condition (9% effect size) in 2017, and a decrease in 2018 (3%) and 2019 (-1%; Figure 34).

The predicted condition (weight-at-length) was not significantly different before and after the flow regime change for both juvenile (100 mm; $P = 0.7$; effect size: -1%, CRI: -7% to 5%) and adult Mountain Whitefish (250 mm; $P = 0.4$; effect size: -2%, CRI: -6% to 2%). There was a difference in the slope and intercept (both $P < 0.001$) of the weight-length relationship by season. Adult Mountain Whitefish had significantly greater body condition in the fall than in the spring. Site was not included as an effect in the body condition model in this analysis.

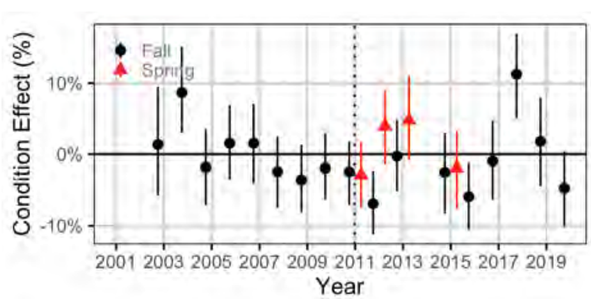

Figure 33: Body condition effect size estimates (with 95% credible intervals) by year for a 100 mm FL juvenile Mountain Whitefish in the middle Columbia River study area, 2002 to 2019. The dotted line represents the implementation of the minimum flow release and REV5 operations.

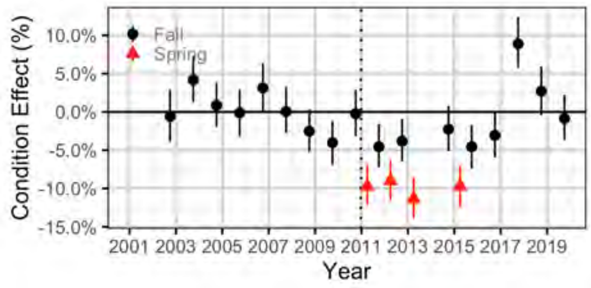

Figure 34: Body condition effect size estimates (with 95% credible intervals) by year for a 250 mm FL adult Mountain Whitefish in the middle Columbia River study area, 2002 to 2019. The dotted line represents the implementation of the minimum flow release and REV5 operations.

3.8.4 Rainbow Trout

Body condition of juvenile Rainbow Trout varied little among study years and credible intervals overlapped for all estimates (Figure 35). However, estimates of juvenile body condition were greater in 2017 (9% effect size) than all other years. For adult Rainbow Trout, the results did not suggest an effect of flow regime on body condition. Body condition estimates of adult Rainbow Trout in fall fluctuated between -6% and 6% effect sizes between 2003 and 2017 and were lowest in 2018 and 2019 (-7% effect size). Body condition was not greater in 2017 than previous years, as was observed for other species (Section 3.8.1 to 3.8.3). 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 captured in 2002.

The predicted condition (weight-at-length) was not significantly different before and after the flow regime change for both juvenile (150 mm; P = 0.9; effect size: 0%, CRI: -6% to 7%) and adult Rainbow Trout (300 mm; P = 0.2; effect size: -3%, CRI: -9% to 2%). The slope of the weight-length relationship did not differ by season (P = 0.6) but the intercept did differ by season (P < 0.001), indicating a significantly lower body condition in the spring than the fall.

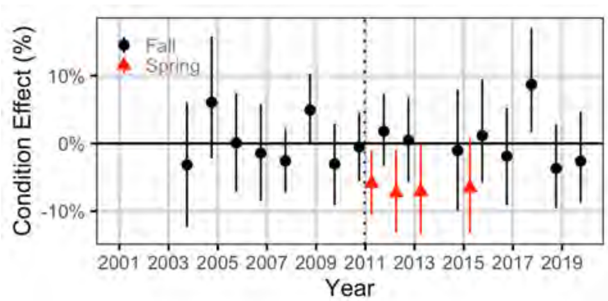

Figure 35: Body condition effect size estimates (with 95% credible intervals) by year for a 150 mm FL juvenile Rainbow Trout in the middle Columbia River study area, 2003 to 2019. The dotted line represents the implementation of the minimum flow release and REV5 operations.

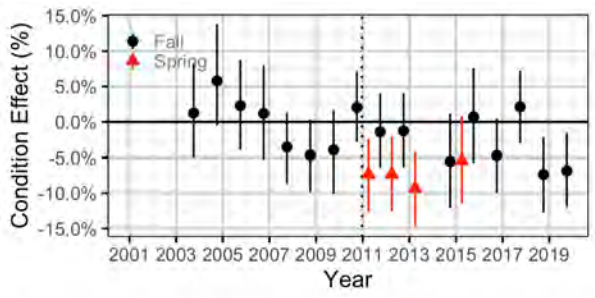

Figure 36: Body condition effect size estimates (with 95% credible intervals) by year for a 300 mm FL adult Rainbow Trout in the middle Columbia River study area, 2003 to 2019. The dotted line represents the implementation of the minimum flow release and REV5 operations.

3.8.5 Other Species

Length and weight data were recorded for all species encountered between 2010 and 2019. However, body condition is not presented for Lake Whitefish, Northern Pikeminnow, Prickly Sculpin (*Cottus asper*), and Redside Shiner because wide CRIs precluded any meaningful interpretation of the results for these species.

3.9 Summary of Effect of Flow Regime

The four fish population metrics used in this program are abundance, distribution, growth, and body condition. To assess differences in the metrics before and after the flow regime change, an effect of flow regime was included in the models. The statistical significance and effect size of the difference in fish population metrics before and after the flow regime change were assessed (Table 8; Figure 37). For all four species where a mark-recapture estimate of abundance was possible, the flow regime did not have a statistically significant effect on the rate of population growth; however, negative effect sizes for juvenile Bull Trout (-14%) and juvenile Mountain Whitefish (-15%) suggested lower rates of population growth after the flow regime than before. The rate of population growth based on count densities was lower after the flow regime change than before for Burbot (-33%), Northern Pikeminnow (-46%), and Rainbow Trout (-29%), although the difference was not statistically significant for Burbot ($P = 0.06$). The rate of population growth could not be assessed for sucker species but the estimated count density was 78% greater after the flow regime change than before.

Body condition was analyzed using a weight-length regression. The estimated body condition was not significantly different before and after the flow regime change for Mountain Whitefish and Rainbow Trout, with effect size estimates close to 0% (Table 8). For Bull Trout, body condition was 7% lower after the flow regime change than before for adults and 9% lower for juveniles. There was an incremental decrease in the body condition of adult Largescale Sucker in the first five years following the flow regime change (23% decrease), but the before/after comparison could not be assessed because sucker species were not captured or measured before 2010. The effect of the flow regime on the von Bertalanffy growth coefficient was not significant for Bull Trout or Mountain Whitefish, suggesting no difference in growth between flow regimes. The large credible intervals around effect size estimates for Bull Trout (-31% to 24%) and Mountain Whitefish (-30% to 64%) indicate considerable uncertainty in the assessment of growth (Figure 37).

Estimates of the distribution suggested an upstream shift in spatial distribution during some years after the flow regime change for adult Bull Trout, Mountain Whitefish, Rainbow Trout, and sucker species (Figure 37). This difference in distribution was statistically significant for Rainbow Trout but not for

Mountain Whitefish, sucker species or Bull Trout (Table 8). The effect size of 2% for Bull Trout and Mountain Whitefish, 3% for sucker species, and 5% for Rainbow Trout can be interpreted as the percent change in the relative density per kilometre upstream.

Table 8. Statistical significance and effect size for the effect of flow regime on fish population metrics in the MCR, 2001–2019. Direction of Effect indicates a positive or negative change after the flow regime change for significant effects (*P*<0.05; bold text). Effect sizes include the lower 95% credible limit (LCL) and the upper 95% credible limit (UCL).

Test	Species	Life Stage	*P*-value	Direction of Effect	Effect Size		
					Estimate	LCL	UCL
Rate of Population Growth (Abundance)	Bull Trout	Juvenile	0.06		-14%	-27%	1%
	Bull Trout	Adult	0.9		-1%	-10%	10%
	Mountain Whitefish	Juvenile	0.4		-15%	-44%	21%
	Mountain Whitefish	Adult	0.5		2%	-5%	9%
	Rainbow Trout	Adult	0.6		9%	-25%	56%
Rate of Population Growth (Count Density)	Rainbow Trout	All	**0.01**	–	-29%	-46%	-11%
	Burbot	All	0.06		-33%	-57%	3%
	Northern Pikeminnow	All	**0.002**	–	-46%	-63%	-28%
Count Density	Sucker species	All	**0.02**	+	78%	7%	198%
Condition[a]	Bull Trout	Juvenile	**0.02**	–	-9%	-16%	-3%
	Bull Trout	Adult	**0.03**	–	-7%	-13%	-1%
	Mountain Whitefish	Juvenile	0.7		-1%	-7%	5%
	Mountain Whitefish	Adult	0.4		-2%	-6%	2%
	Rainbow Trout	Juvenile	0.9		0%	-6%	7%
	Rainbow Trout	Adult	0.2		-3%	-9%	2%
Growth[b]	Bull Trout	All	0.7		-7%	-31%	24%
	Mountain Whitefish	< 250 mm	0.7		8%	-30%	64%
Distribution[c]	Bull Trout	Juvenile	0.4		0%	-1%	1%
	Bull Trout	Adult	0.1		2%	0%	5%
	Mountain Whitefish	Adult	0.3		2%	-2%	6%
	Rainbow Trout	All (count)	**0.04**	+	5%	0%	11%
	Sucker	All (count)	0.3		3%	-2%	7%
	Burbot	All (count)	>0.9		0%	-1%	1%
	Northern Pikeminnow	All (count)	0.7		0%	-2%	3%

a. Statistical tests and effect sizes for condition are based on the predicted weight-at-length for a representative sized fish

b. Statistical tests and effect sizes for growth are based on the growth coefficient (k) from the von Bertalanffy model

c. A positive distribution effect (+) indicates a more upstream distribution after the flow regime change and a negative effect (−) indicates a more downstream distribution after the flow regime change.

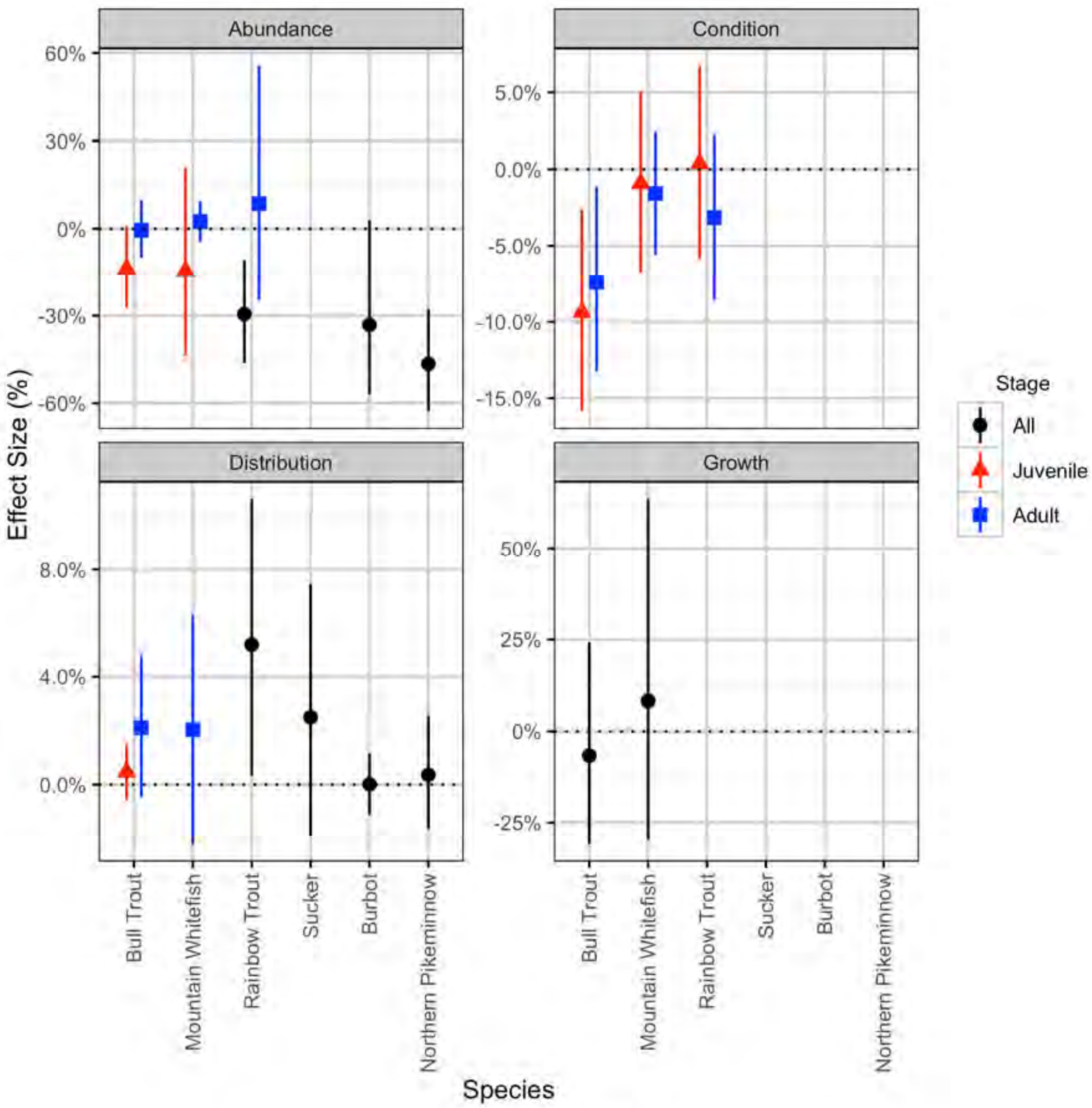

Figure 37: Estimates (with 95% credible intervals) of the effect of the flow regime change by species, analysis, and life stage. The abundance estimates are the percent change in the annual population growth rate. The distribution estimates are the percent change in the relative upstream density per km.

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

The statistical models in this report include the effect of flow regime to test for differences before and after the flow regime change. This type of before/after test is most appropriate for time-series that were relatively stable during the "before" period, and for effects that resulted in a permanent step-change in the response variable. Before/after tests are less useful for other situations, such as variables that were changing drastically during the "before" period, changes that have a delayed or temporary response, or incremental changes after the new flow regime, all of which are possible responses for fish population metrics in the MCR. Therefore, statistical tests of the effect of the flow regime are used to address the management questions, but trends in the fish population metrics throughout the time-series should also be considered when interpreting the results.

4.1 Discharge, Temperature, and Revelstoke Dam Operations

In 2019, discharge in the MCR was lower than average for the majority of the year, but within the range of values observed previously between 2001 and 2018. Reservoir elevation in ALR in 2019 was above average for parts of the year, including during fall sampling, and near average for other parts of the year. Mean water temperature was 1°C to 2°C lower than average during spring in 2019, but near average during summer and fall. Discharge and water temperature in the MCR and reservoir elevation in ALR are affected by operations at Revelstoke Dam but also are highly dependent on inter-annual variation in weather. Both natural inter-annual variability and the flow regime change have the potential to influence fish populations in the MCR.

Variation in discharge before and after the flow regime change was not analyzed in detail within this study. However, discharges were presented (Section 3.1 and Appendix C) to provide context when interpreting trends in fish populations in the MCR. The effects of the flow regime change on water levels and other habitat variables are assessed as part of BC Hydro's MCR Physical Habitat Monitoring Project (CLBMON-15a). A key finding of that study based on modelling results in years past was a predicted 32% increase in permanently wetted riverbed area during times of low reservoir elevation and no backwatering effect from ALR (Golder 2013). An increase in the permanently wetted riverbed area would be expected to increase the benthic productivity in the study area, which could result in benefits to the fish community (Perrin et al. 2004). In addition, the results suggested greater diel variation in water levels at some sites after the flow regime change (Golder 2013). Greater diel variation is plausible because the range of possible discharges at REV changed from 0–1,700 m^3/s to 142–2,124 m^3/s with the flow regime change.

There also were possible differences in diel temperature variations, with narrower daily temperature ranges after the flow regime change than before, although modelled differences were small (<1°C) and may or may not be biologically significant (Golder 2013).

The changes in hydrology after the new flow regime have the potential to affect fish populations through direct effects such as habitat suitability and bioenergetics, or through "bottom-up" effects related to changes in primary production and food availability. The MCR Ecological Productivity Monitoring Project (CLBMON-15b) found that a greater area of permanently submerged substrate associated with the minimum flow increased the biomass of periphyton and benthic invertebrates in the MCR, with a larger effect in Reach 4 than Reach 3 and during months when ALR was not backwatering the MCR study area (Schleppe et al. 2018). The estimated habitat suitability for juvenile fishes in the MCR was lower after than before the flow regime change due to reduced availability of shallow, low velocity habitats that were preferred by juvenile Bull Trout, Mountain Whitefish, Rainbow Trout, Redside Shiner, and Prickly Sculpin (Healey et al. 2019).

4.2 Species Richness and Diversity

As the calculation of species richness did not include species that were always encountered or very rarely encountered, the estimates of richness represent the number of "moderately rare" species encountered in a typical site each year. Estimates of species richness increased from 0.2 species in a typical site in 2001 to 2.5 species per site in 2008. The increase in richness from 2001 to 2008 was related to increases in the probability of occupancy of several species, including Burbot, Lake Whitefish, Northern Pikeminnow, Rainbow Trout, Redside Shiner, and sculpin species. During years when species richness increased, electroshocking protocols (Section 2.1.6) and capture efficiencies of tagged species (Section 3.6.8) were similar. Therefore, the observed increases in the probability of occupancy likely reflect real changes in abundance and not sampling biases, such as increased netting efficiency over time.

The increase in evenness from 2001 to 2007 (17% to 29%) was the result of less common species becoming relatively more common during that time period. Density estimates showed increasing trends for Burbot, Northern Pikeminnow, and Rainbow Trout, whereas densities of the most common species, 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.

During the period after the flow change in 2010, species richness decreased from ~2.5 to ~1.5 species per site from 2012 to 2014 but has remained relatively stable since 2014. The decline in richness (2012 to 2014) was related to decreasing probability of occupancy for most taxa, including Burbot, Northern Pikeminnow, Rainbow Trout, and sculpin species. Species evenness was relatively stable in years since the flow regime change (23%–28% from 2011–2019).

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

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

In summary, increasing trends from 2001 to 2008 in richness, evenness, and the probability of occupancy for several less common species suggest a substantial change in the fish community during that time period. A second change in the fish community occurred beginning in 2012, with declining richness and occupancy of many of the less common species, whereas species evenness was relatively constant in the years following the flow regime change.

4.3 Management Question #1 – Abundance

4.3.1 Bull Trout

Trends in the estimated abundance of juvenile and adult Bull Trout did not suggest any changes related to the flow regime. Juvenile Bull Trout abundance estimates declined in some years after the flow regime change (2012 to 2014) but increased from 2014 to 2018. Adult Bull Trout abundance estimates were relatively stable in the first six years after the flow regime change (1,500–1,800 individuals in 2011 to 2016) and greater than average in 2017 to 2019 (1,900 to 2,400 individuals; Figure 9).

Recent modelling of creel data from the recreational fishery in ALR (van Poorten and Woodruff 2018) are available for comparison to abundance estimates in the MCR. The statistical catch-at-age model predicted the greatest biomass of adult (age-3 to age-5 and age-6+ groupings) Bull Trout in ALR in 2000 to 2004, years that had some of the lowest estimated abundances in the MCR. Predicted recruitment of age-2 Bull Trout was greatest in 2012, and low in 2010 and 2013 (van Poorten and Woodruff 2018). Effects of relatively high/low recruitment from these cohorts were not evident in abundance trends in the MCR, assuming most of the boat electrofishing catch was age-3 to age-7 (approximately 400 to 700 mm), based on the length-at-age data (Figure 26 and Figure 1 in van Poorten and Woodruff 2018). Lack of correspondence between predicted trends in ALR and the MCR could be because of the different types of data and modelling approaches, or because the data represent separate populations of Bull Trout, or both.

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 juveniles 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 H15). 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.

4.3.2 Sucker Species

Count density of sucker species was relatively constant from 2004 to 2013 (8–23 fish/km), greater in 2014 and 2015 (29–42 fish/km), and lower in 2016 to 2019 (5–14 fish/km). From 2011 to 2015, density of sucker species increased three-fold from 14 to 42 fish per kilometre. Abundance estimates of Largescale Sucker also increased from 2010 to 2015 (4,400 to 9,100 individuals) and decreased to low levels in 2016 to 2019 (2,300–4,200 individuals). 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 benefit from increased productivity caused by flow regime through greater food availability. The increasing estimates of density and abundance in some years after the flow regime change may indicate a positive effect of the flow regime on the abundance of suckers in the MCR.

One factor that could limit the ability to detect changes related to the flow regime is the long-lived nature of suckers (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). This life history could result in a time-lag before changes in habitat conditions affect abundance of mature adult suckers originating from the MCR. Therefore, the observed increases in sucker species density may be explained by increased usage of the MCR by fish originating from ALR, increased production of sucker species within the MCR, or both.

Of the sucker species captured in the spring sessions, a large percentage (26% to 42% in 2011 to 2013) were identified as spawners, through the release of eggs or milt or the presence of tubercles (both species combined). These observations suggest that the MCR could be a major spawning area for these species. During surveys, sucker species were routinely observed in suitable spawning habitats (shallow riffles over small gravel substrate) at Sites 232.6-R, 231.0-R, and 229.7-R. If sucker species 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). The area near the Trans-Canada highway bridge (near 231.0-R and 229.7-R) was ranked as high risk for stranding juvenile fishes, compared to other sites assessed in the MCR, and dewatered Kokanee redds have been observed at this location (Tomlinson and Sykes 2013). However, spawning by suckers at this location has not been confirmed and stranded sucker eggs or juveniles have not been detected at this site; therefore, there is no evidence of significant stranding of early life history stages of sucker species in the MCR.

4.3.3 Mountain Whitefish

Abundance estimates of both juvenile and adult Mountain Whitefish did not suggest any significant change after the new flow regime. There were relatively higher densities of juvenile Mountain Whitefish in 2010 (before the flow regime change) and 2011 (after the flow regime change) compared to other study years, which were likely the result of large numbers of age-0 fish in 2009 and 2010 (Appendix E, Figure E2). These two cohorts represent spawning that occurred during the winters of 2008/2009 and 2009/2010, time periods that were characterized by water temperatures and river discharges comparable to other study years, but higher than average water elevation during winter in ALR, especially in 2008/2009 (Appendix C, Figure C3). The estimated abundance of adult Mountain Whitefish fluctuated between similar values before and after the flow regime change and did not suggest any change related to the flow regime. Estimated abundance of adult Mountain Whitefish was greater in 2018 and 2019 (23,000 and 26,000 individuals) than all previous years (14,000–22,000 individuals), suggesting a healthy population in recent years.

Mountain Whitefish abundance could potentially be affected by the new flow regime if food availability or habitat suitability changed in a way that affected recruitment or survival. A modelling study in the MCR found that during the summer and winter, habitat suitability for juvenile fishes including Mountain Whitefish was lower after the flow regime than before, due to less availability of shallow, low water velocity habitats under the new flow regime (Healey et al. 2019). However, these authors noted that lower habitat suitability does not necessarily result in lower recruitment or survival of juveniles because of the other possible effects of the flow regime that can influence fishes, such as changes in productivity. A previous study in the MCR based on telemetry data found that the activity of adult Mountain Whitefish was not correlated with within-hour changes in discharge but was correlated with discharge magnitude (Taylor and Lewis 2011). This suggests that the greater possible discharge magnitude of the new flow regime may affect swimming activity of Mountain Whitefish but it is unknown if this has implications for their survival or abundance. The flow regime change could also potentially affect Mountain Whitefish populations through effects on spawning in the mainstem. However, the extent and location of spawning by Mountain Whitefish in the MCR mainstem is unknown and the abundance estimates do not suggest any significant changes since the flow regime change.

The abundance of juveniles was not different between spring and fall. However, 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. 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 winter and into tributaries for spawning. Sampling occurred slightly later in 2018 and 2019 than previous years (i.e., mid-October to early November, rather than early October to late October like in many previous years; Table 2). If larger numbers of adult Mountain Whitefish migrate into the MCR prior to spawning later in the fall, then the later sampling in 2018 and 2019 may help explain the higher than average abundance estimates during these years.

Recapture rates of adult Mountain Whitefish were higher in the spring (~3% to 6%) than in the fall (~1% to 3%; Appendix H, Figure H11). 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 H17). 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) but more likely related to seasonal changes in behaviour of adult Mountain Whitefish. 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.

4.3.4 Rainbow Trout

Low catches of this species resulted in high uncertainty in density and abundance estimates. Count density estimates for Rainbow Trout gradually increased from 2001 to 2008, decreased in 2012 to 2014, and were relatively stable from 2014 to 2019. Mark-recapture abundance estimates showed a different trend, with stable estimates from 2007 to 2015 (43 to 72 individuals) and greater abundance from 2016 to 2019 (83 to 144 individuals). The decrease in count density in some years after the flow regime change (2012 to 2014) resulted in a significant negative effect (effect size: -29%, CRI: -46% to -11%) of the flow regime on the rate of population growth. However, abundance estimates did not support an effect of the flow regime on the Rainbow Trout abundance in the MCR. The different trends suggested by estimates of count density versus mark-recapture-based abundance result in uncertainty in whether or not the flow regime affected the abundance of Rainbow Trout in the MCR.

Abundance estimates of Rainbow Trout increased with proximity to ALR, with the greatest abundance in sites in the transition zone between ALR and the MCR. The upstream extent of the transition zone, which depends on the ALR elevation, may therefore influence the distribution of Rainbow Trout in the study area.

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

4.3.5 Burbot

Count densities (≤1.0 fish/km) suggest relatively low densities of Burbot compared to most other species in the study area. Estimated count densities of Burbot increased from 2001 to 2008, decreased in 2009, and increased in 2010 and 2011. Densities decreased from 2012 to 2015 and remained low in 2016. Burbot density was slightly greater from 2017 to 2019 than from 2012 to 2016 but estimated count densities remained low (<0.5 fish/km). The count density model indicated a negative effect of the flow regime on the rate of population growth, although the effect was not statistically significant (effect size: -33%, CRI: -57% to 3%). The negative growth rate after the flow regime change was likely related to the decrease in density from 2012 to 2015. However, there were large inter-annual fluctuations, such as low density in 2009 and 2010, that make it more difficult to interpret these time trends relative to the effect of the flow regime.

Based on catch-rates recorded during BC Hydro's Arrow Reservoir Burbot Life History and Habitat Use Study (CLBMON-31; LGL 2009), Burbot are relatively common in upper Arrow Lake (i.e., Reaches 1 and 2) when compared to Reaches 3 and 4. During the 2008 and 2011 field seasons when Burbot densities were greatest, ALR levels were higher than during any other study years (Appendix C, Figure C3), with the reservoir backing up into Reach 4 for most of the field season during both years. Higher water elevation levels during the 2008 and 2011 field seasons may help explain higher Burbot count densities observed during those study years. In 2017 to 2019, reservoir level was above average most of the time and there was a small increase in the estimated density of Burbot.

Densities of Burbot were very low in 2014 to 2016, with very few Burbot caught or observed in the fall of 2014 (*n* = 3), 2015 (*n* = 0), 2016 (*n* = 2). In comparison, the number of Burbot caught or observed was greater in 2017 (*n* = 7), 2018 (*n* = 24), and 2019 (*n* = 12; Appendix D, Table D1). Burbot are uncommon in the study area and are difficult to net and observe because they typically remain on the substrate near cover after being subjected to the electric field. It is possible that years with very low densities were related to new and less experienced netters on the field crew in 2014 to 2016. Alternatively, estimates of Burbot densities may have been low simply because of fewer chance encounters of this uncommon species, or because of real declines of their abundance within the study area.

4.3.6 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.

The number of Kokanee caught or observed was low in 2018 (*n* = 41) and 2019 (*n* = 3) compared to the high abundance recorded in 2017 (*n* = 9961). Spawner surveys in index tributaries of ALR in 2017 indicated the highest spawner abundance since 2004, and the second highest spawner abundance since 1995 (unpublished data, Ministry of Forests, Lands, Natural Resource Operations, and Rural Development [MFLNRORD] 2018). Reasons for the increase in Kokanee spawners in 2017 are unknown. Preliminary data from the limnology monitoring program showed no abnormal trends in the levels of phytoplankton, proportions of edible to inedible zooplankton, or in the densities of *Mysis diluviana* in the years prior to 2017 when this cohort of Kokanee was rearing (unpublished data, MFLNRORD 2018). Kokanee abundance was very low from 2012 to 2016 (Basset et al. 2016). Low abundance of Kokanee in Upper Arrow Lakes Reservoir in 2012 to 2016 was attributed to poor growth and survival of juvenile Kokanee, which was related to declines in edible phytoplankton and zooplankton, and possibly a large disease-related die-off of the 2010 cohort (Bassett et al. 2016).

4.3.7 Northern Pikeminnow

The estimated density of Northern Pikeminnow in the MCR increased from 2007 to 2010 but drastically decreased from 2011 to 2013 and remained low in 2014 to 2019. The start of the decrease in the density of Northern Pikeminnow in 2011 coincided with the implementation of the flow regime change. The decreasing density estimates in years after the flow regime change resulted in a statistically significant negative effect of flow regime on rate of population growth in the count density model. The effect size estimate indicated a 46% (CRI: -63% to -28%) lower rate of population growth after the flow regime than before (Table 8). Because of the observational study design, it not possible to discern whether the flow regime caused the decrease in population growth rate or only happened at the same time.

Northern Pikeminnow density was nearly 10 times greater in the fall than in spring in 2011 to 2015, which suggests that this species uses habitat in the MCR in the fall but may migrate out of the study area sometime before the spring. Northern Pikeminnow spawn in the spring, typically at locations in streams with water velocity less than 0.4 m/s but occasionally in lakes (McPhail 2007). Little is known about spawning behaviour of Northern Pikeminnow in the MCR, so it is unclear if the very low densities observed in the spring are due to spawning migration out of the area or other factors.

4.3.8 Sculpin Species

The probability of occupancy of sculpin species at a typical site increased from 3% in 2001 to >80% in 2006 to 2008, decreased to 55% in 2009 and increased in 2010 (68%) and 2011 (83%). Occupancy in the fall declined following the flow regime change from 83% in 2011 to 31% to 46% in 2014 to 2018. Occupancy of sculpin species increased to 69% in 2019.

As sampling protocols were relatively consistent from 2001 to 2008, these results suggest a substantial change in sculpin species abundance during this period. Reasons for the increase in sculpin abundance (2001–2008) are unknown. Typically during boat electroshocking surveys, the electrical field does not 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 review of habitat data recorded at the time of sampling (Appendix B, Table B3) did not indicate poorer observational conditions during any particular study year.

Occupancy estimates for sculpin species declined after 2011, with the largest declines in 2014 and 2015, 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. Most of the decrease in occupancy occurred in 2014 and 2015, which were years with new and less experienced netters on the field crew, and sculpin are difficult to observe and capture because of their small size and behaviour. Therefore, it is possible that the decrease could be in part related to the changes in field crew. The boat electrofishing methods used for this program are not efficient for sculpin species and therefore the resulting data may not provide reliable estimates of abundance to answer management questions for these species. Sculpin species were routinely captured as part of BC Hydro’s MCR Juvenile Fish Habitat Use Program (CLBMON-17; Triton 2014). If necessary, it may be more practical to answer specific management questions regarding these species using data collected under that program.

4.4 Management Question #2 – Growth Rate

Growth rate was examined using a von Bertalanffy model of inter-year recaptured fish. There were sufficient recapture data to estimate growth for Bull Trout, Largescale Sucker, and Mountain Whitefish but not for other species. For Rainbow Trout, the annual growth based on the change in length between inter-year recaptures was plotted as a visual assessment of growth of this species.

4.4.1 Bull Trout

The estimated growth coefficient of Bull Trout declined in years following the flow regime change, although growth rates following the change were within the range previously observed. The difference in growth rate before and after the flow regime change was not statistically significant. However, the decrease in growth following the flow regime change was large (>40% decrease in growth coefficient) and could be biologically important. The decreasing trend in the growth coefficient of Bull Trout following the flow regime change was associated with a similar trend in their body condition, and a decline in condition of Largescale Sucker. Kokanee in upper Arrow Lakes Reservoir, which are an important prey for Bull Trout in the study area, declined in abundance during most of the years when Bull Trout growth and condition were decreasing (2012–2016), and this change in prey availability could have been a causal factor of the decline in Bull Trout growth rates. In 2017, the growth coefficient of Bull Trout increased, as did the body condition of most recorded fish species and life stages, and the abundance of Kokanee in ALR. The similar trends in several species suggest a possible broad-scale changes, with poor conditions for growth in 2011 to 2016 and improved conditions in 2017. Bull Trout growth decreased in 2018 and 2019, when the predicted maximum growth rates were 157 and 136 mm/yr, respectively, compared to 211 mm/yr in 2017, and values of 114 to 143 mm/yr in other years after the flow regime change (2011-2016). The predicted maximum growth rate before the flow regime change ranged from 105 to 199 mm/yr.

4.4.2 Largescale Sucker

Largescale Sucker were not netted or measured for length during years prior to the flow regime change, and therefore annual growth could not be compared before and after the flow regime change. The growth model for Largescale Sucker indicated a decline to close to zero growth in some years (2013–2016) after the flow regime change. This trend is based primarily on recaptured adults (>350 mm) and may not reflect the trend in juvenile Largescale Sucker. The low annual growth in 2013 to 2016 (0.6 to 4 mm/yr) coincided with a decline in body condition of Largescale Sucker, which supports poor growth conditions for adult Largescale Sucker during these years. In subsequent years (2017 to 2019), both annual growth and body condition of Largescale Sucker increased. A study of the growth of Largescale Sucker in the Kootenai River in Idaho found that incremental growth in fork length was strongly correlated with the annual amount of nutrient addition to the river, but not correlated with mean river discharge or mean water temperature during the growing season (Watkins et al. 2017). These results suggest that, in the Kootenai River, nutrient concentration and primary productivity have a greater impact on the growth of suckers than mean discharge and temperature.

4.4.3 Mountain Whitefish

Overall, the results did not suggest a significant difference in growth rate of Mountain Whitefish before and after the flow regime change. The predicted maximum growth rate during early life history was similar in years before and after the flow regime change (34–79 mm/hr), with the exception of 2018, when the predicted maximum growth rate was much higher than normal (122 mm/yr). For a Mountain Whitefish of ~180 mm in fork length, the observed growth was approximately 30 to 40 mm in 2018 compared to 15 to 30 mm in other years (data not shown). Reasons for very high growth rates in 2018 are unknown, as body condition of Mountain Whitefish and growth or body condition of other species were not anomalously high in 2018.

The von Bertalanffy model for Mountain Whitefish only used fish ≤250 mm in fork length because the data suggested there were two groups of fish that stop growing at different sizes. The majority of recaptured fish had slow or no growth beginning at approximately 275 mm in size but a smaller number of fish had considerable growth (5-25 mm per year) when recaptured at sizes between 300 and 400 mm in fork length. There are many possible reasons for the two groups of Mountain Whitefish with different growth trajectories including: 1) populations from different habitats, such as river residents versus adfluvial fish from ALR; 2) sex differences in the asymptotic size; or 3) a dietary shift that allows larger fish to continue growing. Omitting fish >250 mm provided better estimates of the growth coefficient to assess changes over time but does not reflect continued growth of large fish (>250 mm) in the study area.

Changes in river discharge related to the new flow regime could affect the growth of Mountain Whitefish in several ways. The increased permanently wetted area is expected to result in greater primary productivity, which could result in increases in secondary productivity including invertebrates that would increase food availability for Mountain Whitefish. In the Skeena River, another large river in British Columbia, food abundance was the main factor limiting growth and abundance for Mountain Whitefish (Godfrey 1955 as cited by Ford et al. 1995). The flow regime could also affect the growth of Mountain Whitefish if changes in the magnitude or variability in discharge affect foraging efficiency, energetic costs of swimming, or habitat suitability. A telemetry study in the MCR found that swimming activity of Mountain Whitefish was positively correlated with discharge magnitude, although the amount of variation explained by discharge magnitude was small (14%; Taylor et al. 2012). This suggests that energetic costs of swimming for Mountain Whitefish could be greater, if discharges are higher under the new flow regime. It is unknown how large a change in discharge would be required to result in a biologically significant change in energetic costs of swimming.

4.4.4 Rainbow Trout

The number of recaptures was too small to model growth using von Bertalanffy curves for Rainbow Trout. In past years, a von Bertalanffy growth model was estimated for Rainbow Trout, but the coefficients had wide credibility intervals and did not indicate much variability among years (Golder et al. 2017). There were not enough recaptured Rainbow Trout to estimate growth from 2013 to 2019 so the model was not included here. A plot of the annual growth by fork length did not suggest any substantial differences in growth before and after the flow regime change (Appendix H, Figure H20).

For species like Rainbow Trout and Largescale Sucker where von Bertalanffy growth curves were not possible or uncertain due to limited sample sizes, management questions regarding the effect of the flow regime on growth can be addressed by using supporting information from body condition analyses (weight-at-length), which does not require recaptured fish, and may be a reasonable proxy for growth in many cases (Lambert and Dutil 1997; Pothoven et al. 2001).

4.5 Management Question #3 – Body Condition

In previous years of this program, body condition was analyzed for Lake Whitefish, Northern Pikeminnow, Prickly Sculpin, and Redside Shiner (in addition to Bull Trout, Largescale Sucker, Mountain Whitefish, and Rainbow Trout; see below); however, limited data for these species resulted in wide CRIs surrounding all estimates. In addition, only one year of data prior to the flow regime change (i.e., 2010) exists for these species, which makes assessing the effects the flow regime more difficult. For these reasons, body condition is only presented for species with sufficient data to adequately assess trends in body condition and address the management question.

4.5.1 Bull Trout

Estimates of Bull Trout body condition decreased by approximately 10% to 15% in the years following the flow regime change and remained low until 2016. Body condition increased by >20% in 2017 for both juveniles and adults. In 2018 and 2019, body condition returned to below average values (approximately -10% effect size for juveniles and adults). Previous analysis suggested a correlation between the trends in Bull Trout body condition and the abundance of Kokanee in Arrow Lakes Reservoir, both of which declined to very low levels in 2012 to 2016 (Golder et al. 2016). Spawner counts of Kokanee in tributaries to Arrow Lakes Reservoir were the second highest ever recorded in 2017 (Jeff Burrows, MFLNRORD, pers. comm.), which coincided with the large increase in Bull Trout body condition. 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). These results suggest that Kokanee abundance is an important determinant of Bull Trout body condition in the study area. The high condition of Bull Trout during years with high abundance of Kokanee could be partly related to stomach fullness, as high Kokanee numbers provide more feeding opportunities for Bull Trout. Field crews frequently observed Kokanee in the mouths of captured Bull Trout, which could result in short-term increases in weight-at-length values.

Bassett et al. (2016) suggested that region-wide climatic variability could be influencing Kokanee abundance because Kokanee stocks also declined after 2010 in Kinbasket Reservoir (Sebastian and Weir 2013) and Kootenay Lake (Andrusak and Andrusak 2015). In the MCR, the similar trends among species in body condition (Bull Trout and Largescale Sucker) and growth (Bull Trout), all of which declined at some point since 2011 and were high in 2017, support the idea of a broad-scale change in growing conditions in the study area.

Bull Trout body condition decreased to the lowest levels observed in the study following the flow regime change in 2010 and have remained low, with the exception of 2017. 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. The large inter-annual variation in Kokanee abundance and its effect on Bull Trout condition could mask any effect the flow regime may have on body condition.

4.5.2 Largescale Sucker

Estimates of the body condition of adult Largescale Sucker decreased more than 20% from 2010 to 2015. Some of these years (2013 to 2015) also had a decrease in maximum annual growth to close to 0 mm/yr, based on the von Bertalanffy model of inter-year recaptured individuals. The decreases in body condition and growth coincided with a large increase in the estimated density of sucker species (Largescale and Longnose Sucker) from 2010 to 2015. The increase in body condition in 2016 to 2018 coincided with lower estimates of the abundance of Largescale Sucker and count density of Sucker species. The inverse relationship between abundance and condition of sucker species suggests competition for resources and density-dependent growth.

It is unknown whether the low abundance of suckers in 2016 to 2019 following the period of rapid population growth (2011–2015) was related to the change in flow regime, natural demographic processes, or other factors. The observed decrease in body condition was the opposite of predicted effects of the new flow regime, which was expected to result in a greater area of permanently wetted substrate that would translate in greater algal productivity, and increases in the body condition of organisms like suckers that consume algae.

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

4.5.3 Mountain Whitefish

The body condition of juvenile and adult Mountain Whitefish declined to near or below average values in 2018 and 2019, after a year of high body condition in 2017 (>10% increase). High body condition of Mountain Whitefish in 2017 coincided with similar increases in the condition of Bull Trout and Largescale Sucker, and a large increase in the abundance of Kokanee in Arrow Lakes Reservoir. Reasons for these increases are unknown but these similar trends suggest good conditions for growth in both ALR and the MCR in 2017. After 2017, trends in body condition varied between species, but in general, the condition of most species returned to typical values by 2019.

During the first six years following the flow regime change (2011–2016), the body condition of adult Mountain Whitefish was lower than average (-2% to -5% effect sizes). However, the period of low body condition of adult Mountain Whitefish started in 2008, a few years before the flow regime change. The fact that body condition decreased before 2010 means that the new flow regime was not the cause of initial decrease in body condition in 2008, although the possibility that the new flow regime had some effect, either positive or negative, on body condition after 2010 cannot be ruled out. For instance, if the flow regime change had a positive effect on body condition, it could have prevented body condition from decreasing further. Or if the flow change had a negative effect on body condition, it may have prevented body condition from recovering after the initial decrease in 2008. The most parsimonious interpretation is that the flow change did not have any significant effect on Mountain Whitefish body condition because estimates were relatively stable between 2008 and 2016. Although the cause of low body condition of Mountain Whitefish in the first six years after the flow regime change is unknown, it coincided with lower than average condition of other species including Bull Trout and Largescale Sucker.

The flow regime change, which included an increase in the minimum and maximum flows, could potentially result in increases in both the mean and 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, although cortisol levels still fell within the normal range for unstressed fish (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. Bioenergetic modelling as part of CLBMON-18, another monitoring program in the MCR, will help improve understanding of the relationship between discharge and energy use (Guy Martel, BC Hydro, pers. comm.).

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

4.5.4 Rainbow Trout

The results did not support a significant difference in the body condition of Rainbow Trout before and after the flow regime change. The body condition of adult Rainbow Trout decreased in the first three years after the flow regime change, which was also observed for other species including Bull Trout and Largescale Sucker. Small sample sizes for Rainbow Trout contributed to greater uncertainty in body condition and CRIs overlapped for all estimates. In 2018 and 2019, estimated body condition of Rainbow Trout was lower than all previous years with a -7% effect size. 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 and possibly because some of the larger Rainbow Trout could be in post-spawning condition during the spring.

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 using a distribution model. The model used the residual variation in density, after accounting for site within year effects, as the response variable. This variable was used to assess trends over time in the distribution of fishes in the MCR. In the model, if the interaction between river kilometre 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.

In previous years, the interaction between river kilometre and flow regime was included in the abundance model to assess the effects of the flow regime on distribution. However, due to the additional model complexity of including more predictor variables, the distribution effect could only be included for a few species with larger sample sizes. Using a separate distribution model allowed the effect of the flow regime on distribution to be assessed for all species that had estimates of count density or abundance.

Values of the distribution effect suggested a further upstream distribution after the flow regime change than before for several species. The river kilometre by flow regime interaction was statistically significant for Rainbow Trout (5% change) but not for Bull Trout (2% change), Mountain Whitefish (2% change), or sucker species (3% change). If there was a real upstream shift in distribution of some species after the flow regime, it could be because the year-round minimum flow and greater permanently wetted area made habitat in the upstream riverine portion of the MCR more attractive for these species. The spatial distribution of fishes in the MCR, including seasonal and temporal trends, is discussed for each species in the following sections. The fine-scale distributions of Bull Trout, Mountain Whitefish, and sucker species as recorded during the geo-referenced visual survey in 2019 are provided on maps in Appendix I.

4.6.1 Bull Trout

In a typical year, 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 further upstream after the flow regime change than before. The estimated effect size was a 2% (CRI: 0% to 5%) change in density per upstream river kilometre, but the change was not statistically significant. The upstream shift in distribution began the first year after the flow regime change (2011) and was apparent in all years since then, except 2018 (Figure 10). One possible explanation for this change in distribution is that the minimum flow implemented in December 2010 made the upstream portions of the study area more suitable or attractive to Bull Trout. Reductions to zero discharge during some nights under the previous flow regime (prior to 2011) could have resulted in reduced habitat use in the upstream portions of the study area closest to the dam, if fish moved to seek more suitable water depths or velocities during these discharge reductions.

4.6.2 Sucker Species

For all sucker species combined, density generally increased with increased distance downstream of the dam. Sucker species prefer lower water velocity areas, except during their spawning season. In general, water velocities in the MCR are lower in Reach 3 than in Reach 4. Reach 3 also contains more backwater habitat areas (e.g., upstream of the Tonkawatla Creek confluence, behind the islands upstream of the Centennial Park Boat Launch, upstream of the Illecillewaet River confluence, and immediately downstream of the rock groyne; Appendix A, Figure A2) that are suitable for rearing and feeding. Because of their preference for low velocity habitats, the extent of backwatering from ALR is expected to have an effect on the distribution of sucker species, as well as changes in discharge related to the flow regime. The distribution model indicated further upstream distribution in some years after the flow regime change (2014–2019) but not in other years (2011–2013). The effect of flow regime on distribution (3% effect size, CRI: -2% to 7%) was not statistically significant.

4.6.3 Mountain Whitefish

There was no significant difference in the distribution of adult Mountain Whitefish before and after the flow regime change. In the last four years (2016 to 2019), distribution was further upstream than most previous years, with an estimated effect size of 7% in 2018 and 2019. 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.

4.6.4 Rainbow Trout

Between 2001 and 2019, 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. Distribution of Rainbow Trout was significantly further upstream after the flow regime than before. The estimated effect size was a 5% (CRI: 0% to 11%) change in density per upstream river kilometre. This difference was related to further upstream distribution in 2012 to 2019, and further downstream distribution in 2007 to 2008, whereas other years had similar distribution. Therefore, the flow regime may have had some effect on Rainbow Trout distribution, but if so, it was not a consistent effect in all years, which could be due to other factors that also affect habitat, such as back-watering of the MCR by ALR.

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

4.6.5 Burbot

Density of Burbot was greatest at Site 231.0-L, which is along the left bank between the Revelstoke Golf Course and the rock groyne. This site contains rip-rap substrate, steep banks, and high water velocities. Higher catch-rates of Burbot were recorded in similar habitats downstream of HLK as part of BC Hydro's LCR Fish Population Indexing Program (CLBMON-45; Golder et al. 2018b). Based on the distribution model, the distribution of Burbot was not different before and after the flow regime change. Model results suggested a distribution that was further upstream in 2011, further downstream in 2018, and similar between all other years.

4.6.6 Kokanee

Abundance and spatial distribution of Kokanee was not assessed using HBMs due to extremely variable data that prevented models from converging. In most years, Kokanee catches were higher at sites that included confluences of major tributaries or were immediately downstream of tributaries (Moses Creek, Scales Creek, Jordan River; Appendix D, Table D2). Schools of Kokanee were also observed near the Trans-Canada Highway bridge in all years. Kokanee are in the study area primarily during the fall for spawning; for that reason, densities are higher near tributaries (either spawning at the creek mouths or migrating into the creeks to spawn). In most years, distribution was patchy, with large numbers of fish observed in small areas, reflecting schooling behaviour of pre-spawning Kokanee. In addition to adult Kokanee, small number of age-0 Kokanee are occasionally captured during this program (e.g., seven in 2017, one in 2018, two in 2019).

The flow regime is not expected to have a significant effect on the abundance of Kokanee in the study area, which is likely determined more by conditions in ALR. However, the flow regime could have minor effects on Kokanee spawning in the mainstem and habitat suitability for age-0 Kokanee. The MCR study area is not known as a significant spawning area for Kokanee, but spawning has been observed in some locations including near the Trans-Canada Highway bridge. Both the minimum flow and the increase in maximum discharge associated with the new flow regime could affect spawning success and site selection because of changes to the amount of substrate dewatering, and effects on water depth and velocity near redds. Changes in water velocity and depth associated with the flow regime change would also affect habitat suitability and survival for age-0 Kokanee. Assessing these effects is beyond the scope of this monitoring program and we speculate that they are unlikely to have a large effect of the overall abundance of Kokanee, because the mainstem is not known to be an important spawning or rearing area.

4.6.7 Northern Pikeminnow

The distribution of Northern Pikeminnow was not different before and after the flow regime change. Northern Pikeminnow densities were higher in Reach 3 than in Reach 4 and density increased with proximity to ALR. Credible intervals overlapped for all estimates, but densities for this species were generally higher in sites that contained backwater habitat areas or had lower water velocities, such as Site 228.5-L (upstream of the Illecillewaet River confluence), Site 231.3-L (Big Eddy), Site 227.2-R (Salmon Rocks), and Site 229.2-L (between the rock groyne and the Centennial Park Boat Launch). This distribution reflects this species' preference for low velocity habitats (Scott and Crossman 1973). Northern Pikeminnow were more abundant in the MCR during the fall than during the spring. Given the large size of the Northern Pikeminnow present during the fall season, it is possible that these fish were in the study area to feed on spawning Kokanee, as was reported in Pend d'Oreille Lake, Washington (Clarke et al. 2005).

4.6.8 Sculpin Species

Catches of sculpin species were highest in Big Eddy and along the rip-rap on the left bank of Reach 3. Of the sculpin species captured since 2010, 94% were Prickly Sculpin (n = 382) and 6% were Slimy Sculpin (*Cottus cognatus*) (n = 26). Sculpin were observed and captured in both Reach 3 and 4, but 68% of sculpin recorded since 2010 were in Reach 3. Greater catch in Reach 3 than 4, even though these reaches are close to the same length (Appendix B, Table B2), could be because sculpin are more common, or because the slower water or other habitat differences make capturing sculpin more efficient in Reach 3 than in Reach 4. Differences in the spatial distribution of sculpin before and after the flow regime were not statistically tested, because the count density model was not used for sculpin.

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 9 years since the flow regime change. These data were analyzed using hierarchical Bayesian methods as a robust and defensible way to assess trends over time and space, and the effects of the flow regime change on fish populations. Several fish population variables changed in years following the flow regime but because of the observational design of the study, it is difficult to determine whether the change in flow regime caused these changes or merely coincided with them.

Body condition estimates for Bull Trout and adult Largescale Sucker both declined during the first five years following the flow regime change (2011–2015). The low body condition of Bull Trout was correlated with declines in the abundance of Kokanee, which are an important prey for Bull Trout. The decrease in body condition of Largescale Sucker was associated with a rapid increase in abundance estimates of this species, which suggests density-dependence and intra-species competition. The similar declines in condition of Bull Trout and Largescale Sucker as well as Kokanee abundance in Arrow Lakes Reservoir suggest a broad-scale decline in growing conditions that affected fish across various trophic levels, including primary consumers, insectivores, and piscivores. In recent years, body condition increased, including high body condition for Largescale Sucker in 2017 and 2018, and high body condition for Bull Trout in 2017 that was associated with high abundance of Kokanee. The increases in body condition in 2017 and 2018 suggest that factors other than long-term flow regime influence body condition in the MCR. It is unknown whether the flow regime played a role in the decreases in body condition in the first five years following the flow regime change.

