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Lower Columbia River Fish Management Plan

Lower Columbia River Fish Population Indexing Surveys

Implementation Year 15

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Technical Report

Study Period 2021

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Fish Population Indexing Survey
2021 Report

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Executive Summary

BC Hydro has conducted flow management actions to reduce egg losses in the Lower Columbia River (LCR) during Mountain Whitefish (*Prosopium williamsoni*) and Rainbow Trout (*Oncorhynchus mykiss*) spawning and incubation since the mid-1990s. These actions include decreasing flows from Hugh L. Keenleyside Dam (HLK) in early winter to encourage Mountain Whitefish spawning at lower water level elevations and thereby reduce egg dewatering over the winter egg incubation period. In early spring during Rainbow Trout spawning season, flows are managed to provide stable or increasing water levels to reduce the likelihood of Rainbow Trout eggs and other larval fish from becoming stranded, which is referred to as spawning protection flows.

In 2007, BC Hydro completed the Water Use Planning process for its hydroelectric and storage facilities on the Columbia River. The Water Use Plan (WUP) Consultative Committee recommended the commissioning of the LCR Fish Population Indexing Program (CLBMON-45) to address data gaps regarding the effects of HLK operations on downstream fish communities. CLBMON-45 represents a continuation of BC Hydro's LCR Large River Fish Indexing Program (LRFIP), first established in 2001 to gather baseline information on fish distribution, life history characteristics, and population abundance data for select index species (i.e., Mountain Whitefish, Rainbow Trout, and Walleye [*Sanders vitreus*]). CLBMON-45 was conducted as part of the WUP from 2007 to 2019. Because of remaining uncertainty in the effects of the Mountain Whitefish and Rainbow Trout spawning protection flows (BC Hydro 2018a), the monitoring program was extended in 2020 to collect data through 2023 to monitor the effects of Mountain Whitefish and Rainbow Trout egg dewatering on index fish species.

The two key management questions to be answered by CLBMON-45 are:

- What are the abundance, growth rate, survival rate, body condition, age distribution, and spatial distribution of subadult and adult Whitefish, Rainbow Trout, and Walleye in the LCR?
- What is the effect of inter-annual variability in the Whitefish and Rainbow Trout flow regimes on the abundance, growth rate, survival rate, body condition, and spatial distribution of subadult and adult Whitefish, Rainbow Trout, and Walleye in the LCR?

The study area for CLBMON-45 includes the portion of the Columbia River between HLK and the Canada-US border (approximately 56.5 km of river habitat) and the 2.8 km section of the Kootenay River from Brilliant Dam (BRD) downstream to the confluence with the Columbia River.

Fish were sampled by boat electrofishing at night within nearshore habitats. In addition to the indexing sites sampled since 2001, additional sample sites were randomly selected annually from 2011 to 2021. Captured Mountain Whitefish, Rainbow Trout, and Walleye were measured for fork length, weighed, and implanted with a Passive Integrated Transponder (PIT) tag. Hierarchical Bayesian Models (HBMs) were used to estimate temporal and spatial variation in abundance, spatial distribution, growth, survival, and body condition. A maximum likelihood model was used to estimate mean annual length-at-age based on length-frequency data. To assess the effects of egg dewatering on recruitment of juvenile fish, two analyses were used. First, the proportional ratio of age-1:2 Mountain Whitefish was used as an indicator of recruitment to assess annual variation and the effects of egg dewatering. The second analysis, which was used for Mountain Whitefish and Rainbow Trout, was a Beverton-Holt stock-recruitment model that included egg dewatering as a covariate.

The estimated abundance of adult Rainbow Trout increased from ~22,000 in 2002 to ~42,000 in 2018 before decreasing to 37,000 in 2019, 32,000 in 2020, and 33,000 in 2021. Rainbow Trout abundance was negatively associated with body condition and growth, with high abundance coinciding with low body condition and growth in 2017 and 2018, and lower abundance coinciding with higher body condition and growth in 2019 to 2021. These results suggest intraspecies competition and density-dependent growth in the LCR.

Walleye abundance estimates were stable from 2012 to 2020 (10,000–15,000). Walleye abundance was greatest from 2003 to 2005 and in 2011 (25,000–30,000). The body condition of Walleye was high from 2012 to 2016 (3% to 5% effect sizes based on the predicted weight-at-length), declined to more typical values during 2017 to 2020 (-1% to 0%) and increased to 2% in 2021.

The estimated abundance of Mountain Whitefish subadults was lower from 2018 to 2021 (10,000–20,000) than the previous five years (29,000–32,000). Estimates of adult Mountain Whitefish abundance were relatively stable between 2010 and 2021 (45,000–50,000), except for 2018 when the estimate was substantially higher (59,000). Growth of Mountain Whitefish was highly variable with a decrease in the estimated maximum growth rate (at a theoretical fork length of 0 mm) from 244 mm/yr in 2016 to 135 mm/yr in 2017, followed by an increase to 267 mm/yr by 2021. In earlier years, the maximum growth rate of Mountain Whitefish increased from 87 mm/yr in 2005 to 244 mm/yr in 2016. The body condition of adult Mountain Whitefish was fairly stable between 2010 and 2018 but greater in 2019 to 2021 (4% to 7% effect sizes relative to typical year).

For Mountain Whitefish, the estimated effect of egg loss on the age-1:2 ratio recruitment index was negative, but the relationship was not statistically significant ($P = 0.5$). The largest estimated egg loss (59%) on record occurred in the 2016 spawning year and corresponded to a large decrease in the age ratio recruitment index and a more than 50% decrease in the estimated abundance of age-1 Mountain Whitefish in 2018. This suggests that a 59% egg loss due to dewatering could have contributed to the large and biologically significant reduction in recruitment. In the most recent spawning year for which recruitment index data are available (2019), estimated egg loss (28%) was within the range of typical values and the age-1:2 ratio increased to 67%. The uncertain relationship between age-1:2 ratio and egg loss suggests that other factors, such as environmental conditions or ecological interactions, strongly influence survival and recruitment.

The stock-recruitment analyses suggest that an increase in eggs deposited by spawners (“stock”) had little to no effect on the number of age-1 recruits for Mountain Whitefish or Rainbow Trout, based on the fitted Beverton-Holt relationship. This suggests that the number of spawners was sufficient to maintain the population near the carrying capacity of the habitat. The estimated effect of egg loss on recruitment was uncertain and not statistically significant for Mountain Whitefish (P=0.7) or Rainbow Trout (P=0.09), which did not support an effect of dewatering on subsequent recruitment at the observed levels of stock abundance and egg loss. There were no years of data on the steeper part of the stock-recruitment curves, where decreases in spawners or egg losses would be expected to decrease subsequent recruitment. Therefore, the effects of egg losses at lower adult abundance are unknown based on these stock-recruitment models. These conclusions should be considered tentative because of the poor fit in the stock-recruitment relationships, and the possibility that sampling biases or environmental variability masked real effects of egg dewatering.

Keywords: Columbia River, Hugh L. Keenleyside Dam (HLK), Density Estimation, Fish Abundance

Table E1. Status of Management Questions and Hypotheses after Year 15 (2021) of the Lower Columbia River Fish Population Indexing Survey (CLBMON-45).

Management Questions	Management Hypotheses	Sub-Hypotheses	Year 15 (2021) Status
What is the abundance, growth rate, survival rate, body condition, age distribution, and spatial distribution of subadult and adult Whitefish, Rainbow Trout and Walleye in the Lower Columbia River?	**$H_0$1:** There is no change in the population levels of Whitefish in the Lower Columbia River over the course of the monitoring period.	**$H_0$1a:** There is no change in the abundance of subadult and adult Mountain Whitefish.	The hypothesis is rejected. Subadult Mountain Whitefish abundance was 59,000 to 66,000 in 2001 to 2002 but fluctuated between 6,000 and 41,000 from 2003 to 2021. The estimated abundance of subadult Mountain Whitefish in 2018 to 2021 (10,000–20,000) was lower than during the previous five years (29,000–32,000). Estimates of adult Mountain Whitefish abundance were greater from 2001 to 2009 (54,000–70,000) than during 2010 to 2021, when estimates were lower and relatively stable (45,000–50,000) with the exception of 2018 when the estimated adult abundance was 59,000.
		$H_0$1b: There is no change in the mean size-at-age of subadult and adult Mountain Whitefish.	The hypothesis is rejected. Although the mean length of age-0 Mountain Whitefish was relatively stable in most years, with mean fork lengths between 120 and 140 mm, there were exceptions, such as low mean length in 2001 (102 mm) and greater than average mean length in 2016 (154 mm), 2018 (142 mm), and 2019 (150 mm). For older Mountain Whitefish, growth was assessed using the von Bertalanffy model instead of length-at-age. The growth coefficient had considerable inter-annual variation with effect sizes of -45% to +71%. The predicted maximum growth rate during early life (at a theoretical fork length of 0 mm) increased from 87 mm/yr in 2005 to 244 mm/yr in 2016, decreased to 135 mm/yr in 2017, followed by an increase to 267 mm/yr by 2021. The large range of variation in estimated parameters from the von Bertalanffy growth model demonstrates substantial variation in growth among years.
		$H_0$1c: There is no change in the mean survival of subadult and adult Mountain Whitefish.	The hypothesis is rejected. Estimated survival of adult Mountain Whitefish ranged from 21% to 93% but has been between 64% and 86% since 2011. Annual variation in survival could not be estimated for subadults because of small numbers of recaptures.
		$H_0$1d: There is no change in the morphological (condition factor) index of body condition of subadult and adult Mountain Whitefish.	The hypothesis is rejected. The body condition of Mountain Whitefish varied significantly among years with effects sizes ranging from -7% to +6% for subadults and -16% to +8% for adults. The body condition of subadult and adult Mountain Whitefish was fairly stable (<6% change) between 2010 and 2018. Adult body condition was greater in 2019 to 2021 (4% to 7% effect sizes relative to typical year).
		$H_0$1e: There is no change in the distribution of subadult and adult Mountain Whitefish.	The hypothesis is rejected. The evenness in the distribution of subadult Mountain Whitefish among index sites decreased by 8% in 2021 and was lower than nearly all previous years. There was a 11% decrease in the evenness in distribution between index sites for adult Mountain Whitefish between 2001 and 2007, but evenness was relatively stable since 2008. In addition, as their abundance in the study area increased, densities of adult Mountain Whitefish actually decreased at high density sites.
	$H_0$2: There is no change in the population levels of Rainbow Trout in the Lower Columbia River over the course of the monitoring period.	**$H_0$2a:** There is no change in the abundance of subadult and adult Rainbow Trout	The hypothesis is rejected. The abundance of subadult Rainbow Trout declined significantly from 2001 to 2005 and fluctuated with no consistent trend from 2006 to 2021. The estimated abundance of subadult Rainbow Trout was relative stable between 2012 and 2021 (16,000 to 20,000), except in 2018 and 2019 when estimates were lower (9,000 and 8,000, respectively). The estimated abundance of adult Rainbow Trout increased from ~22,000 in 2002 to 42,000 in 2018, with a decrease to 37,000 in 2019, 32,000 in 2020, and 33,000 in 2021.
		$H_0$2b: There is no change in the mean size-at-age of subadult and adult Rainbow Trout	The hypothesis is rejected. The estimated mean length of age-0 Rainbow Trout ranged from 90 mm to 144 mm between 2001 and 2021. Mean length of age-0 Rainbow Trout increased from 106 mm in 2011 to 144 mm in 2015 and varied from 102 to 127 mm between 2016 and 2021.

Management Questions	Management Hypotheses	Sub-Hypotheses	Year 15 (2021) Status
			Length-at-age of older age-classes was not assessed. The von Bertalanffy growth coefficient decreased from a 57% effect size to -40% in 2006 to 2018, suggesting a significant decrease in growth during this period. This corresponded to a decrease in the predicted maximum growth rate during early life of 664 mm/yr in 2006 to 253 mm/yr in 2018. Maximum growth rate increased to 308 mm/yr in 2019, 402 mm/yr in 2020, and 466 mm/yr in 2021.
		$H_0$2c: There is no change in the mean survival of subadult and adult Rainbow Trout	The hypothesis is rejected for adults but cannot be assessed for subadults. Survival estimates of Rainbow Trout increased gradually from 32% in 2003 to 54% in 2011, followed by a decrease to 34% in 2012, a gradual increase to 48% in 2020 and a decrease to 40% in 2021 Survival of subadults could not be estimated because of small numbers of recaptures.
		$H_0$2d: There is no change in the morphological (condition factor) index of body condition of subadult and adult Rainbow Trout	The hypothesis is rejected. Body condition estimates for subadult and adult Rainbow Trout varied annually but were higher for both age-classes in 2002 and 2006 than other study years. Adult body condition declined from a +3% effect size in 2011 to -7% in 2018, which coincided with increasing abundance estimates, and was near average between 2019 and 2021 (-1% to 2%).
		$H_0$2e: There is no change in the distribution of subadult and adult Rainbow Trout	The hypothesis is rejected. The evenness in the distribution between sites increased (~8% change) during the sampling period for subadult Rainbow Trout. And as their abundance in the study area increased, densities of adult Rainbow Trout increased more at low density sites than at high density sites.
	$H_0$3: There is no change in the population levels of Walleye in the Lower Columbia River over the course of the monitoring period.	**$H_0$3a:** There is no change in the abundance of subadult and adult Walleye.	The hypothesis is rejected. Walleye abundance was significantly greater in 2003 to 2005 and 2011 (25,000–30,000) than in all other years. Estimates of Walleye abundance were greater in 2003 to 2011 (15,000–30,000) and lower in 2012 to 2021 (10,000–15,000).
		$H_0$3b: There is no change in the mean size-at-age of subadult and adult Walleye.	The hypothesis cannot be rejected at this time. Age data for Walleye were not available so assessment of growth relied on inter-year recaptures and the von Bertalanffy model. The results suggest large inter-annual variation in growth (-40% to 84% effect sizes) but there was considerable uncertainty in growth estimates due to highly variable growth among individuals and poor fit of the growth model. Predicted values of maximum growth rate during early life ranged from 36 to 82 mm, except in 2013 when the rate was 112 mm/yr.
		$H_0$3c: There is no change in the mean survival of subadult and adult Walleye.	The hypothesis cannot be rejected at this time. Survival estimates ranged from 33% to 63% between 2001 and 2021 but all credible intervals overlapped.
		$H_0$3d: There is no change in the morphological (condition factor) index of body condition of subadult and adult Walleye.	This hypothesis is rejected. Walleye body condition varied from a -4% effect size to +5% between 2001 and 2021. Body condition was greatest in years when abundance was low, such as 2012 to 2015.

Management Questions	Management Hypotheses	Sub-Hypotheses	Year 15 (2021) Status
		$H_0$3e: There is no change in the distribution of adult and subadult Walleye.	The hypothesis cannot be rejected at this time. Walleye densities were similar among sites, except for greater densities in the Kootenay River. Evenness in the distribution of Walleye between sites was similar in all study years.
What is the effect of inter-annual variability in the Whitefish and Rainbow Trout flow regimes on the abundance, growth rate, survival rate, body condition, and spatial distribution of subadult and adult Whitefish, Rainbow Trout, and Walleye in the Lower Columbia River?			The effect of egg dewatering on fish abundance was analyzed using stock-recruitment models that included egg loss as a covariate. For Mountain Whitefish, age ratios were also used as a recruitment index to test the effects of egg loss. For Mountain Whitefish, the data were most consistent with a small negative effect of egg dewatering mortality on recruitment, but a large negative effect, or no effect, cannot be ruled out. There was also a negative but uncertain and not statistically significant relationship between the age-1:2 recruitment index and estimated egg losses across all years of the study (1999 to 2019 spawning years). However, the large estimated egg loss (59%) in the 2016 spawning year corresponded to a large decrease in the recruitment index and a more than 50% decrease in the estimated abundance of age-1 Mountain Whitefish. In the stock-recruitment model, the direction of the effect of egg dewatering on recruitment was uncertain and not statistically significant, but a small negative effect was most likely, given the data. For Rainbow Trout, there was no evidence of negative effects of egg losses on recruitment at the observed levels of egg loss, which were less than 2% in all years. These conclusions for both Mountain Whitefish and Rainbow Trout should be considered uncertain because of the poor fit in modelled relationships, and the possibility that sampling biases or environmental variability masked real effects of egg dewatering. Flow variability in the LCR is expected to have little effect on Walleye abundance because spawning and early life history occur outside of the study area. Effects of flow variability on the growth, survival, body condition, and spatial distribution of the three index species are possible but likely involve indirect mechanisms such as changes in primary and secondary productivity (food availability) or habitat quality. Possible effects of flow variability on these fish population metrics are discussed in this report.

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1.0 INTRODUCTION

In the mid-1990s, BC Hydro initiated water management from Hugh L. Keenleyside Dam (HLK) during the Mountain Whitefish (*Prosopium williamsoni*) and Rainbow Trout (*Oncorhynchus mykiss*) spawning seasons to reduce egg losses downstream of the dam. During Mountain Whitefish spawning and incubation (December to February), BC Hydro decreases flow from HLK (24 December to 21 January; Golder 2010a) to encourage spawning at lower water level elevations and to reduce egg dewatering over the winter and early spring when annual minimum flows typically occur. Subsequently, flows are managed (within the constraints of the Columbia River Treaty and flood protection considerations) to provide stable or increasing water levels during Rainbow Trout spawning (early April to late June) and incubation to reduce the likelihood that Rainbow Trout eggs (and other larval fishes) are dewatered.

BC Hydro implemented a Water Use Plan (WUP; BC Hydro 2005) for the Columbia River in 2007. As part of the WUP, the Columbia River Water Use Plan Consultative Committee recommended the establishment of the Lower Columba River (LCR) Fish Indexing Program (CLBMON-45) to address data gaps regarding the effects of water management at HLK (particularly during the Mountain Whitefish and Rainbow Trout spawning seasons) on downstream fish populations. The LCR Fish Indexing Program represents a continuation of the Large River Fish Indexing Program (LRFIP), a program initiated by BC Hydro in 2001 to monitor the fish community downstream of HLK.

In 2001, the LRFIP gathered baseline information on fish distribution, life history characteristics, and population abundance of fish species present in the LCR (Golder 2002). Between 2002 and 2006 (Golder 2003, 2004, 2005, 2006, 2007), the night-time boat electroshocking program was refined, based on the results of previous study years, to provide reliable estimates of fish population parameters for three index species: Mountain Whitefish, Rainbow Trout, and Walleye (*Sanders vitreus*). A detailed summary of the life history requirements for these three species was prepared by Golder (2009a, 2010b).

The final year of monitoring under the Water Use Plan was 2019. Because of remaining uncertainty in the effects of the Mountain Whitefish and Rainbow Trout spawning protection flows (BC Hydro 2018a), the monitoring program was extended to continue data collection in 2020 to 2023. Data collected under the LRFIP (2001–2006) and the current program (CLBMON-45; 2007–2021) were used to monitor populations of index fish species over time and to estimate the effects of the Mountain Whitefish and Rainbow Trout spawning protection flows on the fish populations.

1.1 Study Objectives

The objectives of CLBMON-45 (BC Hydro 2007) are:

- to extend time series data on the abundance, distribution, and biological characteristics of nearshore and shallow water fish populations in the LCR;
- to examine long-term trends in key index fish populations (i.e., Mountain Whitefish, Walleye, and Rainbow Trout) during the continued implementation of Mountain Whitefish and Rainbow Trout flows in the LCR;
- to build upon previous investigations for the further refinement of sampling strategy, sampling program, and analytical procedures to establish a long-term monitoring program for fish populations in the LCR;
- to update the existing electronic storage and retrieval system for fish population and habitat monitoring data for the Columbia River;
- to establish linkages between other biological monitoring programs being undertaken in the LCR, in particular, the Physical Habitat and Ecological Productivity Monitoring Program (CLBMON-44); and
- to identify gaps in data and understanding of current knowledge about fish populations and procedures for sampling them, and to provide recommendations for future monitoring and fisheries investigations.

Although the study objectives, management questions (Section 1.2), and management hypotheses (Section 1.3) from the Terms of Reference for 2007 to 2019 still apply, the focus of the monitoring program in from 2020 onward is to assess the effects of experimental manipulation of the Rainbow Trout spawning protection flows. During these years, discharge from HLK will be varied during the protection flow period, depending on operational constraints and environmental conditions, to dewater different percentages of Rainbow Trout eggs. Monitoring results from CLBMON-45 will be used to assess the effects of egg dewatering on the Rainbow Trout population in subsequent years.

1.2 Key Management Questions

Key management questions to be addressed by CLBMON-45 are:

- What is the abundance, growth rate, survival rate, body condition, age distribution, and spatial distribution of subadult and adult Whitefish, Rainbow Trout, and Walleye in the LCR?
- What is the effect of inter-annual variability in the Whitefish and Rainbow Trout flow regimes on the abundance, growth rate, survival rate, body condition, and spatial distribution of subadult and adult Whitefish, Rainbow Trout and Walleye in the LCR?

1.3 Management Hypotheses

Specific hypotheses to be tested under CLBMON-45 include:

- Ho_1: There is no change in the population levels of Whitefish in the LCR over the course of the monitoring period.
  - Ho_{1a}: There is no change in the abundance of adult and subadult Whitefish.
  - Ho_{1b}: There is no change in the mean size-at-age of subadult and adult Whitefish.
  - Ho_{1c}: There is no change in the mean survival of adult and subadult Whitefish.

- Ho_{1d}: There is no change in the morphological (condition factor) index of body condition of adult and subadult Whitefish.
- Ho_{1e}: There is no change in the distribution of adult and subadult Whitefish.

- Ho_2: There is no change in the population levels of Rainbow Trout in the LCR over the course of the monitoring period.
  - Ho_{2a}: There is no change in the abundance of adult and subadult Rainbow Trout.
  - Ho_{2b}: There is no change in the mean size-at-age of subadult and adult Rainbow Trout.
  - Ho_{2c}: There is no change in the mean survival of adult and subadult Rainbow Trout.
  - Ho_{2d}: There is no change in the morphological (condition factor) index of body condition of adult and subadult Rainbow Trout.
  - Ho_{2e}: There is no change in the distribution of adult and subadult Rainbow Trout.
- Ho_3: There is no change in the population levels of Walleye in the LCR over the course of the monitoring period.
  - Ho_{3a}: There is no change in the abundance of adult and subadult Walleye.
  - Ho_{3b}: There is no change in the mean size-at-age of subadult and adult Walleye.
  - Ho_{3c}: There is no change in the mean survival of adult and subadult Walleye.
  - Ho_{3d}: There is no change in the morphological (condition factor) index of body condition of adult and subadult Walleye.
  - Ho_{3e}: There is no change in the distribution of adult and subadult Walleye.

1.4 Study Area and Study Period

The study area for the LCR Fish Indexing Program encompasses the 56.5 km section of riverine habitat from HLK to the Canada-U.S. border (Figure 1). This study area also includes the Kootenay River below Brilliant Dam (BRD) and the Columbia-Pend d'Oreille rivers confluence below Waneta Dam. For the purposes of this study, the study area was divided into three sections. The upstream section of the Columbia River extended 10.7 km from HLK (river kilometre [RKm] 0.0) downstream to the Kootenay River confluence (RKm 10.7). The downstream section of the Columbia River extended 48.5 km from the Kootenay River confluence downstream to the Canada-U.S. border (RKm 56.5). The Kootenay River section was established as a separate sample section that extended 2.8 km from the Kootenay-Columbia rivers confluence upstream to BRD.

In 2021, sample sites were distributed throughout the study area in locations similar to all other study years since 2001. In total, nine index sites were sampled in the upstream section of the Columbia River (Appendix A, Figure A1), 15 index sites were sampled in the downstream section of the Columbia River (Appendix A, Figures A2 and A3), and four index sites were sampled in the Kootenay River (Appendix A, Figure A1). Site descriptions and UTM locations for all sites are listed in Appendix A, Table A1. Each of the 28 index sites was sampled four times (i.e., 4 sessions) between 4 October and 1 November 2021. In addition to the four sessions at the index sites, a visual enumeration survey was also conducted at the index sites, as described in Section 2.1.8. Field sampling was also conducted in the late summer to fall during previous study years (Table 1).

In addition to the four sampling sessions at index sites described above, a fifth sampling session was conducted at 20 randomly selected, non-index sites. These sites were selected using a Generalized Random Tessellation Stratified (GRTS) survey (see Section 2.1.5). Session 5 was completed between 1 and 5 November 2021.

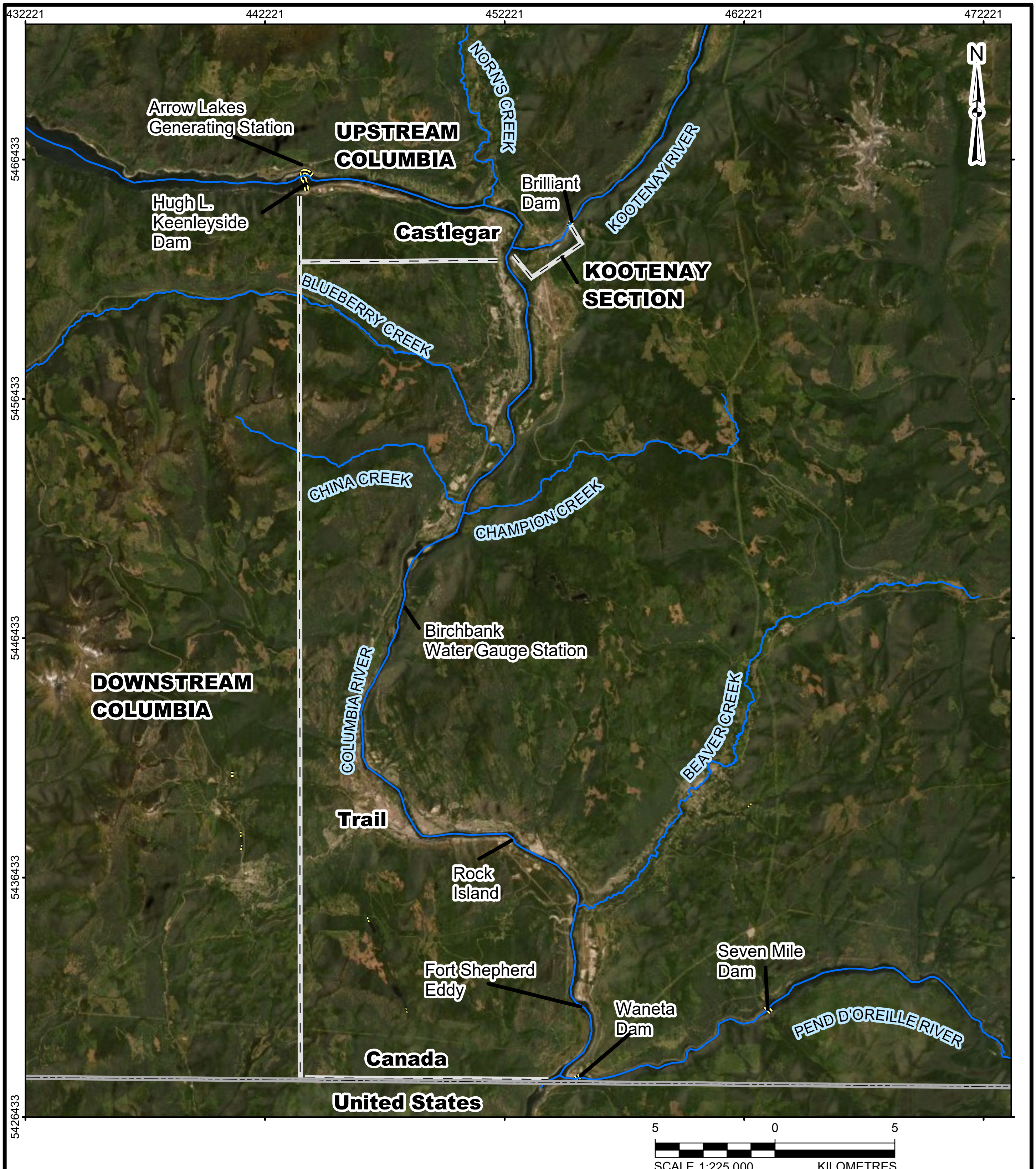
Table 1: Summary of annual study periods and number of sites sampled for boat electrofishing surveys conducted in the lower Columbia River, 2001 to 2021.

Year	Start Date	End Date	Number of Sites			Number of Sessions	Duration (in days)
			Index Sites[a]	GRTS Sites[b]	Geo-referenced Visual Survey[c]		
2001	13 August	23 September	21	-	-	5	42
2002	16 September	27 October	24	-	-	6	42
2003	15 September	26 October	23	-	-	6	42
2004	13 September	30 October	23	-	-	7	48
2005	19 September	1 November	23	-	-	6	44
2006	18 September	2 November	23	-	-	6	46
2007	27 September	6 November	23	-	-	5	41
2008	22 September	3 November	23	-	-	5	43
2009	28 September	30 October	22	-	-	5	33
2010	27 September	30 October	28	-	-	5	34
2011	26 September	5 November	28	20	-	6	41
2012	24 September	25 October	28	20	-	5	32
2013	2 October	6 November	28	20	47	5	36
2014	6 October	7 November	28	20	28	5	33
2015	13 October	10 November	28	20	28	5	29
2016	3 October	4 November	28	20	28	5	33
2017	2 October	7 November	28	20	28	5	37
2018	1 October	4 November	28	20	28	5	35
2019	30 September	3 November	28	20	28	5	35
2020	5 October	7 November	28	20	28	5	34
2021	4 October	5 November	28	20	28	5	33

a. Index sites that were longer than one habitat type were split up in 2002 and 2010. The same bank length was sampled in all years of the program and the difference in the number of sites sampled reflects changes in site naming. Exceptions were sites that were occasionally not sampled in some years because they could not be safely accessed.

b. GRTS sites were added to the program in 2011. See Section 2.1.5 for details.

c. Geo-referenced visual surveys started in 2013. See Section 2.1.8 for details. GRTS sites were also included in the visual survey in 2013 whereas only index sites were included in the visual survey in 2014 to 2021.



Document Path: \\golder.gds\gal\burnaby\CAD-GIS\Client\ONALCR\99_PROJECTS\1537874\02_PRODUCTION\INDEXING\MXD\Report\2021\FIG1_21466986_2021_OVERVIEW_2021.mxd

LEGEND

- WATERCOURSE
- DAM

REFERENCE

1. WATERCOURSE AND DAM CONTAINS INFORMATION LICENCED UNDER THE OPEN GOVERNMENT LICENCE – BRITISH COLUMBIA
2. SERVICE LAYER CREDITS: SOURCE: ESRI, MAXAR, EARTHSTAR GEOGRAPHICS, AND THE GIS USER COMMUNITY

PROJECTION: UTM ZONE 11 DATUM: NAD 83

PROJECT
LOWER COLUMBIA RIVER FISH POPULATION INDEXING SURVEY

TITLE
STUDY AREA OVERVIEW

wsp

PROJECT		21466986-2021	FILE No.
DESIGN	DR	2022-05-31	SCALE AS SHOWN REV. 0
GIS	JG	2022-05-31	
CHECK	DR	2022-05-31	**FIGURE: 1**
REVIEW	SR	2022-05-31	

2.0 METHODS

2.1 Data Collection

2.1.1 Discharge

Discharge data were obtained from BC Hydro's Columbia Basin Hydrological Database. Data used in this report included discharge for the Columbia River below HLK (combined discharge from HLK and Arrow Lakes Generating Station), the Columbia River at Birchbank (Water Survey of Canada gauging station No. 08NE049), and the Kootenay River (combined discharge through the BRD and Brilliant Expansion [BRX] plants). Discharge values throughout this report are presented as cubic metres per second (m^3/s).

2.1.2 Water Temperature

Water temperatures for the mainstem Columbia River from 2001 to 2021 (except 2012 and 2017) were obtained at hourly intervals from the Water Survey of Canada gauging station at Birchbank. In 2012 and 2017, water temperature data from the Birchbank station were not available for a large portion of the year because of a data logger malfunction. Columbia River water temperatures presented for 2012 were measured near Fort Shepherd (used with permission from Columbia Power Corporation; Golder 2013a). Columbia River water temperature presented for 2017 were measured in Kinnaird Eddy, approximately 3 km downstream of the Kootenay-Columbia confluence (J. Crossman, BC Hydro, pers. comm.) during March to November and measured at Birchbank for the remainder of the year. Water temperatures for the mainstem Kootenay River were obtained at hourly intervals using an Onset Tidbit™ temperature data logger (accuracy ± 0.5°C) installed 1.8 km upstream of the Columbia-Kootenay rivers confluence. All available temperature data were summarized to provide daily average temperatures. Spot measurements of water temperature were obtained at all sample sites at the time of sampling using a hull-mounted digital thermometer (accuracy ± 0.2°C).

2.1.3 Habitat Conditions

Several habitat variables were qualitatively assessed at all sample sites (Table 2). Variables selected were limited to those for which information had been obtained during previous study years and were intended to detect gross changes in habitat availability or suitability in the sample sites between study years. The data collected were not intended to quantify habitat availability or imply habitat preferences.

The type and amount of instream cover for fish were qualitatively estimated at all sites (Table 2). Surface water velocities were visually estimated and categorized at each site as low (less than 0.5 m/s), medium (0.5 to 1.0 m/s), or high (greater than 1.0 m/s). Water clarity was visually estimated and categorized at each site as low (less than 1.0 m depth), medium (1.0 to 3.0 m depth), or high (greater than 3.0 m depth). To determine visibility categories, the boat operator called out depths displayed on the boats depth sounder while driving the boat from the thalweg towards the shore. The netters looked over the bow of the boat to become familiar with how deep they could see based on the depths relayed by the boat operator. Mean and maximum depths were estimated by the boat operator based on the boat's sonar depth display.

Habitat at each site was categorized using the Bank Habitat Types Classification System (Appendix B, Table B1; R.L.&L. 1995). The length of each bank habitat type within each site was calculated using ArcView® GIS software (Appendix B, Table B2). While electrofishing, netters estimated the number of observed fish that were not captured by species within each 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 observed fish counts.

Table 2: List and description of habitat variables recorded at each sample site in the lower Columbia River.

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

2.1.4 Fish Capture

Fish were captured using night-time boat electrofishing and methods similar to previous years of the project (Golder et al. 2021). Physiological stress on fish associated with capture and processing is greater at warmer water temperatures (Golder 2002; Gale et al. 2013). Therefore, sampling in the present study (as in during most other study years) did not commence until after water temperatures decreased below 15°C.

Boat electrofishing was conducted at all sites along the channel margin, typically within a range of 0.5 to 4.0 m water depth. Boat electrofishing employed a Smith-Root Inc. high-output Generator Powered Pulsator (GPP 7.5) electrofisher operated out of an outboard jet-drive riverboat with a three-person crew. The electrofishing 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 electrofishing unit. The two netters attempted to capture all three index species. Captured fish were immediately sorted by the bank habitat type that they were captured in and placed into an onboard live well. Index species that avoided capture and all other species that were positively identified but not captured were enumerated by bank habitat type and recorded as “observed”. Both time sampled (seconds of electrofisher operation) and length of shoreline sampled (in kilometres) were recorded for each sample site. Electrofishing sites ranged from 0.44 to 3.79 km in length. If a site could not be completed because of logistical reasons, the distance that was actually sampled was estimated and recorded on the site form, then used as the sampled length in the subsequent analyses.

To further reduce fish mortalities and stress on the fish associated with capturing and handling, compressed oxygen was pumped into the live well through an air stone.

Voltage was adjusted to the lowest voltage that had the desired effect on fishes, which was forced swimming towards the anode (known as electrotaxis or galvanotaxis), or immobilization by the electric field (known as narcosis). This typically correspond to an amperage output of ~1.75 A on the electroshocking boat used from 2001 to 2016. The boat used in 2017 to 2021 had a different amperage gauge that measured a different part of the electrical wave form than the previous boat. Amperages in 2021 ranged from 3.2 to 4.0 A. A pulsed direct current with a frequency of 30 Hz was used. These settings result in less electrofishing-induced injuries on Rainbow Trout than when using greater frequencies (60 or 120 Hz) and amperages (1.5 to 3.3. A as measured on older amperage gauges; Golder 2004, 2005).

To reduce the possibility of capturing the same fish at multiple sites in one session, fish were released near the middle of the site where they were captured so they were less likely to move upstream or downstream into an adjacent site after release. In previous years when releasing fish in the middle of site, fish were occasionally recaptured in a different site during the same session, but this was fairly rare (typically less than 5 times per year).

2.1.5 Generalized Random Tessellation Stratified Survey

In 2001, sites selected for inclusion in the LRFIP (Golder 2002) were based on sites established and data collected during surveys conducted in the early 1980’s (Ash et al. 1981) and early 1990’s (R.L.&L. 1991). During those two programs, nearly all areas of the LCR were surveyed with individual site lengths determined by the length of shoreline traversed by the boat in the amount of time it took netters to fill the live well with fish (L. Hildebrand, Golder Associates Ltd., pers. comm.). A subsample of sites established during those original programs was selected for inclusion in the LRFIP in 2001 to provide a representative sample of general bank habitat types available throughout the LCR; however, emphasis was placed on sites known to contain higher densities of the three index species, which may result in overestimates of abundance in the entire LCR study area. This same subsample of sites has been used for annual sampling since 2001, including the continuation of the survey program as part of CLBMON-45, which was initiated in 2007. Approximately 30% of the total shoreline habitat available in the LCR was repetitively sampled each year as part of the LRFIP and CLBMON-45.

The stratified sampling design detailed above represents a repeated measures concept, where a mark-recapture program is conducted annually at each site over an approximately five-week study period. The same sites are surveyed each year, resulting in annual estimates of abundance with relatively constant temporal and spatial sample design parameters. Stratified sampling programs like this may result in biased estimates because not all portions of a study area are surveyed or potentially available to be surveyed in any particular year. This bias can arise if inter-annual fish distribution changes with abundance rather than only with fish density. Additionally, repetitively sampling the same sites each session (i.e., within a year) may introduce biases due to fish moving between sampled and non-sampled sections of the study areas within or between sessions.

Starting in 2011, additional sites were randomly selected using the GRTS survey design (Stevens and Olsen 2004) and sampled after field crews completed the conventional mark-recapture program. The GRTS survey was conducted to identify potential biases and to provide a better understanding of the population dynamics of the three index species.

Portions of shoreline habitat that were not sampled as part of CLBMON-45 prior to 2011 were divided up into potential sites. Upstream and downstream boundaries of each site were established using several different criteria, including historic site delineations (i.e., sites surveyed during the 1990s; R.L.&L. 1991), sampling effectiveness (e.g., overall length, ease of access, etc.), natural breaks in bank habitat type, and the location of obvious geographical boundaries (e.g., islands, tributary mouths, bridges, etc.). Established CLBMON-45 indexing sites ranged in length from 0.4 to 3.8 km; these lengths were used as general guidelines when establishing the GRTS survey sites. Overall, 62 new GRTS survey sites ranging from 0.6 to 3.9 km in length, were established in areas of the LCR that were not sampled between 2001 and 2010 (Table A2). The same habitat variables recorded for indexing sites were also recorded for GRTS survey sites (Appendix B, Table B3). In general, there was a similar range of habitat types at indexing and GRTS survey sites.

The GRTS sampling design combines the features of stratified sampling with the benefits of a totally random design, ensuring full spatial coverage and randomization so that all potential habitats are surveyed. A feature of the GRTS strategy is that new sites may be selected during each study year; therefore, all fish habitats are included within the potential sampling “frame”. Software used to create the GRTS design included the *spsurvey* package (Kincaid and Olsen 2016) in the statistical program R (R Core Team 2022), and ArcGIS. Each year since 2011, the GRTS methodology was used to select a subsample of 20 sites from the 62 GRTS survey sites. In addition, 15 “oversample” sites also were selected to replace selected GRTS sites that were unable to be sampled for logistical reasons. For the current project, excluded sites included those located immediately downstream of HLK, BRD, and Waneta Dam and inside the log booms at Zellstoff Celgar (all due to safety concerns), the perimeter of Waldie Island (a nature preserve), and the west shore of Zuckerberg Island (too shallow to safely navigate). Oversample sites also were used if the same site was selected more than once by the software. The use of oversample sites ensured that both randomness and spatial balance were maintained as part of the study design. GRTS sites selected in 2021 are presented in Appendix A, Table A2.

A single-pass boat electrofishing survey was conducted at each GRTS survey site between 1 and 5 November 2021 using the same procedures described above. The GRTS surveys were always conducted after sampling at index sites was completed. Fish captured during GRTS surveys were processed in the same manner as fish captured during the conventional mark-recapture program (Section 2.1.6).

2.1.6 Fish Processing

Site habitat conditions (Table 2) and the number of fish observed were recorded after sampling each site. Data collection for each captured fish included the variables in Table 3. The length (to the nearest 1 mm) and weight (to the nearest 1 g) of each fish was measured. All sampled fish were automatically assigned a unique identifying number by the database that provided a method of cataloguing associated ageing structures.

All index fish > 120 mm were marked with a Passive Integrated Transponder (PIT) tag (Food-safe BioPolymer, 11.4 x 2.8 mm, FUSION 134.2 kHz PIT tags, 11BPF, Swiss Plus ID, Australia). For fish between 120 and 160 mm FL, tags were implanted into the abdominal cavity of the fish just off the mid-line and anterior to the pelvic girdle using a single shot applicator (model MK7, Biomark Inc., Boise, Idaho, USA). For fish >160 mm FL, tags were inserted with a single shot 12 mm polymer PIT tag applicator gun (Hallprint Pty Ltd., Australia) into the dorsal musculature on the left side below the dorsal fin near the pterygiophores. Only fish that were in good condition received PIT tags whereas fish in poor physical condition (e.g., large open wounds, unable to maintain upright orientation) were not tagged. 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 LCR Fish Indexing Database.

During the 2001 to 2005 studies, fish were marked exclusively with T-bar anchor tags (i.e., PIT tags were not used). Fish captured during the present study that had previously been marked with and retained a T-bar anchor tag did not receive a second tag (i.e., a PIT tag) unless the T-bar anchor tag was not inserted properly, the tag number was illegible, or a large wound was present at the tag's insertion point (on these occasions, the T-bar anchor tag was carefully removed and a PIT tag was applied).

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

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

Scale samples were collected from Mountain Whitefish and Rainbow Trout in accordance with the methods outlined in Mackay et al. (1990). All scales were stored in appropriately labelled coin envelopes and air-dried before processing. Scale samples were not collected from Walleye because scales are not a reliable ageing structure for Walleye (Mackay et al. 1990). Walleye are primarily seasonal residents in the LCR, which is used for feeding by adult and subadult cohorts. As a result, sensitive early life stages of Walleye are unlikely to be affected by river regulation in the study area.

2.1.7 Scale Ageing

In 2021, fish were not aged using scale samples. Various techniques have been used in past years of the program to assign ages using scale samples. For all ageing methods used in past years, only age-0, age-1, and sometimes age-2 fish could be reliably aged and there was considerable uncertainty and error in ages assigned to all age-3 and older age-classes (Golder et al. 2018). Therefore, Mountain Whitefish and Rainbow Trout captured between 2001 and 2021 were assigned age-classes based on their fork length and the length-at-age model (Section 2.2.3). Scale-based ages assigned during previous years of the program were not used in this report.

2.1.8 Geo-referenced Visual Enumeration Survey

A visual enumeration survey was conducted at each index site during the week before the mark-recapture indexing surveys began. The survey consisted of a boat electrofishing pass using the same methods as the mark-recapture survey (Section 2.1.4), except that fish were only counted and not captured. Two observers were positioned in the same location as they would have been for netting, where they identified, enumerated, and estimated the length of all fishes observed. Two other individuals recorded all the observation data dictated by the observers, and recorded the geographical location of each observation using a hand-held Global Positioning System (GPS) unit. The rationale behind these geo-referenced visual enumeration surveys was that continuous direct counts of observed fish would be more accurate than the intermittent observations made by netters during the mark-recapture surveys, because during the visual survey observers do not need to net fish and turn to put capture fish in the live well (and thereby stop counting or capturing additional fish). In addition, the visual surveys provide fine-scale distribution data, which could be used to understand mesohabitat use by fishes in the LCR and better address management questions regarding spatial distribution. Fish species counted and recorded in the survey were the three index species. The only other species recorded was Northern Pike (*Esox lucius*) because they are an invasive species of concern in the study area.

2.1.9 Historical Data

In addition to the data collected between 2001 and 2021, data collected in the study area between 1990 and 1996 (R.L.&L. 1995, 1997) were also used in some analyses. Studies conducted during this period involved boat electrofishing and mark-recapture programs, with protocols very similar to the 2001 to 2021 monitoring studies, including many of the same sample sites. There were some differences in sampling methodology between the 1990s and the current sampling program including different electrofisher settings and tag types. Despite these relatively minor differences, the 1990s data were considered comparable to data collected between 2001 and 2021 and data from the 1990s with sufficient sample sizes were used in the analyses of length-at-age, growth, and body condition. Incorporating data from the 1990s in the analyses provides a longer time series and historical context to better address management questions about fish population trends in the LCR.

2.2 Data Analyses

2.2.1 Data Compilation and Validation

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

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

All raw data collected as part of the program between 2001 and 2021 are included in the LCR Fish Indexing Database (Attachment A).

For all figures in this report, sites are ordered by increasing distance from HLK (RKm 0.0) based on the upstream boundary of each site. Unless stated otherwise, black points represent sites located on the left bank (as viewed facing downstream) and red points represent sites located on the right bank (as viewed facing downstream).

2.2.2 Hierarchical Bayesian Analyses

The temporal and spatial variation in abundance, growth, body condition, and survival were analyzed using Hierarchical Bayesian Models (HBMs). The book ‘Bayesian Population Analysis using WinBUGS: A hierarchical perspective’ by Kéry and Schaub (2011) provides an excellent reference for hierarchical Bayesian methods. In short, a hierarchical Bayesian approach:

- Allows complex models to be logically defined using the BUGS language (Kéry and Schaub 2011: 41).
- Permits the incorporation of prior information (Kéry and Schaub 2011: 41).
- Readily handles missing values.
- Provides readily interpretable parameter estimates whose reliability does not depend on the sample size.

- Allows derived quantities, such as the percent change in the expected weight of a 200 mm Mountain Whitefish at a particular site in a typical year, to be readily calculated (Kéry and Schaub 2011: 41).
- Enables the efficient modelling of spatial and temporal variations and correlations (Kéry and Schaub 2011: 78-82).
- Permits the separation of ecological and observational processes (Kéry and Schaub 2011: 44).

The analyses were implemented using R version 4.2.0 (R Core Team 2022) and the mbr family of packages. Models were fit using JAGS (Plummer 2015) and STAN (Carpenter et al. 2017). The one exception is the length-at-age estimates which were produced using the *mixdist* package (Macdonald 2012) in R, which implements Maximum Likelihood with Expectation Maximization. The technical aspects of the analyses, including the general approach, model definitions, and the resultant parameter estimates are provided in Appendix C. In addition, the statistical methodology, sample code, parameter estimates, and figures of results are available online (Thorley and Hussein 2022).

The parameters are summarized in terms of the point estimates, the lower and upper 95% confidence/credible limits (CLs), the p-value (Kéry and Schaub 2011, 37, 42), and the s-value (Greenland 2019). For Bayesian models, the point estimate is the median (50th percentile) of the Markov Chain Monte Carlo (MCMC) samples and the 95% credible limits are the 2.5th and 97.5th percentiles. Credible limits are the Bayesian equivalent of confidence limits. The range from the lower CL to the upper CL is referred to as the credible/confidence interval (CI). For maximum likelihood models, the point estimate is the maximum likelihood estimate (MLE), and 95% confidence intervals are the MLE±1.96×SD, where SD is the standard deviation. Model adequacy was assessed using posterior predictive checks described in Thorley and Hussein (2022).

P-values were used to assess statistical significance. As p-values are not always intuitive and are easy to misinterpret, s-values are presented as an alternative statistic to help understand the significance of the results. An s-value can be considered a test of directionality. More specifically it indicates how surprising it would be to discover that the true value of the parameter is in the opposite direction to the estimate. An s-value (Rafi and Greenland 2020) is the Shannon transform (-log to base 2) of the corresponding p-value (Kéry and Schaub 2011; Greenland and Poole 2013). A surprisal value of 4.3, which is equivalent to a p-value of 0.05 indicates that the surprise would be equivalent to throwing 4.3 heads in a row.

The results were displayed graphically by plotting the modeled relationships between a particular variable (e.g., year) and the response variable with the remaining variables 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 (expected values of the underlying hyperdistributions) (Kéry and Schaub 2011, 77-82). When informative, the influence of particular variables was expressed in terms of the effect size (i.e., percent change in the response variable) with 95% CIs (Bradford et al. 2005).

If the model assumptions are correct, there is 95% probability that the actual values lie within the credible intervals (CIs). Consequently, if two estimates have non-overlapping CIs, then the direction of the difference between them is relatively certain and the difference is statistically significant. It is important to note that estimates can have overlapping CIs but the direction of the difference between them can still be relatively certain and significantly different. For example, the uncertainty in the annual abundance estimates depend on the differences between years, as well as the abundance in a typical year. As the uncertainty in the abundance in a typical year affects all the estimates, it can cause the CIs to overlap even if the direction of the differences between years are significantly different. If it is important to establish the statistical significance of a difference or trend where the CIs overlap, this can be determined from the posterior probability distributions.

2.2.3 Length-At-Age

The length-at-age analysis was conducted to 1) determine length-at-age cutoffs by life stage (age-0 fry, age-1 subadult, or age-2 and older adult); and 2) compare length-at-age among years. The expected length-at-age of Mountain Whitefish and Rainbow Trout was estimated from annual length-frequency distributions using a finite mixture distribution model (Macdonald and Pitcher 1979).

There were assumed to be four distinguishable normally-distributed age-classes for Mountain Whitefish (age-0, age-1, age-2 and age-3+) and three for Rainbow Trout (age-0, age-1, age-2+). Initially the model was fitted to the data from all years combined. The model was then fitted to the data for each year separately with the initial values set to the estimates from the combined values. The only constraints were that the standard deviations of the Mountain Whitefish age-classes were identical in the combined analysis and fixed at the value from the combined analysis in the individual years. For each Mountain Whitefish and Rainbow Trout, the probability of belonging to each age-class was predicted by the model, and the age-class with the highest probability was assigned to each fish.

Rainbow Trout and Mountain Whitefish were categorized as fry (age-0), subadult (age-1) or adult (age-2 or older) based on their length-based ages. Walleye could not be separated by life stage due to a lack of discrete modes in the length-frequency distributions for this species. Spawning by Walleye is not known to occur in the study area and all individuals captured are likely age-1 or older. For example, the minimum size of Walleye caught ranged from 205 to 320 mm in years from 2001 to 2021, but 95% of all Walleye captured were greater than 300 mm in fork length. Studies of Walleye in Washington State reported typical lengths of age-1 Walleye from 130 to 180 mm (Lower Columbia Fish Recovery Board 2004) although average length of age-1 Walleye in Lake Roosevelt on the Columbia River was reportedly higher (approximately 300 mm; Schmuck 2017). Therefore, in this report, Walleye could not be separated by life stage but the data are considered to represent mostly age-2 and older fish, which are considered representative of subadult and adult life stages, with a small number of age-1, and no age-0 fish.

Because of low numbers of recaptured fish in the 1990s historical data, only years between 1990 and 1996 with sufficient recapture data were used for length-at-age analyses. The results include plots of the age-class density for each year by length as predicted by the length-at-age model. Density is a measure of relative frequency for continuous values. To compare among years, mean length-at-age was plotted for age-0 fish. Length-at-age of age-1 and older age-classes are not presented because the size depends on growth during more than one year, which complicates interpretation.

2.2.4 Observer Length Correction

The annual bias (inaccuracy) and error (imprecision) in observer's estimates of fish length during the geo-referenced visual survey were quantified and used to correct lengths before assigning life stages based on length-at-age cutoffs. Bias and error were quantified using a function that minimized the divergence of the length distribution of the observed fish (visual survey) and the length distribution of the measured fish (mark-recapture survey). The percent length correction that minimized 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.

Key assumptions of the length correction model include the following:

- The length-frequency distribution varied among years.
- The expected length bias and error for a given observer varied among but not within years.

2.2.5 Growth

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

Key assumptions of the growth model include the following:

- The mean value of maximum length (L_∞) was constant.
- The growth coefficient (k) varied randomly with year.
- The residual variation in growth was normally distributed.

In the von Bertalanffy growth model, the growth coefficient, k, represents the rate at which fish approach the asymptotic size (L_∞). Plots of growth show the effect size (percent change) relative to a typical year in the annual estimates of the mean growth coefficient. 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 was plotted for each year. The maximum growth rate can be interpreted as the maximum growth during early life (i.e., theoretical growth rate when fish are 0 mm in length) and can be used to compare between populations or years (Gallucci and Quinn 1979; Shuter et al. 1998).

The estimated growth curve for Walleye predicted unrealistic length-at-age values, which was attributed to highly variable growth even for large fish (e.g., 0–60 mm per year for 500 mm Walleye). To try to address this concern, the growth model was re-run using only Walleye less than 450 mm in fork length and these results are included in the report to represent the growth coefficient of smaller adult Walleye (mostly 300–450 mm) in the study area. As predictions of length-at-age were not realistic for younger fish, even after removing fish larger than 450 mm, Walleye were not included in the plot showing length-at-age predicted by the von Bertalanffy curve. Despite this limitation, estimates of the growth coefficient and maximum growth rate, which are of interest for assessing the management questions, are considered reliable indicators of growth for typical adult Walleye (300-450 mm) in the study area.

2.2.6 Site Fidelity

The extent to which fish remained at the same site between sample sessions was evaluated using a logistic analysis-of-covariance (ANCOVA; Kéry 2010). The model estimated the probability of a recaptured fish being caught at the same site where it was previously encountered.

Key assumptions of the site fidelity model include the following:

- Expected site fidelity varied with body length.
- Observed site fidelity was described by a Bernoulli distribution.

Length as a second-order polynomial was not found to be a significant predictor for site fidelity and was therefore not included in the model.

Site fidelity was defined as the probability of fish remaining at the same site between sessions in a particular year. The estimated probability of being caught at the same site versus a different site from the logistic ANCOVA was converted into the site fidelity by assuming that those fish which were recaptured at a different sampling site represented 32% of fish that left the site. The correction factor corresponds to the proportion of shoreline of the LCR that is included in index sites. This correction accounts for the fact that fish that leave the site where they were initially captured may move to different index sites within the study area, or to parts of LCR that are not index sites.

Site fidelity estimates also were used to adjust the capture efficiencies in the analysis of mark-recapture data (see Section 2.2.7).

2.2.7 Capture Efficiency

The probability of capture was estimated using a recapture-based binomial model (Kéry and Schaub 2011: 134-136, 384-388).

Key assumptions of the capture efficiency model include the following:

- The capture probability varied randomly by session within year.
- The probability of a marked fish remaining at a site was the estimated site fidelity.
- The number of recaptures was described by a binomial distribution.

2.2.8 Abundance

The abundance of each index fish species was estimated using the catch data from the mark-recapture survey and the observer count data from geo-referenced visual surveys using an over-dispersed Poisson model (Kéry and Schaub 2011: 55-56). The model used the estimates of capture efficiency from the mark-recapture data (Section 2.2.7) to generate the estimated density of captured and uncaptured fish at each site. Observer count efficiency was estimated for the geo-referenced visual surveys, and was calculated by adjusting the capture efficiency based on the ratio of counted (visual surveys) to captured fish (four mark-recapture sessions). Count efficiency was then used in the model to estimate the total density of counted and uncounted fish present at each site. Abundance estimates represent the total number of fish in the study area.

Key assumptions of the abundance model include the following:

- The capture efficiency at a typical fish density was the point estimate for a typical sample session from the capture efficiency model.
- The count efficiency from the visual survey varied from the capture efficiency from the mark-survey.
- The capture efficiency (but not the count efficiency) varied with fish density.
- The fish density varied randomly with site, year and site within year.
- The change in fish density with overall abundance varied by site density.
- The overdispersion varied by visit type.
- The catches and counts were described by a Poisson-gamma distribution.

In 2021, the only change to the model from the previous year was the addition of a variable that allowed the effect of year to depend on the density of the site, such that sites with low density may increase more than high density with increasing annual abundance.

Plots of annual abundance represent the estimated total number of fish at all sites combined. Plots showing the variation in abundance by site show the lineal density (fish/km) at each site. Abundance was estimated separately for subadults (age-1) and adults (age-2 and older), where ages were based on fork length and the cutoffs from the length-at-age model (Section 2.2.3).

2.2.9 Spatial Distribution

Changes in the spatial distribution of index species over time were assessed by calculating the Shannon index of evenness (Shannon and Weaver 1949; Pielou 1966) in each year for each species and life stage. The index was calculated using the following formula where S is the number of sites and p is the proportion of the total density belonging to the ith site.

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

An evenness value of 100% would indicate the same density at all sites while an evenness of 0% would indicate that all the fish are clustered a single site.

2.2.10 Survival

The annual survival rate was estimated by fitting a Cormack-Jolly-Seber (CJS) model (Kéry and Schaub 2011: 172-175, 220) to inter-annual recapture data. Survival was only estimated for adults because sparse recapture data for subadults resulted in uninformative estimates.

Key assumptions of the survival model include the following:

- Survival varied randomly with year.
- The encounter probability varied with the total bank length sampled.

In addition to the recapture-based CJS estimate of survival, survival was estimated based on the estimated abundances of subadult (age-1) and adult (age-2 and older) fish. The subadult (S_t) and adult (A_t) abundance estimates were used to calculate the subadult and adult survival ($\emptyset_t$) in year t based on the relationship:

$$\emptyset_t = \frac{A_t}{S_{t-1} + A_{t-1}}$$

Abundance-based survival was estimated for Mountain Whitefish and Rainbow Trout. This analysis assumes the same survival rate for subadult and adult fish.

2.2.11 Body Condition

Condition was estimated via an analysis of the weight-length relationship (He et al. 2008), which is represented by the equation $W = \alpha L^{\beta}$, where W is weight, L is length, and α and β are estimated coefficients. Key assumptions of the condition model include the following:

- Weight varied with length and date.
- Weight varied randomly with year.
- The relationship between length and weight varied with date.
- The relationship between length and weight varied randomly with year.
- The residual variation in weight was log-normally distributed.

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

2.2.12 Age Ratios

This program's management questions regard the effect of variability in the flow regime, which can result in variable amounts of egg mortality due to dewatering, on abundance of fish in the LCR. The abundance of fish in the LCR is determined in part by the number of eggs that hatch, survive, and are recruited to the subadult and adult populations. To monitor inter-annual changes in recruitment, ratios of age-1:age-2 fish were calculated and used as an index of annual recruitment. The age ratio analysis used ages assigned based on the length-at-age model (Section 2.2.3). Age ratio analyses were conducted for Mountain Whitefish, which was the only species for which there were data regarding the proportion of age-1 and age-2 fish from 2001 to 2021. The age ratio could not be assessed for Rainbow Trout because age-2 individuals could not be reliably distinguished from age-3 and older based on their fork lengths.

The proportional ratio of age-1 to age-2 Mountain Whitefish (age-1:2 ratio) for each year from 2001 to 2021 was obtained from the length-at-age models. Years with strong recruitment are expected to result in greater age-1:2 ratios than years with weaker recruitment. This ratio does not depend on estimates of capture efficiency and is not affected by violations of the assumptions of the mark-recapture models.

The age-1:2 ratio for a given spawning year (r_t) was calculated based on the abundance of age-1 (N^1) and age-2 (N^2) fish two years after the spawning year ($t + 2$):

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

Mountain Whitefish in the LCR spawn in November and December, hatch primarily in March and April of the following year (referred to as the hatch year), and are therefore age-1 two years after the spawning year ($t + 2$). To test for effects of egg loss from dewatering on the recruitment index (r_t), the ratio of estimated egg loss (L_t) affecting each spawning year was calculated:

$$L_t = \log(Q_t/Q_{t-1})$$

This ratio was used to represent egg loss because the losses during the spawning year (Q_t) are expected to affect the proportion of age-1 fish two years later ($N^1_{t+2)}$) whereas the proportion of age-2 fish (N^2_{t+2}) is expected to be affected by egg losses three years prior (Q_{t-1}). The ratio was logged to ensure it was symmetrical about zero (Tornqvist et al. 1985). Annual egg loss estimates were provided by BC Hydro and were calculated using the Mountain Whitefish Egg Stranding Model, which estimates egg dewatering and mortality using hourly hydrological data, bathymetry, and information regarding spawning timing and location (Golder 2013b).
The relationship between the recruitment index, r_t, and egg losses, L_t, was estimated using a hierarchical Bayesian logistic regression (Kéry 2010) loss model. Key assumptions of the final model include the following:

- The log odds of the proportion of age-1 fish varied linearly with the log of the ratio of the percent egg losses.
- The residual variation was normally distributed.

The relationship between egg dewatering and subsequent recruitment is expected to depend on stock abundance (Subbey et al. 2014), which might be changing over the course of the study. Consequently, preliminary analyses allowed the slope of the regression line to change through time. The change was not significant and was therefore removed from the final model. The effect of dewatering on Mountain Whitefish recruitment was expressed in terms of the predicted percent change in age-1 Mountain

Whitefish abundance by egg loss in the spawn year relative to 10% egg loss in the spawn year. The egg loss in the previous year was fixed at 10%. The percent change could not be calculated relative to 0% in the spawn or previous year because L_t is undefined in either case.

2.2.13 Adjusted Recruitment

A new analysis in 2021 was conducted to assess the effect of egg dewatering on recruitment of age-1 Rainbow Trout after accounting for inter-annual variation in salmonid abundance in the study area. In this analysis, the abundance of age-1 Mountain Whitefish was used as a predictor variable in the model as an indicator of variation of salmonid abundance in the study area that is not related to dewatering of Rainbow Trout eggs. The abundance of age-1 Mountain Whitefish was used as a proxy for salmonid abundance variation not related to dewatering because their spawning and egg incubation period does not overlap with that of Rainbow Trout. The relationship was estimated using a generalized linear model (GLM) where the abundance estimate of age-1 Rainbow Trout was the response variable, and the abundance of age-1 Mountain Whitefish the same year and the proportion of Rainbow Trout dewatered the previous year were predictor variables.

Key assumptions of the final model include the following:

- The abundance of age-1 Rainbow Trout varied with proportion of the eggs dewatered the previous year and the number of age-1 Mountain Whitefish caught in the same year.
- The residual variation is log-normally distributed.

2.2.14 Fecundity and Egg Deposition

The number of eggs produced per spawning female, known as the fecundity, and the total number of eggs deposited by the population per spawning year were calculated to be used in the stock-recruitment analysis (Section 2.2.15).

The relationship between fecundity (F) and body weight (W) for Mountain Whitefish was estimated from data collected by Boyer et al. (2017) for the Madison River, Montana. The data were analysed using an allometric model of the form: $F = \alpha W^{\beta}$, where α and β are estimated coefficients. The model assumed that the residual variation in fecundity was log-normally distributed.

For Rainbow Trout, the fecundity (F) in year t of an adult female Rainbow Trout was calculated from the expected weight (W) in grams using the equation: $F_t = 3.8 \times W_t^{0.9}$. This equation was developed using data from Rainbow Trout in Kootenay Lake (Andrusak and Thorley 2019).

The weights used in fecundity calculations were the year-specific expected weights from an average-length fish from the condition model (Section 2.2.11).

The total egg deposition (E_t) in year t was calculated from the estimated fecundity (F_t) and adult abundance (A_t), assuming that the population was 50% female, using the equation: $E_t = F_t \times A_t \times 0.5$.

2.2.15 Stock-Recruitment Relationship

Understanding the relationship between the number of spawning adults, which is sometimes referred to as the “stock”, and the resulting number of individuals recruited to the catchable population of fish (“recruitment”) is one of the most important issues in fisheries biology and management (Myers 2001). At low spawner abundance, recruitment is expected to be driven by density-independent factors and the number of recruits will increase with the number of spawners. At high spawner abundance, density-dependent factors such as competition for limited resources can result in a decrease in per capita recruitment with increasing numbers of spawners. Stock-recruitment relationships often use the number of spawners as a proxy for the reproductive output of the population (Subbey et al. 2014) but this approach does not account for differences in body size and fecundity of the population. Estimates of egg production or deposition may provide a more accurate estimate of reproductive output of the population.

For the LCR, the relationship between the estimated number of eggs deposited ("stock") and the resultant number of subadults the following year ("recruitment") was estimated using a Bayesian Beverton-Holt stock-recruitment model (Walters and Martell 2004):

$$R = \frac{\alpha E}{1 + \beta E}$$

where E is the estimated number of eggs deposited, R is the estimated number of age-1 subadults (recruits), α is the recruits per egg (survival from egg to age-1) at low density and β determines the density-dependence. The ratio of α to β defines the carrying capacity, which is the predicted maximum value of the mean number of recruits at large values of egg deposition.

With respect to the Mountain Whitefish and Rainbow Trout protection flows, it is important to understand if and when egg losses due to dewatering affect the number of recruits in the LCR. Mortality of incubating eggs due to dewatering could affect density-dependent mortality of eggs or rearing juveniles, which would change the stock-recruitment curve compared to in the absence of dewatering. To test for effects of egg loss, the estimated proportional egg loss was included as a predictor variable affecting the number of recruits in the stock-recruitment model. Egg loss estimates were obtained from the Mountain Whitefish Egg Stranding Model (Golder 2013b) and from Amies-Galonski et al. (2022) for Rainbow Trout.

Key assumptions of the stock-recruitment model include the following:

- The egg to recruit survival at low numbers of egg deposition was likely less than 1% (the prior distribution of α was a zero truncated normal distribution with a standard deviation of 0.003.
- The expected log number of recruits varied with the proportional egg loss.
- The residual variation in the number of recruits was log-normally distributed.

The expected egg survival for a given egg deposition is S/E_t which is given by the equation:

$$\phi_E = \frac{\alpha}{1 + \beta * E}$$

The stock-recruitment relationship was calculated for Mountain Whitefish and Rainbow Trout. Age ratio and stock-recruit results are presented in terms of the spawning year. For Rainbow Trout, which spawn from March to July and hatch in June to August in the LCR (Irvine et al. 2015), the spawning year is the same as the hatch year. For Mountain Whitefish, spawning occurs mostly in November to December in the LCR and hatch occurs mostly between March and April; therefore, the hatch year is one year greater than the corresponding spawning year. For both species, the age-0 life stage is defined as the first year beginning on the hatch date.

3.0 RESULTS

3.1 Physical Habitat

3.1.1 Columbia River Discharge

Discharge in the LCR downstream of the confluence of the Kootenay and Columbia rivers in 2021 was near average for most of the year including during the sampling period (Figure 2; Appendix D, Figure D1). Exceptions were in February and December when mean daily discharge exceeded the historic maximum value from 2001 to 2020 and in March when it was lower than the historic minimum value from 2001 to 2020. As in previous years of the study, discharge in the LCR followed a bimodal pattern with a peak during spring freshet and a smaller second peak during early winter associated with hydropower generation.

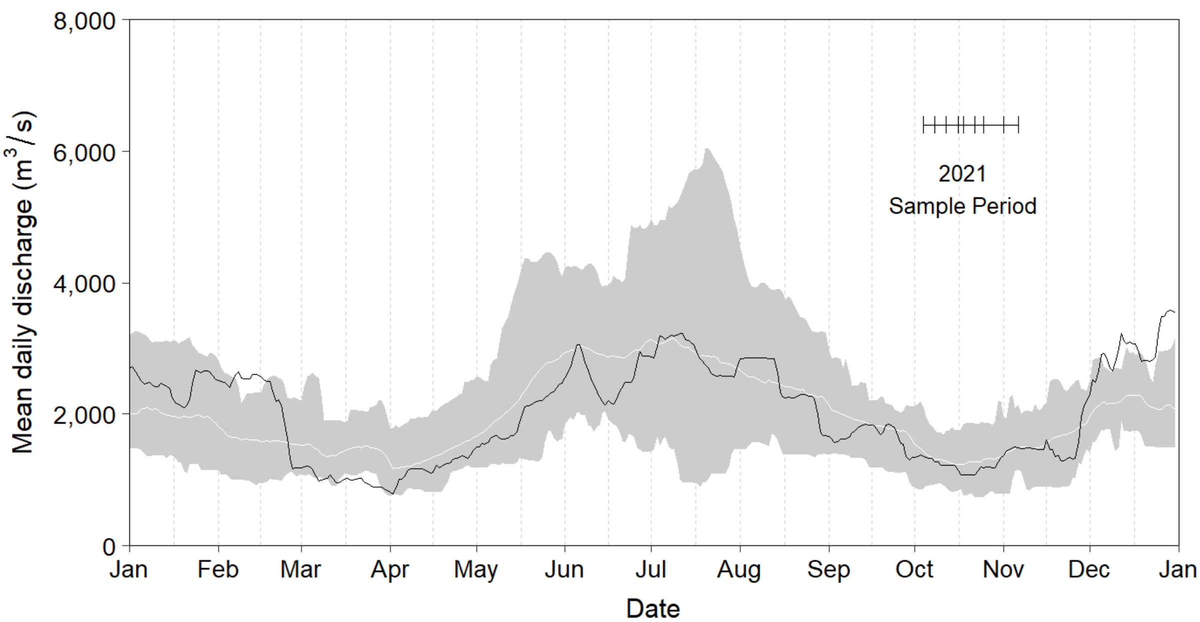


Figure 2: Mean daily discharge (m^3/s) for the Columbia River at the Birchbank water gauging station, 2021 (black line). The shaded area represents minimum and maximum mean daily discharge values recorded at Birchbank from 2001 to 2020. The white line represents average mean daily discharge values over the same time period.

In 2021, mean daily discharge in the Columbia River below HLK (upstream of the confluence with the Kootenay River) was near average for most of the year (Figure 3; Appendix D, Figure D2). Similar to discharge in the Columbia River below Birchbank, mean daily discharge upstream of the confluence with the Kootenay River exceeded the historic (2001 to 2020) maximum for part of February and December. Mean daily discharge was near average during the sampling period in 2021.

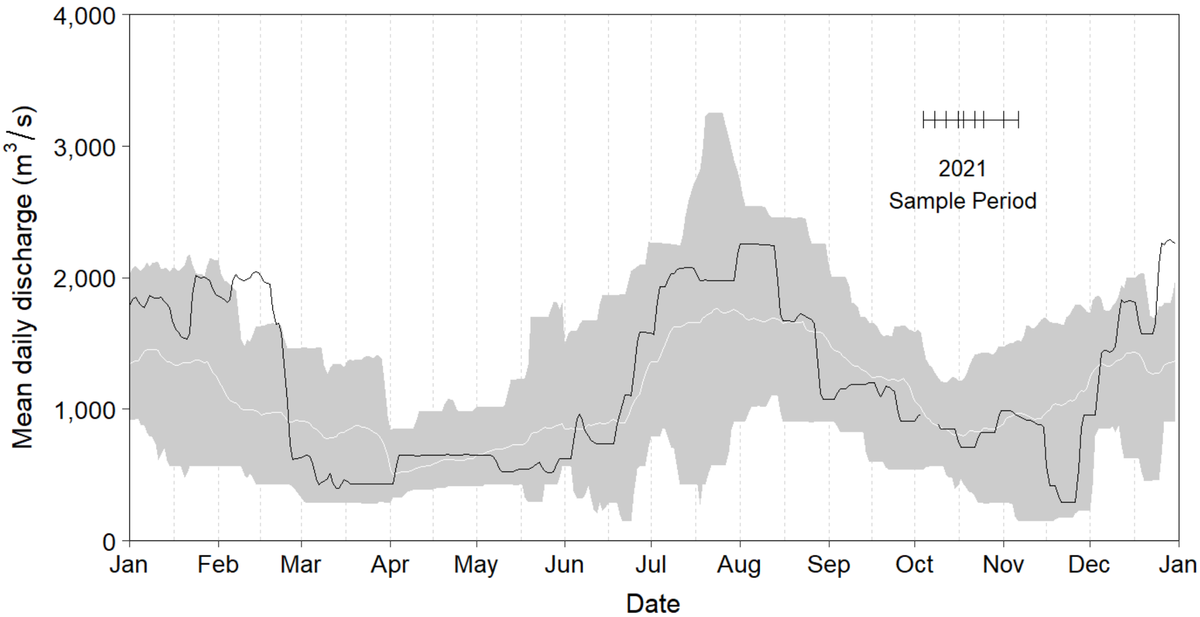


Figure 3: Mean daily discharge (m^3/s) for the Columbia River at Hugh L. Keenleyside Dam, 2021 (black line). The shaded area represents minimum and maximum mean daily discharge values recorded at the dam from 2001 to 2020. The white line represents average mean daily discharge values over the same time period.

3.1.2 Columbia River Temperature

In 2021, daily mean water temperature in the Columbia River was approximately 1°C above average from January to June and above the historic maximum in late June and early July (Figure 4). For the remainder of the year, mean daily water temperature was near average. Between 2001 and 2021, water temperature in the Columbia River at Birchbank reached a maximum daily mean temperature of approximately 16°C to 19°C, with peak temperatures typically occurring during mid-August. Spot temperature readings for the Columbia River taken at the time of sampling ranged between 9.5°C and 13.4°C (Appendix B, Table B3).

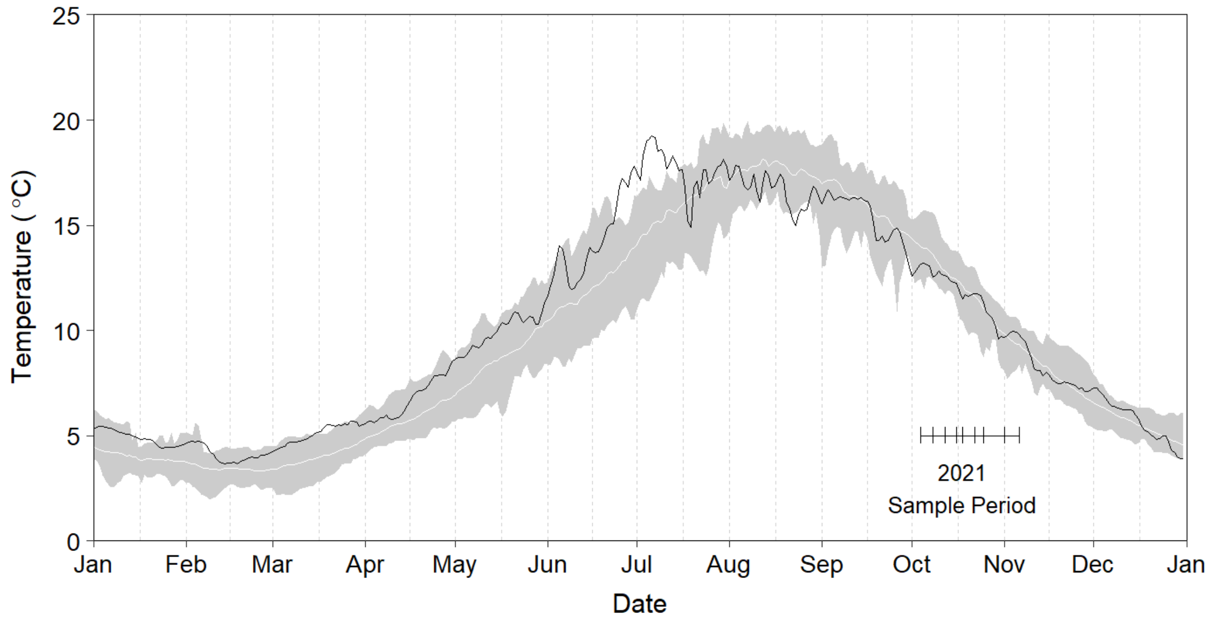


Figure 4: Mean daily water temperature (°C) for the Columbia River downstream of the confluence of the Kootenay River, 2021 (black line). The shaded area represents the minimum and maximum mean daily water temperature values from 2001 to 2020. The white line represents the average mean daily water temperature during the same time period.

3.1.3 Kootenay River Discharge

In 2021, mean daily discharge in the Kootenay River below BRD was approximately 100 to 300 m^3/s less than average during most of the spring and summer (Figure 5). Mean daily discharge was near average during the sampling period in 2021 and greater than the historic (2001 to 2020) maximum during most of December.

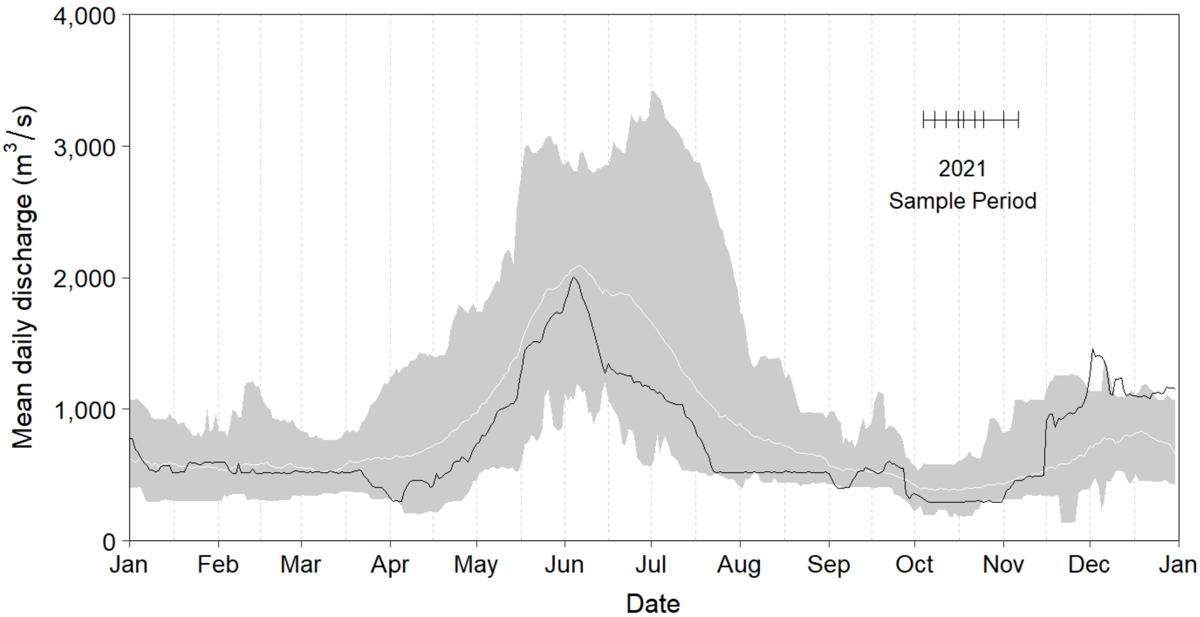


Figure 5: Mean daily discharge (m^3/s) for the Kootenay River at BRD, 2021 (black line). The shaded area represents minimum and maximum mean daily discharge values recorded at the dam from 2001 to 2020. The white line represents average mean daily discharge values over the same time period.

3.1.4 Kootenay River Temperature

In 2021, mean daily water temperature in the Kootenay River downstream of BRD was slightly (<1°C) above average for most of the winter in 2021, 1 to 3°C greater than average from mid-June to mid-August, and near average for the remainder of the year. The historical data from 2001 to 2020 indicate that annual maximum mean water temperatures of approximately 19°C occur in August and annual minimum average temperatures of 4°C occur in January and February (Figure 6). Spot temperature readings for the Kootenay River taken at the time of sampling ranged between 11.3°C and 14.3°C (Appendix B, Table B3).

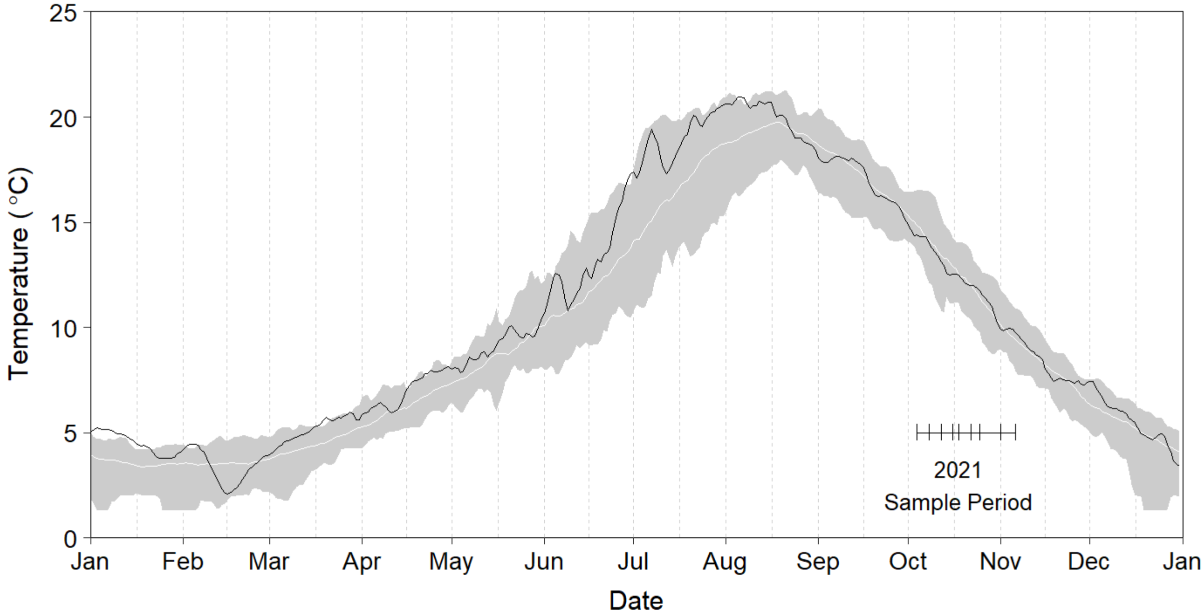


Figure 6: Mean daily water temperature (°C) for the Kootenay River downstream of BRD, 2021 (black line). The shaded area represents minimum and maximum mean daily water temperature values recorded from 2001 to 2020. The white line represents average mean daily water temperature values over the same time period.

3.2 Catch

In total, 17,643 fish were recorded in the LCR in 2021 (Table 4). This total included both captured fish and observed fish that were identified to species at both the index and GRTS sites combined. Comparison of catch between years was limited to index sites, which were sampled in all study years (Appendix E, Table E1). At index sites, the total number of fish recorded in 2021 (n = 13,786) was comparable to the previous three years (n = 10,615 to 13,149 in 2018 to 2020) but lower than in 2016 (n = 20,170) and 2017 (n = 29,080). The total number of sportfish species, defined in Table 4, captured and observed in 2021 (n = 6,153) and 2020 (n = 6,255) was lower than all previous years from 2001 to 2019 (range: 6,701 to 28,472).

Table 4: Number of fish caught and observed during boat electrofishing surveys and their frequency of occurrence in sampled sections of the LCR, 4 October to 5 November 2021. This table includes data from index and GRTS sites.

Species	Columbia River Upstream		Kootenay River		Columbia River Downstream		All Sections	
	n[a]	%[b]	*n*[a]	%[b]	*n*[a]	%[b]	*n*[a]	%[b]
Sportfish								
Brook Trout (*Salvelinus fontinalis*)[c]	0	0	0	0	2	<1	2	<1
Brown Trout (*Salmo trutta*)[c]	0	0	0	0	1	<1	1	<1
Bull Trout (*Salvelinus confluentus*)	2	<1	0	0	1	<1	3	<1
Burbot (*Lota lota*)	0	0	0	0	43	1	43	<1
Kokanee (*Oncorhynchus nerka*)	183	9	1	<1	26	<1	210	2
Lake Whitefish (*Coregonus clupeaformis*)[c]	34	2	65	9	325	5	424	5

Species	Columbia River Upstream		Kootenay River		Columbia River Downstream		All Sections	
	n[a]	%[b]	*n*[a]	%[b]	*n*[a]	%[b]	*n*[a]	%[b]
Mountain Whitefish (*Prosopium williamsoni*)	1041	51	350	46	1371	23	2762	31
Northern Pike (*Esox lucius*)[c]	4	<1	0	0	1	<1	5	<1
Rainbow Trout (*Oncorhynchus mykiss*)	549	27	193	25	3661	61	4403	50
Smallmouth Bass (*Micropterus dolomieui*)[c]	0	0	0	0	1	<1	1	<1
Walleye (*Sanders vitreus*)[c]	189	9	113	15	498	8	800	9
White Sturgeon (*Acipenser transmontanus*)	49	2	41	5	43	1	133	2
Yellow Perch (*Perca flavescens*)[c]	0	0	1	<1	1	<1	2	<1
Sportfish Subtotal	2051	100	764	100	5974	100	8789	100
Non-sportfish								
Common Carp (*Cyprinus carpio*)[c]	0	0	3	<1	1	<1	4	<1
Longnose Dace (*Rhinichthys cataractae*)	0	0	0	0	1	<1	1	<1
Northern Pikeminnow (*Ptychocheilus oregonensis*)	84	3	17	3	29	1	130	1
Peamouth (*Mylocheilus caurinus*)	21	1	0	0	1	<1	22	<1
Redside Shiner (*Richardsonius balteatus*)	229	8	12	2	141	3	382	4
Sculpin spp. (*Cottidae*)[d]	1728	60	475	70	4718	89	6921	78
Sucker spp. (*Catostomidae*)[d]	815	28	170	25	409	8	1394	16
Non-Sportfish Subtotal	2877	100	677	100	5300	100	8854	100
Total	4928	100	1441	100	11274	100	17643	100

[a] Includes fish observed and identified to species; does not include intra-year recaptured fish.
[b] Percent composition of sportfish or non-sportfish catch.
[c] Non-native species in the study area.
[d] Not identified to species or species combined for analysis.

Summaries of catch and effort and life history metrics were used to provide supporting information and to help set initial parameter values in some of the statistical models. Although these summaries are important, they are not presented nor specifically discussed in detail in this report. However, these metrics are provided in the appendices for reference purposes and are referred to when necessary to support or discount results of the models. Metrics presented in the appendices include:

- captured and observed fish count data by site and bank habitat type (Appendix B, Table B4), 2021;
- catch and percent composition by species, 2001 to 2021 (Appendix E, Table E1);
- catch-rates for all sportfish (Appendix E, Table E2) and non-sportfish (Appendix E, Table E3), 2021;
- length-frequency histograms by section for Mountain Whitefish (Appendix F, Figure F1), Rainbow Trout (Appendix F, Figure F2), and Walleye (Appendix F, Figure F3), 2021;
- length-frequency histograms by year for Mountain Whitefish (Appendix F, Figure F4), Rainbow Trout (Appendix F, Figure F5), and Walleye (Appendix F, Figure F6), 2001 to 2021; and
- length-weight relationships by year for Mountain Whitefish (Appendix F, Figure F7), Rainbow Trout (Appendix F, Figure F8), and Walleye (Appendix F, Figure F9), 2001 to 2021.

3.3 Length-At-Age and Growth Rate

Outputs from the length-at-age model are presented in Table 5 and represent the best estimates of the length cutoffs between age-classes of Mountain Whitefish and Rainbow Trout during each sample year. Based on the length-at-age model, four age-classes were distinguishable for Mountain Whitefish and three were distinguishable for Rainbow Trout (Table 5). Length-density plots show the relative frequency of lengths by age-class (Appendix G; Figures G1 and G2). Separate age-classes were not distinguishable based on length-frequency data for Walleye so all individuals were classified as adults. The von Bertalanffy growth curves show the average rate of growth and asymptotic size for Mountain Whitefish and Rainbow Trout (Figure 7). The von Bertalanffy growth curve for Walleye is not shown because predictions of length-at-age were not realistic for younger fish, as discussed in Section 3.3.3.

Table 5: Estimated minimum and maximum fork lengths (in mm) by age-class and year for Mountain Whitefish and Rainbow Trout in the lower Columbia River, 1990 to 1991 and 2001 to 2021. Estimates were derived from the length-at-age model (Section 2.2.3).

Year	Mountain Whitefish				Rainbow Trout		
	Age-0	Age-1	Age-2	Age-3+	Age-0	Age-1	Age-2+
1990	≤163	164–274	≥275	≥275	≤155	156–355	≥356
1991	≤144	145–226	227–296	≥297	≤129	130–347	≥348
2001	≤141	142–258	259–344	≥345	≤133	134–326	≥327
2002	≤163	164–261	262–344	≥345	≤154	155–352	≥353
2003	≤159	160–263	264–354	≥355	≤161	162–345	≥346
2004	≤158	159–249	250–342	≥343	≤142	143–335	≥336
2005	≤168	169–263	264–363	≥364	≤164	165–349	≥350
2006	≤175	176–284	285–357	≥358	≤170	171–367	≥368
2007	≤171	172–280	281–337	≥338	≤166	167–377	≥378
2008	≤170	171–247	248–340	≥341	≤145	146–342	≥343
2009	≤169	170–265	266–355	≥356	≤147	148–341	≥342
2010	≤177	178–272	273–352	≥353	≤143	144–339	≥340
2011	≤163	164–269	270–348	≥349	≤156	157–346	≥347
2012	≤162	163–268	269–347	≥348	≤152	153–346	≥347
2013	≤185	186–282	283–349	≥350	≤169	170–357	≥358
2014	≤178	179–284	285–362	≥363	≤155	156–340	≥341
2015	≤167	168–278	279–366	≥367	≤166	167–337	≥338
2016	≤164	165–283	284–352	≥353	≤154	155–340	≥341
2017	≤158	159–270	271–354	≥355	≤133	134–320	≥321
2018	≤177	178–262	263–346	≥347	≤139	140–312	≥313
2019	≤188	189–282	283–363	≥364	≤160	161–317	≥318
2020	≤166	167–291	292–365	≥366	≤154	155–349	≥350
2021	≤165	166–275	276–349	≥350	≤169	170–349	≥350

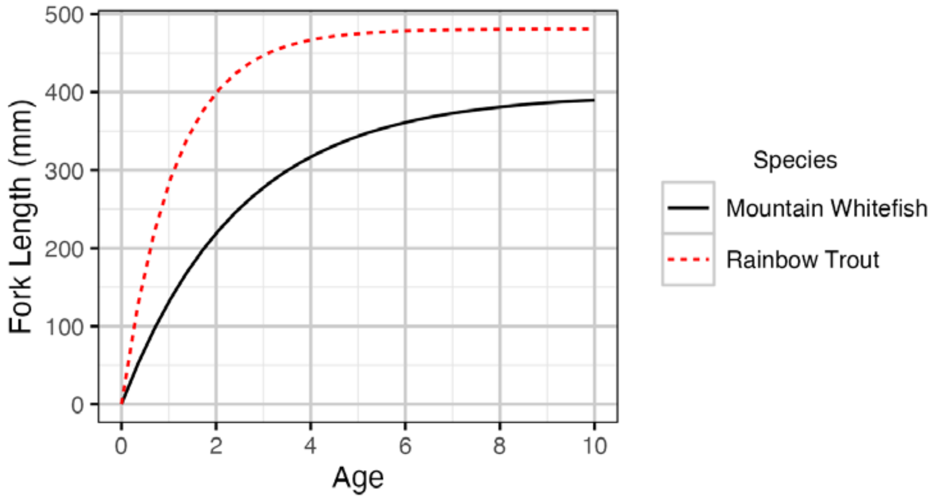


Figure 7: **Growth curve showing length-at-age by species as predicted by the von Bertalanffy model for the lower Columbia River, 2001–2021.**

3.3.1 Mountain Whitefish

The mean fork length of Mountain Whitefish fry (age-0) in 2021 (130 mm; Figure 8) was within the typical range of most previous years (120 to 140 mm). In 2016, 2018 and 2019, age-0 length-at-age was greater than average (156, 142 and 150 mm, respectively). Two years, 1991 and 2001, had smaller length-at-age (approximately 100 mm) for age-0 Mountain Whitefish than all other years. The length-at-age of age-1, age-2, and age-3 and older age-classes are not presented because they depend on growth in more than one previous year, which complicates interpretation.

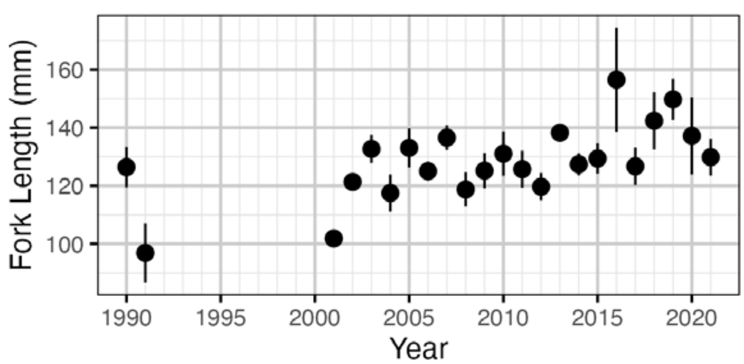


Figure 8: **Mean fork length of age-0 Mountain Whitefish in the lower Columbia River, 1990 to 1991 and 2001 to 2021.**

Analysis of growth of recaptured Mountain Whitefish indicated generally increasing annual growth between 2005 and 2016 with the exception of 2010 and 2012 (Figure 9). Growth was lower in 2017 to 2019, with effect sizes of -0.3% to -14%, but increased to 47% in 2020 and 71% in 2021. These effect sizes are based on the growth coefficient, k, in a particular year compared to a typical year. The predicted maximum growth rate during early life (at a fork length of 0 mm) increased from 87 mm/yr in 2005 to 244 mm/yr in 2016, decreased to 135 mm/yr in 2017, followed by an increase to 267 mm/yr by 2021 (Figure 10).

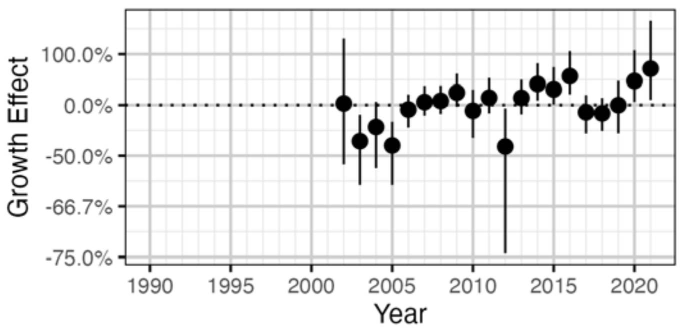


Figure 9: **Estimated percent change in the von Bertalanffy growth coefficient (mean with 95% CIs) relative to a typical year for Mountain Whitefish based on recaptured individuals in the lower Columbia River, 2001 to 2021.**

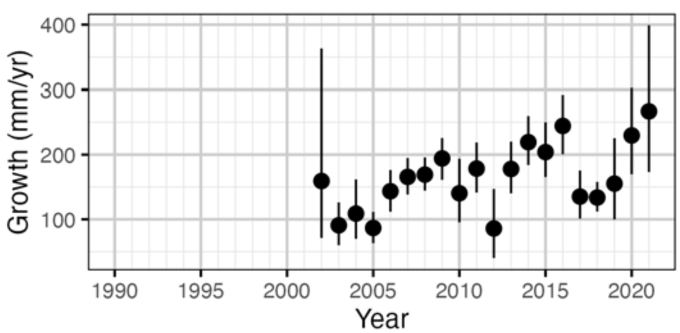


Figure 10: **Predicted maximum growth rate (mean with 95% CIs) from the von Bertalanffy model for Mountain Whitefish based on recaptured individuals in the lower Columbia River, 2001 to 2021.**

3.3.2 Rainbow Trout

The length-at-age model indicated an increase in the mean length of Rainbow Trout fry (age-0) from 106 mm in 2011 to 144 mm in 2015 (Figure 11). Mean length of age-0 Rainbow Trout varied from 102 to 127 mm between 2016 and 2021. The greater uncertainty in the estimates from 2015 to 2020 than previous years was due to lower catches of age-0 Rainbow Trout during these years. Catches of age-0 Rainbow Trout ranged from 2 to 18 fish per year between 2015 and 2020 and between 20 and 316 fish per year between 2001 and 2014. In 2021, 30 Rainbow Trout were assigned a life stage of age-0 based on their body length. Mean length-at-age of fry was much lower in 1991 (91 mm) and 2001 (90 mm) than other years. Length-at-age is not presented for subadult (age-1) or adult (age-2 and older) Rainbow Trout because more than one previous year affects the length-at-age, which complicates interpretation.

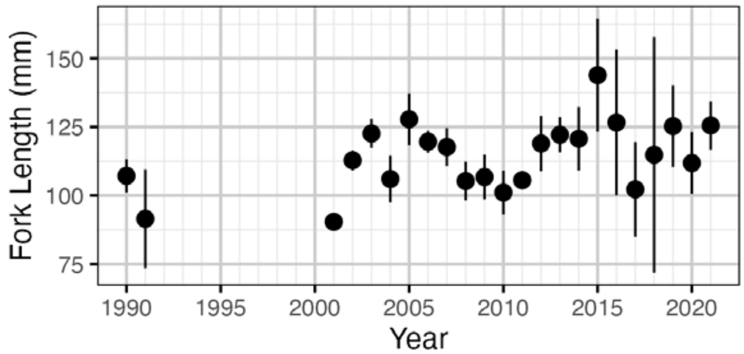


Figure 11: Mean fork length of age-0 Rainbow Trout in the lower Columbia River, 1990 to 1991 and 2001 to 2021.

Analysis of annual growth of recaptured Rainbow Trout indicated a low growth coefficient in 2003 and 2004 (-14% to -30% effect size; Figure 12). Estimates of the growth coefficient generally declined from a 57% effect size in 2006 to -40% in 2018. The estimated growth coefficient increased to -27% in 2019 and -4% in 2020, and 11% in 2021, suggesting a recovery in growth to near-average values.

The predicted maximum growth during early life suggested a similar trend as the growth coefficient with a decrease from 664 mm/yr in 2006 to 253 mm/yr in 2018 and an increase to 402 mm/yr in 2020 and 466 mm/yr in 2021 (Figure 13). These maximum growth rates represent the theoretical maximum growth rate when fish are 0 mm in length, and therefore should not be interpreted as the rate for the entire first year of life. The large decrease in maximum growth rate during the study period (664 to 253 mm/yr) suggests a substantial change in growth.

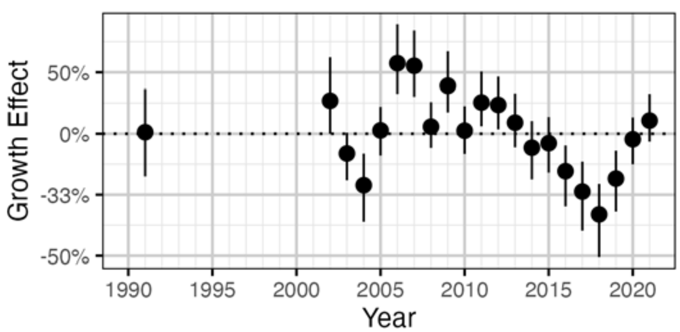


Figure 12: Estimated percent change in the von Bertalanffy growth coefficient (mean with 95% CIs) relative to a typical year for Rainbow Trout based on recaptured individuals in the lower Columbia River, 2001 to 2021.

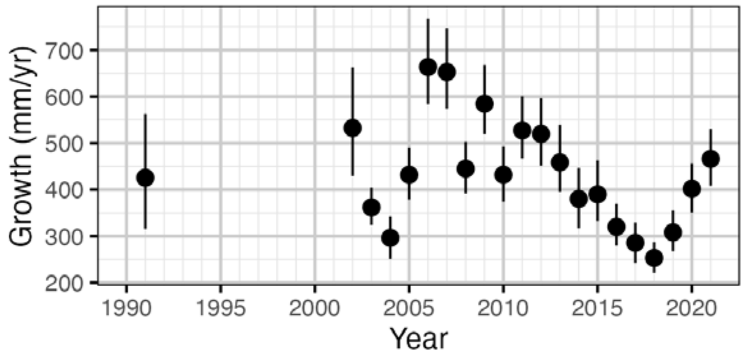


Figure 13: Predicted maximum growth rate (mean with 95% CIs) from the von Bertalanffy model for Rainbow Trout based on recaptured individuals in the lower Columbia River, 2001 to 2021.

3.3.3 Walleye

Analysis of annual growth of recaptured Walleye indicated a near-average growth coefficient in 2021 with an effect size of 17%, which was within the range of effect sizes observed in most years (typical range of -25% to 34%; Figure 14). The estimated growth coefficient generally increased from 2010 (-23% effect size) until 2016 (31%), but there was a very high growth coefficient (84%) in 2013. Credible intervals for the growth coefficient were large because of large variability in the annual growth among recaptured Walleye of all sizes. For instance, annual growth of Walleye initially captured at ~300 mm in fork length varied from ~15 to 70 mm/year, and growth of Walleye initially captured at ~500 mm ranged from ~5 to 60 mm (data not shown). Because of the large variability in annual growth, especially for the largest Walleye, the von Bertalanffy curve (Figure 7) and effect size based on the model's growth coefficient (Figure 14) were calculated using only Walleye <450 mm in fork length. Predicted values of maximum growth rate during early life ranged from 36 to 82 mm, except in 2013 when the maximum growth rate was 112 mm/yr (Figure 15).

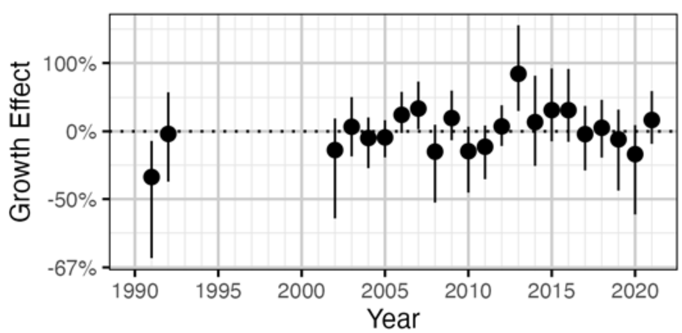


Figure 14: Estimated percent change in the von Bertalanffy growth coefficient (mean with 95% CIs) relative to a typical year for Walleye based on recaptured individuals <450 mm in fork length in the lower Columbia River, 2001 to 2021.

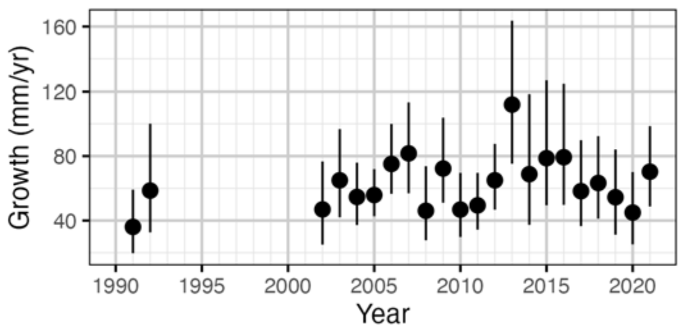


Figure 15: Predicted maximum growth rate (mean with 95% CIs) from the von Bertalanffy model for Walleye based on recaptured individuals in the lower Columbia River, 2001 to 2021.

3.3.4 Observer Length Correction

The lengths of fish estimated by observers were compared to the measured lengths of captured fish to estimate bias in the observer's estimates. The length bias model using this data suggested that most observers underestimated fork lengths for all three index species (Appendix G, Figure G3). The inaccuracy for Mountain Whitefish varied by observer with bias of -40 to 40 mm relative to captured fish of known length (Appendix G, Figure G4). Inaccuracy of Rainbow Trout lengths varied between -60 and 10 mm. Inaccuracy in estimated Walleye fork lengths ranged between -80 and 40 mm. Estimates of observer bias were used to correct estimated fork lengths (Appendix G, Figure G5) before classifying fish into age-classes for abundance analyses.

3.4 Spatial Distribution and Abundance

3.4.1 Site Fidelity

Site fidelity was greater for Rainbow Trout (20% to 61%) and Walleye (29% to 50%) than for Mountain Whitefish (15% to 25%; Figure 16). Site fidelity decreased with increasing fork length for all three species, but the predicted slope indicated a larger effect of length for Rainbow Trout than for Mountain Whitefish or Walleye (Figure 16).

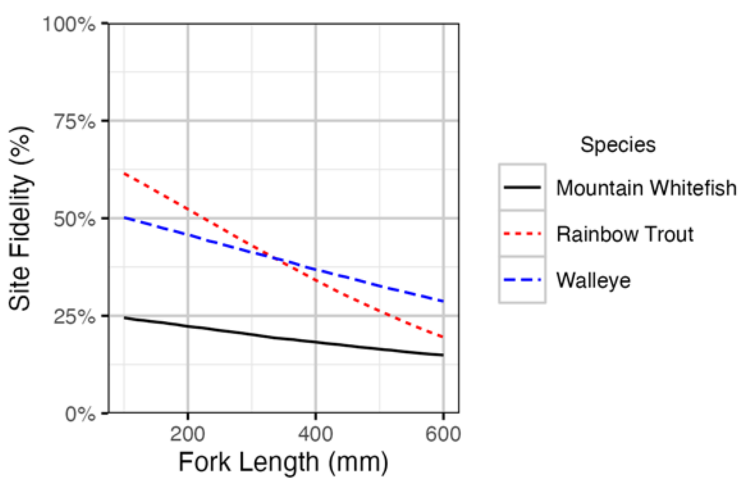


Figure 16: Site fidelity, defined as the expected probability that a fish is recaptured at the same site where it was marked, by species and fork length in the lower Columbia River, 2001 to 2021.

3.4.2 Efficiency

Estimated capture efficiency was greatest for Rainbow Trout (3.1% to 4.7%) and lowest for Mountain Whitefish (~1%; Figure 17). Capture efficiency was lower for adult (3.1%) than subadult (4.7%) Rainbow Trout but similar between subadult and adult Mountain Whitefish. The estimated capture efficiency of Walleye was 2.0%. For most species and age-classes, capture efficiency was similar among sampling sessions and years without any apparent seasonal or temporal trends (Appendix G, Figures G6–G10). One exception was that in some years the capture efficiency of subadult Rainbow Trout and Walleye decreased in subsequent sample sessions (Appendix G, Figures G8 and G10). Estimates of capture efficiency were used to estimate total abundance in the sample sites (Section 3.4.3–3.4.5). Capture efficiency did change substantially with fish increasing density for Mountain Whitefish or Walleye (Appendix G, Figure G9). Capture efficiency decreased with increasing density of Rainbow Trout for both subadult and adult life stages (Appendix G, Figure G11).

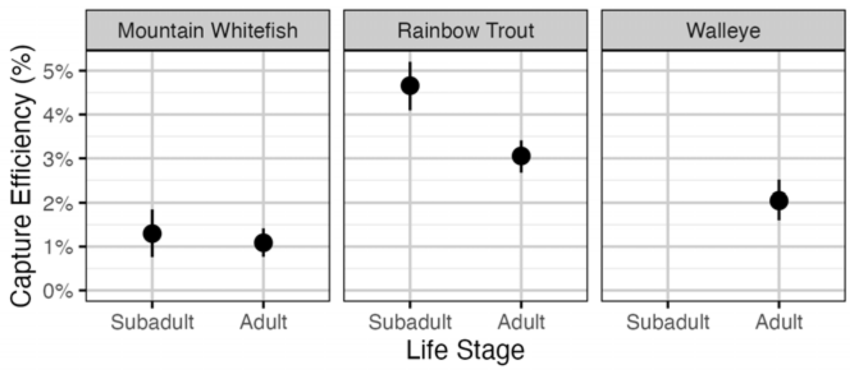


Figure 17: Capture efficiency (mean with 95% CIs) by species from mark-recapture data from the lower Columbia River, 2001–2021.

3.4.3 Mountain Whitefish

The estimated abundance of subadult Mountain Whitefish in index sites in the LCR was much greater in 2001 and 2002 (59,000–66,000) than all other years (Figure 18). In 2018 to 2021, the estimated abundance of subadult Mountain Whitefish (10,000–20,000) was less than the values from the previous five years (29,000–32,000). Estimates of adult Mountain Whitefish abundance have been relatively stable between 2010 and 2021 (45,000–50,000) with the exception of 2018 when the estimate was higher (59,000).

A change to the abundance model implemented in 2021 was made to allow the effect of year to depend on the density of the site, such that sites with low density can increase more than sites with high density, as overall abundance increases. For subadult Mountain Whitefish, low and high density sites increased in density at similar rates between years of low and high abundance (Appendix G, Figure G12). In contrast, for adult Mountain Whitefish at high density sites, there was little difference in density between years with low and high overall abundance. At low density sites, the density of adults increased as expected with increasing overall abundance.

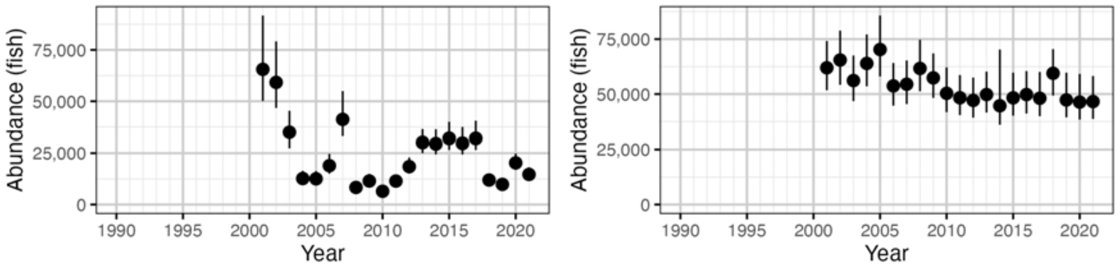


Figure 18: Abundance (means with 95% CIs) of subadult (age-1; left panel) and adult (age-2 and older; right panel) Mountain Whitefish at index sites in the lower Columbia River, 2001–2021.

The density of both subadult and adult Mountain Whitefish was highest near the confluence of the Columbia and Kootenay rivers and lowest near the Canada-US border (Figure 19). Subadult Mountain Whitefish densities were highest in low water velocity areas, such as Balfour Bay (RKm 2.8), just downstream of the log booms near Zellstoff-Celgar (both banks; RKm 4.5), upstream and downstream of Norn's Creek Fan (RKm 7.4), and along the left bank between Waldie Island and Tin Cup Rapids (RKm 9.2; Figure 19). Subadult Mountain Whitefish densities were low in the Kootenay River and in the Columbia River downstream of the Kootenay River confluence, river sections that typically have higher water velocities. Density estimates of adult Mountain Whitefish were generally higher in sites known to contain suitable spawning habitat for this species. These areas include Norn's Creek Fan (RKm 7.4) downstream to CPR Island, the Kootenay River, between the Kootenay River confluence (RKm 10.6) and Kinnaird Bridge (RKm 13.4), and the Genelle area (RKm 27.0).

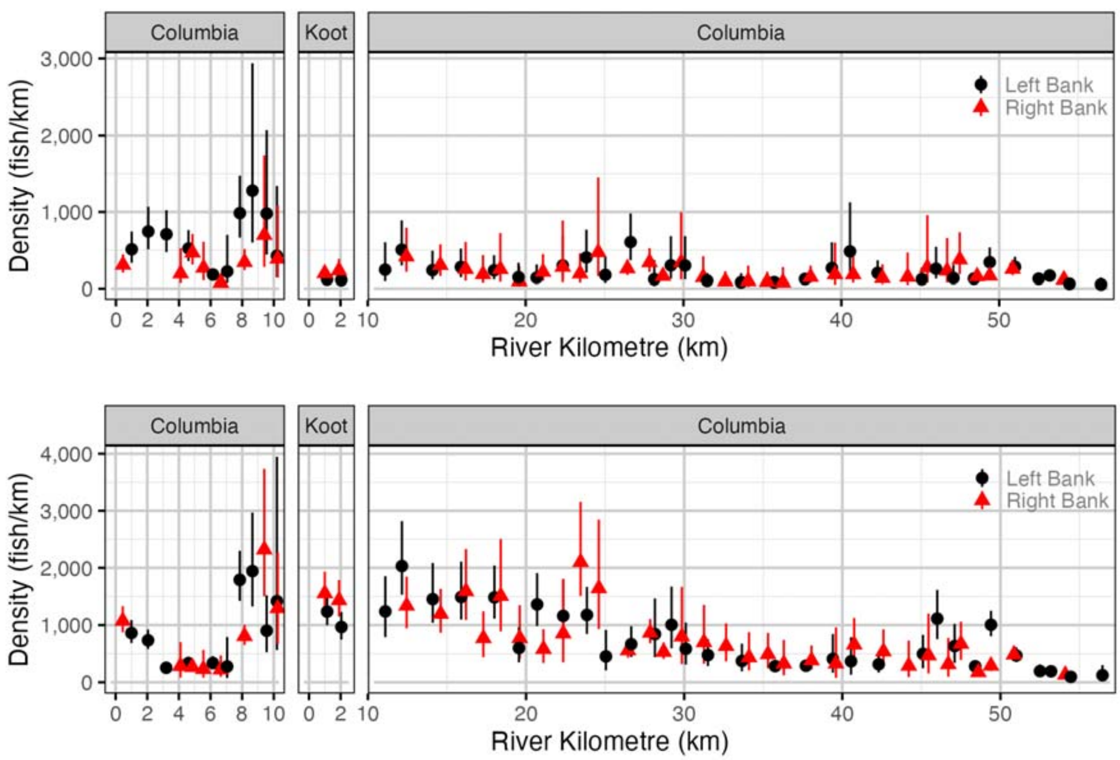


Figure 19: Density (means with 95% CIs) of subadult (age-1; top panel) and adult (age-2 and older; bottom panel) Mountain Whitefish by river kilometre in the lower Columbia River, 2001–2021.

The evenness in the distribution of subadult Mountain Whitefish among index sites decreased by 8% in 2021 and was lower than nearly all previous years (Figure 20; left panel). Evenness of adult Mountain Whitefish distribution declined by 11% from 2001 (97%) to 2007 (91%) and ranged from 85% to 93% between 2008 and 2021 (Figure 20; right panel). The density of subadult Mountain Whitefish at randomly selected non-index sites sampled during the GRTS survey was similar, on average, to the density at index sites (Appendix G, Figure G13). The density of adult Mountain Whitefish was greater at random sampled GRTS sites than at index sites, with the difference ranging from 10% to 100% (Appendix G, Figure G14).

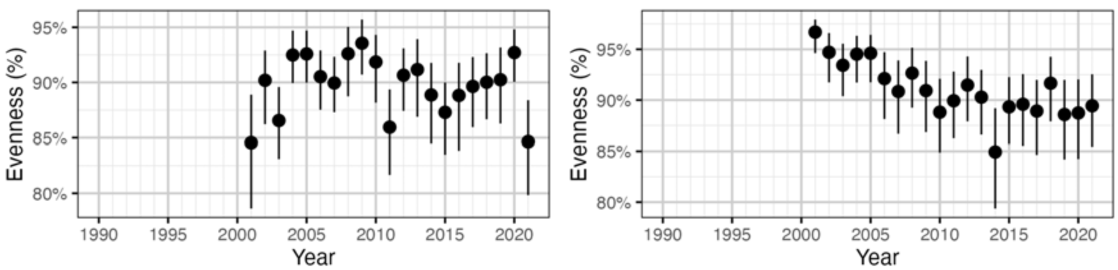


Figure 20: Estimated evenness in abundance between index sites for subadult (left) and adult (right) Mountain Whitefish by year.

3.4.4 Rainbow Trout

The abundance of subadult Rainbow Trout declined from 2001 to 2005 and fluctuated with no long-term increase or decrease from 2006 to 2017 (Figure 21). The estimated abundance of subadult Rainbow Trout was relative stable between 2012 and 2021 (16,000 to 20,000), except in 2018 and 2019 when estimates were lower (9,000 and 8,000, respectively). Adult Rainbow Trout abundance estimates increased from ~22,000 in 2002 to 42,000 in 2018, with a decrease to 37,000 in 2019, 32,000 in 2020, and 33,000 in 2021.

For subadult Rainbow Trout, low and high density sites increased in density at similar rates between years of low and high abundance (Appendix G, Figure G12). For adult Rainbow Trout at high density sites, there was little difference in density between years with low and high overall abundance. At low density sites, the density of adults increased as expected with increasing overall abundance.

Site-specific density estimates of Rainbow Trout had large credible intervals (Figure 22), particularly at sites that were only sampled in some years between 2012 and 2021 (i.e., GRTS sites). The analysis suggests higher densities of subadult Rainbow Trout in most sites between Genelle (RKm 21.0) and Beaver Creek (RKm 47.8) than in other sections of the study area (Figure 22). The distribution of adult Rainbow Trout was similar to that of subadults with greater densities in the Columbia River between the Kootenay River confluence and the Beaver Creek confluence and lower densities in the Columbia River upstream of the Kootenay River confluence (Figure 22). Adult Rainbow Trout densities were substantially higher below the Bear Creek confluence (Sites C46.4-L and C45.6-L), from the Birchbank side channel to Murphy Creek (both banks; C30.5-R and C30.6-L), between the Champion Creek and Jordan Creek confluences (Site C24.3-L), and on the opposing bank downstream of the Kootenay River confluence (Site C11.5-R) when compared to neighbouring sites.

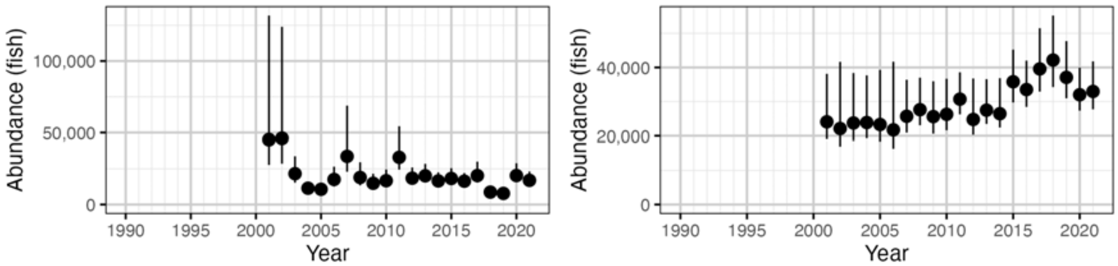


Figure 21: Abundance (means with 95% CIs) of subadult (age-1; left panel) and adult (age-2 and older; right panel) Rainbow Trout at index sites in the lower Columbia River, 2001–2021.

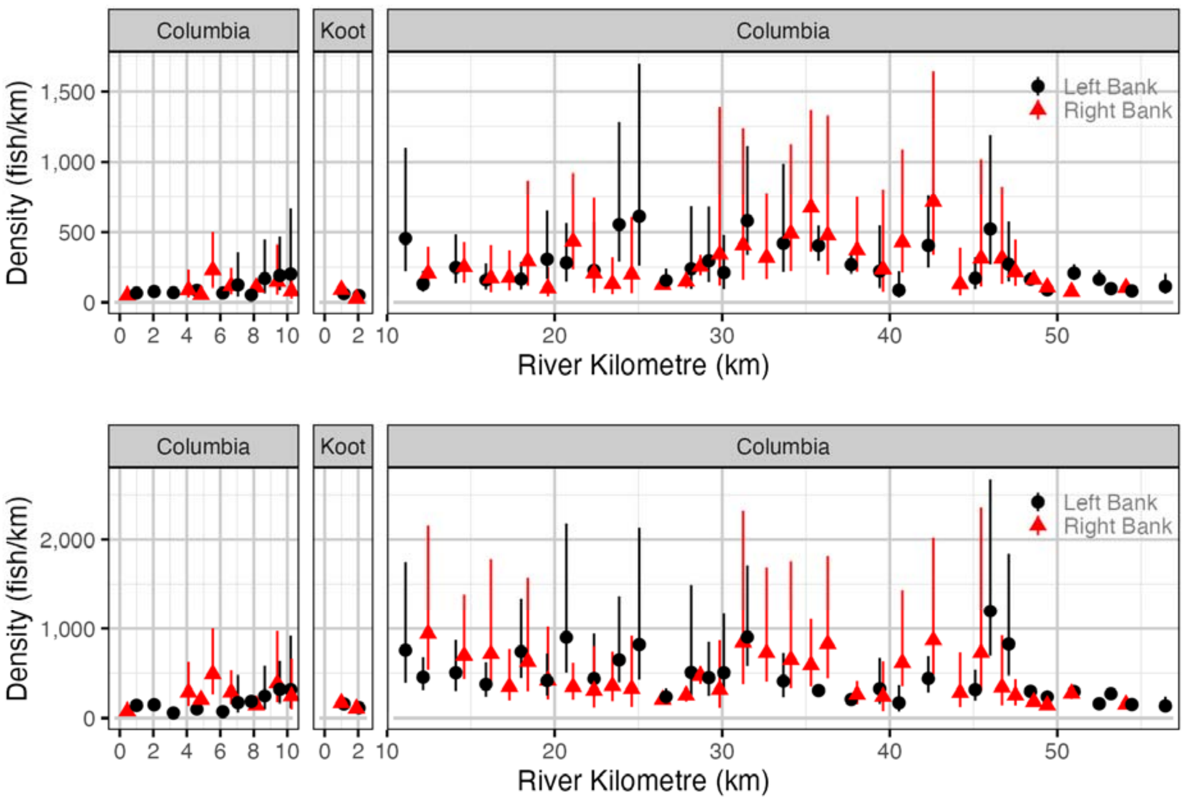
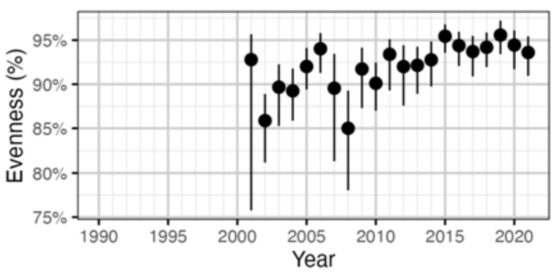


Figure 22: Density (means with 95% CIs) of subadult (age-1; top panel) and adult (age-2 and older; bottom panel) Rainbow Trout by river kilometre in the lower Columbia River, 2001–2021.

Evenness in the abundance of subadult Rainbow Trout between index sites generally increased from 2002 (86%) to 2021 (94%), with the exception of lower evenness in 2008 (Figure 23; left panel). The evenness of adult Rainbow Trout distribution in index sites increased between the early 2000s (92% to 94%) and 2021 (97%; Figure 23; right panel). The density of Rainbow Trout was approximately 100% to 250% greater at randomly selected non-index sites sampled during the GRTS survey than at index sites for both subadults and adults (Appendix G, Figure G15).



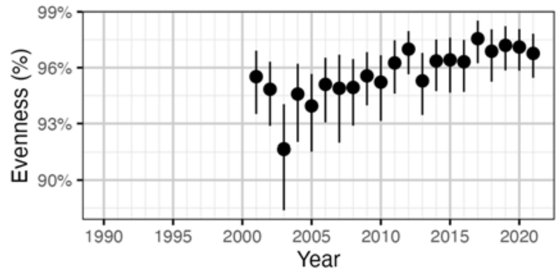


Figure 23: Estimated evenness in abundance between index sites for subadult (left) and adult (right) Rainbow Trout by year.

3.4.5 Walleye

Since 2001, Walleye abundance fluctuated with peaks in 2003 to 2005 and in 2011 (Figure 24). Walleye abundance estimates remained relatively stable between 2012 and 2021 (10,000–15,000). Low and high density sites increased in density at similar rates between years of low and high abundance for adult Walleye (Appendix G, Figure G12).

Density estimates for Walleye were greatest in the Kootenay River (Sites K0.6-R, K0.3-L and K1.38L), downstream of HLK (Site C1.3-L), in a small bay downstream of Bear Creek (Site C45.6-L), and at the site adjacent to the Canada-US border (C56.0-L; Figure 25). Density estimates for all other areas were similar and did not suggest differences in Walleye densities among sites.

The evenness in abundance of Walleye between index sites decreased from ~99% in the early 2000s to values 97% to 98% in 2010 to 2021 (Figure 26). The density at sites randomly selected non-index sites sampled during the GRTS survey was comparable to but slightly lower than the density at index sites (Appendix G, Figure G16).

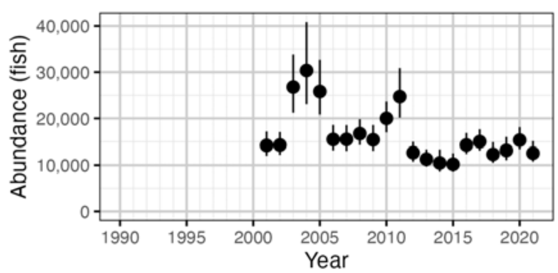


Figure 24: Abundance (means with 95% CIs) of Walleye (all age-classes) at index sample sites in the lower Columbia River, 2001–2021.

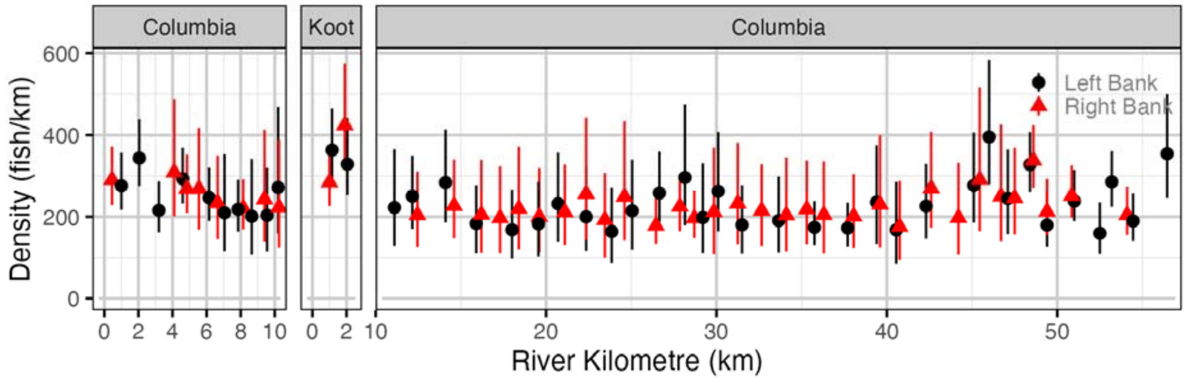


Figure 25: Density (means with 95% CIs) of Walleye (all age-classes) by river kilometre in the lower Columbia River, 2001–2021.

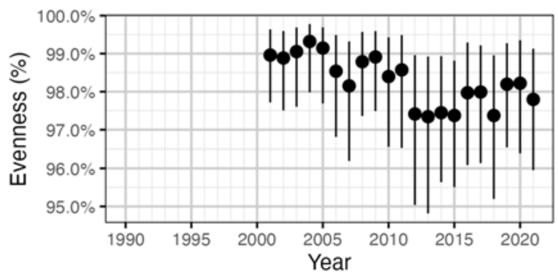


Figure 26: Estimated evenness in abundance between index sites for Walleye at index sites by year.

3.4.6 Geo-referenced Visual Enumeration Surveys

The visual surveys provided data regarding the within-site distribution of fish in the LCR. Maps showing the observed densities of the three index species by age-class distributed throughout sample sites are provided as an example of the spatial dataset (Appendix H). This type of map can be used to identify important fish habitats, and to compare to future years to assess the effects of flow regime variations on fish distribution and habitat usage.

3.5 Survival

3.5.1 Mountain Whitefish

For adult Mountain Whitefish, annual survival estimates varied from 21% to 93%. Adult survival generally increased between 2002 and 2008 and was relatively stable between 2011 and 2021 (64%–86%; Figure 27). The inter-annual capture efficiency, on which the survival estimate was based, was approximately 1%–4% (Appendix G, Figure G17).

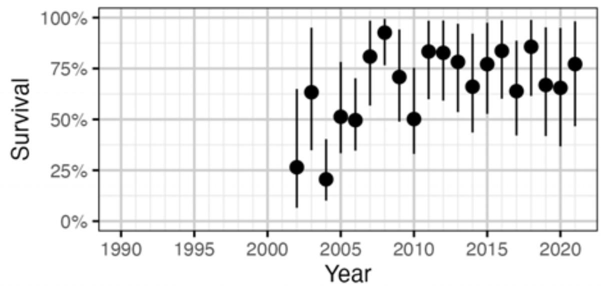


Figure 27: Survival estimates (mean with 95% CIs) for adult (age-2 and older) Mountain Whitefish in the lower Columbia River, 2001–2021.

The abundance-based survival estimates for subadult and adult Mountain Whitefish generally increased from 2002 to 2011, decreased from 2012 to 2017, and were near average in 2018 to 2021 (Figure 28). Overall, annual abundance-based survival estimates ranged between 60% and 91% except for lower values in 2002, 2003 and 2014 (45% to 56%). Abundance-based estimates of survival in the last four years (66% to 81%; Figure 28) were comparable to survival estimates from mark-recapture data (65% to 86%; Figure 27).

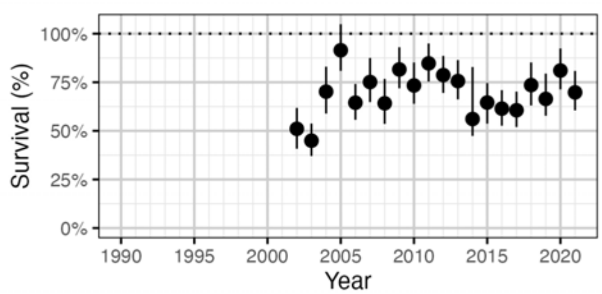


Figure 28: Abundance-based survival estimates (mean with 95% CIs) for subadult and adult Mountain Whitefish by year.

3.5.2 Rainbow Trout

Survival estimates of Rainbow Trout increased gradually from 32% in 2003 to 54% in 2011, followed by a decrease to 34% in 2012, a gradual increase to 48% in 2020 and a decrease to 40% in 2021 (Figure 29). The inter-annual capture efficiency was 7%–8% (Appendix G, Figure G18).

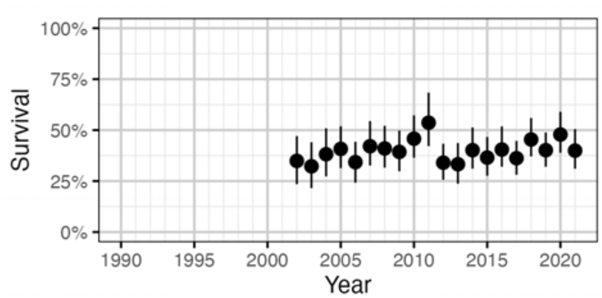


Figure 29: Survival estimates (mean with 95% CIs) for adult (age-2 and older) Rainbow Trout in the lower Columbia River, 2001–2021.

Abundance-based survival of Rainbow Trout showed an increasing trend between 2002 and 2011 and high inter-annual variation from 2012 to 2016 (Figure 30). Abundance-based survival estimates decreased from 79% in 2017 to 62% in 2021. Estimates were lowest in 2002 (32%) and highest in 2015 (82%).