In the count density models, there was a statistically significant negative effect of the flow regime on the rate of population growth for Burbot (-33%), Northern Pikeminnow (-46%), and Rainbow Trout (-29%). However, the time-series of density show that these species had shown large increases in density during the years before the flow regime change (2001–2008), which makes it difficult to relate changes to the flow regime. Therefore, the interpretation is that these species showed negative population growth after the flow regime, but it is unclear whether the flow regime was the cause of these decreases. In contrast, density of sucker species increased three-fold and estimated abundance of Largescale Sucker doubled in years after the flow regime change with most of the increase occurring from 2013 to 2016. Abundance estimates of Bull Trout and Mountain Whitefish did not suggest any significant change after the new flow regime.

The spatial distribution also changed for some fish species after the flow regime change. The distribution models suggested an upstream shift in distribution after the flow regime change that was statistically significant for Rainbow Trout (effect size: 5%, CRI: 0% to 11%) but not for Bull Trout (2%, CRI: 0% to 5%) or sucker species (3%, CRI: -2% to 7%). It could be that the minimum flow makes habitat in the upstream portion of the study area more suitable or attractive to some fish species.

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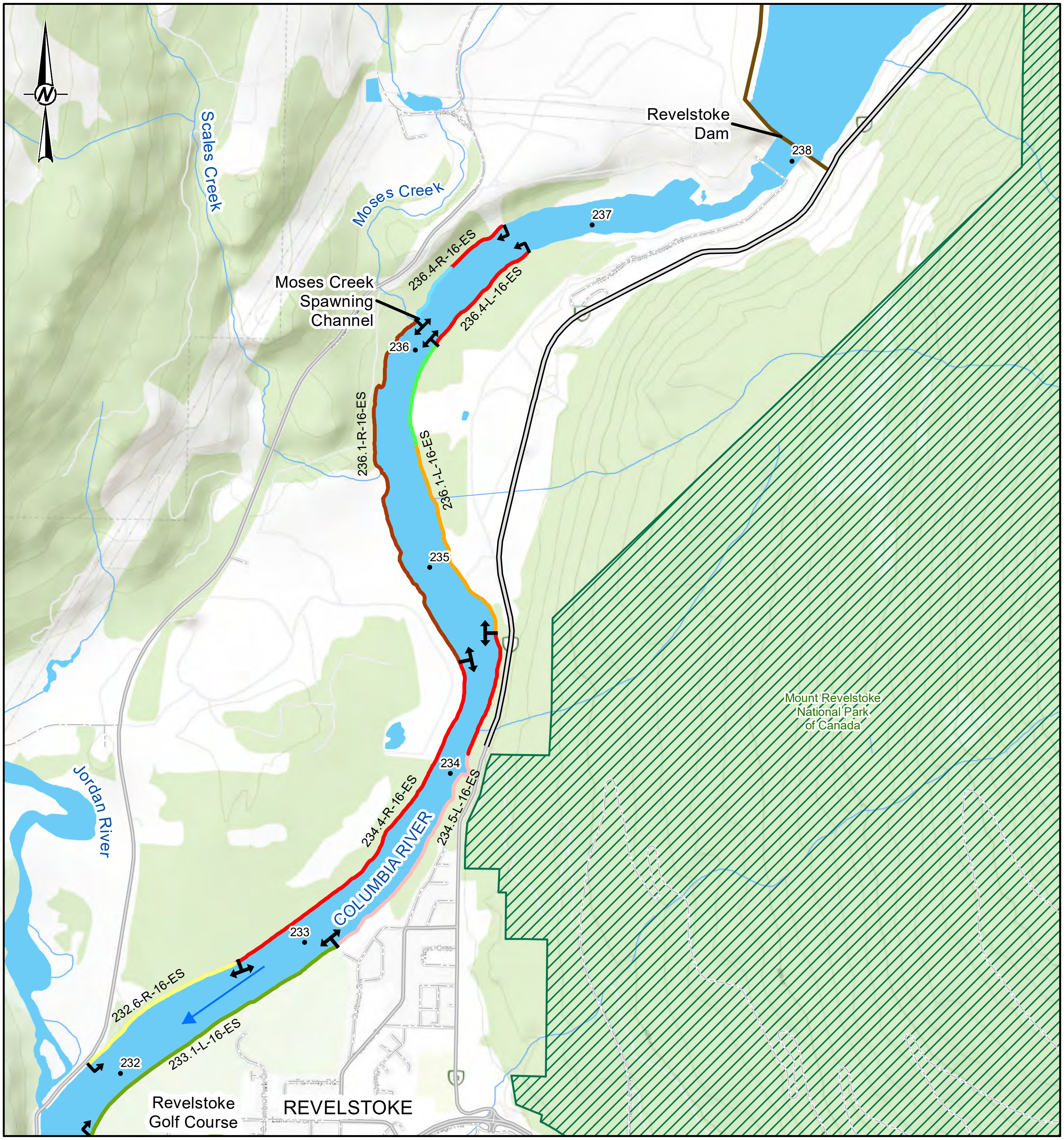
Appendix A - Maps

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

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.



LEGEND

- RIVER KMS FROM HLK DAM
- DIRECTION OF FLOW
- HIGHWAY
- MAJOR ROAD
- LOCAL ROAD
- WATERCOURSE
- DAM BASE
- NATIONAL PARK
- WATERBODY

BANK HABITAT TYPE

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

0 400 800

1:25,000 METRES

REFERENCES

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

CLIENT
BC HYDRO

PROJECT
MIDDLE COLUMBIA RIVER FISH POPULATION INDEXING STUDY

TITLE
BANK HABITAT TYPE AND SAMPLE LOCATIONS - REACH 4

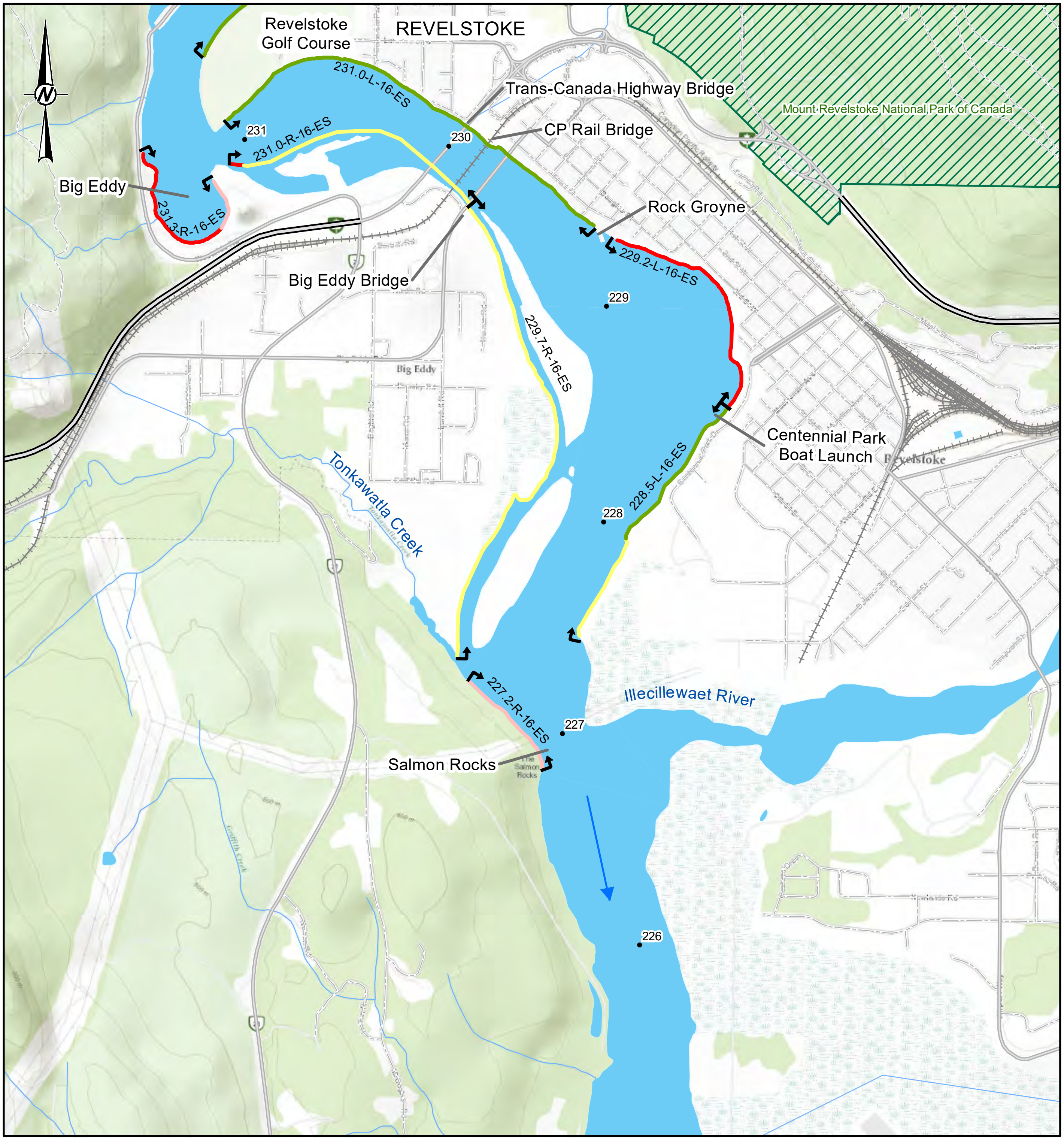
CONSULTANT

GOLDER

YYYY-MM-DD	2020-03-31
DESIGNED	DR
PREPARED	JG
REVIEWED	DR
APPROVED	SR

PROJECT NO.	PHASE	REV.	FIGURE
1784190	2018	0	A1

PATH: Y:\burnaby\CAD-GIS\Client\ONA\MCR\99_PROJECTS\13-1492-0004\02_PRODUCTION\INDEXING\MXD\Report\2019\1784190_2019_FIG_A1_INDEXING_Rev0.mxd



LEGEND

- • RIVER KMS FROM HLK DAM
- DIRECTION OF FLOW
- HIGHWAY
- MAJOR ROAD
- LOCAL ROAD
- RAILWAY
- WATERCOURSE
- WATERBODY
- NATIONAL PARK

BANK HABITAT TYPE

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

0 400 800

1:25,000 METRES

CLIENT
BC HYDRO

PROJECT
MIDDLE COLUMBIA RIVER FISH POPULATION INDEXING STUDY

TITLE
BANK HABITAT TYPE AND SAMPLE LOCATIONS - REACH 3

CONSULTANT
GOLDER

YYYY-MM-DD	2020-03-31
DESIGNED	DR
PREPARED	GS
REVIEWED	DR
APPROVED	SR

PROJECT NO.	PHASE	REV.	FIGURE
1784190	2019	0	A2

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

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

25mm

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.

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, 15 October to 06 November 2019.

Reach	Site[a]	Session	Air Temperature (°C)	Water Temperature (°C)	Conductivity (µS)	Cloud Cover[b]	Water Surface Visibility	Instream Velocity[c]	Water Clarity[d]	Cover Types (%)					
										Substrate Interstices	Woody Debris	Turbulence	Terrestrial Vegetation	Shallow Water	Deep Water
4	236.4-R-16-ES	84	5	8.90	140	Overcast	High	High	High	60	0	10	0	0	30
4	236.4-R-16-ES	85	5	7.20	130	Overcast	High	High	High	85	0	5	0	0	10
4	236.4-R-16-ES	86		8.20	140	Partly cloudy	High	High	High	100	0	0	0	0	0
4	236.4-L-16-ES	84	5	8.30	140	Overcast	High	Medium	High	60	0	0	0	0	40
4	236.4-L-16-ES	85	3	7.70	130	Overcast	High	Medium	High	100	0	0	0	0	0
4	236.4-L-16-ES	86		8.30	140	Partly cloudy	High	High	High	90	0	0	0	10	0
4	236.1-R-16-ES	84	5	9.10	140	Overcast	High	Medium	High	80	0	5	0	0	15
4	236.1-R-16-ES	85	3	8.60	130	Partly cloudy	High	Low	High	70	0	5	0	0	25
4	236.1-R-16-ES	86		8.20	140	Clear	High	High	High	100	0	0	0	0	0
4	236.1-L-16-ES	84	5	8.80	140	Overcast	High	High	High	60	0	0	0	0	40
4	236.1-L-16-ES	85	1	7.90	130	Overcast	High	Medium	High	70	0	0	0	0	30
4	236.1-L-16-ES	86		8.20	130	Clear	High	High	High	80	0	0	0	20	0
4	234.5-L-16-ES	84	5	8.80	140	Overcast	High	Medium	High	50	5	10	0	0	35
4	234.5-L-16-ES	85	1	8.70	140	Clear	High	Low	High	60	0	0	0	10	30
4	234.5-L-16-ES	86		7.80	140	Overcast	High	High	High	40	5	40	5	10	0
4	234.4-R-16-ES	84	5	8.90	140	Overcast	High	Low	High	85	10	0	0	0	5
4	234.4-R-16-ES	85	1	8.50	140	Clear	High	Low	High	90	10	0	0	0	0
4	234.4-R-16-ES	85	0	8.00	130	Clear	High	High	High	98	2	0	0	0	0
4	234.4-R-16-ES	86		7.80	140	Overcast	High	High	High	50	20	10	20	0	0
4	233.1-L-16-ES	84	5	9.00	140	Overcast	High	Low	High	90	5	0	0	0	5
4	233.1-L-16-ES	85	0	8.00	130	Clear	High	High	High	65	5	0	0	0	30
4	233.1-L-16-ES	86		7.80	140	Partly cloudy	High	High	High	95	5	0	0	0	0
4	232.6-R-16-ES	84	5	9.00	140	Overcast	High	Low	High	90	5	0	0	0	5
4	232.6-R-16-ES	85	0	8.00	130	Clear	High	High	High	100	0	0	0	0	0
4	232.6-R-16-ES	86		7.80	140	Overcast	High	Medium	High	100	0	0	0	0	0

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

Continued...

[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	84	5	8.80	130	Overcast	High	Low	High	30	30	0	0	0	30	10
3	231.3-R-16-ES	85		8.50	130	Partly cloudy	High	Medium	High	80	10	0	0	0	10	0
3	231.3-R-16-ES	86		7.80	140	Partly cloudy	High	Medium	High	40	30	0	0	10	20	0
3	231.0-R-16-ES	84	2	8.90	140	Overcast	High	Medium	High	60	0	0	0	0	40	0
3	231.0-R-16-ES	85		8.50	130	Clear	High	Medium	High	90	5	0	0	0	5	0
3	231.0-R-16-ES	86		7.80	140	Partly cloudy	High	High	High	80	5	0	0	15	0	0
3	231.0-L-16-ES	84	5	8.90	140	Overcast	High	Medium	High	50	20	10	0	0	10	10
3	231.0-L-16-ES	85		8.50	130	Clear	High	High	High	95	5	0	0	0	0	0
3	231.0-L-16-ES	86		7.80	140	Partly cloudy	High	High	High	80	15	5	0	0	0	0
3	229.7-R-16-ES	84	5	8.70	140	Overcast	Medium	Low	High	30	40	0	0	0	30	0
3	229.7-R-16-ES	85		18.10	130	Clear	High	Low	High	40	50	0	5	5	0	0
3	229.7-R-16-ES	86		8.30	160	Clear	High	Low	High	20	60	0	0	20	0	0
3	229.2-L-16-ES	84	5	8.90	140	Overcast	Medium	Low	High	30	5	0	0	0	60	5
3	229.2-L-16-ES	85		8.10	130	Partly cloudy	High	Low	High	60	35	0	0	5	0	0
3	229.2-L-16-ES	86		8.10	160	Clear	High	Low	High	30	40	0	20	10	0	0
3	228.5-L-16-ES	84	1	8.80	140	Overcast	Medium	Low	Medium	60	10	0	0	0	10	20
3	228.5-L-16-ES	85		8.10	130	Partly cloudy	High	Medium	High	98	2	0	0	0	0	0
3	228.5-L-16-ES	86		8.10	160	Partly cloudy	High	Medium	High	40	30	0	30	0	0	0
3	227.2-R-16-ES	84	1	8.60	140	Overcast	Medium	Low	Medium	20	0	0	0	0	80	0
3	227.2-R-16-ES	85		8.10	130	Partly cloudy	High	Medium	High	40	20	0	0	0	40	0
3	227.2-R-16-ES	86		8.10	160	Partly cloudy	High	Medium	High	30	30	0	0	0	40	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, 15 October to 06 November 2019.

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	1							9		**9**
	232.6-R-16-ES	Bull Trout	3							2		**2**
	232.6-R-16-ES	Burbot	1							1		**1**
	232.6-R-16-ES	Lake Whitefish	1							4		**4**
	232.6-R-16-ES	Largescale Sucker	1							4		**4**
	232.6-R-16-ES	Mountain Whitefish	1							146		**146**
	232.6-R-16-ES	Mountain Whitefish	3							70		**70**
	232.6-R-16-ES	Rainbow Trout	1							1		**1**
	232.6-R-16-ES	Sucker Spp.	1							14		**14**
	Site 232.6-R-16-ES Total			**0**	**0**	**0**	**0**	**0**	**0**	**251**	**0**	**251**
	233.1-L-16-ES	Bull Trout	1		13			14				**27**
	233.1-L-16-ES	Bull Trout	3		3			6				**9**
	233.1-L-16-ES	Lake Whitefish	1					1				**1**
	233.1-L-16-ES	Largescale Sucker	1		4			25				**29**
	233.1-L-16-ES	Longnose Sucker	3					1				**1**
	233.1-L-16-ES	Mountain Whitefish	1		63			41				**104**
	233.1-L-16-ES	Mountain Whitefish	3		32			12				**44**
	233.1-L-16-ES	Mountain Whitefish	All					2				**2**
	233.1-L-16-ES	Prickly Sculpin	2					1				**1**
	233.1-L-16-ES	Rainbow Trout	1					1				**1**
	233.1-L-16-ES	Sculpin Spp.	2		6			3				**9**
	233.1-L-16-ES	Sucker Spp.	1		19			4				**23**
	233.1-L-16-ES	Sucker Spp.	3		10			1				**11**
	Site 233.1-L-16-ES Total			**0**	**150**	**0**	**0**	**112**	**0**	**0**	**0**	**262**
	234.4-R-16-ES	Bull Trout	1	26								**26**
	234.4-R-16-ES	Bull Trout	3	7								**7**
	234.4-R-16-ES	Bull Trout	All	1								**1**
	234.4-R-16-ES	Lake Whitefish	1	3								**3**
	234.4-R-16-ES	Largescale Sucker	1	23								**23**
	234.4-R-16-ES	Longnose Sucker	1	2								**2**
	234.4-R-16-ES	Mountain Whitefish	1	578								**578**
	234.4-R-16-ES	Mountain Whitefish	3	366								**366**
	234.4-R-16-ES	Mountain Whitefish	4	2								**2**
	234.4-R-16-ES	Mountain Whitefish	All	1								**1**
	234.4-R-16-ES	Northern Pikeminnow	1	1								**1**
	234.4-R-16-ES	Rainbow Trout	1	1								**1**
	234.4-R-16-ES	Sculpin Spp.	2	2								**2**
	234.4-R-16-ES	Sucker Spp.	1	34								**34**
	234.4-R-16-ES	Sucker Spp.	3	4								**4**
	Site 234.4-R-16-ES Total			**1051**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1051**
	234.5-L-16-ES	Bull Trout	1	3			18					**21**
	234.5-L-16-ES	Bull Trout	3				6					**6**
	234.5-L-16-ES	Burbot	1				1					**1**
	234.5-L-16-ES	Largescale Sucker	1	8			13					**21**
	234.5-L-16-ES	Longnose Sucker	1				3					**3**
	234.5-L-16-ES	Mountain Whitefish	1	186			471					**657**
	234.5-L-16-ES	Mountain Whitefish	3	76			242					**318**
	234.5-L-16-ES	Mountain Whitefish	All	1								**1**
	234.5-L-16-ES	Rainbow Trout	1				1					**1**
	234.5-L-16-ES	Sculpin Spp.	2	10			20					**30**
	234.5-L-16-ES	Sucker Spp.	1	7			21					**28**
	234.5-L-16-ES	Sucker Spp.	3	2			5					**7**
	Site 234.5-L-16-ES Total			**293**	**0**	**0**	**801**	**0**	**0**	**0**	**0**	**1094**

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

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

Continued...

Table B4 Continued.

Reach	Site[a]	Species	Size Class	Bank Habitat Type[a]								Total
				A1	A3	A4	A5	A6	A1+A2	D1	D2	
3	227.2-R-16-ES	Sucker Spp.	1				1					**1**
	227.2-R-16-ES	Mountain Whitefish	3				1					**1**
	227.2-R-16-ES	Northern Pikeminnow	1				1					**1**
	227.2-R-16-ES	Rainbow Trout	4				1					**1**
	227.2-R-16-ES	Prickly Sculpin	2				2					**2**
	227.2-R-16-ES	Mountain Whitefish	4				3					**3**
	227.2-R-16-ES	Largescale Sucker	1				4					**4**
	227.2-R-16-ES	Bull Trout	3				5					**5**
	227.2-R-16-ES	Rainbow Trout	3				7					**7**
	227.2-R-16-ES	Bull Trout	1				9					**9**
	227.2-R-16-ES	Mountain Whitefish	1				9					**9**
	227.2-R-16-ES	Sculpin Spp.	2				23					**23**
	Site 227.2-R-16-ES Total			**0**	**0**	**0**	**66**	**0**	**0**	**0**	**0**	**66**
	228.5-L-16-ES	Brook Trout	1							1		**1**
	228.5-L-16-ES	Bull Trout	1					5		5		**10**
	228.5-L-16-ES	Bull Trout	3					9		11		**20**
	228.5-L-16-ES	Burbot	1					1				**1**
	228.5-L-16-ES	Kokanee	4					1				**1**
	228.5-L-16-ES	Largescale Sucker	1					4		10		**14**
	228.5-L-16-ES	Largescale Sucker	3					1				**1**
	228.5-L-16-ES	Mountain Whitefish	1					18		109		**127**
	228.5-L-16-ES	Mountain Whitefish	3					4		52		**56**
	228.5-L-16-ES	Mountain Whitefish	4					5		6		**11**
	228.5-L-16-ES	Mountain Whitefish	All							1		**1**
	228.5-L-16-ES	Northern Pikeminnow	1							1		**1**
	228.5-L-16-ES	Prickly Sculpin	2					2				**2**
	228.5-L-16-ES	Rainbow Trout	1					3		3		**6**
	228.5-L-16-ES	Rainbow Trout	3					7		3		**10**
	228.5-L-16-ES	Redside Shiner	2					7				**7**
	228.5-L-16-ES	Sculpin Spp.	2					47		26		**73**
	228.5-L-16-ES	Sucker Spp.	1					9		10		**19**
	228.5-L-16-ES	Sucker Spp.	3							3		**3**
	Site 228.5-L-16-ES Total			**0**	**0**	**0**	**0**	**123**	**0**	**241**	**0**	**364**
	229.2-L-16-ES	Bull Trout	1	4								**4**
	229.2-L-16-ES	Bull Trout	3	3								**3**
	229.2-L-16-ES	Largescale Sucker	1	13								**13**
	229.2-L-16-ES	Mountain Whitefish	1	37								**37**
	229.2-L-16-ES	Mountain Whitefish	3	17								**17**
	229.2-L-16-ES	Mountain Whitefish	4	9								**9**
	229.2-L-16-ES	Mountain Whitefish	All	1								**1**
	229.2-L-16-ES	Northern Pikeminnow	1	1								**1**
	229.2-L-16-ES	Prickly Sculpin	2	2								**2**
	229.2-L-16-ES	Rainbow Trout	1	1								**1**
	229.2-L-16-ES	Rainbow Trout	3	3								**3**
	229.2-L-16-ES	Redside Shiner	2	69								**69**
	229.2-L-16-ES	Sculpin Spp.	2	55								**55**
	229.2-L-16-ES	Sucker Spp.	1	12								**12**
	Site 229.2-L-16-ES Total			**227**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**227**

[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] A1	A3	A4	A5	A6	A1+A2	D1	D2	Total
	229.7-R-16-ES	Bull Trout	1							28		**28**
	229.7-R-16-ES	Bull Trout	3							6		**6**
	229.7-R-16-ES	Kokanee	1							1		**1**
	229.7-R-16-ES	Lake Whitefish	1							1		**1**
	229.7-R-16-ES	Largescale Sucker	1							38		**38**
	229.7-R-16-ES	Mountain Whitefish	1							103		**103**
	229.7-R-16-ES	Mountain Whitefish	3							109		**109**
	229.7-R-16-ES	Mountain Whitefish	4							102		**102**
	229.7-R-16-ES	Northern Pikeminnow	1							3		**3**
	229.7-R-16-ES	Rainbow Trout	1							2		**2**
	229.7-R-16-ES	Rainbow Trout	3							1		**1**
	229.7-R-16-ES	Sculpin Spp.	2							18		**18**
	229.7-R-16-ES	Sucker Spp.	1							42		**42**
	229.7-R-16-ES	Sucker Spp.	3							6		**6**
	229.7-R-16-ES	Yellow Perch	2							1		**1**
	Site 229.7-R-16-ES Total			**0**	**0**	**0**	**0**	**0**	**0**	**461**	**0**	**461**
	231.0-L-16-ES	Bull Trout	1					16				**16**
	231.0-L-16-ES	Bull Trout	3					18				**18**
	231.0-L-16-ES	Burbot	1					4				**4**
	231.0-L-16-ES	Burbot	3					2				**2**
	231.0-L-16-ES	Lake Whitefish	1					1				**1**
	231.0-L-16-ES	Largescale Sucker	1					42				**42**
	231.0-L-16-ES	Longnose Sucker	3					2				**2**
	231.0-L-16-ES	Mountain Whitefish	1					218				**218**
	231.0-L-16-ES	Mountain Whitefish	3					103				**103**
	231.0-L-16-ES	Mountain Whitefish	4					1				**1**
	231.0-L-16-ES	Mountain Whitefish	All					1				**1**
	231.0-L-16-ES	Prickly Sculpin	2					1				**1**
	231.0-L-16-ES	Rainbow Trout	1					9				**9**
	231.0-L-16-ES	Rainbow Trout	3					6				**6**
	231.0-L-16-ES	Sculpin Spp.	2					45				**45**
	231.0-L-16-ES	Sucker Spp.	1					39				**39**
	231.0-L-16-ES	Sucker Spp.	3					2				**2**
	Site 231.0-L-16-ES Total			**0**	**0**	**0**	**0**	**510**	**0**	**0**	**0**	**510**
	231.0-R-16-ES	Bull Trout	1	10						21		**31**
	231.0-R-16-ES	Bull Trout	3	2						6		**8**
	231.0-R-16-ES	Lake Whitefish	1							1		**1**
	231.0-R-16-ES	Largescale Sucker	1	2						14		**16**
	231.0-R-16-ES	Mountain Whitefish	1	65						289		**354**
	231.0-R-16-ES	Mountain Whitefish	3	16						173		**189**
	231.0-R-16-ES	Mountain Whitefish	4	4						6		**10**
	231.0-R-16-ES	Mountain Whitefish	All	1								**1**
	231.0-R-16-ES	Rainbow Trout	1							2		**2**
	231.0-R-16-ES	Sculpin Spp.	2	6						1		**7**
	231.0-R-16-ES	Sucker Spp.	1	3						23		**26**
	231.0-R-16-ES	Sucker Spp.	3							5		**5**
	Site 231.0-R-16-ES Total			**109**	**0**	**0**	**0**	**0**	**0**	**541**	**0**	**650**

[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	1	21			9					**30**
	231.3-R-16-ES	Bull Trout	3	15								**15**
	231.3-R-16-ES	Burbot	1				1					**1**
	231.3-R-16-ES	Lake Whitefish	1	1								**1**
	231.3-R-16-ES	Largescale Sucker	1	8								**8**
	231.3-R-16-ES	Largescale Sucker	3	1								**1**
	231.3-R-16-ES	Longnose Sucker	3	2								**2**
	231.3-R-16-ES	Mountain Whitefish	1	131			2					**133**
	231.3-R-16-ES	Mountain Whitefish	3	108								**108**
	231.3-R-16-ES	Mountain Whitefish	4	3								**3**
	231.3-R-16-ES	Rainbow Trout	1	9								**9**
	231.3-R-16-ES	Rainbow Trout	3	1								**1**
	231.3-R-16-ES	Redside Shiner	2	1								**1**
	231.3-R-16-ES	Sculpin Spp.	2	7								**7**
	231.3-R-16-ES	Sucker Spp.	1	14								**14**
	231.3-R-16-ES	Sucker Spp.	3	3								**3**
Reach 3 Total				**661**	**0**	**0**	**78**	**633**	**0**	**1243**	**0**	**2615**
	Site 231.3-R-16-ES Total			**325**	**0**	**0**	**12**	**0**	**0**	**0**	**0**	**337**

[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

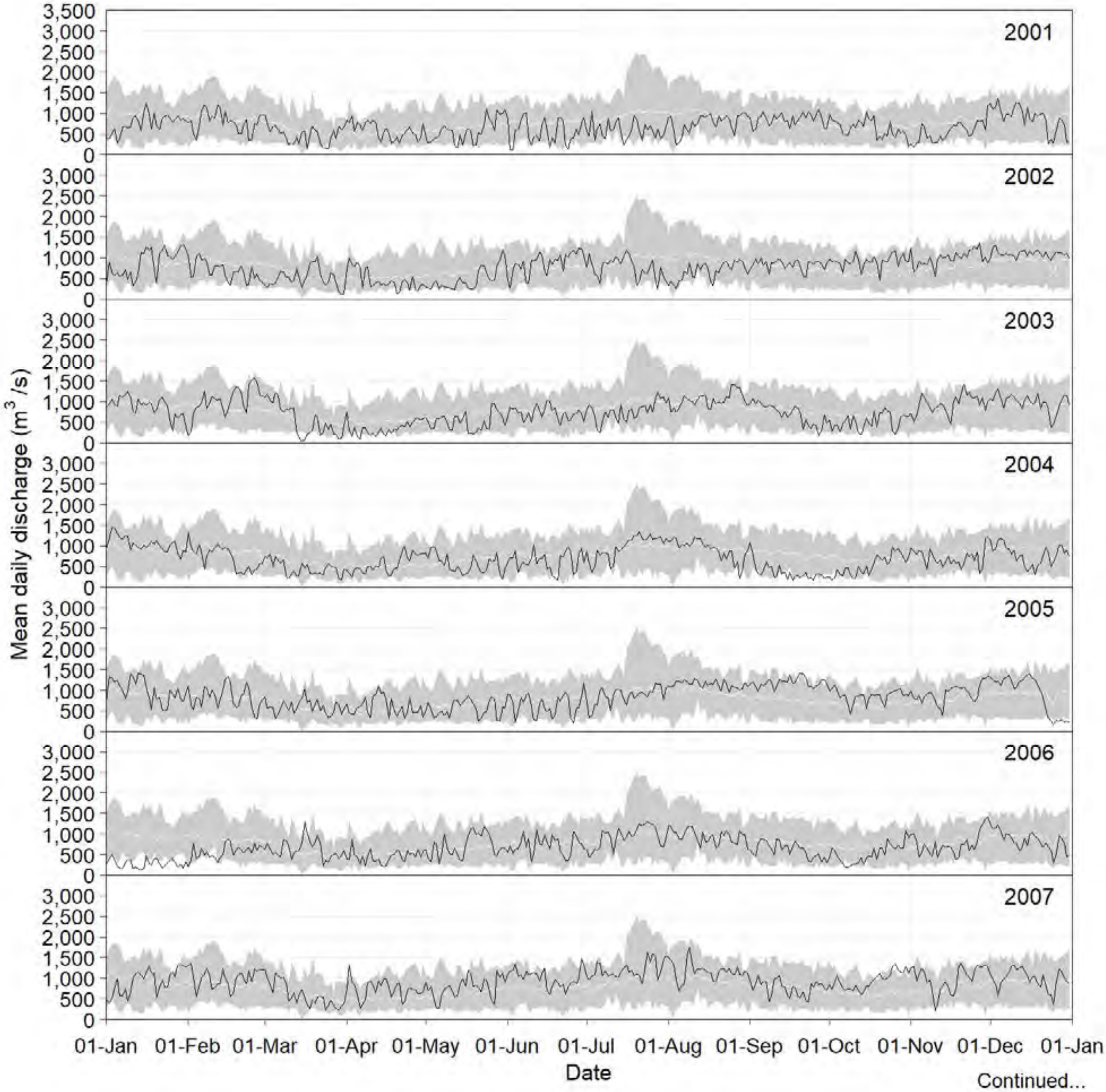
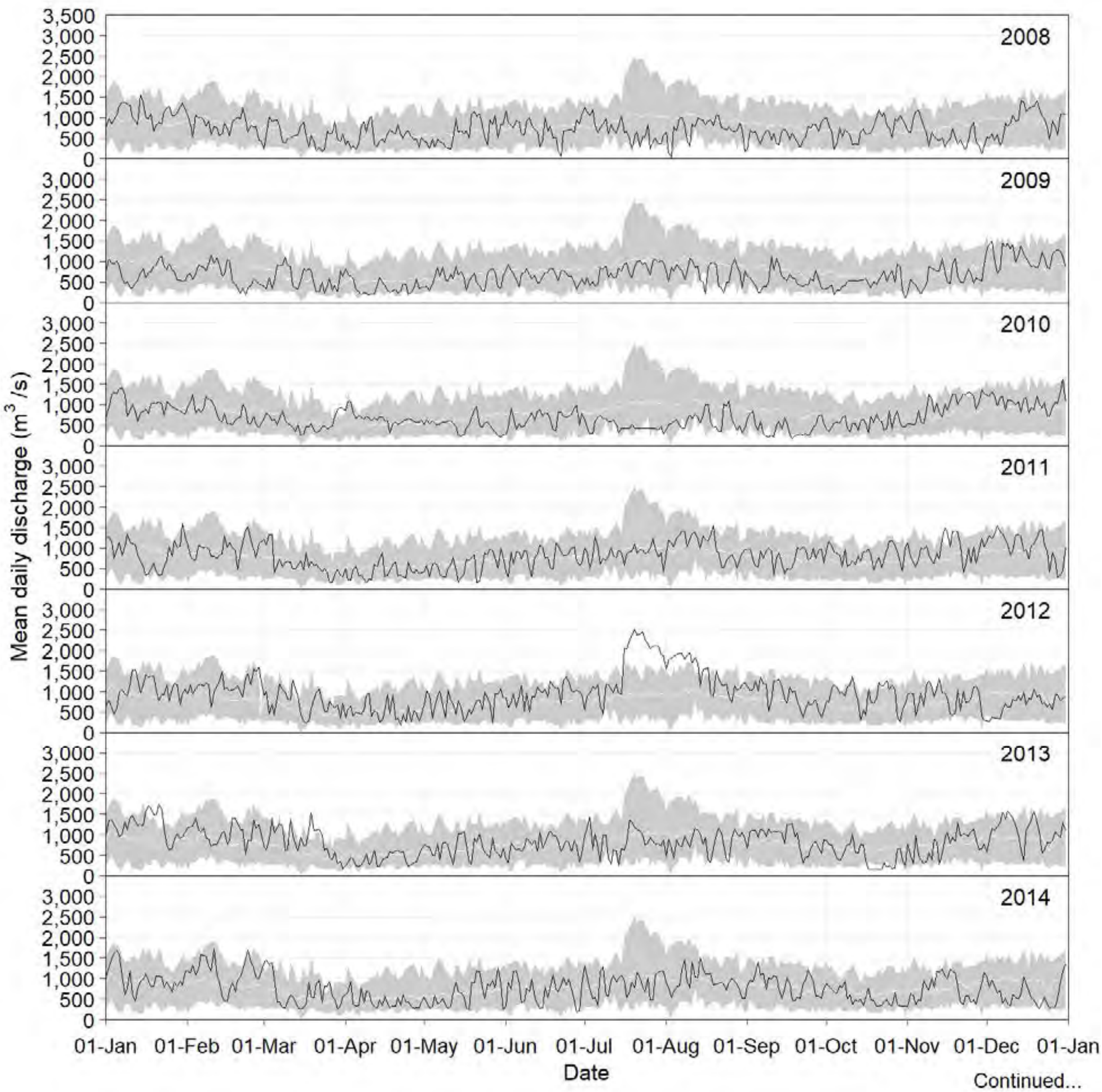


Figure C1 Mean daily discharge (m³/s) for the Columbia River at Revelstoke Dam, 2001 to 2019. The shaded area represents minimum and maximum mean daily discharge values recorded at Revelstoke Dam during other study years (between 2001 and 2019). The white line represents average mean daily discharge values over the same time period.



Continued...

Figure C1 Continued.

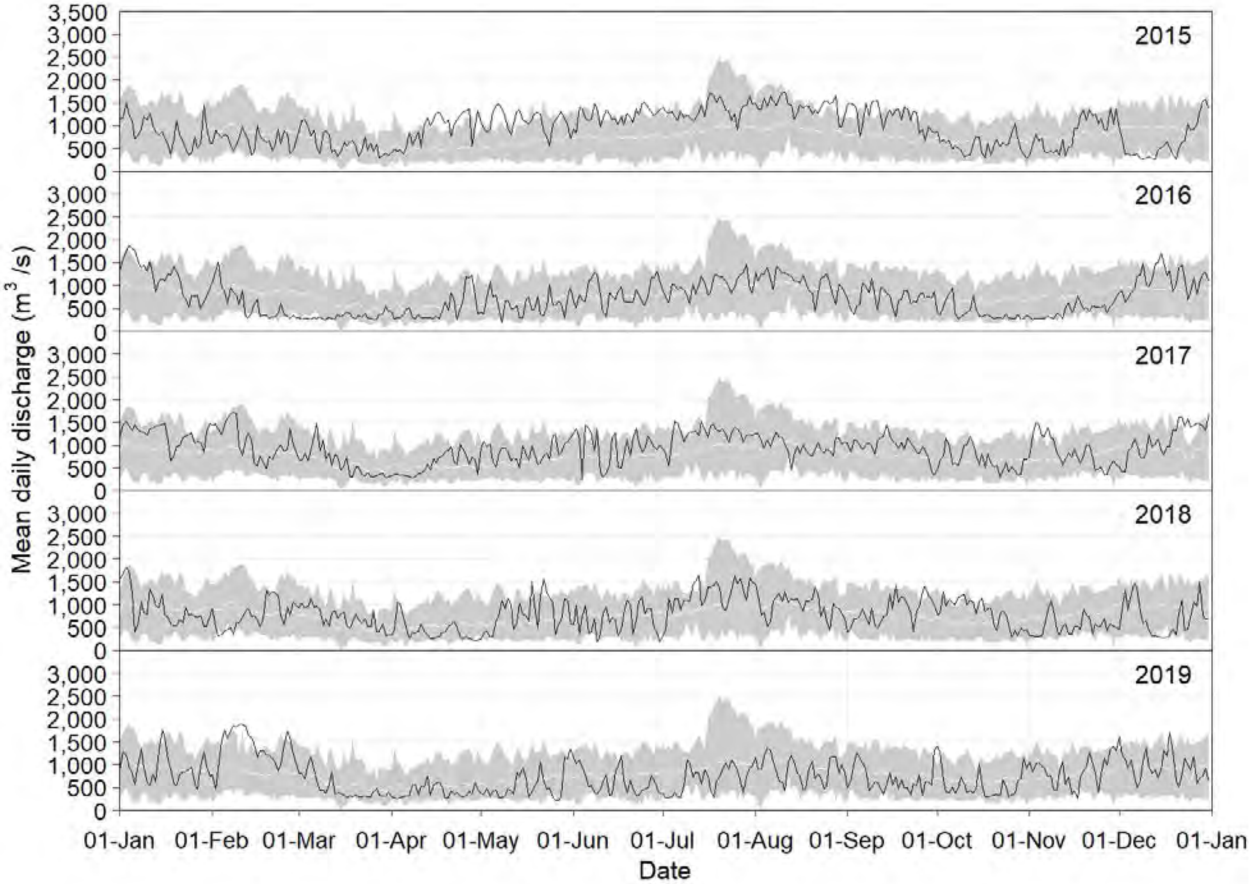


Figure C1 Concluded.

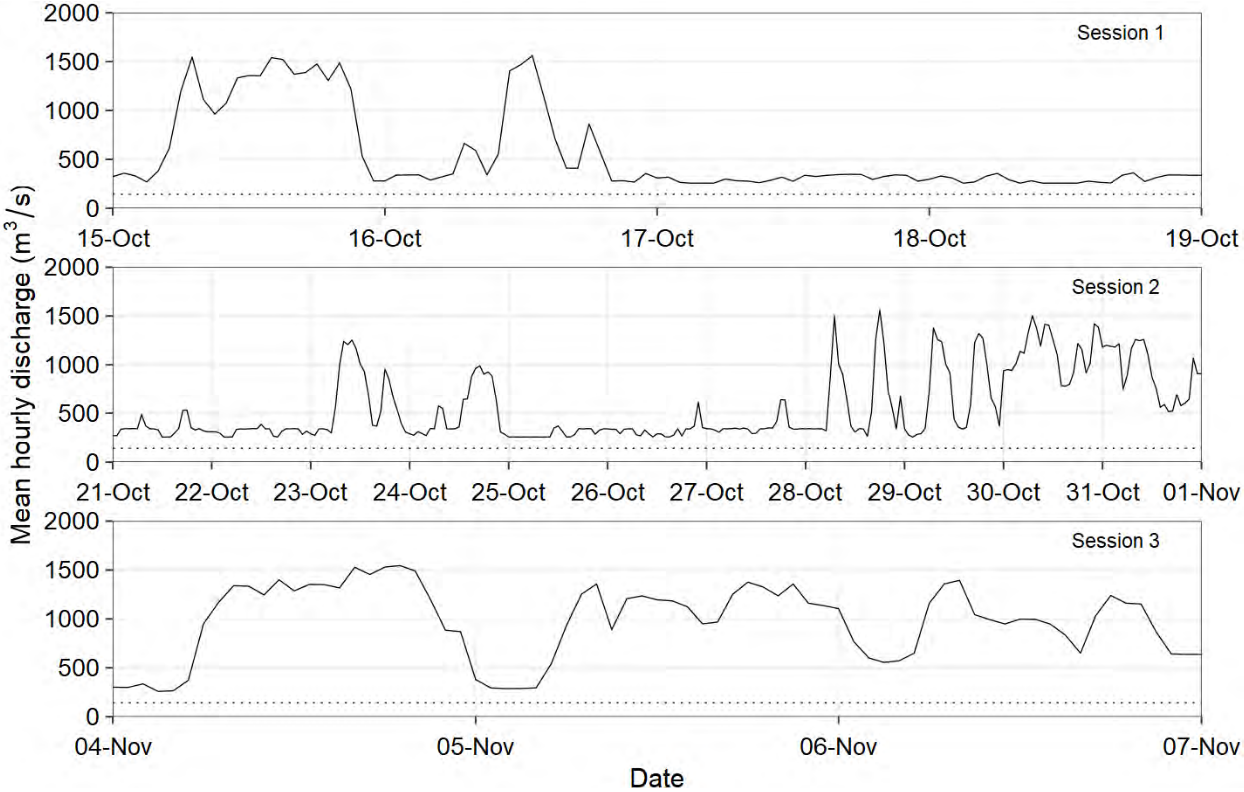
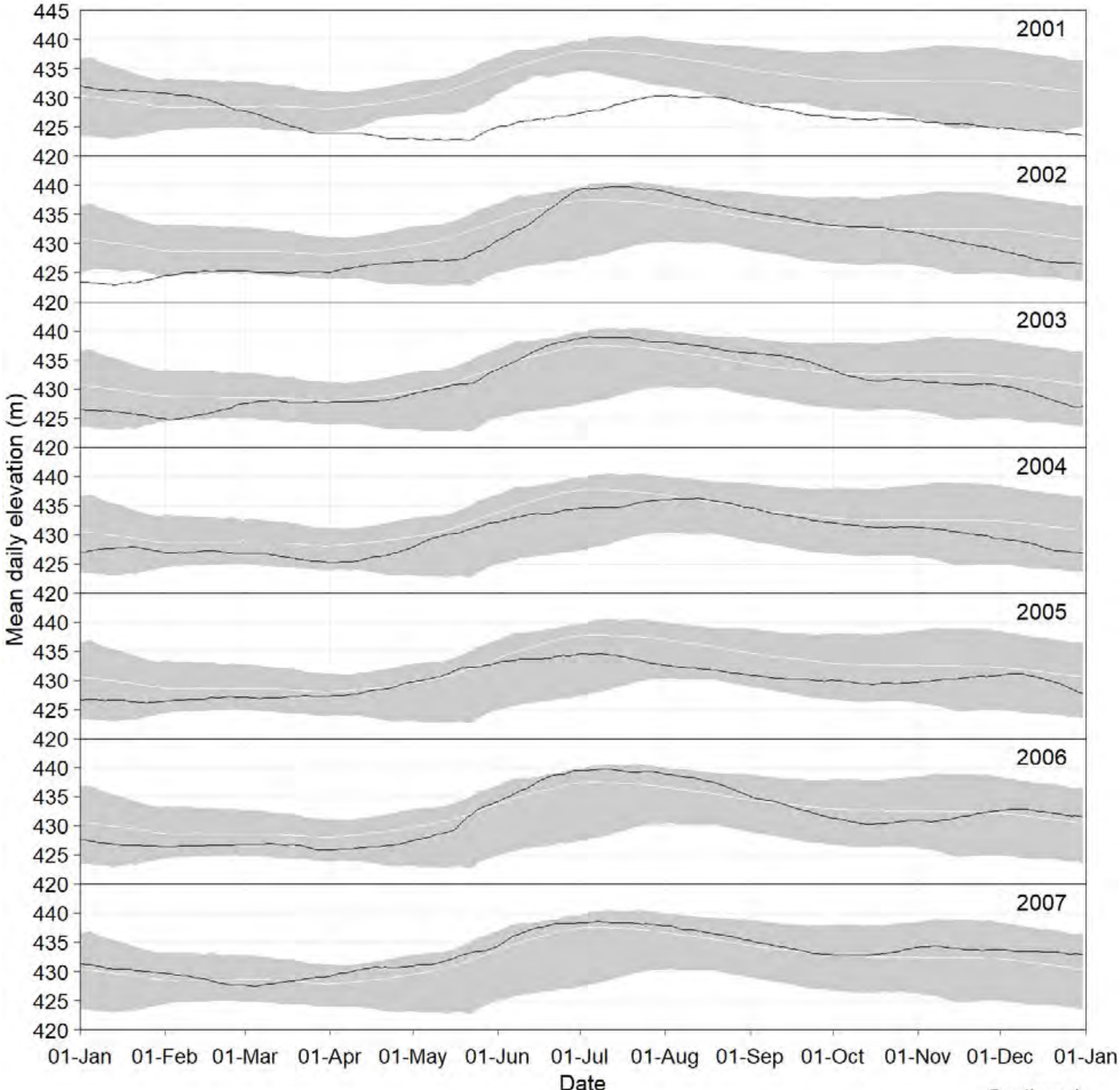


Figure C2 Mean hourly discharge (m^3/s) for the Columbia River at Revelstoke Dam by sample session, 15 October to 6 November 2019. The dotted line denotes the 142 m^3/s minimum flow release.



Continued...

Figure C3 Mean daily water level elevation (in metres above sea level) for the Columbia River at Nakusp, 2001 to 2019. The shaded area represents minimum and maximum mean daily water elevations recorded at Nakusp during other study years (between 2001 and 2019). The white line represents average mean daily water elevation over the same time period.

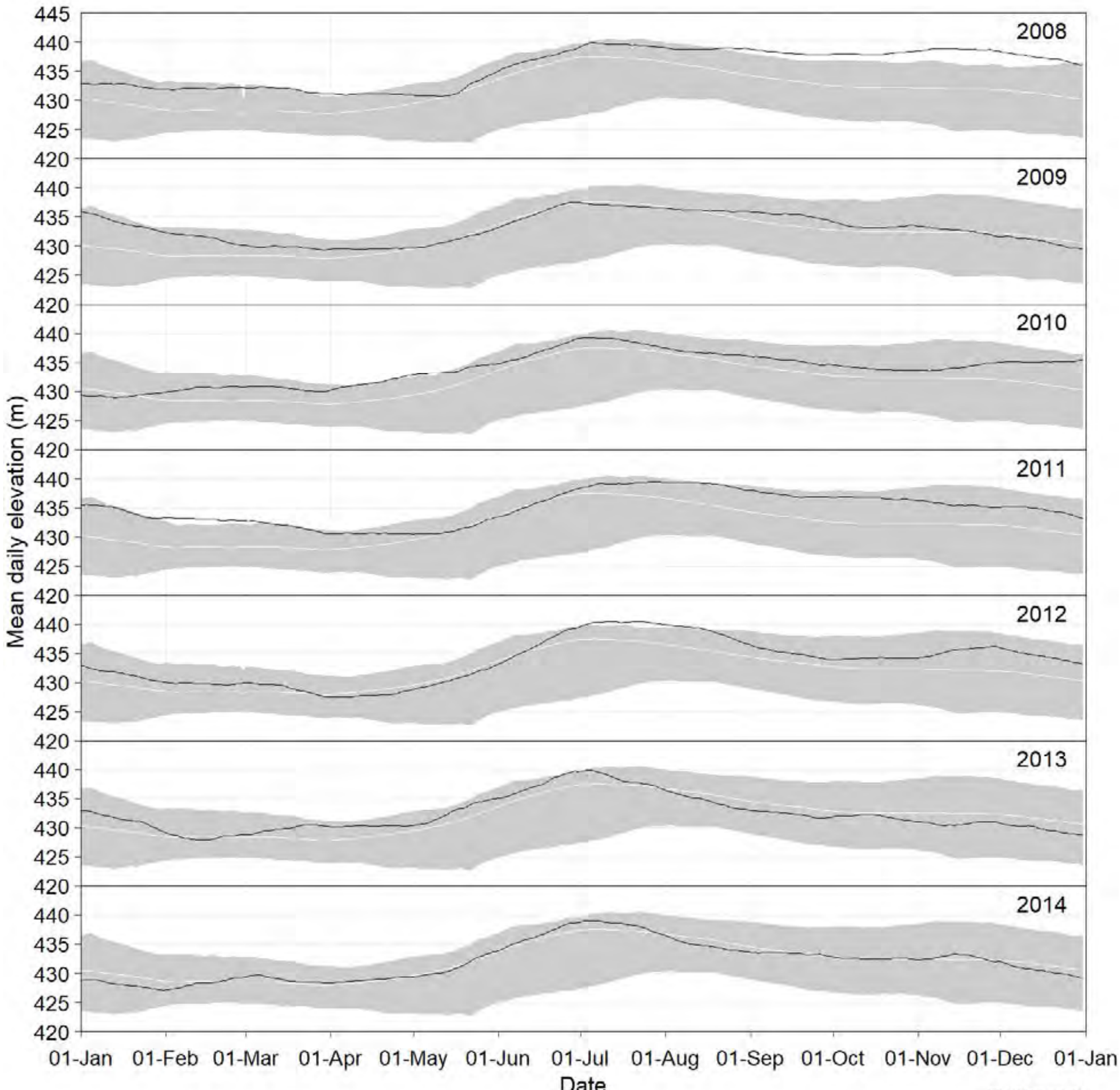


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Figure C3 Continued.