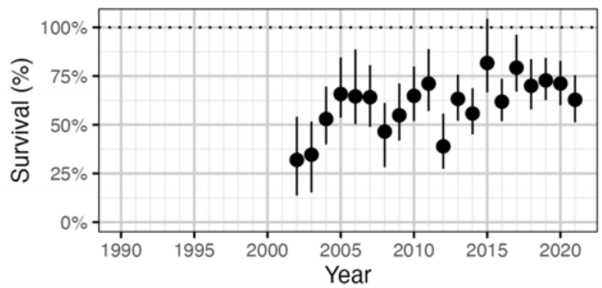


Figure 30: Abundance-based survival estimates (mean with 95% CIs) for subadult and adult Rainbow Trout.

3.5.3 Walleye

The estimated survival of Walleye ranged between 42% and 63% throughout the study period, with the exception of a drop in survival to 33% in 2004 (Figure 31). In recent years, the results indicated a decrease in survival from 63% in 2016 to 45% in 2019, but an increase to 57% in 2020 and 61% in 2021. However, credible intervals overlapped for all years. The inter-annual capture efficiency was 3%–4% (Appendix G, Figure G19).

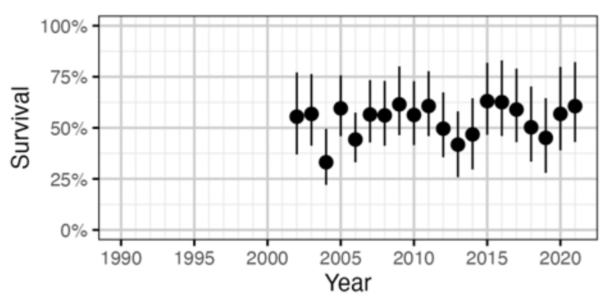


Figure 31: Survival estimates (mean with 95% CIs) for Walleye (all age-classes) in the lower Columbia River, 2001–2021.

3.6 Body Condition

3.6.1 Mountain Whitefish

The body condition of subadult Mountain Whitefish varied little from 2008 to 2015 (-1% to 2%), was stable between 2016 and 2021 (2%–3%) except for lower condition (-2%) in 2017 (Figure 32; left panel). Adult Mountain Whitefish body condition was stable between 2010 and 2015, with effect sizes of 2% to 3%, but was greater in 2019 to 2021 (4%–7%; Figure 32; right panel). Adult body condition was much lower in the 1990s than between 2001 and 2021, with effect sizes 6% to 16% lower than a typical year.

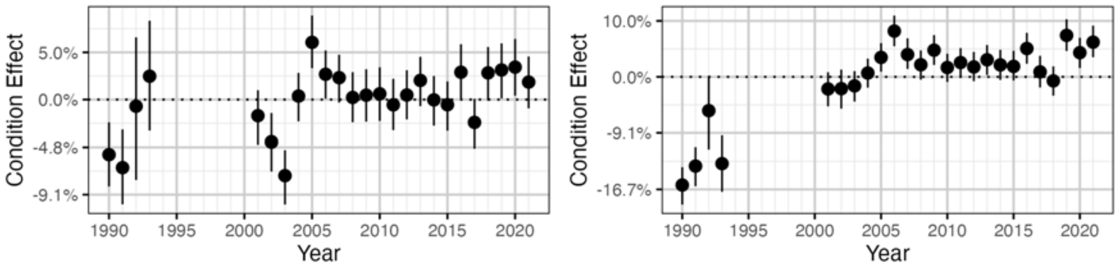


Figure 32: Body condition effect size estimates (mean with 95% CIs) for subadult (200 mm; left panel) and adult (350 mm; right panel) Mountain Whitefish in the lower Columbia River, 1990 to 1993 and 2001 to 2021.

3.6.2 Rainbow Trout

The estimated body condition of subadult and adult Rainbow Trout was higher in 2002 and 2006 than in other study years (Figure 33). Since 2008, subadult body condition was relatively stable with effect sizes near 0% except for higher body condition in 2013 (3%) and low body condition in 2017 (-4%). Adult body condition declined from 3% in 2011 to -7% in 2018, which coincided with increasing abundance estimates (Section 3.4.4). Adult body condition was near average between 2019 and 2021 (-1% to 2%).

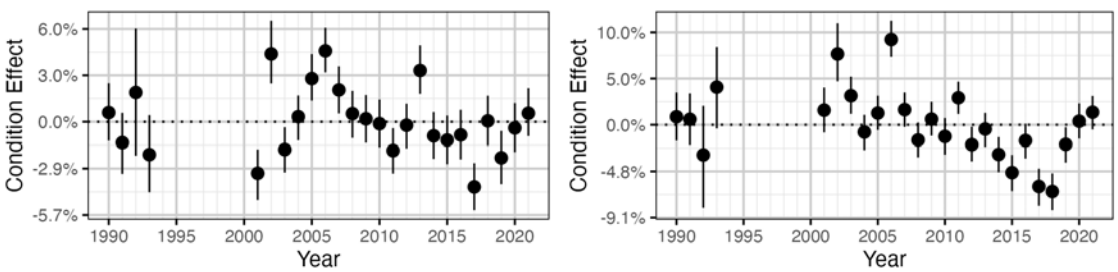


Figure 33: Body condition effect size estimates (mean with 95% CIs) for subadult (250 mm; left panel) and adult (500 mm; right panel) Rainbow Trout in the lower Columbia River, 1990 to 1993 and 2001 to 2021.

3.6.3 Walleye

Walleye body condition fluctuated with no consistent trend between 1990 and 2011 (Figure 34). Body condition estimates were high in 2012 to 2016 (3% to 5%), declined to more typical values during 2017 to 2020 (-1% to 0%) and increased to 2% in 2021.

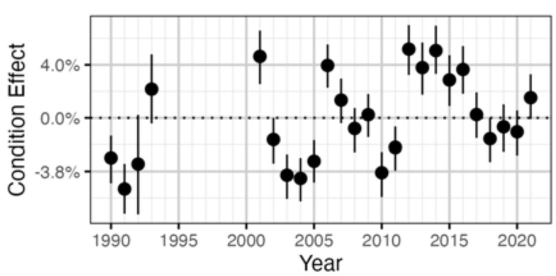


Figure 34: Body condition effect size estimates (median with 95% CIs) by year for a 600 mm Walleye in the lower Columbia River, 1990 to 1993 and 2001 to 2021.

3.7 Age Ratios

The estimated proportion of Mountain Whitefish egg mortality due to dewatering ranged from 7% in 2010 to 59% in 2016 (Figure 35). The age-1:2 ratio for Mountain Whitefish was used as an indicator of annual recruitment strength and ranged from a minimum of 25% for the 2003 spawning year to a maximum of 79% in 2005 (Figure 36). For the 2016 spawning year, which corresponds to catch of age-1 and age-2 individuals during the 2018 survey, the age-1:2 ratio decreased to 34%, which was substantially lower than the previous six years when the ratio ranged from 63% to 74%. The decrease in age-1:2 ratio for the 2016 spawning year coincided with the large estimated egg loss that year, when an estimated 59% of eggs were dewatered. However, the age-1:2 ratio remained low (44%) in 2017 when the egg loss estimate was only 14%. In the most recent spawning year for which data are available (2019), estimated egg loss (28%) was within the range of typical values and the age-1:2 ratio increased to 67%.

To test for the effect of egg loss on the age-1:2 ratio, the logged ratio of age-1 egg loss to age-2 egg loss was used as the predictor variable to account for both age-1 egg loss one year prior and age-2 egg loss two years prior. There was no clear directionality in the relationship between the age-1:2 ratio and estimated egg losses (s-value=0.9, *P*=0.5). The data suggested a negative relationship between age-1:2 ratio and logged egg loss ratio (Figure 37) but large variability resulted in a non-statistically significant regression slope. Although this relationship was not significant, the effect size of egg loss on recruitment is shown in Figure 38. The model predicts a 21% decrease in recruitment at 50% egg loss compared to the recruitment at 10% egg loss (Figure 38). At 50% egg loss, although the mean prediction was a 21% decrease (relative to 10% egg loss), the 95% credible interval for the effect on recruitment ranged from a 62% decrease to a 73% increase, which indicates considerable uncertainty in the relationship. This uncertainty was due to highly variable recruitment at similar levels of egg loss. For instance, recruitment was either high (2011 and 2012) or low (2002, 2008, and 2016) during the greatest levels of egg loss (Figure 37). This suggests that there was not a consistent negative effect of egg loss on the age-1:2 recruitment index based on the available data, and that factors other than egg loss are contributing to the large variability in age-1:2 ratio.

Age ratios could not be estimated for Rainbow Trout because reliable scale-based ages were not available and age-2 fish could not be identified by fork length alone, like they were for Mountain Whitefish, because of overlapping length distributions between age-2 and older age classes of Rainbow Trout.

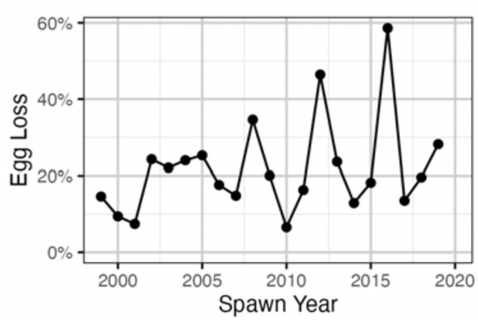


Figure 35: Estimated proportion of Mountain Whitefish egg loss due to dewatering in the lower Columbia River by spawning year, 1999 to 2019, based on the egg loss model.

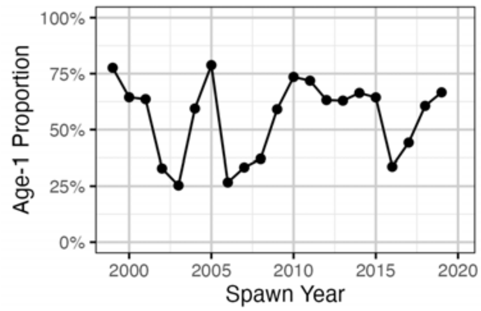


Figure 36: Proportion of age-1 to age-2 Mountain Whitefish in boat electrofishing catch in the lower Columbia River by spawning year, 1999 to 2019.

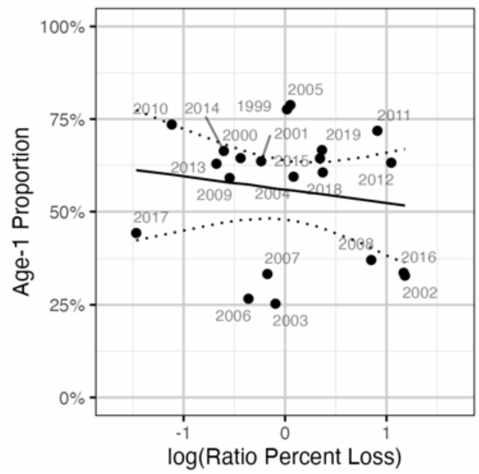


Figure 37: Relationship between the proportion of age-1 to age-2 Mountain Whitefish and the estimated proportion of Mountain Whitefish egg loss due to dewatering. Year labels represent the spawning year. The predicted relationship is indicated by the solid black line and dotted line represents the 95% CI.

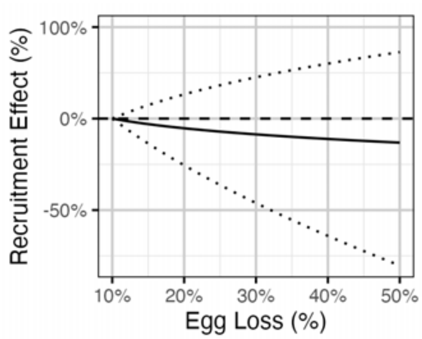


Figure 38: Predicted percent change in age-1 Mountain Whitefish abundance by egg loss in the spawn year relative to 10% egg loss in the spawn year (with 95% CIs).

3.8 Stock-Recruitment Relationship

3.8.1 Mountain Whitefish

The stock-recruitment relationship indicated large variation in the recruitment for Mountain Whitefish data in the LCR (Figure 39). Based on the available data, the variability in recruitment was not related to the number of spawning adults or the estimated egg loss due to dewatering. The majority of years suggested little effect of increasing the estimated number of eggs deposited by spawning adults ("stock") on the resulting number of age-1 recruits, which is consistent with density-dependent survival, where egg survival is lower at high numbers of spawners (Figure 40). An exception was the 2005 spawning year which had the greatest number of adults and greater recruitment than all other years. There were no years with data that allowed assessment of the shape of the curve at small stock size. Therefore, the egg survival at low stock abundance and the number of spawners below which the number of recruits is predicted to decrease is not known based on this analysis.

The direction of the effect of egg dewatering mortality on recruitment was highly uncertain (Figure 41). The effect of egg dewatering mortality on recruitment had an s-value of 0.5, which is equivalent to a p-value of 0.7, and suggests that the effect is not statistically significant. However, the stock-recruitment curve did not have any data on the lower part of the curve where decreased stock or increased egg loss would be expected to result in a large decrease in recruitment. Estimates of the effect of egg dewatering mortality showed high uncertainty with the possible effect size ranging from a 121% increase to a 63% decrease in recruitment when egg dewatering mortality was 40%. The most likely effect (i.e., predicted mean value) was a 17% decrease in recruitment when egg dewatering mortality was 40%. Therefore, the data were most consistent with a small negative effect of egg dewatering mortality on recruitment but a large negative effect, or positive effect, cannot be ruled out.

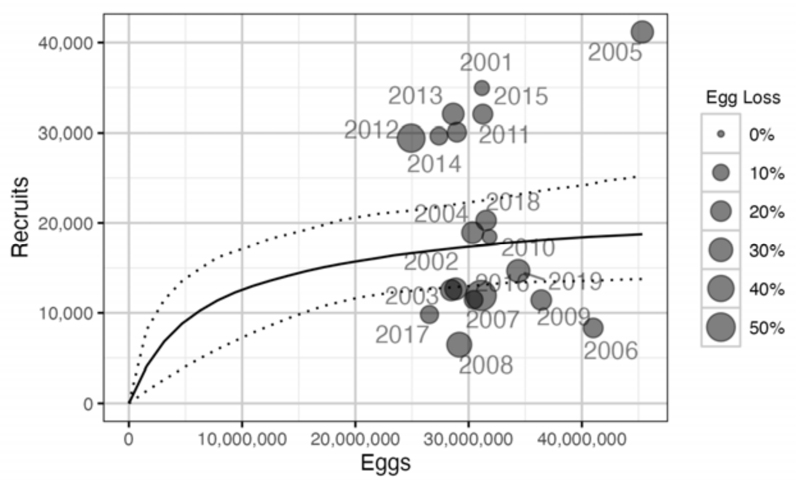


Figure 39: Predicted stock-recruitment relationship between age-2+ spawners ("Stock") and subsequent age-1 Mountain Whitefish ("Recruits") by spawning year (with 95% CIs). Estimated proportion of egg loss due to dewatering for each spawning year is shown by size of shaded circles.

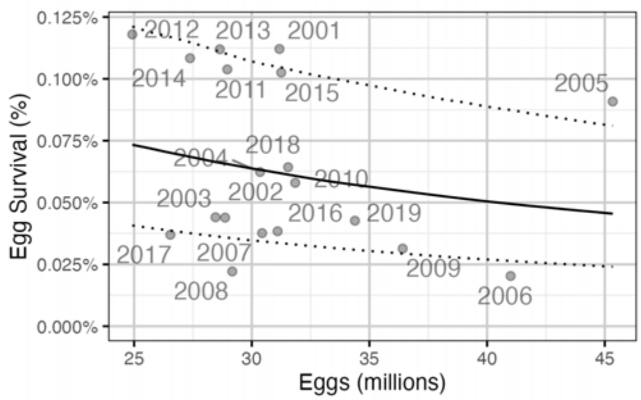


Figure 40: Predicted egg to age-1 survival by total egg deposition (with 95% CIs) for Mountain Whitefish.

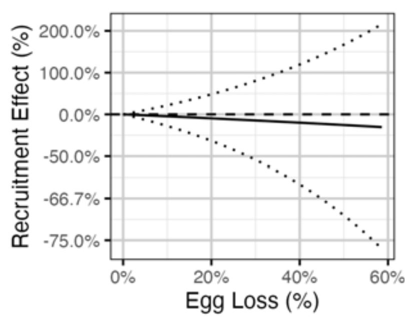


Figure 41: Predicted effect of egg loss on the number of age-1 Mountain Whitefish recruits (with 95% CIs).

3.8.2 Rainbow Trout

The stock-recruitment model for Rainbow Trout predicted little effect of increasing number of eggs deposited by spawners (“stock”) on the resulting number of age-1 recruits (Figure 42). The actual recruitment decreased with increasing number of eggs, especially in 2017 and 2018 when the estimated number of eggs was the greatest, and recruitment was the lowest (Figure 42). In the most recent spawning year for which data are available, 2020, the estimated number of eggs spawned was the fourth largest, and the number of recruits was near-average and consistent with the density-dependent stock-recruitment curve.

There were no data points on the lower part of the stock-recruitment curve (< 10 million eggs) where a decrease in recruitment but an increase in egg survival is predicted by the curve. As with Mountain Whitefish, no data are available to inform the number of spawners (or egg deposition) required to reach the carrying capacity for recruits, or the egg survival rate at low spawner abundance.

The effect of egg loss on recruitment was positive but not statistically significant, and the 95% CIs included the possibility of a negative effect (s-value=3.5; *P*=0.09) (Figure 44). The predicted effect size at an egg loss of 1.0% was a 55% increase in recruitment (Figure 44). However, at an egg loss of 1.0%, the credible interval showed that the effect size could be anywhere between a 7% decrease and a 156% increase in recruitment, given the data. This indicates considerable uncertainty in the effect of egg loss on recruitment of Rainbow Trout. Overall, observed egg losses were relatively small, with estimates of less than 1.0% in 17 of 20 years, and a maximum of 1.6%, which occurred in 2006. In the most recent spawning year for which data are available, 2020, egg loss was greater than average (1.1%), but this did not result in lower recruitment than other years with similar amounts of egg deposition.

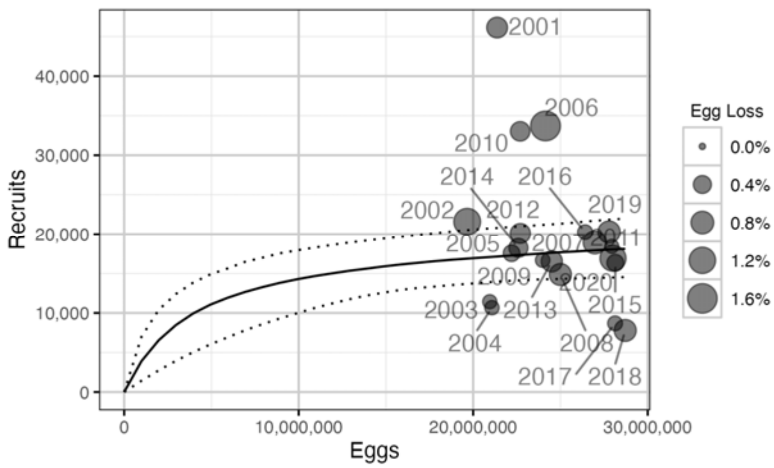


Figure 42: Predicted stock-recruitment relationship between age-2+ spawners ("Stock") and subsequent age-1 Rainbow Trout ("Recruits") by spawning year (with 95% CIs). Estimated proportion of egg loss due to dewatering for each spawning year is shown by size of shaded circles.

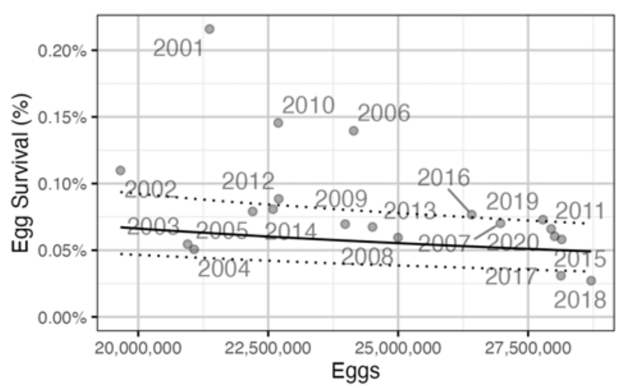


Figure 43: Predicted egg to age-1 survival by total egg deposition (with 95% CIs) for Rainbow Trout.

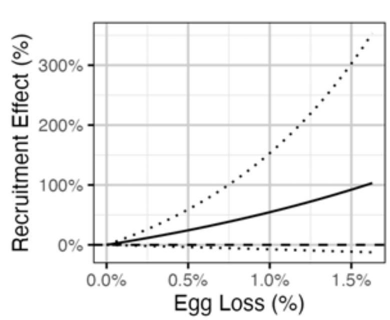


Figure 44: Predicted effect of egg loss on the number of age-1 Rainbow Trout recruits (with 95% CIs).

3.9 Adjusted Recruitment

There was a positive relationship between the abundances of age-1 Mountain Whitefish and Rainbow Trout, suggesting similar trends in recruitment of these species in the study area (Figure 45). As the spawning and incubation periods of Mountain Whitefish and Rainbow Trout do not overlap, this common variation is related to factors other than egg dewatering. A GLM was used to assess the effect of egg dewatering on the abundance of age-1 Rainbow Trout after accounting for common variation in abundance of these two species. The GLM indicated a positive effect of egg dewatering on the estimated abundance of age-1 Rainbow Trout, after accounting for the abundance of age-1 Mountain Whitefish (Figure 46). This supported the results of the stock-recruitment analyses (Figure 44), which also indicated a positive effect of egg loss on recruitment. In the stock-recruitment analysis, the estimated effect was a 55% increase in recruitment at 1.0% egg loss, whereas the effect was smaller in the adjusted recruitment analysis, with a 20% increase in recruitment at 1.0% egg loss, after accounting for the abundance of age-1 Mountain Whitefish.

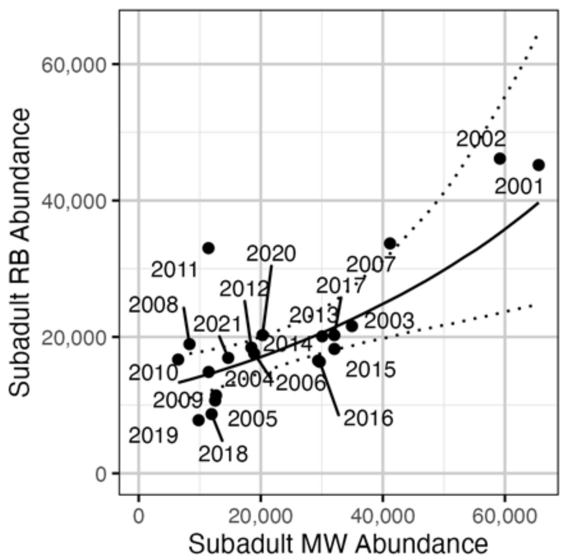


Figure 45: Relationship between age-1 Rainbow Trout (RB) and age-1 Mountain Whitefish (MW) in the same year of capture by Rainbow Trout spawn year (with 95% CIs).

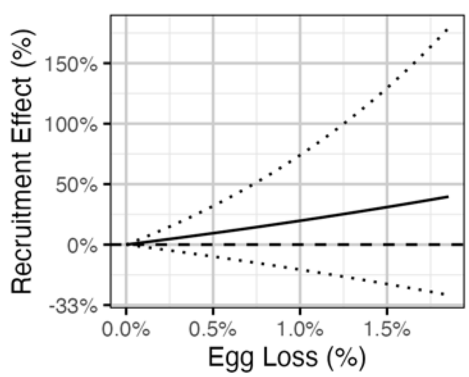


Figure 46: Predicted effect of egg loss on the number of age-1 Rainbow Trout recruits by egg loss relative to 10% egg loss (with 95% CRIs).

3.10 Other Species

Northern Pike were first observed during the LCR Fish Indexing Program in 2010 and the number of individuals captured and observed increased in successive years from 2010 to 2013 (Table 6). Encounters with Northern Pike on the LCR Fish Indexing Program began to decline in 2014 with the introduction of a Northern Pike gill netting suppression program (Wood 2018, ONA 2019), and have remained low since those efforts have been in effect. In 2021, five Northern Pike were captured during the indexing program. The on-going suppression and monitoring program captured and removed 38 Northern Pike from the LCR in 2021 (ONA 2022).

Since 2010, Northern Pike have been recorded during the LCR Fish Indexing Program in all three sections of the study area (Upper Columbia, Lower Columbia, and Kootenay River). However, 90% of the Northern Pike captured or observed were from the upper section upstream of the Columbia-Kootenay confluence. During the 2021 indexing survey, four of the five Northern Pike were captured in the upper section of the Columbia River and one was captured in the lower section of the Columbia River. As required by the provincial fish collection permit issued by MFLNRORD, all captured Northern Pike were euthanized.

Table 6: Number of Northern Pike captured and observed in the lower Columbia River Fish Population Indexing program by year.

Year	# Observed	# Captured	Total #
Prior to 2010	0	0	0
2010	3	4	7
2011	1	8	9
2012	10	1	11
2013	90	45	135
2014	16	9	25
2015	6	3	9
2016	0	4	4
2017	7	4	11
2018	1	2	3
2019	8	17	25
2020	2	2	4
2021	0	5	5

Other aquatic invasive species captured or observed within the LCR in 2021 (Table 4) include two Brook Trout (*Salvelinus fontinalis*), one Brown Trout (*Salmo trutta*), four Common Carp (*Cyprinus carpio*), one Smallmouth Bass (*Micropterus dolomieui*), and two Yellow Perch (*Perca flavescens*).

In 2021, 41 Burbot (*Lota lota*) were recorded at index sites in the LCR, which slightly greater than the catches from 2013 to 2020 (6–25 Burbot per year) but lower than many years between 2003 to 2012, when catches ranged from 33 to 247 Burbot per year (Appendix E, Table E1).

One hundred and thirty-three White Sturgeon (*Acipenser transmontanus*; 71 adults and 62 immatures) were recorded (all observed; none captured) during the 2021 survey. Observational information for these fish is provided in Attachment A.

The number of sculpin (*n* = 5,774) captured and observed in index sites in 2021 was greater than in 2018 to 2021 but on the lower end of the range reported in earlier years, which was 2,724 to 51,925 from 2001 to 2017 (Appendix E, Table E1). The number of Redside Shiner (*Richardsonius balteatus*) captured and observed in 2021 (n = 382) was greater than 2020 (n = 125) but lower than most previous years (range: 375 to 40,151). Observations of these small-bodied species are often clustered in a few locations (e.g., near HLK) and numbers are highly variable among years. Variability in the numbers observed is likely partly due to difficulty in observing these smaller fishes, especially if water surface visibility is affected by weather.

4.0 DISCUSSION

The first management question of this monitoring program assesses annual fish population metrics in the LCR. Overall, the abundance of Rainbow Trout increased substantially since 2010, whereas the abundance of Mountain Whitefish and Walleye was relatively stable during this period. Annual estimates and observed trends or differences are summarized in Sections 4.1 to 4.5.

The second management question is whether variability in the Mountain Whitefish or Rainbow Trout flow regimes is related to fish population metrics. The most important aspect of flow regime variability that could affect fish populations is reduction in discharge that could dewater incubating eggs or early life stages. The effect of discharge reductions on Mountain Whitefish and Rainbow Trout populations is addressed with the analyses of age ratio (Section 4.6) and stock-recruitment (Section 4.7). Based on the available data, the effect of egg dewatering on recruitment of either species is highly uncertain. Variability in the flow regime could also affect populations of the index species in other ways, such as effects on availability or suitability of habitat, water temperature, or ecological interactions. Where relevant, we discuss which of the metrics (length-at-age, abundance, condition, and survival) are most likely to be affected by annual variability in the flow regime, and whether trends in fish metrics occurred in years of atypical discharge or water temperature. Key results regarding both management questions are summarized in Section 4.9.

4.1 Length-at-Age and Growth

For Mountain Whitefish and Rainbow Trout, the mean length of age-0 individuals was used as an indicator of growth during the first year of life. For all three index species, a von Bertalanffy growth model was parameterised using data from inter-year recaptured fish. The growth coefficient from the model represents the rate of approach to the asymptotic length. A lower value of the growth coefficient indicates a flatter curve and a slower rate of approach to the asymptotic length. The maximum growth rate during represents the growth rate at a theoretical fork length of zero and has units (mm/yr) that are easier to understand than the growth coefficient (units of yr^{-1}). Together, the growth coefficient and maximum growth rate were used to assess inter-annual variation in growth of subadult and adult fish of the index species.

4.1.1 Mountain Whitefish

There was little variation in the mean length of age-0 Mountain Whitefish from 2001 to 2015, when mean fork lengths were between approximately 120 and 140 mm (Figure 8). Mean length of age-0 Mountain Whitefish was greater than average in 2018 and 2019, but returned to more typical values in 2020 and 2021. Recent years with increased length of young-of-the-year Mountain Whitefish in 2018 and 2019 corresponded to low abundance of subadults, which could indicate increased growth due to decreased competition for resources.

The length-at-age model was used to assign age-class groupings based on length-frequency data. For Mountain Whitefish, the model classified age-0, age-1, and age-2 fish, whereas age-3 and older fish (age-3+) were grouped together because individual age-classes for older fish could not be distinguished by fork length. Separating age-2 fish from the age-3 and older age-class allowed these length-based ages to be used for the age-1:2 ratio, which was used as an indicator of annual recruitment strength (Section 4.7).

The von Bertalanffy growth model based on inter-year recapture suggested generally increasing growth from 2006 to 2016, slower growth from 2017 to 2019, and fast growth in 2020 and 2021. The effect size for the growth coefficient was -0.3% to -14% in 2017–2019 and increased to 47% in 2020 and 71% in 2021. The predicted maximum growth rate declined from 244 mm/yr in 2016 to approximately 140 mm/yr in 2017–2019 but increased to 230 mm/yr in 2020 and 267 mm/yr in 2021. The decline in the von Bertalanffy growth coefficient and predicted maximum growth during early life history in 2017 to 2019 was relatively large, compared to the range observed from other years between 2001 and 2021, but the population-level impacts of these changes in growth are not known.

To provide context of growth in the LCR compared to other rivers, estimates of von Bertalanffy growth parameters and length-at-age of juvenile age-classes were compared to values from the literature (Table 7). Estimates of the growth coefficient, k, were greater in the LCR than other populations, but the asymptotic size (L_∞) and length-at-age were comparable, based on the selected literature reviewed. Rapid growth during early life stages in the LCR, as suggested by the relatively large values of k and maximum growth rate, may be related to the warm water temperatures, large volume, and low elevation of the LCR, attributes that correspond to faster growth of Mountain Whitefish, compared to smaller, cooler streams (Pettit and Wallace 1975; Meyer et al. 2009). Larger streams with warmer temperatures often have greater primary and secondary productivity than smaller, cooler streams (Finlay 2011), which can result in greater food availability and faster growth of fish (Filbert and Hawkins 1995).

Table 7: Comparison of growth parameters and length-at-age between the LCR and other populations of Mountain Whitefish.

von Bertalanffy Parameters[a]			Mean Length-At-Age (mm) in Fall		Source[c]	Study Location
k	L_∞	Max. Growth[b]	Age-0	Age-1		
0.39	397	156	130	226	This report	Lower Columbia River, BC
0.31 – 0.33	453 – 472	148	140	230	Boyer 2016	Madison River, Montana, USA
0.26 – 0.31	382 – 409	113	134	226	Meyer et al. 2009	5th to 7th order streams, Idaho, USA
0.20	446	88	88	169	Golder and Gazey 2019	Peace River, BC

a. Values are mean, or typical values. If a range is presented, it corresponds to the range of values for different groupings such as sexes or samples sites.
b. Predicted maximum growth during early life history was calculated by multiplying estimates of k and L_∞ (Gallucci and Quinn 1979; Shuter et al. 1998).
c. A non-exhaustive literature search was conducted and selected studies are included for comparison.

4.1.2 Rainbow Trout

The mean length of age-0 Rainbow Trout ranged between 100 and 130 mm in all years except 2015 (144 mm) and 1991/2001 (~90 mm; Figure 11). The trend in length-at-age of age-0 Rainbow Trout did not agree with the trend in growth for older individuals suggested by the von Bertalanffy growth coefficient, which decreased from a 57% effect size in 2006 to -40% in 2018 (Figure 12). A decrease in growth coefficient indicates a flatter growth curve and slower approach to the asymptotic size than in recent years. The corresponding decrease for the maximum growth rate was from 664 mm/yr in 2006 to 253 mm/yr in 2018. These maximum growth rates correspond to growth at a theoretical fork length of zero and therefore do not suggest that Rainbow Trout grow at that rate (e.g., 664 mm/yr) for the entire first year of life. However, the large difference in values between 2006 (664 mm/yr) and 2018 (253 mm/yr) suggest a substantial and biologically important change in the growth of Rainbow Trout during this period.

The increases in maximum growth rate in 2019 (308 mm/yr), 2020 (402 mm/yr), and 2021 (466 mm/yr) indicate increasing growth, and corresponded with a decrease in adult abundance estimates, which suggests density dependent growth of Rainbow Trout in the LCR.

Compared to populations in other rivers, Rainbow Trout in the LCR had high values of the growth coefficient (k), maximum growth, and length-at-age (Table 8), suggesting relatively rapid growth during early life stages. As with Mountain Whitefish, rapid growth during early life of Rainbow Trout in the LCR may be related to relatively warm and stable water temperatures and abundant food availability, compared to smaller or higher elevation streams. Metrics of primary and secondary productivity in the LCR were on the moderate to high end of values reported in the literature from other large rivers (Plewes et al. 2017), which supports the hypothesis of good food availability supporting rapid growth rates of Rainbow Trout in the LCR.

The different trends suggested by length-at-age (fluctuating up and down between 2006 and 2021) and the growth model (continuous decline from 2006 to 2018, and increase from 2019 to 2021) could reflect differences in growth between life stages. This is because mean length of age-0 fish reflects growth during the first year of life, whereas the growth rate and the coefficient from the von Bertalanffy model were primarily driven by larger subadult and adult fish that were more commonly recaptured during the survey. Therefore, the interpretation is that growth of age-0 Rainbow Trout has fluctuated up and down over the past 16 years, but growth of subadult and adult Rainbow Trout consistently declined from 2006 to 2018 and increased in 2019 to 2021. The decreasing growth of subadult and adult Rainbow Trout from 2006 to 2018 coincided with increasing adult abundance and may reflect density-dependence and reduced growth due to intraspecific competition. Mean length-at-age of age-0 Rainbow Trout may not have consistently declined over the same time because they were not in direct competition with adults for food or other resources.

Table 8: Comparison of growth parameters and length-at-age between the LCR and other populations of Rainbow Trout.

von Bertalanffy Parameters[a]			Mean Length-At-Age (mm) in Fall		Source[c]	Study Location
k	L_∞	Max. Growth[b]	Age-0	Age-1		
0.87	481	421	116	271	This report	Lower Columbia River, BC
0.51	409	209	n/a	n/a	Seals et al. 2014	Deschutes River, Oregon, USA
0.47	522	245	n/a	n/a	Baker et al. 1991	Kenai River, Alaska, USA
0.37	425	157	n/a	n/a	Fetherman et al. 2014	Colorado River, Colorado, USA
0.34 – 1.0	330 – 740	288	n/a	n/a	FishBase.org	Canada, Australia, Mexico
0.21	566	116	n/a	163	Golder and Gazey 2019	Peace River, BC
0.17	924	157	n/a	n/a	Andrusak and Andrusak 2015	Kootenay Lake, BC
0.19 – 0.36	416 – 887	n/a	n/a	~190 –240	Cox 2000	Lakes in southern interior BC
n/a	n/a	n/a	~100	n/a	Korman 2009	Colorado River, Arizona, USA

a. Values are mean, or typical values. If a range is presented, it corresponds to the range of values for different groupings such as sexes or samples sites.

b. Predicted maximum growth during early life history was calculated by multiplying estimates of k and L_∞ (Gallucci and Quinn 1979; Shuter et al. 1998).

c. A non-exhaustive literature search was conducted and selected studies are included for comparison.

4.1.3 Walleye

Estimates of the von Bertalanffy growth coefficient for Walleye were variable and uncertain. For instance, effect sizes relative to a typical year ranged from -40% to 84% across years (high variability), and the 95% CI of the 2021 estimate ranged from -16% to 60% (high uncertainty). The predicted maximum growth rate in 2021 was 70 mm/yr with a 95% CI of 49 to 99 mm/yr.

One of the main issues leading to variable and uncertain estimates of growth is the variability in annual growth across the whole range of sizes. If some 450 mm fish grow 5 mm per year but others grow 60 mm per year, then the model has a difficult time predicting the size at which growth slows as fish approach the asymptotic length. Another limitation of the von Bertalanffy model for Walleye was the lack of small, young fish in the data set. Lack of information about the size-at-age or inter-year growth of age-0 and age-1 hinders estimation of the growth coefficient. For these reasons, predictions of length-at-age for Walleye were not realistic and the von Bertalanffy curve was not presented in Figure 7. However, the growth coefficient and maximum growth rate can be used as relative indicators of growth, to compare inter-annual variation of growth of Walleye of the sizes used in the model (~300 to 450 mm).

Highly variable growth of Walleye is likely related to sexual dimorphism, sexual maturity, and investment of energy in reproduction versus somatic growth. The amount of energy used for somatic growth (i.e., increase in body size) versus reproduction is expected to change throughout the lifespan of fishes, which may require different growth models for before and after sexual maturity, and can differ between males and females (Lester et al. 2004). Male Walleye have slower growth rates before and after sexual maturity than females (Henderson et al. 2003) and had smaller asymptotic size that was reached at a younger age than females (Rennie et al. 2008). Differences between mature and immature fish and males and females likely explain the highly variable growth rates that led to uncertain estimates of growth parameters in the LCR. Alternative growth models that account for sex differences and different phases of growth are possible (Quince et al. 2008; Ohnishi et al. 2012) and could be considered for modelling growth in the LCR but may require additional data (e.g., sex ratios, reproductive information, energy budgets) that are not available for the LCR.

The large differences in the growth coefficient (-40% to 84% effect sizes; Figure 14) and maximum growth rate (36 to 112 mm/yr; Figure 15) suggested substantial variability in Walleye growth between years. However, a lack of age data, limited number of inter-year recaptures, and high variability in growth are all factors that hinder growth analyses. Substantially more recaptures would be required to generate more certain estimates of changes in Walleye growth using current methods. Walleye feed in the LCR during the summer and fall but a large number of individuals migrate out of the LCR into Lake Roosevelt in the late fall and early winter months (R.L.&L. 1995). The seasonal residency of a proportion of the Walleye population means that factors outside of the LCR likely also influence the growth of Walleye in the study area.

4.2 Abundance

4.2.1 Mountain Whitefish

In 2018 to 2021, the estimated abundance of subadult Mountain Whitefish (10,000–20,000) was lower than during the previous five years (29,000–32,000). The estimated abundance of subadults was particularly low in 2018 and 2019 (10,000–12,000), which was attributed to poor recruitment from the 2016 and 2017 spawning years (Figure 36). Poor recruitment from the 2016 cohort may have been related to the large estimated egg dewatering mortality that year (59%) whereas estimated egg loss for the 2017 spawning year was much lower (14%).

Overall, the data indicated stable abundance of adult Mountain Whitefish in the LCR during the last ten years. The estimated abundance of adult Mountain Whitefish ranged between 45,000 and 50,000 from 2010 to 2021 with the exception of 2018 when the estimate was 59,000 (Figure 18). The increase in adult abundance in 2018 may be related to high proportions of age-1 Mountain Whitefish in 2016 and 2017 (2014 and 2015 spawning years) recruiting into to the adult population (Appendix F, Figure F4). Relatively strong recruitment from the 2014 and 2015 spawning years was supported by the age-1:2 ratio (Figure 36) and coincided with relatively low levels of estimated egg loss (13% to 18%; Figure 35).

Differences in electrofisher settings during the first two years of the monitoring program in 2001 and 2002 may have contributed to high abundance estimates of subadult Mountain Whitefish in 2001 and 2002. Pulse frequencies used were 120 or 60 Hz in 2001 and 2002, 60 or 30 Hz in 2003, and 30 Hz from 2004 to 2021. Higher pulse frequencies are more effective for catching smaller-bodied fish than lower frequencies (Dolan and Miranda 2003) and therefore the high catch of age-1 Mountain Whitefish in 2001 and 2002 could have been because of the high pulse frequency used. If this was the case, greater capture efficiency estimates 2001 and 2002 would also be expected, but this was not observed in the LCR data (Appendix G, Figure G6). It may be that higher pulse frequency led to greater catch of age-1 in 2001 and 2002, but a change in capture efficiency was not detected because of the small number of age-1 recaptures. If age-1 abundance estimates in 2001 and 2002 are biased high, then it would also affect the stock-recruitment analysis.

Little is known about the factors influencing the abundance of Mountain Whitefish in the LCR but there is some information to suggest that predation on Mountain Whitefish by piscivorous fish species could play a role. Walleye feed on Mountain Whitefish (Wydoski and Bennett 1981), and densities of subadult Mountain Whitefish decreased from 2001 to 2005, while Walleye densities generally increased during that time period. Walleye stomach content data collected in the fall of 2009 (Golder 2010b) and 2010 (Ford and Thorley 2011) did not indicate that young Mountain Whitefish are a major food source for

Walleye. However, age-0 Mountain Whitefish may be more susceptible to Walleye predation during the early to mid-summer (i.e., when they are smaller) than during the fall (i.e., when they are larger). Mountain Whitefish were the most common prey item found in the stomachs of Northern Pike caught by gill-netting in the upstream section of the LCR, comprising 42% of the prey fish identified (Baxter and Doutaz 2017) and 100% of the prey identified in the fall (Baxter and Neufeld 2015). Therefore, there is potential for Northern Pike to influence the abundance and distribution of Mountain Whitefish in the upper LCR.

Since 2002, more than 148,000 hatchery-reared juvenile White Sturgeon were released into the Transboundary Reach section of the LCR (BC Hydro 2018b). Since 2015, all juvenile White Sturgeon released into the LCR were wild-spawned, hatchery reared fish and the number of individuals released per year was reduced, ranging from 76 to 1095 per year. Although most of the White Sturgeon released since 2022 would have been too small to prey on Mountain Whitefish during the early 2000s, predation by White Sturgeon may have influenced Mountain Whitefish abundance in more recent years. White Sturgeon are capable of feeding on both subadult and adult Mountain Whitefish, and as many as 12 adult Mountain Whitefish have been recorded in the stomach contents of a single adult White Sturgeon (R.L.&L. 2000). White Sturgeon become piscivorous at approximately 500 mm in fork length (Scott and Crossman 1973). In the LCR, this equates to an approximately age-3 individual (Golder 2009b); therefore, predation by White Sturgeon on Mountain Whitefish is expected to have increased since approximately 2005.

One of the management questions is related to the effects of variation in flow regime on Mountain Whitefish abundance. This program estimated subadult and adult abundance but the multiple cohorts and large number of factors that can affect survival and abundance of adults likely make it difficult to detect a relationship with annual flow variation. The effects of flow variability and specifically, egg dewatering, would most likely be detected by measuring fry (age-0) abundance. However, reliable estimates of fry density were not possible using the current sampling method because boat electrofishing is not efficient for sampling very shallow (< 30 cm) habitats that are likely preferred by fry. The analysis of age ratios as a recruitment index (Section 4.7) provides an alternative way to assess the effects of flow variation on recruitment.

4.2.2 Rainbow Trout

The estimated abundance of subadult Rainbow Trout was relatively stable between 2012 and 2021 (16,000 to 20,000), except in 2018 and 2019 when estimates were lower (9,000 and 8,000, respectively; Figure 21).The estimated abundance of adults increased from 22,000 in 2002 to 42,000 in 2018 and decreased to 37,000 in 2019, 32,000 in 2020, and 33,000 in 2021. In comparison, estimates of spawner abundance based on visual observations and an area-under-the-curve model increased from ~3,000 spawners in 2001 to a peak of 13,000 in 2018, and 10,000–12,000 in 2019 to 2021 (Amies-Galonski et al. 2022). It is not clear why spawner estimates had a larger increasing trend than adult population estimates or why subadult abundance did not increase at all over the same time period. Possible reasons for these discrepancies include:

1) capture efficiency for adults was low (<3%), which provided little information about annual or inter-session variation in recapture rates, and could have masked real changes in Rainbow Trout abundance;

2) some of the adults counted during the spawner surveys migrate into the study area to spawn but leave before the fall and are therefore not sampled by the indexing program;

3) with increasing total abundance, Rainbow Trout could be more widely distributed in the river during the non-spawning season, with little change in density in the index sites, which would result in underestimates of total abundance based on only indexing sites.

Another discrepancy between the spawner survey and mark-recapture estimates was that the abundance of spawners remained at similarly high levels from 2013 to 2021, suggesting the system may have reached carrying capacity for adult Rainbow Trout, whereas the mark-recapture abundance estimates continued to increase between 2013 and 2018, followed by small decreases in 2019 and 2020. This difference could be because not all the age-2 and older Rainbow Trout included in the abundance estimate are mature spawners, or because of sampling biases and differences between the survey methods like those listed above. Despite the differences in the spawner and mark-recapture estimates, both data sets suggest that the carrying capacity for adult Rainbow Trout has been reached, as the abundance was stable or decreasing slightly in recent years.

The abundance of age-1 Rainbow Trout was lower in 2018 and 2019 (9,000 and 8,000) than in the previous six years when abundance was relatively stable (16,000–20,000). This coincided with a similar decrease in age-1 Mountain Whitefish in 2018 and 2019. Intuitively, the decrease in age-1 Mountain Whitefish could be related to the large estimated egg loss due to dewatering for the 2016 spawning year (Section 3.7); however, the discharge reduction that caused the Mountain Whitefish egg loss for the 2016 spawning year occurred in the winter of 2017, which was before the age-1 Rainbow Trout from 2018 were spawned. Therefore, the decrease in age-1 Rainbow Trout could not have been caused by the discharge reductions that dewatered a high proportion of Mountain Whitefish eggs from the 2016 spawning year. This raises the possibility that some common factor other than egg dewatering caused the decrease in age-1 recruits of both Mountain Whitefish and Rainbow Trout in 2018. For this reason, the analysis of ‘adjusted recruitment’ was conducted to assess the effect of egg dewatering on abundance of age-1 Rainbow Trout, after accounting for the abundance of age-1 Mountain Whitefish as a proxy for other common sources of variation in salmonid abundance in the study area (Section 4.7).

In 2021, the abundance model was modified to allow the effect of year to depend on the density of the site, such that sites with low density can increase more than sites with high density, as overall abundance increases. For adult Rainbow Trout, the density of fish at high density sites changed little between years of high and low overall abundance. At low density sites, however, there was a large increase in density between years of low and high overall abundance. These results suggest that high density sites may be near their carrying capacity at low and high overall abundance, whereas low density sites, which may have lower quality habitat, have larger changes in density between years of low and high abundance. This trend was observed for adult Mountain Whitefish as well as Rainbow Trout, but not for subadults of either species. These results suggest that monitoring only at higher density sites could lead to failure to detect changes in abundance over time and demonstrate the need to sample a variety of sites, including index sites and randomly sampled GRTS sites in the study area.

4.2.3 Walleye

Walleye abundance was greater in 2003 to 2005 and 2011 than in other study years. These results likely reflect strong year-classes of Walleye present in the study area during those years. Walleye migrate into the LCR to feed in summer and fall but spawn and complete early life history further downstream in the Columbia River watershed (e.g., Lake Roosevelt and its tributaries). Abundance in the LCR depends on suitable feeding conditions but also largely on factors that influence spawning success and early life stage survival and growth outside of the study area. Based on length-frequency from the LCR and length-at-age data from Lake Roosevelt (unpublished data, Washington Department of Fish and Wildlife, Spokane Tribe of Indians, and Colville Confederated Tribes), age-2 and age-3 fish are the most dominant age-classes present in the study area during most study years; therefore, the abundance of this species in the study area during any particular year is strongly influenced by the spawning success of this species during the previous two to three years.

Years with high abundance (e.g., 2003–2005, 2011) were generally associated with lower than normal body condition and survival, suggesting density-dependence and resource competition in years of high abundance in the LCR. Variability in the flow regime in the LCR is less likely to be related to the abundance of Walleye than the abundance of other index species because the abundance of Walleye in the LCR is thought to depend on spawning and early life history in Lake Roosevelt.

4.3 Spatial Distribution

4.3.1 Mountain Whitefish

Subadult Mountain Whitefish densities were greatest in the 10-km section between HLK and the Kootenay River confluence. This distribution is likely related more to channel morphology than the presence or operation of the dam. Large bays and backwater areas, which are preferred habitats for subadult Mountain Whitefish, are more common near HLK than downstream of the Kootenay River confluence. Specific examples include Balfour Bay (RKm 2.6), downstream of the log booms near Zellstoff-Celgar (RKm 5.1), and upstream of Norn's Creek Fan (i.e., Lions Head RKm 7.4). These areas have exhibited increases in aquatic vegetation abundance (dominantly Eurasian watermilfoil [*Myriophyllum spicatum*]) between 2001 and 2021 (Attachment A). Since 2010, Northern Pike have been captured in these same areas. Mountain Whitefish were found to be one of the main components of Northern Pike diets in this reach, based on stomach content analysis (Baxter and Doutaz 2017; ONA 2022). Effects of predation by Northern Pike on the distribution or survival of subadult Mountain Whitefish are not known. Fine scale distributional data are only available since 2013 and not prior to colonization by Northern Pike.

The spatial distribution of adult Mountain Whitefish during the fall sample period may be related to the location of key spawning areas for this species. Densities of adults were highest near Norn's Creek Fan, in the downstream portions of the Kootenay River, upstream of Sullivan Creek, and near the City of Trail Airport. Norn's Creek Fan, the Kootenay River, and the City of Trail Airport area are known Mountain Whitefish spawning locations (Golder 2012), whereas the site located upstream of Sullivan Creek is close to a known spawning area (i.e., Lower Cobble Island), which may indicate that Mountain Whitefish use these areas for holding purposes prior to spawning. The densities of adult Mountain Whitefish were greater at randomly sampled non-index sites than at index sites, with the difference ranging from 10% to 100% depending on the year. A similar trend, but even larger difference, was observed for Rainbow Trout, as discussed in Section 4.3.2.

The evenness in the distribution of subadult Mountain Whitefish between index sites decreased by 8% in 2021 but did not indicate any long-term trends during the study period. For adult Mountain Whitefish, the evenness decreased between 2001 and 2006 but was stable between 2006 and 2021 (Figure 20). Overall, these results do not suggest any large changes in the spatial distribution of Mountain Whitefish.

4.3.2 Rainbow Trout

Subadult Rainbow Trout densities were noticeably higher in the Columbia River between the Kootenay River confluence and Genelle, and from Birchbank downstream to the Beaver Creek confluence, compared to other portions of the study area. A large portion of these areas are not included in the index sites and are only occasionally sampled during the GRTS survey. Low sampling effort in the areas with the highest densities of age-1 Rainbow Trout could make it more difficult to detect trends in recruitment and may help explain why estimates of subadult abundance did not increase while adult abundance increased drastically during recent years. No large changes in the evenness of the spatial distribution of subadults across index sites were observed during the study period.

The densities of adult Rainbow Trout at randomly sampled non-index sites (i.e., sites that were not systematically sampled prior to 2011) were 100% to 250% greater than densities at index sites. The high densities of Rainbow Trout in previously unsampled portions of the study area indicate that a large portion of the overall Rainbow Trout population is potentially missed during the typical mark-recapture sampling at index sites. These results suggest the importance of continuing to sample in randomly sampled sites, as well as the indexing sites, to detect changes in fish abundance and distribution that may not be detected by sampling only the indexing sites.

The results indicated increasing evenness in distribution of Rainbow Trout between index sites between the early 2000s and 2017 and stable evenness for the last five years. The period of increasing evenness corresponded to increasing abundance of Rainbow Trout in the LCR. This could be because at low abundance, Rainbow Trout were more concentrated in sites with the highest quality habitat, whereas at higher overall abundance, density increased disproportionately more at lower quality sites, because higher quality sites had reached their carrying capacity. The modeled effect of site density on the change in fish density with overall abundance (Appendix G, Figure G12) supports this idea that density increases more at lower quality sites and high quality sites with increasing overall abundance.

4.3.3 Walleye

Walleye densities were high immediately downstream of HLK and BRD (Figure 25). Sculpin species and Redside Shiner are a common prey fish for Walleye based on stomach sample analyses and in 2010, results indicated higher densities of sculpin species and Redside Shiner in this portion of the study area (Ford and Thorley 2011). In addition, Walleye densities are probably higher immediately downstream of HLK and BRD because they are feeding on fish entrained through the dams.

Walleye densities were similar throughout the remaining sections of the LCR. Their wide distribution throughout the study area indicates an ability to utilize a wide variety of habitats and tolerate a wide range of habitat conditions. This reflects the primary use of the LCR as a summer and fall feeding area, and as a result, this species is generally found wherever prey fish are present.

The data did not suggest any temporal change in the evenness in the spatial distribution across index sites during the study period.

4.4 Survival

4.4.1 Mountain Whitefish

Estimated survival of adult Mountain Whitefish varied substantially among study years (21% to 93%) but was above 50% in all years except for 2002 and 2004 (Figure 27). In recent years, adult survival was relatively stable with estimates ranging from 64% to 86% between 2011 and 2021. The high survival rate of adults was not unexpected, as Mountain Whitefish are known to be a relatively long-lived species with most populations containing individuals greater than 10 years of age (McPhail 2007; Meyer et al. 2009). In comparison, estimated survival rates ranged between 63% and 91% (mean 82%) for Mountain Whitefish in Idaho (Meyer et al. 2009).

Currently, each of the management hypotheses is tested using separate models, which simplifies the testing of the hypotheses. To check for consistency between estimates of survival and abundance, two types of survival estimates were generated. The CJF model used recapture data to estimate inter-year survival, whereas abundance-based survival was estimated using the estimates of abundance of fish in consecutive years. In previous years of the analysis, there were inconsistencies in some of the estimates, such as adult abundance estimates much larger than expected based on survival estimates and the number of subadults the previous year, which resulted in abundance-based survival estimates that were greater than 100%. In 2021, a change to the abundance model that allowed site-specific density responses resulted in greater consistency between survival estimates from the two methods.

Mountain Whitefish recapture probabilities were less than half of those for Rainbow Trout and Walleye. Low capture efficiencies may be partly due to pre-spawning movements of Mountain Whitefish in the study area during sampling in the fall. During BC Hydro's MCR Fish Population Indexing Program (CLBMON-16), recapture rates for adult Mountain Whitefish were greater in the spring than in fall from 2011 to 2016, possibly because Mountain Whitefish were moving into and out of the study area in the fall study period for spawning migrations (Golder et al. 2017). Based on telemetry data collected under CLBMON-48 (Golder 2009c), a substantial proportion of the adult Mountain Whitefish population in the LCR undertakes spawning related movements, often to other areas of the river during the fall study period. The site fidelity model provides estimates of the probability of tagged fish moving out of the sampled area that are used to account for fish movements in the abundance model. However, if the site fidelity model underestimates the rates of movement out of the sampled area, it could result in an underestimation of capture efficiency and a concomitant overestimation of abundance.

4.4.2 Rainbow Trout

Adult survival ranged from 32% to 54% across all study years (Figure 29). For adult Rainbow Trout, both survival and abundance increased gradually between 2003 and 2011. However, survival decreased from 54% in 2011 to 34% in 2012, and ranged from 33% to 48% since 2013. Lower survival beginning in 2021 coincided with high abundances, as indicated by mark-recapture estimates (Section 3.4.4) and spawner surveys (Amies-Galonski et al. 2022), which may reflect density-dependent survival and intraspecific competition for resources.

Survival of adults is unlikely to be affected directly by variability in the flow regime, although changes in productivity related to flow variability could affect growth or condition, which could ultimately affect survival. Flow variability is more likely to affect the survival of juvenile fish, through effects on habitat, displacement, or stranding. This is true for Rainbow Trout as well as Mountain Whitefish. Survival cannot be assessed using the mark-recapture data for juvenile fish because they are not effectively sampled by boat electrofishing. The effect of flow variability on survival and recruitment of juveniles can be assessed using the stock-recruitment models and age ratio analyses.

4.4.3 Walleye

The estimated survival of Walleye was 61% in 2021, which was near average compared to previous years. Some years that had lower survival, such as 2004 (33% survival), were associated with high abundance of Walleye but there was not a consistent relationship between abundance and survival, which suggest that factors other than density are also influencing adult survival. As a large portion of the Walleye population is thought to be migratory and spend only part of the year in the LCR before moving downstream into Lake Roosevelt (R.L.&L. 1995), annual survival could be confounded by fish movements and affected by factors outside of the study area. Based on the length frequency data of the catch from the LCR and length-at-age data from Lake Roosevelt discussed above, these survival estimates pertain primarily to age-2 and older age classes, which is considered representative of the subadult and adult life stages referenced in management question #1.

4.5 Body Condition

4.5.1 Mountain Whitefish

The body condition of subadult and adult Mountain Whitefish was fairly stable (Figure 32) between 2010 and 2018. The body condition of adult Mountain Whitefish was higher in 2019 to 2021 (4% to 7% effect size, relative to a typical year). Across all years when data were available, the effect sizes for the body condition of subadult Mountain Whitefish ranged between -7% to 6% and between -16% to 8% for adult Mountain Whitefish (Figure 32). Fluctuations in body condition are known to affect reproductive potential and population productivity in other fish species (Ratz and Lloret 2003). However, it is not known what percent change in body condition is biologically significant and could affect populations of Mountain Whitefish. The Canadian Environmental Effects Monitoring (EEM) program for mining and pulp and paper effluents considers a 10% change in fish body condition to be the critical threshold for higher risk to the environment (Munkittrick et al. 2009; Environment Canada 2012). This criterion suggests that the range of 24% variation (-16% to 8%) in adult Mountain Whitefish body condition could be biologically significant. Studies of the effects of body condition on reproduction and other life history processes would be required to understand the implications of body condition variation in Mountain Whitefish and other index fish species in the LCR.

Lower body condition (-6% to -16% effect size) of adult Mountain Whitefish in the early 1990s compared to between 2001 and 2021 could be related to lower water quality and industrial pollution. A number of industries including a pulp and paper mill, a fertilizer plant, and a metal smelter contributed to much poorer water quality in the 1980s and early 1990s than since the mid-1990s (MacDonald Environmental Services Ltd. 1997). Fish health monitoring studies in the early 1990s found that Mountain Whitefish had higher rates of stress-related abnormalities compared to fish from reference sites, which was thought to be related to degraded water quality (Nener et al. 1995). Reductions in industrial pollution have resulted in improved water quality and fish health in the LCR since the mid-1990s (CRIEMP 2005), which likely explains the greater body condition in 2001 to 2021 than during the early 1990s.

Little is known about what factors influence changes in body condition or growth of Mountain Whitefish in the LCR. In the Skeena River, a large, unregulated river in British Columbia, food abundance was the main factor limiting growth and abundance for Mountain Whitefish (Godfrey 1955 as cited by Ford et al. 1995). Mountain Whitefish body condition also is likely related to the abundance of invertebrate prey in the LCR. With regard to the program's second management question, variability in the flow regime could affect invertebrate abundance, which in turn could affect the body condition of insectivorous fish including Mountain Whitefish. The LCR Physical Habitat and Ecological Productivity program suggested that water velocity and discharge variability can affect invertebrate productivity, especially during the Mountain Whitefish protection flow period (Olson-Russello et al. 2015), which supports a potential pathway between flow variability, food availability, and Mountain Whitefish body condition. Information about the relative abundance of invertebrates in the LCR has been collected (Olson-Russello et al. 2015) but is only available for five years (2008–2010, 2012, and 2014), which means that relationships between annual flow variability, invertebrates, and fish cannot be compared across the entire timespan of the fish indexing program (2001–2021).

The small spatial differences in body condition suggest that either there is little variation attributable to habitat differences among sites, or that fish do not stay within particular sites long enough to result in large inter-site differences in body condition. Therefore, sample site was not included in the body condition models for Mountain Whitefish or other species. The low site fidelity estimates support the idea that fish movements may prevent large inter-site differences in body condition, especially for Mountain Whitefish, which had the lowest site fidelity estimates.

4.5.2 Rainbow Trout

The body condition of Rainbow Trout was greater in 2002 and 2006 than in other study years for both subadult and adult life stages. Both water temperature and discharge in the Columbia River were near historical averages in 2002 and 2006 which suggests that variations in flow regime do not explain the inter-annual differences in Rainbow Trout body condition. However, the relationship between flow variability and invertebrate productivity suggested by Olson-Russello et al. (2015) and discussed in Section 4.5.1 also has implications for Rainbow Trout. Changes in invertebrate abundance due to flow variability would be expected to affect food availability and possibly body condition of Rainbow Trout.

The 10% decrease in body condition of adult Rainbow Trout between 2011 and 2018 coincided with high and increasing abundance. This may indicate an increase in intraspecific competition for food that caused the decrease in body condition and growth (Section 4.1) during this period. Conversely, adult Rainbow Trout body condition and growth estimates increased in 2019 to 2021, which coincided with a decrease in abundance. These trends suggest that the population was at carrying capacity when above 40,000 adults, as reduced growth in the post-recruit (i.e., adult) life stage is expected when populations are near carrying capacity (Lorenzen 2008).

4.5.3 Walleye

Body condition of Walleye was greater in 2012 to 2016 than in most previous years and was near average in 2017 to 2021. Some of the years with high body condition (2012 to 2014) had low abundance estimates of Walleye, suggesting density-dependent growth that could be due to intraspecific competition for food and cover, similar to that reported for this species by other researchers (Forney 1977; Hartman and Margraf 1992; Porath and Peters 1997). However, there was not a consistent relationship between abundance and body condition across all years of the monitoring program. Variability in the flow regime is less likely to have direct effects on food availability and body condition of Walleye compared to insectivorous fish species, because Walleye are piscivorous.

4.6 Age Ratios

The proportional ratio of age-1:2 Mountain Whitefish was used as an indicator of recruitment to assess the effects of egg dewatering. Greater egg dewatering is expected to reduce subsequent recruitment of age-1 Mountain Whitefish, which would be reflected by lower age-1:2 ratios. The age-1:2 ratio ranged from 25% to 79% between the 1999 and 2019 spawning years, which suggests substantial inter-annual variation in recruitment during the monitoring period. Across all years of available data, the direction of the relationship between the age-1:2 ratio recruitment index and the estimated annual egg loss ratio was uncertain. The data indicated a negative relationship between estimated egg loss ratio and age-1:2 ratio but the relationship was uncertain and not statistically significant. The large credible intervals around the relationship (Figures 39 and 40) indicate that although a small negative effect of egg loss on Mountain Whitefish recruitment is most likely, a large negative or positive effect of egg dewatering cannot be excluded. The uncertainty in the relationship between age-1:2 ratio and egg loss ratio (Figure 37) and large variability in this recruitment index was likely because of other factors, such as environmental conditions and ecological interactions, that influenced survival and recruitment more than egg dewatering during most study years.

The 2016 spawning year had a large decline in the recruitment index (33% compared to 64%–73% in previous six years) and coincided with the largest estimated egg loss on record (59%). This suggests that 59% egg loss due to dewatering could have had a negative effect on the recruitment of Mountain Whitefish. The abundance estimate of age-1 Mountain Whitefish decreased from 29,000–32,000 in the previous five years to 12,000 in 2018, suggesting a biologically significant change in recruitment. However, there was also a decrease in recruitment of age-1 Rainbow Trout in 2018, which could not have been related to the discharge reductions that affected Mountain Whitefish recruitment in 2018 because that cohort of Rainbow Trout had not yet been spawned (Section 4.2.2). In addition, the recruitment index for Mountain Whitefish remained low in the 2017 spawning year (44%), even though egg dewatering was much lower (14%) than in 2016. These results suggest that factors other than egg dewatering could have contributed to the decrease in age-1 recruits of both Mountain Whitefish and Rainbow Trout in 2018.

Mark-recapture population estimates of subadults could also be used to assess recruitment and the effects of egg dewatering. However, capture efficiencies for subadult Mountain Whitefish are low (<1%) and the mark-recapture estimates are based on several untested assumptions, such as no migration out of the study area between capture sessions. If assumptions are violated or low recapture rates are not accurately reflecting changes in capture efficiency, then it could mask trends in subadult abundance and make it difficult to detect the effects of dewatering. Because the age-1:2 ratio is based on proportions of ages in the catch, this recruitment index would not be affected by undetected changes in capture efficiency, and therefore is likely a more robust method to assess the effects of egg dewatering in the LCR.

Age-1:2 ratios were not used for Rainbow Trout in the LCR because age data are only available for Rainbow Trout from 2001 to 2012, whereas scales were collected but not analyzed for Rainbow Trout from 2013 to 2021. Ages assigned using scale analysis were not reliable for age-2 and older fish and were therefore not used in the data analysis. Using length-based ages for the age-1:2 ratio is not possible for Rainbow Trout because the length-at-age model cannot distinguish age-2 and age-3 fish, and therefore all age-2 and older fish are grouped in a single category.

4.7 Stock-Recruitment Relationship

For both Mountain Whitefish and Rainbow Trout, the stock-recruitment data indicated no relationship between the estimated number of eggs deposited by spawners and age-1 recruits, and large variability in the number of recruits produced by a particular number of eggs. The lack of relationship between stock and recruitment was interpreted as being consistent with density-dependent survival and recruitment at the observed stock sizes. There may not have been a clear relationship between stock and recruitment because even at the smaller stock sizes, the number of spawners was sufficient to fully seed the habitat with eggs or fry.

In other words, it may appear that there is no clear relationship between spawners and recruitment if the range of spawner abundance observed is not sufficiently large (Myers and Barrowman 1996). Alternatively, errors in the measurement of either stock or recruits can mask real relationships and make recruitment appear independent of spawning stock size (Walters and Ludwig 1981). In the LCR, it could be that imprecise estimates of abundance, especially for age-1 fish that have lower recapture rates, could be masking trends in abundance and relationships between adults and age-1 recruits.

For Mountain Whitefish, the estimated effect of egg loss on recruitment was negative but the CIs included a positive effect. However, the only data points were on the relatively flat part of the estimated stock-recruitment curve, where a decrease in spawners or egg loss due to dewatering would not be predicted to decrease the resulting recruits substantially. Based on the estimated stock-recruitment curve, years with substantially fewer adults and/or larger egg loss would be needed to detect a decrease in recruitment related to egg dewatering. Predictions of the effect of egg dewatering from the stock-recruitment indicated a high degree of uncertainty in the relationship between egg dewatering and recruitment. These predictions showed that the data were most consistent with a small negative effect of egg dewatering mortality on recruitment but a large negative or positive effect cannot be ruled out.

For Rainbow Trout, estimated egg losses were small between 2001 and 2020, with estimates less than 1.0% in 17 of 20 years, and the greatest observed egg loss of 1.6%. The stock-recruitment model predicted a positive effect of egg loss on recruitment of age-1 Rainbow Trout (Figure 44) but the direction of the effect was uncertain and not statistically significant.

Egg mortality due to dewatering cannot mechanistically have a positive causal effect on recruitment of juveniles. The unexpected positive effect of egg loss on recruitment was likely due to other, unmeasured factors that are correlated with both egg dewatering and recruitment success. For instance, lower water levels during the spawning season could be associated with lower amounts of subsequent egg dewatering, but have some other negative effect on spawning and recruitment success, such as less available spawning habitat and greater competition than during higher water levels.

Based on the available data, there is no evidence of negative effects of egg losses less than 2% on recruitment of Rainbow Trout in the LCR. Although the data do not support an effect of egg loss on recruitment at the range of adult abundances observed, the effects of egg loss at lower abundance, or higher levels of egg loss (>1.6%) are unknown based on this analysis.

Conclusions regarding the effect of egg dewatering drawn from the stock-recruitment analyses should be considered uncertain because of the poor fit of modeled relationships, and the possibility that sampling biases or environmental variability masked real effects of egg dewatering. Poor fit of stock-recruitment models with fisheries data is common in the literature for marine and freshwater environments. Failure of these models has been attributed to numerous possible factors, such as errors in measurement (Walters and Ludwig 1981), incorrect spatio-temporal scales (Hutchinson 2008), or environmental variability (Myers 1998). In the LCR, estimates of capture efficiency and abundance of age-1 Mountain Whitefish and age-1 Rainbow Trout are hindered by small numbers of recaptured fish. This is partly because this age-class is not as effectively sampled as larger fish by the boat electrofisher and because a large proportion of this life stage likely uses shallow habitat not sampled during this program. Low and uncertain estimates of capture efficiency mean that changes in abundance of age-1 fish may not be detected by abundance estimates. For this reason, the age-1:2 ratio is considered a more reliable test of the effect of egg loss than the stock-recruitment analysis.

4.8 Adjusted Recruitment

A GLM was used to assess the effect of egg dewatering on the abundance of age-1 Rainbow Trout after accounting for the abundance of age-1 Mountain Whitefish as a proxy for common variation in salmonid abundance due to factors other than dewatering. The analysis indicated a positive effect of egg dewatering on recruitment, with a predicted 20% increase in age-1 recruitment at an egg loss of 1.0%. The adjusted recruitment model supported the results of the stock-recruitment analysis, which also indicated a positive effect of egg dewatering at the low levels of egg dewatering observed (≤1.6%). This analysis confirms that the positive relationship between egg dewatering and recruitment of Rainbow Trout was still present after controlling for common variation in salmonid abundance due to factors other than egg dewatering.

4.9 Summary

The sampling program conducted since 2001 provides a high-quality, long-term dataset to address **the first management question**, which is about changes in fish population metrics over time in the LCR. Hierarchical Bayesian models suggested that the abundance of adult **Rainbow Trout** increased substantially between 2001 and 2018, with small decreases in 2019 and 2020, and high abundances in recent years coincided with a decline in body condition, growth, and survival, suggesting density-dependence and that the adult population is near the habitat's carrying capacity. Data for **Walleye** suggested relatively low but stable abundance from 2012 to 2021 compared to earlier years. The estimated abundance of adult **Mountain Whitefish** declined since 2001 but was relatively stable from 2010 to 2021. The estimated abundance of subadult Mountain Whitefish was lower in 2018 to 2021 than during the previous five years. Length-at-age of age-0 Mountain Whitefish and body condition of Mountain Whitefish suggested relatively little change in growth during the monitoring period.

The **second management question** for this monitoring program pertains to the effects of inter-annual flow variability on fish population metrics of the index species. One of the ways that flow variability can affect fish populations is through egg dewatering during discharge reductions. The effect of egg dewatering on fish abundance was assessed through the analysis of age ratios as a recruitment index and through stock-recruitment models that included egg loss as a covariate. For **Mountain Whitefish**, the direction of the relationship between the age-1:2 recruitment index and estimated egg losses across all years of the study (1999 to 2019 spawning years) was uncertain and not statistically significant. However, the large estimated egg loss (59%) in the 2016 spawning year corresponded to a large decrease in the age ratio recruitment index and a greater than 50% decrease in the estimated abundance of age-1 Mountain Whitefish. Egg loss was not a clearly directional or statistically significant covariate in the stock-recruitment model for Mountain Whitefish. The stock-recruitment analysis had large variability in Mountain Whitefish recruitment for a particular level of egg loss or spawner abundance, which resulted in weak predictive ability and suggested that other unknown factors likely have a large influence on recruitment in the LCR.

For **Rainbow Trout**, there was no evidence of negative effects of egg losses on recruitment at the observed levels of egg loss, which were less than 2% in all years. These conclusions for both Mountain Whitefish and Rainbow Trout should be considered tentative because of the poor fit in modelled relationships and the possibility that sampling biases or environmental variability masked real effects of egg dewatering.

Flow variability in the LCR is expected to have less of an effect on **Walleye** than Rainbow Trout and Mountain Whitefish because the abundance of Walleye is thought to depend on spawning and early life history survival outside of the study area. In addition, effects of flow variability on invertebrate productivity, if they occur, would not have direct effects on food availability that could impact the condition or growth of a piscivorous species like Walleye.

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Appendix A - Maps

Table A1 Locations and distances from Hugh L. Keenleyside Dam of boat electrofishing index sites in the lower Columbia River, 2021.

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

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

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

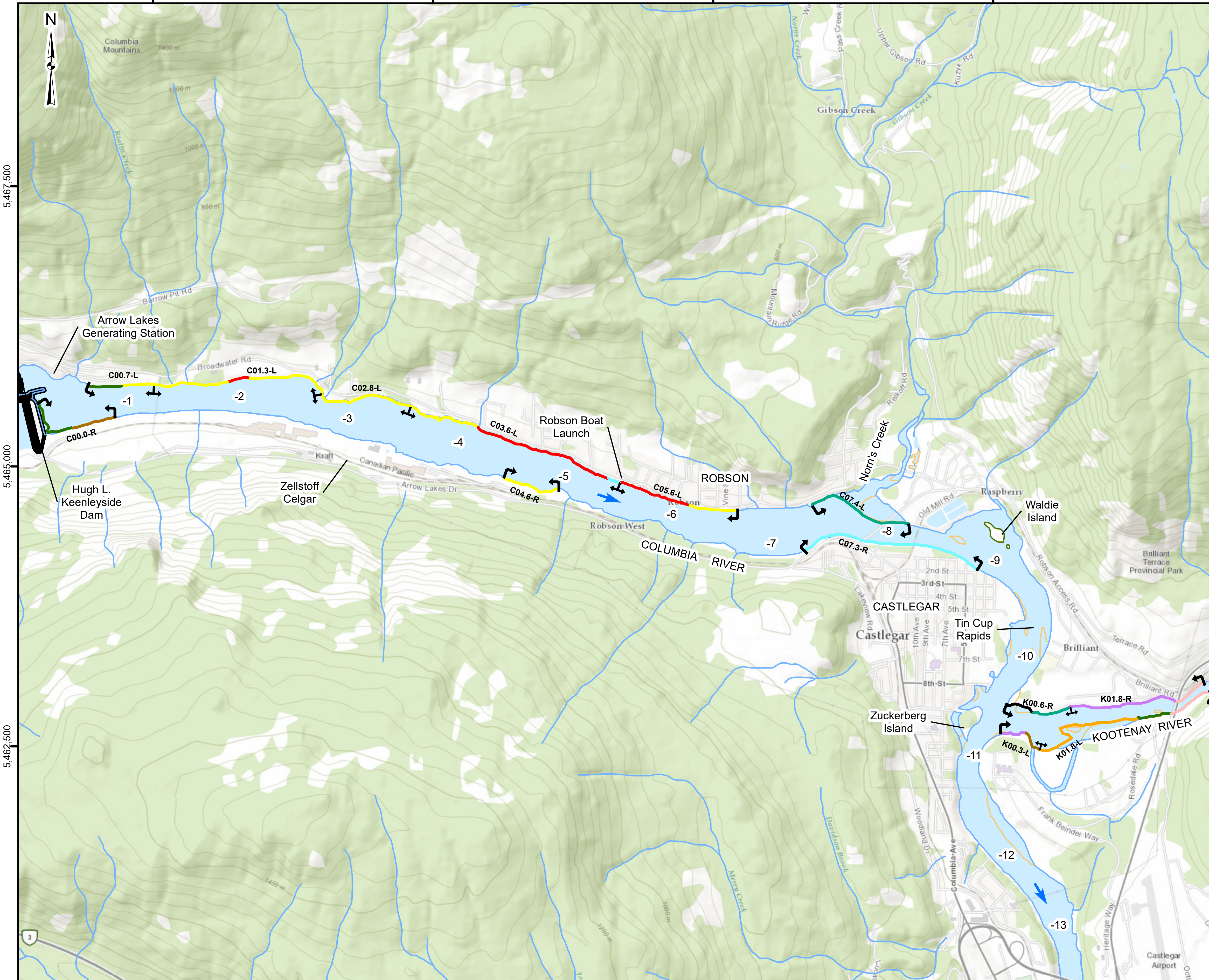
[c] LDB=Left bank as viewed facing downstream; RDB=Right bank as viewed facing downstream.

Table A2 Locations and distances from Hugh L. Keenleyside Dam of randomly sampled (Generalized Random Tessellation Stratified [GRTS] survey) boat electrofishing sites in the lower Columbia River, 2021.

Site Designation	Location (km)[a]	Bank[b]	Upstream UTM Coordinates			Downstream UTM Coordinates			Sites Selected in 2021
			Zone	Easting	Northing	Zone	Easting	Northing	
Columbia River Upstream									
C01.0-R	1.0	RDB	11U	444717	5465448	11U	447236	5465125	
C03.6-R	3.6	RDB	11U	447236	5465125	11U	448125	5464914	X
C05.1-R	5.1	RDB	11U	448612	5464808	11U	449518	5464513	
C06.0-R	6.0	RDB	11U	449518	5464513	11U	450804	5464243	
C06.7-L	6.7	LDB	11U	450223	5464603	11U	450876	5464645	
C08.4-L	8.4	LDB	11U	451833	5464445	11U	452304	5464244	
C08.6-L	8.6	LDB	11U	452132	5464468	11U	452720	5464206	
C08.9-R	8.9	RDB	11U	452375	5464074	11U	452797	5463486	
C09.0-L	9.0	LDB	11U	452286	5462718	11U	452286	5462718	
C09.2-L	9.2	LDB	11U	452720	5464206	11U	452987	5463481	
C09.8-L	9.8	LDB	11U	452926	5463604	11U	452620	5462860	
C09.8-R	9.8	RDB	11U	452761	5463608	11U	452416	5462880	X
Columbia River Downstream									
C10.7-R	10.7	LDB	11U	452416	5462880	11U	452217	5462050	
C10.8-R	10.8	RDB	11U	452154	5462718	11U	452154	5462718	
C10.9-L	10.9	LDB	11U	452584	5462607	11U	453290	5460373	X
C11.5-R	11.5	RDB	11U	452217	5462050	11U	453103	5460426	
C13.4-L	13.4	LDB	11U	453290	5460373	11U	453321	5459007	
C13.4-R	13.4	RDB	11U	453103	5460426	11U	453221	5458057	X
C14.8-L	14.8	LDB	11U	453321	5459007	11U	453210	5456890	X
C15.8-R	15.8	RDB	11U	453221	5458057	11U	453234	5457317	
C16.6-R	16.6	RDB	11U	453234	5457317	11U	452358	5456216	X
C17.0-L	17.0	LDB	11U	453210	5456890	11U	452622	5455322	
C18.0-R	18.0	RDB	11U	452358	5456216	11U	452351	5455401	
C18.8-R	18.8	RDB	11U	452351	5455401	11U	452122	5454012	X
C19.0-L	19.0	LDB	11U	452622	5455322	11U	452444	5454183	
C20.1-L	20.1	LDB	11U	452444	5454182	11U	451645	5453285	X
C20.4-R	20.4	RDB	11U	452122	5454012	11U	451093	5453191	X
C21.3-L	21.3	LDB	11U	451645	5453285	11U	450603	5451637	
C21.8-R	21.8	RDB	11U	451093	5453191	11U	450495	5452148	
C22.9-R	22.9	RDB	11U	450495	5452148	11U	450188	5451058	X
C23.4-L	23.4	LDB	11U	450603	5451637	11U	450368	5450764	
C24.0-R	24.0	RDB	11U	450188	5451058	11U	449356	5450418	
C24.3-L	24.3	LDB	11U	450368	5450764	11U	449178	5449989	
C25.3-L	25.3	MID	11U	448978	5450229	11U	448978	5450229	
C26.2-L	26.2	MID	11U	448938	5449626	11U	448938	5449626	
C27.5-L	27.5	LDB	11U	448193	5449036	11U	448064	5447758	X
C28.8-L	28.8	LDB	11U	448064	5447758	11U	447820	5446998	
C29.2-R	29.2	RDB	11U	447715	5447420	11U	447397	5446252	
C29.6-L	29.6	LDB	11U	447820	5446998	11U	447491	5446079	
C30.5-R	30.5	RDB	11U	447397	5446252	11U	446817	5444824	
C30.6-L	30.6	LDB	11U	447491	5446079	11U	446746	5444432	X
C32.0-R	32.0	RDB	11U	446817	5444824	11U	446256	5443655	
C32.4-L	32.4	LDB	11U	446746	5444432	11U	446353	5442572	X
C33.3-R	33.3	RDB	11U	446256	5443655	11U	446260	5442116	
C34.9-R	34.9	RDB	11U	446260	5442116	11U	446294	5441253	
C35.7-R	35.7	RDB	11U	446294	5441253	11U	447152	5440472	X
C36.9-R	36.9	RDB	11U	447152	5440472	11U	448305	5438607	X
C38.8-L	38.8	LDB	11U	448340	5439017	11U	449001	5438233	
C39.2-R	39.2	RDB	11U	448305	5438607	11U	448995	5438083	
C40.0-L	40.0	LDB	11U	449001	5438233	11U	450090	5438405	
C40.0-R	40.0	RDB	11U	448995	5438083	11U	450459	5438222	X
C41.1-L	41.1	LDB	11U	450090	5438405	11U	452466	5438365	
C41.5-R	41.5	RDB	11U	450459	5438222	11U	452579	5438015	X
C43.5-L	43.5	LDB	11U	452466	5438365	11U	453245	5437597	
C43.7-R	43.7	RDB	11U	452579	5438015	11U	453275	5437384	
C44.6-L	44.6	LDB	11U	453245	5437597	11U	454179	5437228	X
C44.7-R	44.7	RDB	11U	453275	5437384	11U	454560	5436673	
C45.6-L	45.6	LDB	11U	454179	5437228	11U	454855	5436623	X
C46.2-R	46.2	RDB	11U	454560	5436673	11U	455141	5435856	
C46.4-L	46.4	LDB	11U	454855	5436623	11U	455319	5435321	
C47.2-R	47.2	RDB	11U	455141	5435856	11U	455017	5434942	X
C56.0-L	56.0	LDB	11U	454774	5428024	11U	453949	5427733	

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

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



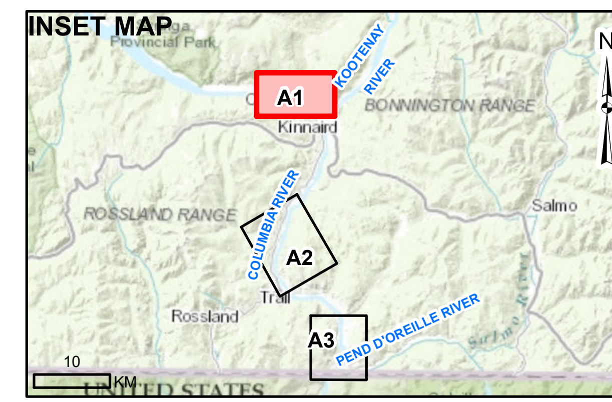
LEGEND

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

BANK HABITAT TYPE

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

INSET MAP



REFERENCE

SERVICE LAYER CREDITS: 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.

PROJECTION: UTM ZONE 11 DATUM: NAD 83

600 0 600
SCALE 1:35,000 METRES

PROJECT
LOWER COLUMBIA RIVER FISH POPULATION INDEXING SURVEY

TITLE
UPPER SECTION OF STUDY AREA SAMPLE SITE LOCATIONS

PROJECT No.	21466986-2021	
DESIGN	DR	2022-05-31
GIS	JG	2022-05-31
CHECK	DR	2022-05-31
REVIEW	SR	2022-05-31

SCALE AS SHOWN REV. 0

FIGURE: A1

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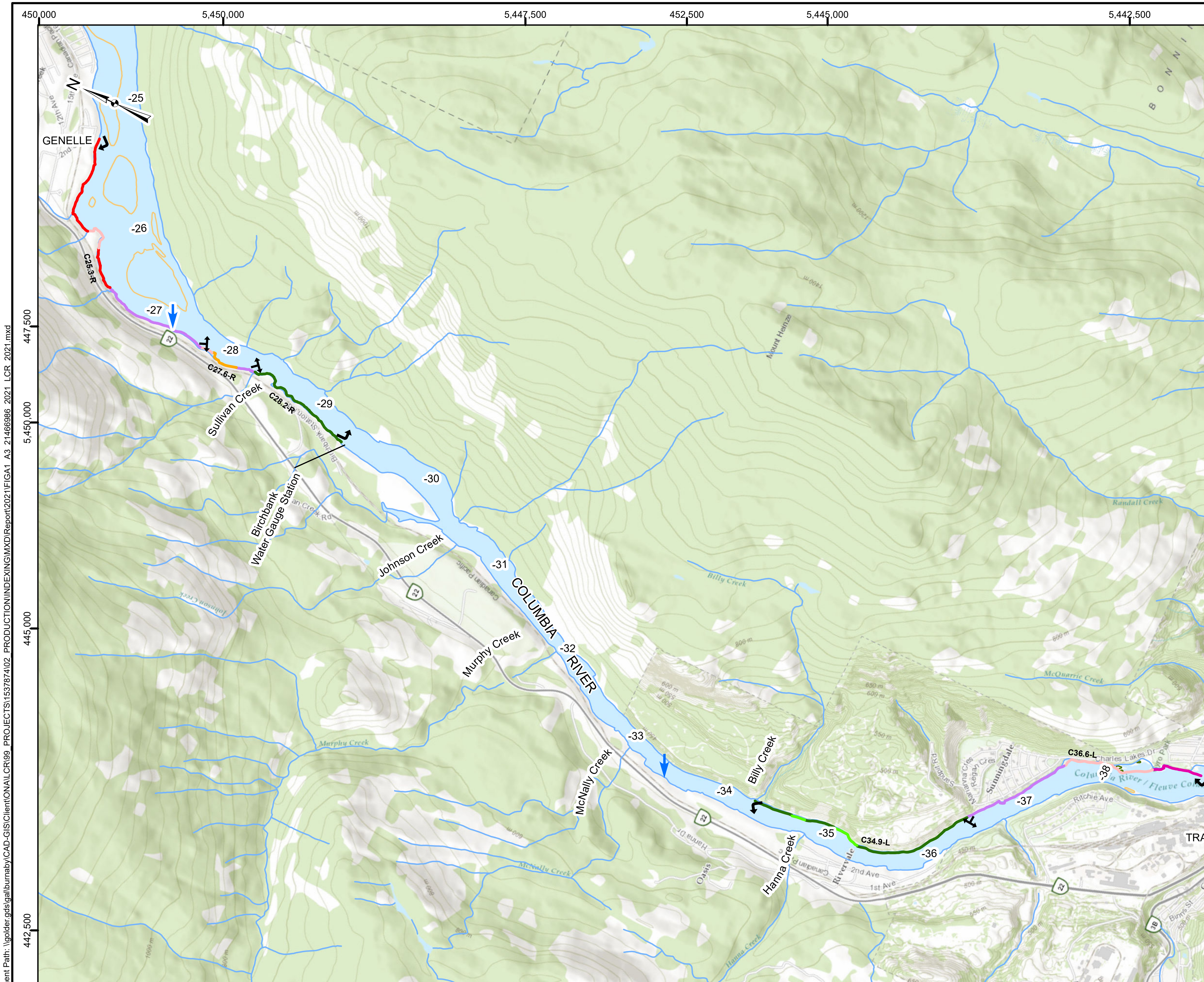

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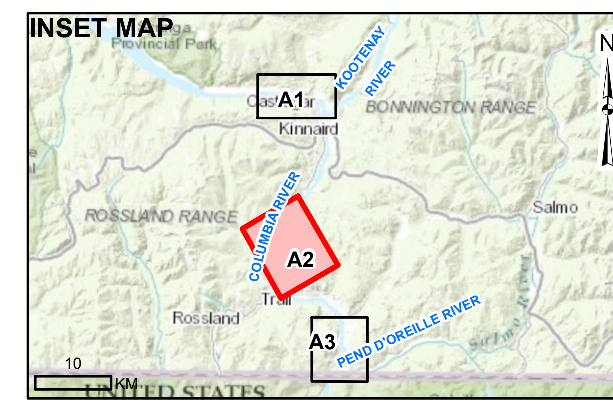
LEGEND

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

BANK HABITAT TYPE

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

INSET MAP



REFERENCE

SERVICE LAYER CREDITS: 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.

PROJECTION: UTM ZONE 11 DATUM: NAD 83

600 0 600

SCALE 1:35,000 METRES

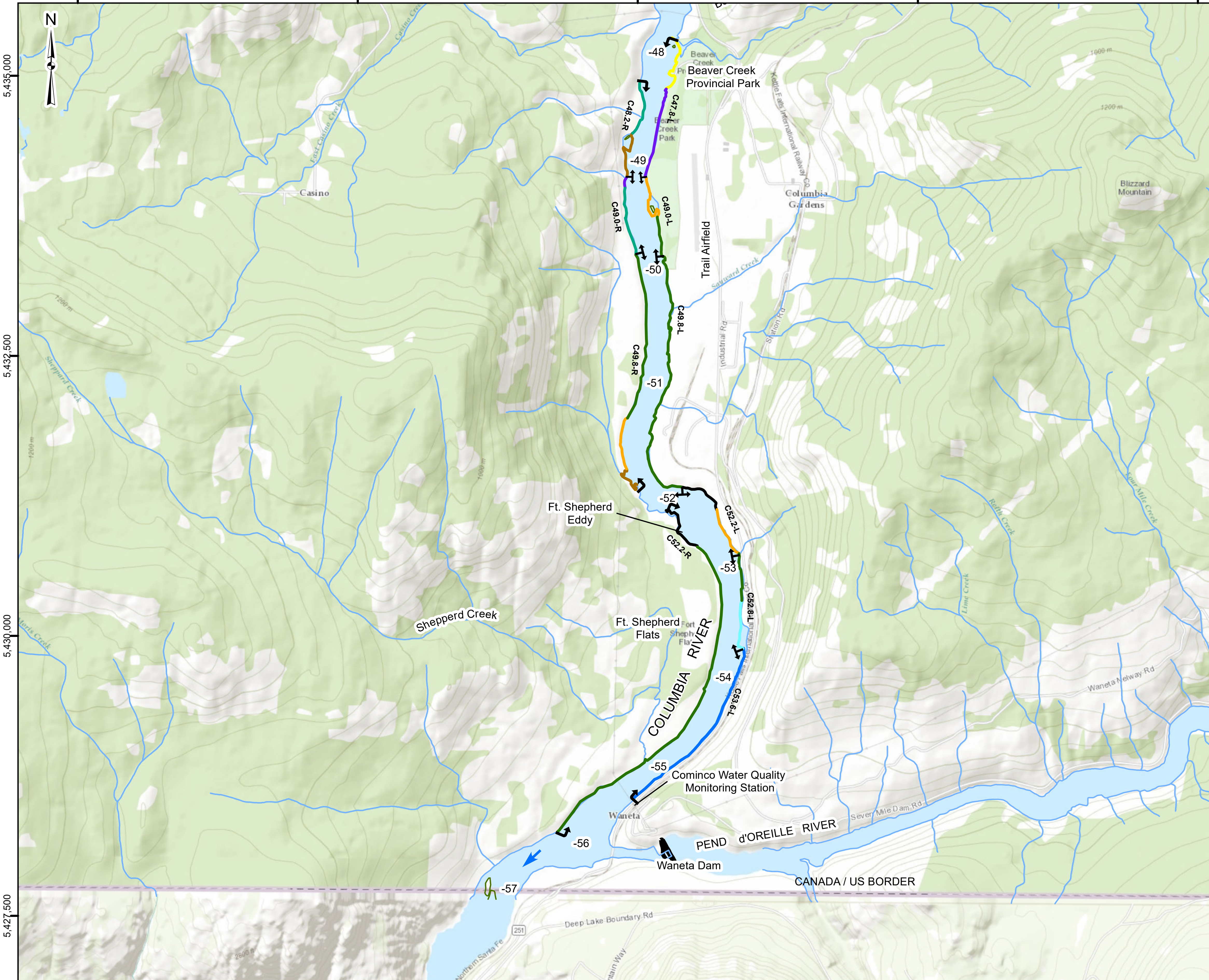
PROJECT

LOWER COLUMBIA RIVER FISH POPULATION INDEXING SURVEY

TITLE

MIDDLE SECTION OF STUDY AREA SAMPLE SITE LOCATIONS

PROJECT No.	21466986-2021		SCALE AS SHOWN	REV. 0
DESIGN	DR	2022-05-31	FIGURE: A2	
GIS	JG	2022-05-31		
CHECK	DR	2022-05-31		
REVIEW	SR	2022-05-31		

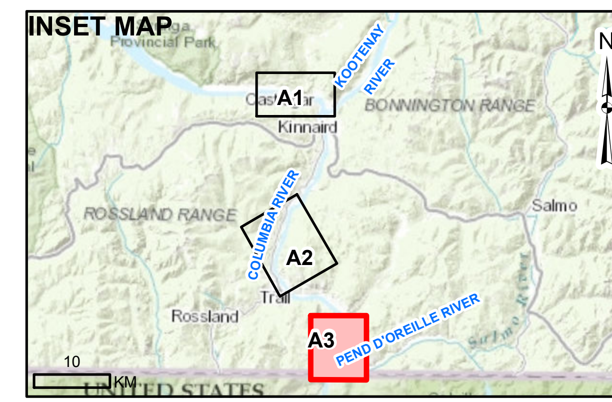


LEGEND

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

BANK HABITAT TYPE

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



REFERENCE

SERVICE LAYER CREDITS: SOURCES: ESRI, HERE, 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.

PROJECTION: UTM ZONE 11 DATUM: NAD 83

600 0 600
SCALE 1:35,000 METRES

PROJECT
LOWER COLUMBIA RIVER FISH POPULATION INDEXING SURVEY

TITLE
LOWER SECTION OF STUDY AREA SAMPLE SITE LOCATIONS

PROJECT No.	21466986-2021	
DESIGN	DR	2022-05-31
GIS	JG	2022-05-31
CHECK	DR	2022-05-31
REVIEW	SR	2022-05-31

SCALE AS SHOWN REV. 0

FIGURE: A3

Appendix B – Habitat Summary Information

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

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

Continued.

Table B1 Concluded.

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

Velocity Classifications:

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

Table B2 Length of bank habitat types at boat electrosfishing index sites within the lower Columbia River.

Section	Site[a]	Length (m) of Bank Habitat Type[b]														Total Length (m)
		A1	A2	A3	A4	A5	A6	A1+A2	A2+A3	D1	D2	D3	D1+D2	BW	Eddy	
Upstream Columbia	C00.0-R		543											394		**937**
	C00.7-L		290							303						**593**
	C01.3-L	200								1401						**1601**
	C02.8-L									882						**882**
	C03.6-L	1276			121					691						**2087**
	C04.6-R									517						**517**
	C05.6-L	654								447						**1101**
	C07.3-R				1705											**1705**
	C07.4-L												998			**998**
Upstream Columbia Total		2130	833		1826					4241			998	394		**10 422**
Kootenay River	K00.3-L								230					207		**436**
	K00.6-R												364		232	**596**
	K01.8-L		304			387					1179					**1871**
	K01.8-R					326			971							**1296**
Kootenay River Total			304			713			1200		1179		364	207	232	**4199**
Downstream Columbia	C25.3-R	1380				317			1029							**2727**
	C27.6-R					122			185		306					**613**
	C28.2-R		1131													**1131**
	C34.9-L		1740	396												**2136**
	C36.6-L					880			1031			483				**2395**
	C47.8-L								826	613						**1439**
	C48.2-R												495	514		**1009**
	C49.0-L		379								550					**930**
	C49.0-R							101					618			**720**
	C49.8-L		2447													**2447**
	C49.8-R		1511								489			391		**2391**
	C52.2-L										458				431	**889**
	C52.2-R		3272												518	**3790**
	C52.8-L		428		464											**893**
	C53.6-L						1518									**1518**
Downstream Columbia Total		1380	10909	396	464	1320	1518	101	3072	613	1802	483	1113	905	949	**25 026**
Grand Total		**3510**	**12047**	**396**	**2290**	**2033**	**1518**	**101**	**4272**	**4854**	**2982**	**483**	**2475**	**1506**	**1181**	**39 648**

[a] See Appendix A, Figures A1 to A3 for sample site locations.

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

Appendix C – Modelling Methods and Parameter Estimates

Lower Columbia River Fish Population Indexing 2021

Methods

Data Preparation

The fish indexing data were provided by Okanagan Nation Alliance and Golder Associates in the form of an Access database. The discharge and temperature data were obtained from the Columbia Basin Hydrological Database maintained by Poisson Consulting. The Rainbow Trout egg dewatering estimates were provided by CLBMON-46 (Irvine, Baxter, and Thorley 2015) and the Mountain Whitefish egg stranding estimates by Golder Associates (2013).

Discharge

Missing hourly discharge values for Hugh-Keenleyside Dam (HLK), Brilliant Dam (BRD) and Birchbank (BIR) were estimated by first leading the BIR values by 2 hours to account for the lag. Values missing at just one of the dams were then estimated assuming $HLK + BRD = BIR$. Negative values were set to be zero. Next, missing values spanning ≤ 28 days were estimated at HLK and BRD based on linear interpolation. Finally any remaining missing values at BIR were set to be $HLK + BRD$.

The data were prepared for analysis using R version 4.2.0 (R Core Team 2018).

Data Analysis

Model parameters were estimated using hierarchical Bayesian methods. The parameters 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).

The one exception is the length-at-age estimates which were produced using the mixdist R package (P. Macdonald 2012) which implements Maximum Likelihood with Expectation Maximization.

Unless stated otherwise, the Bayesian analyses used weakly informative normal and half-normal prior distributions (Gelman, Simpson, and Betancourt 2017). 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 potential scale reduction factor $\hat{R} \leq 1.05$ (Kery and Schaub 2011, 40) and the effective sample size (Brooks et al. 2011) ESS ≥ 150 for each of the monitored parameters (Kery and Schaub 2011, 61).

The parameters are summarised in terms of the point *estimate*, *lower* and *upper* 95% credible limits (CLs) and the surprisal *s-value* (Greenland 2019). The estimate is the median (50th percentile) of the MCMC samples while the 95% CLs are the 2.5th and 97.5th percentiles. The s-value can be considered a test of directionality. More specifically it indicates how surprising (in bits) it would be to discover that the true value of the parameter is in the opposite direction to the estimate. An s-value (Chow and Greenland 2019) is the Shannon transform (-log to base 2) of the corresponding p-value (Kery and Schaub 2011; Greenland and Poole 2013). A surprisal value of 4.3 bits, which is equivalent to a p-value of 0.05 indicates that the surprise would be equivalent to throwing 4.3 heads in a row. The condition that non-essential explanatory variables have s-values ≥ 4.3 bits provides a useful model selection heuristic (Kery and Schaub 2011).

Model adequacy was assessed via posterior predictive checks (Kery and Schaub 2011). More specifically, the number of zeros and the first four central moments (mean, variance, skewness and kurtosis) for the deviance residuals were compared to the expected values by simulating new residuals. In this context the s-value indicates how surprising each metric is given the estimated posterior probability distribution for the residual variation.

Where computationally practical, the sensitivity of the parameters to the choice of prior distributions was evaluated by increasing the standard deviations of all normal, half-normal and log-normal priors by an order of magnitude and then using $\hat{R}$ to test whether the samples where drawn from the same posterior distribution (Thorley and Andrusak 2017).

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 or n-fold change in the response variable) with 95% credible intervals (CIs, Bradford, Korman, and Higgins 2005).

The analyses were implemented using R version 4.2.0 (R Core Team 2020) and the `mbr` family of packages.

Model Templates

Condition

```
 data {
  int nYear;
  int nObs;

  vector[nObs] Length;
  vector[nObs] Weight;
  vector[nObs] Dayte;
  int Year[nObs];

parameters {
  real bWeight;
  real bWeightLength;
  real bWeightDayte;
  real bWeightLengthDayte;
  real<lower=0> sWeightYear;
```

```
  real<lower=0> sWeightLengthYear;

  vector[nYear] bWeightYear;
  vector[nYear] bWeightLengthYear;
  real<lower=0> sWeight;

model {

  vector[nObs] eWeight;

  bWeight ~ normal(5, 4);
  bWeightLength ~ normal(3, 1);

  bWeightDayte ~ normal(0, 1);
  bWeightLengthDayte ~ normal(0, 1);

  sWeightYear ~ normal(0, 1);
  sWeightLengthYear ~ normal(0, 1);

  for (i in 1:nYear) {
    bWeightYear[i] ~ normal(0, sWeightYear);
    bWeightLengthYear[i] ~ normal(0, sWeightLengthYear);
  }

  sWeight ~ normal(0, 5);
  for(i in 1:nObs) {
    eWeight[i] = bWeight + bWeightDayte * Dayte[i] + bWeightYear[Year[i]] +
(bWeightLength + bWeightLengthDayte * Dayte[i] + bWeightLengthYear[Year[i]]) *
Length[i];
    Weight[i] ~ lognormal(eWeight[i], sWeight);
  }
```

Block 1.

Growth

```
.model {
  bK ~ dnorm (0, 5^-2)
  sKYear ~ dnorm(0, 2^-2) T(0,)

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

  bLinf ~ dunif(200, 1000)
  sGrowth ~ dnorm(0, 25^-2) T(0,)
  for (i in 1:length(Year)) {
    eGrowth[i] <- max(0, (bLinf - LengthAtRelease[i]) * (1 - exp(-
sum(eK[Year[i]:(Year[i] + dYears[i] - 1)]))))
    Growth[i] ~ dnorm(eGrowth[i], sGrowth^-2)
  }
```

Block 2.

Movement

```
.model {

  bFidelity ~ dnorm(0, 1^-2)
  bLength ~ dnorm(0, 1^-2)

  for (i in 1:length(Fidelity)) {
    logit(eFidelity[i]) <- bFidelity + bLength * Length[i]
    Fidelity[i] ~ dbern(eFidelity[i])
  }
```

Block 3.

Survival

```
.model{
  bEfficiency ~ dnorm(0, 4^-2)
  bEfficiencySampledLength ~ dnorm(0, 4^-2)

  bSurvival ~ dnorm(0, 4^-2)

  sSurvivalYear ~ dnorm(0, 4^-2) T(0,)
  for(i in 1:nYear) {
    bSurvivalYear[i] ~ dnorm(0, sSurvivalYear^-2)
  }

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

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

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

Block 4.

Capture Efficiency

```
.model {

  bEfficiency ~ dnorm(-4, 2^-2)
```

```
  sEfficiencySessionAnnual ~ dnorm(0, 1^-2) T(0,)
  for (i in 1:nSession) {
    for (j in 1:nAnnual) {
      bEfficiencySessionAnnual[i, j] ~ dnorm(0, sEfficiencySessionAnnual^-2)
    }
  }

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

    logit(eEfficiency[i]) <- bEfficiency + bEfficiencySessionAnnual[Session[i],
Annual[i]]

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

Block 5.

Abundance

```
.model {
  bDensity ~ dnorm(5, 4^-2)
  bDensitySiteAnnual2 ~ dnorm(0, 2^-2)

  sDensityAnnual ~ dnorm(0, 1^-2) T(0,)
  for (i in 1:nAnnual) {
    bDensityAnnual[i] ~ dnorm(0, sDensityAnnual^-2)
  }

  sDensitySite ~ dnorm(0, 1^-2) T(0,)
  sDensitySiteAnnual ~ dnorm(0, 1^-2) T(0,)
  for (i in 1:nSite) {
    bDensitySite[i] ~ dnorm(0, sDensitySite^-2)
    for (j in 1:nAnnual) {
      bDensitySiteAnnual[i, j] ~ dnorm(0, sDensitySiteAnnual^-2)
    }
  }

  bEfficiencyVisitType[1] <- 0
  bEfficiencyVisitTypeDensity[1] ~ dnorm(0, 2^-2)
  for (i in 2:nVisitType) {
    bEfficiencyVisitType[i] ~ dnorm(0, 2^-2)
    bEfficiencyVisitTypeDensity[i] <- 0
  }

  sDispersion ~ dnorm(0, 1^-2)
  sDispersionVisitType[1] <- 0
  for(i in 2:nVisitType) {
    sDispersionVisitType[i] ~ dnorm(0, 2^-2)
  }

  for (i in 1:length(Fish)) {
```

```
    log(eDensity[i]) <- bDensity + bDensitySite[Site[i]] + bDensityAnnual[Annual[i]]
+ bDensitySiteAnnual[Site[i],Annual[i]] + bDensitySiteAnnual2 * exp(bDensity +
bDensitySite[Site[i]]) * bDensityAnnual[Annual[i]]

    eAbundance[i] <- eDensity[i] * SiteLength[i]

    logit(eEfficiency[i]) <- logit(Efficiency[i]) +
bEfficiencyVisitType[VisitType[i]] + bEfficiencyVisitTypeDensity[VisitType[i]] *
(eDensity[i] - exp(bDensity + sDensityAnnual^2/2 + sDensitySite^2/2 +
sDensitySiteAnnual^2/2))

    log(esDispersion[i]) <- sDispersion + sDispersionVisitType[VisitType[i]]

    eDispersion[i] ~ dgamma(esDispersion[i]^-2 + 0.1, esDispersion[i]^-2 + 0.1)
    eFish[i] <- eAbundance[i] * ProportionSampled[i] * eEfficiency[i]
    Fish[i] ~ dpois(eFish[i] * eDispersion[i])
  }
```

Block 6.

Fecundity

```
model {
  bFecundity ~ dnorm(0, 5^-2)
  bFecundityWeight ~ dnorm(1, 1^-2) T(0,)

  sFecundity ~ dnorm(0, 1^-2) T(0,)
  for(i in 1:length(Weight)) {
    eFecundity[i] = bFecundity + bFecundityWeight * log(Weight[i])
    Fecundity[i] ~ dlnorm(eFecundity[i], sFecundity^-2)
  }
```

Block 7.

Stock-Recruitment

```
.model {
  bAlpha ~ dnorm(0, 0.003^-2) T(0,)
  bBeta ~ dnorm(0, 0.007^-2) T(0, )
  bEggLoss ~ dnorm(0, 100^-2)

  sRecruits ~ dnorm(0, 1^-2) T(0,)
  for(i in 1:length(Recruits)){
    log(eRecruits[i]) <- log(bAlpha * Eggs[i] / (1 + bBeta * Eggs[i])) +
bEggLoss * EggLoss[i]
    Recruits[i] ~ dlnorm(log(eRecruits[i]), sRecruits^-2)
  }
```

Block 8.

Age-Ratios

```
.model{
  bProbAge1 ~ dnorm(0, 1^-2)
  bProbAge1Loss ~ dnorm(0, 1^-2)
```

```
  sProbAge1 ~ dnorm(0, 1^-2) T(0,)
  for(i in 1:length(Age1Prop)){
    eAge1Prop[i] <- bProbAge1 + bProbAge1Loss * LossLogRatio[i]
    Age1Prop[i] ~ dnorm(eAge1Prop[i], sProbAge1^-2)
  }
```

Block 9.

Adjusted Recruitment

```
.model{
  b0 ~ dnorm(0, 10^-2)
  bMw ~ dnorm(0, 2^-2)
  bEggLoss ~ dnorm(0, 2^-2)

  sRb ~ dnorm(0, 2^-2) T(0,)
  for (i in 1:nObs) {
    log(eRb[i]) <- b0 + bMw * Mw[i] + bEggLoss * EggLoss[i]
    Rb[i] ~ dlnorm(log(eRb[i]), sRb^-2)
  }
```

Block 10. Model description.

Results

Tables

Condition

`Table 1. Parameter descriptions.`

Parameter	Description
`bWeight`	Intercept of log(eWeight)
`bWeightDayte`	Effect of Dayte on bWeight
`bWeightLength`	Intercept of effect of Length on bWeight
`bWeightLengthDayte`	Effect of Dayte on bWeightLength
`bWeightLengthYear[i]`	Effect of i^{th} Year on bWeightLength
`bWeightYear[i]`	Effect of i^{th} Year on bWeight
`Dayte[i]`	Standardised day of year i^{th} fish was captured
`eWeight[i]`	Expected Weight of i^{th} fish
`Length[i]`	Log-transformed and centered fork length of i^{th} fish
`sWeight`	Log standard deviation of residual variation in log(Weight)
`sWeightLengthYear`	Log standard deviation of bWeightLengthYear
`sWeightYear`	Log standard deviation of bWeightYear
`Weight[i]`	Recorded weight of i^{th} fish
`Year[i]`	Year i^{th} fish was captured

Mountain Whitefish

Table 2. Model coefficients.

term	estimate	lower	upper	svalue

term	estimate	lower	upper	svalue
bWeight	5.4755067	5.4560069	5.4942465	10.55171
bWeightDayte	-0.0212162	-0.0245880	-0.0176117	10.55171
bWeightLength	3.1655960	3.1217713	3.2065635	10.55171
bWeightLengthDayte	-0.0177076	-0.0270115	-0.0085988	10.55171
sWeight	0.1472061	0.1455043	0.1489253	10.55171
sWeightLengthYear	0.1037495	0.0730413	0.1493594	10.55171
sWeightYear	0.0470375	0.0356170	0.0652866	10.55171

Table 3. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
16015	7	3	500	2	406	1.009	TRUE

Table 4. Model posterior predictive checks.

moment	observed	median	lower	upper	svalue
zeros	NA	NA	NA	NA	NA
mean	0.0000735	0.0001773	-0.0153873	0.0157513	0.0154610
variance	0.9967563	0.9999487	0.9786269	1.0219366	0.3880586
skewness	-0.6070306	-0.0022072	-0.0380180	0.0375339	10.5517083
kurtosis	1.7900372	-0.0019176	-0.0739929	0.0788359	10.5517083

Table 5. Model sensitivity.

n	K	nchains	niters	rhat_1	rhat_2	rhat_all	converged
16015	7	3	500	1.009	1.007	1.006	TRUE

Rainbow Trout

Table 6. Model coefficients.

term	estimate	lower	upper	svalue
bWeight	6.0273022	6.0157058	6.0375840	10.55171
bWeightDayte	-0.0035791	-0.0058187	-0.0015225	10.55171
bWeightLength	2.9243024	2.9020301	2.9481417	10.55171
bWeightLengthDayte	0.0393561	0.0327095	0.0462931	10.55171
sWeight	0.1005880	0.0995274	0.1016662	10.55171
sWeightLengthYear	0.0524848	0.0379964	0.0772029	10.55171
sWeightYear	0.0252582	0.0189860	0.0352581	10.55171

Table 7. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
17171	7	3	500	2	321	1.007	TRUE

Table 8. Model posterior predictive checks.

moment	observed	median	lower	upper	svalue
zeros	NA	NA	NA	NA	NA
mean	0.0001685	-0.0001032	-0.0153414	0.0149919	0.0389678

moment	observed	median	lower	upper	svalue
variance	0.9968564	0.9997184	0.9802061	1.0197653	0.3705560
skewness	-0.6822971	0.0001985	-0.0366285	0.0361468	10.5517083
kurtosis	2.3959339	-0.0004343	-0.0706962	0.0709834	10.5517083

Table 9. Model sensitivity.

n	K	nchains	niters	rhat_1	rhat_2	rhat_all	converged
17171	7	3	500	1.007	1.016	1.008	TRUE

Walleye

Table 10. Model coefficients.

term	estimate	lower	upper	svalue
bWeight	6.2882814	6.2743650	6.3025910	10.551708
bWeightDayte	0.0155997	0.0132817	0.0183091	10.551708
bWeightLength	3.2275879	3.1929829	3.2629158	10.551708
bWeightLengthDayte	-0.0056988	-0.0211123	0.0097076	1.223033
sWeight	0.0917645	0.0905086	0.0930050	10.551708
sWeightLengthYear	0.0748556	0.0527848	0.1091235	10.551708
sWeightYear	0.0340421	0.0257027	0.0467774	10.551708

Table 11. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
10302	7	3	500	2	318	1.005	TRUE

Table 12. Model posterior predictive checks.

moment	observed	median	lower	upper	svalue
zeros	NA	NA	NA	NA	NA
mean	0.0005407	0.0001909	-0.0191359	0.0192184	0.0588536
variance	0.9962830	1.0000676	0.9719750	1.0277542	0.3337506
skewness	-0.0352659	0.0003738	-0.0481119	0.0452778	2.8582213
kurtosis	0.9527777	-0.0023943	-0.0967035	0.1012277	10.5517083

Table 13. Model sensitivity.

n	K	nchains	niters	rhat_1	rhat_2	rhat_all	converged
10302	7	3	500	1.005	1.012	1.01	TRUE

Growth

Table 14. Parameter descriptions.

Parameter	Description
`bK`	Intercept of `log(eK)`
`bKYear[i]`	Effect of `i`th `Year` on `bK`
`bLinf`	Mean maximum length
`dYears[i]`	Years between release and recapture of `i`th recapture

Parameter	Description
`eGrowth`	Expected `Growth` between release and recapture
`eK[i]`	Expected von Bertalanffy growth coefficient from `i-1`th to `i`th year
`Growth[i]`	Observed growth between release and recapture of `i`th recapture
`LengthAtRelease[i]`	Length at previous release of `i`th recapture
`sGrowth`	Log standard deviation of residual variation in `Growth`
`sKYear`	Log standard deviation of `bKYear`
`Year[i]`	Release year of `i`th recapture

Mountain Whitefish

Table 15. Model coefficients.

term	estimate	lower	upper	svalue
bK	-0.9334122	-1.1668308	-0.7389528	10.55171
bLinf	397.3922591	391.5009401	402.2493079	10.55171
sGrowth	11.3399966	10.4331213	12.4180163	10.55171
sKYear	0.3923854	0.2529341	0.6175770	10.55171

Table 16. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
287	4	3	500	50	1010	1.004	TRUE

Table 17. Model posterior predictive checks.

moment	observed	median	lower	upper	svalue
zeros	NA	NA	NA	NA	NA
mean	0.0420761	0.0023630	-0.1115548	0.1251557	0.9536558
variance	0.9359583	0.9982861	0.8356099	1.1615095	1.0861419
skewness	-0.1955005	-0.0002373	-0.2871447	0.2859367	2.4589511
kurtosis	0.5620973	-0.0403186	-0.4640294	0.7078076	3.4121569

Table 18. Model sensitivity.

n	K	nchains	niters	rhat_1	rhat_2	rhat_all	converged
287	4	3	500	1.004	1.002	1.001	TRUE

Rainbow Trout

Table 19. Model coefficients.

term	estimate	lower	upper	svalue
bK	-0.1337746	-0.2734122	0.0052791	4.01255
bLinf	481.2234816	476.4854765	485.9129576	10.55171
sGrowth	29.8435671	28.7802542	30.9230946	10.55171
sKYear	0.2927230	0.2135052	0.4179306	10.55171

Table 20. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
1432	4	3	500	50	930	1.005	TRUE

Table 21. Model posterior predictive checks.

moment	observed	median	lower	upper	svalue
zeros	NA	NA	NA	NA	NA
mean	0.0095261	0.0005153	-0.0507503	0.0487427	0.4134365
variance	0.9869659	0.9991168	0.9269479	1.0745174	0.3981562
skewness	0.2811677	-0.0016016	-0.1259689	0.1229332	10.5517083
kurtosis	0.6640704	-0.0158381	-0.2248422	0.2548556	8.9667458

Table 22. Model sensitivity.

n	K	nchains	niters	rhat_1	rhat_2	rhat_all	converged
1432	4	3	500	1.005	1.005	1.004	TRUE

Walleye

Table 23. Model coefficients.

term	estimate	lower	upper	svalue
bK	-2.495586	-3.023231	-2.0519073	10.55171
bLinf	729.536867	620.143076	946.6953696	10.55171
sGrowth	17.540309	16.158432	19.2634101	10.55171
sKYear	0.322550	0.195136	0.5140263	10.55171

Table 24. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
286	4	3	500	50	188	1.006	TRUE

Table 25. Model posterior predictive checks.

moment	observed	median	lower	upper	svalue
zeros	NA	NA	NA	NA	NA
mean	0.0388840	-0.0048799	-0.1132172	0.1185114	1.082066
variance	0.9423009	0.9956184	0.8484579	1.1806375	1.002886
skewness	0.1957728	-0.0060292	-0.2955888	0.2718196	2.858221
kurtosis	1.6030601	-0.0597657	-0.4696239	0.5864294	8.966746

Table 26. Model sensitivity.

n	K	nchains	niters	rhat_1	rhat_2	rhat_all	converged
286	4	3	500	1.006	1.002	1.004	TRUE

Movement

Table 27. Parameter descriptions.

Parameter	Description
`bFidelity`	Intercept of `logit(eFidelity)`
`bLength`	Effect of length on `logit(eFidelity)`
`eFidelity[i]`	Expected site fidelity of `i`th recapture
`Fidelity[i]`	Whether the `i`th recapture was encountered at the same site as the previous encounter

Parameter	Description
`Length[i]`	Length at previous encounter of `i`th recapture

Mountain Whitefish

Table 28. Model coefficients.

term	estimate	lower	upper	svalue
bFidelity	-0.2011430	-0.5550301	0.1564674	1.948082
bLength	-0.0807911	-0.4625010	0.2761610	0.598967

Table 29. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
122	2	3	500	1	910	1.003	TRUE

Table 30. Model posterior predictive checks.

moment	observed	median	lower	upper	svalue
zeros	NA	NA	NA	NA	NA
mean	-0.0298757	-0.0359115	-0.2575027	0.1729537	0.0769883
variance	1.3848284	1.3695164	1.2229456	1.4119391	0.5960584
skewness	0.1978280	0.2238480	-0.2985772	0.7653002	0.0291267
kurtosis	-1.9570150	-1.9201014	-1.9978107	-1.3937389	0.5989670

Table 31. Model sensitivity.

n	K	nchains	niters	rhat_1	rhat_2	rhat_all	converged
122	2	3	500	1.003	1.002	1.003	TRUE

Rainbow Trout

Table 32. Model coefficients.

term	estimate	lower	upper	svalue
bFidelity	0.7138601	0.5686991	0.8517508	10.55171
bLength	-0.3290639	-0.4717737	-0.1795488	10.55171

Table 33. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
841	2	3	500	1	843	1.004	TRUE

Table 34. Model posterior predictive checks.

moment	observed	median	lower	upper	svalue
zeros	NA	NA	NA	NA	NA
mean	0.1072010	0.1048707	0.0255954	0.1767160	0.0749621
variance	1.2372963	1.2386030	1.1558223	1.3089670	0.0389678
skewness	-0.7040137	-0.7043062	-0.9051847	-0.4998678	0.0019236
kurtosis	-1.4424554	-1.4366826	-1.6916828	-1.0999950	0.0369942

Table 35. Model sensitivity.

n	K	nchains	niters	rhat_1	rhat_2	rhat_all	converged
841	2	3	500	1.004	1.001	1.001	TRUE

Walleye

Table 36. Model coefficients.

term	estimate	lower	upper	svalue
bFidelity	0.6639859	0.4076977	0.9368174	10.551708
bLength	-0.1006183	-0.3748077	0.1445717	1.200769

Table 37. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
236	2	3	500	1	912	1.003	TRUE

Table 38. Model posterior predictive checks.

moment	observed	median	lower	upper	svalue
zeros	NA	NA	NA	NA	NA
mean	0.1056183	0.1018887	-0.0411419	0.2426967	0.0449048
variance	1.2729612	1.2682990	1.1131400	1.3755984	0.0851219
skewness	-0.6804434	-0.6802602	-1.0740261	-0.3086979	0.0193523
kurtosis	-1.5310395	-1.5188014	-1.8973838	-0.8360514	0.0389678

Table 39. Model sensitivity.

n	K	nchains	niters	rhat_1	rhat_2	rhat_all	converged
236	2	3	500	1.003	1.003	1.002	TRUE

Length-At-Age

Mountain Whitefish

Table 40. The estimated upper length cutoffs (mm) by age and year.

Year	Age0	Age1	Age2
1990	163	274	NA
1991	144	226	296
2001	141	258	344
2002	163	261	344
2003	159	263	354
2004	158	249	342
2005	168	263	363
2006	175	284	357
2007	171	280	337
2008	170	247	340
2009	169	265	355
2010	177	272	352
2011	163	269	348
2012	162	268	347

Year	Age0	Age1	Age2
2013	185	282	349
2014	178	284	362
2015	167	278	366
2016	164	283	352
2017	158	270	354
2018	177	262	346
2019	188	282	363
2020	166	291	365
2021	165	275	349

Rainbow Trout

Table 41. The estimated upper length cutoffs (mm) by age and year.

Year	Age0	Age1
1990	155	355
1991	129	347
2001	133	326
2002	154	352
2003	161	345
2004	142	335
2005	164	349
2006	170	367
2007	166	377
2008	145	342
2009	147	341
2010	143	339
2011	156	346
2012	152	346
2013	169	357
2014	155	340
2015	166	337
2016	154	340
2017	133	320
2018	139	312
2019	160	317
2020	154	349
2021	169	349

Survival

Table 42. Parameter descriptions.

Parameter	Description
`bEfficiency`	Intercept for `logit(eEfficiency)`
`bEfficiencySampledLength`	Effect of `SampledLength` on `bEfficiency`
`bSurvival`	Intercept for `logit(eSurvival)`

Parameter	Description
`bSurvivalYear[i]`	Effect of `Year` on `bSurvival`
`eEfficiency[i]`	Expected recapture probability in `i`th year
`eSurvival[i]`	Expected survival probability from `i-1`th to `i`th year
`SampledLength`	Total standardised length of river sampled
`sSurvivalYear`	Log SD of `bSurvivalYear`

Mountain Whitefish

Table 43. Model coefficients.

term	estimate	lower	upper	svalue
bEfficiency	-4.2529469	-4.4528223	-4.0614532	10.551708
bEfficiencySampledLength	0.4117789	0.1925864	0.6459047	10.551708
bSurvival	0.8752047	0.3323207	1.7463371	7.744353
sSurvivalYear	1.2564585	0.7112041	2.2848184	10.551708

Table 44. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
20	4	3	500	200	1269	1.002	TRUE

Rainbow Trout

Table 45. Model coefficients.

term	estimate	lower	upper	svalue
bEfficiency	-2.5231214	-2.6866753	-2.3622262	10.5517083
bEfficiencySampledLength	0.0130893	-0.1211983	0.1575440	0.2513557
bSurvival	-0.4203665	-0.6230200	-0.2022955	10.5517083
sSurvivalYear	0.3202229	0.1494315	0.5567204	10.5517083

Table 46. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
20	4	3	500	200	1245	1.004	TRUE

Walleye

Table 47. Model coefficients.

term	estimate	lower	upper	svalue
bEfficiency	-3.4823829	-3.6751832	-3.2836537	10.551708
bEfficiencySampledLength	0.1408444	-0.0096443	0.3072884	3.837463
bSurvival	0.1627794	-0.1159230	0.5335165	1.918713
sSurvivalYear	0.5072542	0.2027299	0.9284454	10.551708

Table 48. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
20	4	3	500	200	1250	1.003	TRUE

Capture Efficiency

Table 49. Parameter descriptions.

Parameter	Description
`Annual[i]`	Year of `i`th visit
`bEfficiency`	Intercept for `logit(eEfficiency)`
`bEfficiencySessionAnnual`	Effect of `Session` within `Annual` on `logit(eEfficiency)`
`eEfficiency[i]`	Expected efficiency on `i`th visit
`eFidelity[i]`	Expected site fidelity on `i`th visit
`Fidelity[i]`	Mean site fidelity on `i`th visit
`FidelitySD[i]`	SD of site fidelity on `i`th visit
`Recaptures[i]`	Number of marked fish recaught during `i`th visit
`sEfficiencySessionAnnual`	SD of `bEfficiencySessionAnnual`
`Session[i]`	Session of `i`th visit
`Tagged[i]`	Number of marked fish tagged prior to `i`th visit

Mountain Whitefish

Subadult

Table 50. Model coefficients.

term	estimate	lower	upper	svalue
bEfficiency	-4.3325555	-4.8716536	-3.972499	10.55171
sEfficiencySessionAnnual	0.5109049	0.0557932	1.199599	10.55171

Table 51. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
1544	2	3	500	100	348	1.007	TRUE

Table 52. Model sensitivity.

n	K	nchains	niters	rhat_1	rhat_2	rhat_all	converged
1544	2	3	500	1.007	1.003	1.018	TRUE

Adult

Table 53. Model coefficients.

term	estimate	lower	upper	svalue
bEfficiency	-4.5105939	-4.8621361	-4.2430894	10.55171
sEfficiencySessionAnnual	0.2421517	0.0099348	0.6899536	10.55171

Table 54. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
1743	2	3	500	100	274	1.005	TRUE

Table 55. Model sensitivity.

n	K	nchains	niters	rhat_1	rhat_2	rhat_all	converged

n	K	nchains	niters	rhat_1	rhat_2	rhat_all	converged
1743	2	3	500	1.005	1.009	1.006	TRUE

Rainbow Trout

Subadult

Table 56. Model coefficients.

term	estimate	lower	upper	svalue
bEfficiency	-3.0188375	-3.1536514	-2.9024322	10.55171
sEfficiencySessionAnnual	0.3913347	0.2806158	0.5274097	10.55171

Table 57. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
1778	2	3	500	100	1210	1.005	TRUE

Table 58. Model sensitivity.

n	K	nchains	niters	rhat_1	rhat_2	rhat_all	converged
1778	2	3	500	1.005	1.006	1.003	TRUE

Adult

Table 59. Model coefficients.

term	estimate	lower	upper	svalue
bEfficiency	-3.4578577	-3.5950825	-3.3440267	10.55171
sEfficiencySessionAnnual	0.1819033	0.0083283	0.3835974	10.55171

Table 60. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
1848	2	3	500	100	413	1.009	TRUE

Table 61. Model sensitivity.

n	K	nchains	niters	rhat_1	rhat_2	rhat_all	converged
1848	2	3	500	1.009	1.006	1.007	TRUE

Walleye

Table 62. Model coefficients.

term	estimate	lower	upper	svalue
bEfficiency	-3.8705161	-4.1191975	-3.6574368	10.55171
sEfficiencySessionAnnual	0.5746183	0.3691441	0.8283321	10.55171

Table 63. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged

n	K	nchains	niters	nthin	ess	rhat	converged
1898	2	3	500	100	984	1.004	TRUE

Table 64. Model sensitivity.

n	K	nchains	niters	rhat_1	rhat_2	rhat_all	converged
1898	2	3	500	1.004	1.004	1.002	TRUE

Abundance

Table 65. Parameter descriptions.

Parameter	Description
`Annual`	Year
`bDensity`	Intercept for `log(eDensity)`
`bDensityAnnual`	Effect of `Annual` on `bDensity`
`bDensitySite`	Effect of `Site` on `bDensity`
`bDensitySiteAnnual`	Effect of `Site` within `Annual` on `bDensity`
`bEfficiencyVisitType`	Effect of `VisitType` on `Efficiency`
`eDensity`	Expected density
`Efficiency`	Capture efficiency
`esDispersion`	Overdispersion of `Fish`
`Fish`	Number of fish captured or counted
`ProportionSampled`	Proportion of site surveyed
`sDensityAnnual`	Log SD of effect of `Annual` on `bDensity`
`sDensitySite`	Log SD of effect of `Site` on `bDensity`
`sDensitySiteAnnual`	Log SD of effect of `Site` within `Annual` on `bDensity`
`sDispersion`	Intercept for `log(esDispersion)`
`sDispersionVisitType`	Effect of `VisitType` on `sDispersion`
`Site`	Site
`SiteLength`	Length of site
`VisitType`	Survey type (catch versus count)

Mountain Whitefish

Subadult

Table 66. Model coefficients.

term	estimate	lower	upper	svalue
bDensity	4.7215469	4.3641478	5.0891416	10.5517083
bDensitySiteAnnual2	0.0002748	-0.0004346	0.0014950	1.0943274
bEfficiencyVisitType[2]	1.3323795	1.1979106	1.4666057	10.5517083
bEfficiencyVisitTypeDensity[1]	0.0000566	-0.0001016	0.0003560	0.8426244
sDensityAnnual	0.6292131	0.4586582	0.9050668	10.5517083
sDensitySite	0.7650127	0.6233089	0.9537284	10.5517083
sDensitySiteAnnual	0.4260734	0.3707332	0.4853979	10.5517083
sDispersion	-0.8013172	-0.8859588	-0.7206539	10.5517083

term	estimate	lower	upper	svalue
sDispersionVisitType[2]	0.6799922	0.5236369	0.8427045	10.5517083

Table 67. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
3020	9	3	500	200	246	1.016	TRUE

Table 68. Model posterior predictive checks.

moment	observed	median	lower	upper	svalue
zeros	NA	NA	NA	NA	NA
mean	-0.2198328	-0.2722096	-0.3079951	-0.2389008	8.966746
variance	0.6983168	0.9911020	0.9445128	1.0348459	10.551708
skewness	0.0440552	0.2601992	0.1889356	0.3368542	10.551708
kurtosis	-0.4749788	-0.3401765	-0.4808510	-0.1664530	3.922352

Adult

Table 69. Model coefficients.

term	estimate	lower	upper	svalue
bDensity	5.7350361	5.4371950	6.0083993	10.55171
bDensitySiteAnnual2	-0.0012229	-0.0015595	-0.0008745	10.55171
bEfficiencyVisitType[2]	1.4221561	1.2281110	1.6012701	10.55171
bEfficiencyVisitTypeDensity[1]	0.0009679	0.0003505	0.0018524	8.22978
sDensityAnnual	0.5004073	0.3636975	0.7130026	10.55171
sDensitySite	0.7866482	0.6085898	1.0190803	10.55171
sDensitySiteAnnual	0.2695262	0.2103980	0.3398227	10.55171
sDispersion	-0.6724000	-0.7386631	-0.6080522	10.55171
sDispersionVisitType[2]	0.4993310	0.3593028	0.6240796	10.55171

Table 70. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
3020	9	3	500	200	183	1.028	TRUE

Table 71. Model posterior predictive checks.

moment	observed	median	lower	upper	svalue
zeros	NA	NA	NA	NA	NA
mean	-0.2181289	-0.2754738	-0.3104299	-0.2362249	6.8512685
variance	0.6784253	0.9995885	0.9542885	1.0455724	10.5517083
skewness	0.0646806	0.2045044	0.1265059	0.2794385	10.5517083
kurtosis	-0.2445684	-0.2919418	-0.4321163	-0.1223153	0.8426244

Rainbow Trout

Subadult

Table 72. Model coefficients.

term	estimate	lower	upper	svalue
bDensity	4.4844163	4.2533695	4.7025400	10.55171
bDensitySiteAnnual2	0.0034010	0.0000069	0.0107329	4.32289
bEfficiencyVisitType[2]	1.4391033	1.2917451	1.6112370	10.55171
bEfficiencyVisitTypeDensity[1]	-0.0012491	-0.0015710	-0.0009401	10.55171
sDensityAnnual	0.2812460	0.1762081	0.4366609	10.55171
sDensitySite	0.8103242	0.6619382	0.9841066	10.55171
sDensitySiteAnnual	0.4594808	0.4128931	0.5103665	10.55171
sDispersion	-0.9931035	-1.0693165	-0.9141010	10.55171
sDispersionVisitType[2]	0.7202672	0.5668938	0.8783220	10.55171

Table 73. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
3020	9	3	500	200	342	1.016	TRUE

Table 74. Model posterior predictive checks.

moment	observed	median	lower	upper	svalue
zeros	NA	NA	NA	NA	NA
mean	-0.1899087	-0.2429425	-0.2792487	-0.2052862	8.966746
variance	0.6332183	1.0252891	0.9782449	1.0750202	10.551708
skewness	-0.1000613	0.1249807	0.0486386	0.1983276	10.551708
kurtosis	-0.1348843	-0.2705761	-0.3988109	-0.0992383	3.202980

Adult

Table 75. Model coefficients.

term	estimate	lower	upper	svalue
bDensity	5.0776552	4.8701680	5.2779643	10.551708
bDensitySiteAnnual2	-0.0015156	-0.0025034	-0.0002746	5.266306
bEfficiencyVisitType[2]	1.2606920	1.1125814	1.4123855	10.551708
bEfficiencyVisitTypeDensity[1]	-0.0005207	-0.0009444	0.0005992	1.647826
sDensityAnnual	0.4264776	0.2976366	0.6184260	10.551708
sDensitySite	0.7409243	0.5698442	0.9549844	10.551708
sDensitySiteAnnual	0.2813581	0.2274583	0.3303467	10.551708
sDispersion	-1.0031767	-1.0876630	-0.9275556	10.551708
sDispersionVisitType[2]	0.5282350	0.3746196	0.6864147	10.551708

Table 76. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
3020	9	3	500	200	472	1.021	TRUE

Table 77. Model posterior predictive checks.

moment	observed	median	lower	upper	svalue
zeros	NA	NA	NA	NA	NA
mean	-0.1727064	-0.2369004	-0.2723400	-0.1984671	10.55171

moment	observed	median	lower	upper	svalue
variance	0.6324302	1.0350861	0.9862599	1.0823075	10.55171
skewness	-0.1471385	0.0855498	0.0097631	0.1573428	10.55171
kurtosis	-0.0219842	-0.2468565	-0.3788988	-0.0956251	8.22978

Walleye

Table 78. Model coefficients.

term	estimate	lower	upper	svalue
bDensity	4.7446058	4.5223653	5.0079572	10.551708
bDensitySiteAnnual2	-0.0033426	-0.0047263	-0.0010526	6.303781
bEfficiencyVisitType[2]	0.9589834	0.7691844	1.1062192	10.551708
bEfficiencyVisitTypeDensity[1]	0.0014959	-0.0006350	0.0066874	1.970508
sDensityAnnual	0.5654281	0.3915802	0.8428269	10.551708
sDensitySite	0.2852635	0.1754512	0.4202860	10.551708
sDensitySiteAnnual	0.2189440	0.1362712	0.3107260	10.551708
sDispersion	-0.8431508	-0.9172370	-0.7710493	10.551708
sDispersionVisitType[2]	0.5412947	0.3641323	0.6940544	10.551708

Table 79. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
3020	9	3	500	200	232	1.014	TRUE

Table 80. Model posterior predictive checks.

moment	observed	median	lower	upper	svalue
zeros	NA	NA	NA	NA	NA
mean	-0.1873520	-0.2562592	-0.2952159	-0.2170104	10.551708
variance	0.6942008	1.0403979	0.9959675	1.0872702	10.551708
skewness	-0.1845375	0.1052695	0.0314730	0.1783667	10.551708
kurtosis	-0.2415461	-0.3446436	-0.4699096	-0.1921884	2.512789

Fecundity

Table 81. Parameter descriptions.