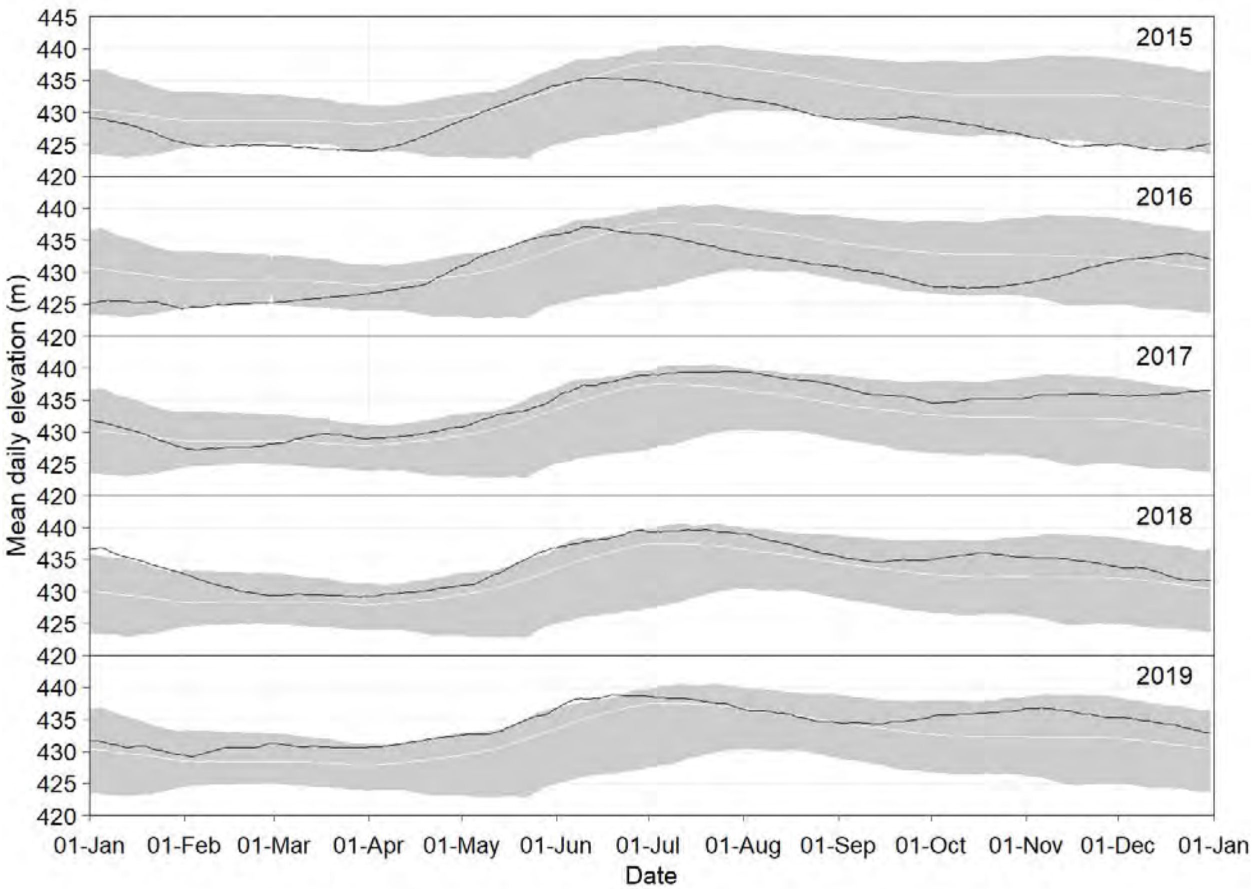

Figure C3 Concluded.

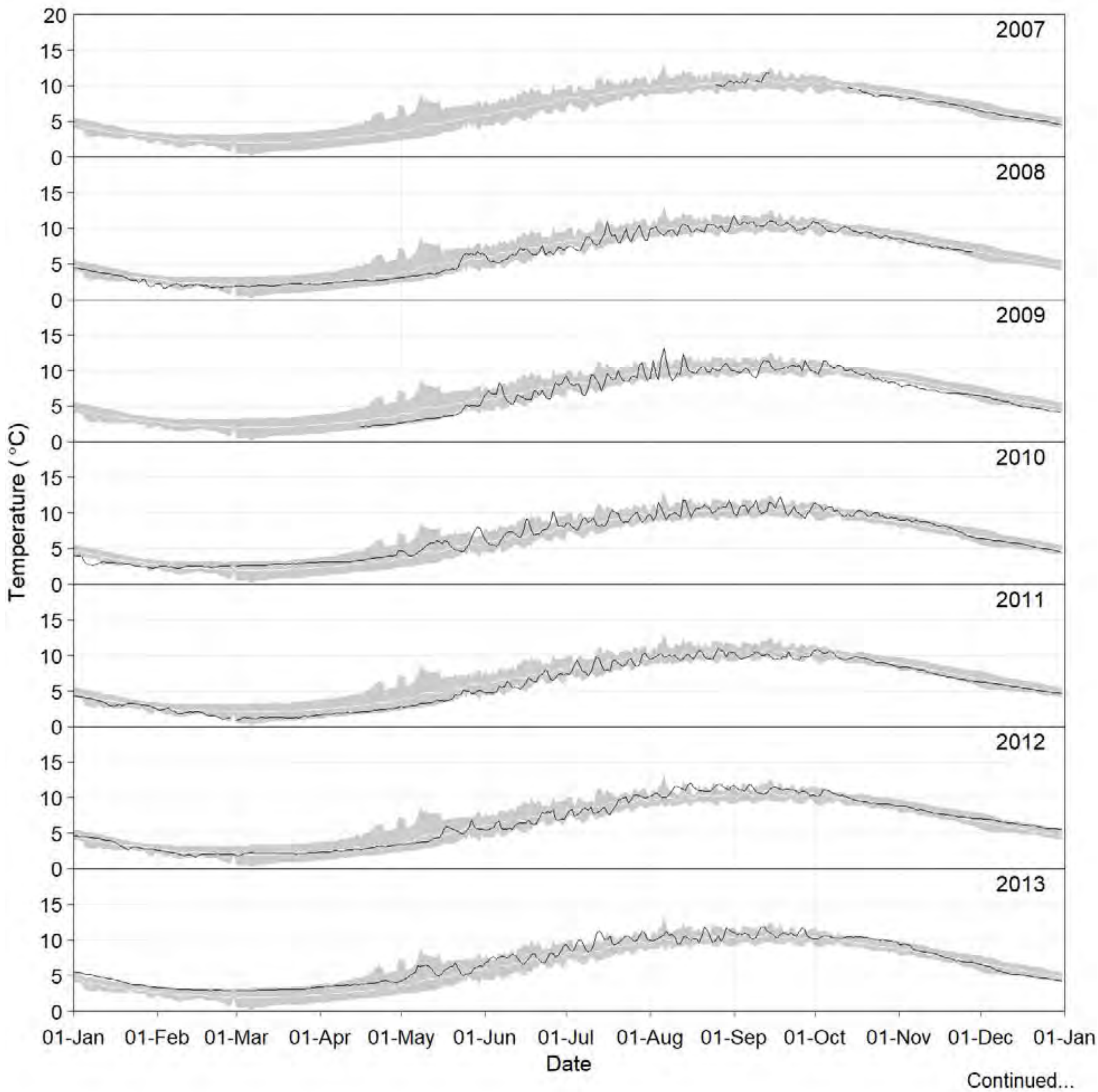

Figure C4 Mean daily water temperature (°C) for the Columbia River at Revelstoke Dam, 2007 to 2019. The shaded area represents minimum and maximum mean daily water temperatures recorded at Revelstoke Dam during other study years (between 2007 and 2019). The white line represents average mean daily water temperature over the same time period. Temperature data for 2007-2013 and 2015-2019 are from Station 2 of the Middle Columbia River Physical Habitat Monitoring Program (CLBMON-15a). Data for 2014 are from Station 2AS because data from Station 2 were not available.

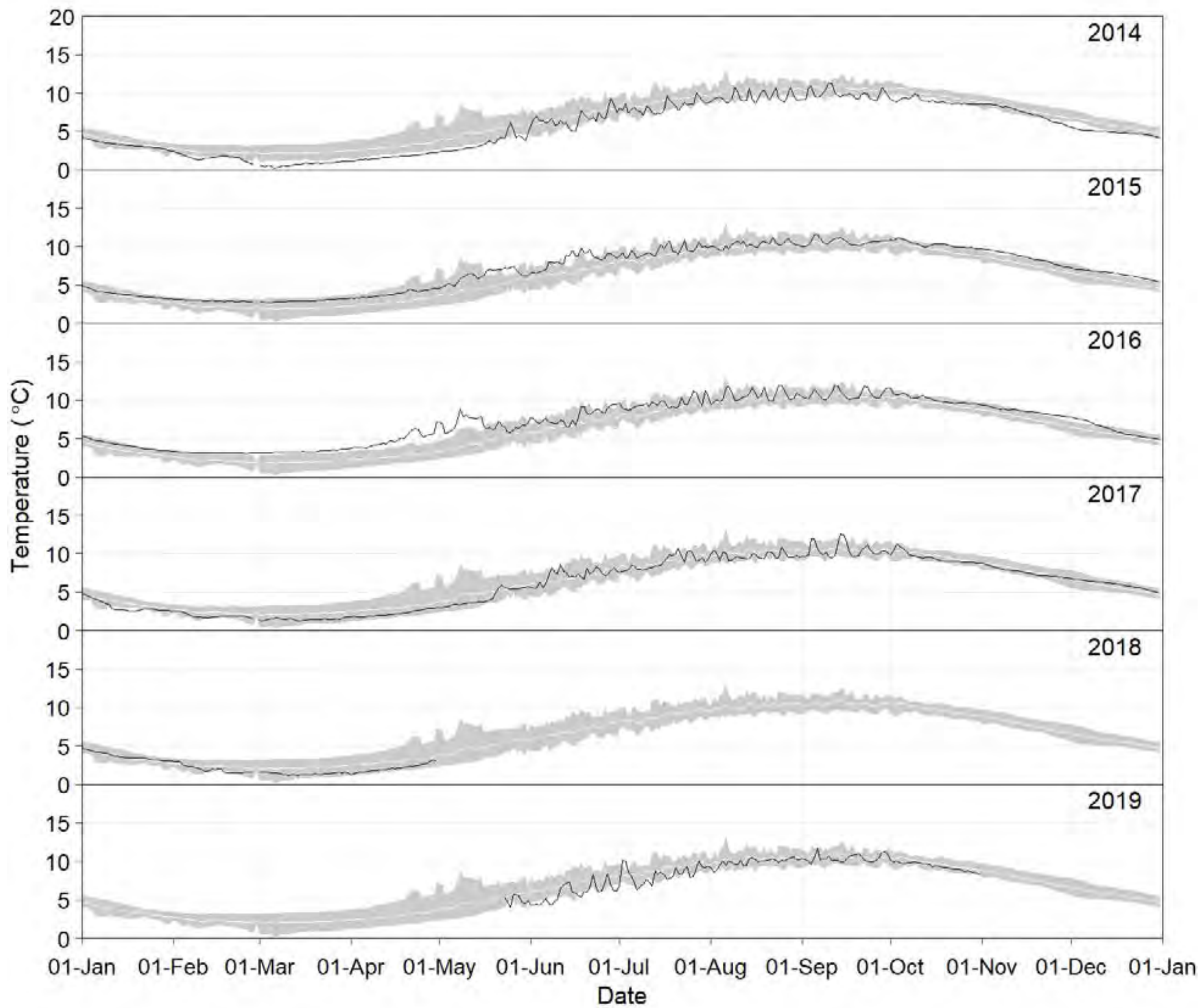

Figure C4 Concluded.

Appendix D – Catch and Effort

Table D1 Number of fish caught and observed during boat electroshocking surveys conducted during the fall season and their frequency of occurrence in sampled sections of the Middle Columbia River, 2001 to 2019.

	2001[a]		2002[a]		2003[a]		2004[a]		2005[a]		2006[a]		2007[a]		2008[a]		2009[a]		2010[a]	
Species	n^b	%[c]	n^b	%[c]	n^b	%[c]	n^b	%[c]	n^b	%[c]	n^b	%[c]	n^b	%[c]	n^b	%[c]	n[b,d]	%[c]	n^b	%[c]
Sportfish																				
Brook Trout					1	<1	1	<1					1	<1					1	<1
Bull Trout	385	2	355	7	416	12	349	9	440	7	358	4	882	3	784	7	598	3	532	2
Burbot			7	<1	1	<1	6	<1	14	<1	14	<1	32	<1	63	1	9	<1	22	<1
Cutthroat Trout													1	<1					1	<1
Kokanee	7654	46	48	1	263	8	107	3	1861	30	5874	62	20 602	70	1892	16	17 295	75	18 304	68
Lake Whitefish	16	<1	34	1	53	2	63	2	275	4	60	1	12	<1	42	<1	17	<1	983	4
Mountain Whitefish	8593	52	4428	91	2706	79	3368	86	3509	57	3133	33	7861	27	8743	73	4973	22	6720	25
Pygmy Whitefish			1	<1													10	<1		
Rainbow Trout	7	<1			5	<1	14	<1	11	<1	15	<1	157	1	320	3	103	<1	111	<1
White Sturgeon	1	<1															1	<1		
Yellow Perch							8	<1	2	<1	3	<1	9	<1	134	1	1	<1	104	<1
Sportfish subtotal	16 656	100	4873	100	3445	100	3916	100	6112	100	9457	100	29 557	100	11 978	100	23 007	100	26 778	100
Non-sportfish																				
Northern Pikeminnow	12	1			1	<1	2	<1	3	<1	2	<1	35	1	124	1	202	8	52	2
Peamouth	3	<1									1	<1	1	<1	6	<1	13	1		
Redside Shiner			11	6	1	<1	239	26	246	29	97	8	553	18	3901	38	736	29	976	33
Sculpin spp.[e]	3	<1	7	4	4	2	268	30	179	21	849	67	1387	45	5086	50	709	27	772	26
Sucker spp.[e]	1189	99	170	90	206	97	393	44	426	50	318	25	1088	36	1043	10	919	36	1168	39
Non-sportfish subtotal	1207	100	188	100	212	100	902	100	854	100	1267	100	3064	100	10 160	100	2579	100	2968	100
All species	17 863		5061		3657		4818		6966		10 724		32 621		22 138		25 586		29 746	

[a] From 2001 to 2006, the study area included all of Reach 4 and the Big Eddy section of Reach; from 2007 to 2019 the study area included all of Reaches 4 and 3.

Continued...

[b] Includes fish observed and identified to species.

[c] Percent composition of sportfish or non-sportfish catch.

[d] Excludes fish recorded during the last session; data were not comparable due to lost observational datasheets.

[e] Species combined for table or not identified to species.

Table D1 Concluded.

Species	2011[a]		2012[a]		2014[a]		2015[a]		2016[a]		2017[a]		2018[a]		2019[a]	
	n^b	%[c]	n^b	%[c]	n^b	%[c]	n^b	%[c]	n^b	%[c]	n^b	%[c]	n^b	%[c]	n^b	%[c]
Sportfish																
Brook Trout	3	<1							2	<1	2	<1			1	<1
Bull Trout	659	4	498	9	442	6	481	10	337	7	615	5	680	13	428	7
Burbot	61	<1	27	<1	3	<1			2	<1	7	<1	24	<1	12	<1
Cutthroat Trout																
Kokanee	8173	53	86	1	2999	43	13	<1	18	<1	9961	78	41	1	3	<1
Lake Whitefish	230	1	92	2	29	<1	464	9	22	<1	12	<1	14	<1	18	<1
Mountain Whitefish	6014	39	5059	87	3529	50	4079	81	4571	91	2133	17	4264	84	5901	92
Pygmy Whitefish																
Rainbow Trout	217	1	70	1	15	<1	24	<1	47	1	64	<1	57	1	66	1
White Sturgeon													1	<1		
Yellow Perch	2	<1	2	<1							9	<1			1	<1
Sportfish subtotal	15 359	100	5834	100	7017	100	5061	100	4999	100	12 803	100	5081	100	6430	100
Non-sportfish																
Northern Pikeminnow	39	1	17	1	10	1	16	1	15	1	5	1	5	1	8	1
Peamouth	1	<1														
Redside Shiner	237	8	286	9	1	<1	61	3	52	5	49	12	205	26	78	7
Sculpin spp.[e]	1807	59	1010	32	107	6	146	6	132	13	122	29	160	20	312	27
Sucker spp.[e]	974	32	1835	58	1705	94	2165	91	832	81	239	58	417	53	760	66
Non-sportfish subtotal	3058	100	3148	100	1823	100	2388	100	1031	100	415	100	787	100	1158	100
All species	18 417		8982		8840		7449		6030		13 218		5868		7588	

[a] From 2001 to 2006, the study area included all of Reach 4 and the Big Eddy section of Reach; from 2007 to 2019 the study area included all of Reaches 4 and 3.
[b] Includes fish observed and identified to species.
[c] Percent composition of sportfish or non-sportfish catch.
[d] Excludes fish recorded during the last session; data were not comparable due to lost observational datasheets.
[e] Species combined for table or not identified to species.

Table D2 Summary of boat electroshocking sportfish catch (includes fish captured and observed and identified to species) and catch-per-unit-effort (CPUE = no. fish/km/hour) during the fall season in the Middle Columbia River, 15 October to 06 November 2019.

Reach	Section	Session	Site	Date	Time Sampled (s)	Length Sampled (km)	Brook Trout No.	Brook Trout CPUE	Bull Trout No.	Bull Trout CPUE	Burbot No.	Burbot CPUE	Kokanee No.	Kokanee CPUE	Lake Whitefish No.	Lake Whitefish CPUE	Mountain Whitefish No.	Mountain Whitefish CPUE	Rainbow Trout No.	Rainbow Trout CPUE	Yellow Perch No.	Yellow Perch CPUE	All Species No.	All Species CPUE
							Number Caught (CPUE = no. fish/km/h)																	
4	Upper	1	0232.6-R	17-Oct-19	527	0.80			3	25.75							50	429.09					53	454.84
			0233.1-L	16-Oct-19	1059	1.41			15	36.22							46	111.06					61	147.28
			0234.4-R	16-Oct-19	1213	1.74			15	25.64							340	581.26	1	1.71			356	608.61
			0234.5-L	16-Oct-19	836	1.65			5	13.02							163	424.37	1	2.6			169	439.99
			0236.1-L	15-Oct-19	776	1.41			11	36.19					2	6.58	101	332.31					114	375.08
			0236.1-R	15-Oct-19	1448	1.73			12	17.22			1	1.43			333	477.73					346	496.38
			0236.4-L	15-Oct-19	311	0.58			1	19.92							75	1494.26					76	1514.19
			0236.4-R	15-Oct-19	382	0.59			3	47.6							82	1300.97					85	1348.56
		Session Summary			819	9.90	0	0	65	28.86	0	0	1	0.44	2	0.89	1190	528.36	2	0.89	0	0	1260	559.44
		2	0232.6-R	28-Oct-19	480	0.80			3	28.27	1	9.42			1	9.42	37	348.62					42	395.73
			0233.1-L	28-Oct-19	666	1.41			10	38.39							63	241.86					73	280.25
			0234.4-R	23-Oct-19	533	0.75			6	54.32							201	1819.84					207	1874.16
			0234.4-R	28-Oct-19	280	0.99									2	25.97	40	519.48					42	545.45
			0234.5-L	22-Oct-19	1293	1.65			13	21.88	1	1.68					299	503.31					313	526.88
			0236.1-L	22-Oct-19	1039	1.41			17	41.78							186	457.07					203	498.84
			0236.1-R	22-Oct-19	1529	1.73			15	20.38					1	1.36	301	408.94	2	2.72			319	433.4
			0236.4-L	21-Oct-19	443	0.58			8	111.9							102	1426.67					110	1538.56
			0236.4-R	21-Oct-19	417	0.59			8	116.27							95	1380.71					103	1496.98
		Session Summary			742	9.90	0	0	80	39.21	2	0.98	0	0	4	1.96	1324	648.86	2	0.98	0	0	1412	691.99
		3	0232.6-R	04-Nov-19	448	0.80			5	50.48					3	30.29	129	1302.27	1	10.1			138	1393.13
			0233.1-L	05-Nov-19	682	1.41			11	41.24					1	3.75	41	153.71	1	3.75			54	202.45
			0234.4-R	04-Nov-19	740	1.74			13	36.43					1	2.8	366	1025.66					380	1064.89
			0234.5-L	04-Nov-19	1002	1.65			9	19.55							514	1116.51					523	1136.06
			0236.1-L	31-Oct-19	743	1.41			10	34.36	2	6.87					145	498.27	1	3.44			158	542.94
			0236.1-R	31-Oct-19	1207	1.73			22	37.86					3	5.16	348	598.93					373	641.96
			0236.4-L	31-Oct-19	327	0.58			8	151.59							86	1629.59	1	18.95			95	1800.12
			0236.4-R	31-Oct-19	339	0.59			2	35.76							51	911.77					53	947.53
		Session Summary			686	9.90	0	0	80	42.41	2	1.06	0	0	8	4.24	1680	890.54	4	2.12	0	0	1774	940.37
	Section Total All Samples				18720	29.74	0		225		4		1		14		4194		8		0		4446	
	Section Average All Samples				749	1.19	0	0	9	36.37	0	0.65	0	0.16	1	2.26	168	677.9	0	1.29	0	0	178	718.63
	Section Standard Error of Mean						0	0	1.11	6.91	0.09	0.46	0.04	0.06	0.19	1.57	26.66	101.84	0.11	0.85	0	0	27.33	106.17
3	Eddy	1	0231.3-R	17-Oct-19	1169	0.90			14	48.12	1	3.44					62	213.09	3	10.31			80	274.96
		Session Summary			1169	0.90	0	0	14	47.9	1	3.42	0	0	0	0	62	212.15	3	10.27	0	0	80	273.74
		2	0231.3-R	29-Oct-19	810	0.90			9	44.64							52	257.94	3	14.88			64	317.46
		Session Summary			810	0.90	0	0	9	44.44	0	0	0	0	0	0	52	256.79	3	14.81	0	0	64	316.05
		3	0231.3-R	05-Nov-19	687	0.90			22	128.66					1	5.85	130	760.29	4	23.39			157	918.2
		Session Summary			687	0.90	0	0	22	128.09	0	0	0	0	1	5.82	130	756.91	4	23.29	0	0	157	914.12
	Section Total All Samples				2666	2.69	0		45		1		0		1		244		10		0		301	
	Section Average All Samples				889	0.90	0	0	15	67.79	0	1.51	0	0	0	1.51	81	367.59	3	15.07	0	0	100	453.46
	Section Standard Error of Mean						0	0	3.79	27.45	0.33	1.15	0	0	0.33	1.95	24.5	175.4	0.33	3.83	0	0	28.71	207.69
3	Middle	1	0227.2-R	18-Oct-19	490	0.52			5	70.78							7	99.09	4	56.62			16	226.5
			0228.5-L	18-Oct-19	1550	1.23	1	1.89	13	24.53	1	1.89	1	1.89			15	28.3	10	18.87			41	77.36
			0229.2-L	17-Oct-19	1401	1.10			2	4.67							7	16.34	2	4.67			11	25.67
			0229.7-R	18-Oct-19	1448	1.82			8	10.93							54	73.77			1	1.37	63	86.06
			0231.0-L	17-Oct-19	1520	1.96			22	26.53							97	116.97	10	12.06			129	155.56
			0231.0-R	17-Oct-19	1117	1.19			10	27.02							157	424.14					167	451.15
		Session Summary			1254	7.80	1	0.37	60	22.08	1	0.37	1	0.37	0	0	337	124.03	26	9.57	1	0.37	427	157.16
		2	0227.2-R	31-Oct-19	944	0.52			6	44.09							4	29.39					10	73.48
			0228.5-L	30-Oct-19	1012	1.23			10	28.9							106	306.32	4	11.56			120	346.77
			0229.2-L	30-Oct-19	988	1.10			2	6.62							29	95.97	1	3.31			32	105.9
			0229.7-R	30-Oct-19	1838	2.27			18	15.53					1	0.86	162	139.78	2	1.73			183	157.9
			0231.0-L	30-Oct-19	1151	1.96			7	11.15	1	1.59					86	136.96	3	4.78			97	154.47
			0231.0-R	29-Oct-19	1034	1.19			9	26.27					1	2.92	169	493.21	2	5.84			181	528.23
		Session Summary			1161	8.30	0	0	52	19.43	1	0.37	0	0	2	0.75	556	207.71	12	4.48	0	0	623	232.74
		3	0227.2-R	06-Nov-19	549	0.52			3	37.9							2	25.27	4	50.54			9	113.71
			0228.5-L	06-Nov-19	1105	1.23			7	18.53							74	195.85	2	5.29			83	219.66
			0229.2-L	06-Nov-19	1073	1.10			3	9.14							28	85.32	1	3.05			32	97.51
			0229.7-R	06-Nov-19	1902	2.27			8	6.67			1	0.83			98	81.71	1	0.83			108	90.05
			0231.0-L	05-Nov-19	1148	1.96			5	7.98	5	7.98			1	1.6	140	223.54	2	3.19			153	244.29
			0231.0-R	05-Nov-19	950	1.19			20	63.53							228	724.22					248	787.75
		Session Summary			1121	8.30	0	0	46	17.8	5	1.93	1	0.39	1	0.39	570	220.54	10	3.87	0	0	633	244.92
	Section Total All Samples				21220	24.38	1		158		7		2		3		1463		48		1		1683	
	Section Average All Samples				1179	1.35	0	0.13	9	19.79	0	0.88	0	0.25	0	0.38	81	183.2	3	6.01	0	0.13	94	210.75
	Section Standard Error of Mean						0.06	0.11	1.41	4.53	0.28	0.45	0.08	0.11	0.09	0.18	16.18	44.98	0.7	3.91	0.06	0.08	17.05	46.21
All Sections Total All Samples					42606	56.81	1	0	428	0.64	12	0.02	3	0	18	0.03	5901	8.78	66	0.1	1	0	6430	9.56
All Sections Average All Samples							0	0.07	9	29.28	0	0.82	0	0.21	0	1.23	128	403.74	1	4.52	0	0.07	140	439.94
All Sections Standard Error of Mean							0.02	0.04	0.86	4.77	0.12	0.31	0.04	0.05	0.11	0.88	16.96	72.2	0.33	1.74	0.02	0.03	17.33	74.77

Table D3 Summary of boat electroshocking non-sportfish catch (includes fish captured and observed and identified to species) and catch-per-unit-effort (CPUE = no. fish/km/hour) during the fall season in the Middle Columbia River, 15 October to 06 November 2019.

Reach	Section	Session	Site	Date	Time Sampled (s)	Length Sampled (km)	Number Caught (CPUE = no. fish/km/h) Northern Pikeminnow No.	Northern Pikeminnow CPUE	Redside Shiner No.	Redside Shiner CPUE	Sculpin spp. No.	Sculpin spp. CPUE	Sucker spp. No.	Sucker spp. CPUE	All Species No.	All Species CPUE
4	Upper	1	0232.6-R	17-Oct-19	527	0.80							7	60.07	7	60.07
			0233.1-L	16-Oct-19	1059	1.41					7	16.9	44	106.23	51	123.13
			0234.4-R	16-Oct-19	1213	1.74	1	1.71			2	3.42	24	41.03	27	46.16
			0234.5-L	16-Oct-19	836	1.65					3	7.81	10	26.04	13	33.85
			0236.1-L	15-Oct-19	776	1.41					1	3.29	6	19.74	7	23.03
			0236.1-R	15-Oct-19	1448	1.73					2	2.87	17	24.39	19	27.26
			0236.4-L	15-Oct-19	311	0.58					1	19.92	4	79.69	5	99.62
			0236.4-R	15-Oct-19	382	0.59							7	111.06	7	111.06
		Session Summary			**819**	**9.90**	**1**	**0.44**	**0**	**0**	**16**	**7.1**	**119**	**52.84**	**136**	**60.38**
		2	0232.6-R	28-Oct-19	480	0.80							3	28.27	3	28.27
			0233.1-L	28-Oct-19	666	1.41							15	57.59	15	57.59
			0234.4-R	23-Oct-19	533	0.75							20	181.08	20	181.08
			0234.5-L	22-Oct-19	1293	1.65					27	45.45	25	42.08	52	87.53
			0236.1-L	22-Oct-19	1039	1.41					1	2.46	66	162.19	67	164.64
			0236.1-R	22-Oct-19	1529	1.73	1	1.36	1	1.36	7	9.51	25	33.97	34	46.19
			0236.4-L	21-Oct-19	443	0.58					5	69.93	14	195.82	19	265.75
			0236.4-R	21-Oct-19	417	0.59					2	29.07	6	87.2	8	116.27
		Session Summary			**800**	**8.90**	**1**	**0.51**	**1**	**0.51**	**42**	**21.24**	**174**	**87.98**	**218**	**110.22**
		3	0232.6-R	04-Nov-19	448	0.80							8	80.76	8	80.76
			0233.1-L	05-Nov-19	682	1.41					3	11.25	5	18.75	8	29.99
			0234.4-R	04-Nov-19	740	1.74							19	53.24	19	53.24
			0234.5-L	04-Nov-19	1002	1.65							24	52.13	24	52.13
			0236.1-L	31-Oct-19	743	1.41					4	13.75	36	123.71	40	137.45
			0236.1-R	31-Oct-19	1207	1.73					10	17.21	41	70.56	51	87.77
			0236.4-L	31-Oct-19	327	0.58					2	37.9	20	378.97	22	416.87
			0236.4-R	31-Oct-19	339	0.59							1	17.88	1	17.88
		Session Summary			**686**	**9.90**	**0**	**0**	**0**	**0**	**19**	**10.07**	**154**	**81.63**	**173**	**91.7**
	Section Total All Samples				**18440**	**28.75**	**2**		**1**		**77**		**447**		**527**	
	Section Average All Samples				**768**	**1.20**	**0**	**0.33**	**0**	**0.16**	**3**	**12.56**	**19**	**72.89**	**22**	**85.94**
	Section Standard Error of Mean						**0.06**	**0.09**	**0.04**	**0.06**	**1.17**	**3.61**	**3.19**	**16.49**	**3.72**	**18.43**
3	Eddy	1	0231.3-R	17-Oct-19	1169	0.90			1	3.44	7	24.06	5	17.19	13	44.68
		Session Summary			**1169**	**0.90**	**0**	**0**	**1**	**3.42**	**7**	**23.95**	**5**	**17.11**	**13**	**44.48**
		2	0231.3-R	29-Oct-19	810	0.90							10	49.6	10	49.6
		Session Summary			**810**	**0.90**	**0**	**0**	**0**	**0**	**0**	**0**	**10**	**49.38**	**10**	**49.38**
		3	0231.3-R	05-Nov-19	687	0.90							13	76.03	13	76.03
		Session Summary			**687**	**0.90**	**0**	**0**	**0**	**0**	**0**	**0**	**13**	**75.69**	**13**	**75.69**
	Section Total All Samples				**2666**	**2.69**	**0**		**1**		**7**		**28**		**36**	
	Section Average All Samples				**889**	**0.90**	**0**	**0**	**0**	**1.51**	**2**	**10.55**	**9**	**42.18**	**12**	**54.23**
	Section Standard Error of Mean						**0**	**0**	**0.33**	**1.15**	**2.33**	**8.02**	**2.33**	**17.01**	**1**	**9.73**
3	Middle	1	0227.2-R	18-Oct-19	490	0.52							3	42.47	3	42.47
			0228.5-L	18-Oct-19	1550	1.23	1	1.89	1	1.89	36	67.92	13	24.53	51	96.22
			0229.2-L	17-Oct-19	1401	1.10	1	2.33	28	65.35	21	49.01	10	23.34	60	140.03
			0229.7-R	18-Oct-19	1448	1.82	2	2.73					37	50.54	39	53.28
			0231.0-L	17-Oct-19	1520	1.96					5	6.03	32	38.59	37	44.62
			0231.0-R	17-Oct-19	1117	1.19					1	2.7	22	59.43	23	62.14
		Session Summary			**1254**	**7.80**	**4**	**1.47**	**29**	**10.67**	**63**	**23.19**	**117**	**43.06**	**213**	**78.4**
		2	0227.2-R	31-Oct-19	944	0.52							1	7.35	1	7.35
			0228.5-L	30-Oct-19	1012	1.23					17	49.13	13	37.57	30	86.69
			0229.2-L	30-Oct-19	988	1.10			1	3.31	12	39.71	13	43.02	26	86.05
			0229.7-R	30-Oct-19	1838	2.27					6	5.18	35	30.2	41	35.38
			0231.0-L	30-Oct-19	1151	1.96					38	60.52	46	73.26	84	133.77
			0231.0-R	29-Oct-19	1034	1.19							14	40.86	14	40.86
		Session Summary			**1161**	**8.30**	**0**	**0**	**1**	**0.37**	**73**	**27.27**	**122**	**45.58**	**196**	**73.22**
		3	0227.2-R	06-Nov-19	549	0.52	1	12.63			25	315.87	1	12.63	27	341.14
			0228.5-L	06-Nov-19	1105	1.23			6	15.88	22	58.22	11	29.11	39	103.22
			0229.2-L	06-Nov-19	1073	1.10			40	121.89	24	73.14	2	6.09	66	201.12
			0229.7-R	06-Nov-19	1902	2.27	1	0.83			12	10.01	14	11.67	27	22.51
			0231.0-L	05-Nov-19	1148	1.96					3	4.79	7	11.18	10	15.97
			0231.0-R	05-Nov-19	950	1.19					6	19.06	11	34.94	17	54
		Session Summary			**1121**	**8.30**	**2**	**0.77**	**46**	**17.8**	**92**	**35.6**	**46**	**17.8**	**186**	**71.97**
	Section Total All Samples				**21220**	**24.38**	**6**		**76**		**228**		**285**		**595**	
	Section Average All Samples				**1179**	**1.35**	**0**	**0.75**	**4**	**9.52**	**13**	**28.55**	**16**	**35.69**	**33**	**74.51**
	Section Standard Error of Mean						**0.14**	**0.71**	**2.62**	**7.45**	**2.95**	**17.3**	**3.14**	**4.37**	**5.18**	**18.95**
All Sections Total All Samples					**42326**	**55.82**	**8**	**0.01**	**78**	**0.12**	**312**	**0.48**	**760**	**1.16**	**1158**	**1.76**
All Sections Average All Samples							**0**	**0.55**	**2**	**5.35**	**7**	**21.39**	**17**	**52.11**	**26**	**79.4**
All Sections Standard Error of Mean							**0.07**	**0.29**	**1.08**	**3.05**	**1.5**	**7.43**	**2.12**	**9.74**	**2.99**	**12.37**

Table D4 Summary of the number (N) of fish captured and recaptured in sampled sections of the Middle Columbia River during the fall season, 15 October to 06 November 2019.

Species	Size-class	Session	N Captured	N Marked	N Recaptured (within year)	N Recaptured (between years)
Burbot	All	1	1	1	-	0
		2	2	2	0	0
		3	3	3	0	0
Burbot Total			6	6	0	0
Bull Trout	All	1	84	71	-	13
		2	69	52	2	15
		3	58	38	9	11
Bull Trout Total			211	161	11	39
Largescale Sucker	All	1	114	91	-	23
		2	129	105	5	19
		3	63	51	3	9
Largescale Sucker Total			306	247	8	51
Longnose Sucker	All	1	5	5	-	0
		2	3	3	0	0
		3	3	2	1	0
Longnose Sucker Total			11	10	1	0
Lake Whitefish	All	1	2	2	-	0
		2	5	5	0	0
		3	8	8	0	0
Lake Whitefish Total			15	15	0	0
Mountain Whitefish	All	1	452	396	-	55
		2	602	514	21	67
		3	548	484	25	39
Mountain Whitefish Total			1602	1394	47	161
Northern Pikeminnow	All	1	4	4	-	0
		2	0	0	0	0
		3	2	2	0	0
Northern Pikeminnow Total			6	6	0	0
Rainbow Trout	All	1	24	22	-	2
		2	7	7	0	0
		3	6	4	1	1
Rainbow Trout Total			37	33	1	3

Appendix E – Life History

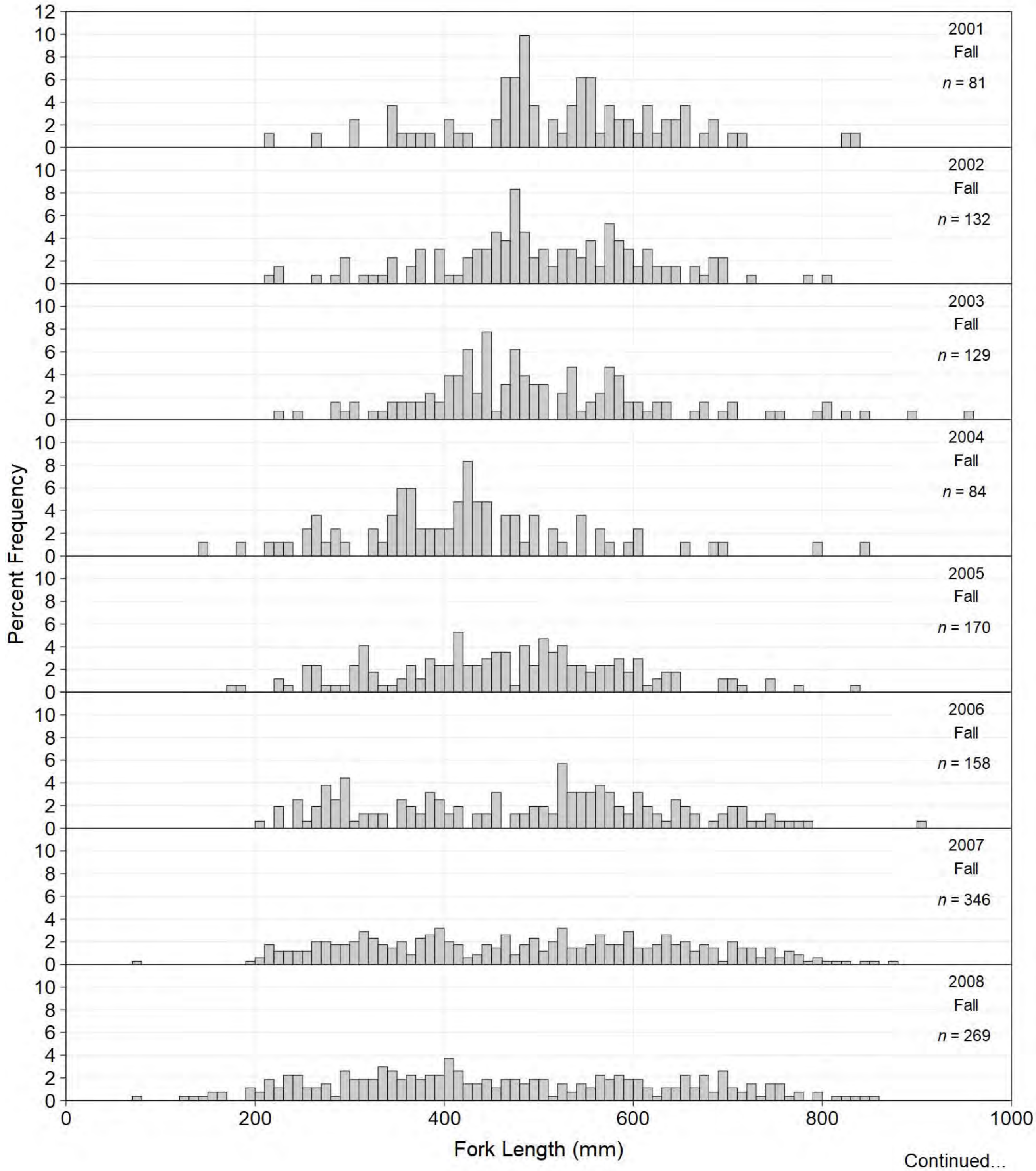

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Figure E1 Length-frequency distributions for Bull Trout captured by boat electroshocking in Reaches 3 and 4 of the Middle Columbia River, 2001 to 2019. Bull Trout that were initially marked during an earlier year of the program were excluded from the analysis due to potential tagging effects on growth. Boat electroshocking surveys were not conducted downstream of Big Eddy for all years prior to 2007.

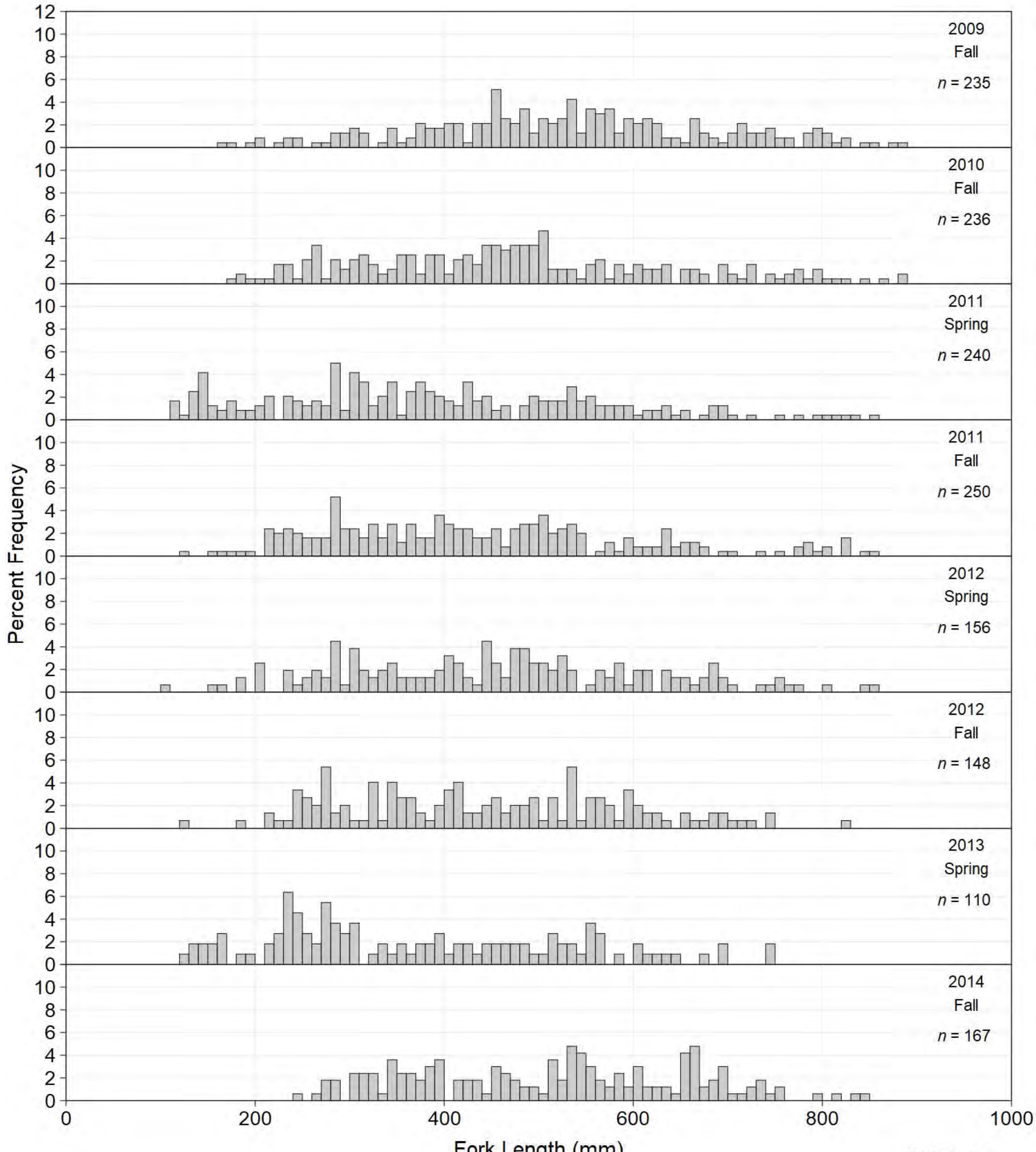

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Figure E1 Continued

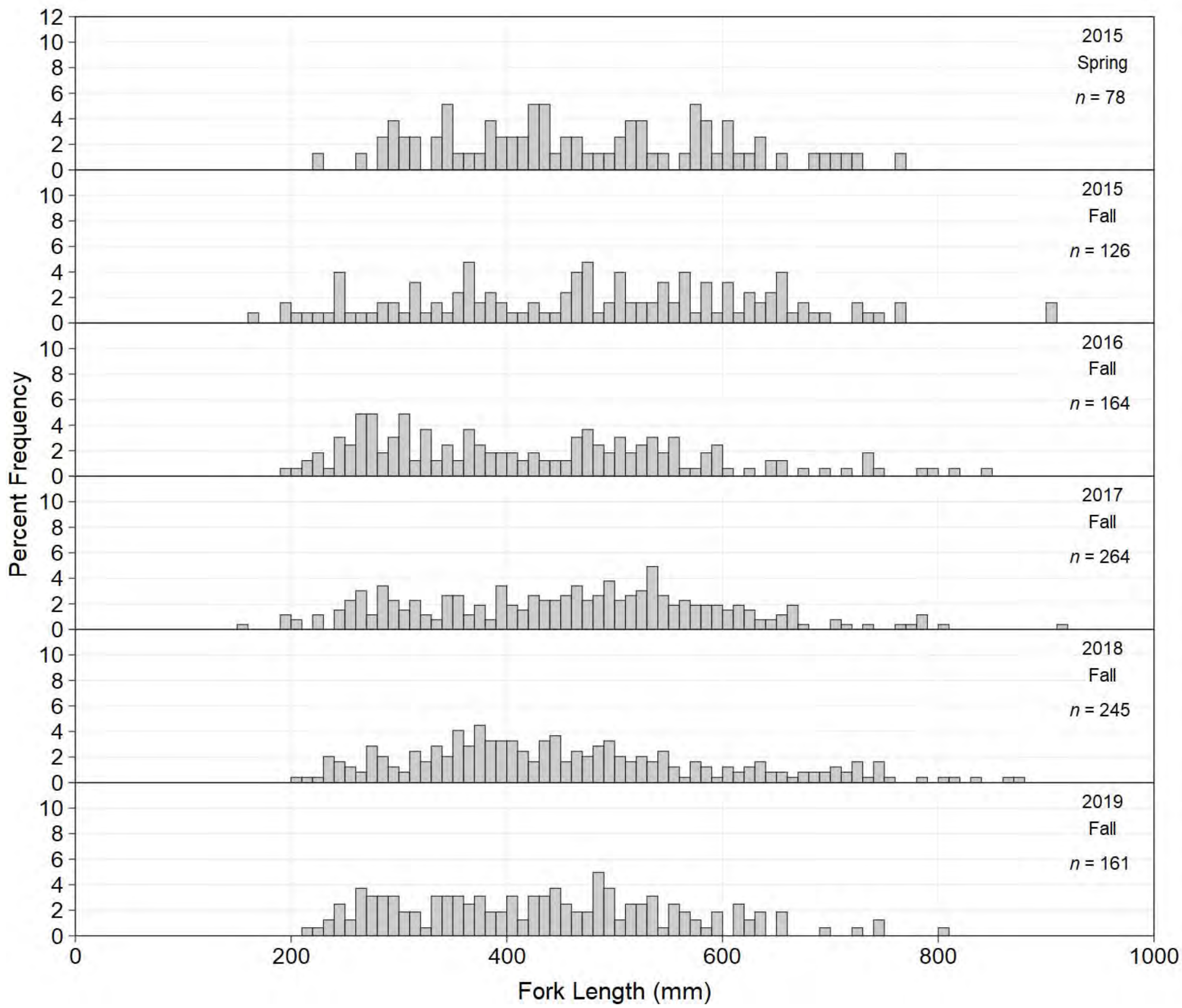

Figure E1 Concluded

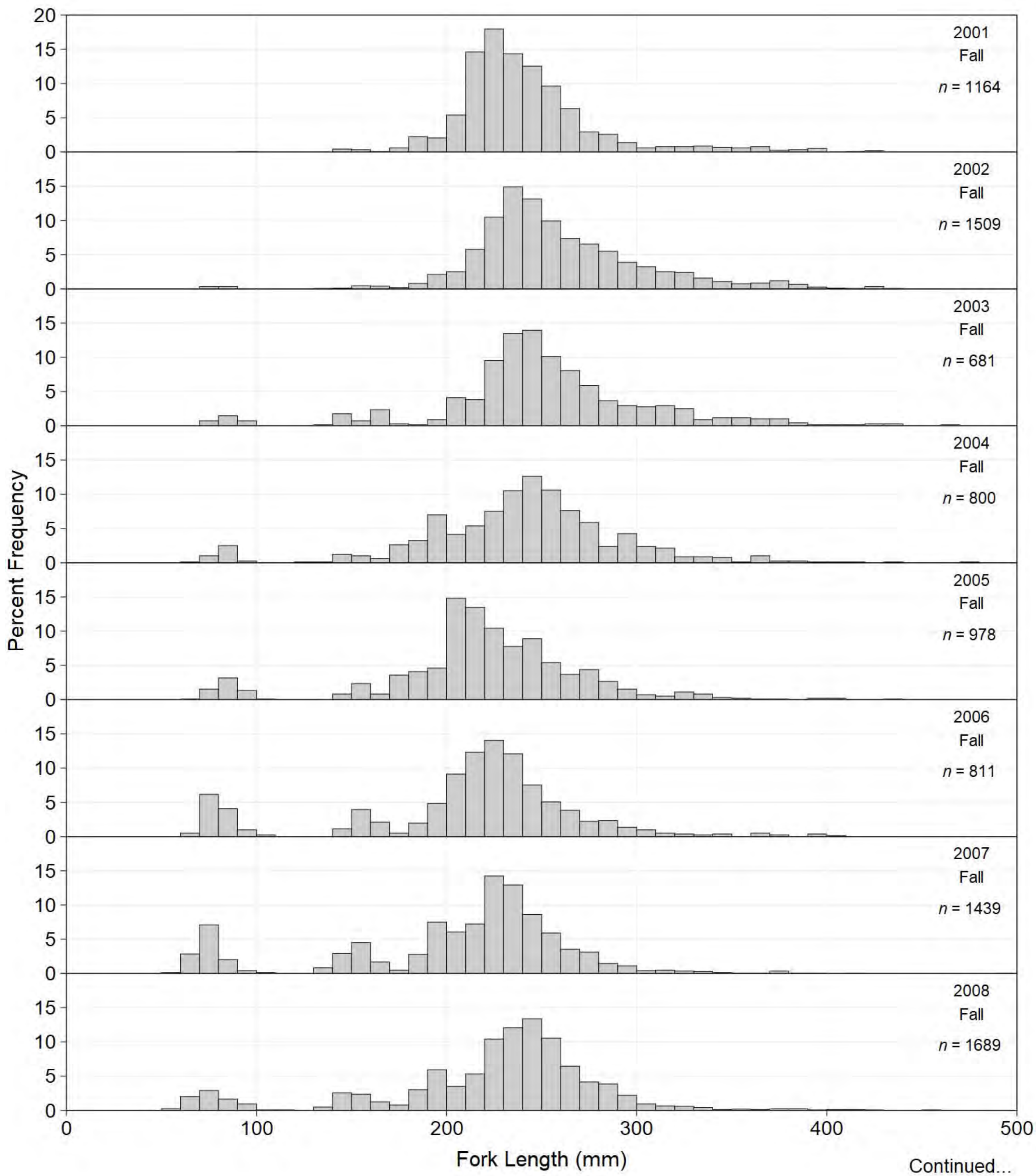

Figure E2 Length-frequency distributions for Mountain Whitefish captured by boat electroshocking in Reaches 3 and 4 of the Middle Columbia River, 2001 to 2019. Mountain Whitefish that were initially marked during an earlier year of the program were excluded from the analysis due to potential tagging effects on growth. Boat electroshocking surveys were not conducted downstream of Big Eddy for all years prior to 2007.

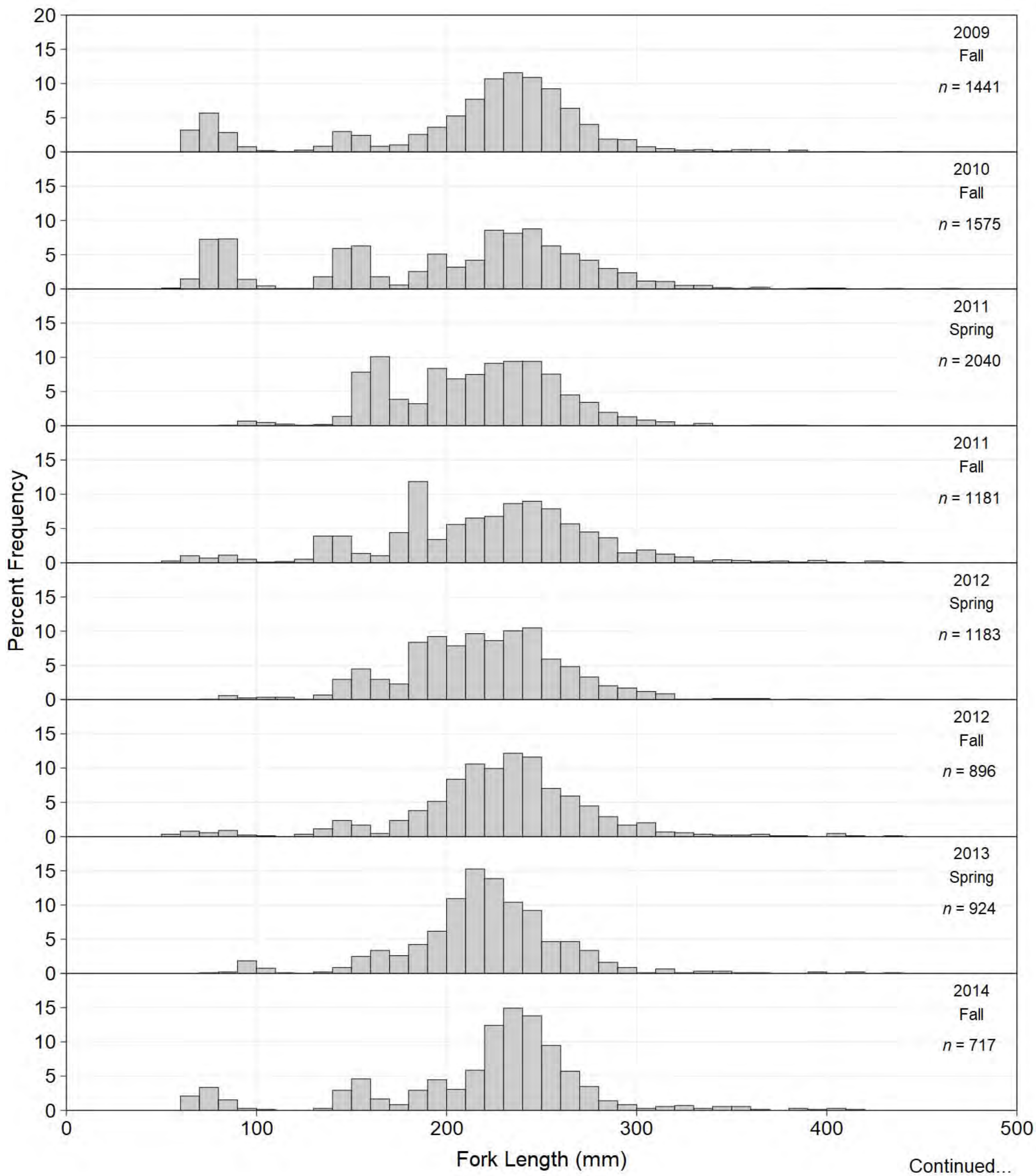

Figure E2 Continued

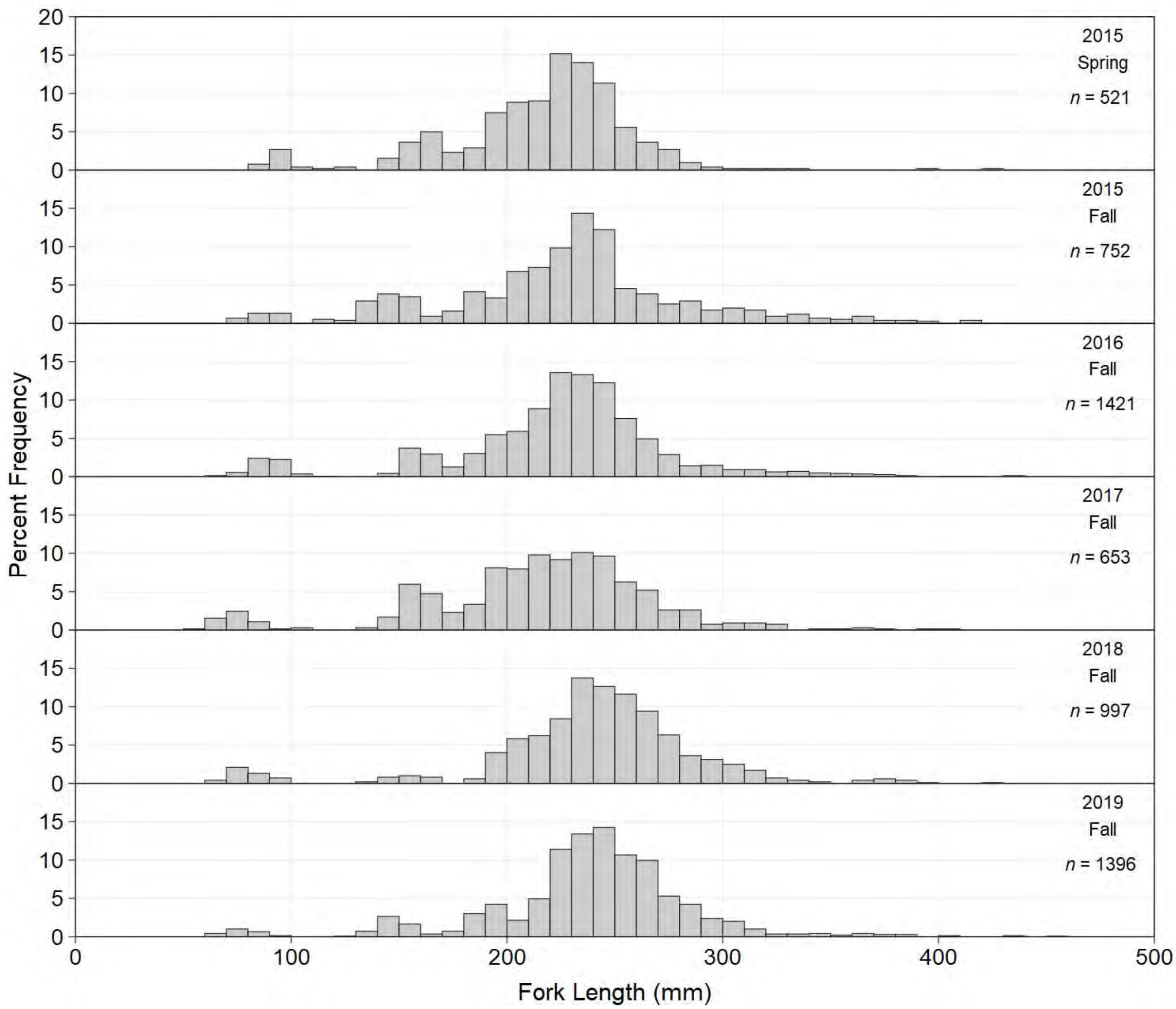

Figure E2 Concluded

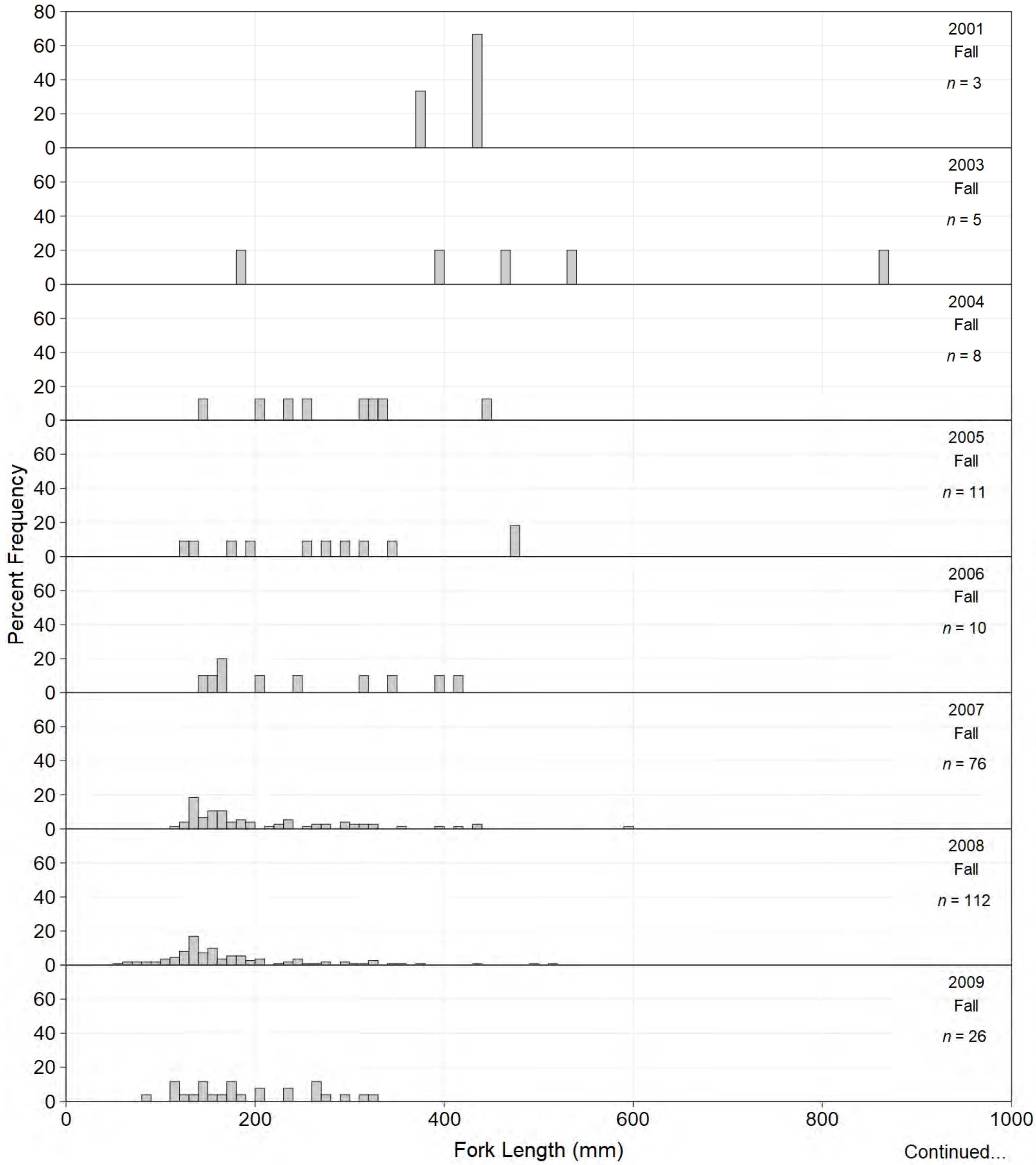

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Figure E3 Length-frequency distributions for Rainbow Trout captured by boat electroshocking in Reaches 3 and 4 of the Middle Columbia River, 2001 to 2019. Rainbow Trout that were initially marked during an earlier year of the program were excluded from the analysis due to potential tagging effects on growth. Boat electroshocking surveys were not conducted downstream of Big Eddy for all years prior to 2007.

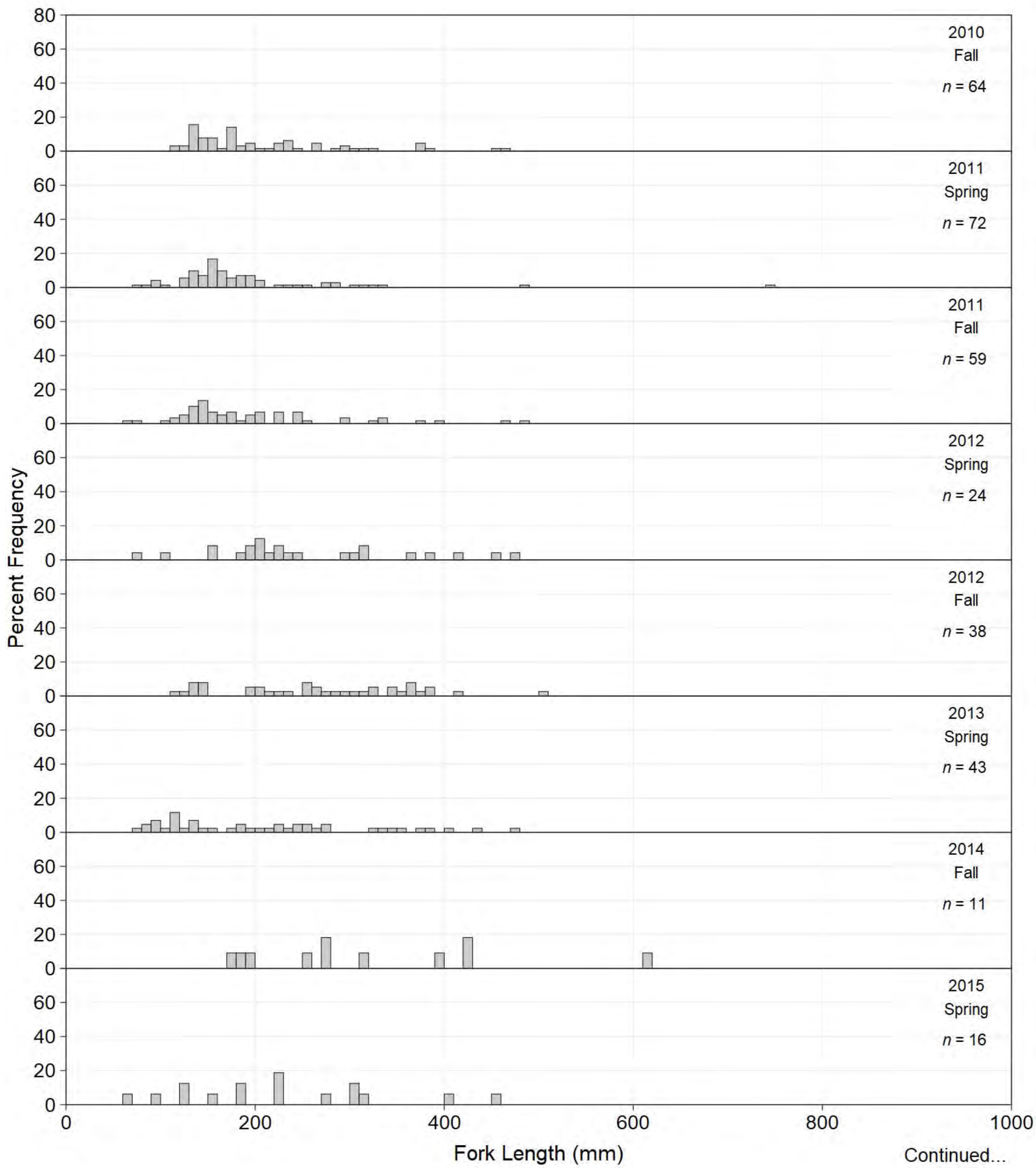
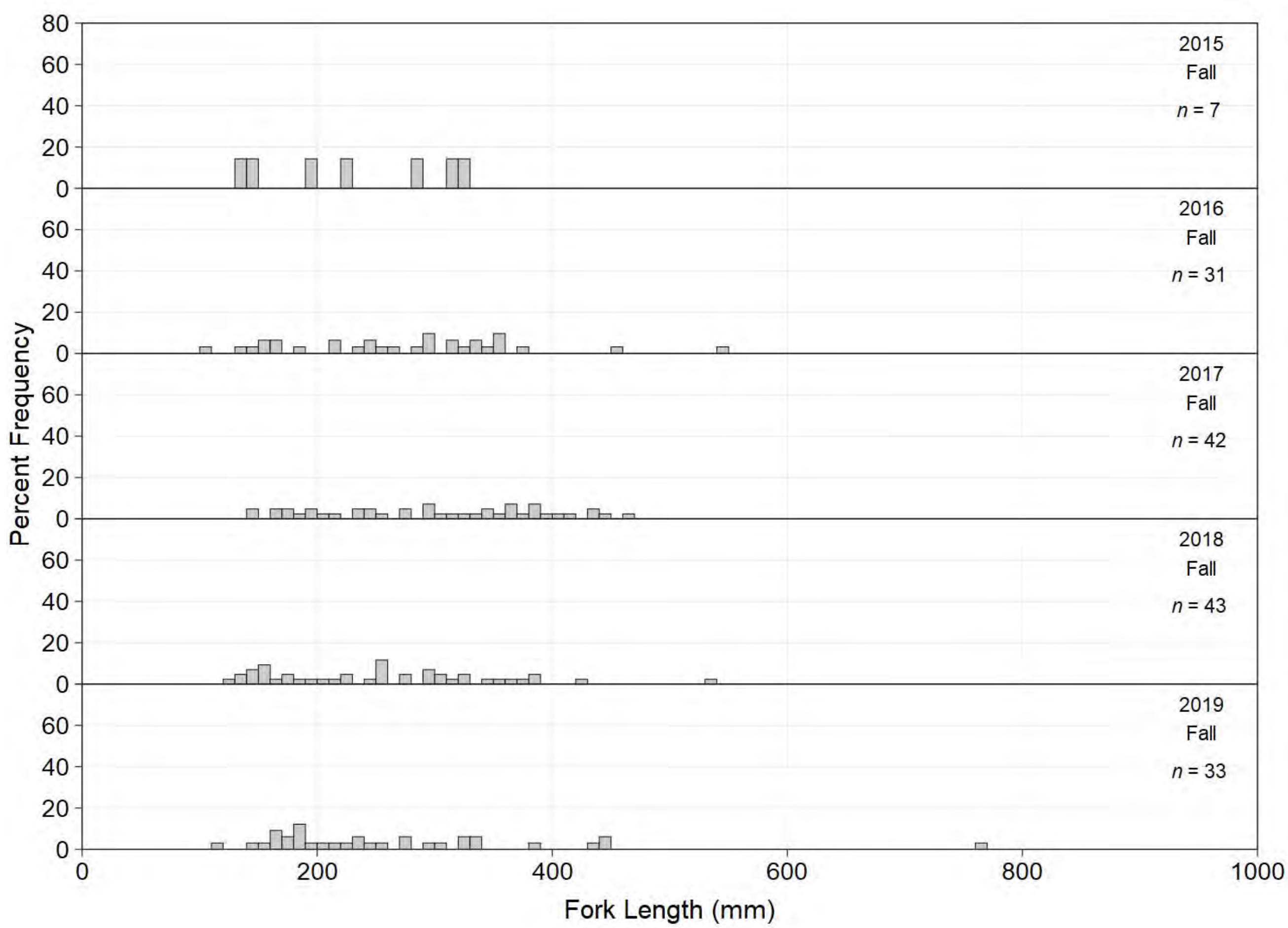


Figure E3 Continued



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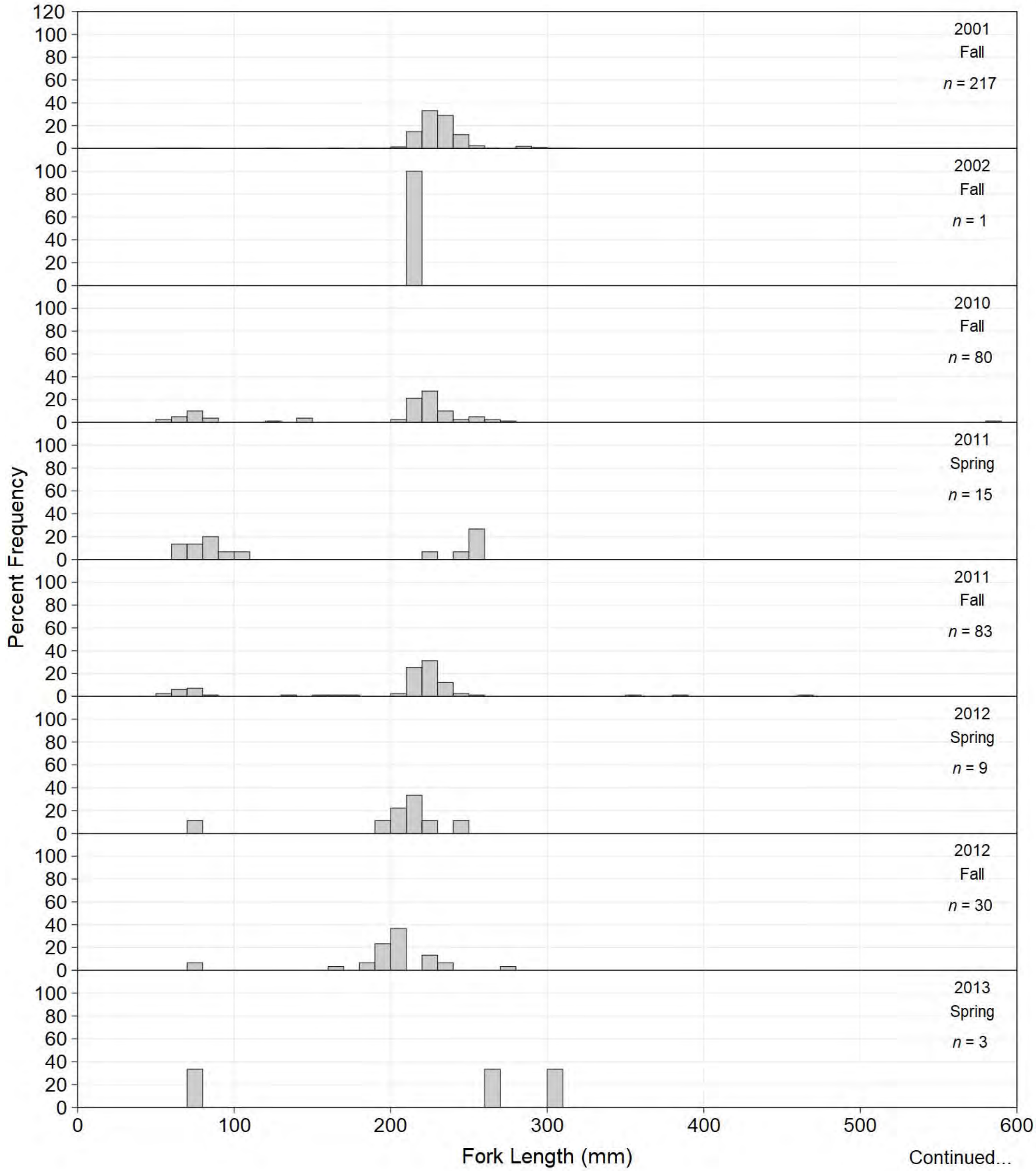
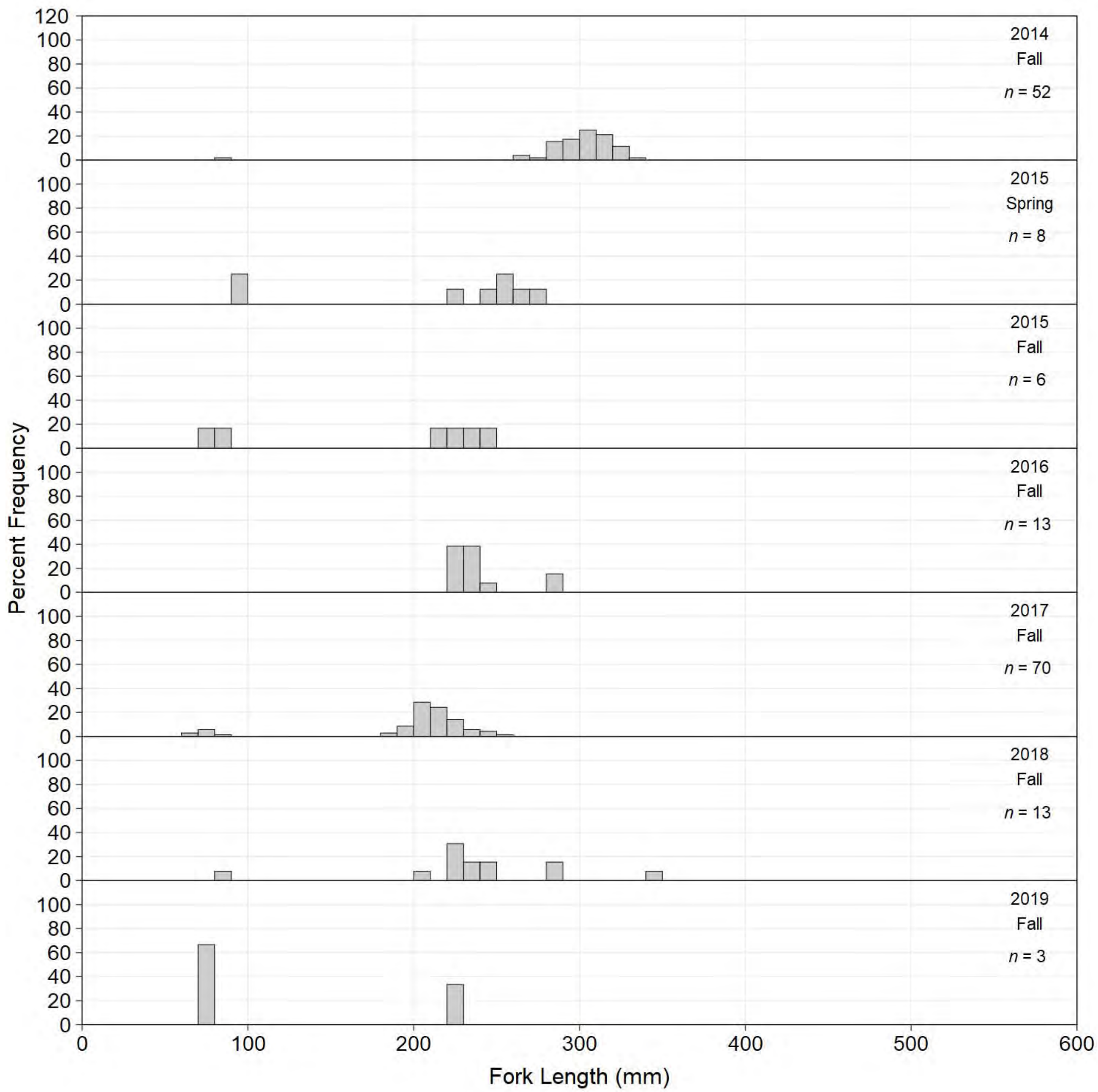


Figure E4 Length-frequency distributions for Kokanee captured by boat electroshocking in Reaches 3 and 4 of the Middle Columbia River, 2001 to 2019. Kokanee that were initially marked during an earlier year of the program were excluded from the analysis due to potential tagging effects on growth. Boat electroshocking surveys were not conducted downstream of Big Eddy for all years prior to 2007.



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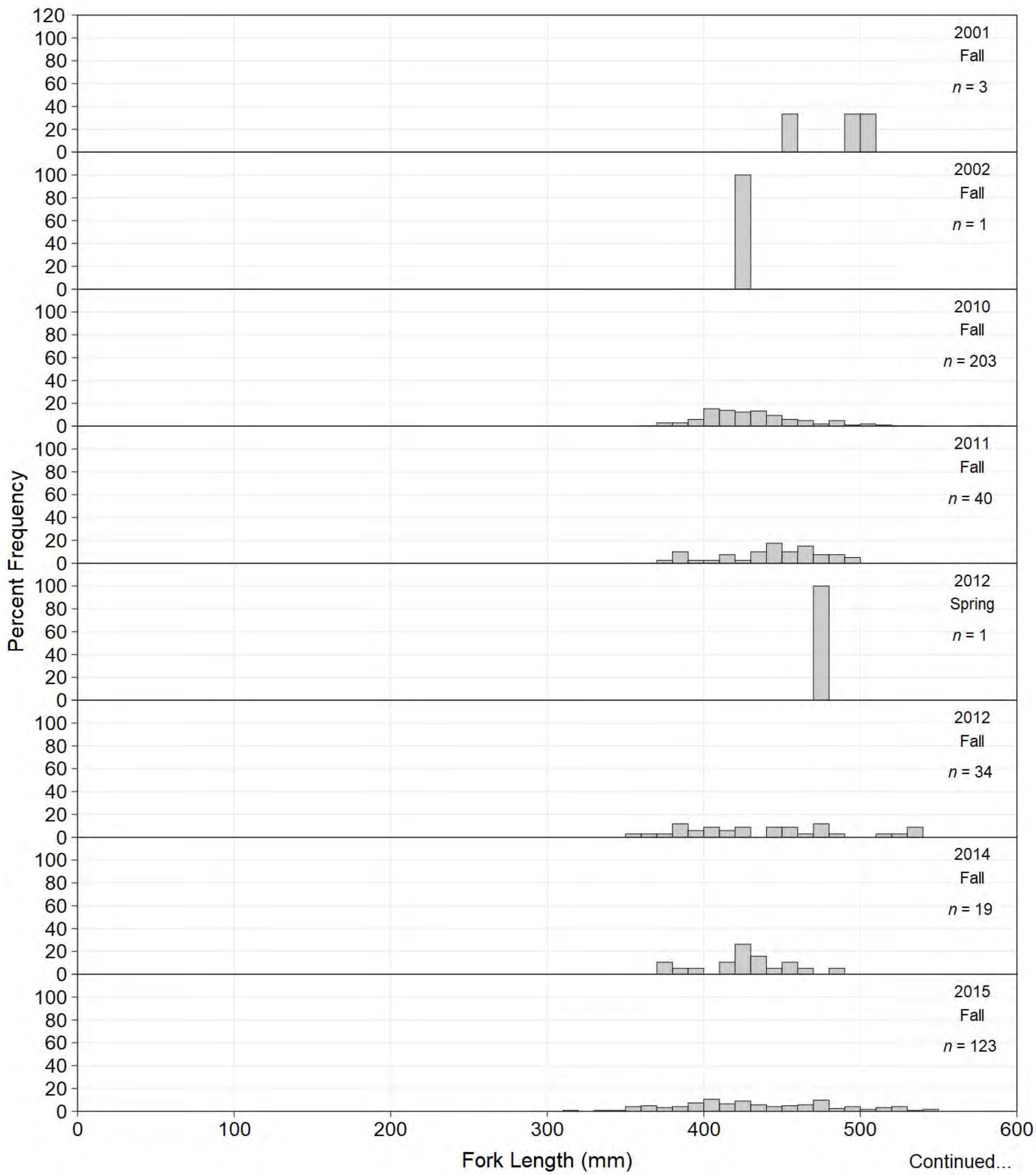
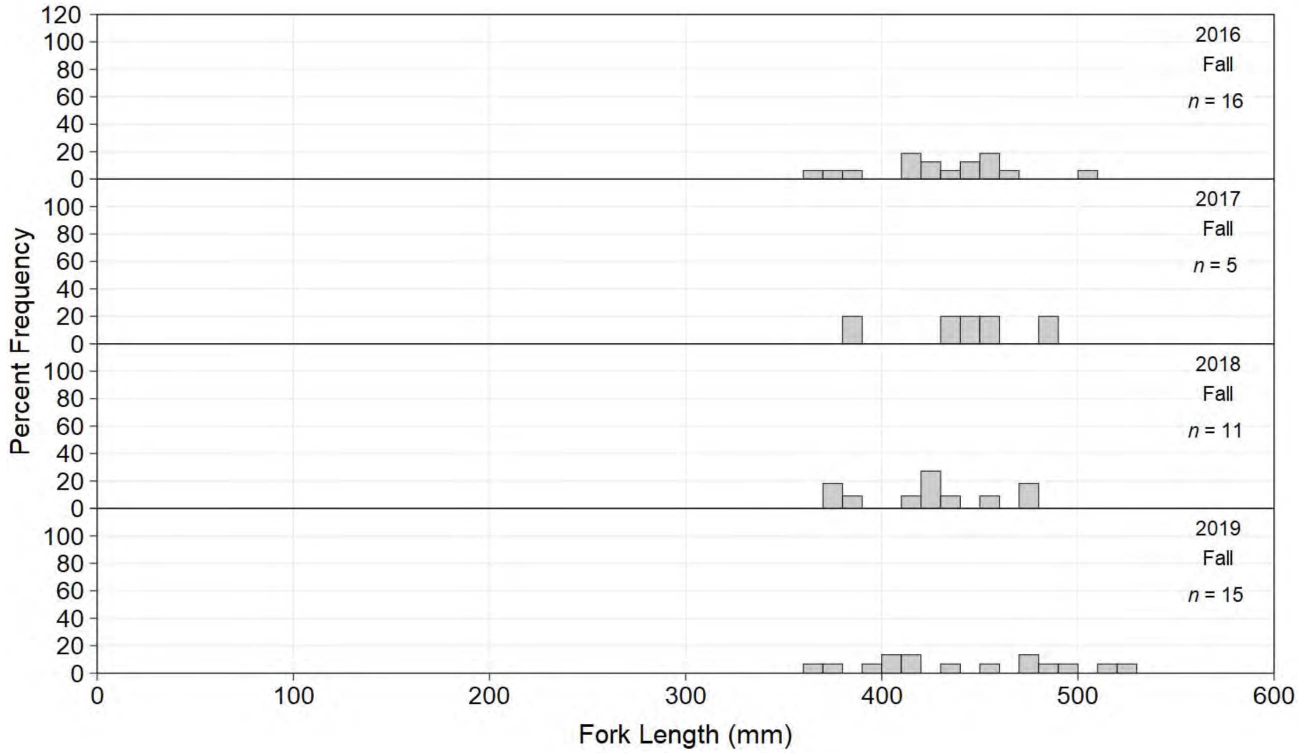


Figure E5 Length-frequency distributions for Lake Whitefish captured by boat electroshocking in Reaches 3 and 4 of the Middle Columbia River, 2001 to 2019. Lake Whitefish that were initially marked during an earlier year of the program were excluded from the analysis due to potential tagging effects on growth. Boat electroshocking surveys were not conducted downstream of Big Eddy for all years prior to 2007.



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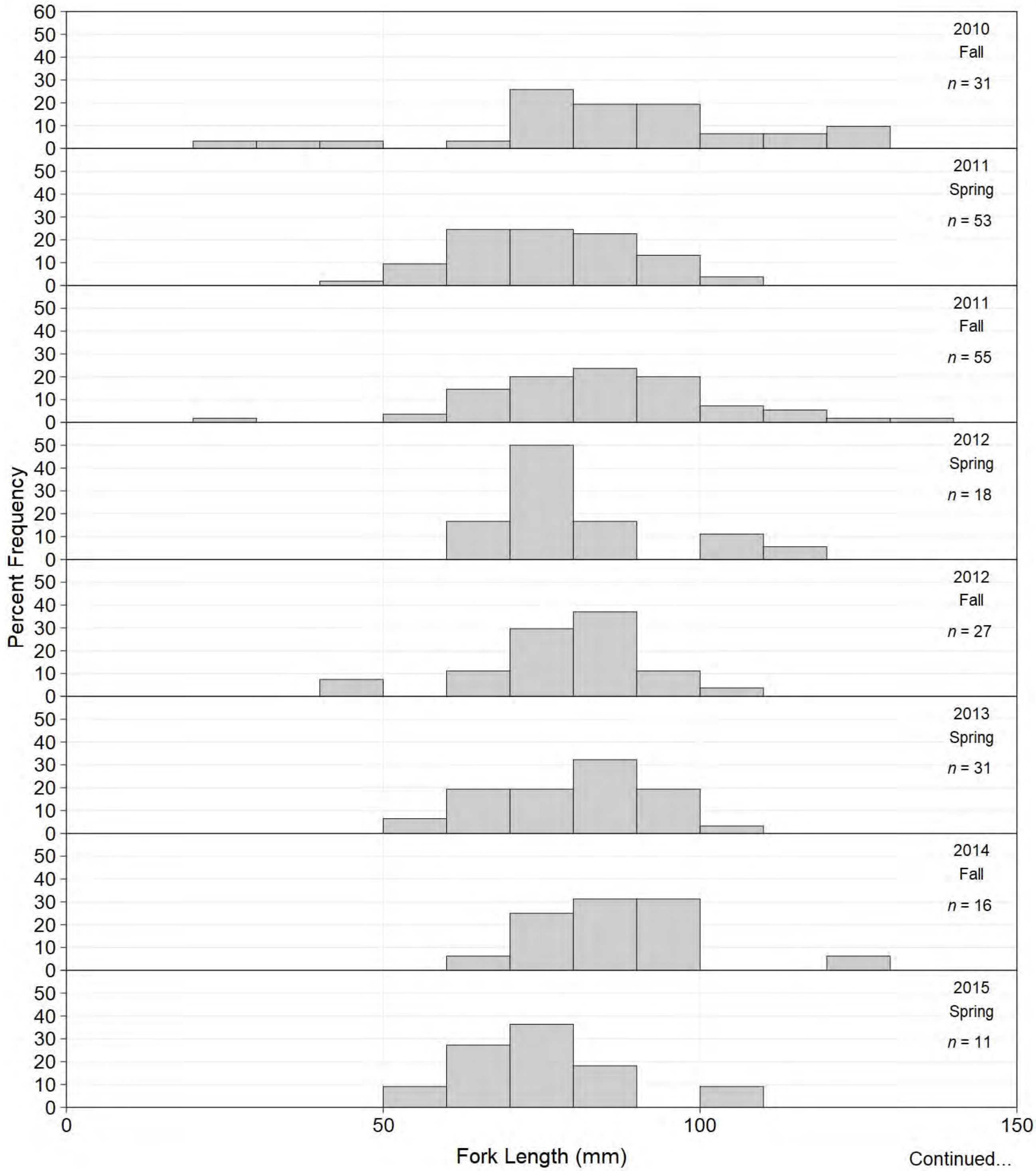

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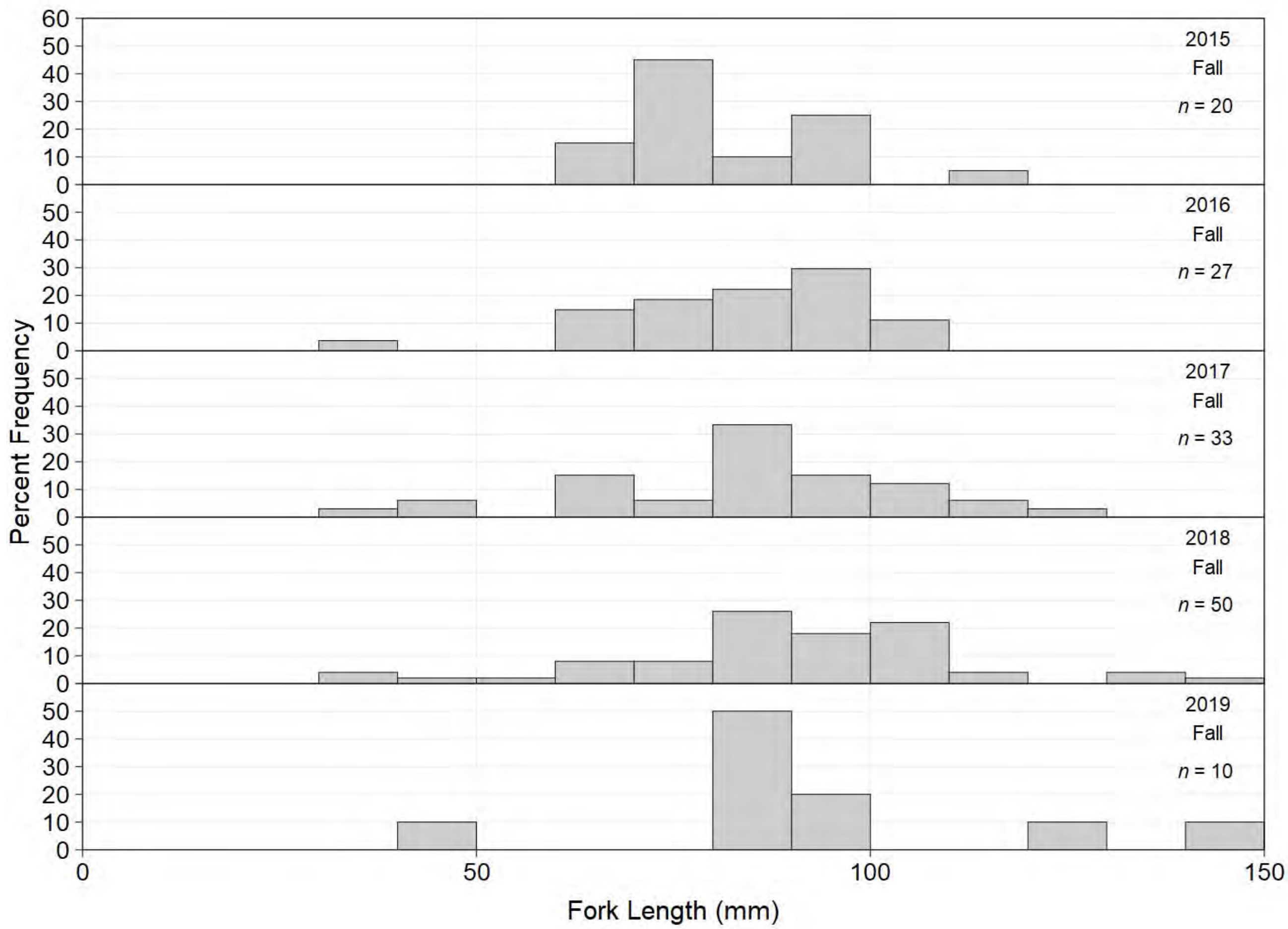
Figure E6 Length-frequency distributions for Prickly Sculpin captured by boat electroshocking in Reaches 3 and 4 of the Middle Columbia River, 2001 to 2019. Prickly Sculpin that were initially marked during an earlier year of the program were excluded from the analysis due to potential tagging effects on growth. Boat electroshocking surveys were not conducted downstream of Big Eddy for all years prior to 2007.



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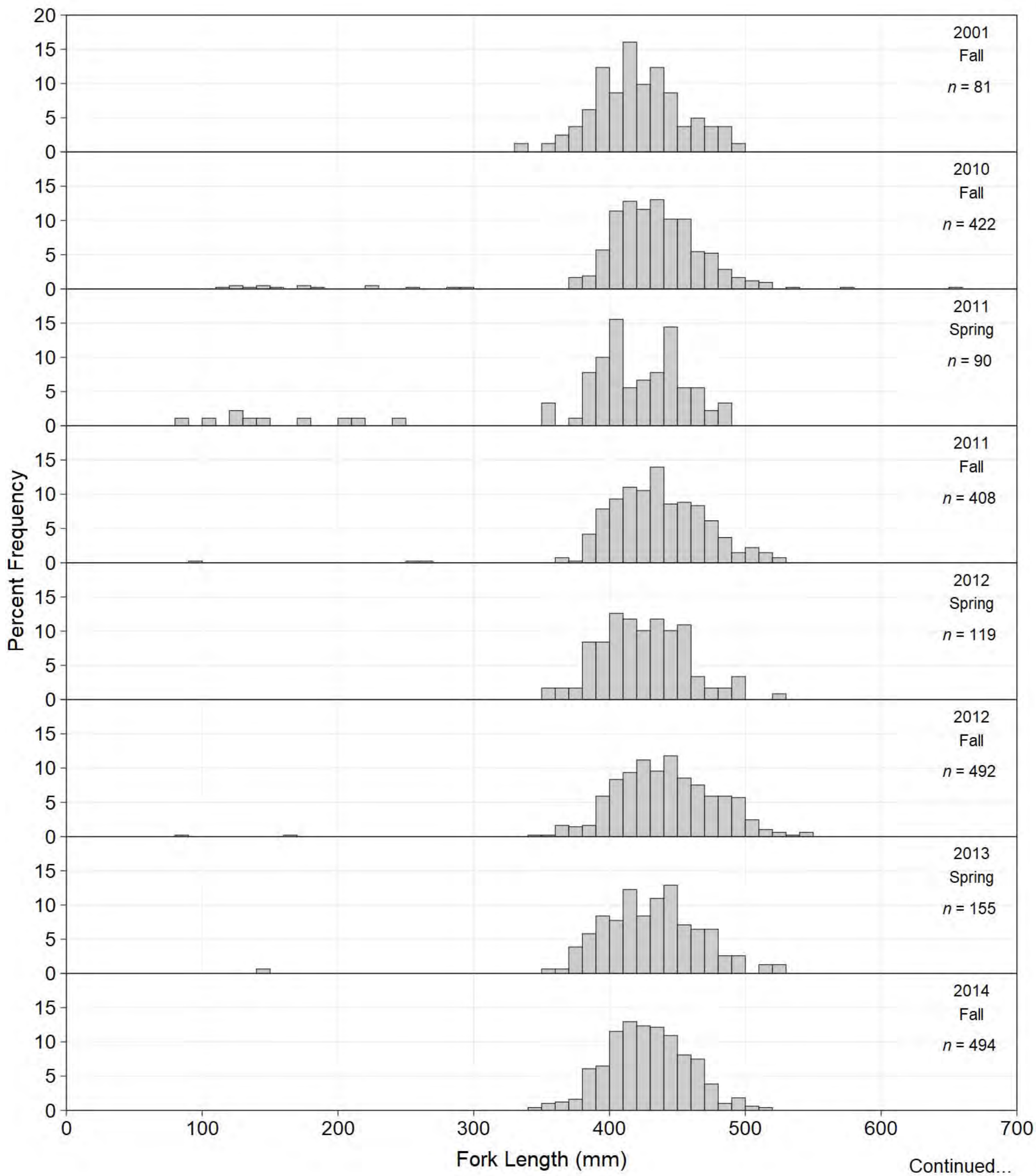
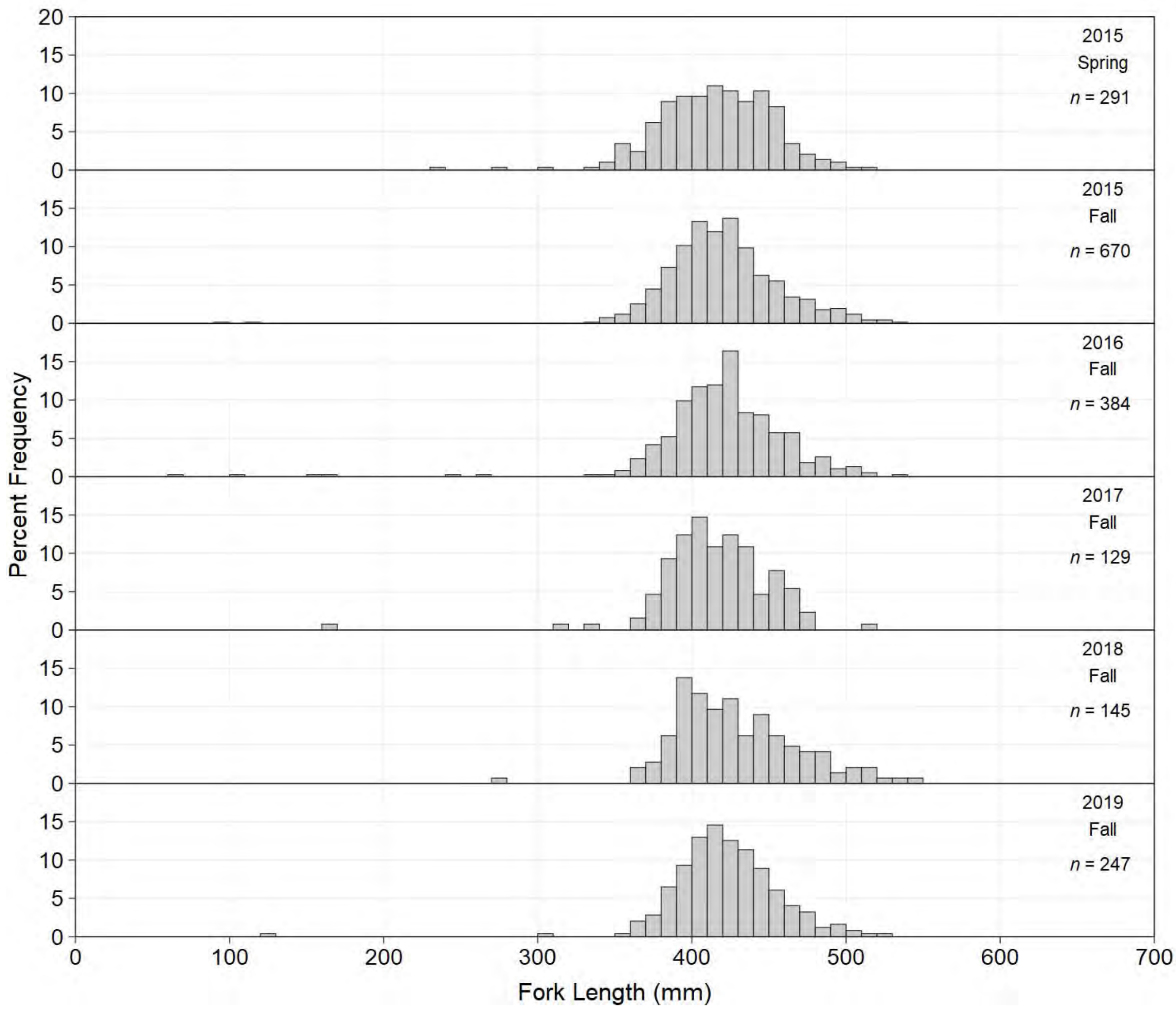


Figure E7 Length-frequency distributions for Largescale Sucker captured by boat electroshocking in Reaches 3 and 4 of the Middle Columbia River, 2001 to 2019. Largescale Sucker that were initially marked during an earlier year of the program were excluded from the analysis due to potential tagging effects on growth. Boat electroshocking surveys were not conducted downstream of Big Eddy for all years prior to 2007.