Parameter	Description
`bFecundity`	Intercept of `eFecundity`
`bFecundityWeight`	Effect of `log(Weight)` on `log(bFecundity)`
`eFecundity[i]`	Expected `Fecundity` of `i`th fish
`Fecundity[i]`	Fecundity of `i`th fish (eggs)
`sFecundity`	SD of residual variation in `log(Fecundity)`
`Weight[i]`	Weight of `i`th fish (g)

Mountain Whitefish

Table 82. Model coefficients.

term	estimate	lower	upper	svalue

term	estimate	lower	upper	svalue
bFecundity	2.9434157	2.1499255	3.7243986	10.55171
bFecundityWeight	0.9941571	0.8747059	1.1132891	10.55171
sFecundity	0.1309413	0.1013519	0.1763504	10.55171

Table 83. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
28	3	3	500	500	890	1.001	TRUE

Table 84. Model posterior predictive checks.

moment	observed	median	lower	upper	svalue
zeros	NA	NA	NA	NA	NA
mean	0.0007544	0.0035540	-0.3718694	0.3767449	0.0096437
variance	0.9031600	0.9833955	0.5273010	1.6138927	0.4392688
skewness	-0.0053713	0.0009168	-0.7991967	0.8153463	0.0154610
kurtosis	-0.7054780	-0.3573449	-1.1378323	1.5474069	1.0419333

Table 85. Model sensitivity.

n	K	nchains	niters	rhat_1	rhat_2	rhat_all	converged
28	3	3	500	1.001	1.007	1.004	TRUE

Stock-Recruitment

Table 86. Parameter descriptions.

Parameter	Description
`bAlpha`	`eRecruits` per `Stock` at low `Stock` density
`bBeta`	Expected density-dependence
`bEggLoss`	Effect of `EggLoss` on `log(eRecruits)`
`EggLoss`	Proportional egg loss
`Eggs`	Total egg deposition
`eRecruits`	Expected `Recruits`
`Recruits`	Number of Age-1 recruits
`sRecruits`	SD of residual variation in `log(Recruits)`

Mountain Whitefish

Table 87. Model coefficients.

term	estimate	lower	upper	svalue
bAlpha	0.0036417	0.0010400	0.0083519	10.5517083
bBeta	0.0000002	0.0000000	0.0000005	10.5517083
bEggLoss	-0.4536097	-2.4498831	1.9636046	0.5390837
sRecruits	0.5839171	0.4265604	0.8513871	10.5517083

Table 88. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
19	4	3	500	50	954	1.004	TRUE

Table 89. Model posterior predictive checks.

moment	observed	median	lower	upper	svalue
zeros	NA	NA	NA	NA	NA
mean	12.8398026	0.0044291	-0.4631205	0.4469220	10.5517083
variance	0.8847771	0.9608151	0.4451833	1.7566240	0.3097251
skewness	-0.0813545	-0.0107121	-0.9332061	0.9698862	0.2063030
kurtosis	-1.2203252	-0.4598808	-1.2562672	1.6686948	3.7572924

Table 90. Model sensitivity.

n	K	nchains	niters	rhat_1	rhat_2	rhat_all	converged
19	4	3	500	1.004	1.009	1.627	FALSE

Rainbow Trout

Table 91. Model coefficients.

term	estimate	lower	upper	svalue
bAlpha	0.0038102	0.0011969	0.0082135	10.551708
bBeta	0.0000002	0.0000000	0.0000006	10.551708
bEggLoss	43.5317082	-7.1889609	92.8321575	3.474893
sRecruits	0.4326012	0.3204554	0.6366434	10.551708

Table 92. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
20	4	3	500	50	772	1.005	TRUE

Table 93. Model posterior predictive checks.

moment	observed	median	lower	upper	svalue
zeros	NA	NA	NA	NA	NA
mean	17.3373632	0.0036790	-0.4433163	0.4316881	10.5517083
variance	0.9608848	0.9743364	0.4874719	1.7549967	0.0608574
skewness	0.1625044	0.0132264	-0.9145807	0.9351975	0.4682289
kurtosis	0.3238386	-0.4688770	-1.2597471	1.6729996	1.8687137

Table 94. Model sensitivity.

n	K	nchains	niters	rhat_1	rhat_2	rhat_all	converged
20	4	3	500	1.005	1.003	1.65	FALSE

Age-Ratios

Table 95. Parameter descriptions.

Parameter	Description
`Age1[i]`	The number of Age-1 fish in the `i`th year
`Age1and2[i]`	The number of Age-1 and Age-2 fish in the `i`th year
`bProbAge1`	Intercept for `logit(eProbAge1)`
`bProbAge1Loss`	Effect of `LossLogRatio` on `bProbAge1`

Parameter	Description
`eProbAge1[i]`	The expected proportion of Age-1 fish in the `i`th year
`LossLogRatio[i]`	The `log` of the ratio of the percent egg losses
`sDispersion`	SD of extra-binomial variation

Table 96. Model coefficients.

term	estimate	lower	upper	svalue
bProbAge1	0.2377570	-0.0902671	0.5640274	2.8582213
bProbAge1Loss	-0.1449130	-0.5952169	0.3394578	0.8704698
sProbAge1	0.7717861	0.5772362	1.0755001	10.5517083

Table 97. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
21	3	3	500	1	682	1.007	TRUE

Table 98. Model posterior predictive checks.

moment	observed	median	lower	upper	svalue
zeros	NA	NA	NA	NA	NA
mean	0.0010306	0.0059828	-0.4062282	0.4028671	0.0252090
variance	0.9088141	0.9562337	0.5005642	1.6728891	0.2331655
skewness	-0.4539816	-0.0101251	-0.9134044	0.9244399	1.6004235
kurtosis	-0.9846608	-0.4087201	-1.2445684	1.6615550	1.9856542

Table 99. Model sensitivity.

n	K	nchains	niters	rhat_1	rhat_2	rhat_all	converged
21	3	3	500	1.007	1.002	1.005	TRUE

Adjusted Recruitment

Table 100. Parameter descriptions.

Parameter	Description
`b0`	Intercept for `eRb[i]`
`bEggLoss`	Effect of `EggLoss` on `eRb[i]`
`bMw`	Effect of `Mw` on `eRb[i]`
`Eggloss[i]`	Proportional RB egg loss for the `i`th spawn year
`eRb[i]`	Expected value of `Rb[i]`
`Mw[i]`	Abundance of age-1 MW caught in the same year as age-1 RB from the `i`th spawn year
`Rb[i]`	Abundance of age-1 RB for the `i`th spawn year
`sRb`	SD of residual variation in `eRb[i]`

Table 101. Model coefficients.

term	estimate	lower	upper	svalue
b0	9.8273576	9.6874121	9.9726553	10.551708
bEggLoss	0.0863422	-0.0901280	0.2654751	1.588812
bMw	0.2991639	0.1229051	0.4786583	10.551708

term	estimate	lower	upper	svalue
sRb	0.3330808	0.2496527	0.4923357	10.551708

Table 102. Model convergence.

n	K	nchains	niters	nthin	ess	rhat	converged
21	4	3	500	50	1322	1.002	TRUE

Table 103. Model posterior predictive checks.

moment	observed	median	lower	upper	svalue
zeros	NA	NA	NA	NA	NA
mean	0.0073628	0.0095887	-0.4186765	0.4191436	0.0057785
variance	0.8271602	0.9832338	0.4648124	1.7211129	0.6553759
skewness	0.5683087	-0.0098563	-0.9260708	0.9488355	2.2525002
kurtosis	1.4564275	-0.4483787	-1.2644998	1.6850341	3.9223516

Table 104. Model sensitivity.

n	K	nchains	niters	rhat_1	rhat_2	rhat_all	converged
21	4	3	500	1.002	1.003	1.003	TRUE

Appendix D – Discharge, Temperature, and Elevation Data

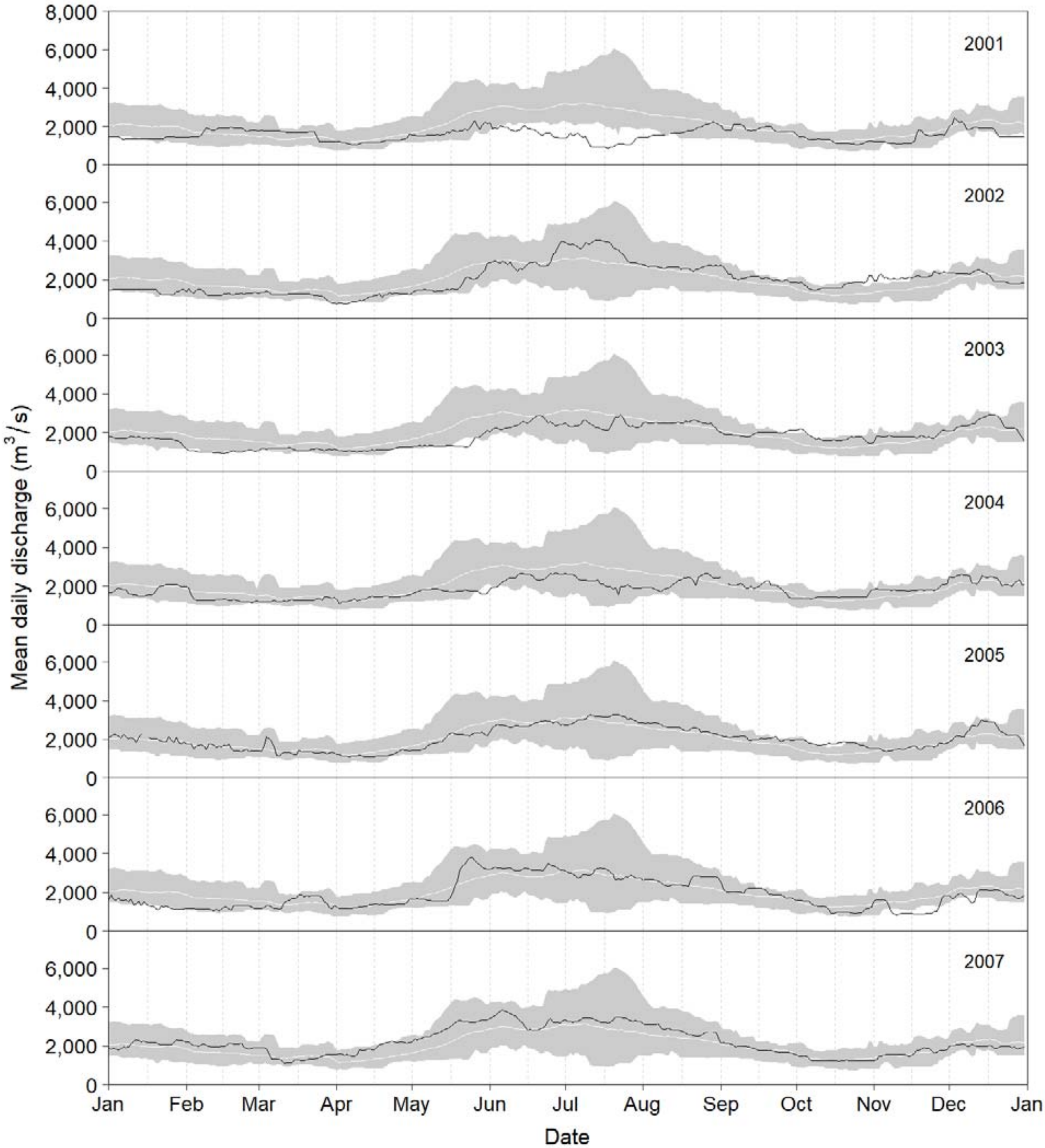


Figure D1. Mean daily discharge (m³/s) for the Columbia River at the Birchbank water gauging station (black line), 2001 to 2021. The shaded area represents minimum and maximum mean daily discharge recorded at Birchbank during other study years between 2001 and 2021. The white line represents average mean daily discharge over the same time period.

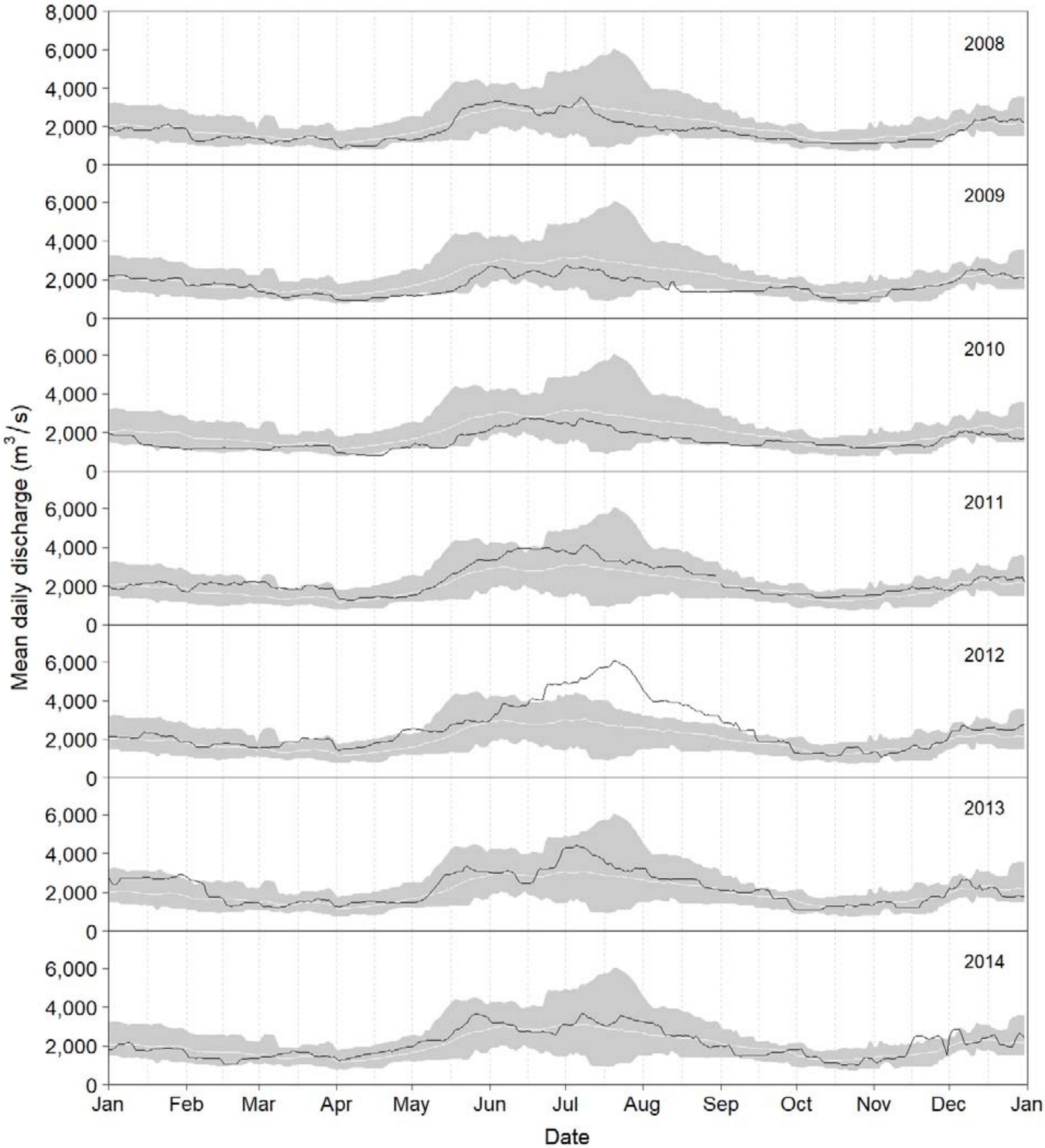


Figure D1. Continued.

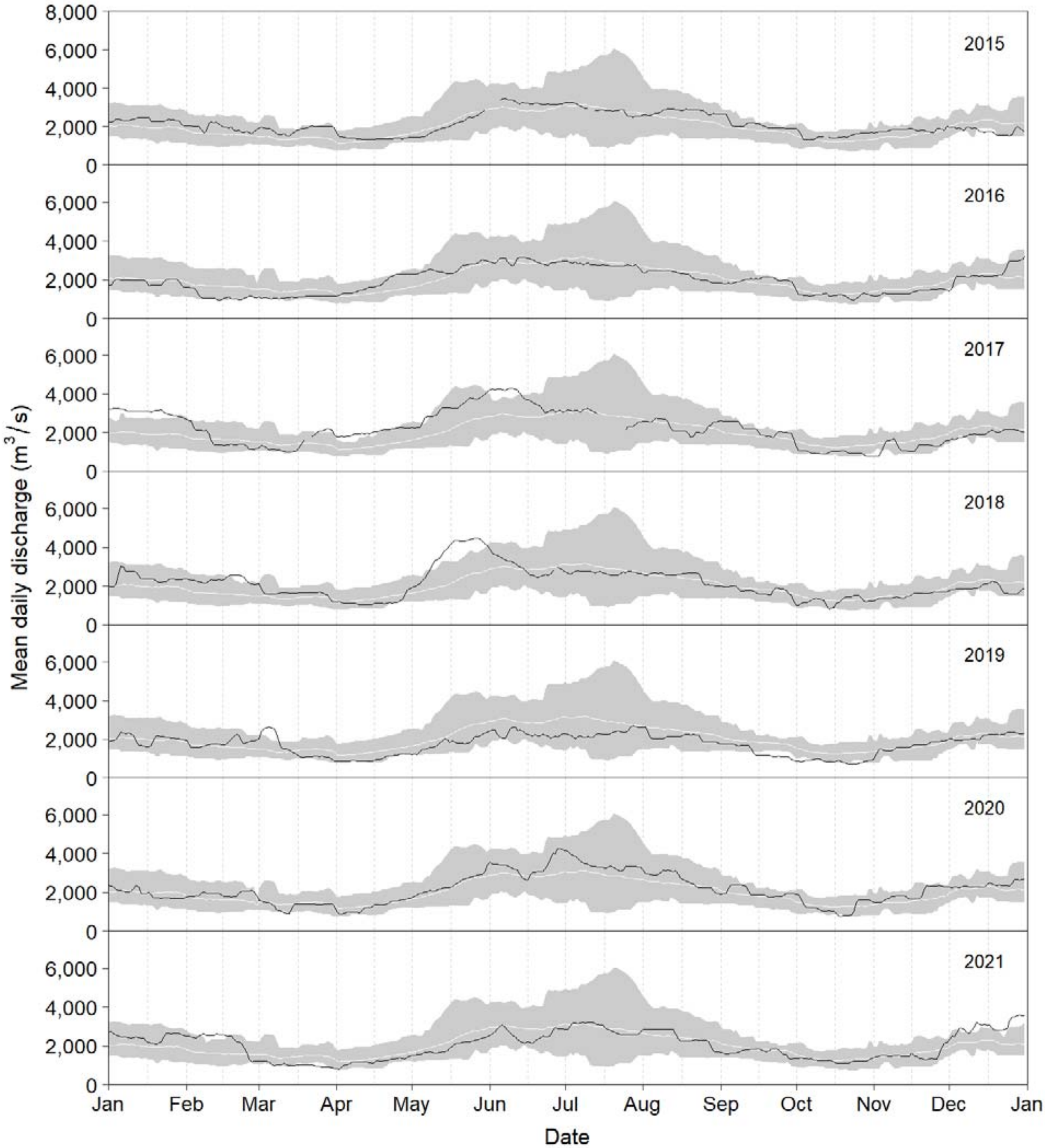


Figure D1. Concluded.

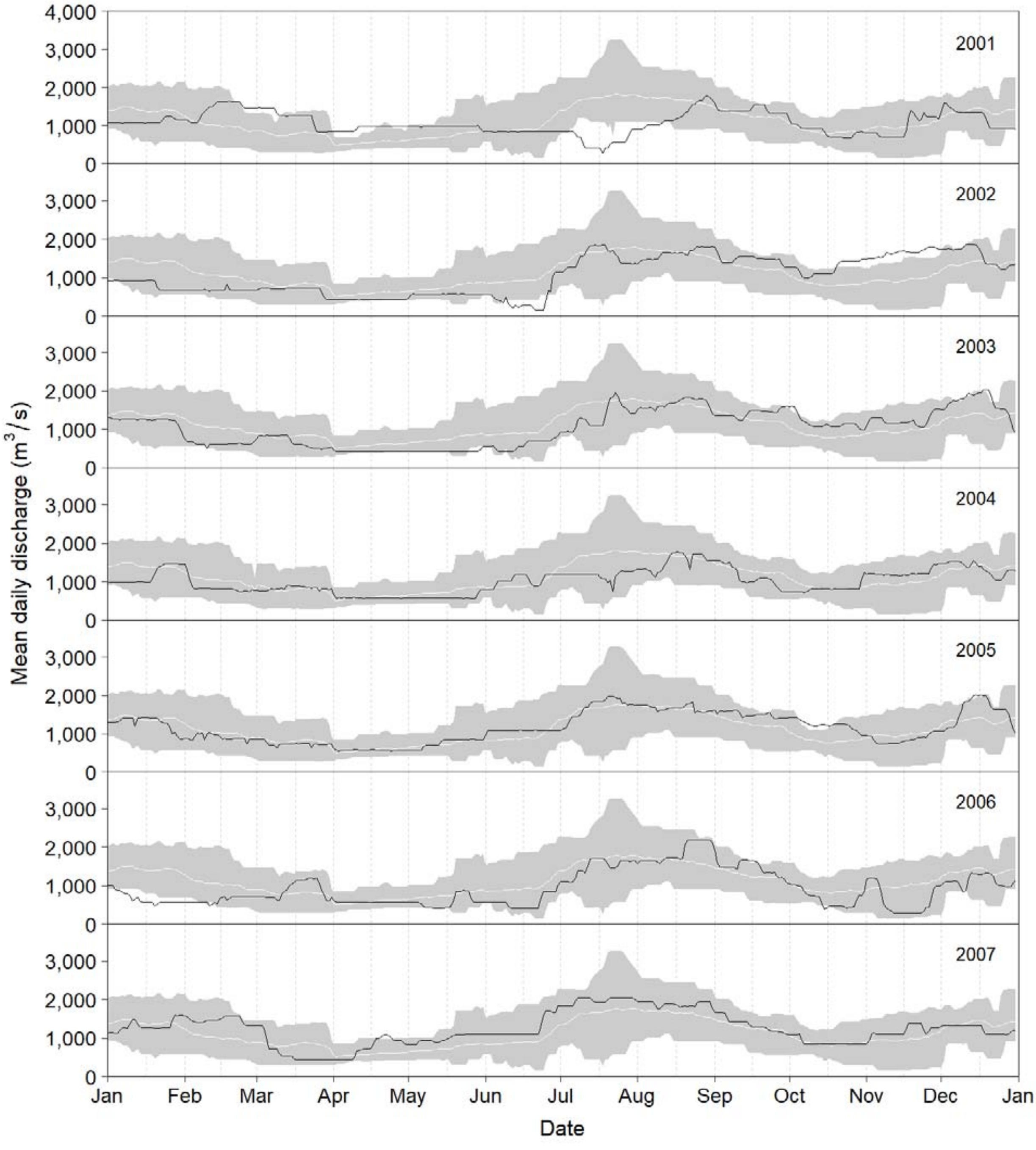


Figure D2. Mean daily discharge (m³/s) for the Columbia River at Hugh L. Keenleyside Dam (HLK), 2001 to 2021 (black line). The shaded area represents minimum and maximum mean daily discharge recorded at HLK during other study years between 2001 and 2021. The white line represents average mean daily discharge over the same time period.

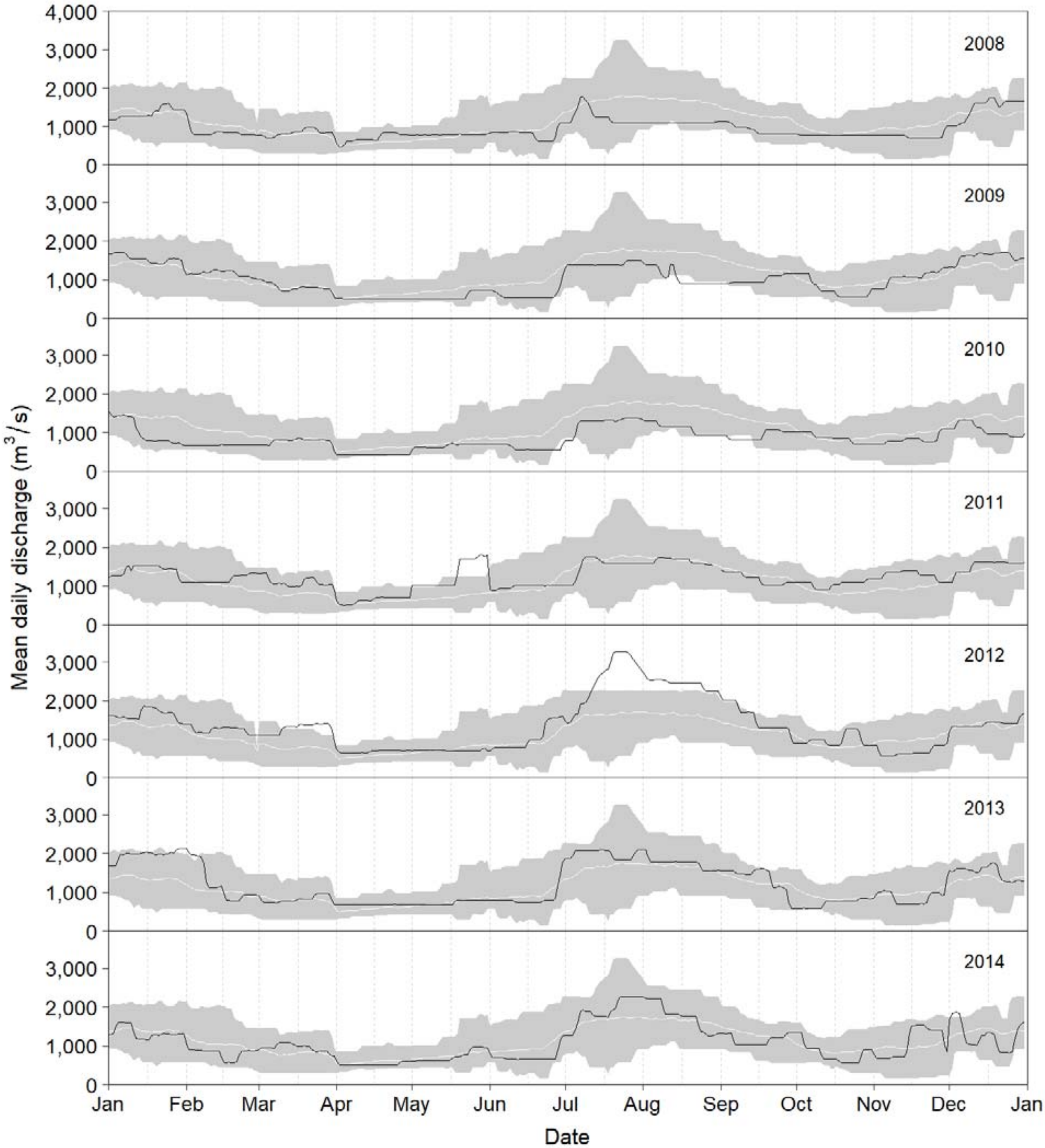


Figure D2. Continued.

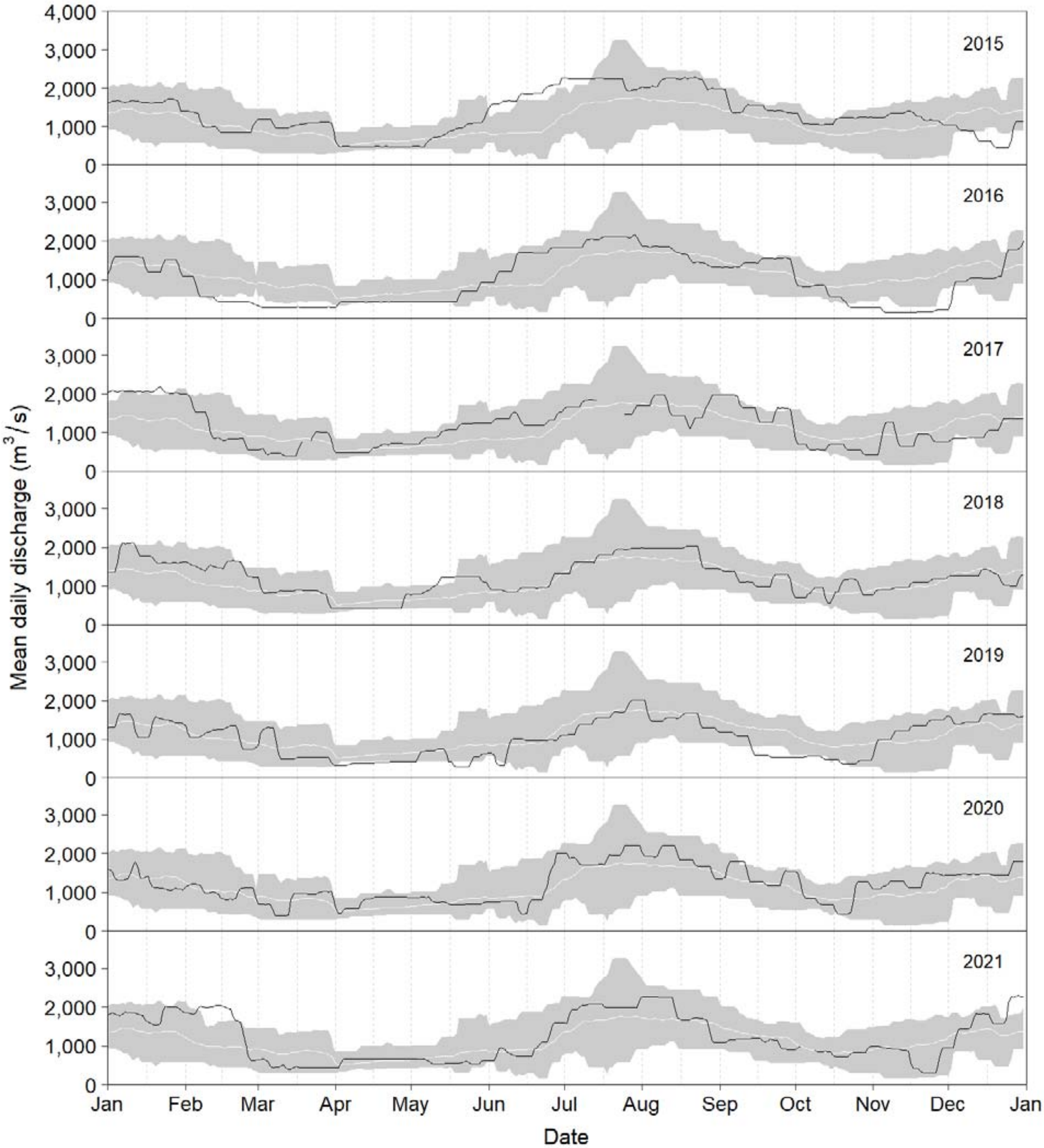


Figure D2. Concluded.

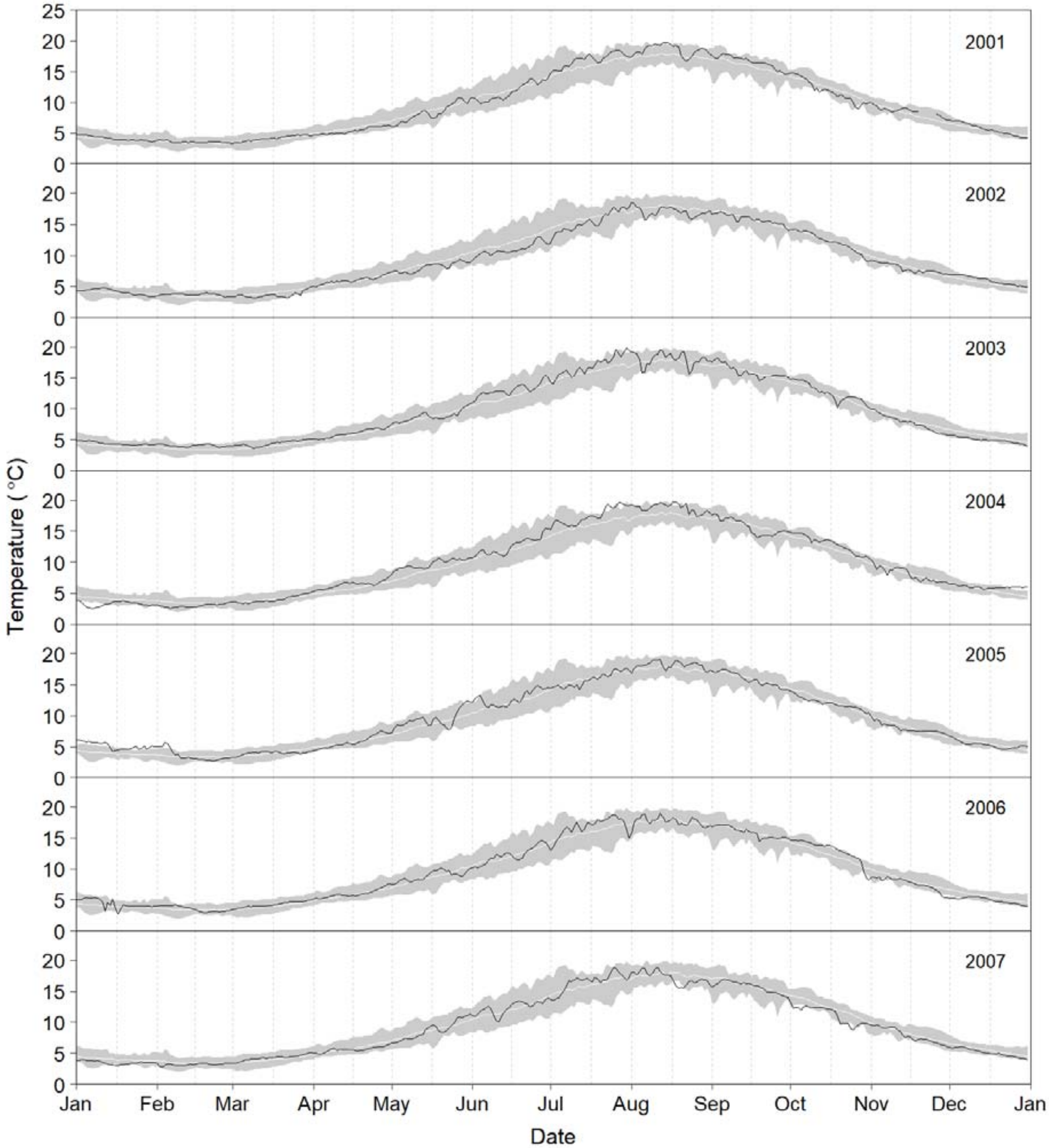


Figure D3. Mean daily water temperatures (°C) for the Columbia River (black line), 2001 to 2021. Data from all years except 2012 and March-April 2017 were recorded at the Birchbank water gauging station. Data from 2012 were recorded near Fort Shepherd. Data from March to November 2017 were recorded at Kinnaird Eddy. The shaded area represents minimum and maximum mean daily water temperatures during other study years between 2001 and 2021. The white line represents average mean daily water temperature over the same time period.

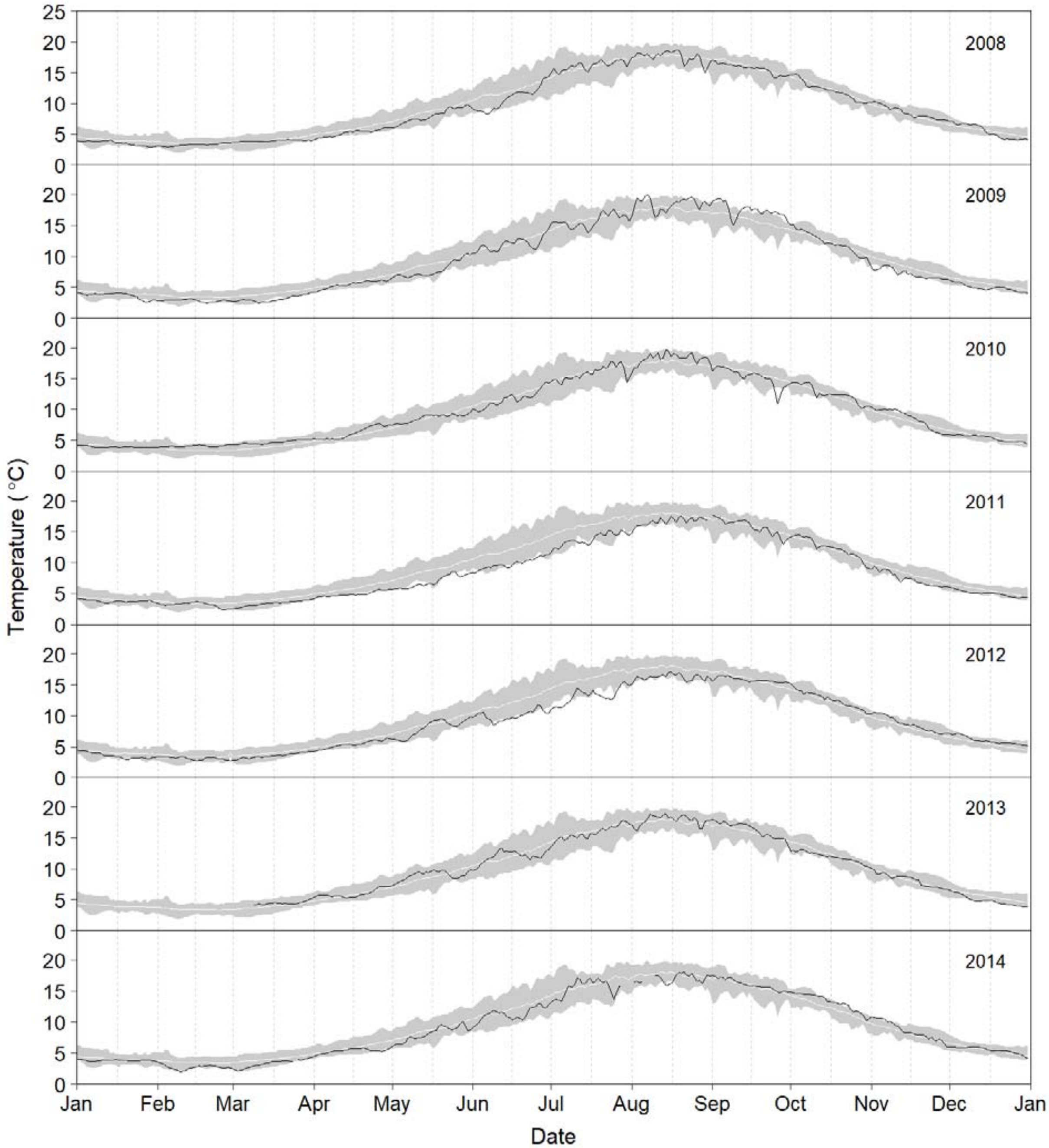


Figure D3. Continued.

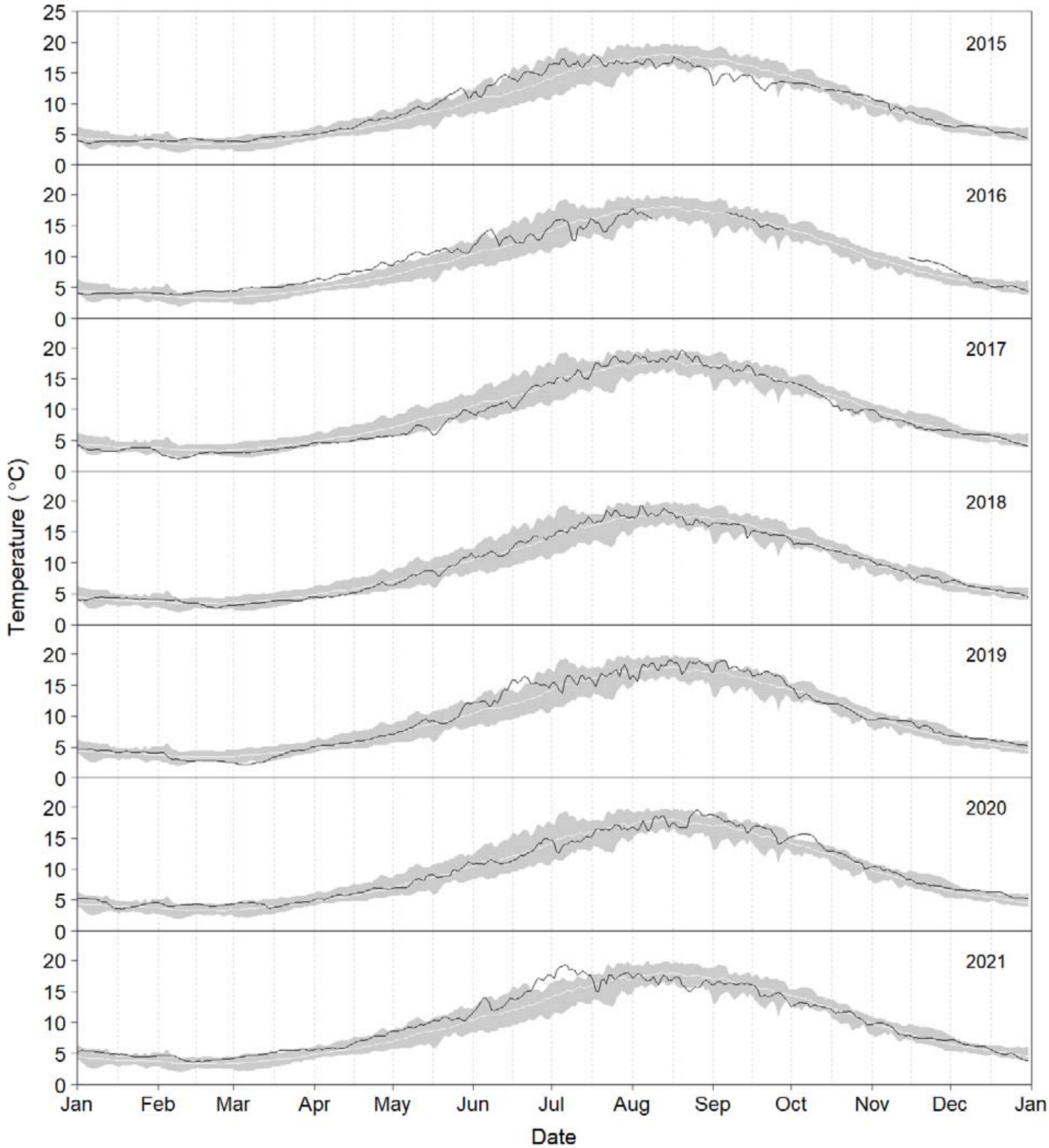


Figure D3. Concluded.

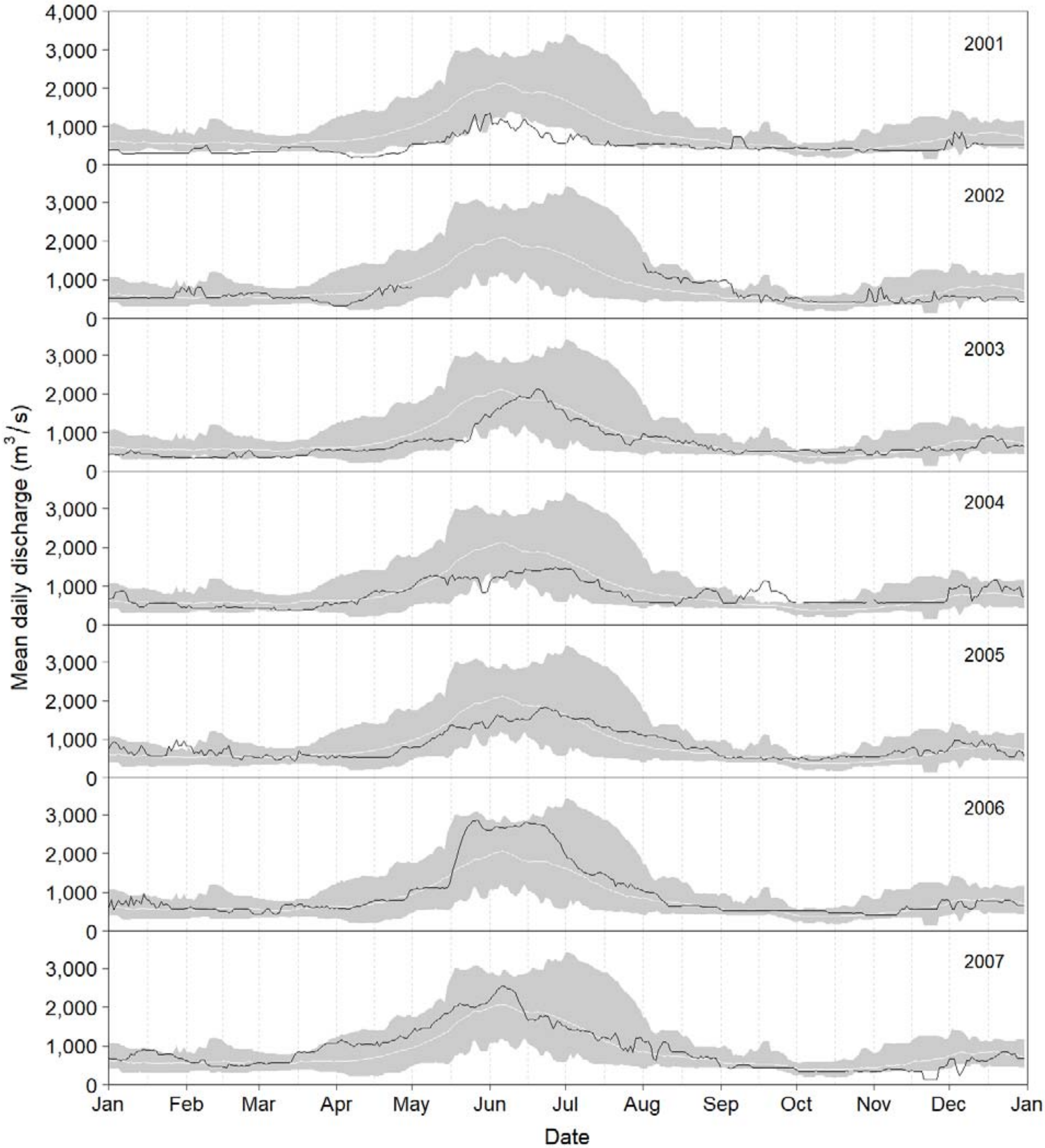


Figure D4. Mean daily discharge (m³/s) for the Kootenay River at Brilliant Dam (BRD), 2001 to 2021 (black line). The shaded area represents minimum and maximum mean daily discharge recorded at BRD during other study years between 2001 and 2021. The white line represents average mean daily discharge over the same time period.

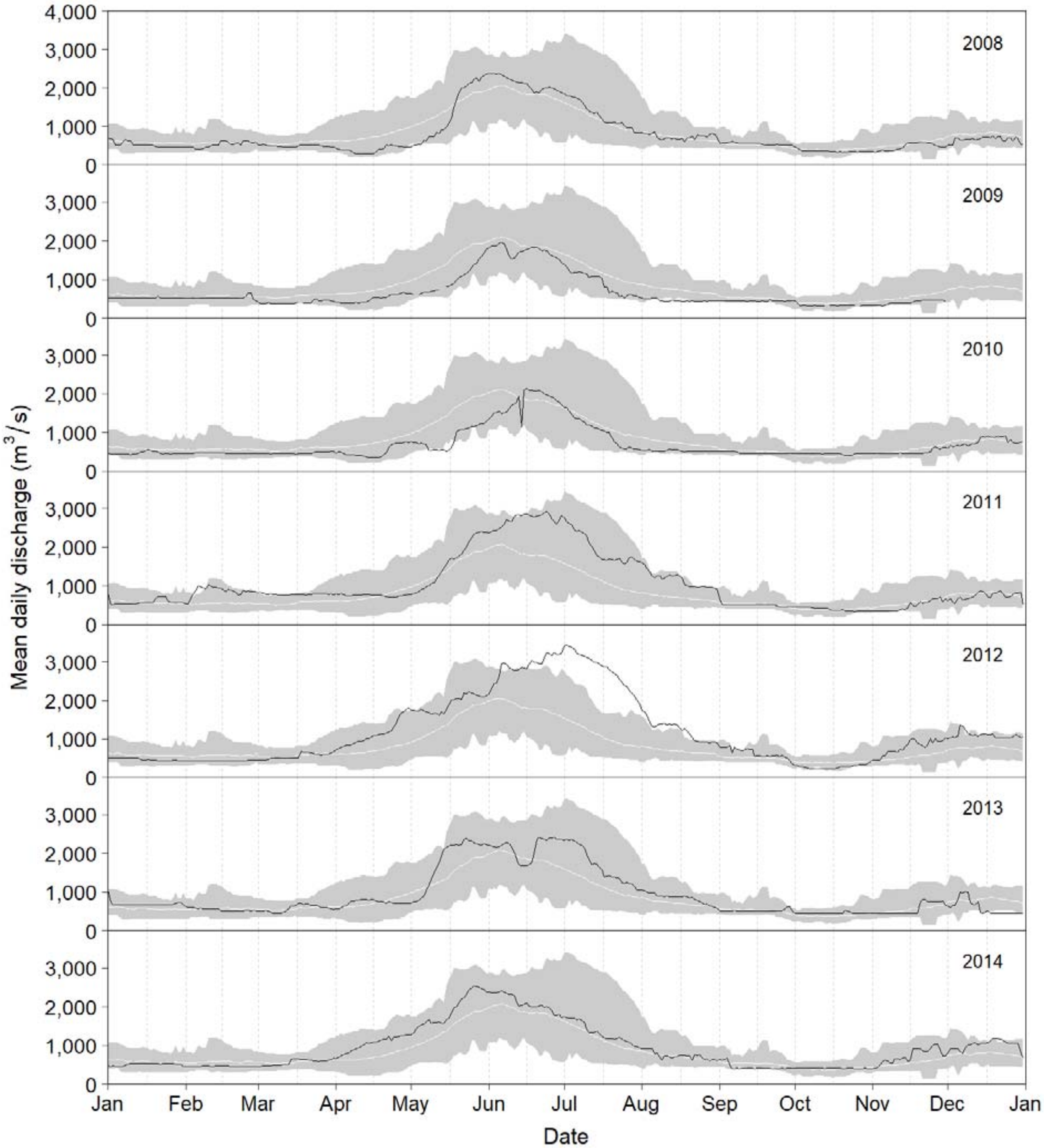


Figure D4. Continued.

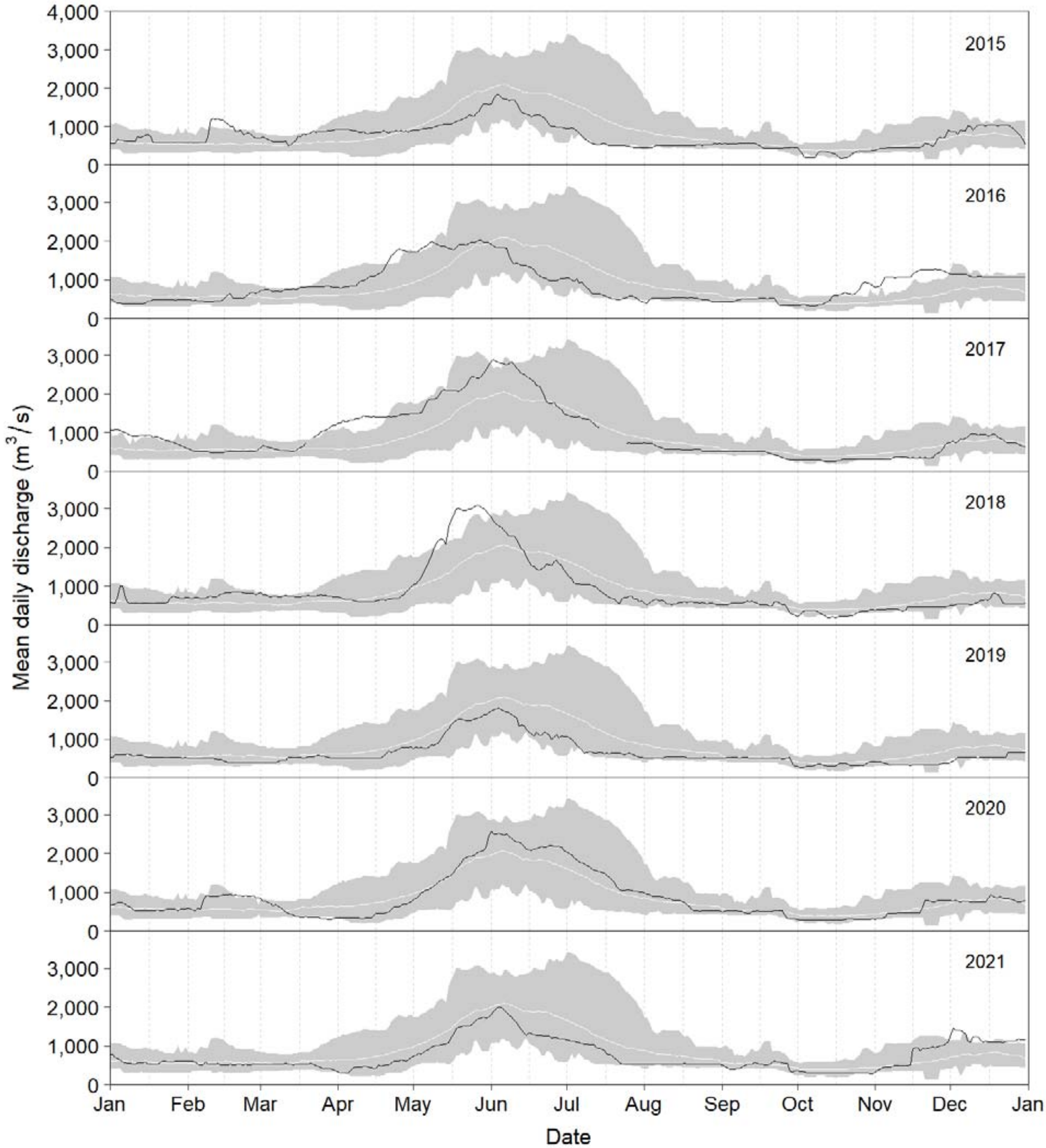


Figure D4. Concluded.

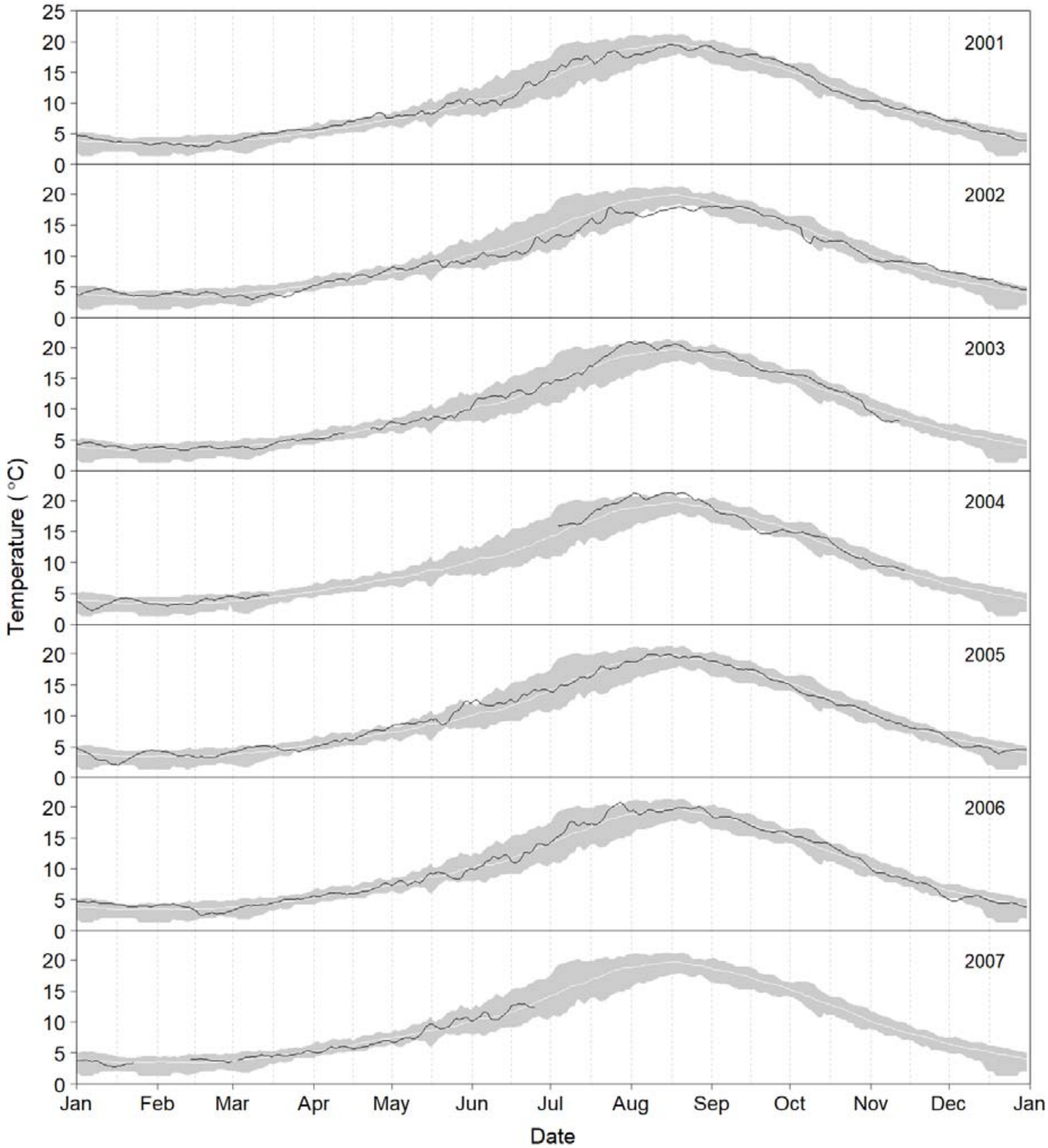


Figure D5. Mean daily water temperatures (°C) for the Kootenay River at Brilliant Dam (BRD), 2001 to 2021 (black line). The shaded area represents minimum and maximum mean daily water temperatures recorded at BRD during other study years between 2001 and 2021. The white line represents average mean daily water temperature over the same time period.

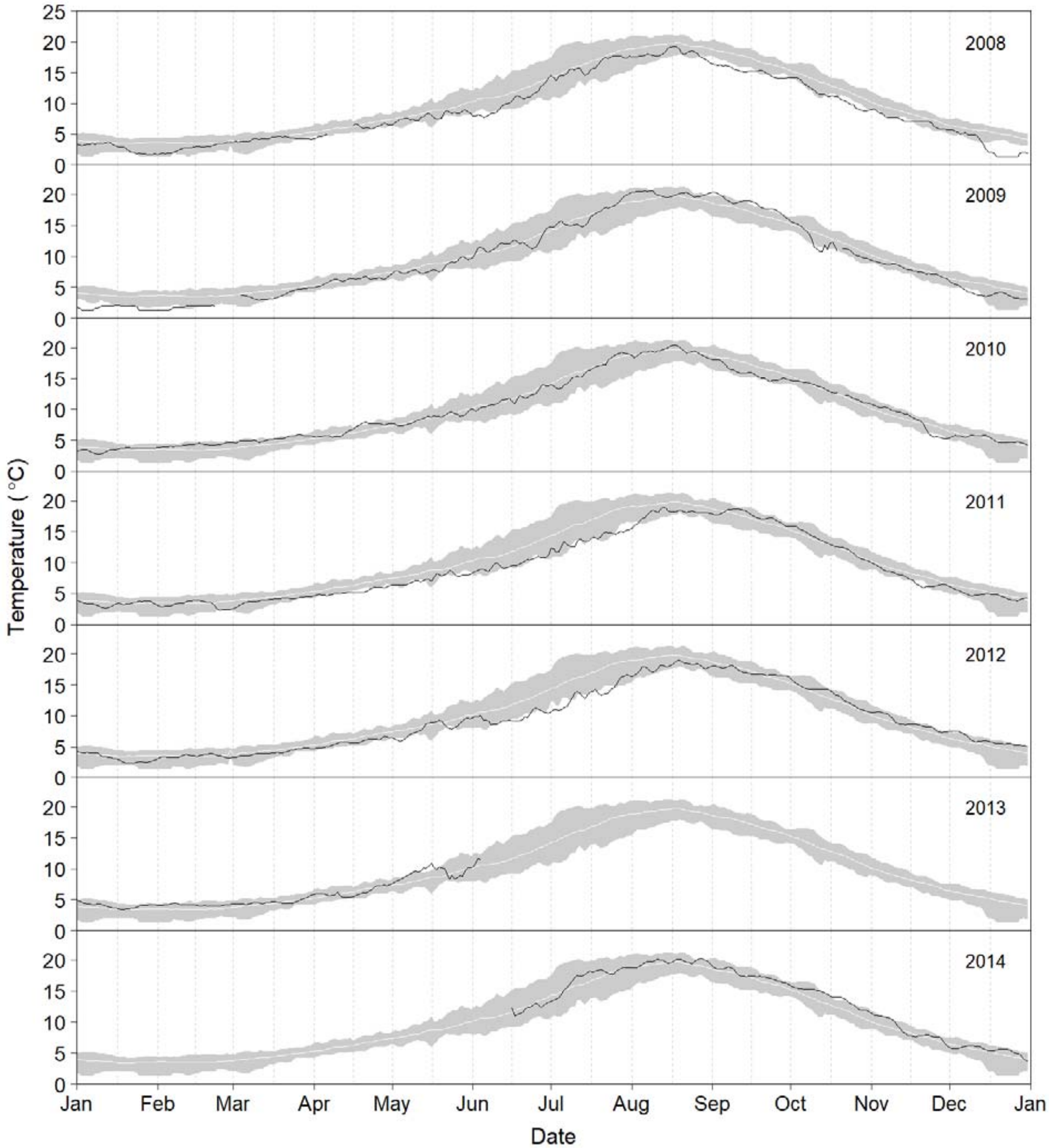


Figure D5. Continued.