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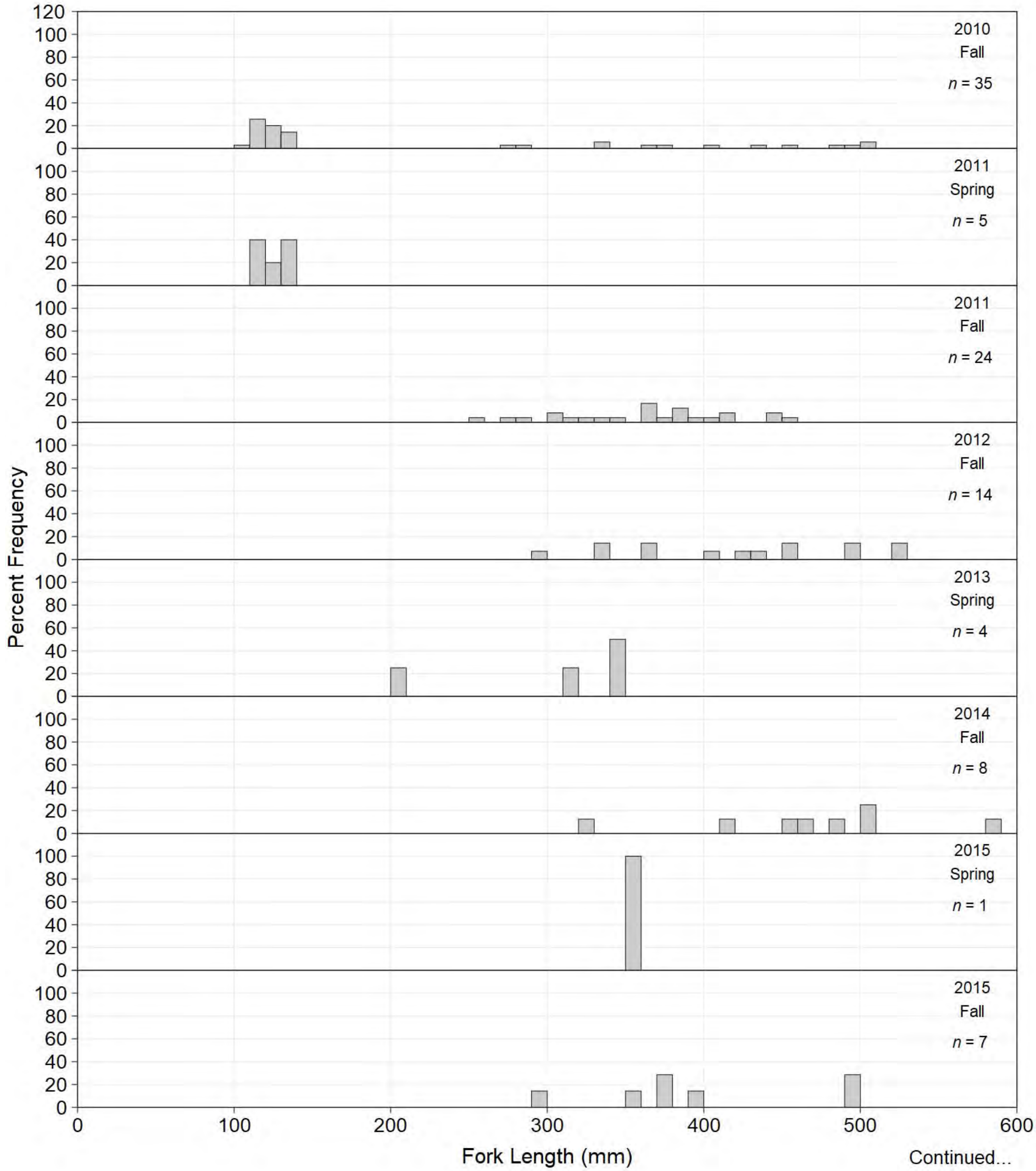

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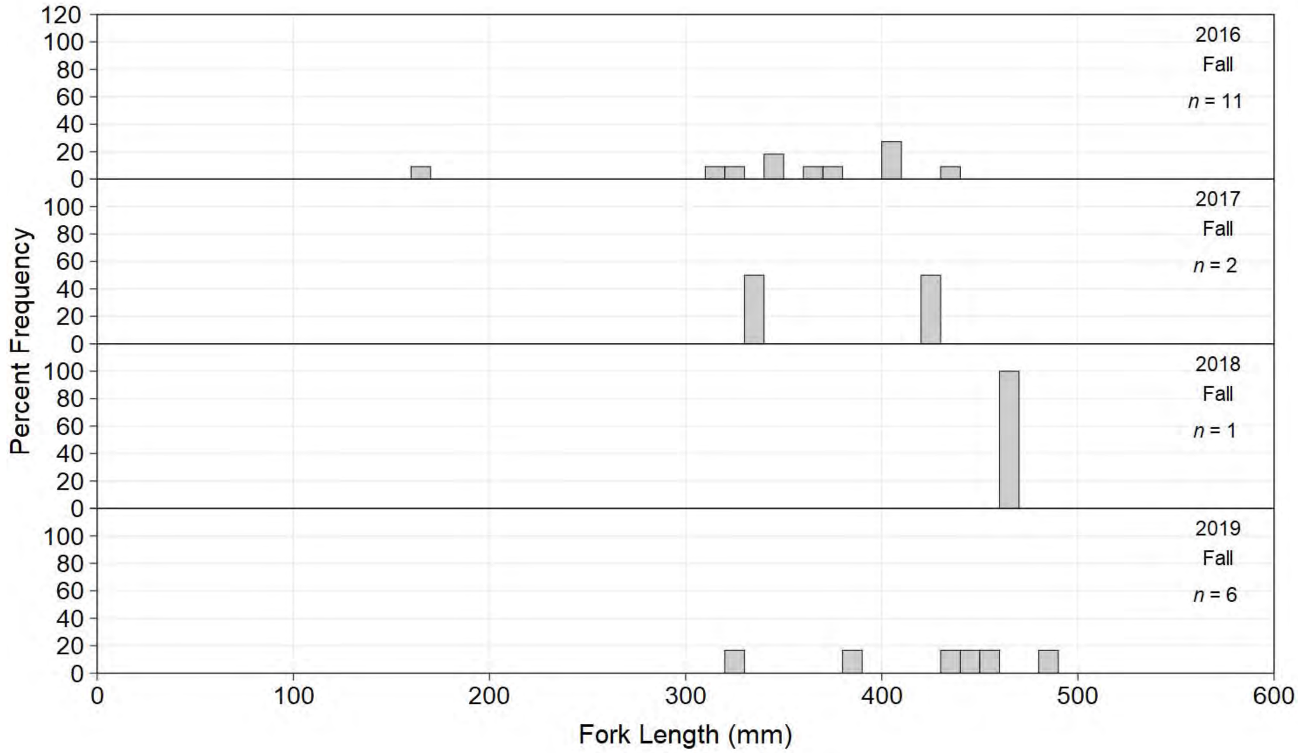
Figure E8 Length-frequency distributions for Northern Pikeminnow captured by boat electroshocking in Reaches 3 and 4 of the Middle Columbia River, 2001 to 2019. Northern Pikeminnow that were initially marked during an earlier year of the program were excluded from the analysis due to potential tagging effects on growth. Boat electroshocking surveys were not conducted downstream of Big Eddy for all years prior to 2007.



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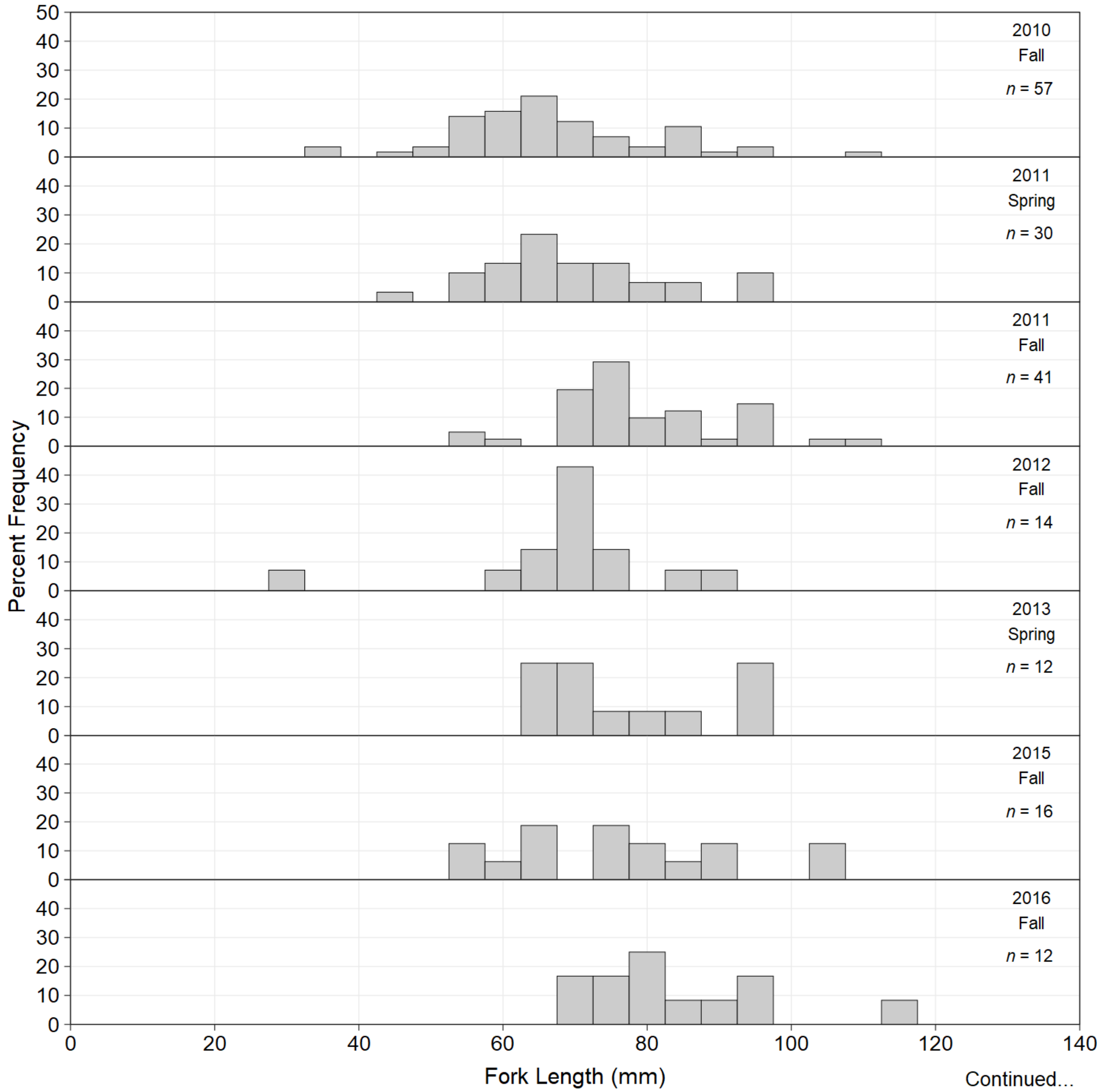

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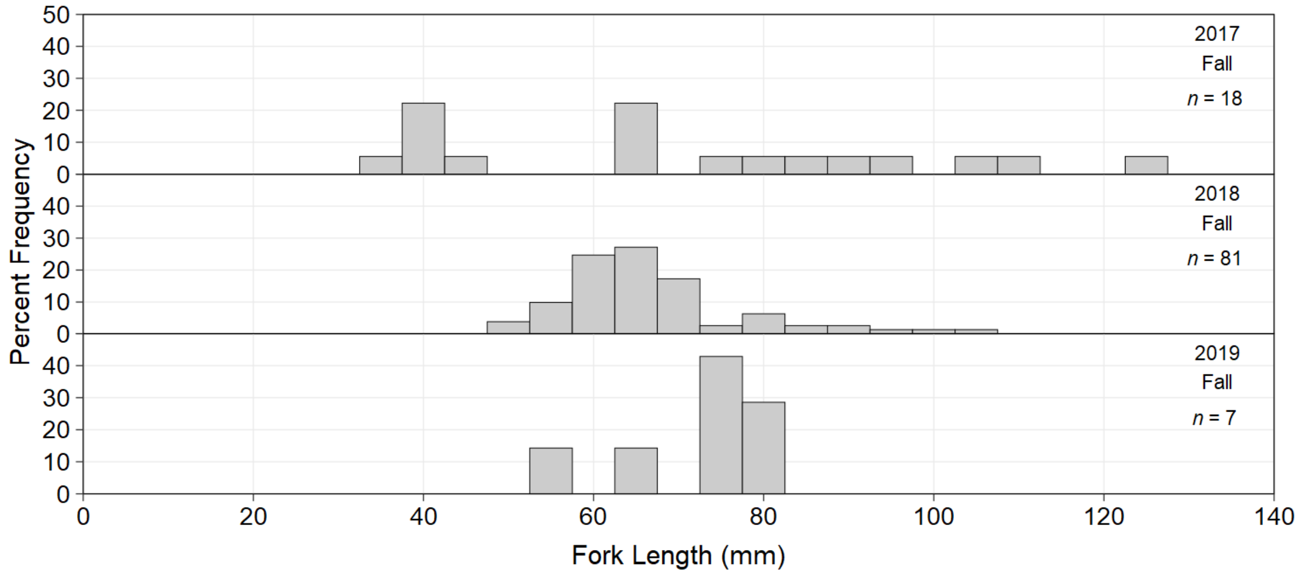
Figure E9 Length-frequency distributions for Redside Shiner captured by boat electroshocking in Reaches 3 and 4 of the Middle Columbia River, 2001 to 2019. Redside Shiner that were initially marked during an earlier year of the program were excluded from the analysis due to potential tagging effects on growth. Boat electroshocking surveys were not conducted downstream of Big Eddy for all years prior to 2007.



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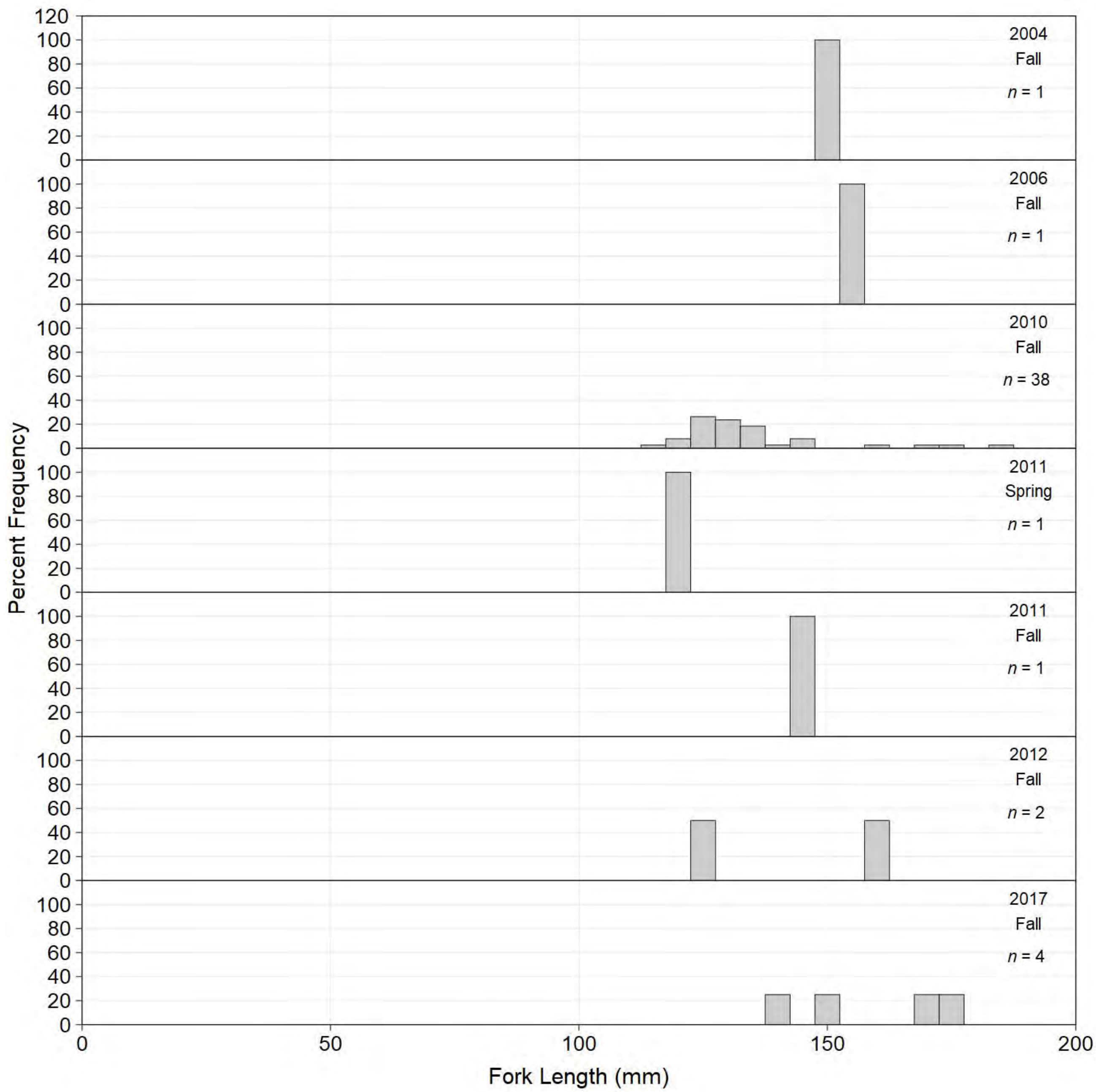

Figure E10 Length-frequency distributions for Yellow Perch captured by boat electroshocking in Reaches 3 and 4 of the Middle Columbia River, 2001 to 2019. Yellow Perch that were initially marked during an earlier year of the program were excluded from the analysis due to potential tagging effects on growth. Boat electroshocking surveys were not conducted downstream of Big Eddy for all years prior to 2007.

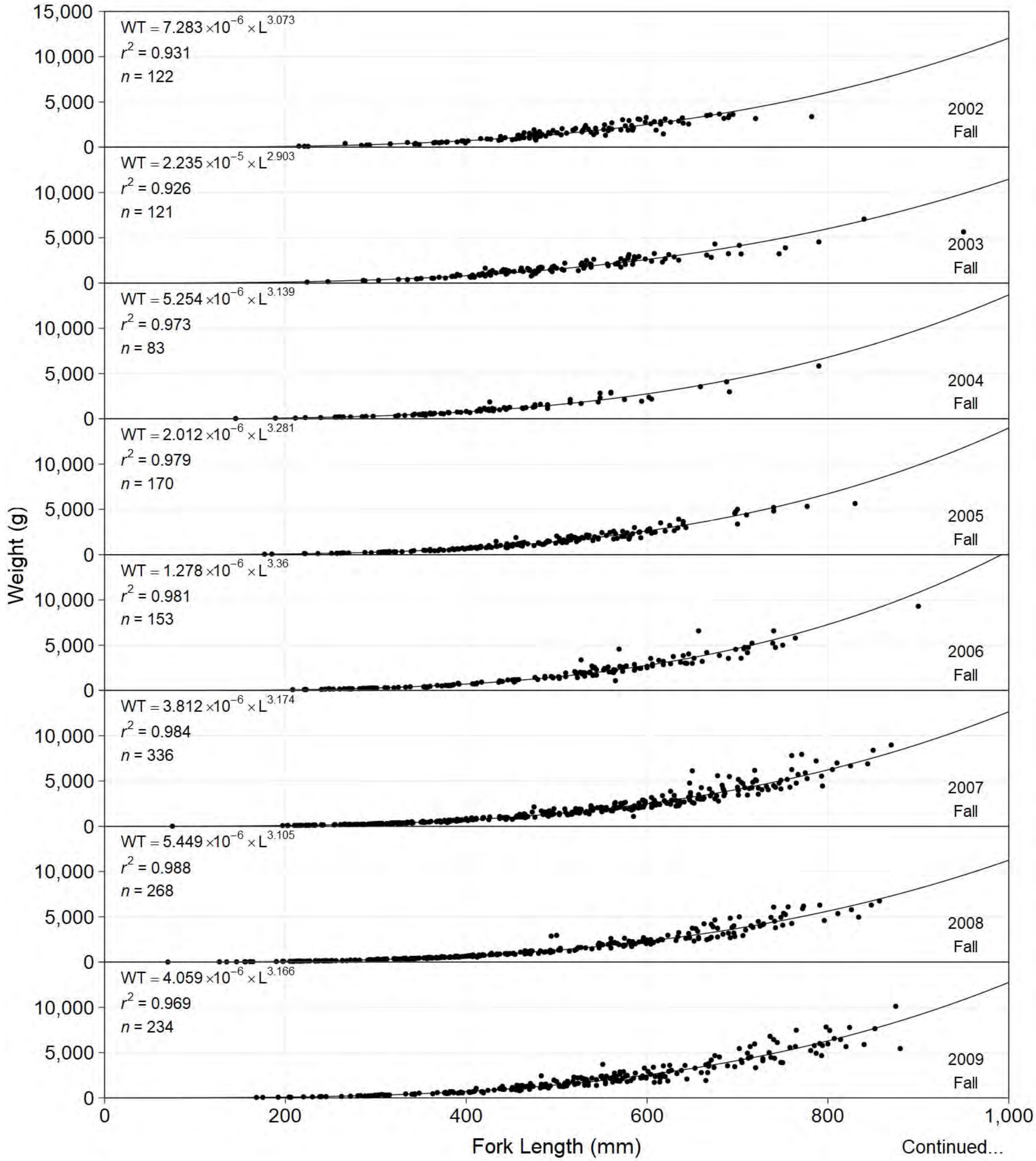

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Figure E11 Length-weight regression for Bull Trout captured by boat electroshocking in Reaches 3 and 4 of the Middle Columbia River, 2001 to 2019. Bull Trout that were initially marked during an earlier year of the program were excluded from the analysis due to potential tagging effects on growth. Boat electroshocking surveys were not conducted downstream of Big Eddy for all years prior to 2007.

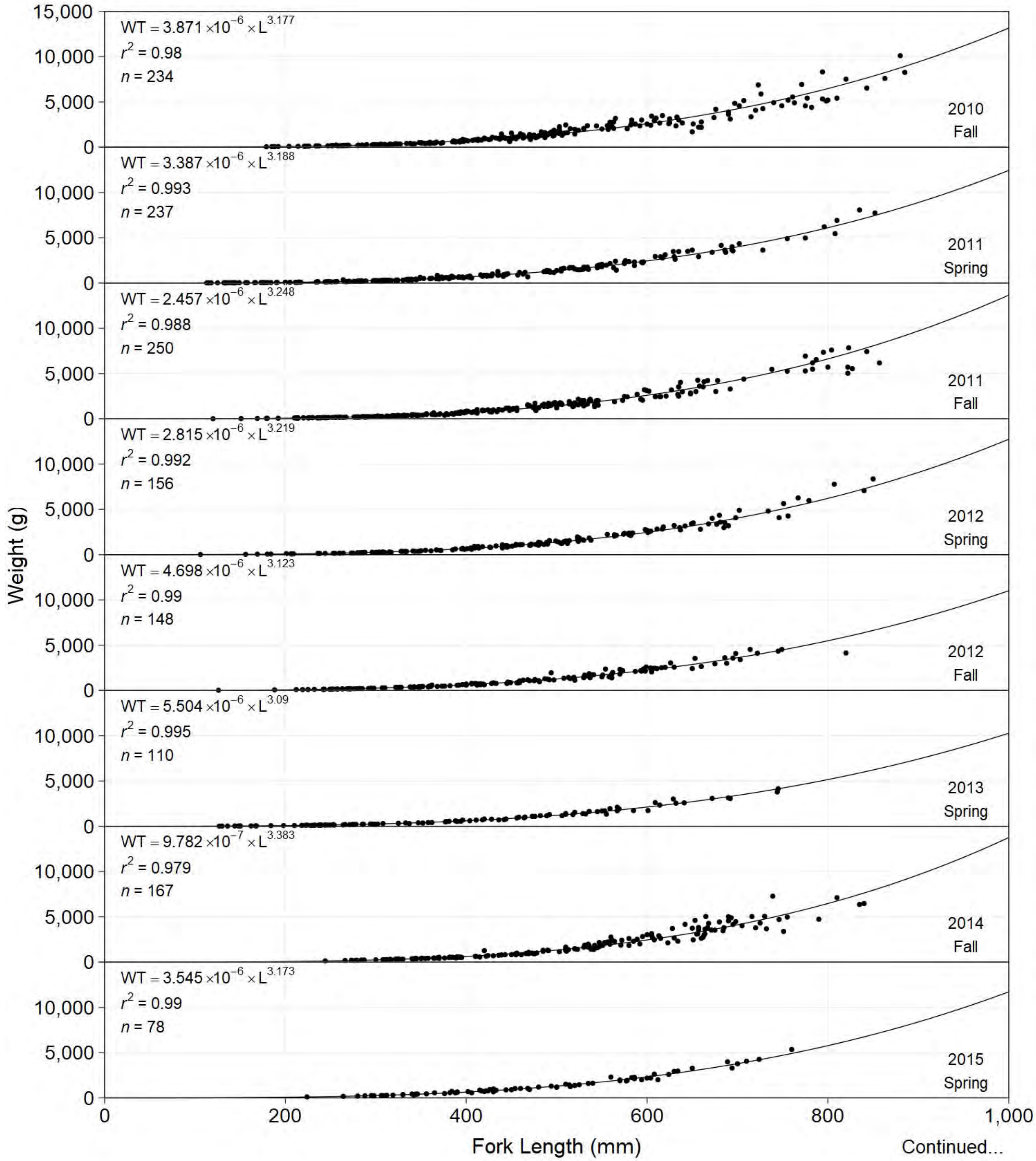

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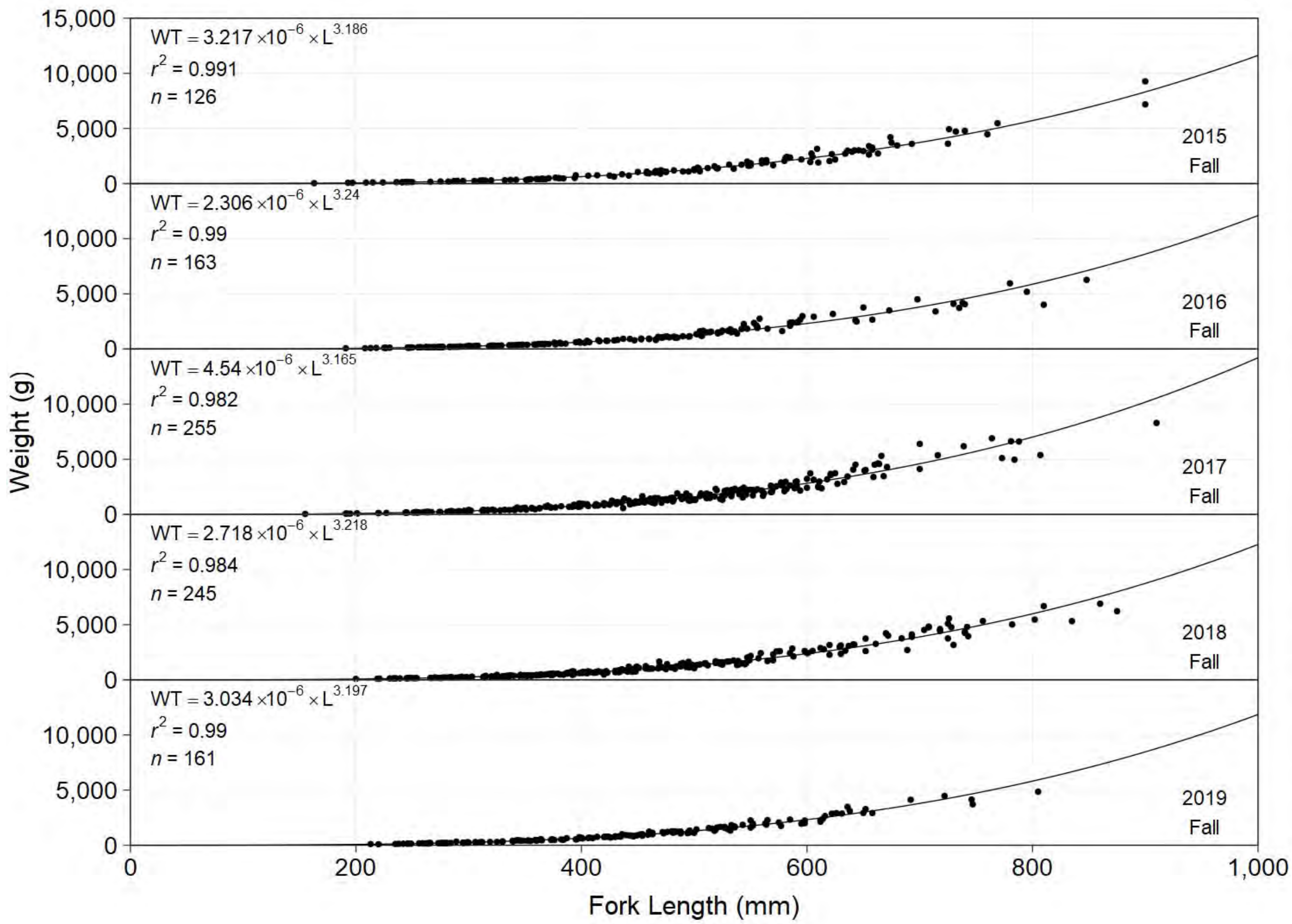
Figure E11 Continued



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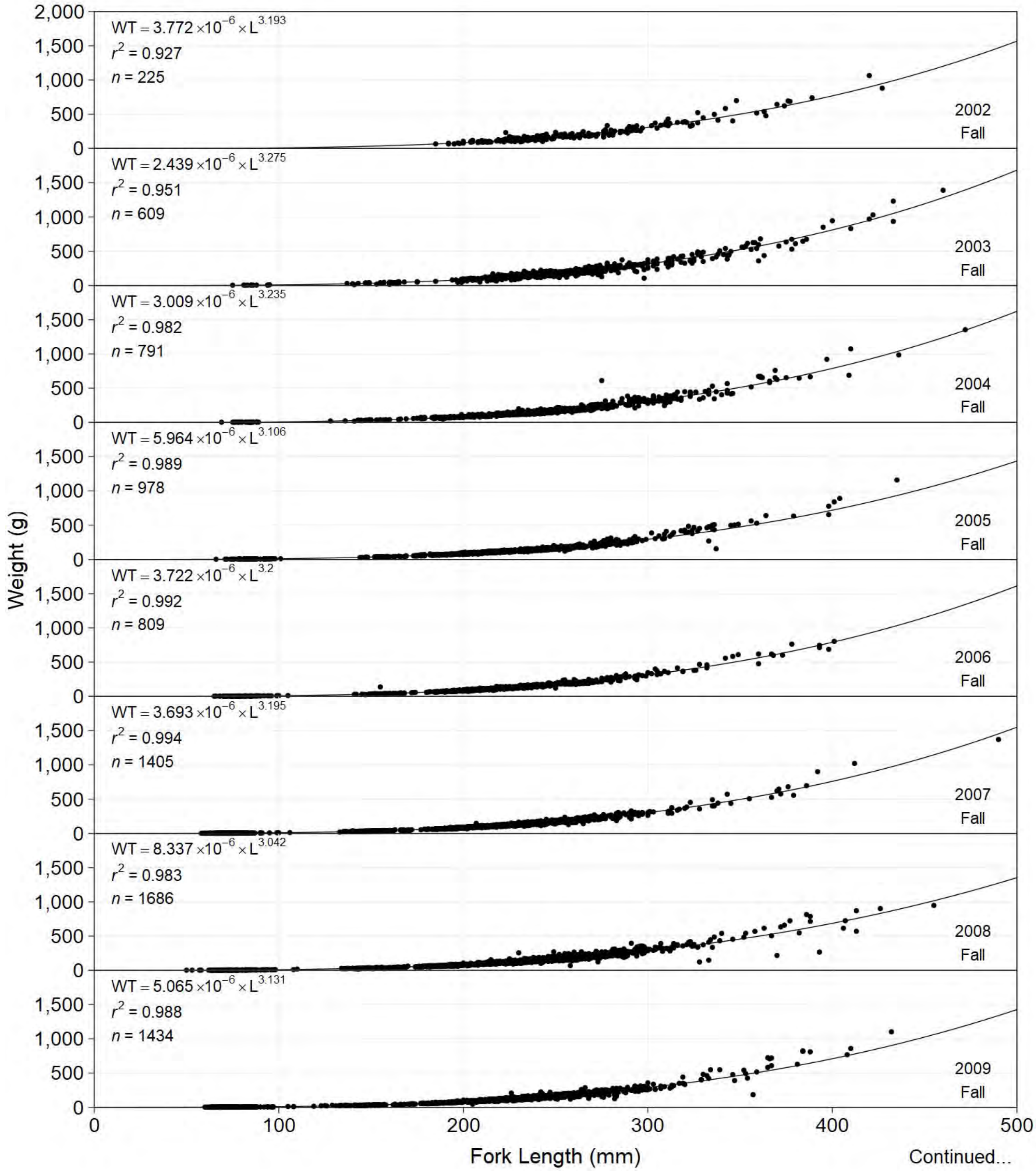

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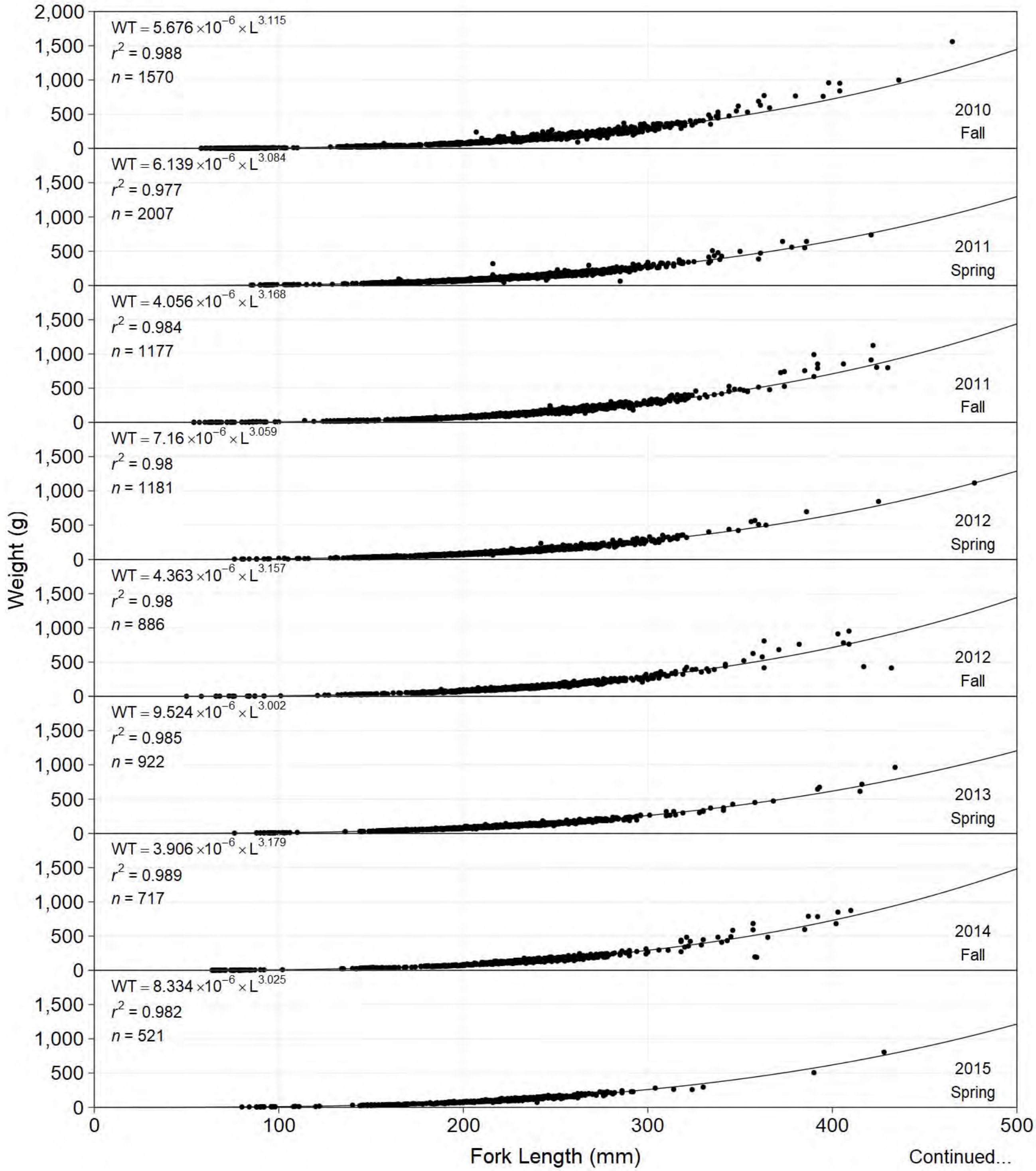
Figure E12 Length-weight regression for Mountain Whitefish captured by boat electroshocking in Reaches 3 and 4 of the Middle Columbia River, 2001 to 2019. Mountain Whitefish that were initially marked during an earlier year of the program were excluded from the analysis due to potential tagging effects on growth. Boat electroshocking surveys were not conducted downstream of Big Eddy for all years prior to 2007.



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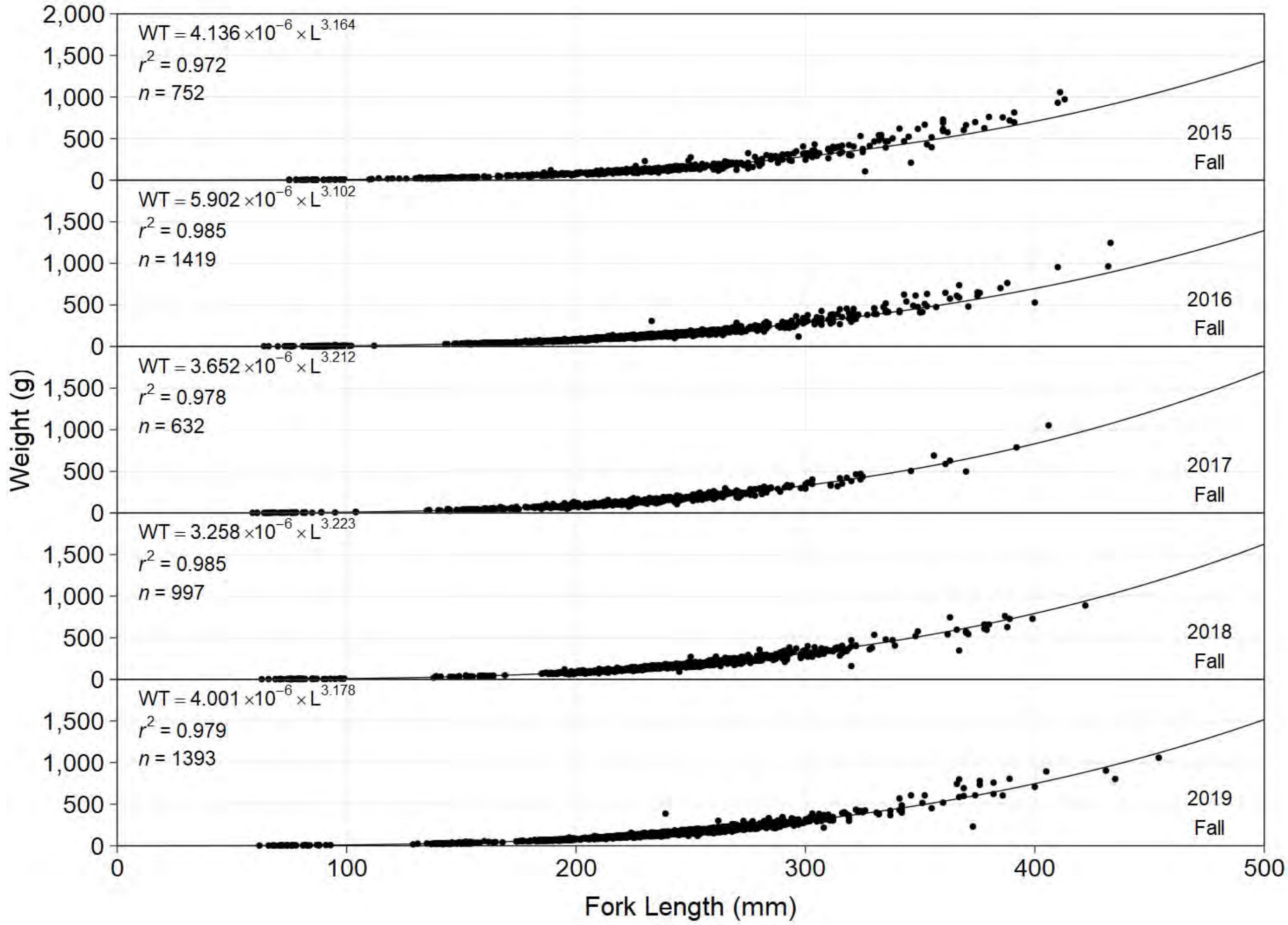

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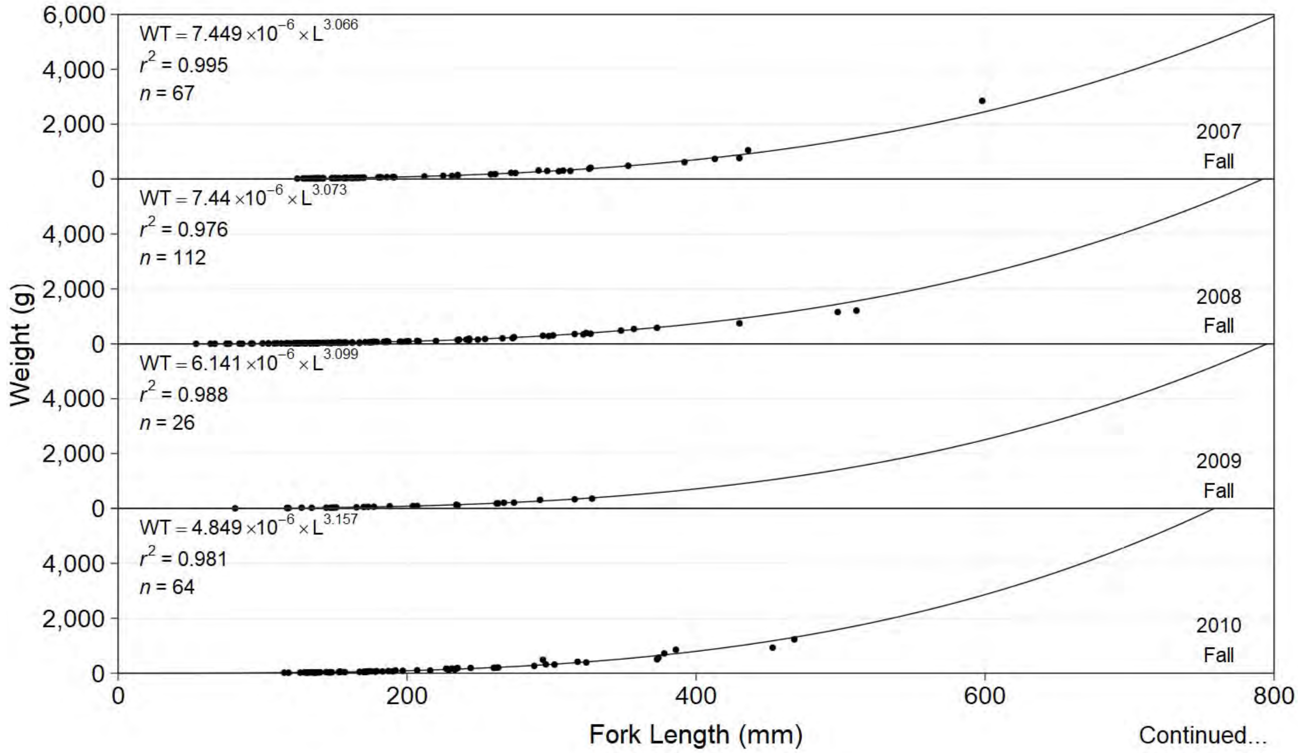

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Figure E13 Length-weight regression for Rainbow Trout captured by boat electroshocking in Reaches 3 and 4 of the Middle Columbia River, 2001 to 2019. Rainbow Trout that were initially marked during an earlier year of the program were excluded from the analysis due to potential tagging effects on growth. Boat electroshocking surveys were not conducted downstream of Big Eddy for all years prior to 2007.

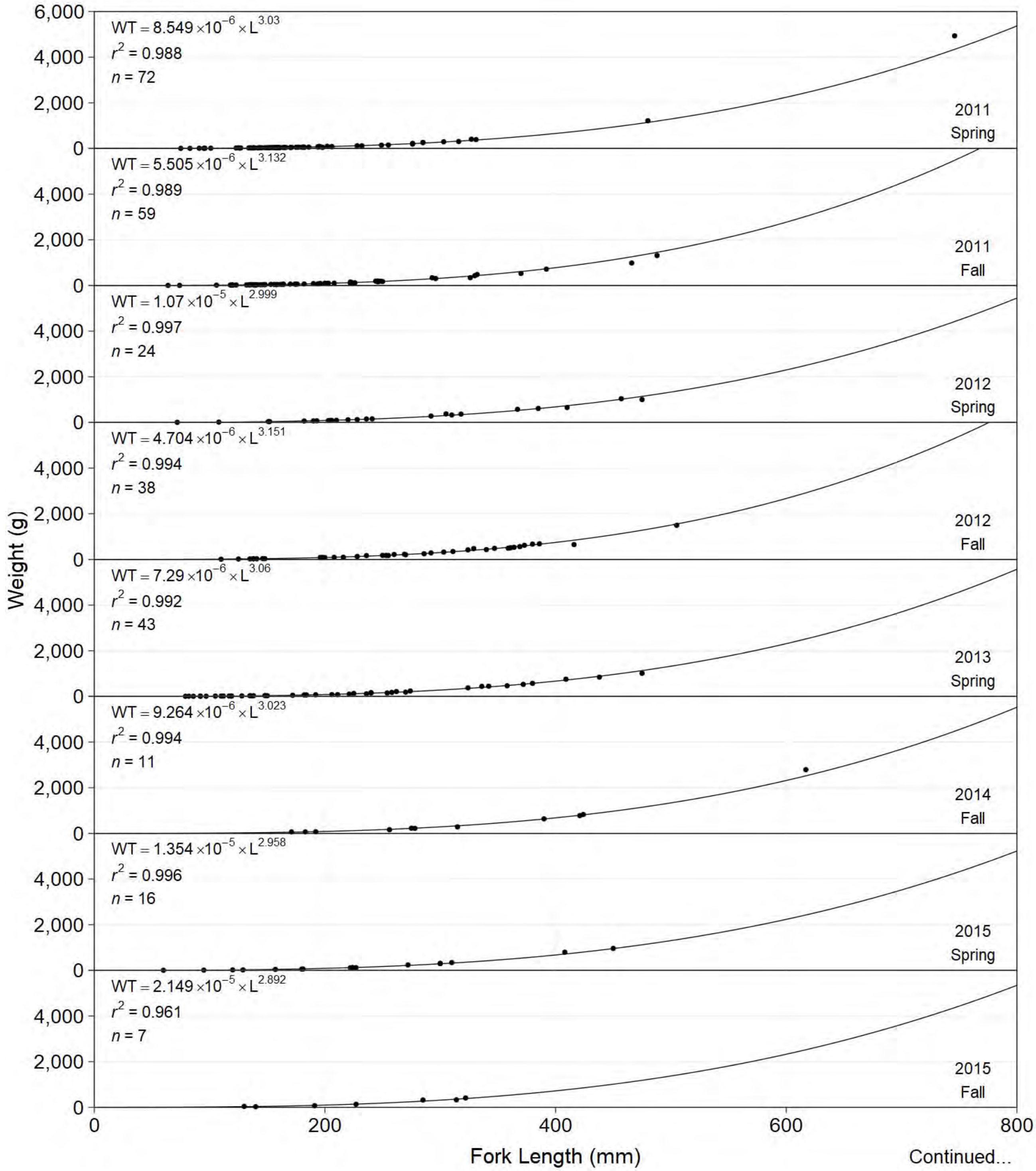

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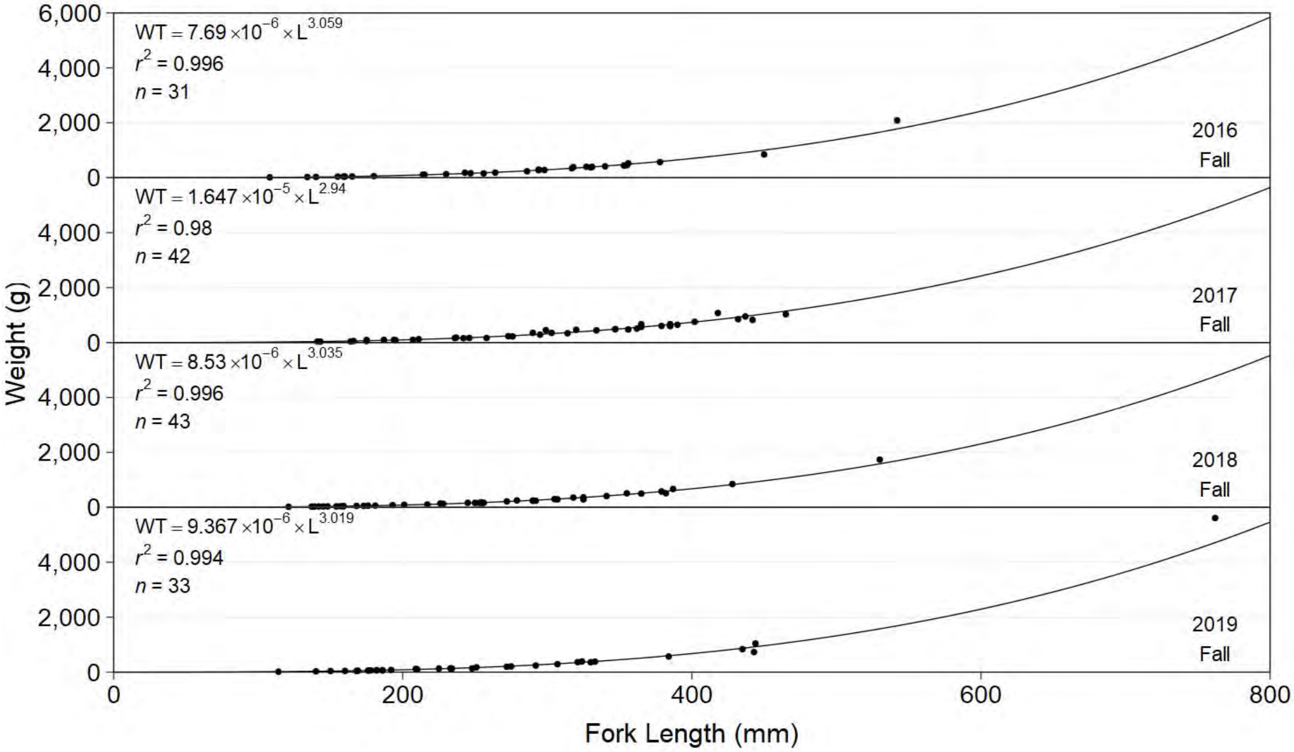
Figure E13 Continued



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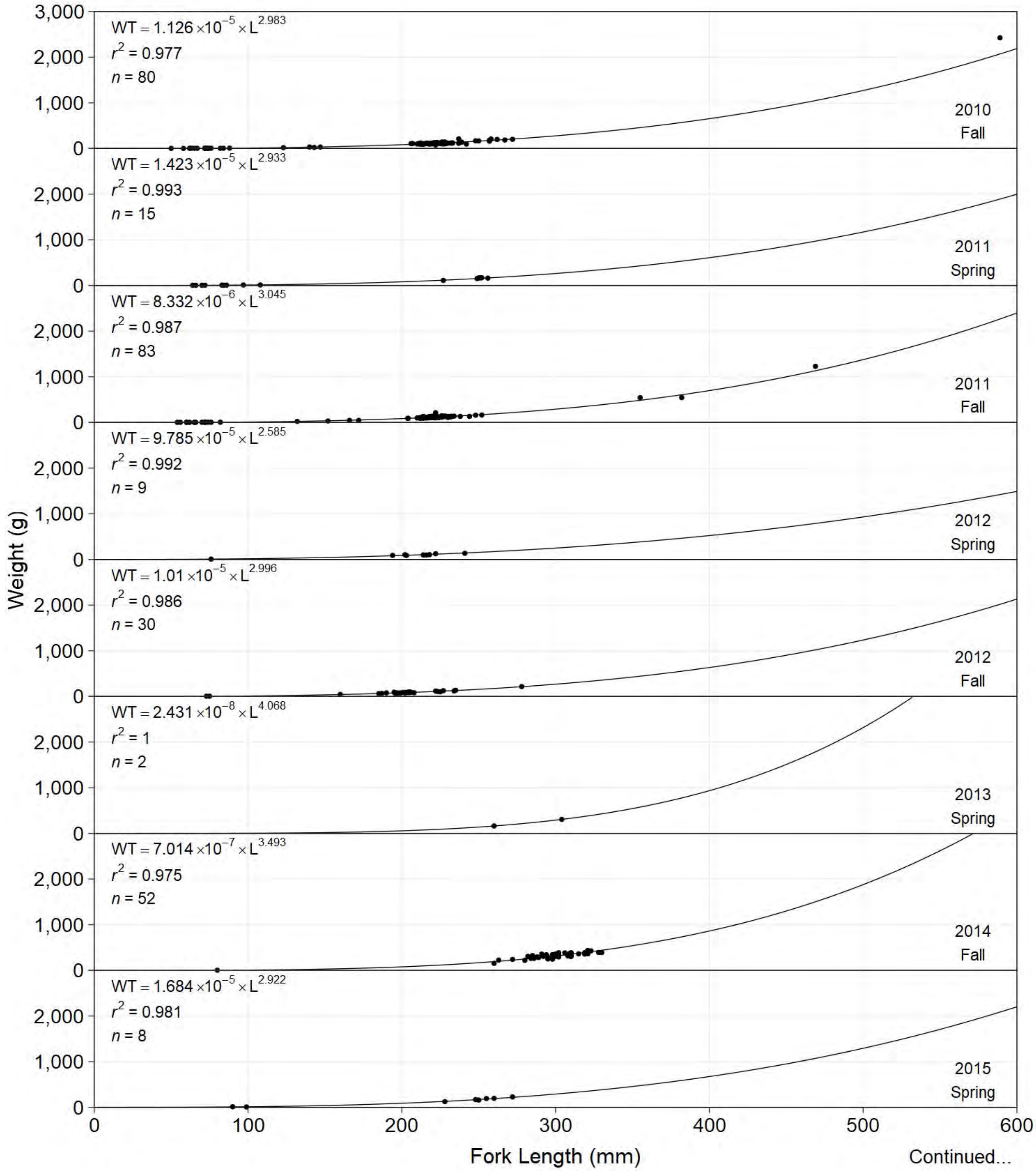
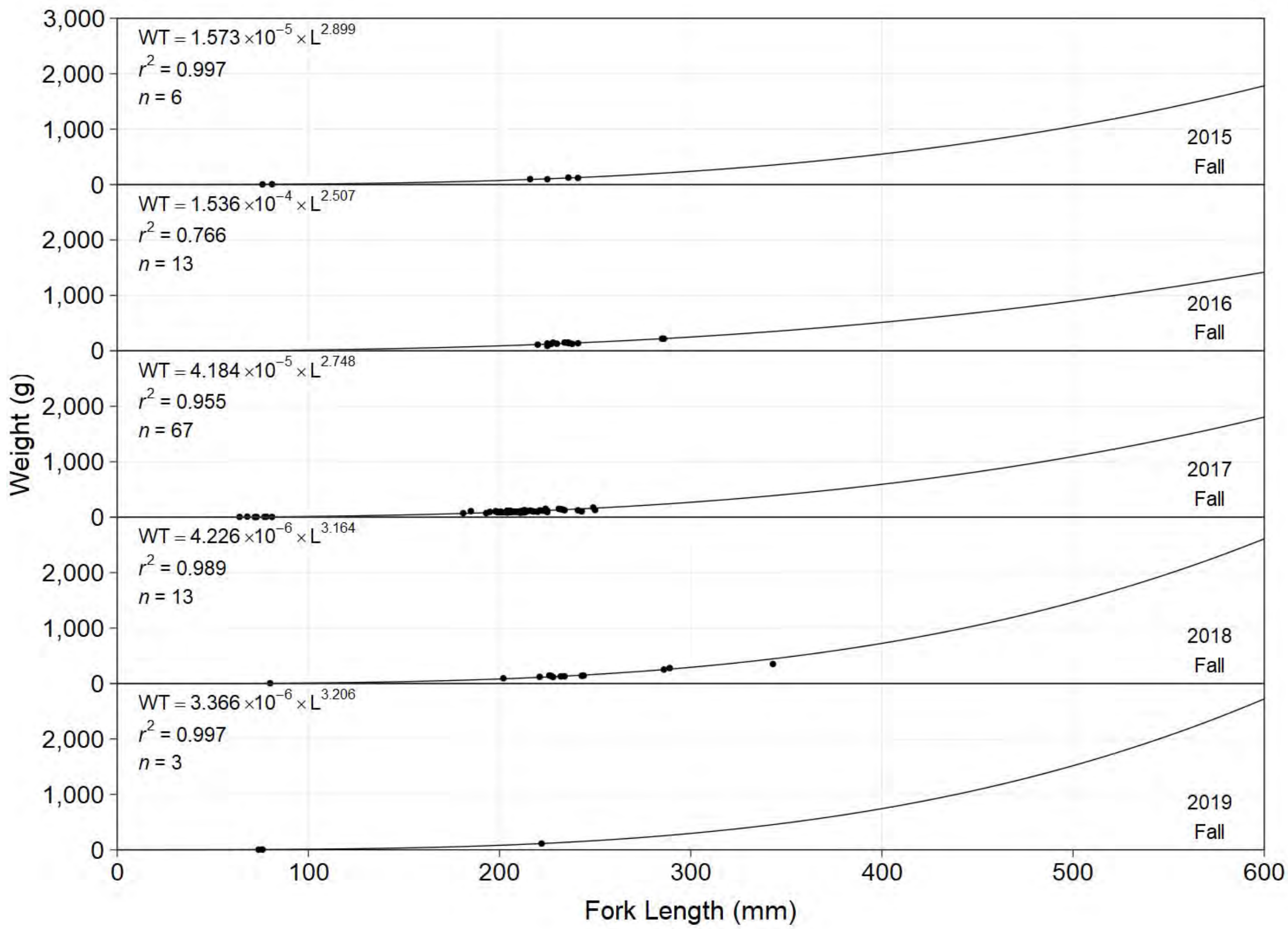


Figure E14 Length-weight regression for Kokanee captured by boat electroshocking in Reaches 3 and 4 of the Middle Columbia River, 2001 to 2019. Kokanee that were initially marked during an earlier year of the program were excluded from the analysis due to potential tagging effects on growth. Boat electroshocking surveys were not conducted downstream of Big Eddy for all years prior to 2007.



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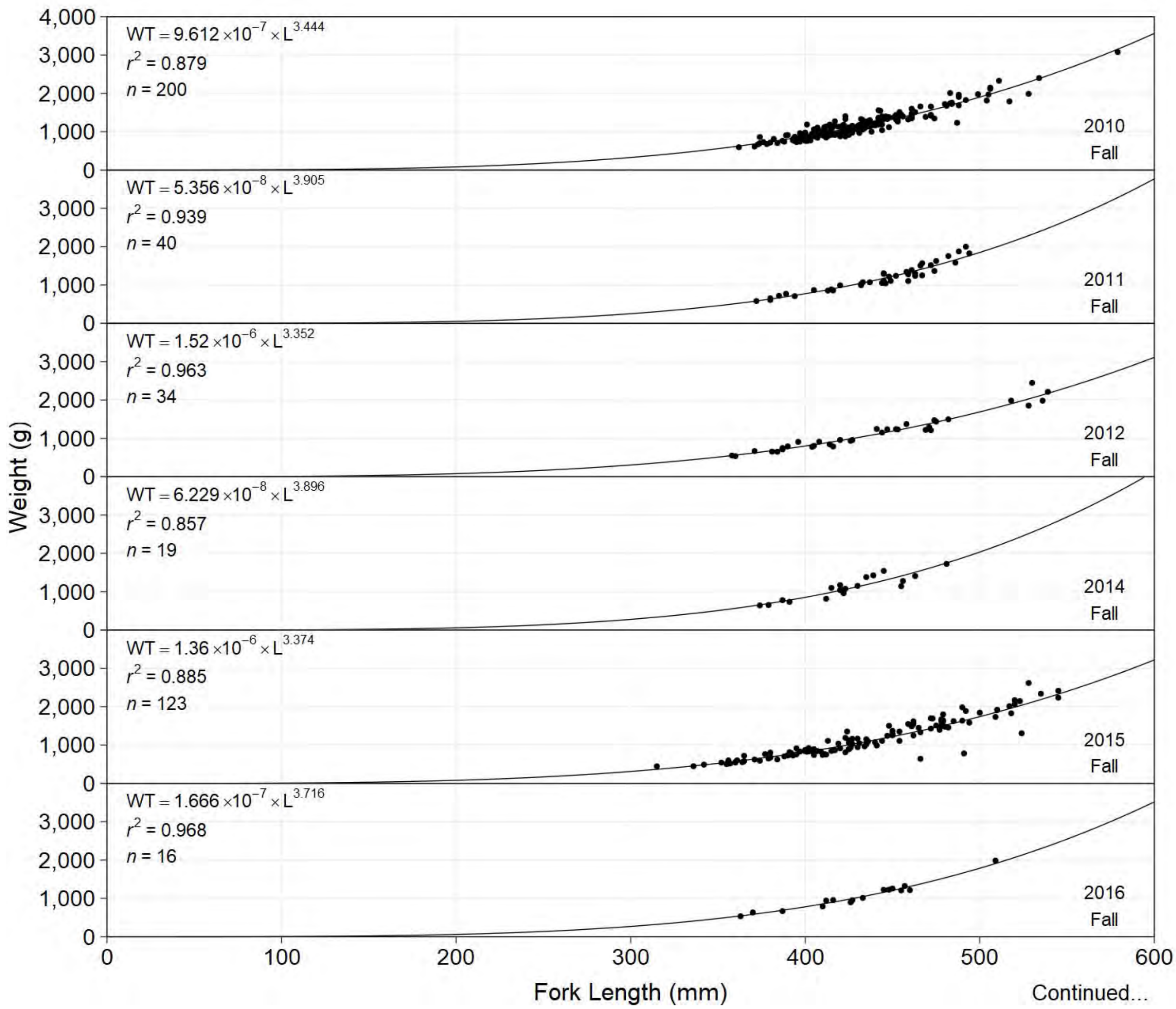

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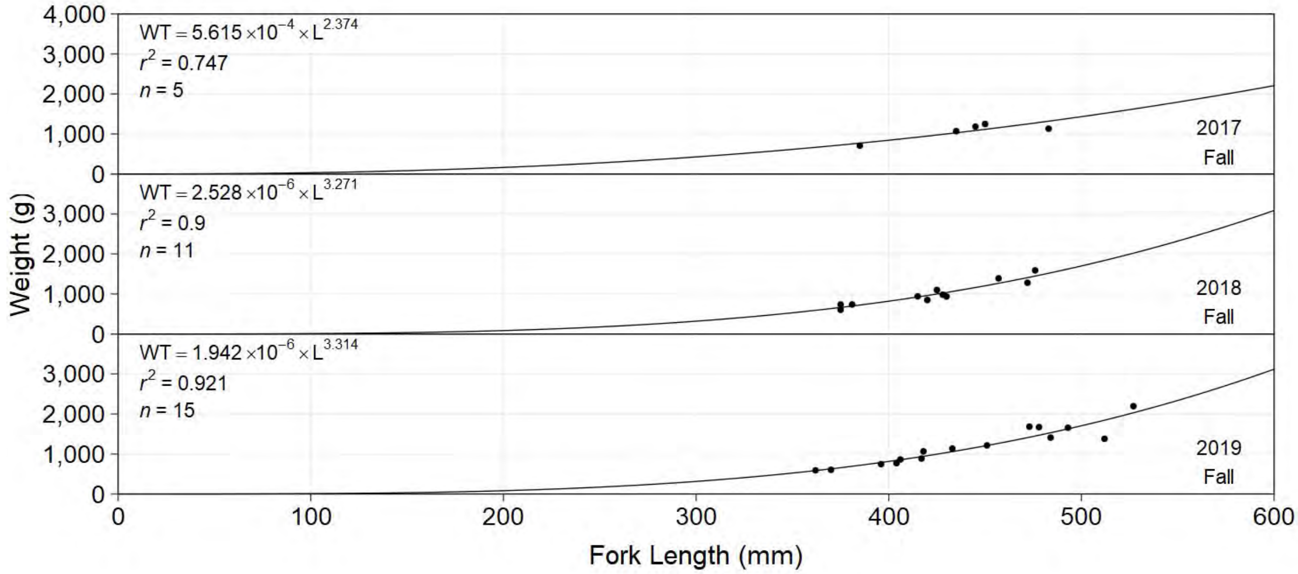
Figure E15 Length-weight regression for Lake Whitefish captured by boat electroshocking in Reaches 3 and 4 of the Middle Columbia River, 2001 to 2019. Lake Whitefish that were initially marked during an earlier year of the program were excluded from the analysis due to potential tagging effects on growth. Boat electroshocking surveys were not conducted downstream of Big Eddy for all years prior to 2007.



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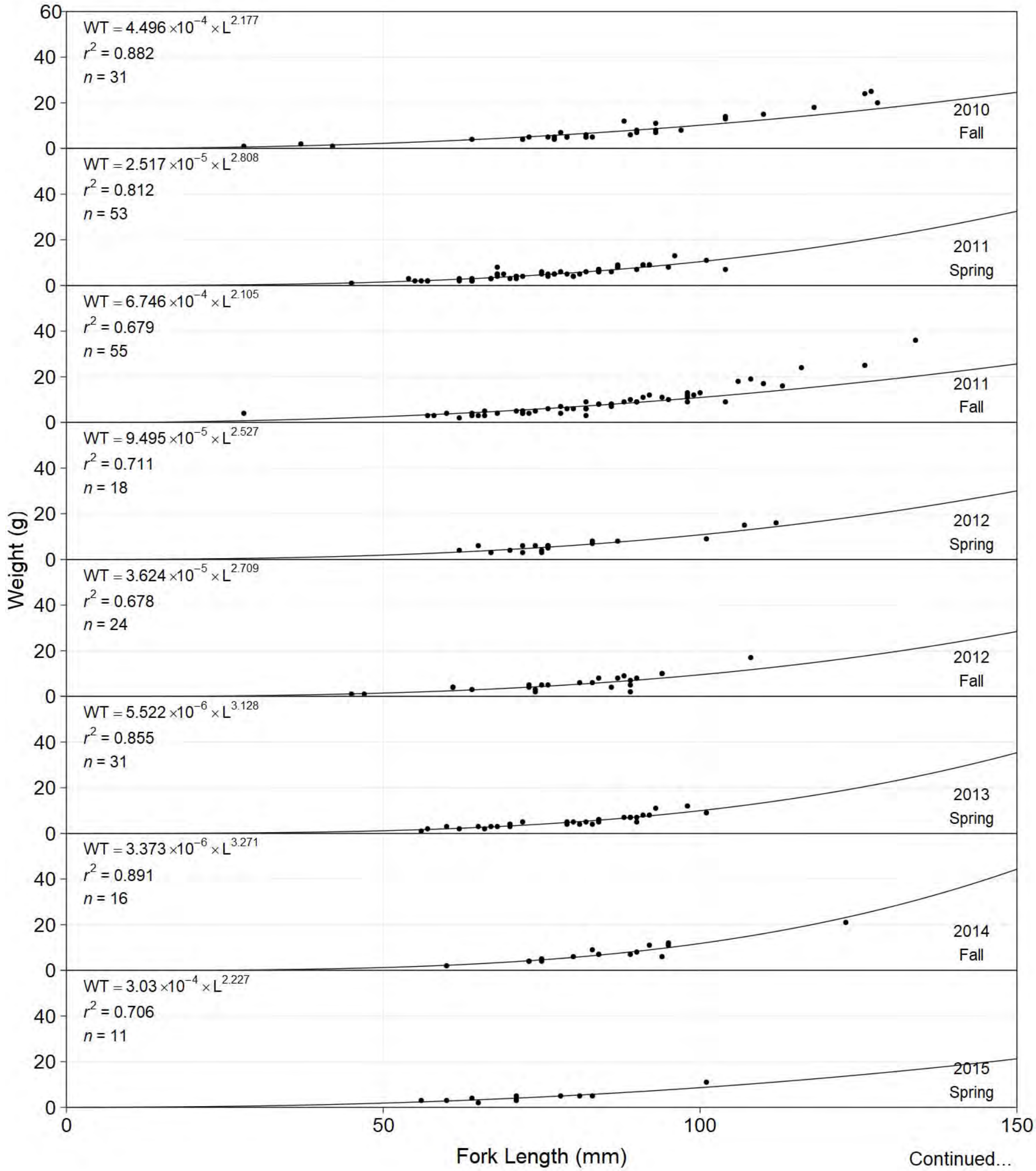

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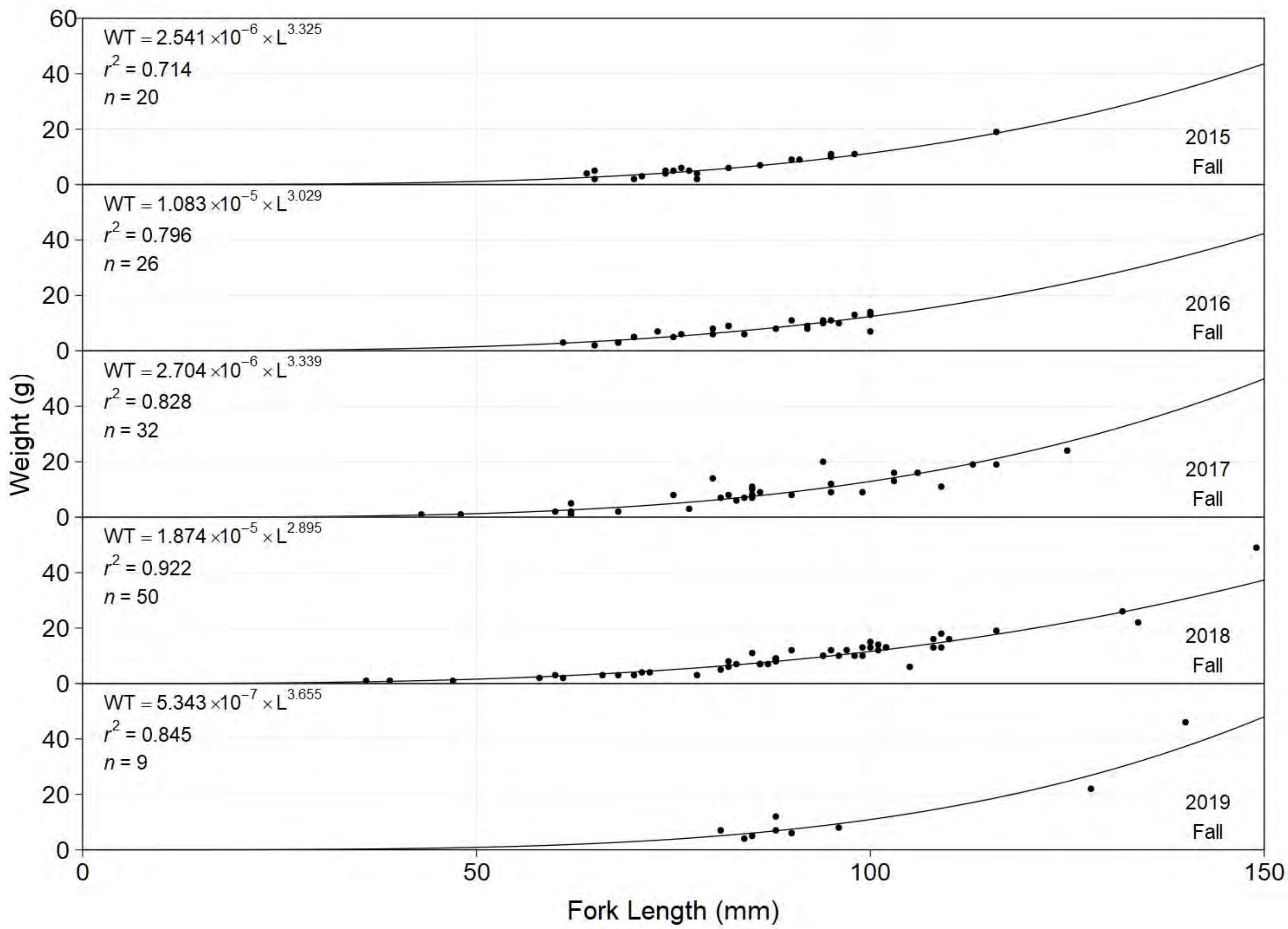
Figure E16 Length-weight regression for Prickly Sculpin captured by boat electroshocking in Reaches 3 and 4 of the Middle Columbia River, 2001 to 2019. Prickly Sculpin that were initially marked during an earlier year of the program were excluded from the analysis due to potential tagging effects on growth. Boat electroshocking surveys were not conducted downstream of Big Eddy for all years prior to 2007.



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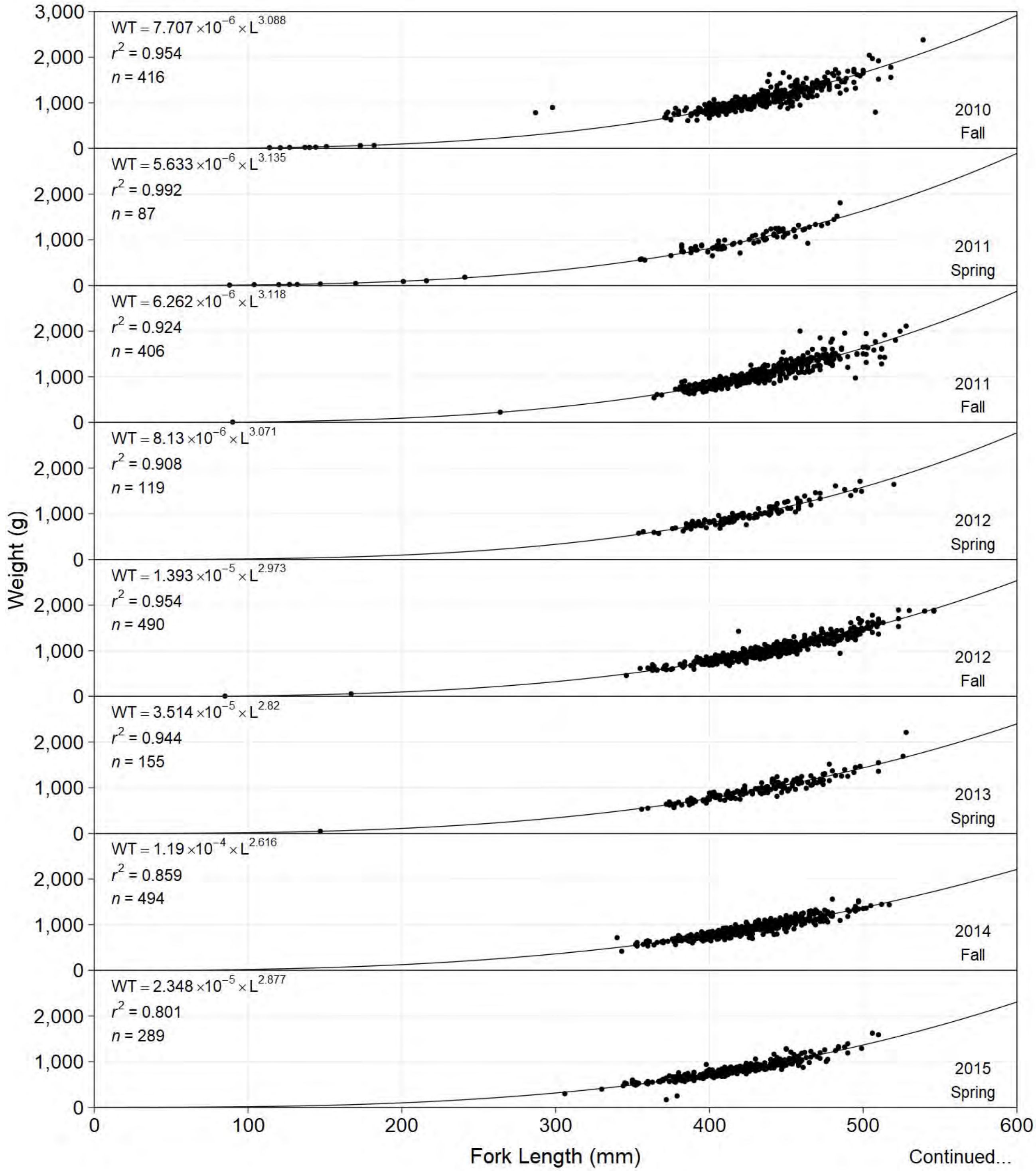

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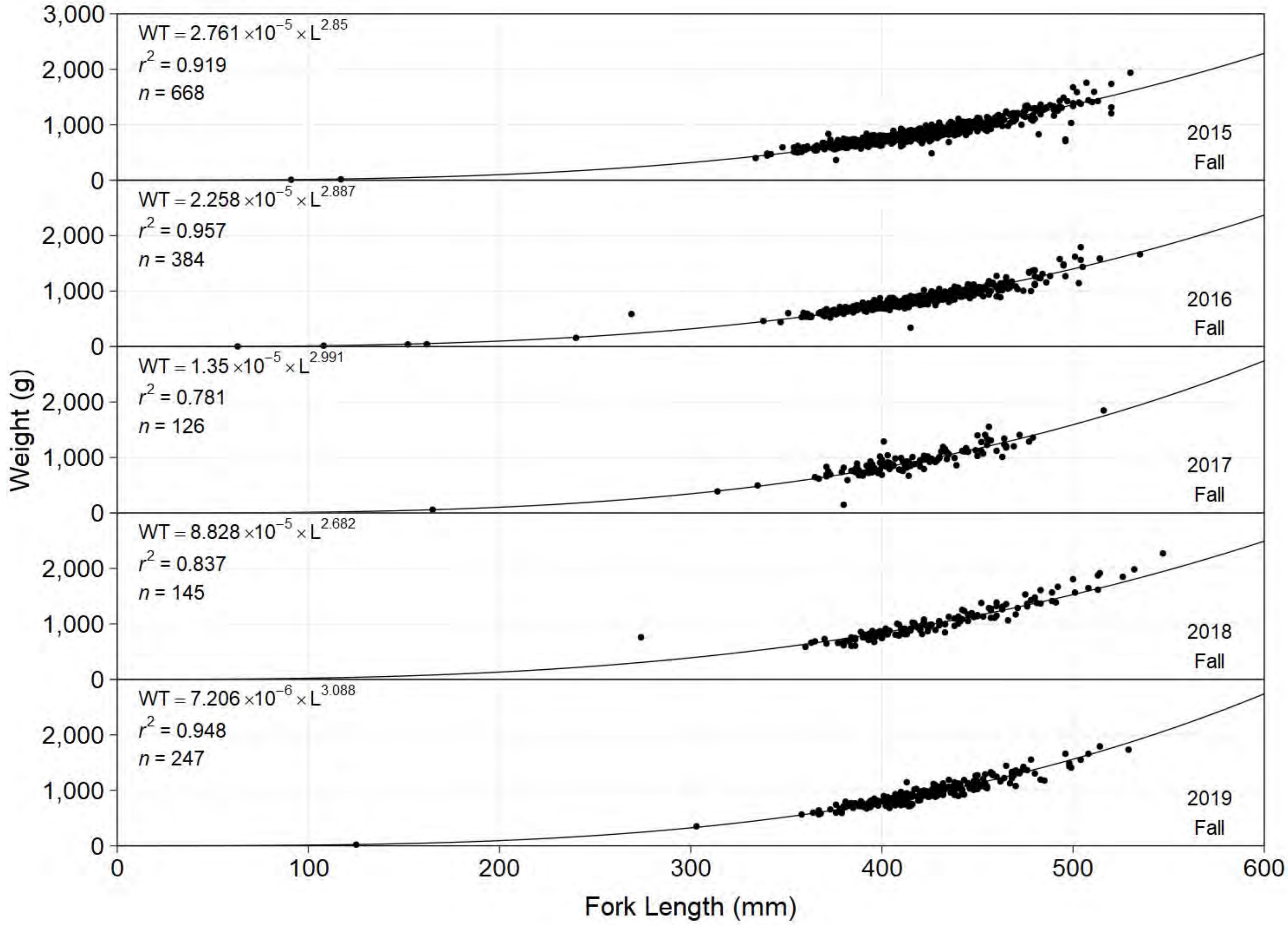
Figure E17 Length-weight regression for Largescale Sucker captured by boat electroshocking in Reaches 3 and 4 of the Middle Columbia River, 2001 to 2019. Largescale Sucker that were initially marked during an earlier year of the program were excluded from the analysis due to potential tagging effects on growth. Boat electroshocking surveys were not conducted downstream of Big Eddy for all years prior to 2007.



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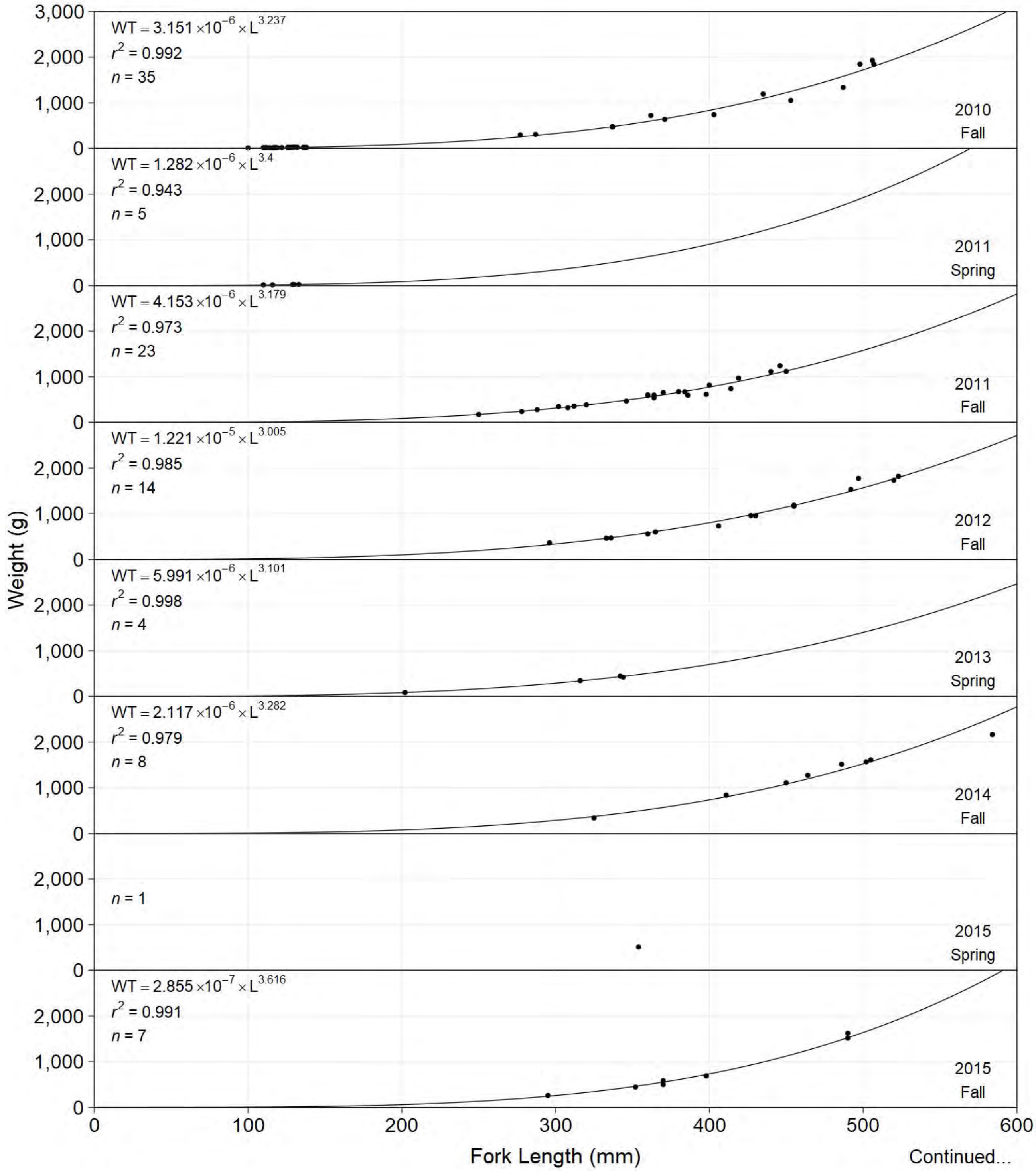

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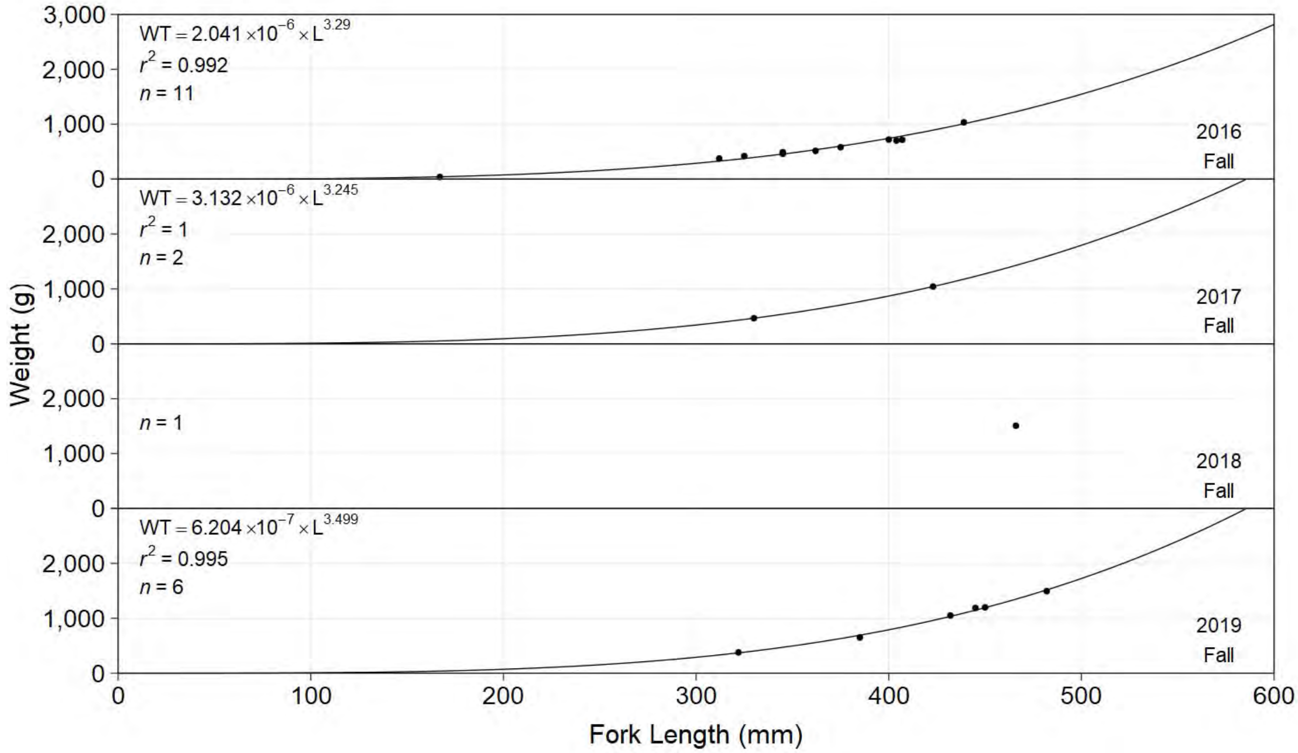
Figure E18 Length-weight regression for Northern Pikeminnow captured by boat electroshocking in Reaches 3 and 4 of the Middle Columbia River, 2001 to 2019. Northern Pikeminnow that were initially marked during an earlier year of the program were excluded from the analysis due to potential tagging effects on growth. Boat electroshocking surveys were not conducted downstream of Big Eddy for all years prior to 2007.



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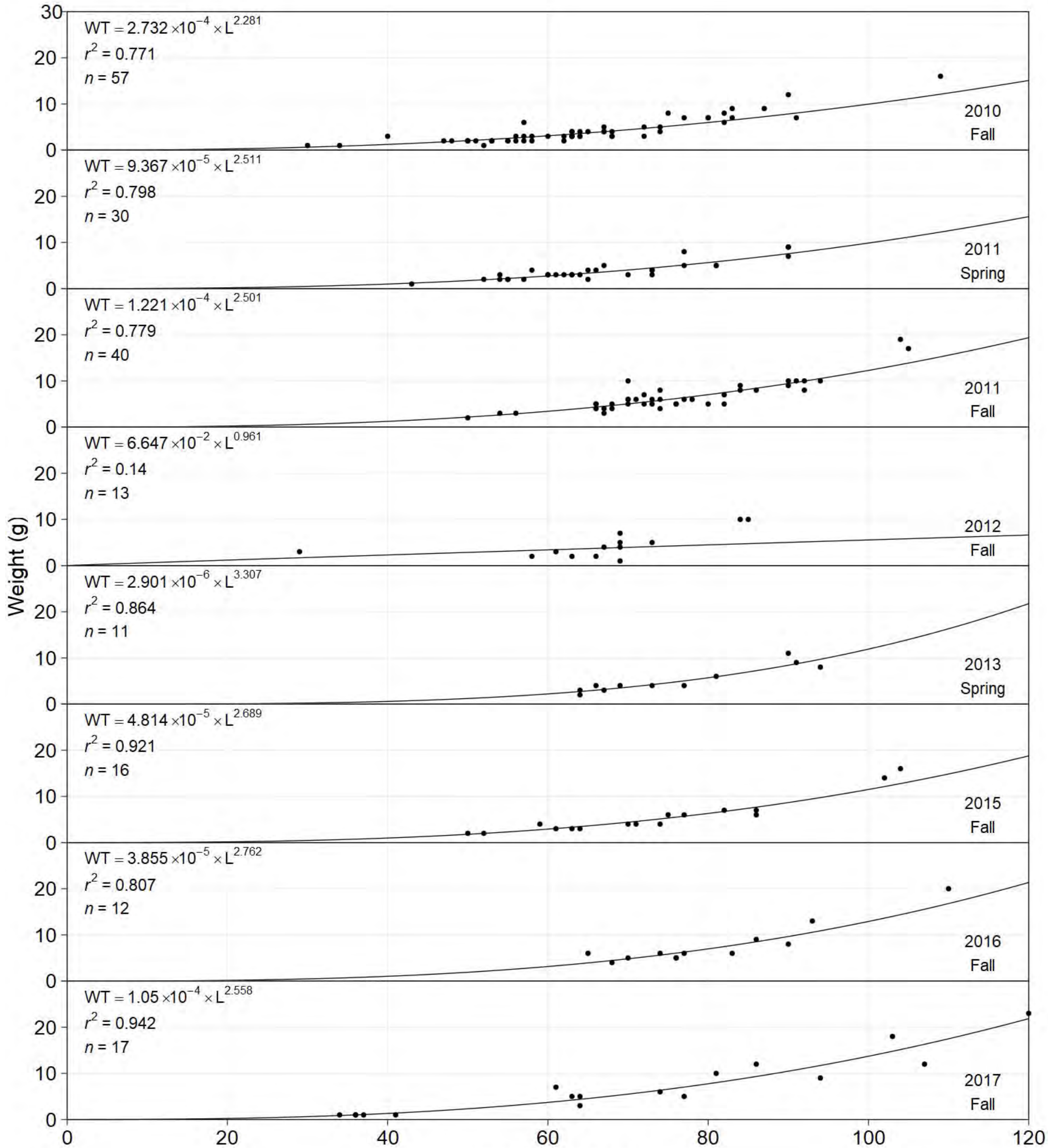

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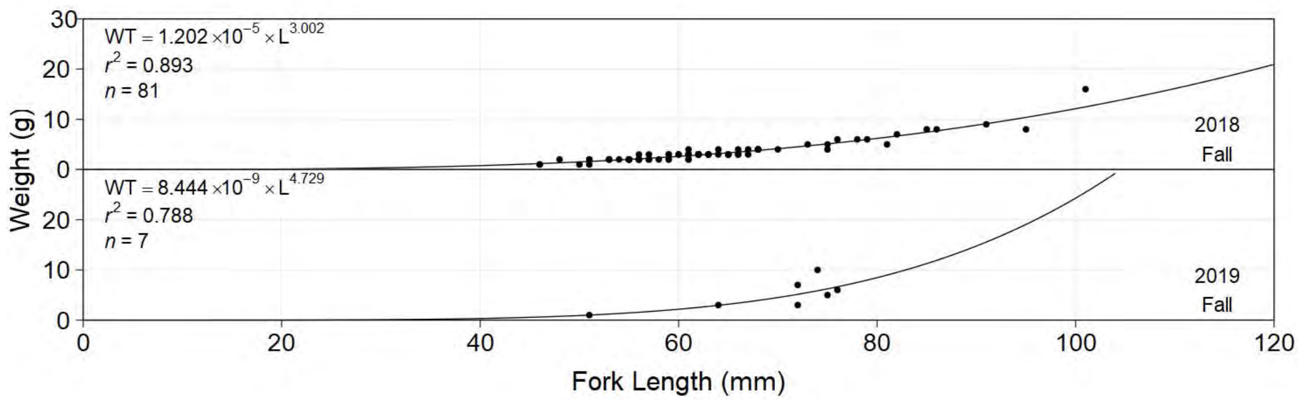
Figure E19 Length-weight regression for Redside Shiner captured by boat electroshocking in Reaches 3 and 4 of the Middle Columbia River, 2001 to 2019. Redside Shiner that were initially marked during an earlier year of the program were excluded from the analysis due to potential tagging effects on growth. Boat electroshocking surveys were not conducted downstream of Big Eddy for all years prior to 2007.



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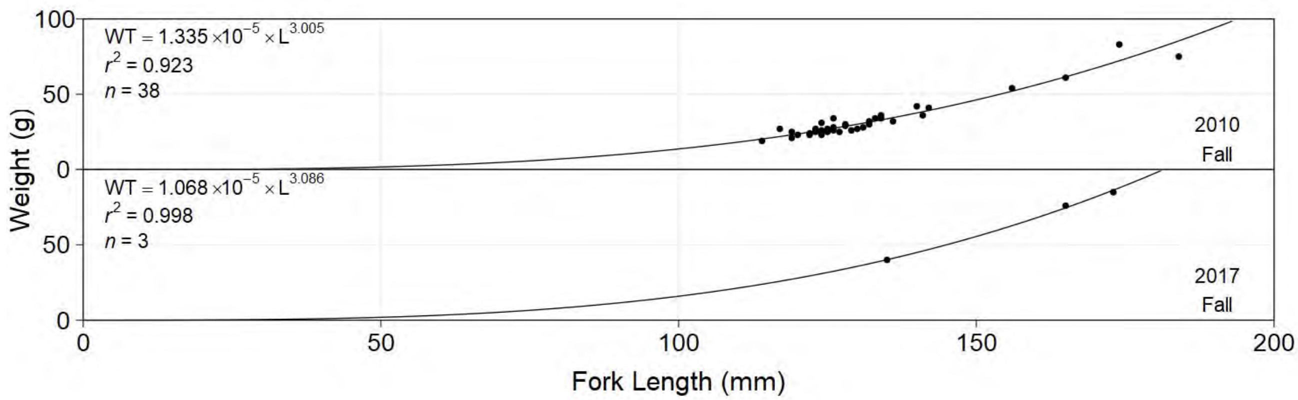

Figure E20 Length-weight regression for Yellow Perch captured by boat electroshocking in Reaches 3 and 4 of the Middle Columbia River, 2001 to 2019. Yellow Perch that were initially marked during an earlier year of the program were excluded from the analysis due to potential tagging effects on growth. Boat electroshocking surveys were not conducted downstream of Big Eddy for all years prior to 2007.

Appendix F – HBM Methods

Middle Columbia River Fish Indexing Analysis 2019

Thorley, J.L. and Amies-Galonski E.

The suggested citation for this analytic report is:

Thorley, J.L. and Amies-Galonski E. (2020) Middle Columbia River Fish Indexing Analysis 2019. A Poisson Consulting Analysis Appendix. URL: http://www.poissonconsulting.ca/f/1050384286.

Methods

Data Preparation

The data were collected by Okanagan Nation Alliance and Golder Associates.

Life-Stage

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

Statistical Analysis

Model parameters were estimated using Bayesian methods. The Bayesian estimates were produced using JAGS (Plummer 2015) and STAN (Carpenter et al. 2017). For additional information on Bayesian estimation the reader is referred to McElreath (2016).

Unless indicated otherwise, the Bayesian analyses used uninformative normal prior distributions (Kery and Schaub 2011, 36). The posterior distributions were estimated from 1500 Markov Chain Monte Carlo (MCMC) samples thinned from the second halves of 3 chains (Kery and Schaub 2011, 38–40). Model convergence was confirmed by ensuring that the split $\hat{R} \leq$ `getOption("mb.rhat")` (Kery and Schaub 2011, 40) and ESS ≥ 150 for each of the monitored parameters (Kery and Schaub 2011, 61). Where $\hat{R}$ is the potential scale reduction factor and ESS is the effective sample size.

The sensitivity of the estimates to the choice of priors was examined by multiplying the standard deviations of the normal (and log-normal) priors by 10 and using $\hat{R}$ to test whether the samples where drawn from the same posterior distribution (Thorley and Andrusak 2017).

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

Where relevant, model adequacy was confirmed by examination of residual plots.

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

The analyses were implemented using R version 3.6.2 (R Core Team 2015) and the `mbr` family of packages.

Growth

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

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

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

Integrating the above equation gives

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

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

The Fabens form allows

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

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

Key assumptions of the growth model include:

- k can vary with discharge regime and randomly with year.
- The residual variation in growth is normally distributed.

Mountain Whitefish with a FL $>$ 250 mm at release were excluded from the growth analysis as they appeared to be undergoing biphasic growth.

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., $\log(L) - \overline{\text{mean}(\log(L))}$, prior to model fitting.

Key assumptions of the condition model include:

- α can vary with the regime and season and randomly with year.
- β can vary with the regime and season and randomly with year.
- The residual variation in weight is log-normally distributed.

Fry were excluded from the condition analysis.

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 and Schaub 2011, 414–18), 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 varies with season.
- Occupancy varies randomly with site and site within year.
- The effect of year on occupancy is autoregressive with a lag of one year and varies with discharge regime.
- Sites are closed, i.e., the species is present or absent at a site for all the sessions in a particular season of a year.
- Observed presence is described by a bernoulli distribution, given occupancy.

Count

The count data were analysed using an overdispersed Poisson model (Kery 2010, pp 168-170; Kery and Schaub 2011, pp 55-56) to provide estimates of the lineal river count density (count/km). The model estimates the expected count which is the product of the abundance and observer efficiency. In order to interpret the estimates as relative densities it is necessary to assume that changes in observer efficiency are negligible.

Key assumptions of the count model include:

- The count density (count/km) varies as an exponential growth model with the rate of change varying with discharge regime.
- The count density varies with season.
- The count density varies randomly with site, year and site within year.
- The counts are gamma-Poisson distributed.

In the case of suckers the count model replaced the first assumption with

- The count density varies with discharge regime.

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, fish length and the interaction between season and fish length.
- Observed site fidelity is Bernoulli distributed.

Fry were excluded from the movement analysis.

Observer Length Correction

The annual bias (inaccuracy) and error (imprecision) in observer's fish length estimates were quantified from the divergence of the length distribution of their observed fish from the length distribution of the measured fish. More specifically, the percent length correction that minimised the Jensen-Shannon divergence (Lin 1991) between the two distributions provided a measure of the inaccuracy while the minimum divergence (the Jensen-Shannon divergence was calculated with log to base 2 which means it lies between 0 and 1) provided a measure of the imprecision.

Abundance

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

Key assumptions of the full abundance model include:

- The density (fish/km) varies as an exponential growth model with the rate of change varying with discharge regime.
- The density varies with season.
- The density varies randomly with site, year and site within 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.
- The overdispersion varies by encounter type (count versus capture).

In the case of Adult Suckers the abundance model replaced the first assumption with

- The density varies with discharge regime.

Distribution

The site within year random effects from the count and abundance models were analysed using a linear mixed model to estimate the distribution.

Key assumptions of the linear mixed model include:

- The effect varies by river kilometer.
- The effect of river kilometer varies by discharge regime.
- The effect of river kilometer varies randomly by year.
- The effect is normally distributed.

The effects are the predicted site within year random effects after accounting for all other predictors including the site and year random effects. As such an increase in the distribution represents an increase in the relative density of fish closer to Revelstoke Dam. A positive distribution does not however necessarily indicate that the density of fish is higher closer to Revelstoke Dam.

Species Richness

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

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 Juvenile and Adult 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 ith species.

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

Species Diversity

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 Adult Bull Trout and Adult Mountain Whitefish from the abundance model to calculate species diversity profiles (Leinster and Cobbold 2012). Species diversity profiles can take similarities among species into account, allow for a range of weightings of rare versus common species (via the q sensitivity parameter), and estimate the effective number of species.

Like the species richness and evenness estimates, the species diversity profile estimates treated all species equally. The q sensitivity parameter, which measures the insensitivity to rare species, ranged from 0 (equivalent to richness) through 1 (equivalent to evenness) to 2 (equivalent to Simpson (1949)).

Model Templates

Growth

```
.model {

  bKIntercept ~ dnorm(0, 5^-2)

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

```
  sKAnnual ~ dnorm(0, 5^-2) T(0, )
  for (i in 1:nAnnual) {
    bKAnnual[i] ~ dnorm(0, sKAnnual^-2)
    log(bK[i]) <- bKIntercept + bKRegime[step(i - Threshold) + 1] +
bKAnnual[i]
  }

  bLinf ~ dnorm(600, 300^-2) T(100, 1000)
  sGrowth ~ dnorm(0, 100^-2) T(0, )
  for (i in 1:length(Growth)) {

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

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

Block 1. The model description.

Condition

```
.model {

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

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

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

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

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

```
  sWeight ~ dnorm(0, 1^-2) T(0,)
  for(i in 1:length(Year)) {

    eWeightIntercept[i] <- bWeightIntercept +
bWeightRegimeIntercept[Regime[i]] + bWeightSeasonIntercept[Season[i]] +
bWeightYearIntercept[Year[i]]

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

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

Block 2. The model description.

Occupancy

```
.model {

  bRate ~ dnorm(0, 5^-2)

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

  bRateRev5 ~ dnorm(0, 5^-2)

  bOccupancyYear[1] ~ dnorm(0, 5^-2)
  for (i in 2:nYear) {
    eRateYear[i-1] <- bRate + bRateYear[i-1] + bRateRev5 * YearRev5[i-1]
    bOccupancyYear[i] <- bOccupancyYear[i-1] + eRateYear[i-1]
  }

  bOccupancySpring ~ dnorm(0, 5^-2)

  sOccupancySite ~ dnorm(0, 5^-2) T(0,)
  sOccupancySiteYear ~ dnorm(0, 5^-2) T(0,)
  for (i in 1:nSite) {
    bOccupancySite[i] ~ dnorm(0, sOccupancySite^-2)
    for (j in 1:nYear) {
      bOccupancySiteYear[i,j] ~ dnorm(0, sOccupancySiteYear^-2)
    }
  }
```

```
  for (i in 1:length(Observed)) {
    logit(eObserved[i]) <- bOccupancyYear[Year[i]] + bOccupancySpring *
Spring[i] + bOccupancySite[Site[i]] + bOccupancySiteYear[Site[i], Year[i]]
    Observed[i] ~ dbern(eObserved[i])
  }
..
```

Block 3. The model description.