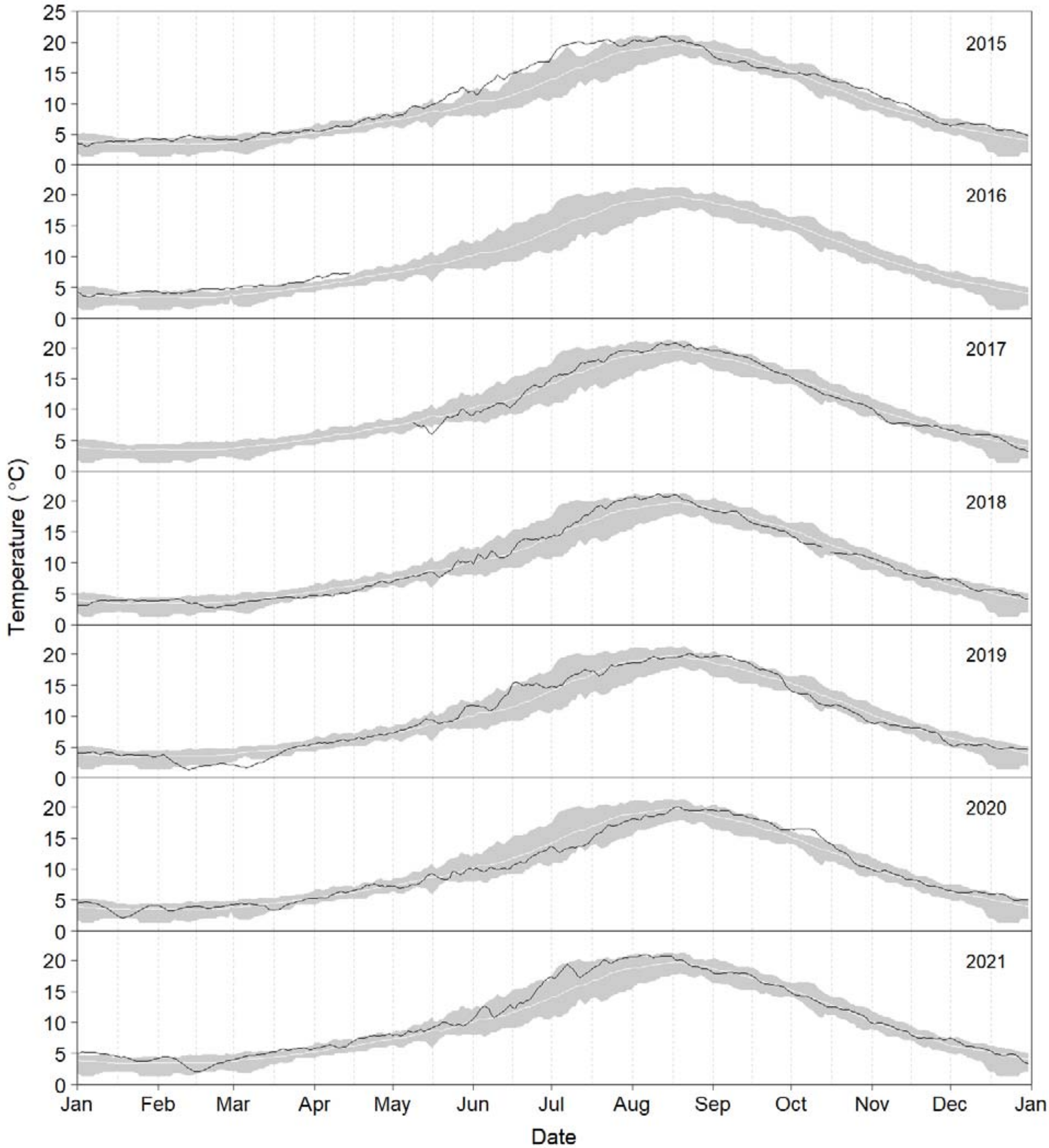


Figure D5. Concluded.

Appendix E – Catch and Effort

Table E1 Number of fish caught and observed during boat electroshocking surveys and their frequency of occurrence in sampled sections of the Lower Columbia River, 2001 to 2021. Data include index sites only; all data from GRTS sites were removed.

	2001		2002		2003		2004		2005		2006		2007		2008		2009		2010		2011		2012		2013		2014		2015		2016		2017		2018		2019		2020		2021		All Years[a]		
Species	n[a]	%[b]	n[a]	%[b]	n[a]	%[b]	n[a]	%[b]	n[a]	%[b]	n[a]	%[b]	n[a]	%[b]	n[a]	%[b]	n[a]	%[b]	n[a]	%[b]	n[a]	%[b]	n[a]	%[b]	n[a]	%[b]	n[a]	%[b]	n[a]	%[b]	n[a]	%[b]	n[a]	%[b]	n[a]	%[b]	n[a]	%[b]	n[a]	%[b]	n[a]	%[b]	n[a]	%[b]	%[c]
Sportfish																																													
Brook Trout	5	<1	8	<1	7	<1	3	<1	3	<1	4	<1	15	<1	8	<1	3	<1	4	<1	14	<1	15	<1	31	<1	17	<1	9	<1	1	<1	8	<1	1	<1	1	<1	4	<1			161	<1	<1
Brown Trout	1	<1	2	<1			1	<1	1	<1	2	<1	7	<1	2	<1	3	<1	8	<1	4	<1	2	<1	3	<1	5	<1	1	<1	2	<1	2	<1	4	<1	2	<1	5	<1	1	<1	58	<1	<1
Bull Trout	16	<1	3	<1	18	<1	8	<1	8	<1	11	<1	30	<1	6	<1	9	<1	8	<1	12	<1	13	<1	6	<1	4	<1	8	<1	3	<1	2	<1	2	<1	1	<1	6	<1	2	<1	176	<1	<1
Burbot	3	<1	10	<1	59	<1	208	1	174	2	195	1	191	2	69	1	33	<1	70	1	247	2	39	<1	14	<1	20	<1	6	<1	11	<1	25	<1	13	<1	11	<1	21	<1	41	1	1460	1	<1
Cutthroat Trout	1	<1	4	<1	2	<1			1	<1	5	<1	8	<1	5	<1	3	<1	6	<1	4	<1	4	<1	2	<1																	45	<1	<1
Kokanee	2562	9	171	1	5180	19	120	1	32	<1	898	7	506	4	148	1	1128	11	57	1	77	1	156	1	18	<1	7	<1	22	<1	24	<1	19	<1	7	<1	59	1	9	<1	209	3	11 409	4	1
Lake Trout			1	<1											1	<1											1	<1															3	<1	<1
Lake Whitefish	61	<1	140	1	230	1	160	1	262	2	290	2	163	1	159	1	192	2	239	3	220	2	61	1	71	1	70	1	71	1	205	2	86	1	90	1	69	1	146	2	323	5	3308	1	<1
Largemouth Bass																											1	<1															1	<1	<1
Mountain Whitefish	14 916	52	12 108	50	9685	35	6020	38	5024	43	5472	40	5595	45	5221	44	3800	36	2748	30	2933	27	4648	41	4880	49	4020	53	2997	45	4353	45	3925	36	3830	41	1885	26	1553	25	1934	31	107 547	41	12
Northern Pike																			7	<1	9	<1	11	<1	125	1	25	<1	9	<1	4	<1	8	<1	3	<1	24	<1	4	<1	2	<1	231	<1	<1
Pumpkinseed																																					1	<1					1	<1	<1
Rainbow Trout	9426	33	10 221	42	8466	30	5763	37	3844	33	5338	39	4953	39	5124	43	4219	40	4420	48	5501	51	5401	48	4110	41	2937	39	3081	46	4046	42	5755	52	4202	45	3683	51	3300	53	2869	47	106 659	41	12
Smallmouth Bass					4	<1	3	<1	4	<1	53	<1	16	<1	1	<1			1	<1	8	<1					9	<1	1	<1	2	<1	4	<1	3	<1			6	<1	1	<1	116	<1	<1
Walleye	1467	5	1478	6	4165	15	3413	22	2230	19	1421	10	1076	9	1208	10	1127	11	1588	17	1814	17	881	8	752	8	484	6	480	7	1047	11	1175	11	1051	11	1319	18	1108	18	660	11	29 944	11	3
White Sturgeon	14	<1	6	<1	18	<1	5	<1	11	<1	14	<1	11	<1	9	<1	4	<1	11	<1	23	<1	9	<1	7	<1	13	<1	14	<1	35	<1	33	<1	49	1	98	1	93	1	109	2	586	<1	<1
Yellow Perch					1	<1	4	<1	1	<1	24	<1	1	<1					12	<1	2	<1			1	<1			2	<1	6	<1	1	<1	1	<1	4	<1			2	<1	62	<1	<1
Sportfish subtotal	28 472	100	24 152	100	27 835	100	15 708	100	11 595	100	13 727	100	12 572	100	11 961	100	10 521	100	9179	100	10 868	100	11 240	100	10 020	100	7613	100	6701	100	9739	100	11 043	100	9256	100	7157	98	6255	100	6153	100	261 767	100	29
Non-sportfish																																													
Carp spp.	2	<1					1	<1	1	<1	3	<1	1	<1	2	<1			3	<1									1	<1					1	<1	1	<1			4	<1	20	<1	<1
Dace spp.	2	<1					3	<1	15	<1	17	<1	1	<1	1	<1			13	<1	3	<1	1	<1																	1	<1	57	<1	<1
Northern Pikeminnow	570	3	2371	10	969	3	1337	3	522	2	1450	2	845	1	1452	2	241	1	393	1	764	2	681	3	453	<1	64	<1	138	2	42	<1	88	<1	184	5	108	2	77	2	105	1	12 854	2	1
Peamouth	80	<1	205	1	45	<1	51	<1	33	<1	52	<1	93	<1	3	<1	4	<1	25	<1	192	<1	488	2	12	<1	25	<1	156	2	3	<1	107	1	9	<1	6	<1	5	<1	22	<1	1616	<1	<1
Redside Shiner	8520	46	9026	40	5710	20	4605	12	1742	5	13 121	17	3119	5	8156	12	1592	5	2269	7	4626	11	5280	21	40 151	41	3437	26	1636	22	1094	10	6053	34	375	10	492	10	125	3	382	5	121 511	19	13
Sculpin spp.[e]	2724	15	7479	33	16 674	59	26 991	67	25 734	79	51 925	68	45 508	76	49 939	71	23 209	73	21 446	67	29 392	72	16 030	62	44 367	45	7856	59	4169	57	6850	66	10 736	60	2018	52	2828	57	3050	70	5774	76	404 699	63	45
Sucker spp.[e]	6509	35	3553	16	4779	17	7033	18	4378	14	9235	12	10 012	17	11 028	16	6896	22	7625	24	5949	15	3194	12	12 736	13	2029	15	1188	16	2441	23	1052	6	1303	33	1519	31	1101	25	1345	18	104 905	16	12
Tench											1	<1	5	<1	1	<1			2	<1					2	<1	1	<1			1	<1	1	<1	3	<1			2	<1			19	<1	<1
Non-sportfish subtotal	18 407	100	22 634	100	28 177	100	40 021	100	32 425	100	75 804	100	59 584	100	70 582	100	31 942	100	31 776	100	40 926	100	25 674	100	97 721	100	13 412	100	7288	100	10 431	100	18 037	100	3893	100	4954	100	4360	100	7633	100	645 681	100	71
All species	46 879		46 786		56 012		55 729		44 020		89 531		72 156		82 543		42 463		40 955		51 794		36 914		107 741		21 025		13 989		20 170		29 080		13 149		12 111		10 615		13 786		907 448		

[a] Includes fish observed and identified to species; does not include recaptured fish.
[b] Percent composition of sportfish or non-sportfish catch.
[c] Percent composition of the total fish catch.
[d] Species combined for table or not identified to species.

Table E2 Summary of boat electroshocking sportfish catch (includes fish captured and observed and identified to species) and catch-per-unit-effort (CPUE = no. fish/km/hour) in the Lower Columbia River, 04 October to 06 November 2021.

Section	Session	Site	Date	Time Sampled (s)	Length Sampled (km)	Number Caught (CPUE = no. fish/km/hr)																													
						Brook Trout		Brown Trout		Bull Trout		Burbot		Kokanee		Lake Whitefish		Mountain Whitefish		Northern Pike		Rainbow Trout		Smallmouth Bass		Walleye		White Sturgeon		Yellow Perch		All Species	
						No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE
Columbia River U/S	1	C00.0-R	04-Oct-21	956	0.94									2	8.04			18	72.33			10	40.18			1	4.02	5	20.09			36	144.66
		C00.7-L	04-Oct-21	953	0.59									2	12.73			14	89.14			14	89.14			5	31.84	2	12.73			37	235.58
		C01.3-L	04-Oct-21	1984	1.60					1	1.13			33	37.4			82	92.92			42	47.59			6	6.8	2	2.27			166	188.11
		C02.8-L	04-Oct-21	788	0.88									6	31.07			34	176.09			4	20.72			1	5.18	4	20.72			49	253.77
		C03.6-L	05-Oct-21	2669	2.09									32	20.68			25	16.16			28	18.09			11	7.11					96	62.04
		C04.6-R	05-Oct-21	579	0.52													2	24.03			2	24.03			3	36.05	1	12.02			8	96.12
		C05.6-L	05-Oct-21	1191	1.10									3	8.24			4	10.98			12	32.95			3	8.24					22	60.41
		C07.3-R	05-Oct-21	971	1.70									5	10.87	6	13.05	39	84.81			34	73.94			12	26.1	2	4.35			98	213.12
		C07.4-L	05-Oct-21	1050	1.00									3	10.3	1	3.43	63	216.39			24	82.44			6	20.61					97	333.18
	Session Summary			**1237.9**	**10.00**	**0**	**0**	**0**	**0**	**1**	**0.29**	**0**	**0**	**86**	**25.01**	**7**	**2.04**	**281**	**81.72**	**0**	**0**	**170**	**49.44**	**0**	**0**	**48**	**13.96**	**16**	**4.65**	**0**	**0**	**609**	**177.11**
	2	C00.0-R	12-Oct-21	840	0.94									1	4.57			8	36.59			4	18.29			5	22.87	2	9.15			20	91.46
		C00.7-L	12-Oct-21	741	0.59									4	32.76			15	122.83			11	90.08			1	8.19	1	8.19			32	262.04
		C01.3-L	12-Oct-21	2022	1.59									16	17.9			49	54.83			45	50.35			9	10.07	2	2.24			121	135.38
		C02.8-L	12-Oct-21	980	0.88									5	20.82			26	108.27			8	33.31			4	16.66					43	179.07
		C03.6-L	12-Oct-21	2319	2.09									18	13.39			29	21.57			24	17.85			22	16.36	4	2.97			97	72.14
		C04.6-R	13-Oct-21	646	0.52													4	43.08			8	86.15			5	53.85					17	183.08
		C05.6-L	13-Oct-21	1298	1.10									2	5.04			15	37.79	1	2.52	12	30.23			8	20.16	2	5.04			40	100.78
		C07.3-R	13-Oct-21	894	1.70									6	14.17	2	4.72	32	75.58			17	40.15			10	23.62					67	158.25
		C07.4-L	13-Oct-21	1073	1.00											1	3.36	89	299.15			12	40.33					3	10.08			105	352.93
	Session Summary			**1201.4**	**10.00**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**52**	**15.58**	**3**	**0.9**	**267**	**80.01**	**1**	**0.3**	**141**	**42.25**	**0**	**0**	**64**	**19.18**	**14**	**4.2**	**0**	**0**	**542**	**162.41**
	3	C00.0-R	18-Oct-21	787	0.94									1	4.88			5	24.41			5	24.41									11	53.69
		C00.7-L	18-Oct-21	800	0.59													13	98.6			3	22.75			1	7.58	1	7.58			18	136.53
		C01.3-L	18-Oct-21	1929	1.60									14	16.32			54	62.94			17	19.81			13	15.15					98	114.22
		C02.8-L	18-Oct-21	900	0.88									2	9.07			27	122.43			1	4.53									30	136.03
		C03.6-L	18-Oct-21	2406	2.09									2	1.43			21	15.05			19	13.62			10	7.17	1	0.72			53	37.99
		C04.6-R	18-Oct-21	803	0.52													1	8.66			6	51.98			1	8.66					8	69.31
		C05.6-L	19-Oct-21	1157	1.10													7	19.78			9	25.44			2	5.65					18	50.88
		C07.3-R	19-Oct-21	909	1.62											1	2.44	15	36.67			12	29.34			3	7.33					31	75.79
		C07.4-L	19-Oct-21	1095	1.00													78	256.91	1	3.29	16	52.7			7	23.06	8	26.35			110	362.3
	Session Summary			**1198.4**	**10.00**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**19**	**5.71**	**1**	**0.3**	**221**	**66.39**	**1**	**0.3**	**88**	**26.44**	**0**	**0**	**37**	**11.11**	**10**	**3**	**0**	**0**	**377**	**113.25**
	4	C00.0-R	25-Oct-21	1147	0.93									2	6.76			11	37.16			14	47.29					1	3.38			28	94.58
		C00.7-L	25-Oct-21	706	0.59									1	8.59			15	128.92							2	17.19	1	8.59			19	163.3
		C01.3-L	25-Oct-21	2091	1.60									14	15.05			49	52.68			10	10.75			2	2.15					75	80.64
		C02.8-L	25-Oct-21	931	0.88									2	8.77			20	87.67			2	8.77			3	13.15					27	118.35
		C03.6-L	25-Oct-21	2975	2.09									5	2.9			31	17.97			29	16.81			8	4.64					73	42.32
		C04.6-R	26-Oct-21	564	0.52																	8	98.68			5	61.68					13	160.36
		C05.6-L	26-Oct-21	1387	1.10													5	11.79			9	21.22			2	4.72					16	37.72
		C07.3-R	27-Oct-21	932	1.67									1	2.31	9	20.76	31	71.49			21	48.43			6	13.84	1	2.31			69	159.13
		C07.4-L	27-Oct-21	1101	1.00					1	3.28			1	3.28	7	22.93	68	222.75			16	52.41			2	6.55	4	13.1			99	324.3
	Session Summary			**1314.9**	**10.00**	**0**	**0**	**0**	**0**	**1**	**0.27**	**0**	**0**	**26**	**7.12**	**16**	**4.38**	**230**	**62.97**	**0**	**0**	**109**	**29.84**	**0**	**0**	**30**	**8.21**	**7**	**1.92**	**0**	**0**	**419**	**114.72**
	5	C03.6-R	06-Nov-21	1023	0.93											5	18.92	8	30.27	2	7.57	19	71.89			9	34.06	1	3.78			44	166.49
		C09.8-R	05-Nov-21	449	0.89											2	18.09	39	352.71			30	271.32			4	36.18	1	9.04			76	687.33
	Session Summary			**736**	**2.00**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**7**	**17.12**	**47**	**114.95**	**2**	**4.89**	**49**	**119.84**	**0**	**0**	**13**	**31.79**	**2**	**4.89**	**0**	**0**	**120**	**293.48**
Section Total All Samples				**46046**	**43.37**	**0**		**0**		**2**		**0**		**183**		**34**		**1046**		**4**		**557**		**0**		**192**		**49**		**0**		**2067**	
Section Average All Samples				**1212**	**1.14**	**0**	**0**	**0**	**0**	**0**	**0.14**	**0**	**0**	**5**	**12.53**	**1**	**2.33**	**28**	**71.63**	**0**	**0.27**	**15**	**38.14**	**0**	**0**	**5**	**13.15**	**1**	**3.36**	**0**	**0**	**54**	**141.55**
Section Standard Error of Mean						**0**	**0**	**0**	**0**	**0.04**	**0.09**	**0**	**0**	**1.31**	**1.59**	**0.35**	**1.05**	**3.87**	**13.8**	**0.06**	**0.22**	**1.78**	**7.42**	**0**	**0**	**0.75**	**2.35**	**0.29**	**1.09**	**0**	**0**	**6.33**	**20.32**

Table E2 Continued.

Section	Session	Site	Date	Time Sampled (s)	Length Sampled (km)	Brook Trout No.	Brook Trout CPUE	Brown Trout No.	Brown 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	Northern Pike No.	Northern Pike CPUE	Rainbow Trout No.	Rainbow Trout CPUE	Smallmouth Bass No.	Smallmouth Bass CPUE	Walleye No.	Walleye CPUE	White Sturgeon No.	White Sturgeon CPUE	Yellow Perch No.	Yellow Perch CPUE	All Species No.	All Species CPUE
						Number Caught (CPUE = no. fish/km/hr)																											
Kootenay River	1	K00.3-L	05-Oct-21	250	0.44													3	99.01			4	132.02			2	66.01	2	66.01			11	363.05
		K00.6-R	05-Oct-21	500	0.59													15	184.41			6	73.76			10	122.94	3	36.88			34	417.99
		K01.8-L	05-Oct-21	1359	1.87									1	1.42			44	62.3			21	29.73			16	22.65	8	11.33			90	127.42
		K01.8-R	05-Oct-21	1085	1.30													11	28.15			10	25.59			9	23.04	2	5.12			32	81.9
	Session Summary			**798.5**	**4.00**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**1.13**	**0**	**0**	**73**	**82.28**	**0**	**0**	**41**	**46.21**	**0**	**0**	**37**	**41.7**	**15**	**16.91**	**0**	**0**	**167**	**188.23**
	2	K00.3-L	13-Oct-21	297	0.44													11	305.6			9	250.04			1	27.78					21	583.42
		K00.6-R	13-Oct-21	562	0.60													11	118.29			6	64.52			4	43.02	7	75.28	1	10.75	29	311.87
		K01.8-L	13-Oct-21	1557	1.86											1	1.24	32	39.76			13	16.15			20	24.85	5	6.21			71	88.21
		K01.8-R	13-Oct-21	1227	1.30											1	2.26	30	67.9			19	43			2	4.53	2	4.53			54	122.22
	Session Summary			**910.8**	**4.00**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**2**	**1.98**	**84**	**83**	**0**	**0**	**47**	**46.44**	**0**	**0**	**27**	**26.68**	**14**	**13.83**	**1**	**0.99**	**175**	**172.92**
	3	K00.3-L	19-Oct-21	296	0.44													2	55.75			3	83.63			1	27.88					6	167.25
		K00.6-R	19-Oct-21	557	0.60													13	141.06			3	32.55			3	32.55	3	32.55			22	238.71
		K01.8-L	19-Oct-21	1378	1.80											3	4.36	31	45.09			23	33.46			6	8.73	2	2.91			65	94.55
		K01.8-R	19-Oct-21	1244	1.30											6	13.39	31	69.2			21	46.88			3	6.7					61	136.17
	Session Summary			**868.8**	**4.00**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**9**	**9.32**	**77**	**79.77**	**0**	**0**	**50**	**51.8**	**0**	**0**	**13**	**13.47**	**5**	**5.18**	**0**	**0**	**154**	**159.53**
	4	K00.3-L	26-Oct-21	276	0.44											7	209.27	3	89.69			5	149.48					1	29.9			16	478.33
		K00.6-R	26-Oct-21	542	0.60											8	89.21	22	245.32			5	55.75			4	44.6					39	434.88
		K01.8-L	26-Oct-21	1447	1.87											24	31.91	52	69.15			23	30.58			22	29.25	3	3.99			124	164.89
		K01.8-R	26-Oct-21	1271	1.30											15	32.77	41	89.58			24	52.44			10	21.85	3	6.55			93	203.2
	Session Summary			**884**	**4.00**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**54**	**54.98**	**118**	**120.14**	**0**	**0**	**57**	**58.03**	**0**	**0**	**36**	**36.65**	**7**	**7.13**	**0**	**0**	**272**	**276.92**
Section Total All Samples				**13848**	**16.70**	**0**		**0**		**0**		**0**		**1**		**65**		**352**		**0**		**195**		**0**		**113**		**41**		**1**		**768**	
Section Average All Samples				**866**	**1.04**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0.25**	**4**	**16.18**	**22**	**87.61**	**0**	**0**	**12**	**48.53**	**0**	**0**	**7**	**28.12**	**3**	**10.2**	**0**	**0.25**	**48**	**191.15**
Section Standard Error of Mean						**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0.06**	**0.09**	**1.7**	**13.66**	**3.92**	**19.38**	**0**	**0**	**2.05**	**15.19**	**0**	**0**	**1.73**	**7.37**	**0.6**	**6.01**	**0.06**	**0.67**	**8.43**	**39.88**

Table E2 Continued.

Section	Session	Site	Date	Time Sampled (s)	Length Sampled (km)	Number Caught (CPUE = no. fish/km/hr)																											
						Brook Trout		Brown Trout		Bull Trout		Burbot		Kokanee		Lake Whitefish		Mountain Whitefish		Northern Pike		Rainbow Trout		Smallmouth Bass		Walleye		White Sturgeon		Yellow Perch		All Species	
						No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE
Columbia River D/S	1	C25.3-R	06-Oct-21	1506	2.73											14	12.27	45	39.45			39	34.19			4	3.51	3	2.63			105	92.05
		C27.6-R	06-Oct-21	353	0.61											1	16.64	5	83.21			23	382.78			7	116.5					36	599.14
		C28.2-R	06-Oct-21	727	1.13											5	21.88	6	26.26			38	166.3			6	26.26					55	240.7
		C34.9-L	06-Oct-21	1877	2.14													3	2.69			87	78.12			5	4.49	2	1.8			97	87.1
		C36.6-L	07-Oct-21	1457	2.39													13	13.41			80	82.53			12	12.38	1	1.03			106	109.36
		C47.8-L	07-Oct-21	1068	1.44							3	7.03			2	4.68	2	4.68			32	74.94			7	16.39					46	107.73
		C48.2-R	08-Oct-21	948	1.01													4	15.06			43	161.9			15	56.48					62	233.44
		C49.0-L	07-Oct-21	432	0.93							1	8.96					18	161.34			16	143.41			3	26.89	1	8.96			39	349.57
		C49.0-R	08-Oct-21	236	0.72							1	21.2			2	42.4	5	106			4	84.8									12	254.41
		C49.8-L	07-Oct-21	1683	2.45							2	1.75			4	3.5	25	21.86			58	50.71			7	6.12	1	0.87			97	84.81
		C49.8-R	08-Oct-21	1179	2.39													19	24.27			17	21.71			7	8.94					43	54.92
		C52.2-L	07-Oct-21	683	0.89											2	11.86	2	11.86			18	106.73			2	11.86	1	5.93			25	148.23
		C52.2-R	08-Oct-21	2103	3.79							5	2.26			9	4.06	10	4.52			65	29.36			11	4.97					100	45.17
		C52.8-L	07-Oct-21	637	0.89													6	37.98			22	139.27			9	56.97					37	234.22
		C53.6-L	08-Oct-21	1015	1.52											3	7.01	5	11.68			16	37.39			3	7.01					27	63.09
	Session Summary			**1060.3**	**25.00**	**0**	**0**	**0**	**0**	**0**	**0**	**12**	**1.63**	**0**	**0**	**42**	**5.7**	**168**	**22.82**	**0**	**0**	**558**	**75.78**	**0**	**0**	**98**	**13.31**	**9**	**1.22**	**0**	**0**	**887**	**120.46**
	2	C25.3-R	14-Oct-21	1601	2.73									9	7.42	13	10.72	15	12.37			53	43.71			8	6.6	5	4.12			103	84.94
		C27.6-R	14-Oct-21	389	0.61													2	30.2			19	286.95			1	15.1					22	332.25
		C28.2-R	14-Oct-21	831	1.13											2	7.66	1	3.83			42	160.81			4	15.31					49	187.61
		C34.9-L	14-Oct-21	2038	2.14											1	0.83	6	4.96			99	81.88			5	4.14	1	0.83			112	92.63
		C36.6-L	15-Oct-21	1587	2.39													5	4.74			67	63.46			8	7.58					80	75.77
		C47.8-L	15-Oct-21	1128	1.44							1	2.22			11	24.39	1	2.22			39	86.48			11	24.39					63	139.69
		C48.2-R	16-Oct-21	1085	1.01													5	16.45			24	78.95			14	46.06	1	3.29			44	144.75
		C49.0-L	15-Oct-21	480	0.93											4	32.27	5	40.34			19	153.27			4	32.27					32	258.15
		C49.0-R	16-Oct-21	415	0.72							0	0			6	72.34	12	144.67			11	132.62			1	12.06					30	361.69
		C49.8-L	15-Oct-21	1755	2.45							3	2.52			12	10.06	24	20.12			86	72.1			12	10.06					137	114.86
		C49.8-R	16-Oct-21	1329	2.39			1	1.13			1	1.13			3	3.4	23	26.06			36	40.79			16	18.13					80	90.65
		C52.2-L	15-Oct-21	900	0.89													3	13.5			25	112.49			5	22.5					33	148.49
		C52.2-R	16-Oct-21	2222	3.79							2	0.85			8	3.42	9	3.85			52	22.23			10	4.27	1	0.43			82	35.05
		C52.8-L	15-Oct-21	541	0.89																	9	67.08			5	37.27					14	104.35
		C53.6-L	16-Oct-21	1036	1.52											9	20.6	3	6.87			10	22.89			2	4.58					24	54.94
	Session Summary			**1155.8**	**25.00**	**0**	**0**	**1**	**0.12**	**0**	**0**	**7**	**0.87**	**9**	**1.12**	**69**	**8.6**	**114**	**14.2**	**0**	**0**	**591**	**73.63**	**0**	**0**	**106**	**13.21**	**8**	**1**	**0**	**0**	**905**	**112.75**
	3	C25.3-R	20-Oct-21	1726	2.73							1	0.76	16	12.24	16	12.24	26	19.89			46	35.19			7	5.35					112	85.67
		C27.6-R	20-Oct-21	371	0.61											1	15.84	21	332.54			17	269.2			2	31.67					41	649.24
		C28.2-R	20-Oct-21	825	1.13											2	7.71	14	53.99			33	127.27			2	7.71					51	196.69
		C34.9-L	20-Oct-21	1897	2.14													1	0.89			48	42.65			6	5.33					55	48.87
		C36.6-L	21-Oct-21	1804	2.39											1	0.83	12	10			61	50.83			13	10.83					87	72.49
		C47.8-L	21-Oct-21	1025	1.44													2	4.88			30	73.21			1	2.44					33	80.53
		C48.2-R	22-Oct-21	1075	1.01													5	16.6			29	96.29			6	19.92					40	132.81
		C49.0-L	21-Oct-21	532	0.93											3	21.84	5	36.39			14	101.9			2	14.56					24	174.69
		C49.0-R	22-Oct-21	444	0.72											2	22.54	3	33.81			5	56.34			1	11.27					11	123.96
		C49.8-L	21-Oct-21	1758	2.45							2	1.67			8	6.7	30	25.11			53	44.36	1	0.84	7	5.86					101	84.54
		C49.8-R	22-Oct-21	1401	2.39							3	3.22					24	25.8			58	62.34			25	26.87					110	118.24
		C52.2-L	21-Oct-21	709	0.89																	4	22.85			3	17.14					7	39.98
		C52.2-R	22-Oct-21	2220	3.79							3	1.28			12	5.13	20	8.56			74	31.66			9	3.85	2	0.86			120	51.34
		C52.8-L	21-Oct-21	642	0.89											2		1				23				6						32	
		C53.6-L	21-Oct-21	1199	1.52											2	3.96	3	5.93			15	29.67			6	11.87					26	51.43
	Session Summary			**1175.2**	**25.00**	**0**	**0**	**0**	**0**	**0**	**0**	**9**	**1.1**	**16**	**1.96**	**49**	**6**	**167**	**20.46**	**0**	**0**	**510**	**62.49**	**1**	**0.12**	**96**	**11.76**	**2**	**0.25**	**0**	**0**	**850**	**104.15**

Table E2 Concluded.

Section	Session	Site	Date	Time Sampled (s)	Length Sampled (km)	Number Caught (CPUE = no. fish/km/hr)																											
						Brook Trout		Brown Trout		Bull Trout		Burbot		Kokanee		Lake Whitefish		Mountain Whitefish		Northern Pike		Rainbow Trout		Smallmouth Bass		Walleye		White Sturgeon		Yellow Perch		All Species	
						No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE
Columbia River D/S	4	C25.3-R	27-Oct-21	1694	2.73											4	3.12	27	21.04			73	56.89			5	3.9					109	84.95
		C27.6-R	27-Oct-21	463	0.61													6	76.13			14	177.64			3	38.07					23	291.84
		C28.2-R	27-Oct-21	703	1.13													8	36.21			29	131.25			5	22.63	1	4.53			43	194.61
		C34.9-L	27-Oct-21	2030	2.14							2	1.66			4	3.32	5	4.15			65	53.97			9	7.47			1	0.83	86	71.41
		C36.6-L	28-Oct-21	1682	2.39							3	2.68			2	1.79	8	7.15			74	66.13			10	8.94					97	86.69
		C47.8-L	29-Oct-21	1152	1.44											1	2.17	3	6.51			33	71.65			10	21.71					47	102.05
		C48.2-R	28-Oct-21	931	1.01													3	11.5			25	95.85			3	11.5					31	118.85
		C49.0-L	29-Oct-21	499	0.93							1	7.76			14	108.64	23	178.48			20	155.2			4	31.04	1	7.76			63	488.87
		C49.0-R	28-Oct-21	431	0.72													3	34.83			10	116.09			2	23.22					15	174.13
		C49.8-L	29-Oct-21	1797	2.45							3	2.46			6	4.91	27	22.11			56	45.85			10	8.19					102	83.52
		C49.8-R	28-Oct-21	1255	2.39							1	1.2			4	4.8	22	26.4			42	50.4			4	4.8					73	87.59
		C52.2-L	29-Oct-21	869	0.89							1	4.66					2	9.32			17	79.22									20	93.2
		C52.2-R	28-Oct-21	2232	3.79							1	0.43			16	6.81	4	1.7			53	22.55			6	2.55					80	34.04
		C52.8-L	01-Nov-21	573	0.89											4	28.15	2	14.07			20	140.75			3	21.11					29	204.08
		C53.6-L	01-Nov-21	996	1.52							1	2.38			16	38.1					20	47.63			2	4.76					39	92.87
	Session Summary			1153.8	25.00	0	0	0	0	0	0	13	1.62	0	0	71	8.86	143	17.85	0	0	551	68.77	0	0	76	9.49	2	0.25	1	0.12	857	106.96
	5	C10.9-L	04-Nov-21	1329	2.18											49	60.89	270	335.49			52	64.61			13	16.15	2	2.49			386	479.63
		C13.4-R	04-Nov-21	1970	2.52	1	0.73									3	2.18	108	78.32			137	99.35			16	11.6	4	2.9			269	195.07
		C14.8-L	05-Nov-21	1677	2.26													100	94.99			102	96.89			7	6.65	7	6.65			216	205.17
		C16.6-R	05-Nov-21	1337	1.44													33	61.83			77	144.28			4	7.5	5	9.37			119	222.98
		C18.8-R	05-Nov-21	1473	1.61													21	31.81	1	1.51	61	92.41			5	7.57					88	133.32
		C20.1-L	05-Nov-21	1045	1.27											1	2.72	33	89.8			87	236.76			8	21.77					129	351.05
		C20.4-R	03-Nov-21	1480	1.47									1	1.65	1	1.65	14	23.1			68	112.22			5	8.25					89	146.87
		C22.9-R	03-Nov-21	871	1.22													82	277.58			54	182.79			5	16.93	2	6.77			143	484.07
		C27.5-L	03-Nov-21	954	1.31											3	8.64	24	69.15			67	193.05			5	14.41	1	2.88			100	288.13
		C30.6-L	04-Nov-21	1690	1.84													13	15.05			137	158.61			4	4.63					154	178.29
		C32.4-L	02-Nov-21	1634	2.00											3	3.31	4	4.41			71	78.33			6	6.62					84	92.67
		C35.7-R	03-Nov-21	1162	1.25																	89	220.92			6	14.89					95	235.81
		C36.9-R	04-Nov-21	1474	2.27											7	7.53	10	10.76			114	122.65			6	6.46					137	147.4
		C40.0-R	02-Nov-21	1124	1.47											1	2.18	13	28.4			89	194.44			3	6.55					106	231.58
		C41.5-R	02-Nov-21	2031	2.16											4	3.28	12	9.84			157	128.72			11	9.02					184	150.85
		C44.6-L	01-Nov-21	880	1.01	1	4.05									4	16.2	5	20.25			30	121.51			8	32.4					48	194.42
		C45.6-L	01-Nov-21	692	0.90							2	11.55					13	75.06			61	352.21			7	40.42					83	479.24
		C47.2-R	01-Nov-21	774	1.06					1	4.39					18	78.98	28	122.86			38	166.74			8	35.1	1	4.39			94	412.46
	Session Summary			1310.9	29.00	2	0.19	0	0	1	0.09	2	0.19	1	0.09	94	8.9	783	74.15	1	0.09	1491	141.19	0	0	127	12.03	22	2.08	0	0	2524	239.01
Section Total All Samples				91773	129.34	2		1		1		43		26		325		1375		1		3701		1		503		43		1		6023	
Section Average All Samples				1177	1.66	0	0.05	0	0.02	0	0.02	1	1.02	0	0.61	4	7.69	18	32.52	0	0.02	47	87.52	0	0.02	6	11.9	1	1.02	0	0.02	77	142.43
Section Standard Error of Mean						0.02	0.05	0.01	0.01	0.01	0.06	0.12	0.35	0.23	0.18	0.79	2.17	3.95	7.56	0.01	0.02	3.73	8.25	0.01	0.01	0.49	1.93	0.15	0.25	0.01	0.01	6.78	15.17
All Sections Total All Samples				151667	189.41	2	0	1	0	3	0	43	0.01	210	0.03	424	0.05	2773	0.35	5	0	4453	0.56	1	0	808	0.1	133	0.02	2	0	8858	1.11
All Sections Average All Samples						0	0.03	0	0.02	0	0.05	0	0.71	2	3.47	3	7.01	21	45.87	0	0.08	34	73.66	0	0.02	6	13.37	1	2.2	0	0.03	67	146.52
All Sections Standard Error of Mean						0.01	0.03	0.01	0.01	0.01	0.04	0.07	0.21	0.44	0.57	0.53	2.15	2.64	6.74	0.02	0.07	2.69	6.08	0.01	0.01	0.42	1.64	0.15	0.91	0.01	0.08	4.62	11.87

Table E3 Summary of boat electroshocking non-sportfish catch (includes fish captured and observed and identified to species) and catch-per-unit-effort (CPUE = no. fish/km/hour) in the Lower Columbia River, 04 October to 06 November 2021.

Section	Session	Site	Date	Time Sampled (s)	Length Sampled (km)	Number Caught (CPUE = no. fish/km/hr) Carp spp. No.	Carp spp. CPUE	Dace spp. No.	Dace spp. CPUE	Northern Pikeminnow No.	Northern Pikeminnow CPUE	Peamouth No.	Peamouth 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
Columbia River U/S	1	C00.0-R	04-Oct-21	956	0.94					1	4.02			6	24.11	32	128.58	6	24.11	45	180.82
		C00.7-L	04-Oct-21	953	0.59					10	63.67	9	57.3	8	50.94	21	133.71	17	108.24	65	413.86
		C01.3-L	04-Oct-21	1984	1.60					4	4.53			7	7.93	60	67.99	25	28.33	96	108.79
		C02.8-L	04-Oct-21	788	0.88					2	10.36					6	31.07	26	134.65	34	176.09
		C03.6-L	05-Oct-21	2669	2.09					2	1.29			3	1.94	27	17.45	29	18.74	61	39.42
		C04.6-R	05-Oct-21	579	0.52													3	36.05	3	36.05
		C05.6-L	05-Oct-21	1191	1.10					7	19.22					57	156.51	19	52.17	83	227.9
		C07.3-R	05-Oct-21	971	1.70					3	6.52			1	2.17	5	10.87	10	21.75	19	41.32
		C07.4-L	05-Oct-21	1050	1.00					5	17.17							21	72.13	26	89.31
	Session Summary			**1237.9**	**10.00**	**0**	**0**	**0**	**0**	**34**	**9.89**	**9**	**2.62**	**25**	**7.27**	**208**	**60.49**	**156**	**45.37**	**432**	**125.63**
	2	C00.0-R	12-Oct-21	840	0.94									23	105.18	61	278.96	3	13.72	87	397.86
		C00.7-L	12-Oct-21	741	0.59					2	16.38	4	32.76	9	73.7	42	343.93	19	155.59	76	622.35
		C01.3-L	12-Oct-21	2022	1.59					2	2.24	1	1.12	19	21.26	59	66.01	31	34.69	112	125.31
		C02.8-L	12-Oct-21	980	0.88					1	4.16			15	62.46	61	254.02	53	220.71	130	541.36
		C03.6-L	12-Oct-21	2319	2.09					9	6.69			12	8.92	48	35.7	66	49.09	135	100.4
		C04.6-R	13-Oct-21	646	0.52											16	172.31	10	107.69	26	280
		C05.6-L	13-Oct-21	1298	1.10					3	7.56					115	289.73	30	75.58	148	372.87
		C07.3-R	13-Oct-21	894	1.70					6	14.17					60	141.72	23	54.33	89	210.22
		C07.4-L	13-Oct-21	1073	1.00											28	94.11	31	104.2	59	198.31
	Session Summary			**1201.4**	**10.00**	**0**	**0**	**0**	**0**	**23**	**6.89**	**5**	**1.5**	**78**	**23.37**	**490**	**146.83**	**266**	**79.71**	**862**	**258.3**
	3	C00.0-R	18-Oct-21	787	0.94									11	53.69	48	234.29	2	9.76	61	297.75
		C00.7-L	18-Oct-21	800	0.59									4	30.34	14	106.19	2	15.17	20	151.7
		C01.3-L	18-Oct-21	1929	1.60									16	18.65	22	25.64	16	18.65	54	62.94
		C02.8-L	18-Oct-21	900	0.88									50	226.72	86	389.97	29	131.5	165	748.19
		C03.6-L	18-Oct-21	2406	2.09					8	5.73	1	0.72	15	10.75	158	113.26	94	67.38	276	197.85
		C04.6-R	18-Oct-21	803	0.52													2	17.33	2	17.33
		C05.6-L	19-Oct-21	1157	1.10					1	2.83					40	113.06	14	39.57	55	155.45
		C07.3-R	19-Oct-21	909	1.62											210	513.43	2	4.89	212	518.32
		C07.4-L	19-Oct-21	1095	1.00											32	105.4	23	75.75	55	181.15
	Session Summary			**1198.4**	**10.00**	**0**	**0**	**0**	**0**	**9**	**2.7**	**1**	**0.3**	**96**	**28.84**	**610**	**183.24**	**184**	**55.27**	**900**	**270.36**
	4	C00.0-R	25-Oct-21	1147	0.93					3	10.13			0	0	79	266.86	11	37.16	93	314.15
		C00.7-L	25-Oct-21	706	0.59					2	17.19	3	25.78	3	25.78	53	455.52	1	8.59	62	532.87
		C01.3-L	25-Oct-21	2091	1.60					2	2.15	1	1.08			24	25.8	12	12.9	39	41.93
		C02.8-L	25-Oct-21	931	0.88									17	74.52	91	398.9	70	306.84	178	780.26
		C03.6-L	25-Oct-21	2975	2.09					8	4.64	2	1.16			61	35.36	33	19.13	104	60.29
		C04.6-R	26-Oct-21	564	0.52													5	61.68	5	61.68
		C05.6-L	26-Oct-21	1387	1.10					1	2.36			10	23.58	47	110.81	28	66.02	86	202.77
		C07.3-R	27-Oct-21	932	1.67					1	2.31					27	62.27	18	41.51	46	106.09
		C07.4-L	27-Oct-21	1101	1.00					1	3.28					20	65.51	24	78.62	45	147.41
	Session Summary			**1314.9**	**10.00**	**0**	**0**	**0**	**0**	**18**	**4.93**	**6**	**1.64**	**30**	**8.21**	**402**	**110.06**	**202**	**55.3**	**658**	**180.15**
	5	C03.6-R	06-Nov-21	1023	0.93											18	68.11	5	18.92	23	87.03
		C09.8-R	05-Nov-21	449	0.89													2	18.09	2	18.09
	Session Summary			**736**	**2.00**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**18**	**44.02**	**7**	**17.12**	**25**	**61.14**
Section Total All Samples				**46046**	**43.37**	**0**		**0**		**84**		**21**		**229**		**1728**		**815**		**2877**	
Section Average All Samples				**1212**	**1.14**	**0**	**0**	**0**	**0**	**2**	**5.75**	**1**	**1.44**	**6**	**15.68**	**45**	**118.34**	**21**	**55.81**	**76**	**197.02**
Section Standard Error of Mean						**0**	**0**	**0**	**0**	**0.47**	**1.81**	**0.27**	**1.82**	**1.61**	**7**	**7.09**	**22.55**	**3.33**	**10.17**	**9.82**	**33.1**

Table E3 Continued.

Section	Session	Site	Date	Time Sampled (s)	Length Sampled (km)	Number Caught (CPUE = no. fish/km/hr)															
						Carp spp.		Dace spp.		Northern Pikeminnow		Peamouth		Redside Shiner		Sculpin spp.		Sucker spp.		All Species	
						No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE	No.	CPUE
Kootenay River	1	K00.3-L	05-Oct-21	250	0.44													5	165.02	5	165.02
		K00.6-R	05-Oct-21	500	0.59	3	36.88			2	24.59					3	36.88	23	282.76	31	381.11
		K01.8-L	05-Oct-21	1359	1.87					2	2.83			1	1.42	15	21.24	20	28.32	38	53.8
		K01.8-R	05-Oct-21	1085	1.30					2	5.12			2	5.12	2	5.12	9	23.04	15	38.39
	Session Summary			**798.5**	**4.00**	**3**	3.38	**0**	0	**6**	6.76	**0**	0	**3**	3.38	**20**	22.54	**57**	64.25	**89**	100.31
	2	K00.6-R	13-Oct-21	562	0.60					2	21.51					33	354.88	17	182.82	52	559.21
		K01.8-L	13-Oct-21	1557	1.86					4	4.97					75	93.18	13	16.15	92	114.3
		K01.8-R	13-Oct-21	1227	1.30					1	2.26			2	4.53	26	58.85	14	31.69	43	97.32
	Session Summary			**1115.3**	**4.00**	**0**	0	**0**	0	**7**	5.65	**0**	0	**2**	1.61	**134**	108.13	**44**	35.51	**187**	150.9
	3	K00.3-L	19-Oct-21	296	0.44											10	278.76	1	27.88	11	306.63
		K00.6-R	19-Oct-21	557	0.60									6	65.1	20	217.01	23	249.56	49	531.68
		K01.8-L	19-Oct-21	1378	1.80											80	116.37	2	2.91	82	119.28
		K01.8-R	19-Oct-21	1244	1.30					1	2.23			1	2.23	2	4.46	3	6.7	7	15.63
	Session Summary			**868.8**	**4.00**	**0**	0	**0**	0	**1**	1.04	**0**	0	**7**	7.25	**112**	116.02	**29**	30.04	**149**	154.35
	4	K00.3-L	26-Oct-21	276	0.44											36	1076.25	1	29.9	37	1106.14
		K00.6-R	26-Oct-21	542	0.60											19	211.87	22	245.32	41	457.18
		K01.8-L	26-Oct-21	1447	1.87											120	159.57	12	15.96	132	175.52
		K01.8-R	26-Oct-21	1271	1.30					3	6.55					34	74.29	5	10.92	42	91.77
	Session Summary			**884**	**4.00**	**0**	0	**0**	0	**3**	3.05	**0**	0	**0**	0	**209**	212.78	**40**	40.72	**252**	256.56
Section Total All Samples				**13551**	**16.27**	**3**		**0**		**17**		**0**		**12**		**475**		**170**		**677**	
Section Average All Samples				**903**	**1.08**	**0**	0.74	**0**	0	**1**	4.17	**0**	0	**1**	2.94	**32**	116.42	**11**	41.67	**45**	165.93
Section Standard Error of Mean						**0.2**	2.46	**0**	0	**0.34**	2.01	**0**	0	**0.42**	4.3	**8.92**	69.81	**2.14**	26.89	**8.9**	75.33

Table E3 Concluded.

Section	Session	Site	Date	Time Sampled (s)	Length Sampled (km)	Carp spp. No.	Carp spp. CPUE	Dace spp. No.	Dace spp. CPUE	Northern Pikeminnow No.	Northern Pikeminnow CPUE	Peamouth No.	Peamouth 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
						Number Caught (CPUE = no. fish/km/hr)															
Columbia River D/S	1	C25.3-R	06-Oct-21	1506	2.73									5	4.38	38	33.31	1	0.88	44	38.57
		C27.6-R	06-Oct-21	353	0.61											29	482.64			29	482.64
		C28.2-R	06-Oct-21	727	1.13					2	8.75	1	4.38			49	214.45	5	21.88	57	249.46
		C34.9-L	06-Oct-21	1877	2.14											48	43.1	4	3.59	52	46.7
		C36.6-L	07-Oct-21	1457	2.39											24	24.76	2	2.06	26	26.82
		C47.8-L	07-Oct-21	1068	1.44									7	16.39	221	517.57	18	42.15	246	576.12
		C48.2-R	08-Oct-21	948	1.01									12	45.18	33	124.25	11	41.42	56	210.85
		C49.0-L	07-Oct-21	432	0.93													1	8.96	1	8.96
		C49.8-L	07-Oct-21	1683	2.45											116	101.42	5	4.37	121	105.79
		C49.8-R	08-Oct-21	1179	2.39											2	2.55	5	6.39	7	8.94
		C52.2-L	07-Oct-21	683	0.89											53	314.25	1	5.93	54	320.18
		C52.2-R	08-Oct-21	2103	3.79											8	3.61	15	6.77	23	10.39
		C52.8-L	07-Oct-21	637	0.89			1	6.33							5	31.65	1	6.33	7	44.31
		C53.6-L	08-Oct-21	1015	1.52											34	79.45			34	79.45
	Session Summary			**1119.1**	**24.00**	**0**	**0**	**1**	**0.13**	**2**	**0.27**	**1**	**0.13**	**24**	**3.22**	**660**	**88.46**	**69**	**9.25**	**757**	**101.47**
	2	C25.3-R	14-Oct-21	1601	2.73									15	12.37	85	70.09	15	12.37	115	94.83
		C27.6-R	14-Oct-21	389	0.61											14	211.43			14	211.43
		C28.2-R	14-Oct-21	831	1.13											109	417.33	3	11.49	112	428.82
		C34.9-L	14-Oct-21	2038	2.14											54	44.66	8	6.62	62	51.28
		C36.6-L	15-Oct-21	1587	2.39											74	70.09	8	7.58	82	77.67
		C47.8-L	15-Oct-21	1128	1.44									5	11.09	81	179.61	26	57.65	112	248.35
		C48.2-R	16-Oct-21	1085	1.01											28	92.11	5	16.45	33	108.56
		C49.0-L	15-Oct-21	480	0.93											19	153.27	3	24.2	22	177.48
		C49.0-R	16-Oct-21	415	0.72	1	12.06											1	12.06	2	24.11
		C49.8-L	15-Oct-21	1755	2.45											152	127.44	7	5.87	159	133.31
		C49.8-R	16-Oct-21	1329	2.39					2	2.27			2	2.27	39	44.19	4	4.53	47	53.26
		C52.2-L	15-Oct-21	900	0.89											20	89.99	4	18	24	107.99
		C52.2-R	16-Oct-21	2222	3.79													7	2.99	7	2.99
		C53.6-L	16-Oct-21	1036	1.52													1	2.29	1	2.29
	Session Summary			**1199.7**	**24.00**	**1**	**0.13**	**0**	**0**	**2**	**0.25**	**0**	**0**	**22**	**2.75**	**675**	**84.4**	**92**	**11.5**	**792**	**99.02**
	3	C25.3-R	20-Oct-21	1726	2.73											66	50.48	6	4.59	72	55.07
		C27.6-R	20-Oct-21	371	0.61											23	364.21	2	31.67	25	395.88
		C28.2-R	20-Oct-21	825	1.13									5	19.28	65	250.68			70	269.96
		C34.9-L	20-Oct-21	1897	2.14											139	123.5	1	0.89	140	124.39
		C36.6-L	21-Oct-21	1804	2.39											125	104.15			125	104.15
		C47.8-L	21-Oct-21	1025	1.44									7	17.08	181	441.67	49	119.57	237	578.32
		C48.2-R	22-Oct-21	1075	1.01											13	43.16	11	36.52	24	79.69
		C49.0-L	21-Oct-21	532	0.93											41	298.42	2	14.56	43	312.98
		C49.0-R	22-Oct-21	444	0.72											37	416.94			37	416.94
		C49.8-L	21-Oct-21	1758	2.45											393	328.94	7	5.86	400	334.8
		C49.8-R	22-Oct-21	1401	2.39											194	208.52	60	64.49	254	273.02
		C52.2-L	21-Oct-21	709	0.89											4	22.85	1	5.71	5	28.56
		C52.2-R	22-Oct-21	2220	3.79											135	57.76			135	57.76
		C53.6-L	21-Oct-21	1199	1.52											20	39.56			20	39.56
	Session Summary			**1213.3**	**24.00**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**12**	**1.48**	**1436**	**177.53**	**139**	**17.18**	**1587**	**196.2**
	4	C25.3-R	27-Oct-21	1694	2.73									50	38.97	120	93.52	2	1.56	172	134.05
		C27.6-R	27-Oct-21	463	0.61											31	393.35	10	126.89	41	520.24
		C28.2-R	27-Oct-21	703	1.13									15	67.89	128	579.31	4	18.1	147	665.3
		C34.9-L	27-Oct-21	2030	2.14											115	95.48	7	5.81	122	101.3
		C36.6-L	28-Oct-21	1682	2.39											60	53.62			60	53.62
		C47.8-L	29-Oct-21	1152	1.44									18	39.08	104	225.8	17	36.91	139	301.79
		C48.2-R	28-Oct-21	931	1.01											6	23	4	15.34	10	38.34
		C49.0-L	29-Oct-21	499	0.93											29	225.04	1	7.76	30	232.8
		C49.0-R	28-Oct-21	431	0.72											20	232.17	2	23.22	22	255.39
		C49.8-L	29-Oct-21	1797	2.45											104	85.16	2	1.64	106	86.8
		C49.8-R	28-Oct-21	1255	2.39													4	4.8	4	4.8
		C52.2-L	29-Oct-21	869	0.89											67	312.23	14	65.24	81	377.47
		C52.2-R	28-Oct-21	2232	3.79											20	8.51			20	8.51
		C53.6-L	01-Nov-21	996	1.52											14	33.34			14	33.34
	Session Summary			**1195.3**	**24.00**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**83**	**10.42**	**818**	**102.65**	**67**	**8.41**	**968**	**121.48**
	5	C10.9-L	04-Nov-21	1329	2.18											60	74.55	5	6.21	65	80.77
		C13.4-R	04-Nov-21	1970	2.52					6	4.35					75	54.39	9	6.53	90	65.26
		C14.8-L	05-Nov-21	1677	2.26					3	2.85					28	26.6	2	1.9	33	31.35
		C16.6-R	05-Nov-21	1337	1.44					6	11.24					95	178.01	5	9.37	106	198.62
		C18.8-R	05-Nov-21	1473	1.61					6	9.09					85	128.77			91	137.86
		C20.1-L	05-Nov-21	1045	1.27											40	108.85	1	2.72	41	111.58
		C20.4-R	03-Nov-21	1480	1.47					4	6.6					215	354.8	4	6.6	223	368
		C22.9-R	03-Nov-21	871	1.22											70	236.96	7	23.7	77	260.65
		C27.5-L	03-Nov-21	954	1.31											12	34.58	1	2.88	13	37.46
		C30.6-L	04-Nov-21	1690	1.84											87	100.72	1	1.16	88	101.88
		C32.4-L	02-Nov-21	1634	2.00											31	34.2	1	1.1	32	35.3
		C35.7-R	03-Nov-21	1162	1.25											16	39.72			16	39.72
		C36.9-R	04-Nov-21	1474	2.27											127	136.64	1	1.08	128	137.72
		C40.0-R	02-Nov-21	1124	1.47											83	181.33			83	181.33
		C41.5-R	02-Nov-21	2031	2.16											10	8.2			10	8.2
		C44.6-L	01-Nov-21	880	1.01											25	101.26	1	4.05	26	105.31
		C45.6-L	01-Nov-21	692	0.90											40	230.96	2	11.55	42	242.51
		C47.2-R	01-Nov-21	774	1.06											30	131.64	2	8.78	32	140.41
	Session Summary			**1310.9**	**29.00**	**0**	**0**	**0**	**0**	**25**	**2.37**	**0**	**0**	**0**	**0**	**1129**	**106.91**	**42**	**3.98**	**1196**	**113.26**
Section Total All Samples				**89781**	**125.94**	**1**		**1**		**29**		**1**		**141**		**4718**		**409**		**5300**	
Section Average All Samples				**1213**	**1.70**	**0**	**0.02**	**0**	**0.02**	**0**	**0.68**	**0**	**0.02**	**2**	**3.32**	**64**	**111.18**	**6**	**9.64**	**72**	**124.9**
Section Standard Error of Mean						**0.01**	**0.16**	**0.01**	**0.09**	**0.15**	**0.25**	**0.01**	**0.06**	**0.78**	**1.35**	**7.65**	**16.41**	**1.13**	**2.74**	**8.36**	**18.34**
All Sections Total All Samples				**149378**	**185.58**	4	0	1	0	130	0.02	22	0	382	0.05	6921	0.9	1394	0.18	8854	1.15
All Sections Average All Samples						0	0.07	0	0.02	1	2.14	0	0.36	3	6.3	54	114.15	11	22.99	70	146.03
All Sections Standard Error of Mean						0.02	0.3	0.01	0.05	0.18	0.64	0.08	0.55	0.68	2.38	5.13	14.17	1.36	5.25	5.81	17.3

Appendix F – Life History

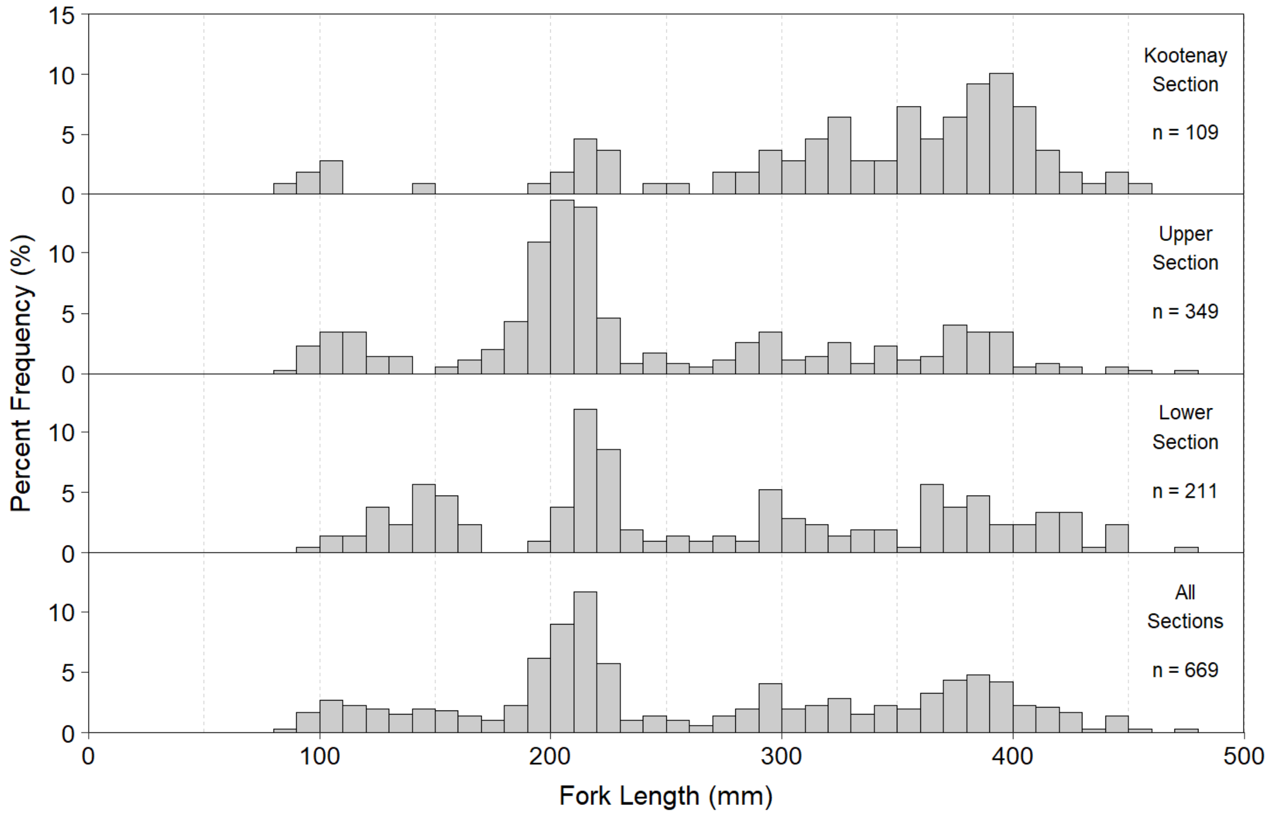


Figure F1. Length-frequency distributions by section for Mountain Whitefish captured by boat electroshocking in the lower Columbia River, 2021.

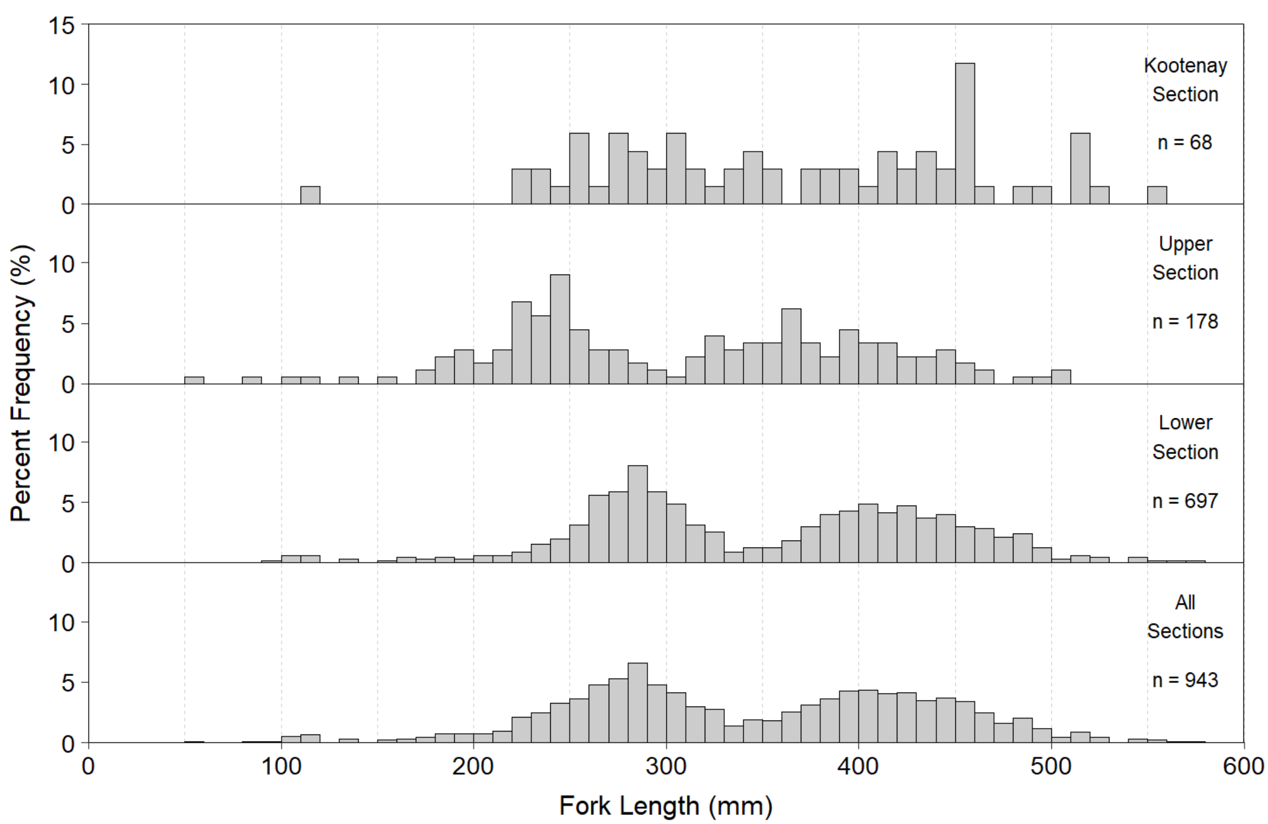


Figure F2. Length-frequency distributions by section for Rainbow Trout captured by boat electroshocking in the lower Columbia River, 2021.