Count

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

  bRate ~ dnorm(0, 5^-2)
  bRateRev5 ~ dnorm(0, 5^-2)

  bTrendYear[1] <- bDensity
  for(i in 2:nYear) {
    bTrendYear[i] <- bTrendYear[i-1] + bRate + bRateRev5 * YearRev5[i-1]
  }

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

  sDensityYear ~ dnorm(0, 5^-2) T(0,)
  for (i in 1:nYear) {
    bDensityYear[i] ~ dnorm(0, sDensityYear^-2)
  }

  sDensitySite ~ dnorm(0, 5^-2) T(0,)
  sDensitySiteYear ~ dnorm(0, 2^-2) T(0,)
  for (i in 1:nSite) {
    bDensitySite[i] ~ dnorm(0, sDensitySite^-2)
    for (j in 1:nYear) {
      bDensitySiteYear[i, j] ~ dnorm(0, sDensitySiteYear^-2)
    }
  }

  sDispersion ~ dnorm(0, 5^-2) T(0,)
  for (i in 1:length(Year)) {

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

    eCount[i] <- eDensity[i] * SiteLength[i] * ProportionSampled[i]
    eDispersion[i] ~ dgamma(1 / sDispersion^2, 1 / sDispersion^2)
```

```
    Count[i] ~ dpois(eCount[i] * eDispersion[i])
  }
  tCount <- bRateRev5
..
```

Block 4. The model description.

Movement

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

  bMovedSpring ~ dnorm(0, 5^-5)
  bLengthSpring ~ dnorm(0, 5^-5)

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

Block 5.

Abundance

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

  bRate ~ dnorm(0, 5^-2)
  bRateRev5 ~ dnorm(0, 5^-2)

  bTrendYear[1] <- bDensity
  for(i in 2:nYear) {
    bTrendYear[i] <- bTrendYear[i-1] + bRate + bRateRev5 * YearRev5[i-1]
  }

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

  sDensityYear ~ dnorm(0, 5^-2) T(0,)
  for (i in 1:nYear) {
    bDensityYear[i] ~ dnorm(0, sDensityYear^-2)
  }

  sDensitySite ~ dnorm(0, 5^-2) T(0,)
  sDensitySiteYear ~ dnorm(0, 2^-2) T(0,)
  for (i in 1:nSite) {
    bDensitySite[i] ~ dnorm(0, sDensitySite^-2)
```

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

  bEfficiency ~ dnorm(0, 5^-2)

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

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

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

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

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

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

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

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

    log(eDensity[i]) <- bTrendYear[Year[i]] + bDensitySeason[Season[i]] +
bDensityYear[Year[i]] + bDensitySite[Site[i]] +
bDensitySiteYear[Site[i],Year[i]]
```

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

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

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

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

    Catch[i] ~ dpois(eCatch[i] * eDispersion[i])
  }
  tAbundance <- bRateRev5
..
```

Block 6. The model description.

Distribution

```
.model {
  bEffect ~ dnorm(0, 1^-2)

  bRkm ~ dnorm(0, 1^-2)
  bRkmRev5 ~ dnorm(0, 1^-2)

  sRkmYear ~ dnorm(0, 1^-2) T(0,)
  for(i in 1:nYear) {
    bRkmYear[i] ~ dnorm(0, sRkmYear^-2)
  }
  sEffect ~ dnorm(0, 1^-2) T(0,)
  for(i in 1:length(Effect)) {
    eEffect[i] <- bEffect + (bRkm + bRkmRev5 * Rev5[i] + bRkmYear[Year[i]]) *
Rkm[i]
    Effect[i] ~ dnorm(eEffect[i], sEffect^-2)
  }
tDistribution <- bRkmRev5
```

Block 7. The model description.

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Appendix G – HBM Results

Parameter Estimates 2019

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Results

Stage

Table 1. Length cutoffs by species and stage.

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

Growth

Table 2. Parameter descriptions.

Parameter	Description
`Annual[i]`	Year
`bK[i]`	Expected growth coefficient in the ith `Annual`
`bKAnnual[i]`	Effect of `i`th `Annual` on `bKIntercept`
`bKIntercept`	Intercept for `log(bK)`
`bKRegime[i]`	Effect of `i`th Regime on `bKIntercept`
`bLinf`	Mean maximum length
`eGrowth[i]`	Expected `Growth` of the `i`th fish
`Growth[i]`	Change in length of the `i`th fish between release and recapture (mm)
`LengthAtRelease[i]`	Length of the `i`th fish when released (mm)
`sGrowth`	SD of residual variation about `eGrowth`
`sKAnnual`	SD of `bKAnnual`
`Threshold`	Last `Annual` of the first regime
`Years[i]`	Number of years between release and recapture for the `i`th fish

Bull Trout

Table 3. Model coefficients.

term	estimate	sd	zscore	lower	upper	pvalue
bKIntercept	-1.7507336	0.1199146	-14.6232718	-1.9888049	-1.5167030	0.0006662
bKRegime2	-0.0600006	0.1428115	-0.4356453	-0.3661568	0.2211612	0.6482345
bLinf	844.0686142	24.6485065	34.3096957	802.3650682	897.4461141	0.0006662
sGrowth	32.0269299	1.2930389	24.8580730	29.9001309	34.8539006	0.0006662
sKAnnual	0.2659911	0.0693731	3.9725837	0.1687522	0.4461194	0.0006662
tGrowth	-0.0600006	0.1428115	-0.4356453	-0.3661568	0.2211612	0.6482345

Table 4. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
344	6	3	500	500	1128	1.002	TRUE

Table 5. Sensitivity of posteriors to choice of priors.

n	K	nchains	niters	rhat_1	rhat_2	rhat_all	converged
344	6	3	500	1.002	1.004	1.002	TRUE

Mountain Whitefish

Table 6. Model coefficients.

term	estimate	sd	zscore	lower	upper	pvalue
bKIntercept	-1.7606502	0.1656696	-10.621613	-2.0833212	-1.4416248	0.0006662
bKRegime2	0.0828494	0.2171573	0.394426	-0.3511366	0.4929744	0.6495670
bLinf	287.1680765	2.3396592	122.772254	282.7681925	292.0508562	0.0006662
sGrowth	9.6000819	0.2015170	47.630110	9.2045096	9.9965840	0.0006662
sKAnnual	0.4095895	0.1020587	4.167034	0.2777268	0.6707852	0.0006662
tGrowth	0.0828494	0.2171573	0.394426	-0.3511366	0.4929744	0.6495670

Table 7. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
1142	6	3	500	500	1136	1.003	TRUE

Table 8. Sensitivity of posteriors to choice of priors.

n	K	nchains	niters	rhat_1	rhat_2	rhat_all	converged
1142	6	3	500	1.003	1.013	1.006	TRUE

Largescale Sucker

Table 9. Model coefficients.

term	estimate	sd	zscore	lower	upper	pvalue
bKIntercept	-2.352517	3.470345	-0.7511485	-10.0123652	3.977219	0.4337109
bKRegime2	-2.898824	3.450703	-0.7691769	-9.1704883	4.534619	0.4603598
bLinf	635.111272	99.015320	6.6794026	536.8266817	928.031775	0.0006662
sGrowth	8.981498	0.366308	24.5662641	8.3355939	9.754696	0.0006662
sKAnnual	2.116388	1.292681	1.8975718	0.9771194	6.022412	0.0006662
tGrowth	-2.898824	3.450703	-0.7691769	-9.1704883	4.534619	0.4603598

Table 10. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
303	6	3	500	500	82	1.064	FALSE

Table 11. Sensitivity of posteriors to choice of priors.

n	K	nchains	niters	rhat_1	rhat_2	rhat_all	converged
303	6	3	500	1.064	1.757	2.912	FALSE

Condition

Table 12. Parameter descriptions.

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`
`bWeightSlope`	Intercept for `eWeightSlope`
`bWeightYearIntercept[i]`	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]`	Effect of `LogLength` on `eWeightIntercept`
`LogLength[i]`	The centered `log(Length)` of the `i`th fish
`sWeight`	SD of residual variation about `eWeight`
`sWeightYearIntercept`	SD of `bWeightYearIntercept`
`sWeightYearSlope`	SD of `bWeightYearSlope`
`Weight[i]`	The Weight of the `i`th fish

Bull Trout

Table 13. Model coefficients.

term	estimate	sd	zscore	lower	upper	pvalue
bWeightIntercept	6.8166826	0.0242804	280.7480460	6.7704401	6.8659191	0.0006662
bWeightRegimeIntercept2	-0.0838463	0.0336963	-2.4701919	-0.1495648	-0.0182574	0.0139907
bWeightRegimeSlope2	0.0402081	0.0460121	0.8920033	-0.0476286	0.1348475	0.3484344
bWeightSeasonIntercept2	0.0009707	0.0086753	0.0922100	-0.0159284	0.0174969	0.9253831
bWeightSeasonSlope2	0.0085434	0.0220951	0.3811584	-0.0356207	0.0515235	0.6828781
bWeightSlope	3.1675132	0.0331265	95.5808860	3.0986533	3.2312403	0.0006662
sWeight	0.1362534	0.0015990	85.1977311	0.1330747	0.1394445	0.0006662
sWeightYearIntercept	0.0675277	0.0140357	4.9424494	0.0483610	0.1030031	0.0006662
sWeightYearSlope	0.0867526	0.0211165	4.2331160	0.0562734	0.1389527	0.0006662
tCondition1	-0.0838463	0.0336963	-2.4701919	-0.1495648	-0.0182574	0.0139907
tCondition2	0.0402081	0.0460121	0.8920033	-0.0476286	0.1348475	0.3484344

Table 14. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
3630	11	3	500	200	675	1.003	TRUE

Table 15. Sensitivity of posteriors to choice of priors.

n	K	nchains	niters	rhat_1	rhat_2	rhat_all	converged
3630	11	3	500	1.003	1.003	1.002	TRUE

Mountain Whitefish

Table 16. Model coefficients.

term	estimate	sd	zscore	lower	upper	pvalue
bWeightIntercept	4.8029945	0.0141002	340.6197156	4.7748676	4.8312753	0.0006662
bWeightRegimeIntercept2	-0.0151951	0.0202780	-0.7538523	-0.0568943	0.0240782	0.4390406
bWeightRegimeSlope2	-0.0061139	0.0247906	-0.2576246	-0.0552766	0.0416127	0.8121252
bWeightSeasonIntercept2	-0.0446255	0.0038943	-11.4842247	-0.0525053	-0.0371512	0.0006662
bWeightSeasonSlope2	-0.1053670	0.0178666	-5.8999711	-0.1408853	-0.0705854	0.0006662
bWeightSlope	3.2078663	0.0175648	182.6059766	3.1724569	3.2416189	0.0006662
sWeight	0.1001294	0.0007745	129.2741614	0.0985946	0.1016629	0.0006662
sWeightYearIntercept	0.0396337	0.0084986	4.8152238	0.0282522	0.0612275	0.0006662
sWeightYearSlope	0.0414961	0.0119166	3.5775354	0.0234636	0.0695947	0.0006662
tCondition1	-0.0151951	0.0202780	-0.7538523	-0.0568943	0.0240782	0.4390406
tCondition2	-0.0061139	0.0247906	-0.2576246	-0.0552766	0.0416127	0.8121252

Table 17. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
8530	11	3	500	500	1004	1.006	TRUE

Table 18. Sensitivity of posteriors to choice of priors.

n	K	nchains	niters	rhat_1	rhat_2	rhat_all	converged
8530	11	3	500	1.006	1.006	1.15	FALSE

Rainbow Trout

Table 19. Model coefficients.

term	estimate	sd	zscore	lower	upper	pvalue
bWeightIntercept	4.7264442	0.0178071	265.4560365	4.6920934	4.7632632	0.0006662
bWeightRegimeIntercept2	-0.0150140	0.0249748	-0.6173774	-0.0650983	0.0335656	0.4856762
bWeightRegimeSlope2	-0.0519394	0.0448721	-1.1628595	-0.1383590	0.0350962	0.2191872
bWeightSeasonIntercept2	-0.0705237	0.0153196	-4.6156100	-0.1000832	-0.0408214	0.0006662
bWeightSeasonSlope2	0.0222651	0.0364029	0.5943697	-0.0485086	0.0933276	0.5536309
bWeightSlope	3.0875166	0.0332232	92.9310496	3.0201936	3.1579685	0.0006662
sWeight	0.1099768	0.0031358	35.1242239	0.1043694	0.1165475	0.0006662
sWeightYearIntercept	0.0398596	0.0120961	3.4381871	0.0232159	0.0696368	0.0006662
sWeightYearSlope	0.0667392	0.0223293	3.1109495	0.0353323	0.1193577	0.0006662
tCondition1	-0.0150140	0.0249748	-0.6173774	-0.0650983	0.0335656	0.4856762
tCondition2	-0.0519394	0.0448721	-1.1628595	-0.1383590	0.0350962	0.2191872

Table 20. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
663	11	3	500	500	1203	1.003	TRUE

Table 21. Sensitivity of posteriors to choice of priors.

n	K	nchains	niters	rhat_1	rhat_2	rhat_all	converged
663	11	3	500	1.003	1.004	1.001	TRUE

Largescale Sucker

Table 22. Model coefficients.

term	estimate	sd	zscore	lower	upper	pvalue
bWeightIntercept	6.8232546	0.0232227	293.810078	6.7778992	6.8667944	0.0006662
bWeightSeasonIntercept2	0.0216273	0.0053627	4.054425	0.0117158	0.0328505	0.0006662
bWeightSeasonSlope2	0.1629237	0.0465700	3.493556	0.0718370	0.2535204	0.0006662
bWeightSlope	2.9127933	0.0734495	39.626157	2.7561414	3.0586804	0.0006662
sWeight	0.0833673	0.0010978	75.946096	0.0812544	0.0856207	0.0006662
sWeightYearIntercept	0.0611456	0.0199913	3.262224	0.0390647	0.1148657	0.0006662
sWeightYearSlope	0.2076533	0.0674905	3.266476	0.1291200	0.3831665	0.0006662

Table 23. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
2769	7	3	500	500	843	1.002	TRUE

Table 24. Sensitivity of posteriors to choice of priors.

n	K	nchains	niters	rhat_1	rhat_2	rhat_all	converged
2765	6	3	500	1.002	1.007	2.633	FALSE

Occupancy

Table 25. Parameter descriptions.

Parameter	Description
`bOccupancySite[i]`	Effect of `i`th site on `bOccupancyYear`
`bOccupancySiteYear[i,j]`	Effect of `i`th site in `j`th year on `bOccupancyYear`
`bOccupancySpring`	Effect of spring on `bOccupancyYear`
`bOccupancyYear[i]`	Expected `Occupancy` in `i`th year
`bRate`	Intercept of `eRateYear`
`bRateRev5[i]`	Effect of Revelstoke 5 regime on `bRate`
`bRateYear[i]`	Effect of `i`th year on `biRate`
`eObserved[i]`	Probability of observing a species on `i`th site visit
`eRateYear[i]`	Change in `bOccupancyYear` between year `i-1` and year `i`
`Observed[i]`	Whether the species was observed on `i`th site visit
`sOccupancySite`	SD of `bOccupancySite`
`sOccupancySiteYear`	SD of `bOccupancySiteYear`
`sRateYear`	SD of `bRateYear`

Rainbow Trout

Table 26. Model coefficients.

term	estimate	sd	zscore	lower	upper	pvalue
bOccupancySpring	-0.0211189	0.2933838	-0.0979971	-0.5964877	0.5512443	0.9427049
bRate	0.2537841	0.3430187	0.6925871	-0.5085145	0.8544788	0.4350433
bRateRev5	-0.2047145	0.5098728	-0.4001313	-1.2226440	0.8787705	0.6628914
sOccupancySite	2.0806027	0.4730078	4.5454854	1.4274104	3.3042769	0.0006662
sOccupancySiteYear	0.5931010	0.2000258	2.8809056	0.0950440	0.9331820	0.0006662
sRateYear	0.9728467	0.3069866	3.3034821	0.5344169	1.7067354	0.0006662

Table 27. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
1096	6	3	500	1000	366	1.005	TRUE

Burbot

Table 28. Model coefficients.

Term	estimate	sd	zscore	lower	upper	pvalue
bOccupancySpring	-0.5055025	0.3039636	-1.646470	-1.0616464	0.0981813	0.1112592
bRate	0.4443332	0.3858177	1.195467	-0.3066406	1.2791748	0.2005330
bRateRev5	-0.6188830	0.5591564	-1.128256	-1.7831547	0.4850129	0.2391739
sOccupancySite	1.0662578	0.3017792	3.686698	0.6769883	1.8392708	0.0006662
sOccupancySiteYear	0.4876430	0.2273156	2.091691	0.0259983	0.8943945	0.0006662
sRateYear	1.1010054	0.3185481	3.575430	0.6365314	1.8663881	0.0006662

Table 29. Model summary.

N	K	nchains	niters	nthin	ess	rhat	converged
1096	6	3	500	1000	423	1.005	TRUE

Lake Whitefish

Table 30. Model coefficients.

Term	estimate	sd	zscore	lower	upper	pvalue
bOccupancySpring	-4.8888136	0.7989035	-6.2296245	-6.7578043	-3.6131507	0.0006662
bRate	0.2390948	0.4966443	0.4704596	-0.7520939	1.1535805	0.6322452
bRateRev5	-0.3323371	0.7794873	-0.4032121	-1.8436480	1.2587995	0.6815456
sOccupancySite	0.5073103	0.1717557	3.1062233	0.2565075	0.9383171	0.0006662
sOccupancySiteYear	0.2061891	0.1606613	1.4294934	0.0075733	0.5900137	0.0006662
sRateYear	1.5804621	0.3645380	4.4716618	1.0709421	2.4733664	0.0006662

Table 31. Model summary.

N	K	nchains	niters	nthin	ess	rhat	converged
1096	6	3	500	1000	194	1.024	TRUE

Northern Pikeminnow

Table 32. Model coefficients.

Term	estimate	sd	zscore	lower	upper	pvalue
bOccupancySpring	-2.1552771	0.4337606	-4.973836	-3.0033473	-1.3202058	0.0006662
bRate	0.3351248	0.2862747	1.212567	-0.1742807	0.9804073	0.1832112
bRateRev5	-0.4626214	0.4161821	-1.144838	-1.3393860	0.3194777	0.2151899
sOccupancySite	1.3647952	0.3589283	3.945096	0.8552119	2.2392677	0.0006662
sOccupancySiteYear	0.5537642	0.2568455	2.104395	0.0483798	1.0224085	0.0006662
sRateYear	0.7056723	0.2677340	2.781286	0.3180342	1.3635894	0.0006662

Table 33. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
1096	6	3	500	1000	513	1.006	TRUE

Redside Shiner

Table 34. Model coefficients.

term	estimate	sd	zscore	lower	upper	pvalue
bOccupancySpring	-0.9379891	0.3706036	-2.5505426	-1.6802086	-0.2304014	0.0099933
bRate	0.3703824	0.5136177	0.7603619	-0.5354205	1.5738008	0.4230513
bRateRev5	-0.5140931	0.7206089	-0.7622041	-2.0820541	0.8429950	0.4083944
sOccupancySite	2.2327082	0.6040548	3.8822362	1.4683617	3.7530884	0.0006662
sOccupancySiteYear	0.2818792	0.2056617	1.5032140	0.0196938	0.7611805	0.0006662
sRateYear	1.3237075	0.4201057	3.3006207	0.7483029	2.3454497	0.0006662

Table 35. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
1096	6	3	500	1000	249	1.007	TRUE

Sculpins

Table 36. Model coefficients.

term	estimate	sd	zscore	lower	upper	pvalue
bOccupancySpring	-0.4346491	0.2748119	-1.6123220	-0.9821016	0.0799755	0.0992672
bRate	0.5347873	0.4357812	1.2439978	-0.2644184	1.4457847	0.2138574
bRateRev5	-0.6518429	0.6551080	-0.9900303	-1.9479542	0.6253316	0.2898068
sOccupancySite	1.3207870	0.3031855	4.4996817	0.9151275	2.1170614	0.0006662
sOccupancySiteYear	0.4126556	0.2059560	1.9538603	0.0180123	0.7767846	0.0006662
sRateYear	1.2839029	0.3284961	4.0313897	0.8045447	2.0550941	0.0006662

Table 37. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
1096	6	3	500	1000	224	1.008	TRUE

Count

Table 38. Parameter descriptions.

Parameter	Description
`bDensity`	`bTrendYear` in the first year
`bDensitySeason`	Effect of season on `bTrendYear`
`bDensitySite[i]`	Effect of `i`th site on `bTrendYear`
`bDensitySiteYear[i,j]`	Effect of `i`th site in `j`th year on `bDensityTrend`
`bDensityYear[i]`	Effect of `i`th year on `bTrendYear`
`bRate`	Exponential population growth rate
`bRateRev5`	Effect of `Rev5` on `bRate`
`bTrendYear[i]`	The intercept for the `log(eDensity)` in the `i`th year
`Count[i]`	Count on `i`th site visit
`eCount[i]`	Expected count on `i`th site visit
`eDensity[i]`	Expected lineal count density on `i`th site visit
`eDispersion[i]`	Overdispersion on `i`th site visit
`ProportionSampled[i]`	Proportion of site sampled on `i`th site visit
`sDensitySite`	SD of `bDensitySite`
`sDensitySiteYear`	SD of `bDensitySiteYear`
`sDensityYear`	SD of `bDensityYear`
`sDispersion[i]`	SD of `eDispersion`
`SiteLength[i]`	Length of site on `i`th site visit
`YearRev5[i]`	Whether the rate of change between the `i`th and `i+1`th year is effectd by `Rev5`

Rainbow Trout

Table 39. Model coefficients.

term	estimate	sd	zscore	lower	upper	pvalue
bDensity	-2.7051949	0.6772050	-4.036072	-4.1463532	-1.4863898	0.0006662
bDensitySeason2	-0.1193521	0.1536112	-0.736468	-0.4120815	0.1798996	0.4710193
bRate	0.2416045	0.0711581	3.452179	0.1123462	0.3984610	0.0019987
bRateRev5	-0.3484113	0.1304420	-2.696805	-0.6201202	-0.1138323	0.0099933
sDensitySite	1.5618622	0.3627564	4.435372	1.0473463	2.4749919	0.0006662
sDensitySiteYear	0.7064079	0.0775009	9.141961	0.5628694	0.8682872	0.0006662
sDensityYear	0.6272727	0.1787453	3.625837	0.3693837	1.0906850	0.0006662
sDispersion	0.7981945	0.0526826	15.192758	0.7014973	0.9106660	0.0006662
tCount	-0.3484113	0.1304420	-2.696805	-0.6201202	-0.1138323	0.0099933

Table 40. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
1096	9	3	500	2000	980	1.006	TRUE

Burbot

Table 41. Model coefficients.

term	estimate	sd	zscore	lower	upper	pvalue
bDensity	-2.9860636	0.7961686	-3.765667	-4.5799083	-1.4077311	0.0006662
bDensitySeason2	-0.7763300	0.2796950	-2.789257	-1.3585135	-0.2739136	0.0046636
bRate	0.1790349	0.1107058	1.603171	-0.0346883	0.3979308	0.0966023
bRateRev5	-0.4014537	0.2131198	-1.882632	-0.8440015	0.0286095	0.0606262
sDensitySite	0.8635717	0.2456301	3.687171	0.5418852	1.4862107	0.0006662
sDensitySiteYear	0.4372803	0.1828296	2.336221	0.0597502	0.7758318	0.0006662
sDensityYear	1.0901883	0.2991498	3.762872	0.6480600	1.8221336	0.0006662
sDispersion	1.2125365	0.1340482	9.033011	0.9569587	1.4710729	0.0006662
tCount	-0.4014537	0.2131198	-1.882632	-0.8440015	0.0286095	0.0606262

Table 42. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
1096	9	3	500	2000	1190	1.006	TRUE

Northern Pikeminnow

Table 43. Model coefficients.

term	estimate	sd	zscore	lower	upper	pvalue
bDensity	-4.1309573	0.7767589	-5.405655	-5.8609401	-2.7906326	0.0006662
bDensitySeason2	-2.3853256	0.4331203	-5.561123	-3.2941309	-1.6211892	0.0006662
bRate	0.3302540	0.0946643	3.565492	0.1626128	0.5379072	0.0006662
bRateRev5	-0.6243164	0.1678747	-3.782043	-0.9864425	-0.3262295	0.0019987
sDensitySite	1.2642294	0.3432588	3.849017	0.8051259	2.1237908	0.0006662
sDensitySiteYear	0.6673665	0.1909880	3.411952	0.2062757	0.9854695	0.0006662
sDensityYear	0.6337221	0.2138734	3.105955	0.3330658	1.1557920	0.0006662
sDispersion	1.3366890	0.1301647	10.310899	1.1002730	1.6054051	0.0006662
tCount	-0.6243164	0.1678747	-3.782043	-0.9864425	-0.3262295	0.0019987

Table 44. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
1096	9	3	500	2000	1070	1.007	TRUE

Suckers

Table 45. Model coefficients.

term	estimate	sd	zscore	lower	upper	pvalue
bDensity	1.9723382	0.2166413	9.093113	1.5432369	2.4011244	0.0006662
bDensityRev5	0.5783026	0.2597159	2.226959	0.0656159	1.0905701	0.0246502
bDensitySeason2	-0.3095755	0.0928386	-3.348808	-0.4865168	-0.1348317	0.0006662
sDensitySite	0.4500476	0.0989077	4.656642	0.3053964	0.6891601	0.0006662
sDensitySiteYear	0.5076887	0.0456408	11.125705	0.4214611	0.6024636	0.0006662
sDensityYear	0.5463992	0.0992974	5.587980	0.4008861	0.7852651	0.0006662
sDispersion	0.7383009	0.0221660	33.311984	0.6957616	0.7845337	0.0006662
tCount	0.5783026	0.2597159	2.226959	0.0656159	1.0905701	0.0246502

Table 46. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
1096	8	3	500	200	142	1.038	FALSE

Movement

Table 47. Parameter descriptions.

Parameter	Description
`bLength`	Effect of `Length` on `bMoved`
`bLengthSpring`	Effect of `Spring` on `bLength`
`bMoved`	Intercept for `logit(eMoved)`
`bMovedSpring`	Effect of `Spring` on `bMoved`
`eMoved[i]`	Probability of different site from previous encounter for `i`th recaptured fish
`Length[i]`	Length of `i`th recaptured fish (mm)
`Moved[i]`	Indicates whether `i`th recaptured fish is recorded at a different site from previous encounter
`Spring[i]`	Whether the `i`th recaptured is from the spring

Bull Trout

Table 48. Model coefficients.

term	estimate	sd	zscore	lower	upper	pvalue
bLength	0.0050559	0.0015796	3.2237394	0.0020402	0.0083934	0.0006662
bLengthSpring	0.0012484	0.0058311	0.3211759	-0.0076176	0.0152995	0.8187875
bMoved	-2.0021253	0.6898047	-2.9212149	-3.4733841	-0.7255709	0.0019987
bMovedSpring	0.3117504	2.5278178	0.0604711	-5.3193628	4.4640225	0.8907395

Table 49. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
157	4	3	500	500	1437	1.001	TRUE

Mountain Whitefish

Table 50. Model coefficients.

term	estimate	sd	zscore	lower	upper	pvalue
bLength	-0.0019543	0.0028975	-0.6847212	-0.0074879	0.0035420	0.4803464
bLengthSpring	-0.0263823	0.0066429	-3.9881570	-0.0401646	-0.0138978	0.0006662
bMoved	0.4406461	0.7379263	0.6124895	-0.9888788	1.8485747	0.5416389
bMovedSpring	5.4182611	1.5846881	3.4179195	2.3832482	8.5514241	0.0006662

Table 51. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
489	4	3	500	500	1268	1	TRUE

Rainbow Trout

Table 52. Model coefficients.

term	estimate	sd	zscore	lower	upper	pvalue
bLength	0.0114662	0.0059343	1.986689	0.0006735	0.0250390	0.0366422
bLengthSpring	0.2159914	0.1212505	1.869137	0.0275220	0.4828487	0.0126582
bMoved	-3.5209461	1.6116435	-2.280991	-7.0724454	-0.6771077	0.0139907
bMovedSpring	-65.7943350	36.6070156	-1.892888	-147.2647827	-9.1633549	0.0099933

Table 53. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
27	4	3	500	500	1167	1.002	TRUE

Largescale Sucker

Table 54. Model coefficients.

term	estimate	sd	zscore	lower	upper	pvalue
bLength	-0.0106151	0.0054874	-1.979825	-0.0224177	-0.0006919	0.0379747
bLengthSpring	-0.1762254	0.0847866	-2.142366	-0.3610148	-0.0343018	0.0086609
bMoved	4.4296540	2.3704001	1.925367	0.1732403	9.4337950	0.0419720
bMovedSpring	77.3757147	37.3347441	2.135704	14.6155554	158.8981791	0.0086609

Table 55. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
81	4	3	500	500	427	1.008	TRUE

Abundance

Table 56. Parameter descriptions.

Parameter	Description
`bDensity`	Intercept for `log(eDensity)` in the 1st year
`bDensitySeason[i]`	Effect of `i`th season on `bTrendYear`
`bDensitySite[i]`	Effect of `i`th site on `bDensity`
`bDensitySiteYear[i,j]`	Effect of `i`th site in `j`th year on `bDensity`
`bDensityYear[i]`	Effect of `i`th year on `bDensity`
`bEfficiency`	Intercept for `logit(eEfficiency)`
`bEfficiencySeason[i]`	Effect of `i`th season on `bEfficiency`
`bEfficiencySessionSeasonYear[i, j, k]`	Effect of `i`th `Session` in `j`th `Season` of `k`th `Year` on `bEfficiency`
`bRate`	Exponential annual population growth rate
`bRateRev5[i]`	Effect of `Rev5` on `bRate`
`bTrendYear[i]`	Intercept for `log(eDensity)` in the `i`th year
`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
`eEfficiency[i]`	Predicted efficiency during `i`th site visit
`Marked[i]`	Number of marked fish caught in `i`th river visit
`sDensitySite`	SD of `bDensitySite`
`sDensitySiteYear`	SD of `bDensitySiteYear`
`sDensityYear`	SD of `bDensityYear`
`sEfficiencySessionSeasonYear`	SD of `bEfficiencySessionSeasonYear`
`Tagged[i]`	Number of fish tagged prior to `i`th river visit

Bull Trout

Juvenile

Table 57. Model coefficients.

term	estimate	sd	zscore	lower	upper	pvalue
bDensity	2.0529633	0.3643553	5.6419537	1.2940096	2.7447415	0.0006662
bDensitySeason2	0.2339380	0.3533404	0.6687714	-0.4216598	0.9338769	0.4990007
bEfficiency	-3.1511169	0.1390130	-22.6589741	-3.4221171	-2.8809197	0.0006662
bEfficiencySeason2	-0.3669385	0.3539413	-1.0534084	-1.0944416	0.3094929	0.2818121
bMultiplierType2	0.4924246	0.1440083	3.4447712	0.2230068	0.7787287	0.0019987
bRate	0.1428264	0.0434402	3.2989324	0.0601781	0.2313121	0.0033311
bRateRev5	-0.1486458	0.0835254	-1.7997614	-0.3177113	0.0086817	0.0566289
sDensitySite	0.6293581	0.1521014	4.2631644	0.4161771	1.0120476	0.0006662
sDensitySiteYear	0.2826389	0.0532901	5.2830055	0.1718522	0.3807650	0.0006662
sDensityYear	0.4003514	0.1084853	3.7611028	0.2304797	0.6409416	0.0006662
sDispersion	-0.8975232	0.1265749	-7.1636252	-1.1868920	-0.6844391	0.0006662
sDispersionType2	0.4042719	0.2373376	1.6527969	-0.1067815	0.8328237	0.1205863
sEfficiencySessionSeasonYear	0.2522319	0.0468564	5.3671331	0.1631056	0.3467806	0.0006662
tAbundance	-0.1486458	0.0835254	-1.7997614	-0.3177113	0.0086817	0.0566289

Table 58. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
1211	14	3	500	500	544	1.006	TRUE

Adult

Table 59. Model coefficients.

term	estimate	sd	zscore	lower	upper	pvalue
bDensity	4.1859710	0.2580021	16.1719566	3.6486484	4.6571261	0.0006662
bDensitySeason2	-0.2033853	0.3449450	-0.5794384	-0.8363666	0.5130081	0.5389740
bEfficiency	-3.6192948	0.1184504	-30.5606299	-3.8540114	-3.3957365	0.0006662
bEfficiencySeason2	-0.0893283	0.3493405	-0.2860700	-0.8024300	0.5389374	0.7828115
bMultiplierType2	0.6087917	0.1190852	5.1062637	0.3835729	0.8434613	0.0006662
bRate	0.0182260	0.0256005	0.7258335	-0.0352378	0.0703218	0.4523651
bRateRev5	-0.0050941	0.0500328	-0.1205790	-0.1048534	0.0929095	0.9280480
sDensitySite	0.5212359	0.1262549	4.3101459	0.3634835	0.8390878	0.0006662
sDensitySiteYear	0.4018795	0.0392624	10.2805731	0.3295881	0.4796723	0.0006662
sDensityYear	0.2002960	0.0824979	2.4730273	0.0379251	0.3794340	0.0006662
sDispersion	-0.9085711	0.0861245	-10.5559208	-1.0893487	-0.7475905	0.0006662
sDispersionType2	0.4059878	0.1669858	2.4245293	0.0692949	0.7318899	0.0179880
sEfficiencySessionSeasonYear	0.1999823	0.0414635	4.8791176	0.1242672	0.2851098	0.0006662
tAbundance	-0.0050941	0.0500328	-0.1205790	-0.1048534	0.0929095	0.9280480

Table 60. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
1211	14	3	500	500	585	1.008	TRUE

Mountain Whitefish

Juvenile

Table 61. Model coefficients.

term	estimate	sd	zscore	lower	upper	pvalue
bDensity	5.6816464	0.6604471	8.6035822	4.3319739	7.0293233	0.0006662
bDensitySeason2	0.3877354	0.6940322	0.5775852	-0.9862879	1.8043141	0.5483011
bEfficiency	-5.7826757	0.4486936	-12.9350860	-6.8125697	-4.9968378	0.0006662
bEfficiencySeason2	0.0998247	0.6950220	0.1240544	-1.3376216	1.4191500	0.8840773
bMultiplierType2	0.8969023	0.1924674	4.6497038	0.5359927	1.2755229	0.0006662
bRate	0.0935275	0.1469269	0.6613852	-0.1639698	0.4075821	0.5043304
bRateRev5	-0.1572920	0.1949248	-0.8265433	-0.5740876	0.1896977	0.4083944
sDensitySite	0.8950822	0.2138415	4.3546389	0.6112824	1.4368639	0.0006662
sDensitySiteYear	0.5395837	0.0618339	8.7534063	0.4259818	0.6700358	0.0006662
sDensityYear	0.4593405	0.1746362	2.7930515	0.2306607	0.8854366	0.0006662
sDispersion	-0.5406260	0.0869359	-6.2824077	-0.7285570	-0.3865931	0.0006662
sDispersionType2	0.6002065	0.1506491	4.0109040	0.3235035	0.9039499	0.0006662
sEfficiencySessionSeasonYear	0.3201542	0.0608110	5.2990462	0.2154955	0.4435075	0.0006662
tAbundance	-0.1572920	0.1949248	-0.8265433	-0.5740876	0.1896977	0.4083944

Table 62. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
995	14	3	500	500	116	1.037	FALSE

Adult

Table 63. Model coefficients.

term	estimate	sd	zscore	lower	upper	pvalue
bDensity	6.6330829	0.2123302	31.2507257	6.2198812	7.0452007	0.0006662
bDensitySeason2	-0.6156399	0.1132639	-5.4645941	-0.8461007	-0.4002648	0.0006662
bEfficiency	-3.9832943	0.0592741	-67.1998023	-4.1011046	-3.8668193	0.0006662
bEfficiencySeason2	0.8643610	0.1134215	7.5850353	0.6440628	1.0801909	0.0006662
bMultiplierType2	0.8309869	0.1170480	7.0989377	0.6029264	1.0579082	0.0006662
bRate	-0.0033987	0.0180606	-0.1833426	-0.0378838	0.0331600	0.8574284
bRateRev5	0.0245543	0.0346176	0.7059429	-0.0464292	0.0904741	0.4963358
sDensitySite	0.5992936	0.1419010	4.3580822	0.4055336	0.9794851	0.0006662
sDensitySiteYear	0.4050866	0.0278353	14.5868181	0.3530109	0.4613234	0.0006662
sDensityYear	0.1187903	0.0625967	1.9073700	0.0099283	0.2524529	0.0006662
sDispersion	-0.8099160	0.0364119	-22.2428965	-0.8809641	-0.7406524	0.0006662
sDispersionType2	0.4337653	0.0943264	4.6141835	0.2467712	0.6173565	0.0006662

sEfficiencySessionSeasonYear	0.2215050	0.0281099	7.9075601	0.1715526	0.2807482	0.0006662
tAbundance	0.0245543	0.0346176	0.7059429	-0.0464292	0.0904741	0.4963358

Table 64. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
1211	14	3	500	500	196	1.017	TRUE

Rainbow Trout

Table 65. Model coefficients.

term	estimate	sd	zscore	lower	upper	pvalue
bDensity	0.5035328	0.5535634	0.8991013	-0.6415210	1.6055876	0.3550966
bDensitySeason2	0.1665738	0.6970374	0.3021429	-1.0665170	1.6045870	0.8001332
bEfficiency	-2.5466367	0.2585561	-9.9087863	-3.1236454	-2.0773126	0.0006662
bEfficiencySeason2	-0.4533962	0.6920429	-0.6990281	-1.8533202	0.8223461	0.4990007
bMultiplierType2	-0.0299201	1.9889840	0.0117350	-3.8220236	4.0732843	0.9906729
bRate	0.0023524	0.1369591	-0.0186858	-0.2877056	0.2683257	0.9853431
bRateRev5	0.0825676	0.1830594	0.4605125	-0.2820071	0.4425316	0.6215856
sDensitySite	1.1631629	0.3093726	3.9208599	0.7671309	1.9162633	0.0006662
sDensitySiteYear	0.5284092	0.1320284	3.9844240	0.2392489	0.7817148	0.0006662
sDensityYear	0.3544851	0.1994533	1.8540220	0.0270004	0.8289877	0.0006662
sDispersion	-1.4727050	1.0531446	-1.6568585	-4.3706970	-0.4486307	0.0006662
sDispersionType2	-0.0967444	2.0336782	-0.0198595	-3.9784430	4.0945658	0.9653564
sEfficiencySessionSeasonYear	0.3314460	0.1346054	2.4330432	0.0448715	0.5855767	0.0006662
tAbundance	0.0825676	0.1830594	0.4605125	-0.2820071	0.4425316	0.6215856

Table 66. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
875	14	3	500	500	132	1.016	FALSE

Largescale Sucker

Table 67. Model coefficients.

term	estimate	sd	zscore	lower	upper	pvalue
bDensity	5.1056970	0.2403126	21.2628672	4.6068258	5.5729691	0.0006662
bDensitySeason2	-0.0089223	0.5552050	0.0502835	-0.9173956	1.2070935	0.9880080
bEfficiency	-3.5133030	0.1438967	-24.4181839	-3.8002228	-3.2455222	0.0006662
bEfficiencySeason2	-1.1053125	0.5598503	-2.0242550	-2.3361830	-0.1496616	0.0193205
bMultiplierType2	0.6392151	0.2209639	2.8979748	0.2108205	1.0853563	0.0059960
sDensitySite	0.4814094	0.1196857	4.1794057	0.3224456	0.7779551	0.0006662
sDensitySiteYear	0.4190435	0.0501355	8.3693694	0.3249745	0.5221869	0.0006662
sDensityYear	0.5051093	0.1780942	2.9973844	0.2689088	0.9405951	0.0006662
sDispersion	-0.6902780	0.0677848	-10.1966320	-0.8308407	-0.5620322	0.0006662
sDispersionType2	0.4027684	0.1289317	3.0948560	0.1457699	0.6401236	0.0033311
sEfficiencySessionSeasonYear	0.4853366	0.0702473	6.9731355	0.3678391	0.6408407	0.0006662

Table 68. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
780	11	3	500	500	436	1.006	TRUE

Distribution

Table 69. Parameter descriptions.

Parameter	Description
`bEffect`	Intercept for `eEffect`
`bRkm`	Effect of `Rkm` on `bEffect`
`bRkmRev5`	Effect of `Rev5` on `bRkm`
`bRkmYear[i]`	Effect of `i`th year on `bRkm`
`eEffect`	Expected `Effect`
`Effect`	Estimated site and year effect from the count or abundance model
`Rkm`	Standardised river kilometre
`sEffect`	SD of residual variation in `Effect`
`sRkmYear`	SD of `bRkmYear`

Bull Trout

Juvenile

Table 70. Model coefficients.

term	estimate	sd	zscore	lower	upper	pvalue
bEffect	0.0005560	0.0070110	0.0624877	-0.0130753	0.0140627	0.9280480
bRkm	-0.0024619	0.0037364	-0.6466934	-0.0093860	0.0050706	0.4963358
bRkmRev5	0.0046702	0.0053132	0.8619732	-0.0057774	0.0147606	0.3777482
sEffect	0.1175736	0.0050325	23.3820282	0.1083647	0.1278787	0.0006662
sRkmYear	0.0036914	0.0034803	1.2626905	0.0001472	0.0126233	0.0006662
tDistribution	0.0046702	0.0053132	0.8619732	-0.0057774	0.0147606	0.3777482

Table 71. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
285	6	3	500	10	180	1.008	TRUE

Table 72. Sensitivity of posteriors to choice of priors.

n	K	nchains	niters	rhat_1	rhat_2	rhat_all	converged
285	6	3	500	1.008	1.007	1.014	TRUE

Adult

Table 73. Model coefficients.

Term	estimate	sd	zscore	lower	upper	pvalue
bEffect	0.0000161	0.0146368	0.0397544	-0.0268423	0.0296271	0.9986676
bRkm	-0.0068287	0.0091752	-0.7582207	-0.0251290	0.0114135	0.4203864
bRkmRev5	0.0209920	0.0135455	1.5354268	-0.0047073	0.0468544	0.1285809
sEffect	0.2532118	0.0112255	22.6257503	0.2333017	0.2753542	0.0006662
sRkmYear	0.0170700	0.0085107	2.0303378	0.0016103	0.0351675	0.0006662
tDistribution	0.0209920	0.0135455	1.5354268	-0.0047073	0.0468544	0.1285809

Table 74. Model summary.

N	K	nchains	niters	nthin	ess	rhat	converged
285	6	3	500	10	270	1.01	TRUE

Table 75. Sensitivity of posteriors to choice of priors.

N	K	nchains	niters	rhat_1	rhat_2	rhat_all	converged
285	6	3	500	1.01	1.017	1.012	TRUE

Mountain Whitefish

Table 76. Model coefficients.

Term	estimate	sd	zscore	lower	upper	pvalue
bEffect	-0.0007872	0.0167896	-0.0522631	-0.0335893	0.0329969	0.9560293
bRkm	-0.0063828	0.0148024	-0.4466699	-0.0356024	0.0228475	0.6335776
bRkmRev5	0.0202507	0.0213924	0.9540819	-0.0226802	0.0609906	0.3257828
sEffect	0.2873738	0.0129032	22.3162554	0.2647355	0.3141468	0.0006662
sRkmYear	0.0354937	0.0104231	3.5071894	0.0184673	0.0601103	0.0006662
tDistribution	0.0202507	0.0213924	0.9540819	-0.0226802	0.0609906	0.3257828

Table 77. Model summary.

N	K	nchains	niters	nthin	ess	rhat	converged
285	6	3	500	10	918	1.003	TRUE

Table 78. Sensitivity of posteriors to choice of priors.

N	K	nchains	niters	rhat_1	rhat_2	rhat_all	converged
285	6	3	500	1.003	1.008	1.004	TRUE

Rainbow Trout

Table 79. Model coefficients.

term	estimate	sd	zscore	lower	upper	pvalue
bEffect	0.0014539	0.0205235	0.0629021	-0.0381008	0.0423060	0.9626915
bRkm	-0.0275127	0.0168693	-1.6326304	-0.0609019	0.0055611	0.1019320
bRkmRev5	0.0506114	0.0251752	2.0188935	0.0034055	0.1011712	0.0353098
sEffect	0.3498825	0.0153002	22.9142667	0.3228388	0.3825013	0.0006662
sRkmYear	0.0401194	0.0127838	3.2422669	0.0195411	0.0692078	0.0006662
tDistribution	0.0506114	0.0251752	2.0188935	0.0034055	0.1011712	0.0353098

Table 80. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
285	6	3	500	10	956	1.004	TRUE

Table 81. Sensitivity of posteriors to choice of priors.

n	K	nchains	niters	rhat_1	rhat_2	rhat_all	converged
285	6	3	500	1.004	1.003	1.002	TRUE

Burbot

Table 82. Model coefficients.

term	estimate	sd	zscore	lower	upper	pvalue
bEffect	0.0050579	0.0054731	0.9266906	-0.0056143	0.0159120	0.3604264
bRkm	-0.0001730	0.0038312	-0.0712277	-0.0077430	0.0074115	0.9653564
bRkmRev5	0.0000940	0.0058511	-0.0095035	-0.0113190	0.0115683	0.9893404
sEffect	0.0926473	0.0039330	23.5786832	0.0852809	0.1005426	0.0006662
sRkmYear	0.0087613	0.0030949	2.9069827	0.0036781	0.0154934	0.0006662
tDistribution	0.0000940	0.0058511	-0.0095035	-0.0113190	0.0115683	0.9893404

Table 83. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
285	6	3	500	10	1007	1.004	TRUE

Table 84. Sensitivity of posteriors to choice of priors.

n	K	nchains	niters	rhat_1	rhat_2	rhat_all	converged
285	6	3	500	1.004	1.004	1.002	TRUE

Northern Pikeminnow

Table 85. Model coefficients.

term	estimate	sd	zscore	lower	upper	pvalue
bEffect	0.0075408	0.0122483	0.5866496	-0.0179544	0.0309517	0.5549634
bRkm	-0.0060325	0.0070691	-0.8410001	-0.0201001	0.0074931	0.4057295
bRkmRev5	0.0036046	0.0105771	0.3636478	-0.0168000	0.0253749	0.7295137
sEffect	0.2073002	0.0090617	22.9017328	0.1904712	0.2255666	0.0006662
sRkmYear	0.0117230	0.0065332	1.8561004	0.0011888	0.0259696	0.0006662
tDistribution	0.0036046	0.0105771	0.3636478	-0.0168000	0.0253749	0.7295137

Table 86. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
285	6	3	500	10	372	1.004	TRUE

Table 87. Sensitivity of posteriors to choice of priors.

n	K	nchains	niters	rhat_1	rhat_2	rhat_all	converged
285	6	3	500	1.004	1.033	1.02	TRUE

Suckers

Table 88. Model coefficients.

term	estimate	sd	zscore	lower	upper	pvalue
bEffect	-0.0033554	0.0193178	-0.141963	-0.0396495	0.0346014	0.8614257
bRkm	-0.0176746	0.0159376	-1.100899	-0.0493184	0.0141814	0.2618254
bRkmRev5	0.0248050	0.0232503	1.075789	-0.0197124	0.0718914	0.2724850
sEffect	0.3216352	0.0142079	22.668846	0.2954979	0.3504725	0.0006662
sRkmYear	0.0388333	0.0117806	3.392725	0.0202747	0.0676331	0.0006662
tDistribution	0.0248050	0.0232503	1.075789	-0.0197124	0.0718914	0.2724850

Table 89. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
285	6	3	500	10	1056	1.003	TRUE

Table 90. Sensitivity of posteriors to choice of priors.

n	K	nchains	niters	rhat_1	rhat_2	rhat_all	converged
285	6	3	500	1.003	1.004	1.003	TRUE

Effect Size

Table 91. The significance levels for the management hypotheses tested in the analyses. The Direction column indicates whether significant changes were positive or negative. The estimates and 95% lower and upper credible intervals are the effect sizes.

Analysis	Species	Stage	Significance	Direction	Estimate	Lower	Upper
Abundance/Count - Density	Sucker	All	0.0246502	+	78 %	7 %	198 %
Abundance/Count - Rate	Bull Trout	Juvenile	0.0566289		-14 %	-27 %	1 %
Abundance/Count - Rate	Bull Trout	Adult	0.9280480		-1 %	-10 %	10 %
Abundance/Count - Rate	Mountain Whitefish	Juvenile	0.4083944		-15 %	-44 %	21 %
Abundance/Count - Rate	Mountain Whitefish	Adult	0.4963358		2 %	-5 %	9 %
Abundance/Count - Rate	Rainbow Trout	All	0.0099933	-	-29 %	-46 %	-11 %
Abundance/Count - Rate	Rainbow Trout	Adult	0.6215856		9 %	-25 %	56 %
Abundance/Count - Rate	Burbot	All	0.0606262		-33 %	-57 %	3 %
Abundance/Count - Rate	Northern Pikeminnow	All	0.0019987	-	-46 %	-63 %	-28 %
Condition	Bull Trout	Juvenile	0.0166556	-	-9 %	-16 %	-3 %
Condition	Bull Trout	Adult	0.0273151	-	-7 %	-13 %	-1 %
Condition	Mountain Whitefish	Juvenile	0.7441706		-1 %	-7 %	5 %
Condition	Mountain Whitefish	Adult	0.4177215		-2 %	-6 %	2 %
Condition	Rainbow Trout	Juvenile	0.8707528		0 %	-6 %	7 %
Condition	Rainbow Trout	Adult	0.2485010		-3 %	-9 %	2 %
Distribution	Bull Trout	Juvenile	0.3777482		0 %	-1 %	1 %
Distribution	Bull Trout	Adult	0.1285809		2 %	0 %	5 %
Distribution	Mountain Whitefish	Adult	0.3257828		2 %	-2 %	6 %
Distribution	Rainbow Trout	All	0.0353098	+	5 %	0 %	11 %
Distribution	Sucker	All	0.2724850		3 %	-2 %	7 %
Distribution	Burbot	All	0.9893404		0 %	-1 %	1 %
Distribution	Northern Pikeminnow	All	0.7295137		0 %	-2 %	3 %
Growth	Bull Trout	All	0.6548967		-7 %	-31 %	24 %
Growth	Mountain Whitefish	All	0.7268488		8 %	-30 %	64 %

Appendix H – Additional Results

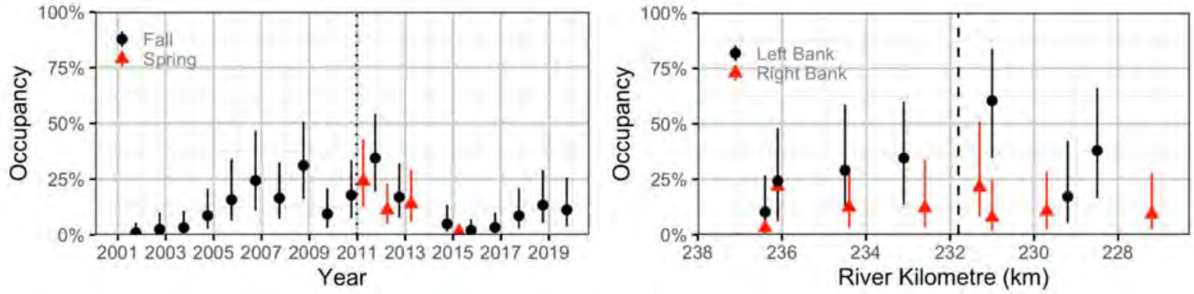


Figure H1. Occupancy estimates (with 95% credible intervals) by year and season (left panel) and site (right panel) for Burbot in the middle Columbia River study area, 2001 to 2019. The dotted line (left panel) represents the implementation of the minimum flow release and REV5 operations. The dashed line (right panel) represents the divide between Reaches 3 and 4 at the Jordan River confluence.

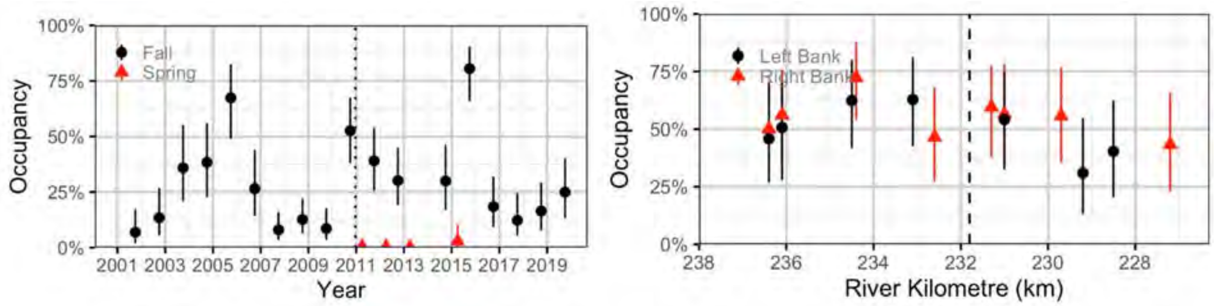


Figure H2. Occupancy estimates (with 95% credible intervals) by year and season (left panel) and site (right panel) for Lake Whitefish in the middle Columbia River study area, 2001 to 2019. The dotted line (left panel) represents the implementation of the minimum flow release and REV5 operations. The dashed line (right panel) represents the divide between Reaches 3 and 4 at the Jordan River confluence.

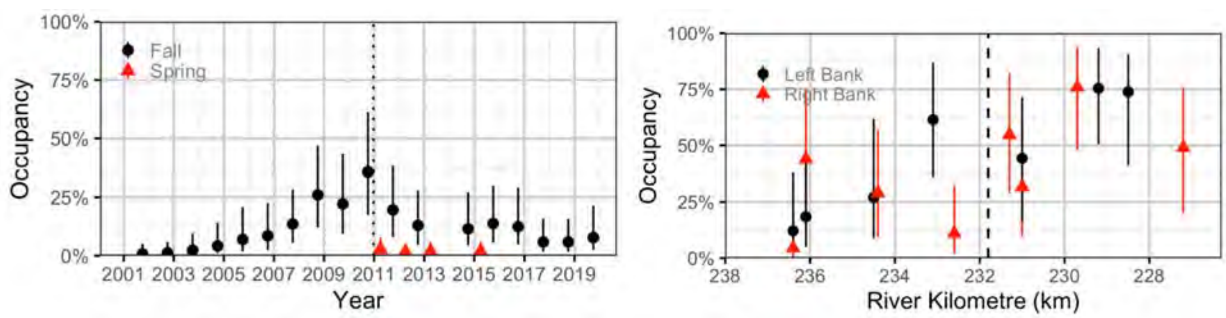


Figure H3. Occupancy estimates (with 95% credible intervals) by year and season (left panel) and site (right panel) for Northern Pikeminnow in the middle Columbia River study area, 2001 to 2019. The dotted line (left panel) represents the implementation of the minimum flow release and REV5 operations. The dashed line (right panel) represents the divide between Reaches 3 and 4 at the Jordan River confluence.

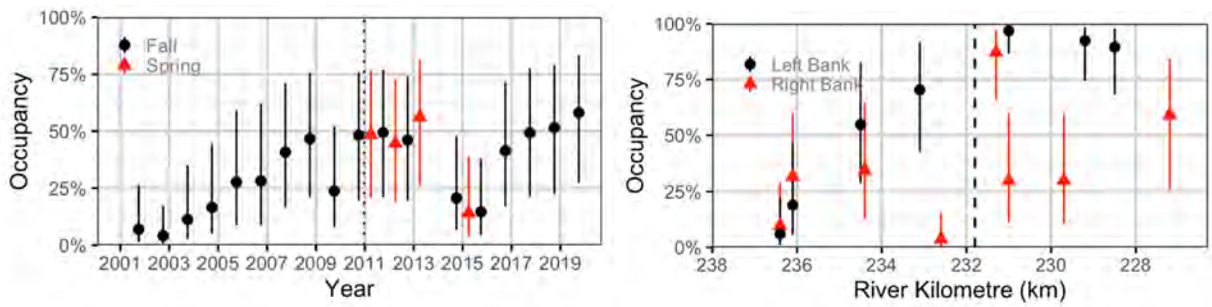


Figure H4. Occupancy estimates (with 95% credible intervals) by year and season (left panel) and site (right panel) for Rainbow Trout in the middle Columbia River study area, 2001 to 2019. The dotted line (left panel) represents the implementation of the minimum flow release and REV5 operations. The dashed line (right panel) represents the divide between Reaches 3 and 4 at the Jordan River confluence.

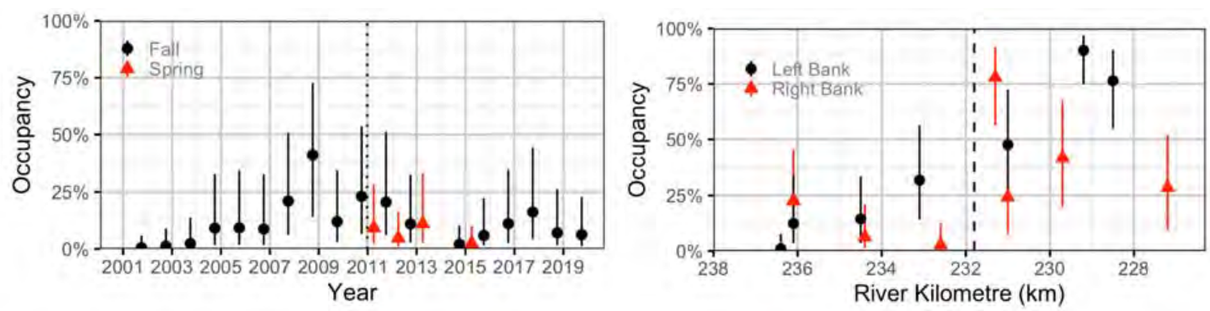


Figure H5. Occupancy estimates (with 95% credible intervals) by year and season (left panel) and site (right panel) for Redside Shiner in the middle Columbia River study area, 2001 to 2019. The dotted line (left panel) represents the implementation of the minimum flow release and REV5 operations. The dashed line (right panel) represents the divide between Reaches 3 and 4 at the Jordan River confluence.

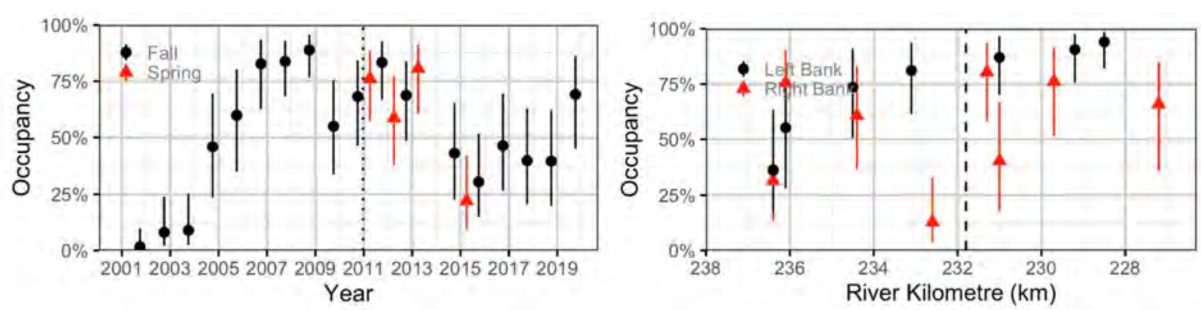


Figure H6. Occupancy estimates (with 95% credible intervals) by year and season (left panel) and site (right panel) for sculpin species in the middle Columbia River study area, 2001 to 2019. The dotted line (left panel) represents the implementation of the minimum flow release and REV5 operations. The dashed line (right panel) represents the divide between Reaches 3 and 4 at the Jordan River confluence.

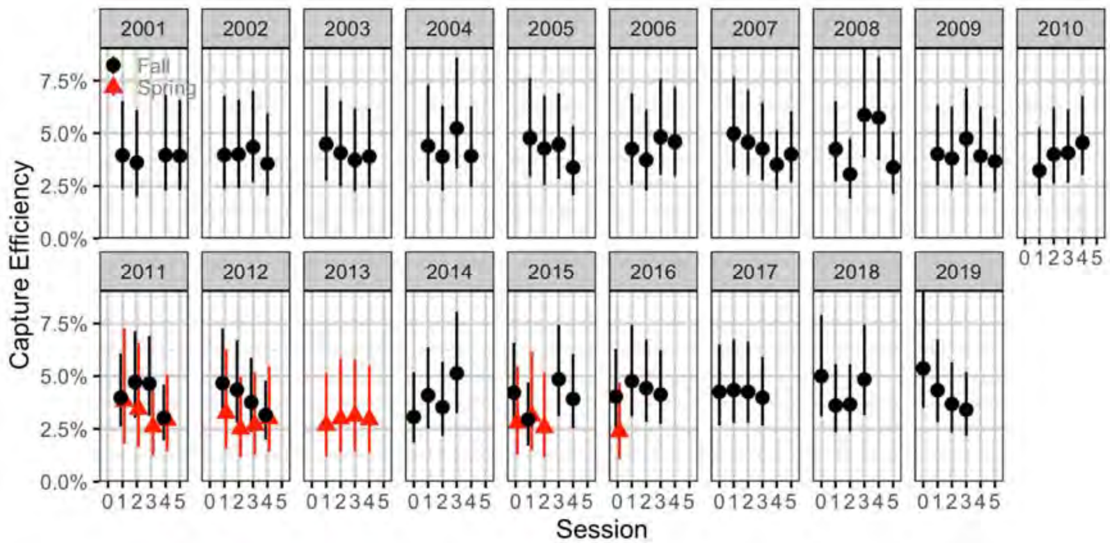


Figure H7. Capture efficiency estimates (with 95% credible intervals) by year, season, and session for juvenile Bull Trout in the middle Columbia River study area, 2001 to 2019. Efficiency was calculated in the hierarchical Bayesian model estimating absolute abundance using mark-recapture data.

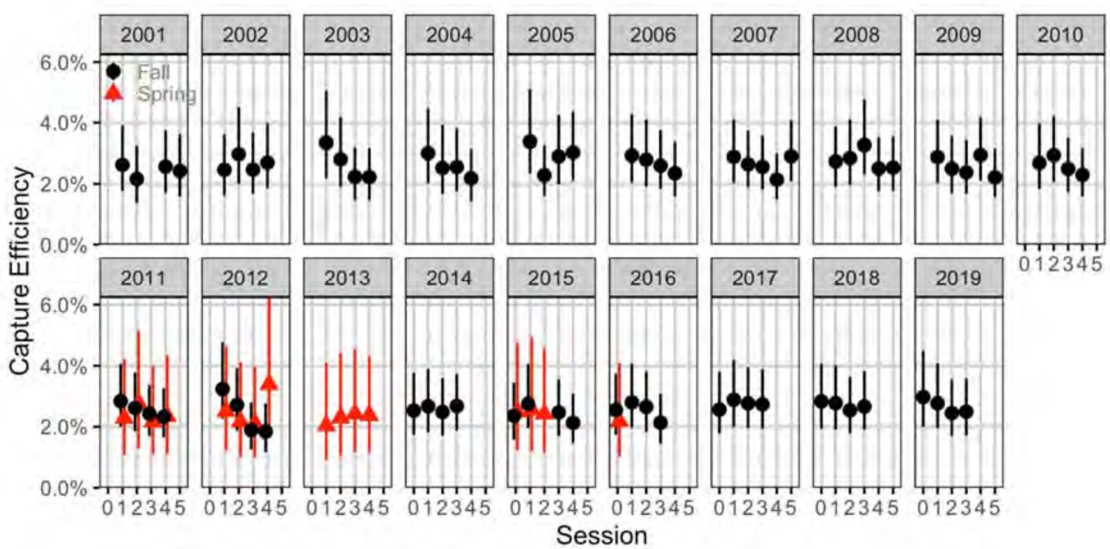


Figure H8. Capture efficiency estimates (with 95% credible intervals) by year, season, and session for adult Bull Trout in the middle Columbia River study area, 2001 to 2019. Efficiency was calculated in the hierarchical Bayesian model estimating absolute abundance using mark-recapture data.

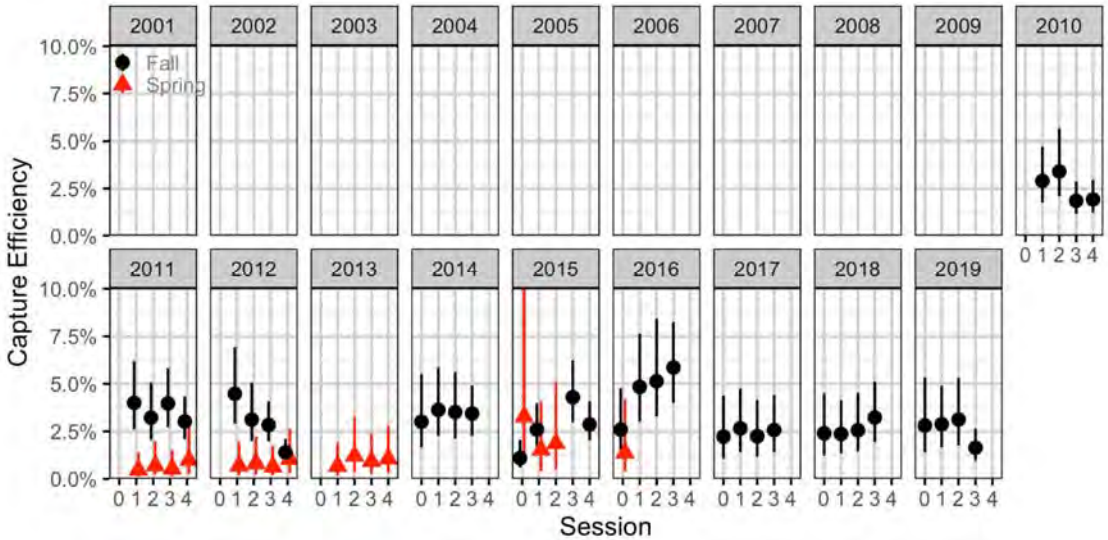


Figure H9. Capture efficiency estimates (with 95% credible intervals) by year, season, and session for Largescale Sucker in the middle Columbia River study area, 2010 to 2019. Efficiency was calculated in the hierarchical Bayesian model estimating absolute abundance using mark-recapture data.

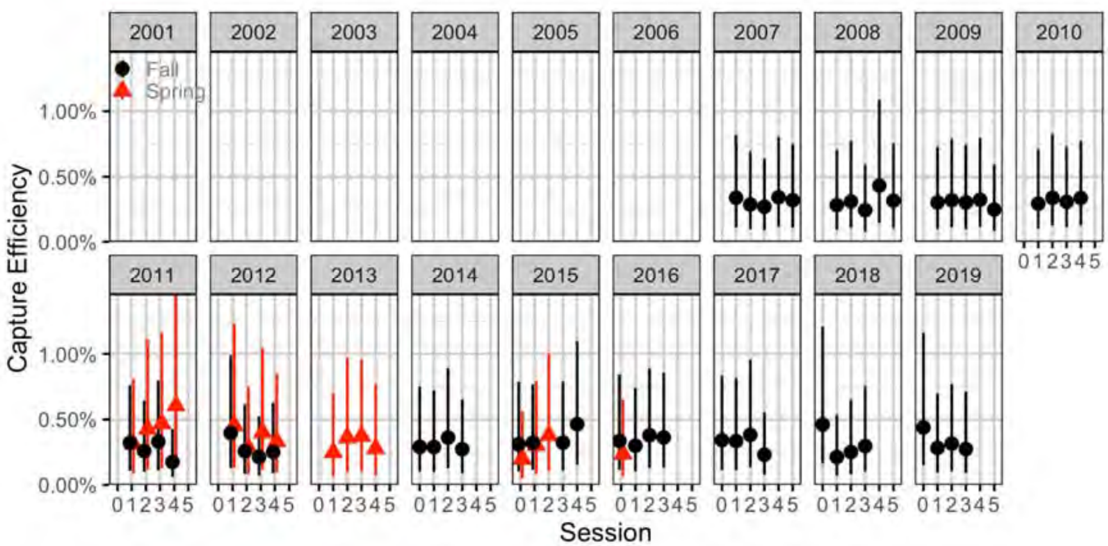


Figure H10. Capture efficiency estimates (with 95% credible intervals) by year, season, and session for juvenile Mountain Whitefish in the middle Columbia River study area, 2007 to 2019. Efficiency was calculated in the hierarchical Bayesian model estimating absolute abundance using mark-recapture data.

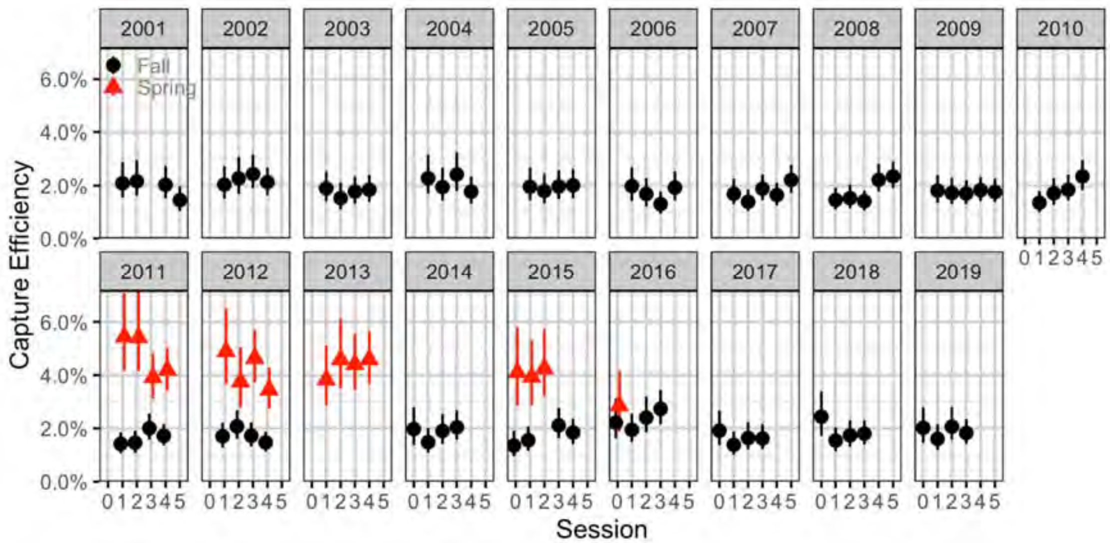


Figure H11. Capture efficiency estimates (with 95% credible intervals) by year, season, and session for adult Mountain Whitefish in the middle Columbia River study area, 2001 to 2019. Efficiency was calculated in the hierarchical Bayesian model estimating absolute abundance using mark-recapture data.

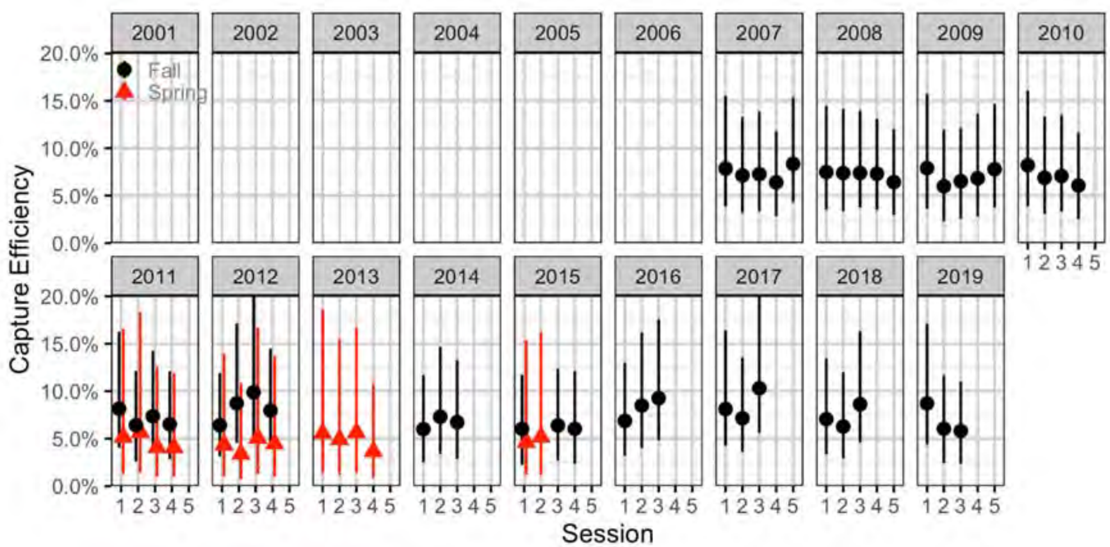


Figure H12. Capture efficiency estimates (with 95% credible intervals) by year, season, and session for adult Rainbow Trout in the middle Columbia River study area, 2007 to 2019. Efficiency was calculated in the hierarchical Bayesian model estimating absolute abundance using mark-recapture data.

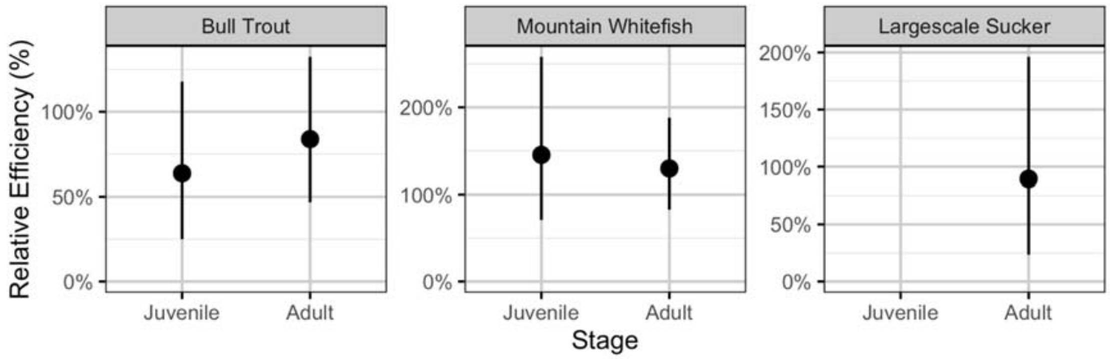


Figure H13. Relative efficiency estimates (with 95% credible intervals) for Bull Trout, Mountain Whitefish, and Largescale Sucker by life stage. Percentages describe the relative number of fish counted to fish captured in the abundance model.

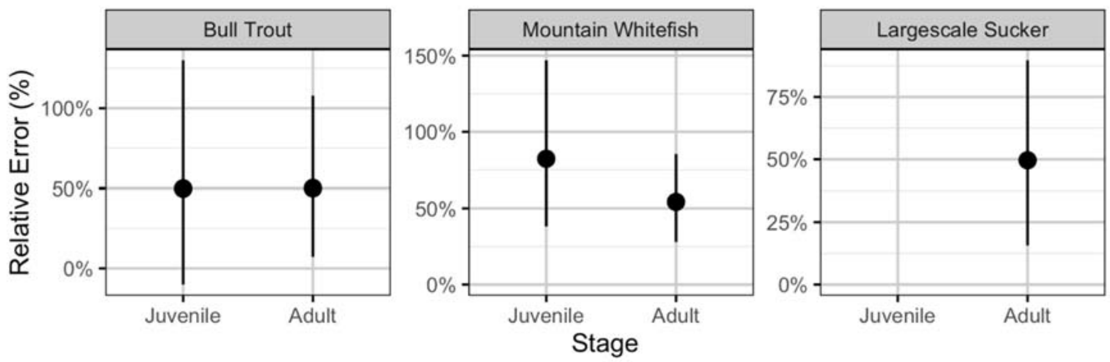


Figure H14. Estimated count overdispersion relative to capture overdispersion by species and stage (with 95% CIs).

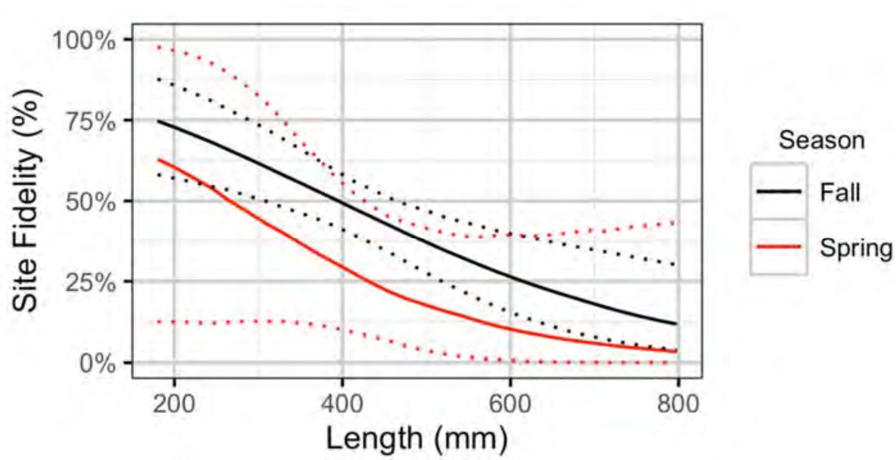


Figure H15. Site fidelity estimates (with 95% credible intervals) by season and fish length for intra-year recaptured Bull Trout in the middle Columbia River study area, 2001–2019.

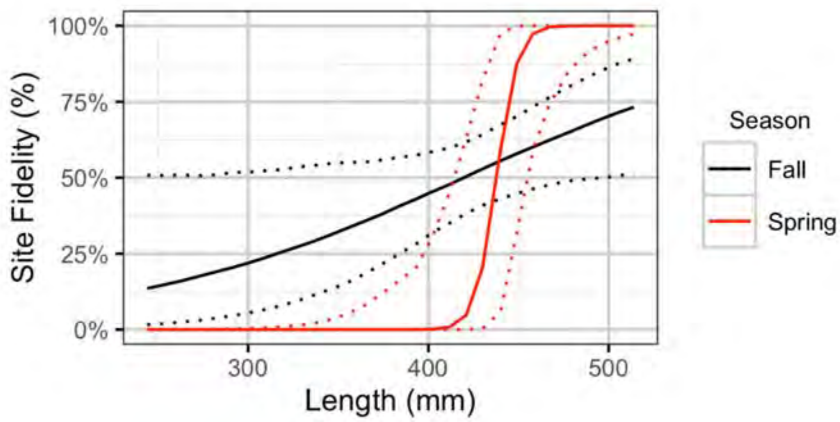


Figure H16. Site fidelity estimates (with 95% credible intervals) by season and fish length for intra-year recaptured Largescale Sucker in the middle Columbia River study area, 2001–2019.

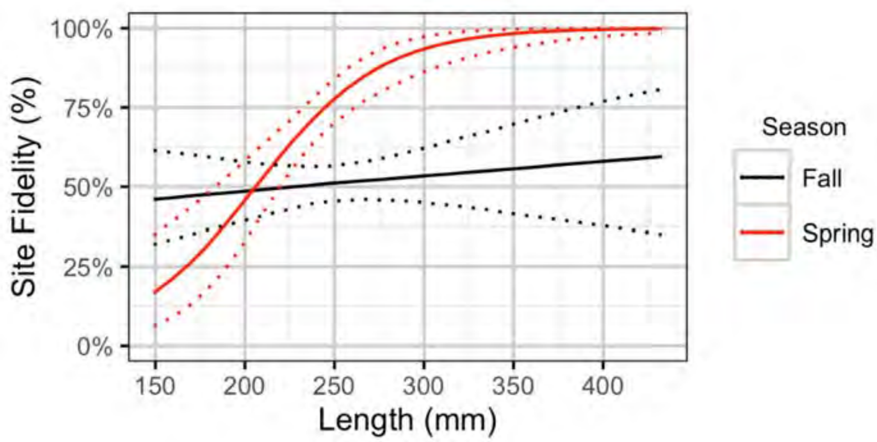


Figure H17. Site fidelity estimates (with 95% credible intervals) by season and fish length for intra-year recaptured Mountain Whitefish in the middle Columbia River study area, 2001–2019.

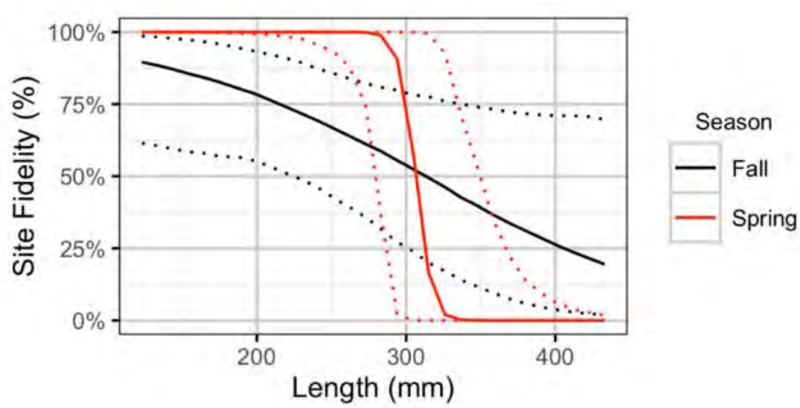


Figure H18. Site fidelity estimates (with 95% credible intervals) by season and fish length for intra-year recaptured Rainbow Trout in the middle Columbia River study area, 2001–2019.

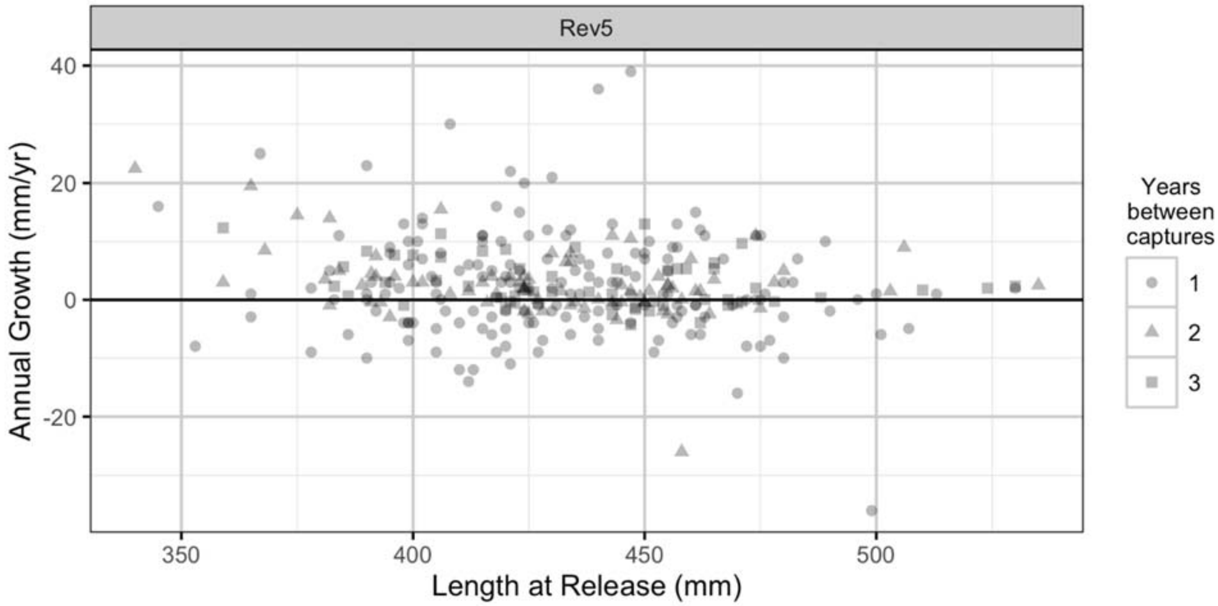


Figure H19. Annual growth of inter-year recaptured Largescale Sucker in the middle Columbia River study area after (2011–2019) the flow regime change.

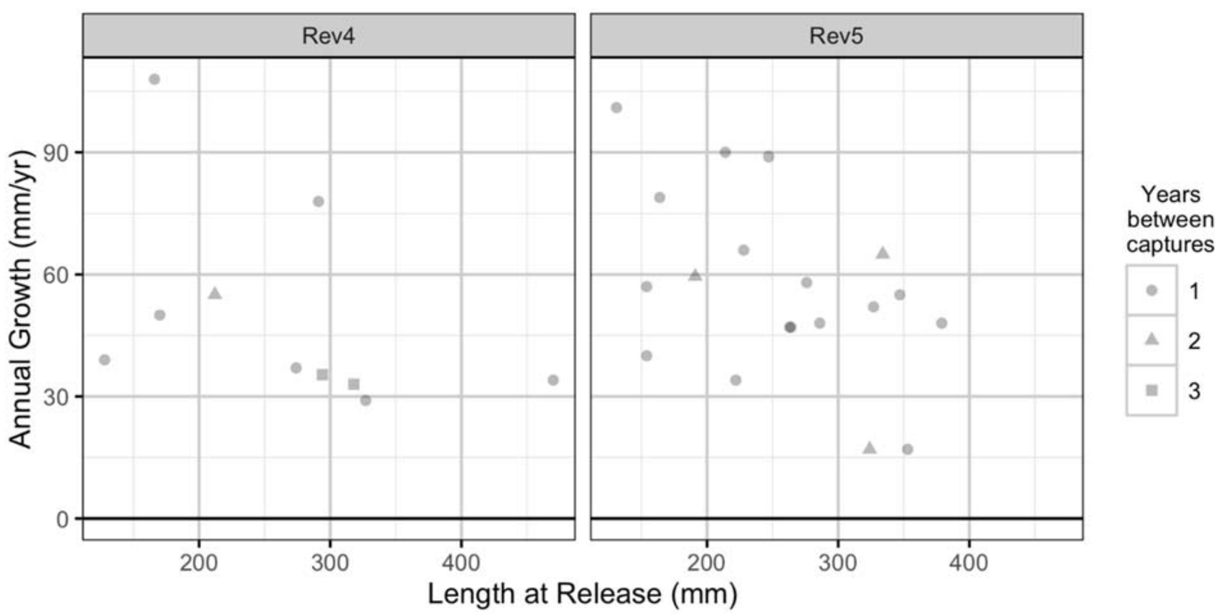


Figure H20. Annual growth of inter-year recaptured Rainbow Trout in the middle Columbia River study area before (2001–2010) and after (2011–2019) the flow regime change.

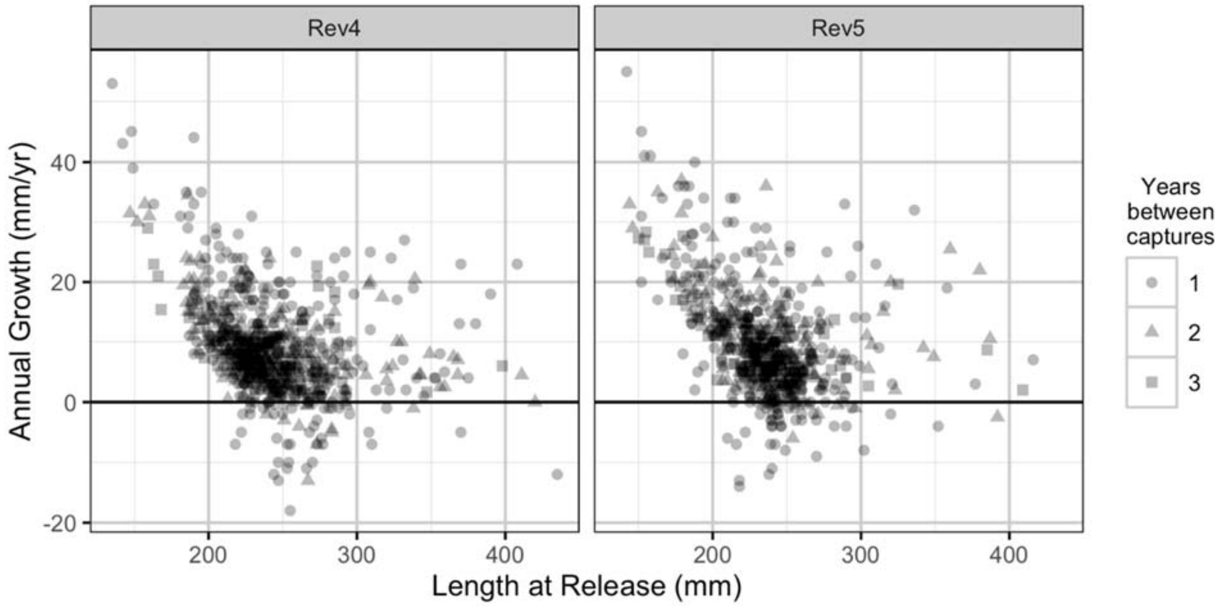
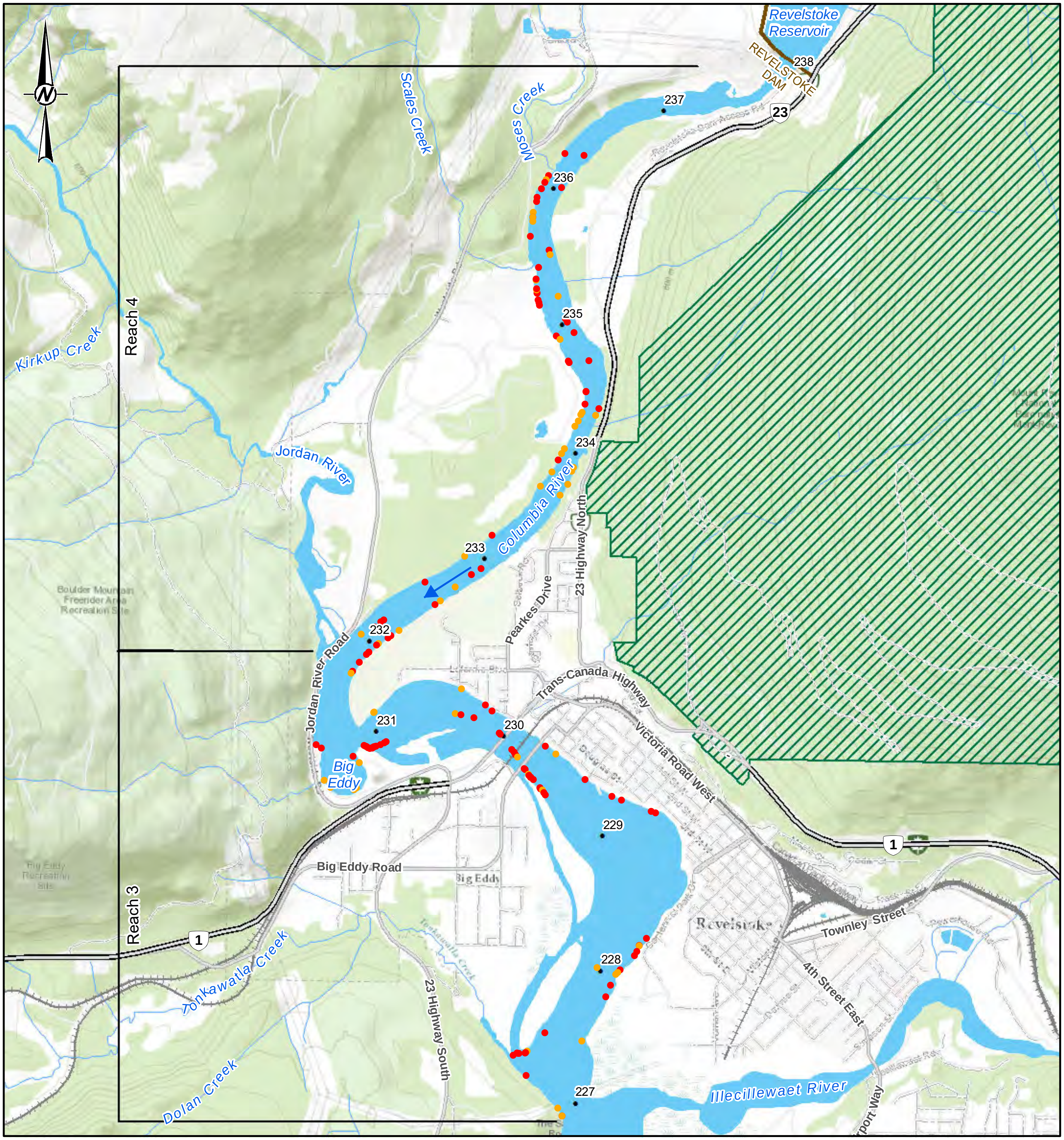


Figure H21. Annual growth of inter-year recaptured Mountain Whitefish in the middle Columbia River study area before (2001–2010) and after (2011–2019) the flow regime change.

Appendix I – Spatial Distribution Maps



LEGEND

BULL TROUT

- JUVENILE
- ADULT

BASE FEATURES

- RIVER KMS FROM HLK DAM
- REACH BOUNDARY
- DAM BASE
- HIGHWAY
- MAJOR ROAD
- LOCAL ROAD
- RAILWAY
- WATERCOURSE
- NATIONAL PARK
- WATERBODY

0 600 1,200

1:40,000 METRES

REFERENCES

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

CLIENT
BC HYDRO

PROJECT
MIDDLE COLUMBIA RIVER FISH POPULATION INDEXING STUDY

TITLE
BULL TROUT - FALL

CONSULTANT

GOLDER

YYYY-MM-DD	2020-03-30
DESIGNED	DR
PREPARED	GS
REVIEWED	DR
APPROVED	SR

PROJECT NO.	PHASE	REV.	FIGURE
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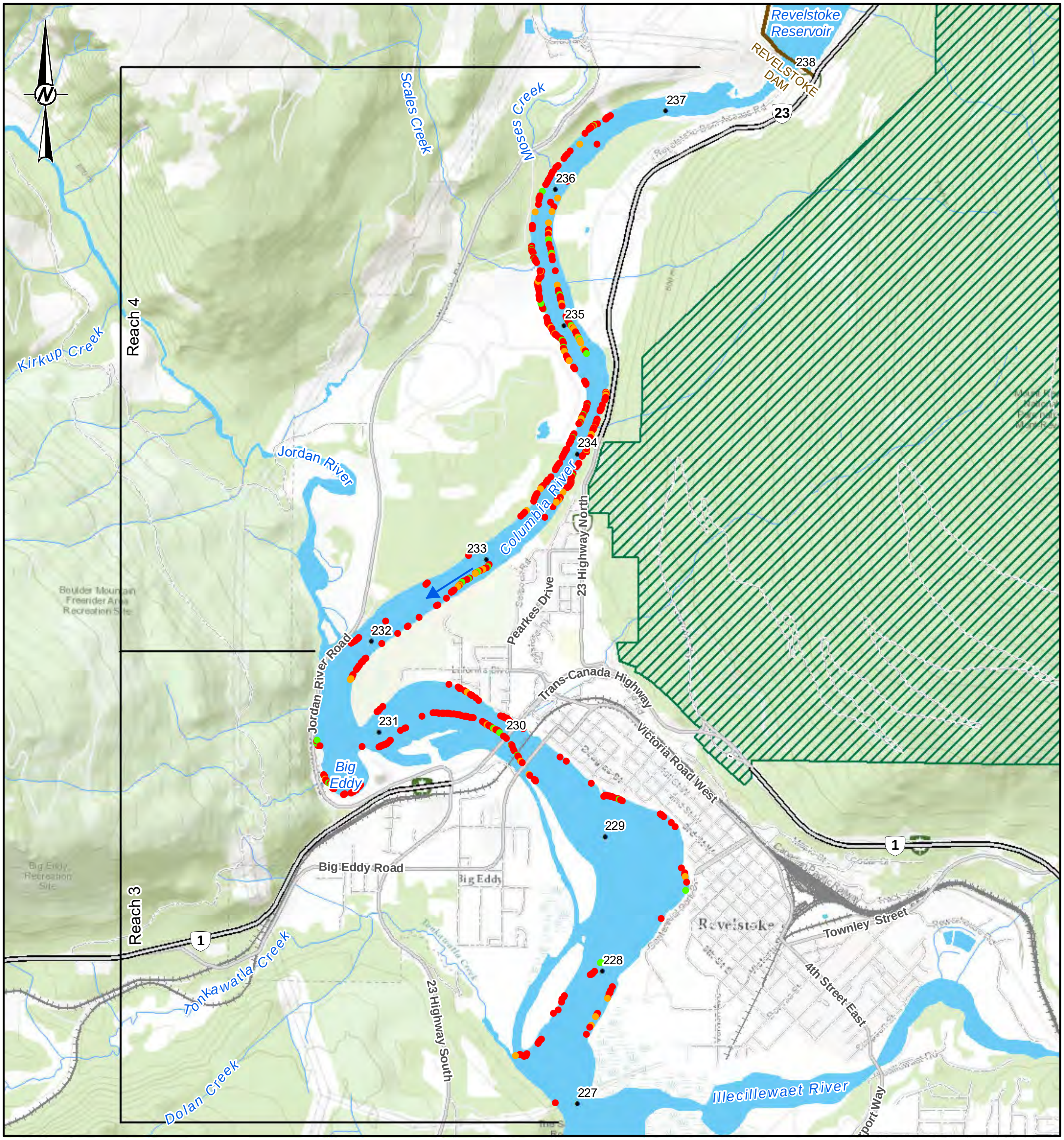

LEGEND

MOUNTAIN WHITEFISH

- FRY
- JUVENILE
- ADULT

BASE FEATURES

- RIVER KMS FROM HLK DAM
- REACH BOUNDARY
- DAM BASE
- HIGHWAY
- MAJOR ROAD
- LOCAL ROAD
- RAILWAY
- WATERCOURSE
- NATIONAL PARK
- WATERBODY

0 600 1,200
1:40,000 METRES

REFERENCES

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5. COORDINATE SYSTEM: NAD 1983 UTM ZONE 11N

CLIENT
BC HYDRO

PROJECT
MIDDLE COLUMBIA RIVER FISH POPULATION INDEXING STUDY

TITLE
MOUNTAIN WHITEFISH - FALL

CONSULTANT

GOLDER

YYYY-MM-DD	2020-03-30
DESIGNED	DR
PREPARED	GS
REVIEWED	DR
APPROVED	SR

PROJECT NO.	PHASE	REV.	FIGURE
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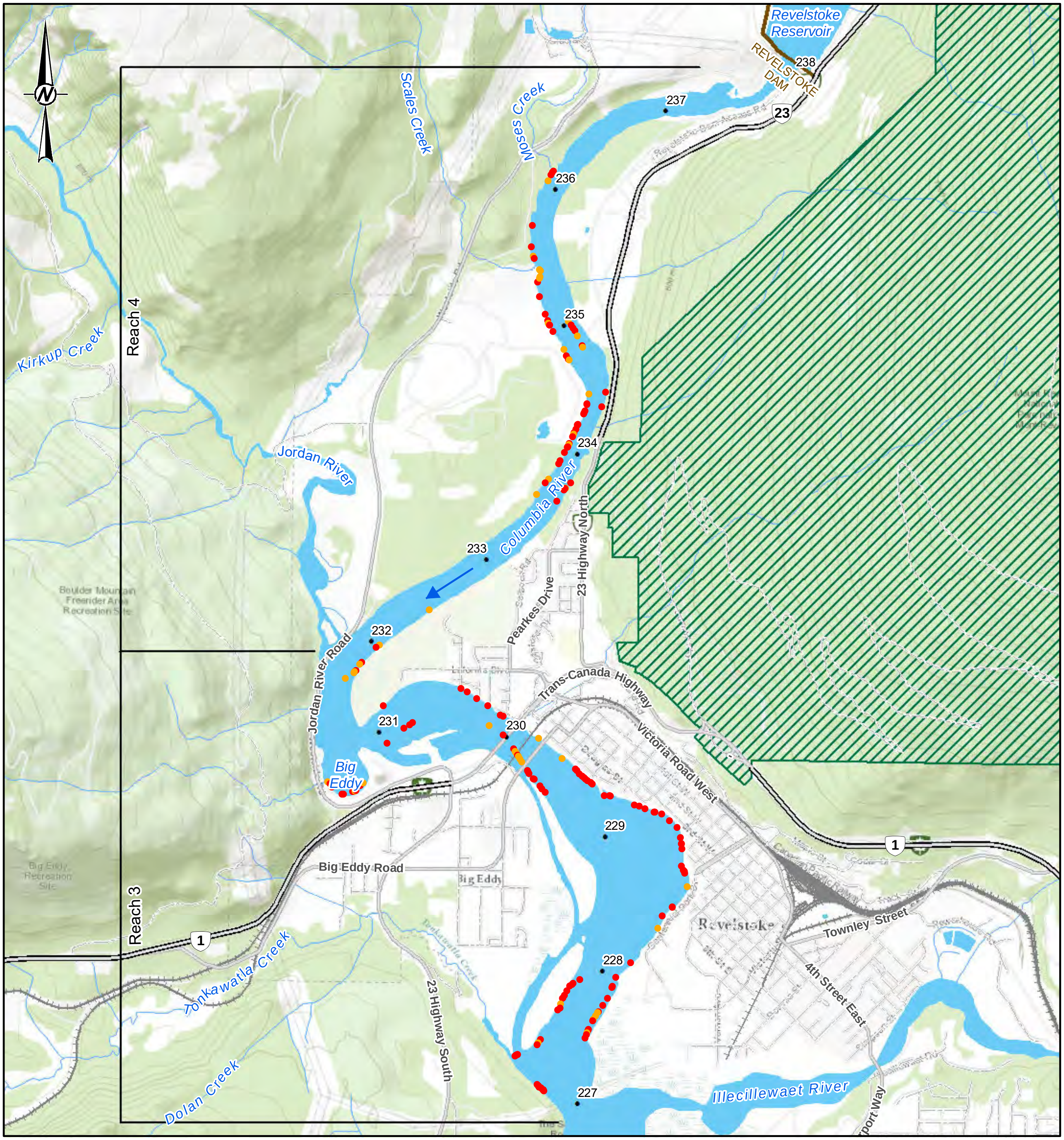

LEGEND

SUCKER SPECIES

- JUVENILE
- ADULT

BASE FEATURES

- RIVER KMS FROM HLK DAM
- REACH BOUNDARY
- DAM BASE
- HIGHWAY
- MAJOR ROAD
- LOCAL ROAD
- RAILWAY
- WATERCOURSE
- NATIONAL PARK
- WATERBODY

0 600 1,200

1:40,000 METRES

REFERENCES

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CLIENT

BC HYDRO

PROJECT

MIDDLE COLUMBIA RIVER FISH POPULATION INDEXING STUDY

TITLE

SUCKER SPECIES - FALL

CONSULTANT

GOLDER

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PROJECT NO.	PHASE	REV.	FIGURE
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