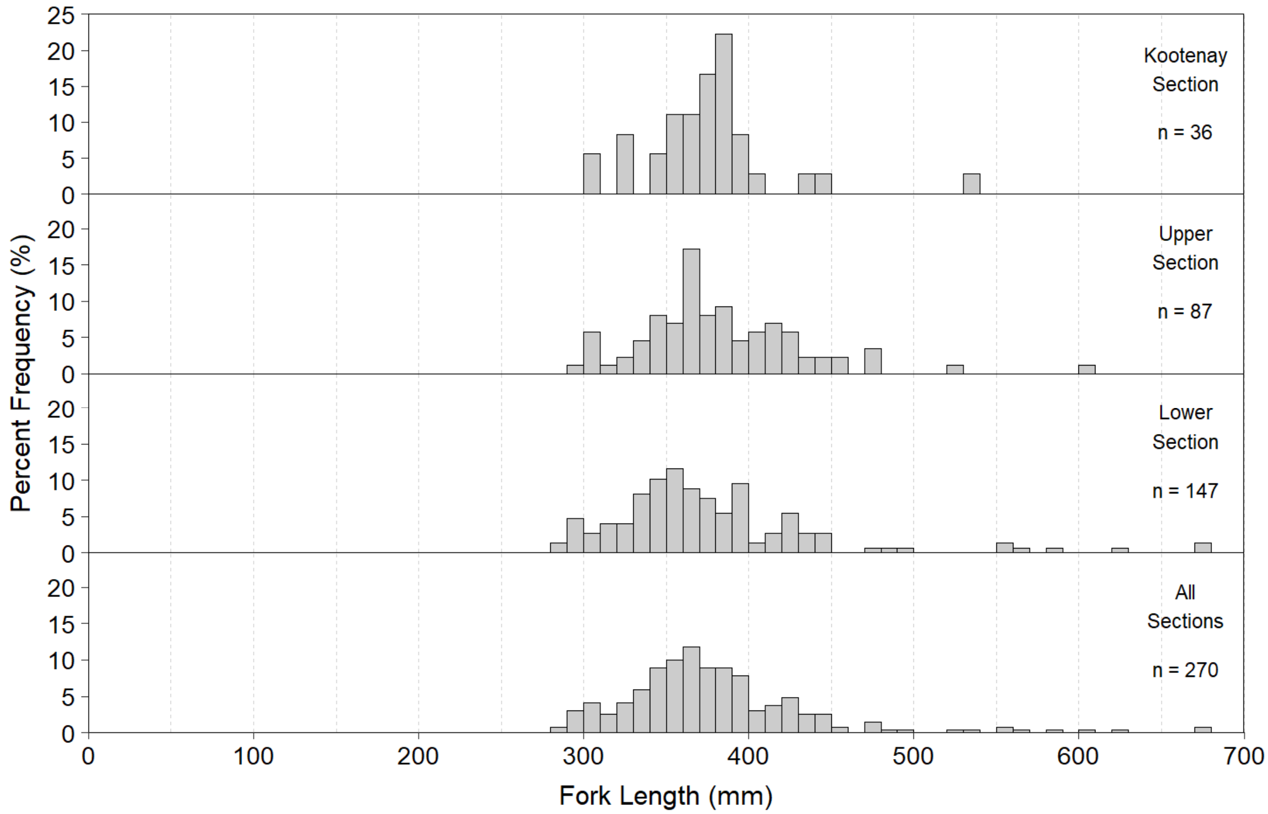


Figure F3. Length-frequency distributions by section for Walleye captured by boat electroshocking in the lower Columbia River, 2021.

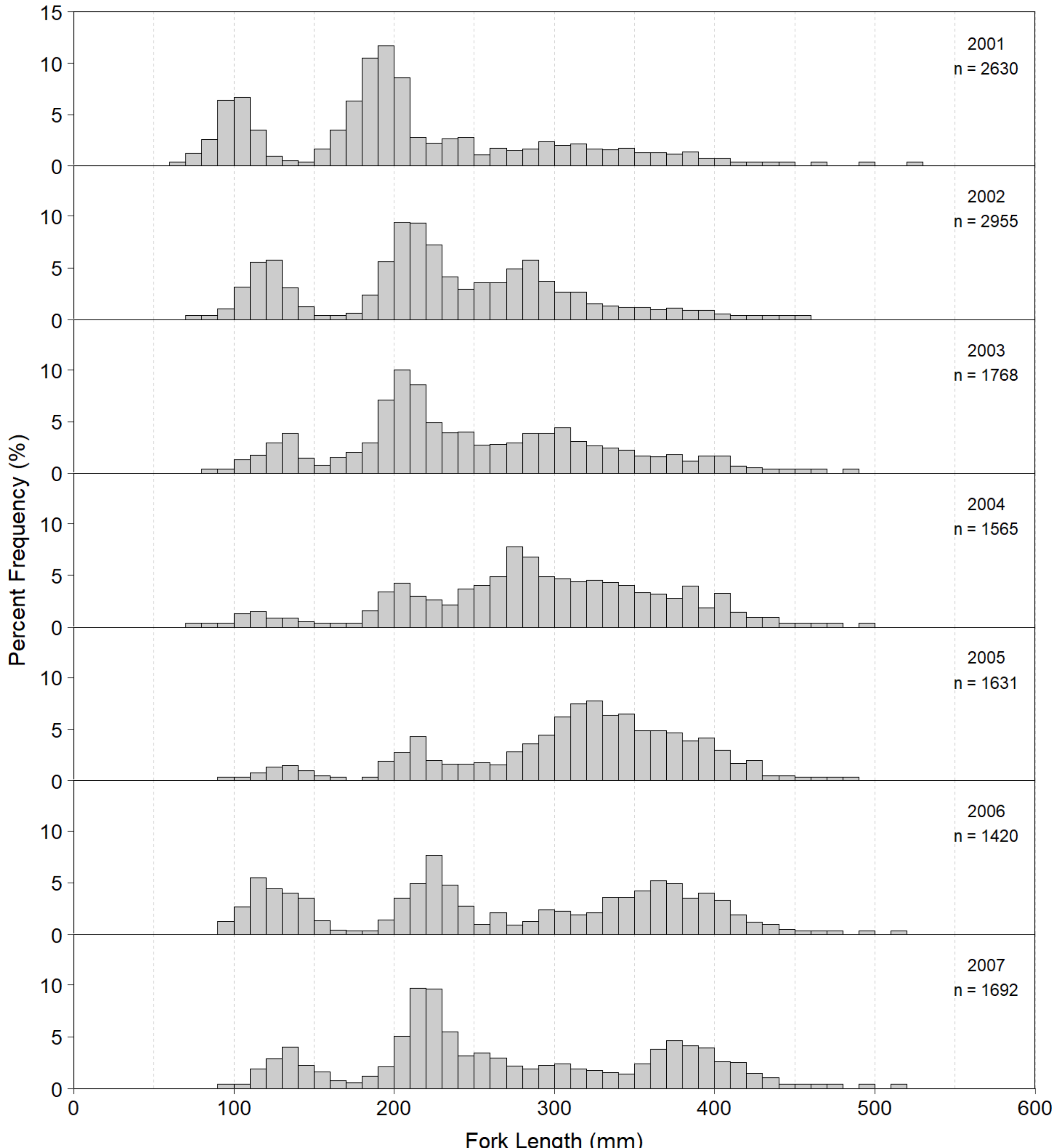


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Figure F4. Length-frequency distributions by year for Mountain Whitefish captured by boat electroshocking in sampled sections of the lower Columbia River, 2001 to 2021.

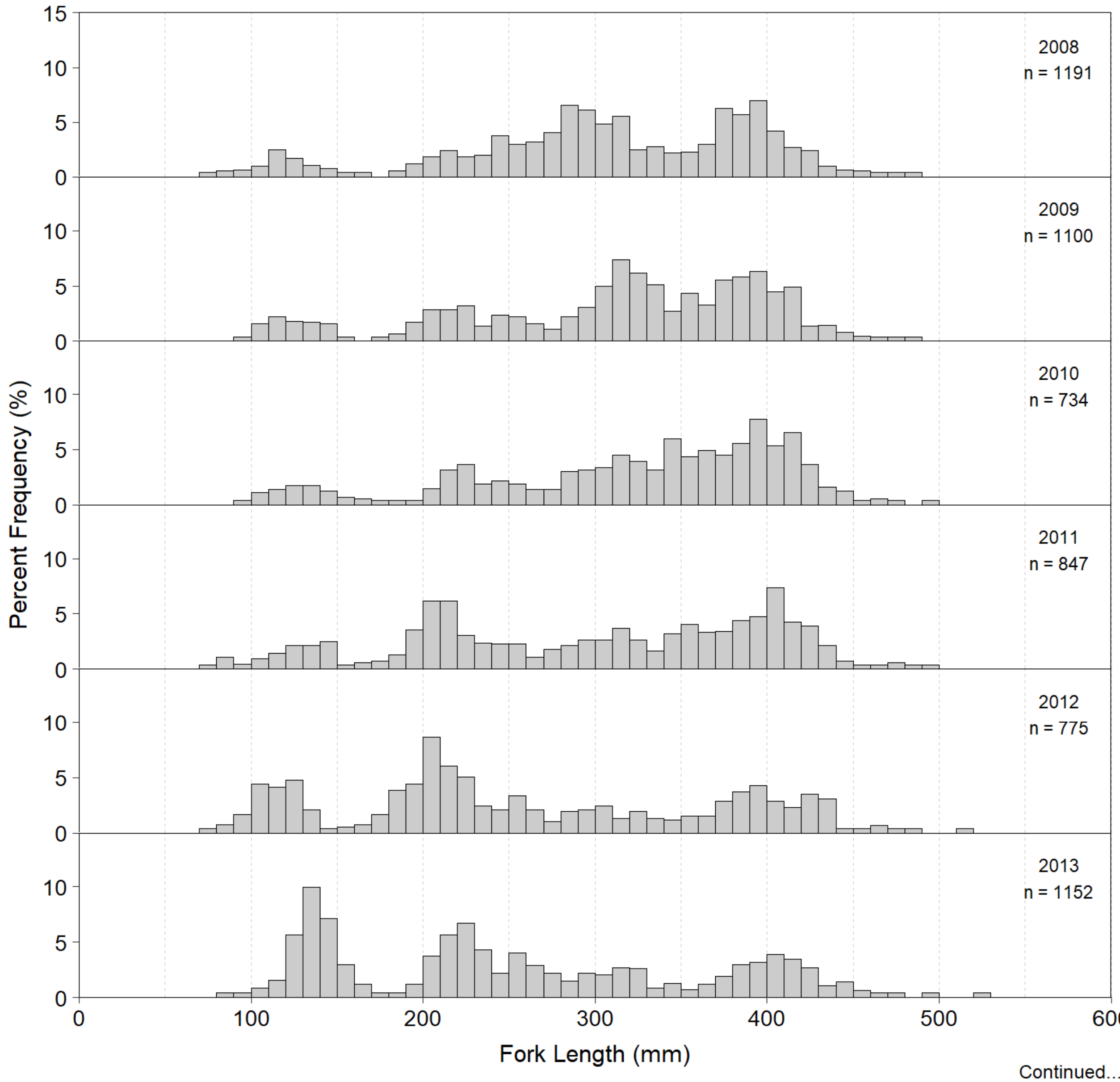

Figure F4. Continued.

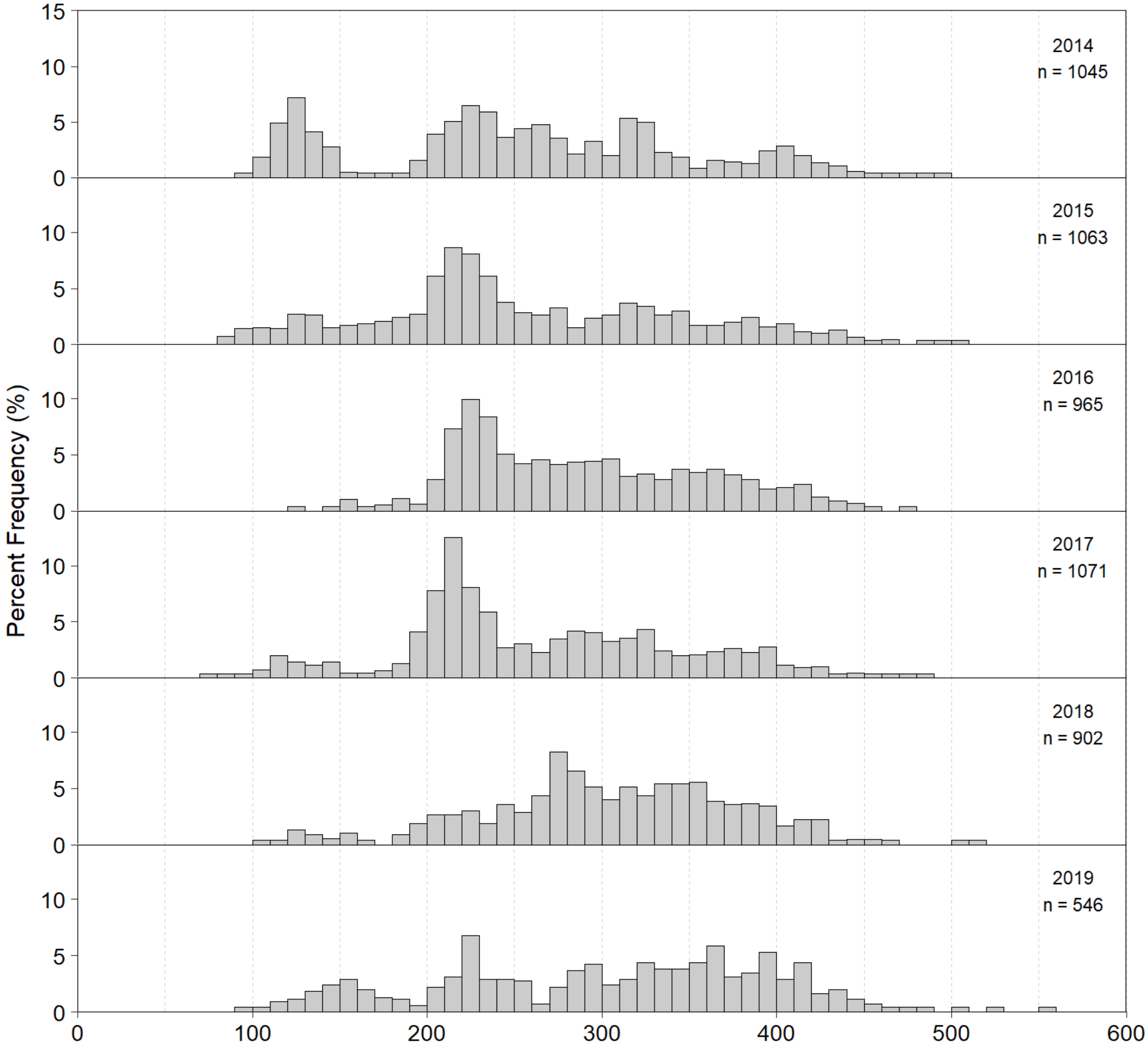

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Figure F4. Continued.

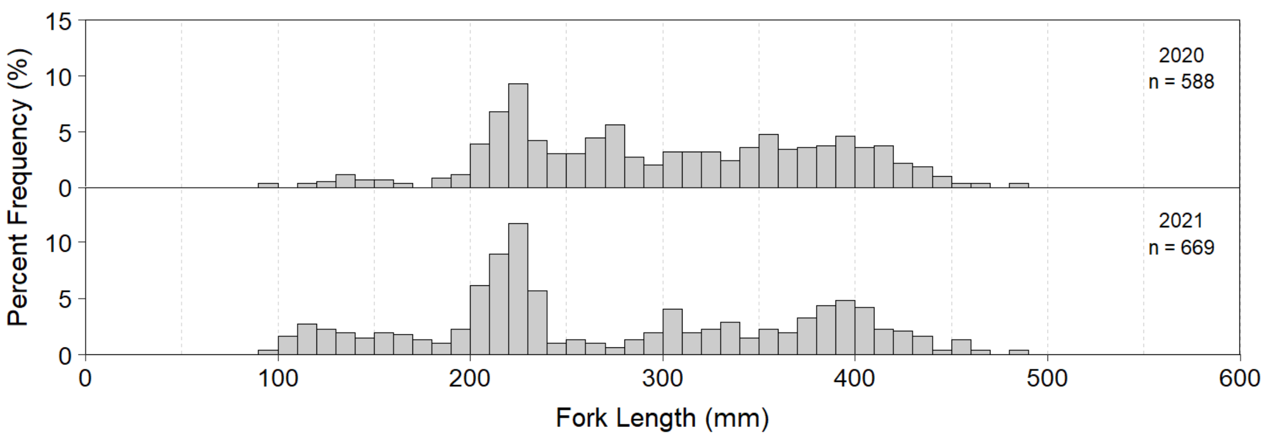

Figure F4. Concluded.

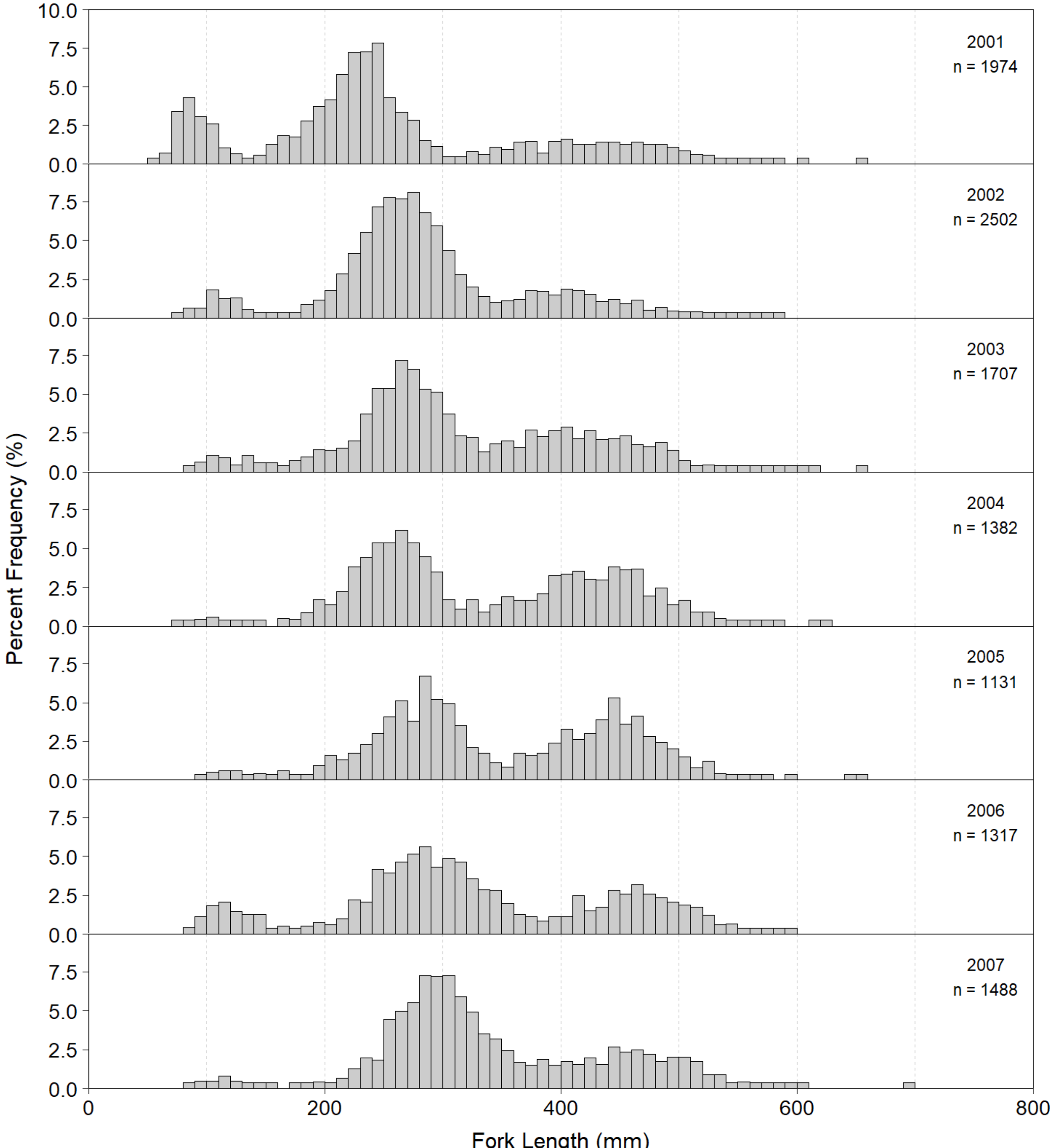

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Figure F5. Length-frequency distributions by year for Rainbow Trout captured by boat electroshocking in sampled sections of the lower Columbia River, 2001 to 2021.

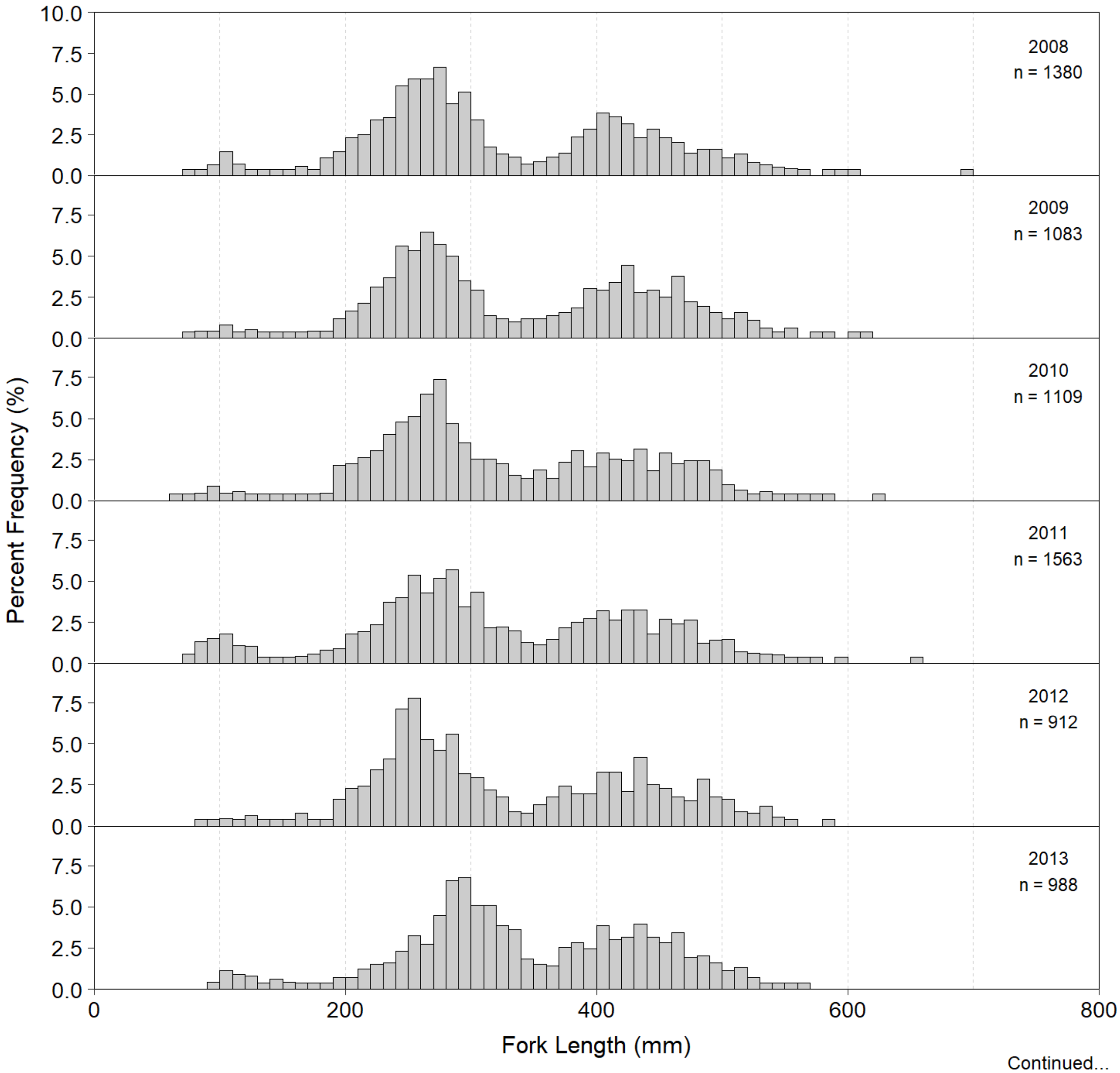

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Figure F5. Continued.

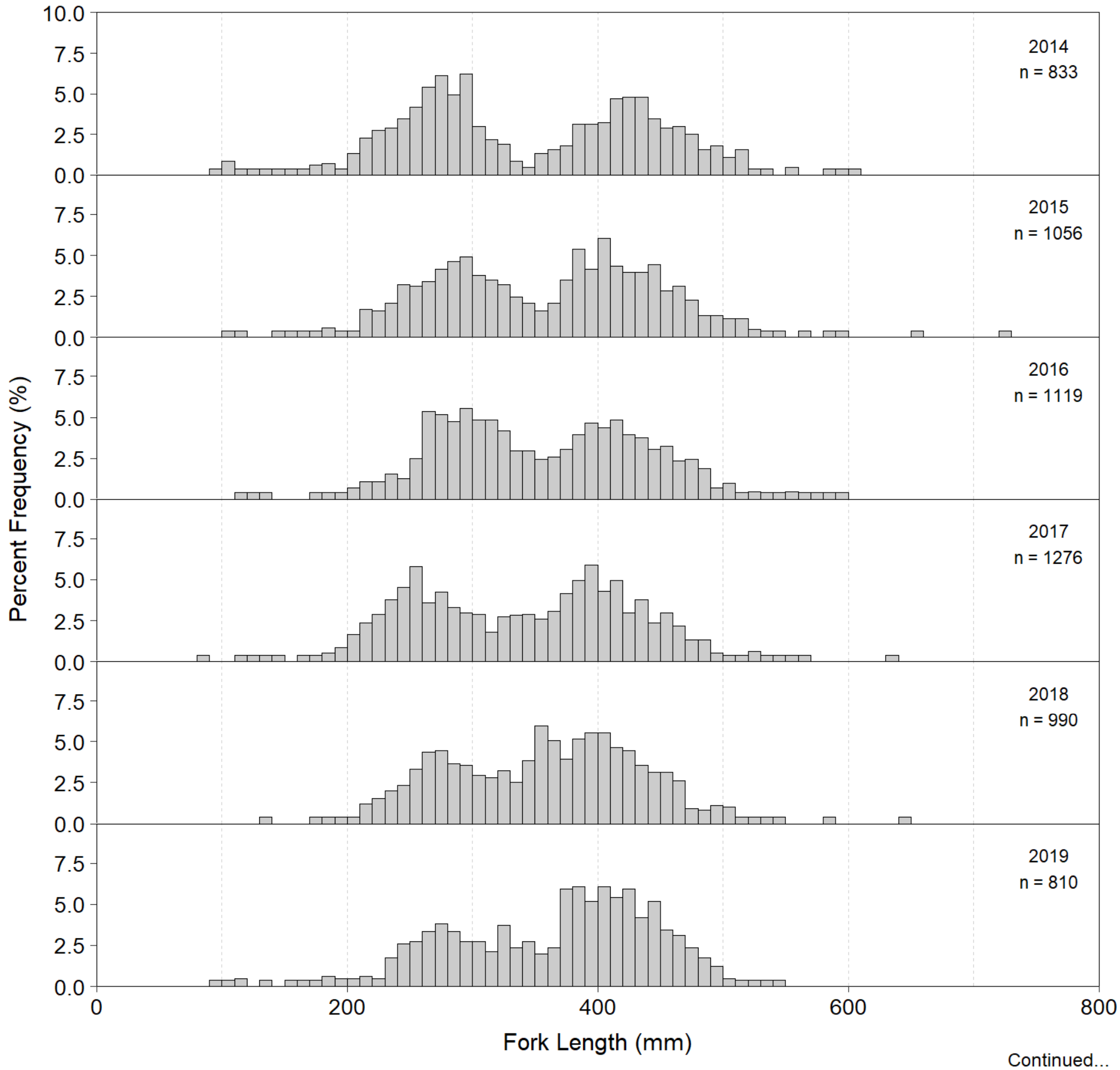

Figure F5. Continued.

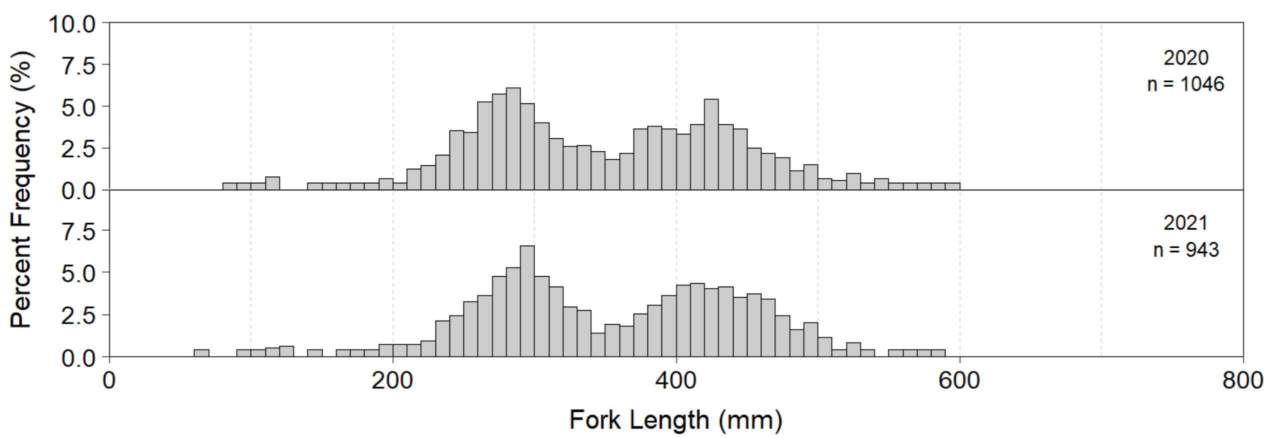

Figure F5. Concluded.

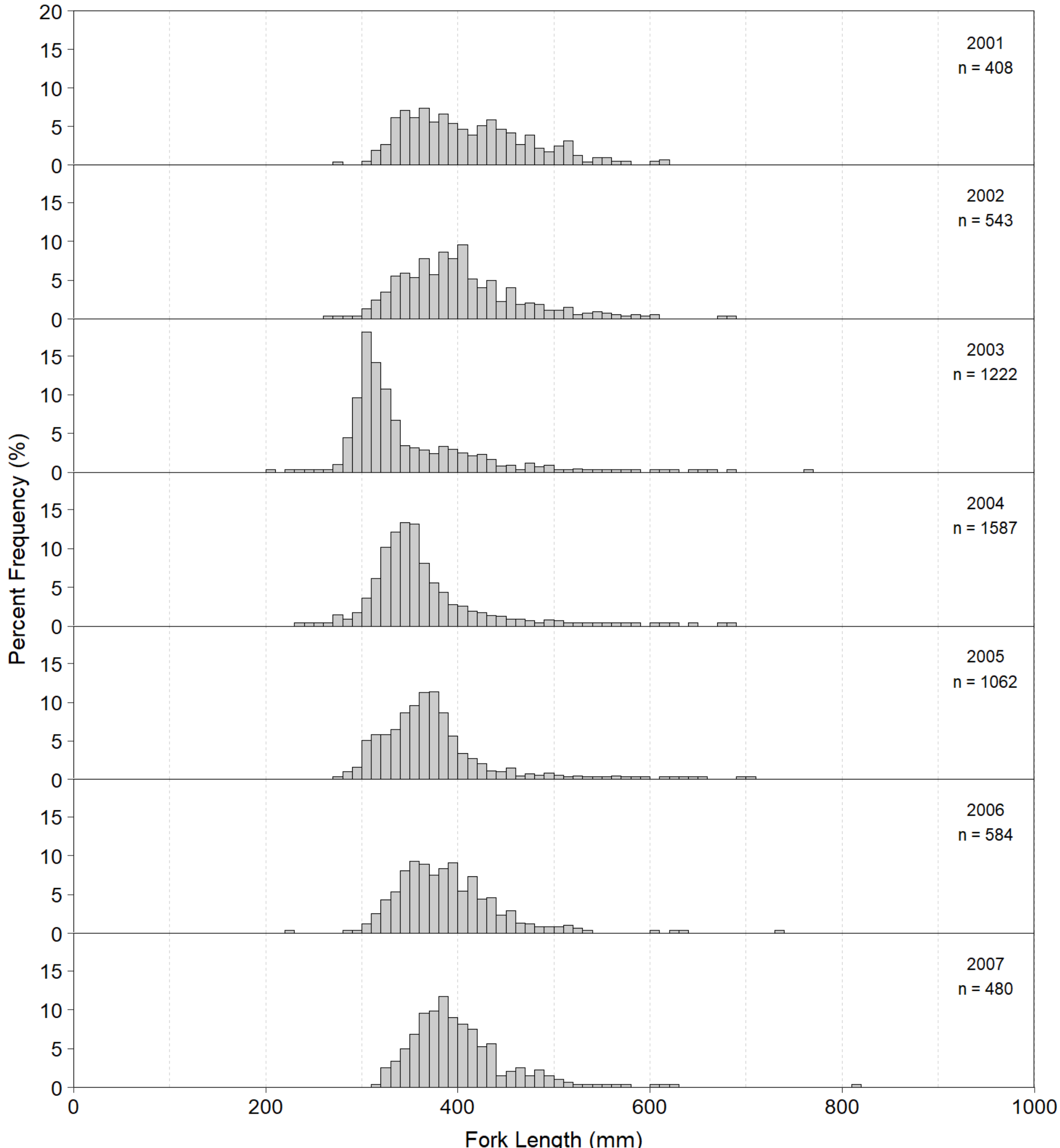

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Figure F6. Length-frequency distributions by year for Walleye captured by boat electroshocking in sampled sections of the lower Columbia River, 2001 to 2021.

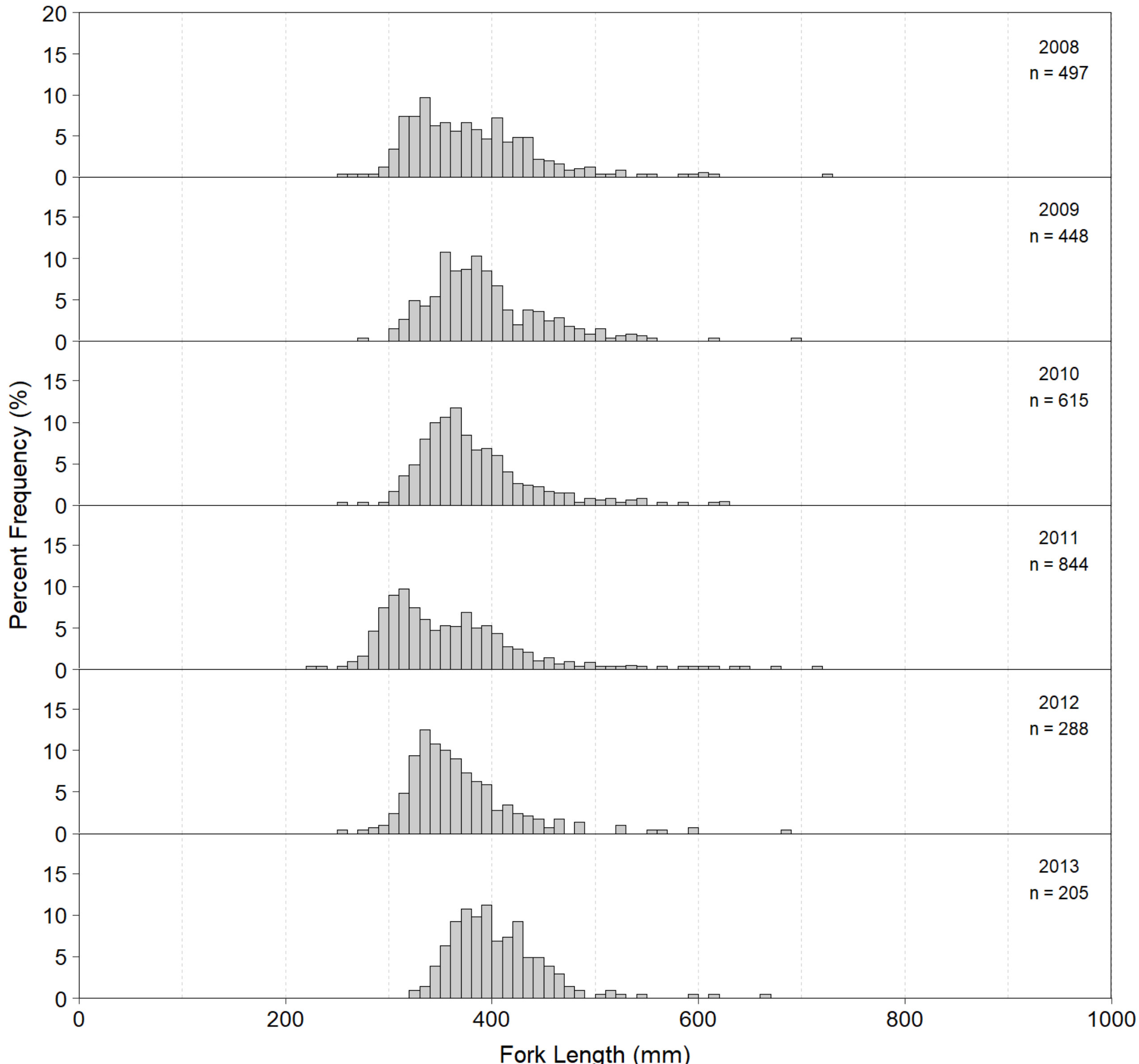

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Figure F6. Continued.

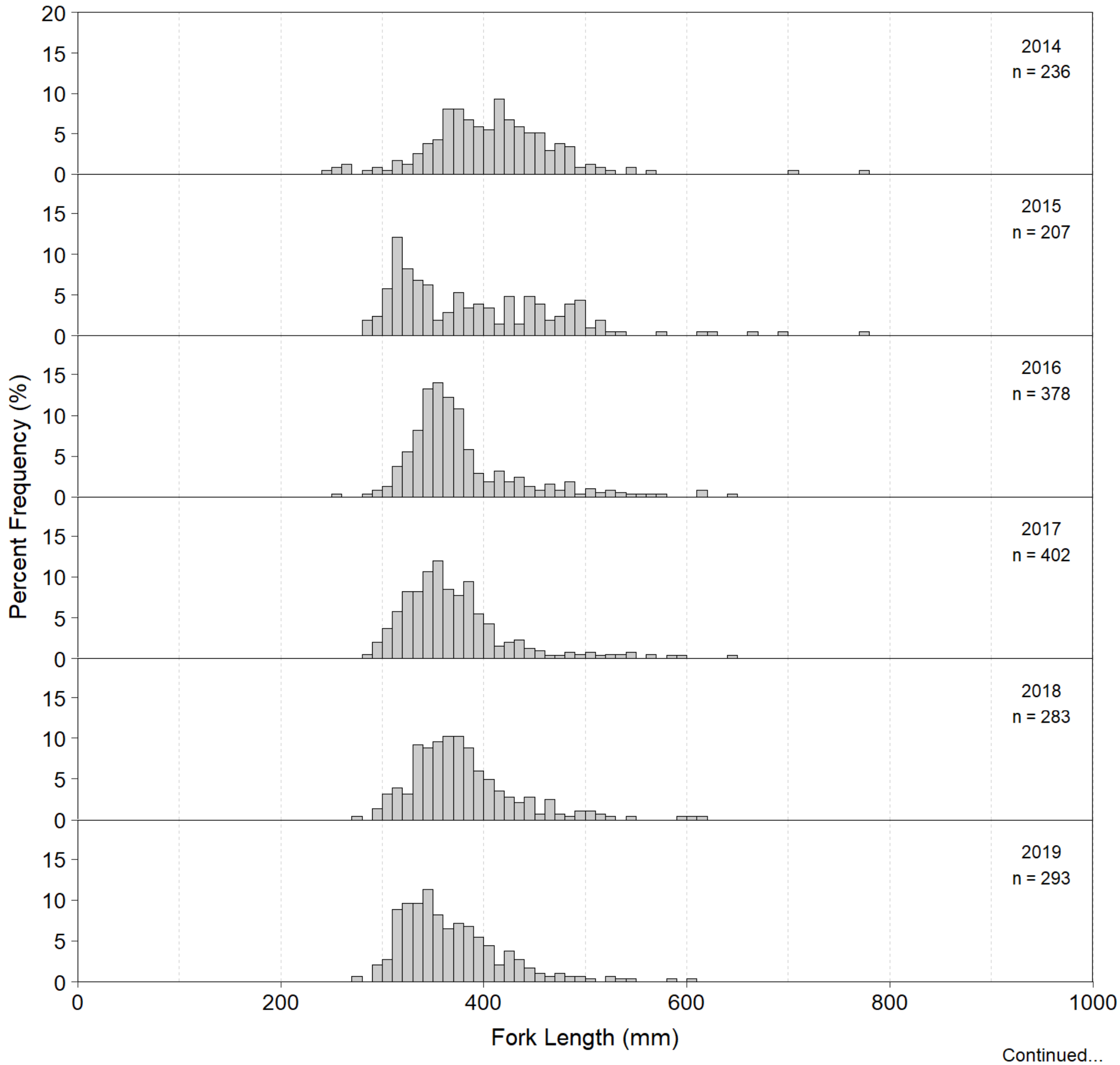

Figure F6. Continued.

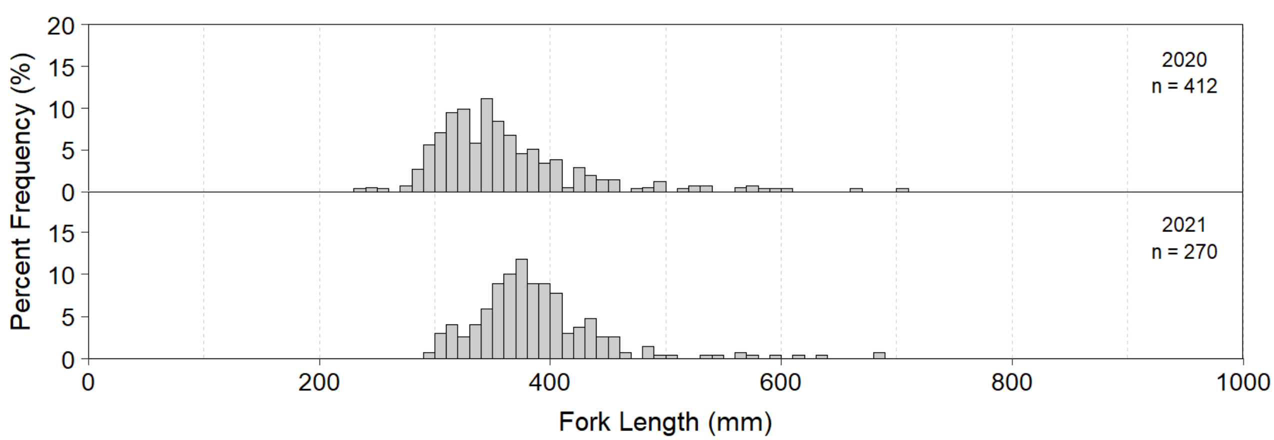

Figure F6. Concluded.

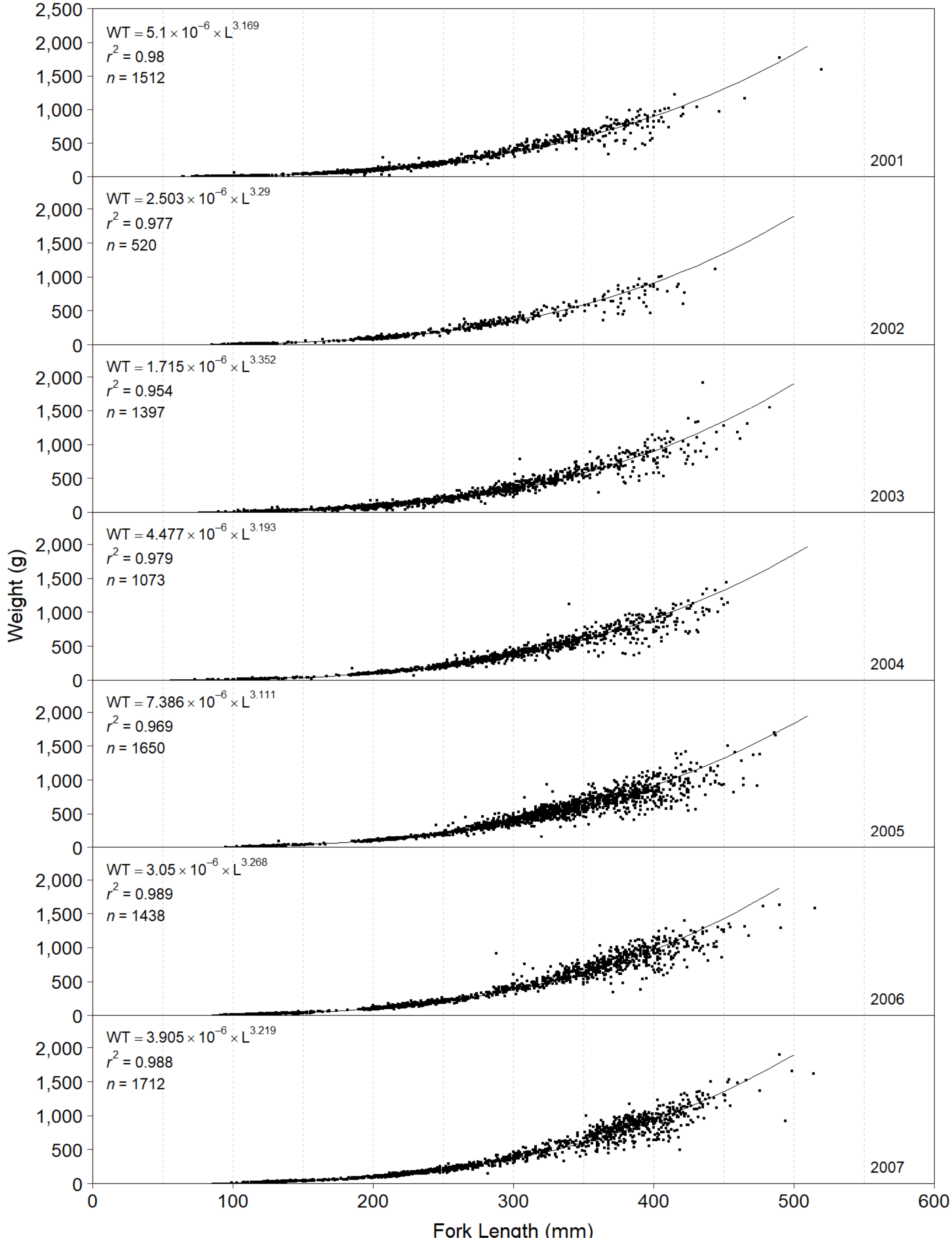

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Figure F7. Length-weight regressions for Mountain Whitefish captured by boat electroshocking in the lower Columbia River, 2001 to 2021.

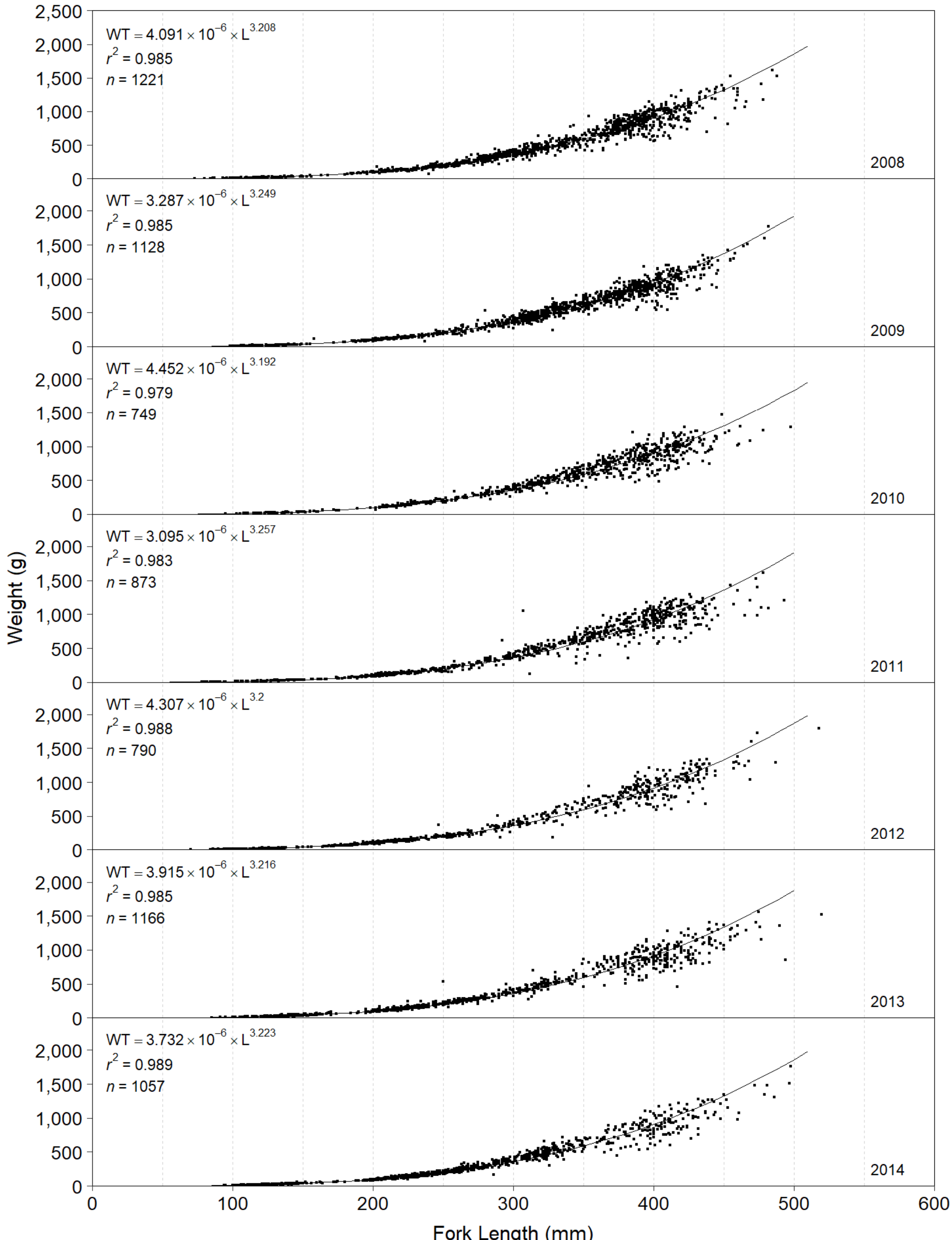

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Figure F7. Continued.

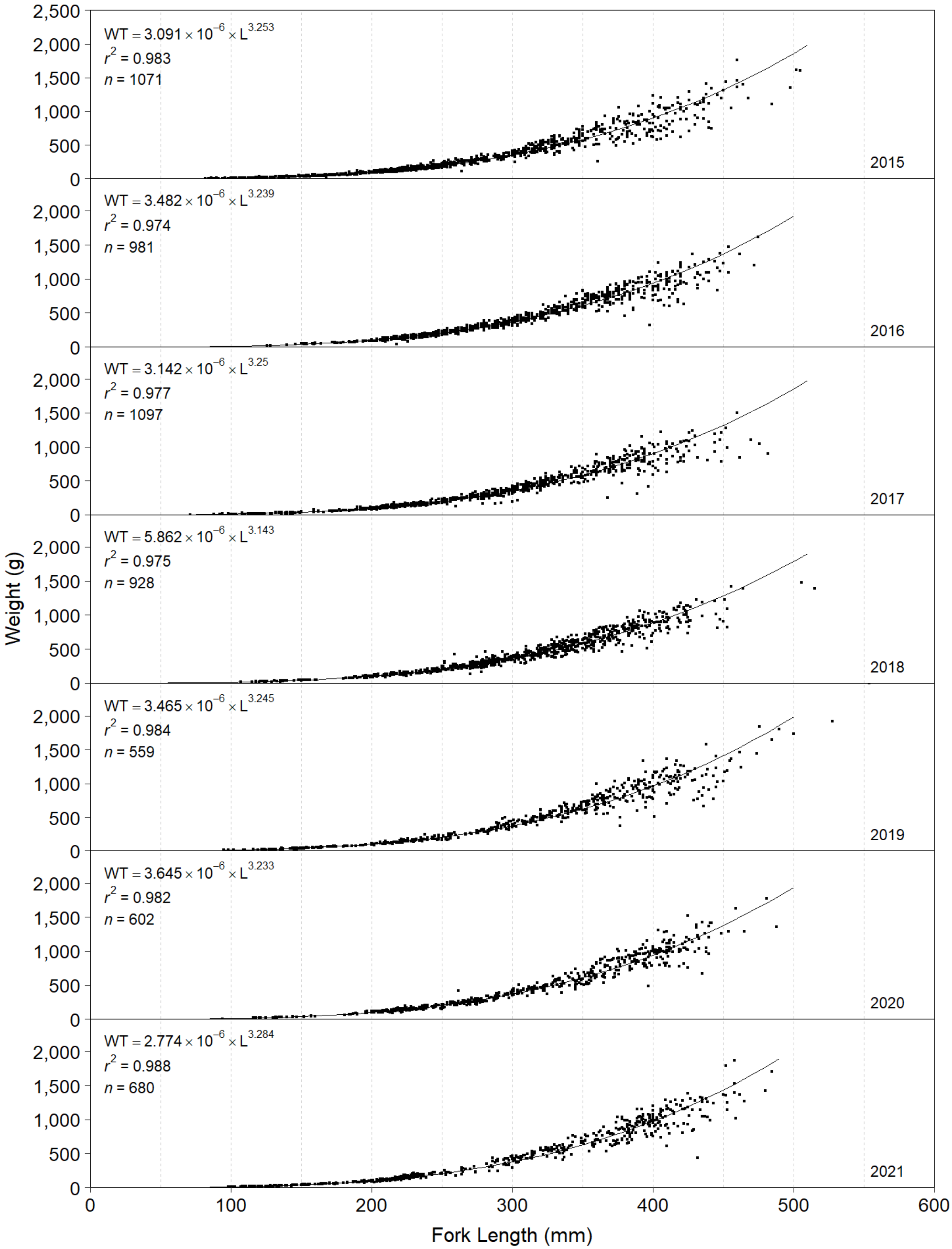

Figure F7. Concluded.

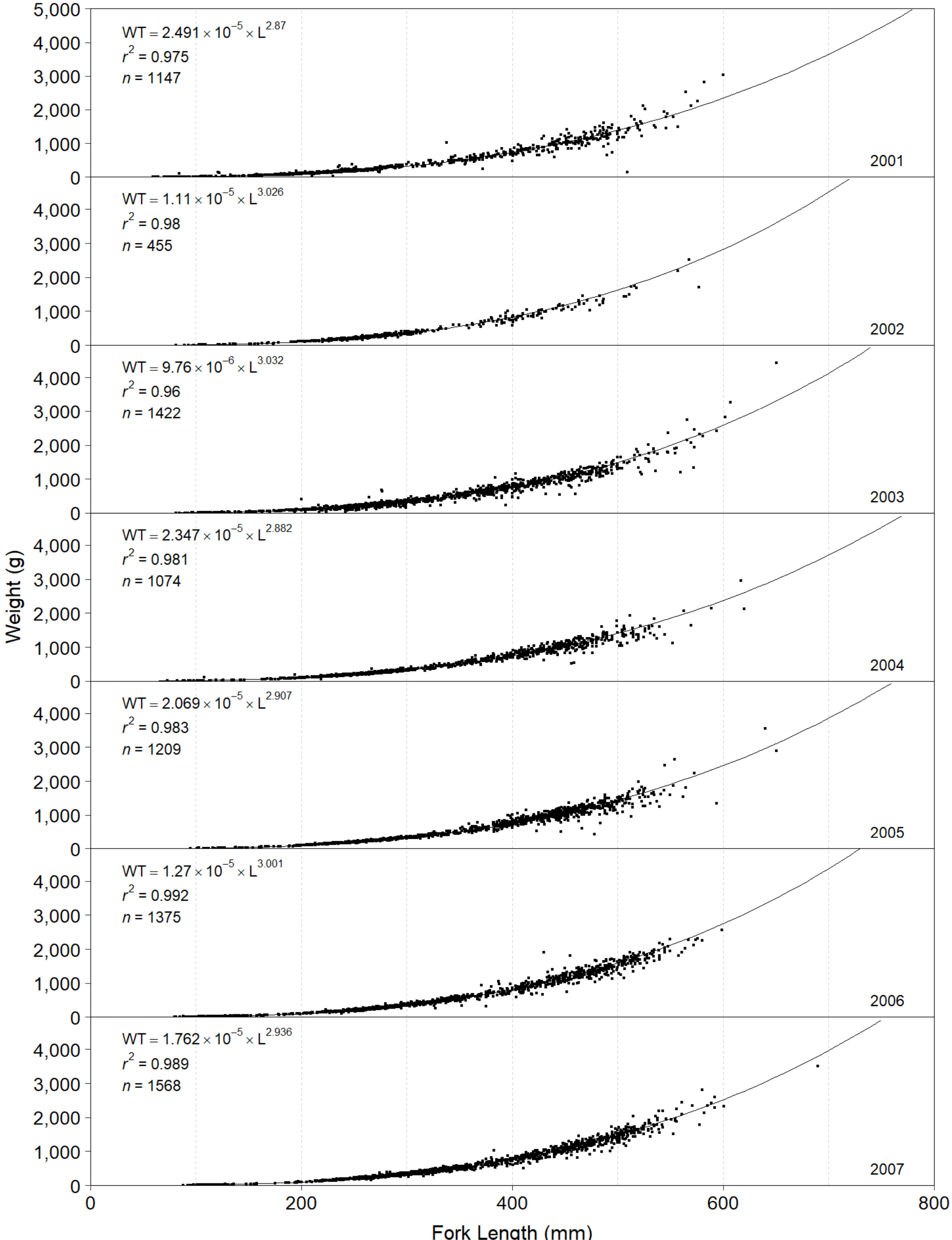

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Figure F8. Length-weight regressions for Rainbow Trout captured by boat electroshocking in the lower Columbia River, 2001 to 2021.

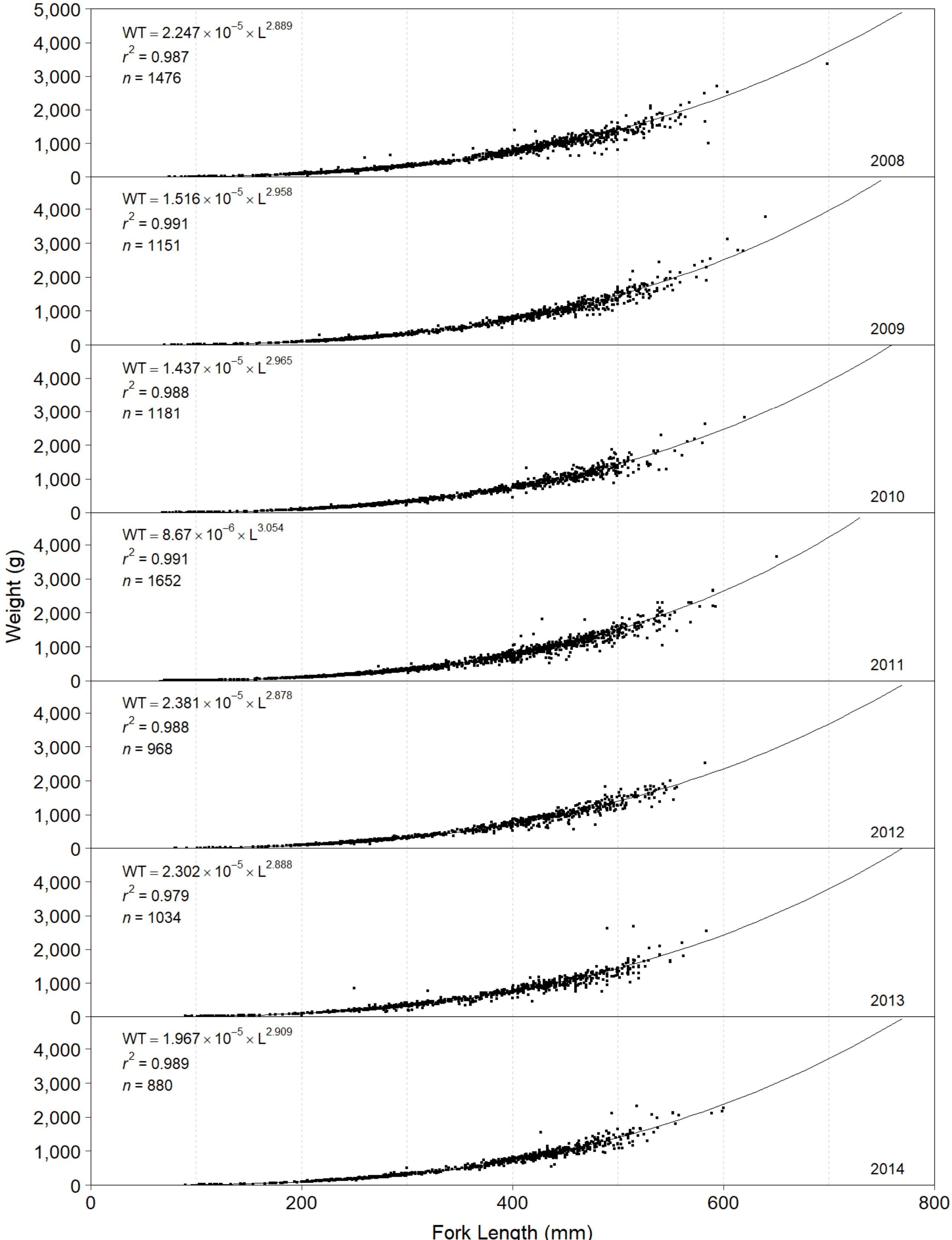

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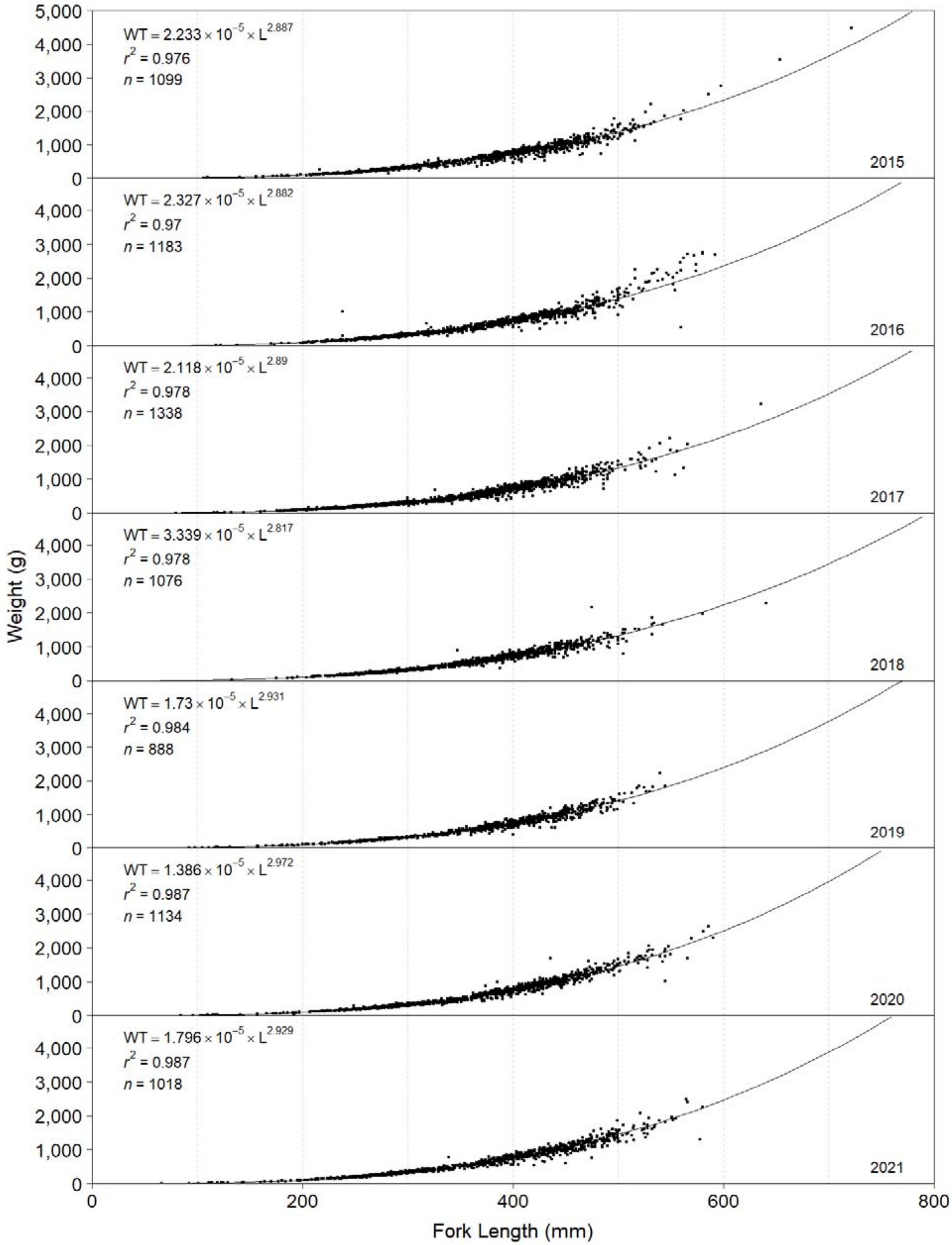
Figure F8. Continued.



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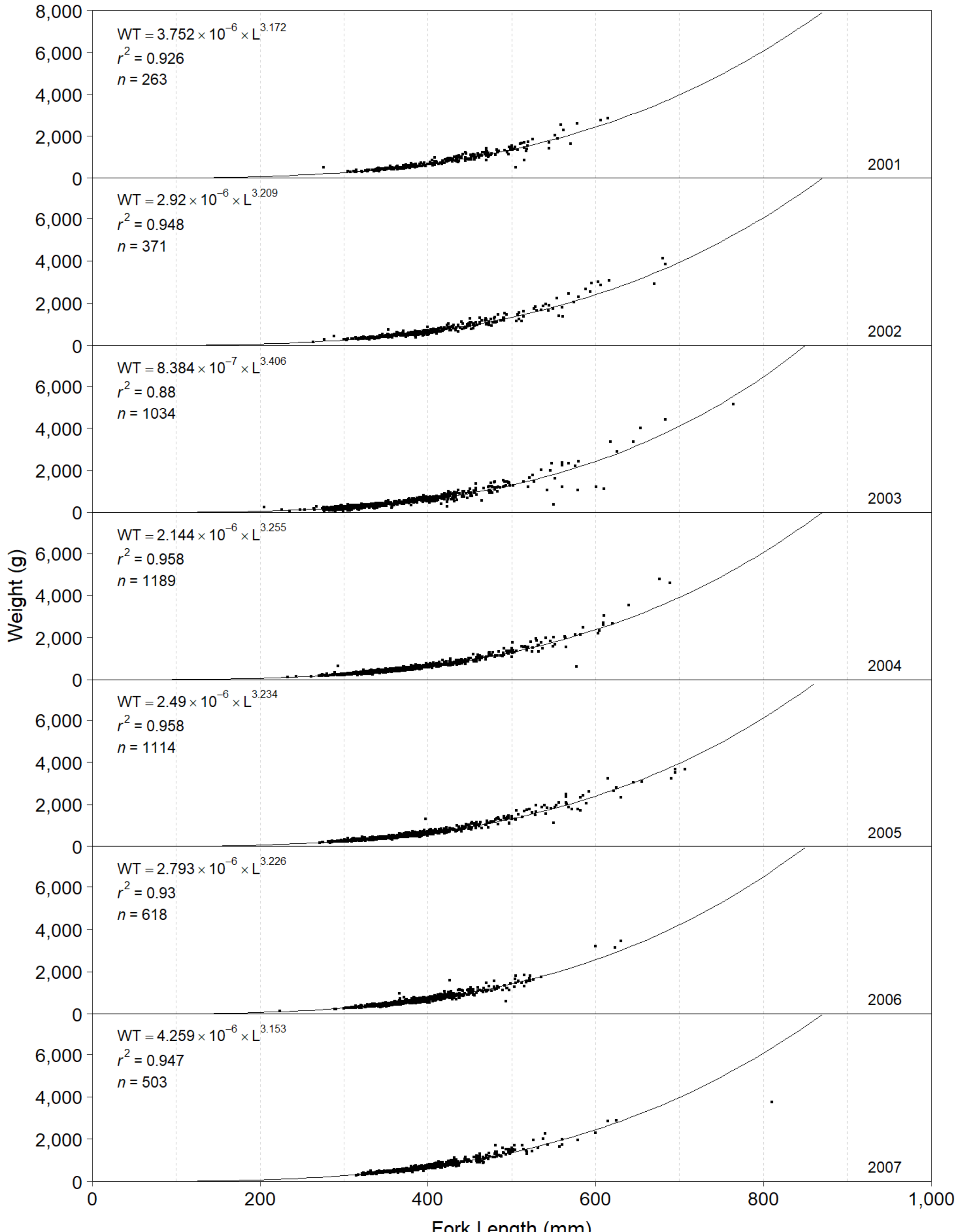

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Figure F9. Length-weight regressions for Walleye captured by boat electroshocking in the lower Columbia River, 2001 to 2021.

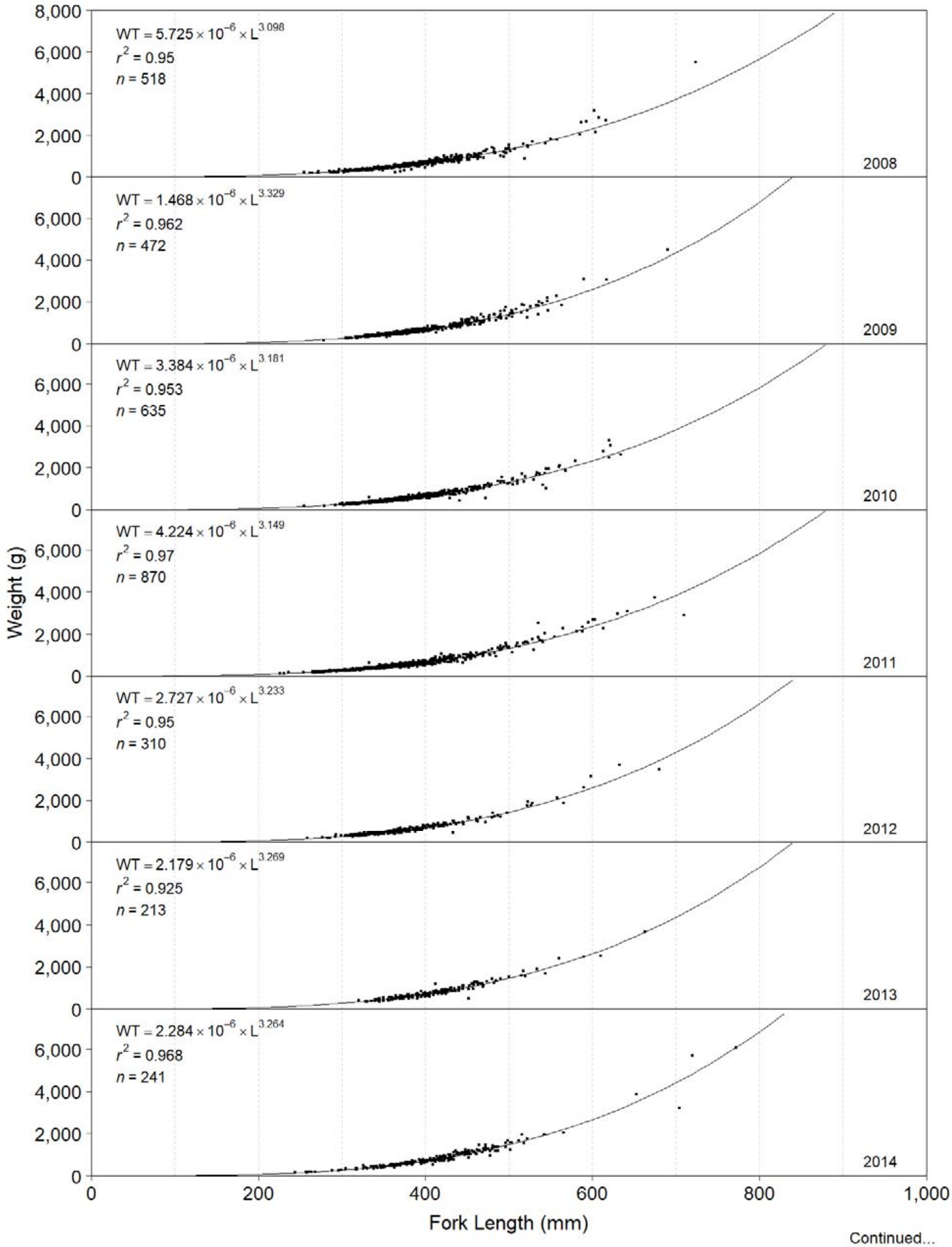

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Figure F9. Continued.

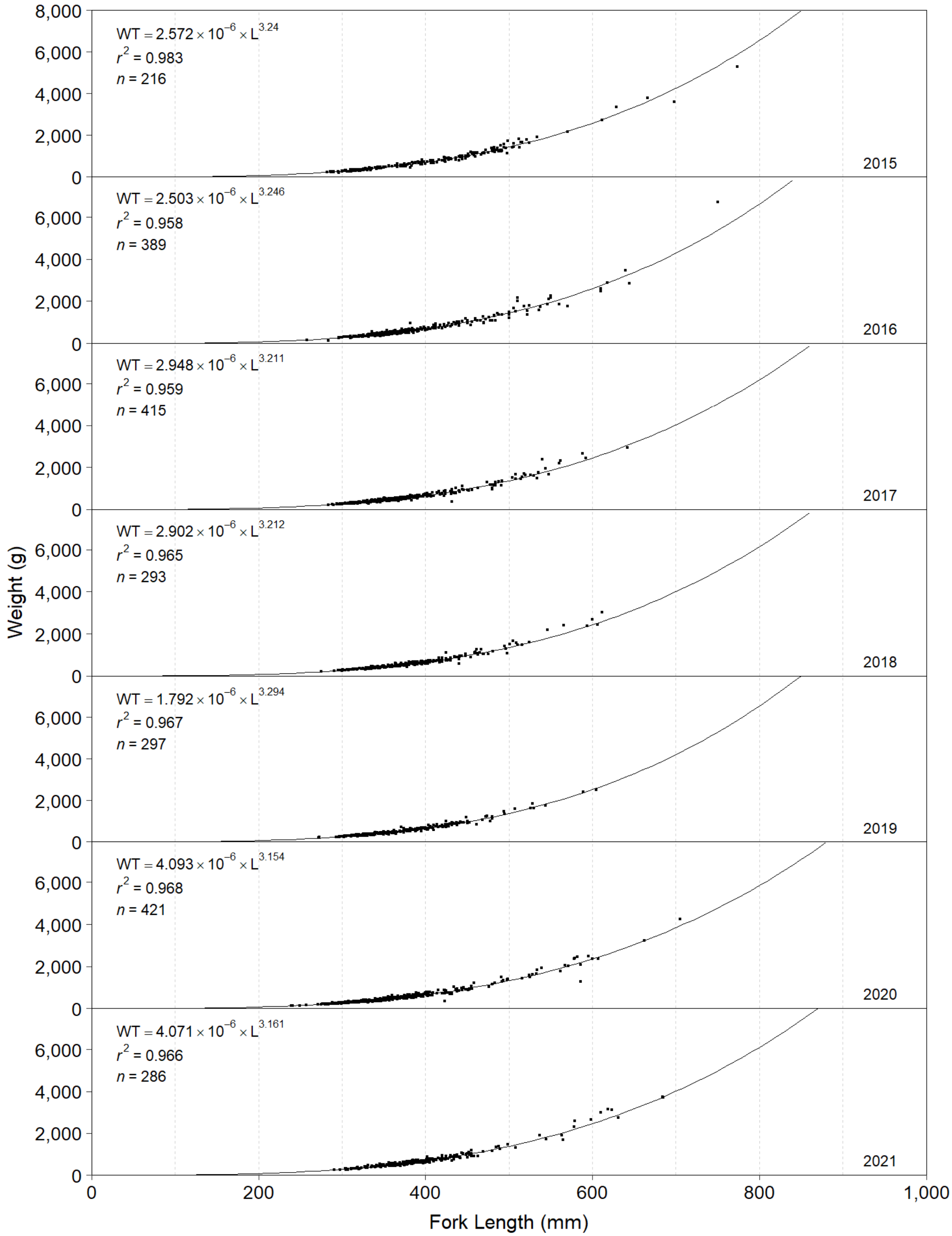


Figure F9. Concluded.

Appendix G – Additional Results

Appendix G: Additional Figures

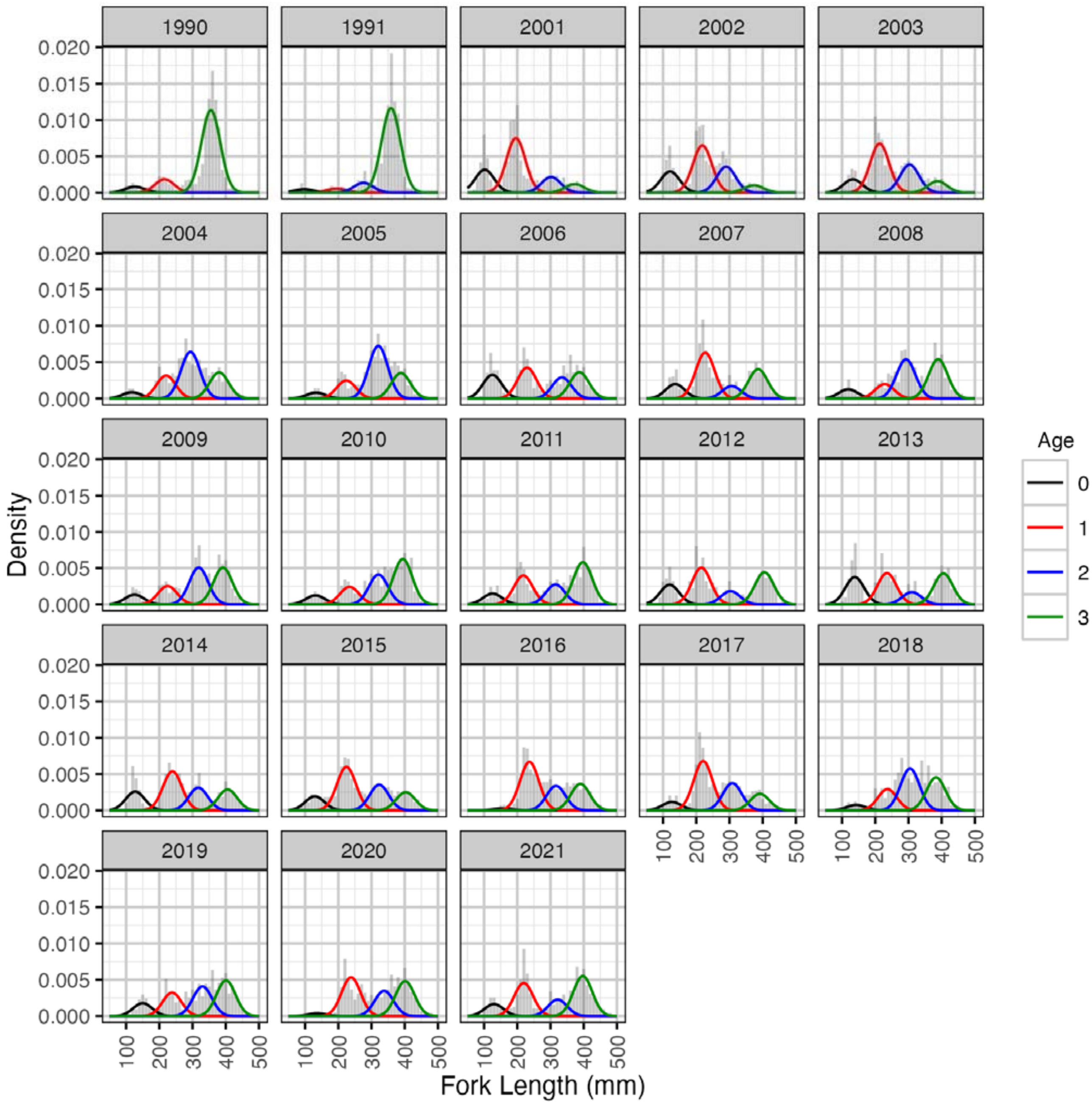


Figure G1: Predicted length-density plot for Mountain Whitefish by life stage and year.

Appendix G: Additional Figures

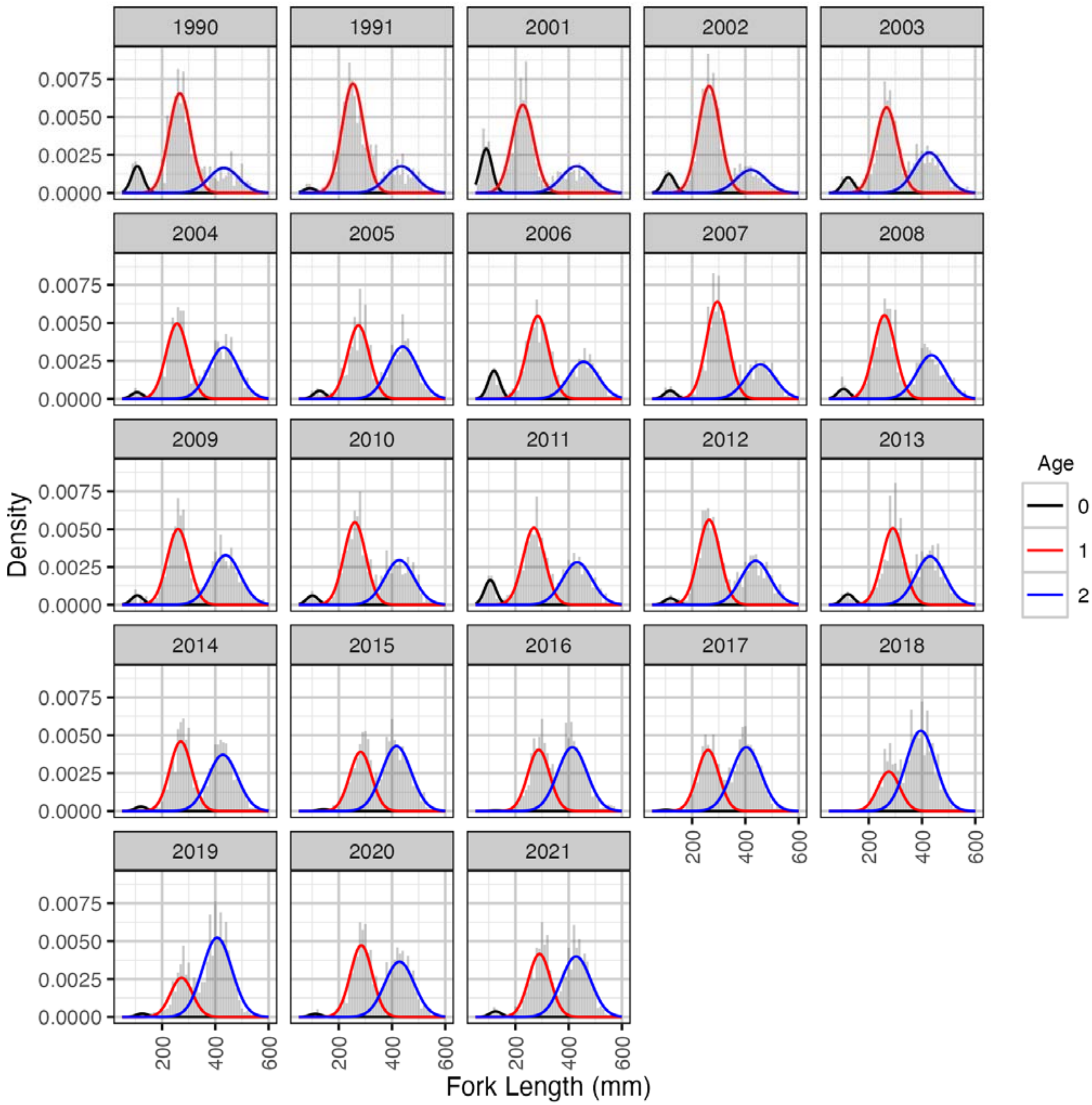


Figure G2: Predicted length-density plot for Rainbow Trout by life stage and year.

Appendix G: Additional Figures

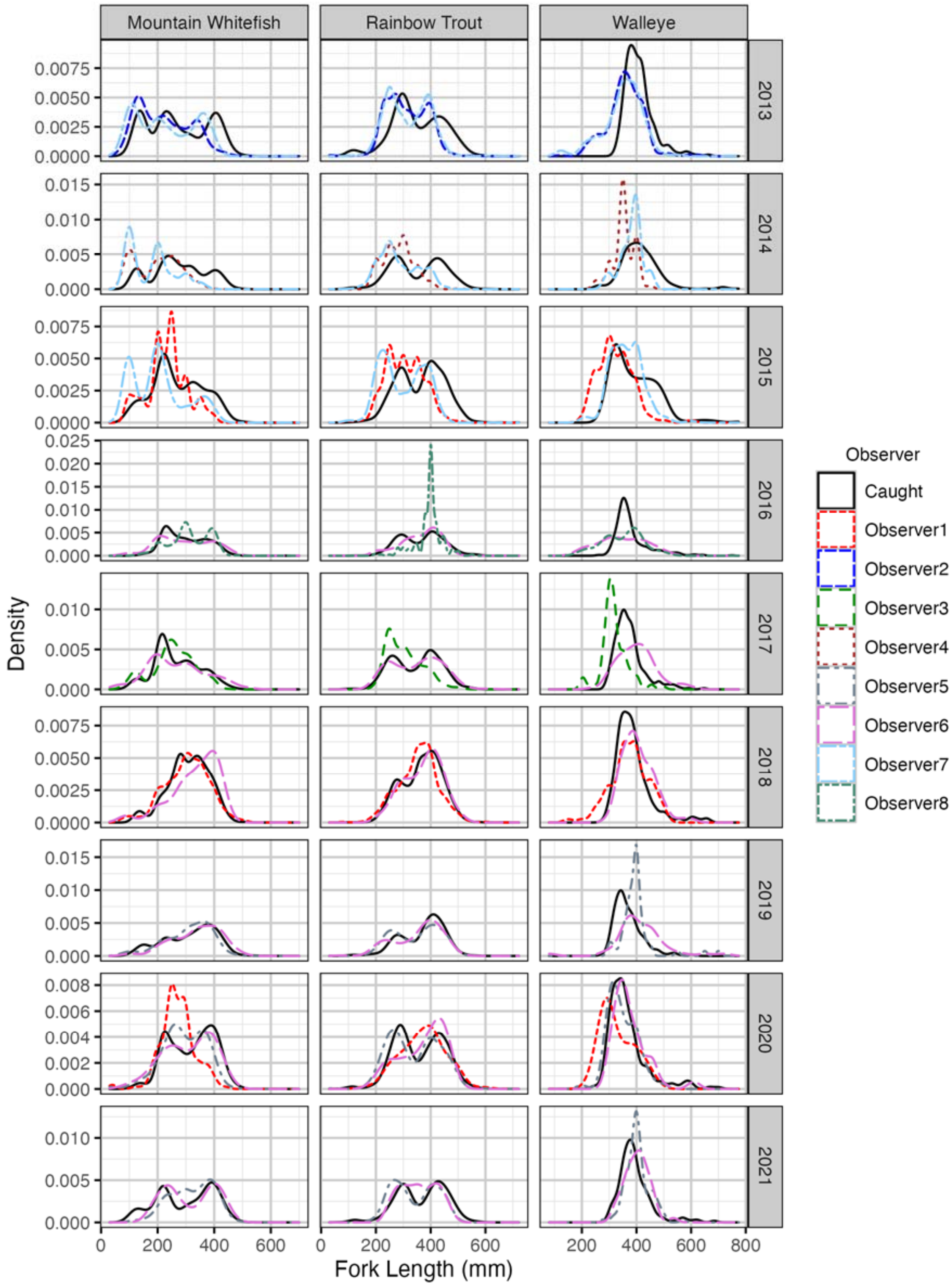


Figure G3: Fork length-density plots for measured and estimated fork lengths of fish caught or observed in the lower Columbia River, 2013–2021. The black line shows fish that were caught. Observed data from the georeferenced visual survey are shown by coloured dashed lines.

Appendix G: Additional Figures

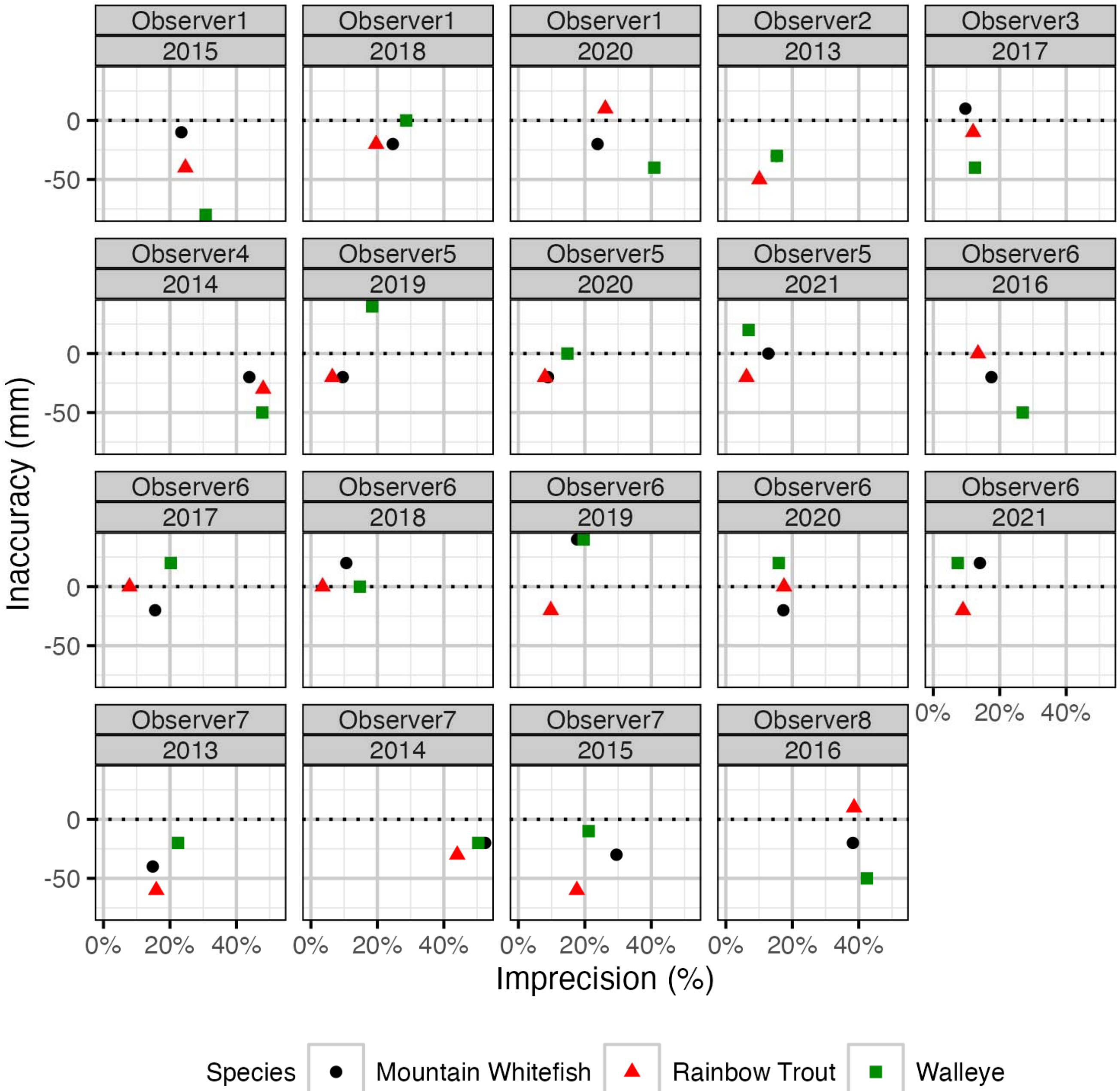


Figure G4: Fish length inaccuracy (bias) and imprecision by observer, year of observation and species. Observations use the length bias model of captured (mark-recapture surveys) compared to estimated (geo-referenced visual surveys) length-frequency distributions from the lower Columbia River, 2013–2021.

Appendix G: Additional Figures

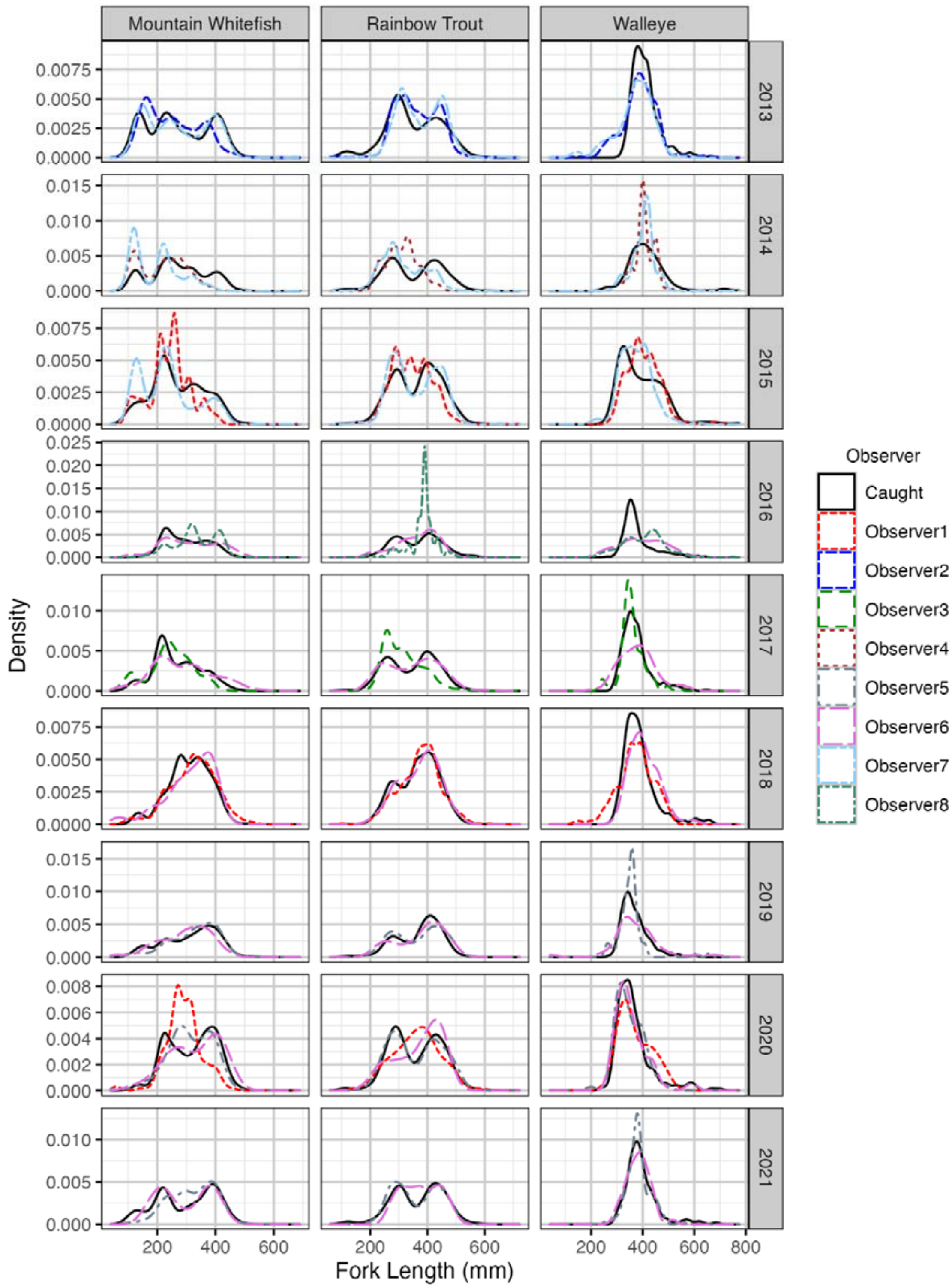


Figure G5: ***Corrected fork length-density plots for measured and estimated fork lengths of fish caught or observed in the lower Columbia River, 2013–2021. The black line shows fish that were caught. Observed data are shown by coloured dashed lines.***

Appendix G: Additional Figures

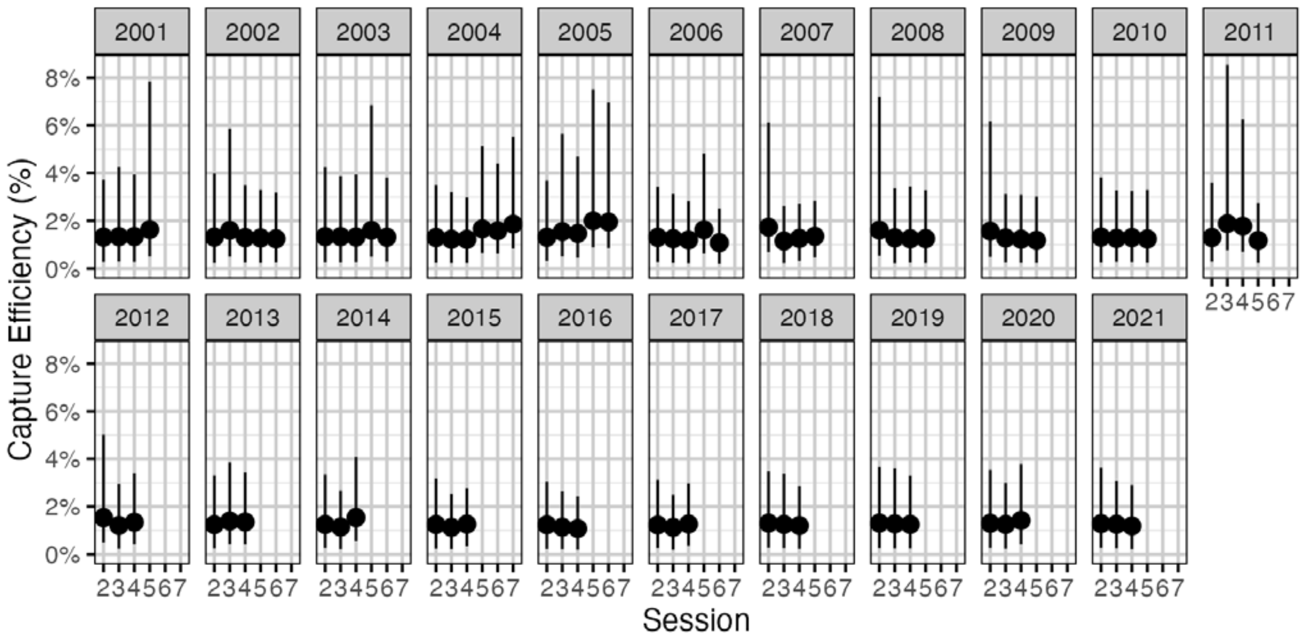


Figure G6: ***Capture efficiency (mean with 95% credible intervals) of subadult Mountain Whitefish by year and sample session in the lower Columbia River, 2001–2021.***

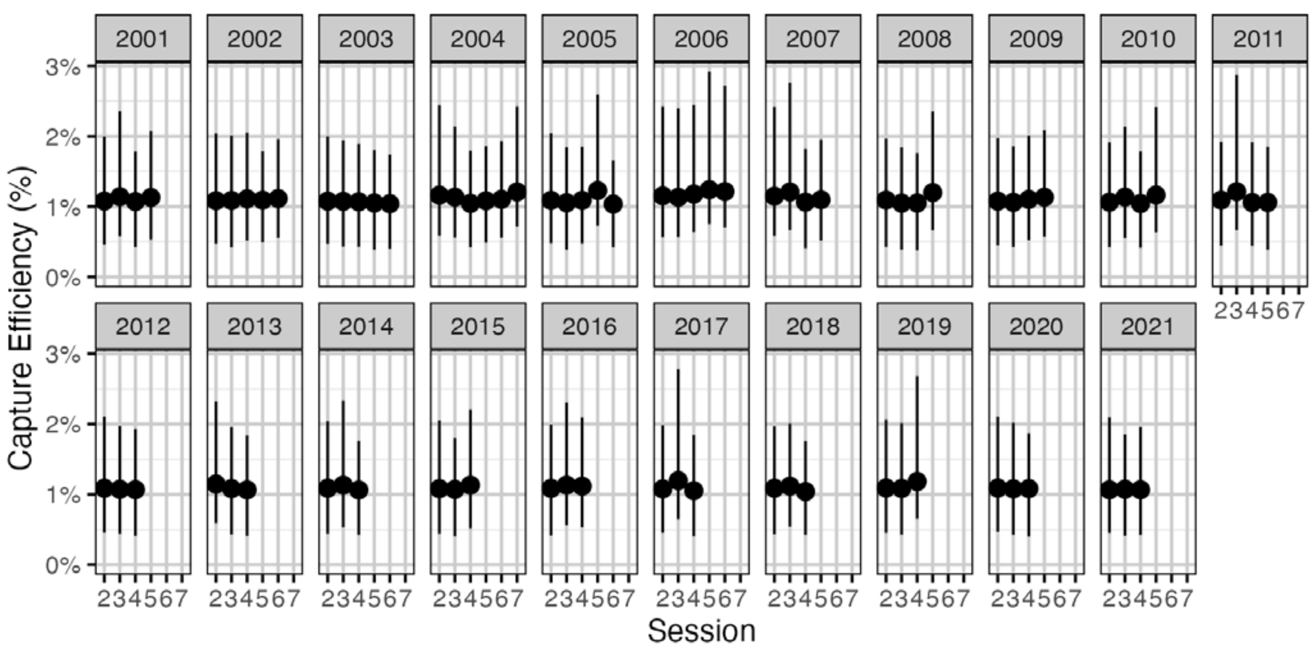


Figure G7: ***Capture efficiency (mean with 95% credible intervals) of adult Mountain Whitefish by year and sample session in the lower Columbia River, 2001–2021.***

Appendix G: Additional Figures

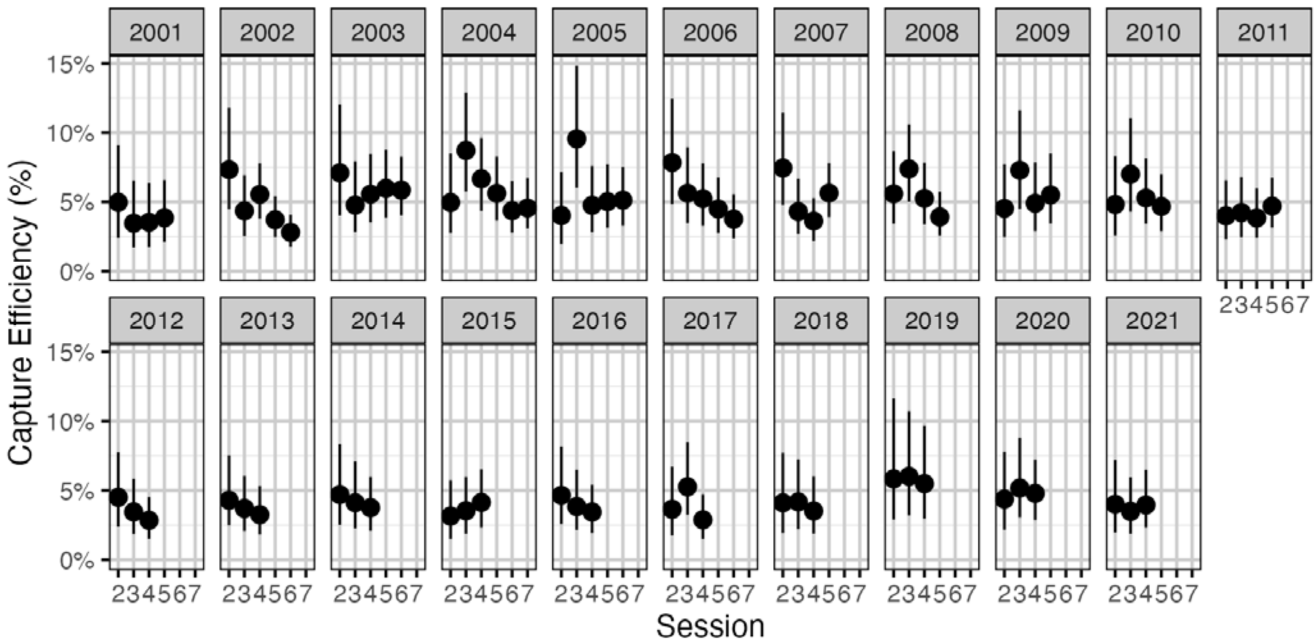


Figure G8: ***Capture efficiency (mean with 95% credible intervals) of subadult Rainbow Trout by year and sample session in the lower Columbia River, 2001–2021.***

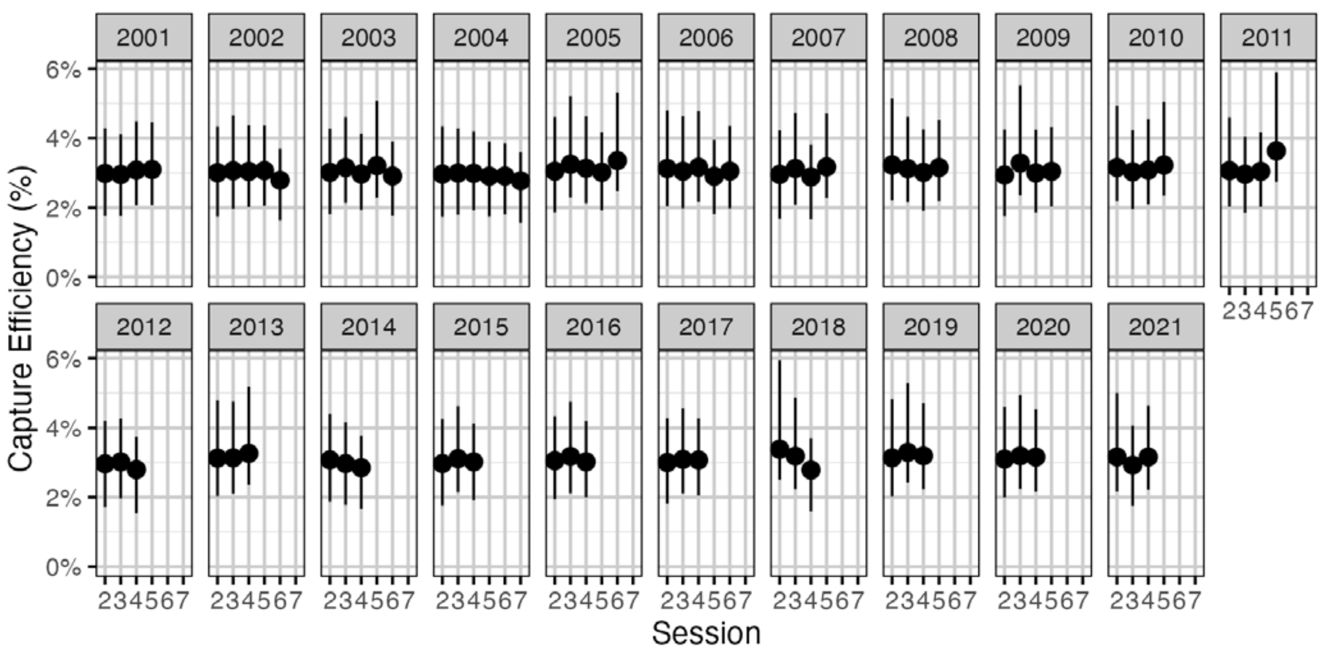


Figure G9: ***Capture efficiency (mean with 95% credible intervals) of adult Rainbow Trout by year and sample session in the lower Columbia River, 2001–2021.***

Appendix G: Additional Figures

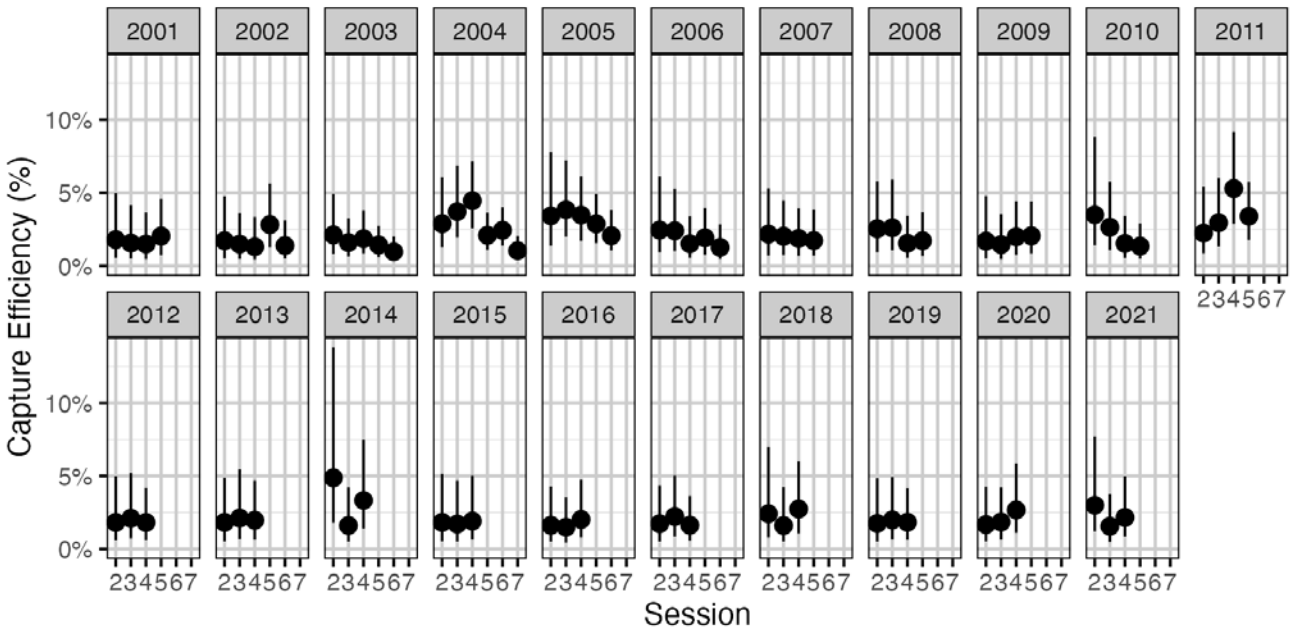


Figure G10: ***Capture efficiency (mean with 95% credible intervals) of Walleye by year and sample session in the lower Columbia River, 2001–2021.***

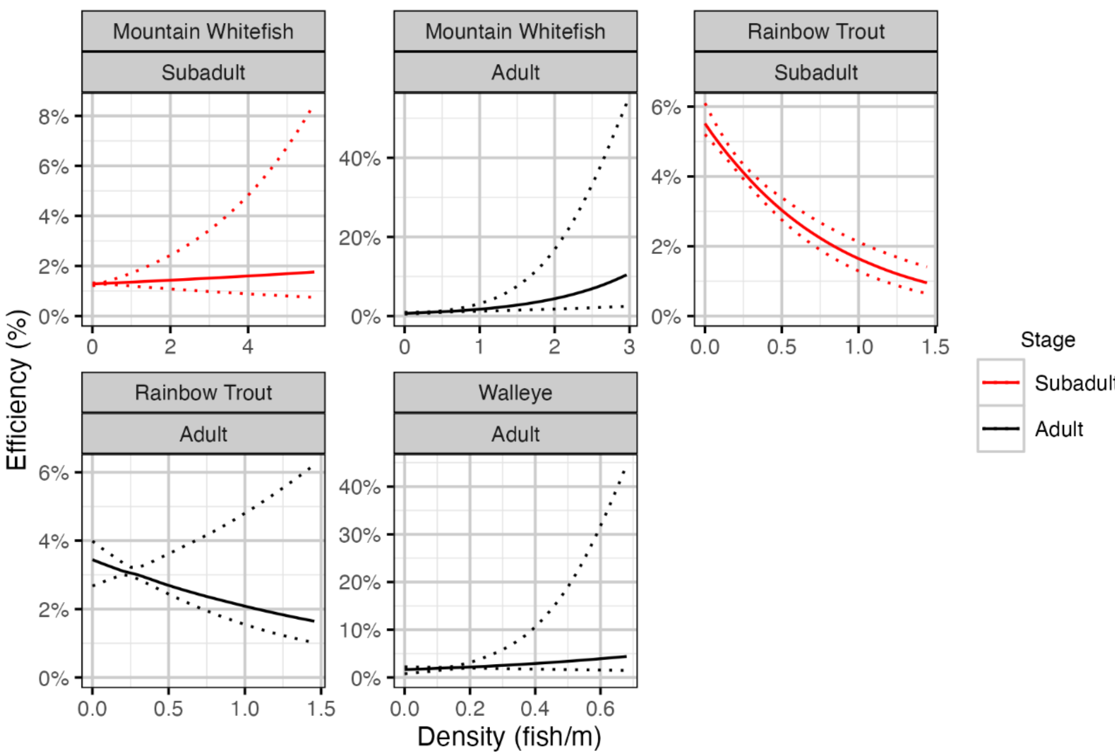


Figure G11: ***Effect of density on capture efficiency by species and stage (with 95% CIs)***

Appendix G: Additional Figures

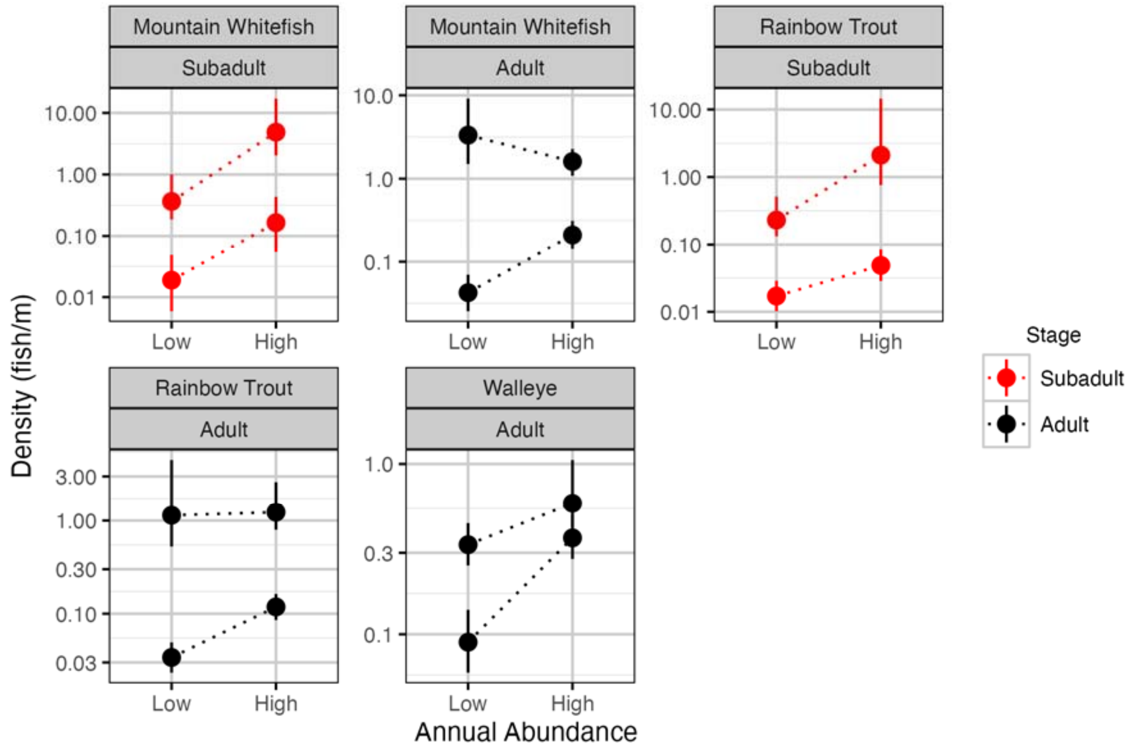


Figure G12: ***Estimated density in the lowest and highest abundance years for the lowest and highest abundance sites by species and stage (with 95% CIs).***

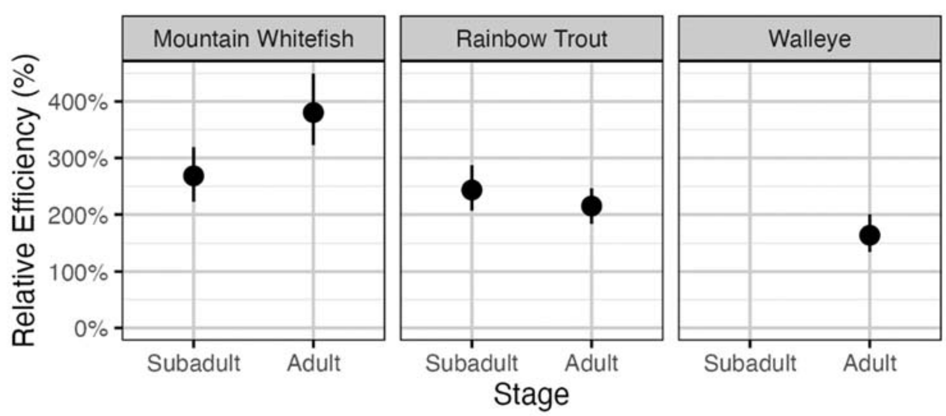


Figure G13: Predicted relative efficiency of capture vs counting for each species by life stage.

Appendix G: Additional Figures

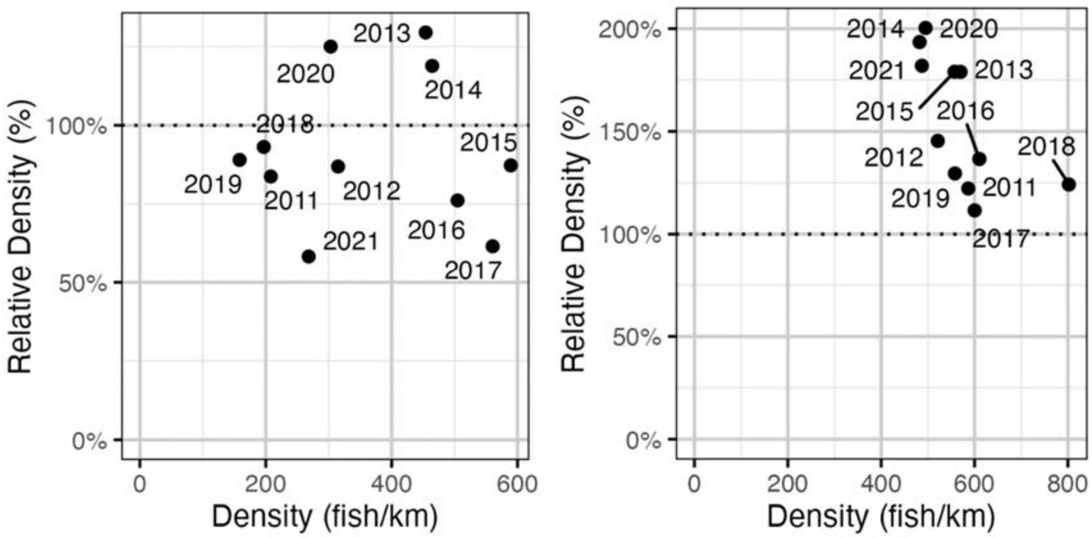


Figure G14: Estimated density of subadult (left) and adult (right) Mountain Whitefish at non-index relative to index sites by year.

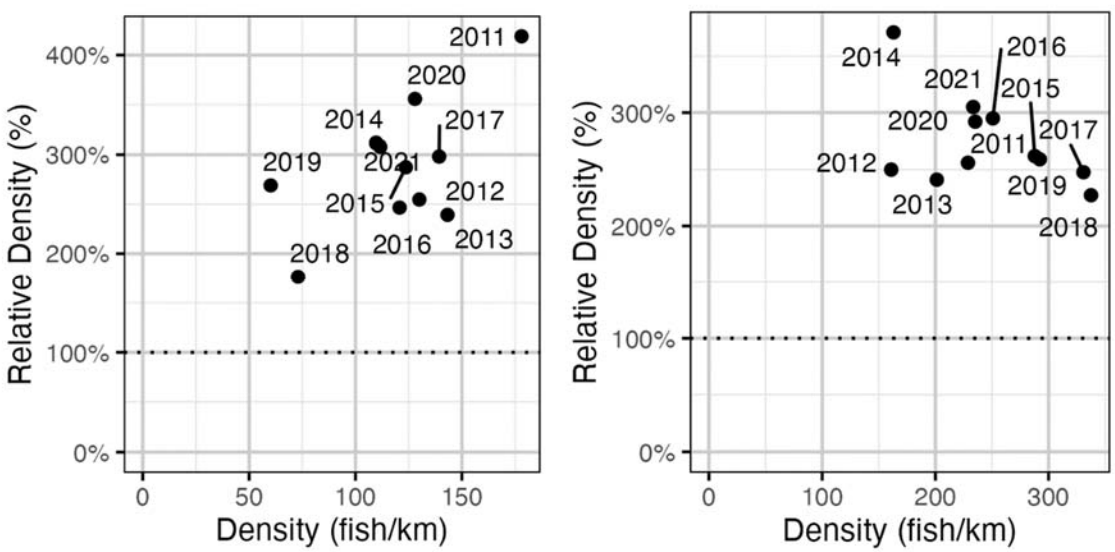


Figure G15: Estimated density of subadult (left) and adult (right) Rainbow Trout at non-index relative to index sites by year.

Appendix G: Additional Figures

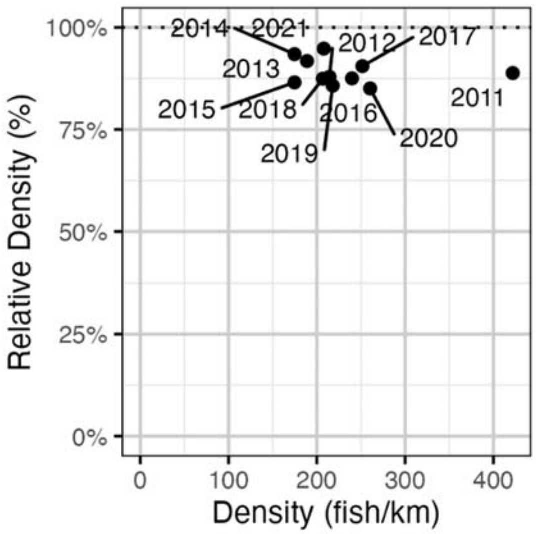


Figure G16: Estimated density of Walleye at non-index relative to index sites by year.

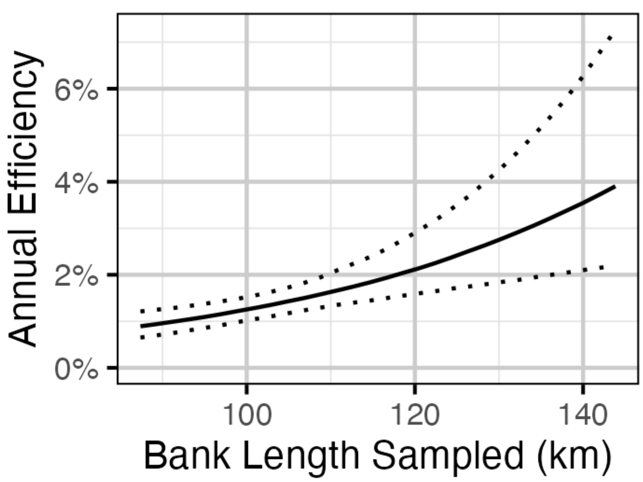


Figure G17: Predicted annual efficiency of capture for adult Mountain Whitefish by amount of bank length sampled (km).

Appendix G: Additional Figures

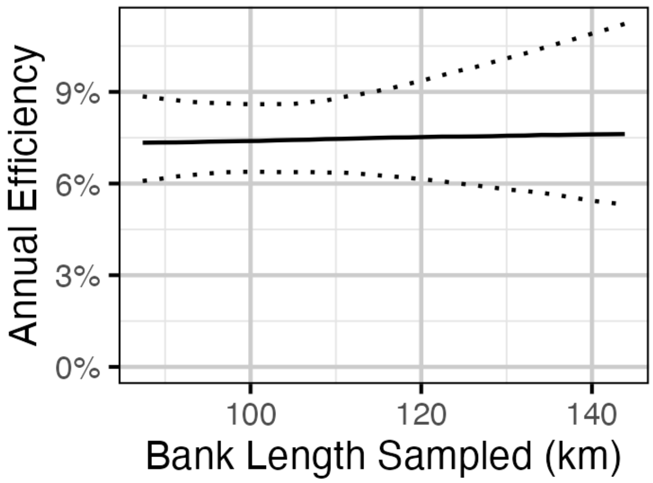


Figure G18: Predicted annual efficiency of capture for adult Rainbow Trout by amount of bank length sampled (km).

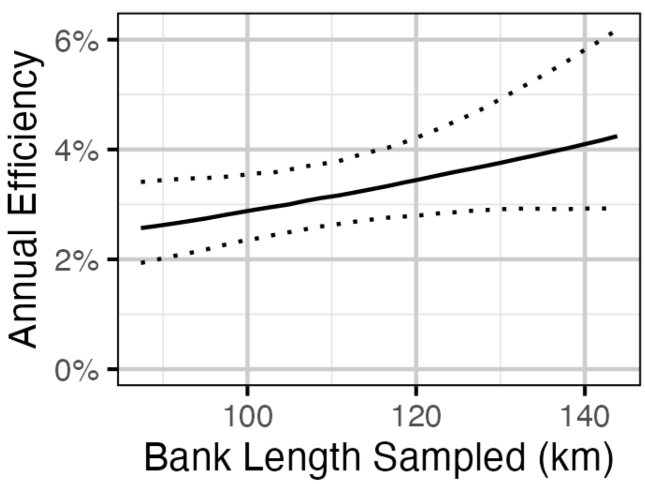


Figure G19: Predicted annual efficiency of capture for Walleye by amount of bank length sampled (km).

Appendix H – Spatial Distribution Maps

LEGEND

- PLACE NAME
- RIVER KILOMETRE POSTS
- RIVER CENTRELINE

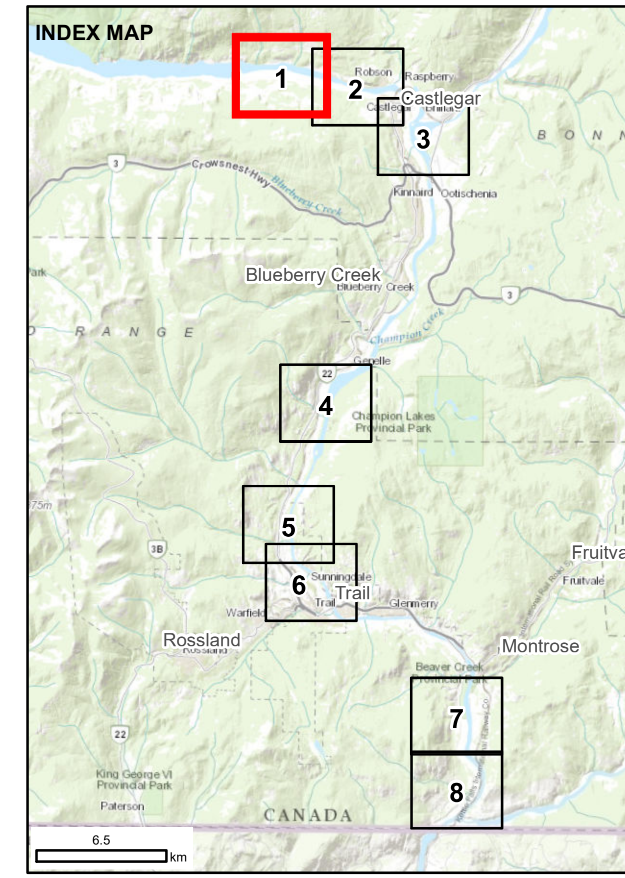
MOUNTAIN WHITEFISH OBSERVATION

- ADULT (AGE - 2 AND OLDER)
- AGE - 1
- AGE - 0

BASE DATA

- MAJOR ROAD
- ROAD - LOCAL
- WATERCOURSE
- WATERBODY

INDEX MAP



REFERENCE

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2. IMAGERY OBTAINED FROM BING MAPS FOR ARCGIS PUBLISHED BY MICROSOFT CORPORATION, REDMOND, WA, 2014
3. INSET: 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.

DATUM: NAD83 PROJECTION: UTM ZONE 11

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SCALE 1:15,000 METRES

PROJECT

LOWER COLUMBIA RIVER
GEO-REFERENCED VISUAL ENUMERATION SURVEY 2021

TITLE

MOUNTAIN WHITEFISH

wsp

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CHECK	DR	2022-05-31	FIGURE H1
REVIEW	SR	2022-05-31	1 OF 8

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LEGEND

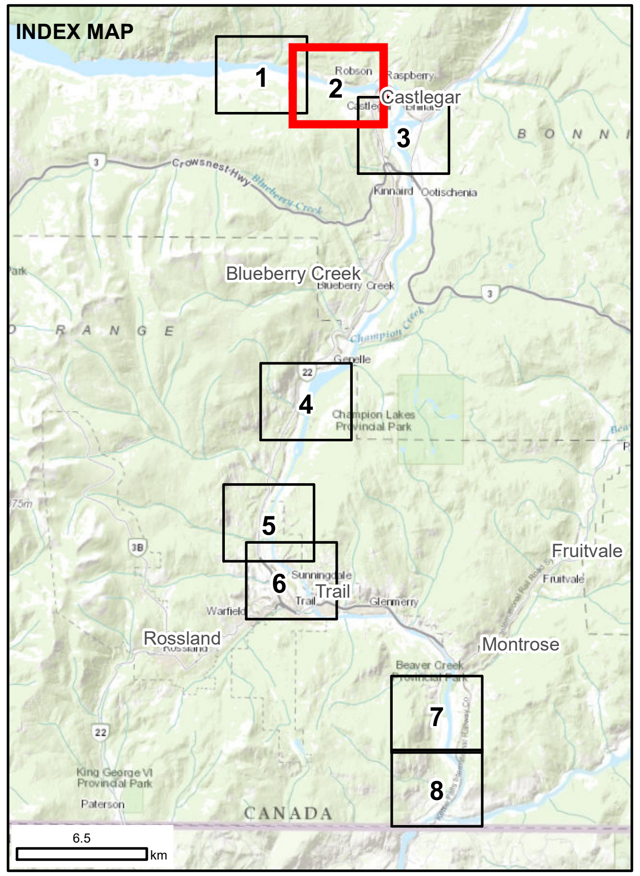
- PLACE NAME
- RIVER KILOMETRE POSTS
- RIVER CENTRELINE

MOUNTAIN WHITEFISH OBSERVATION

- ADULT (AGE - 2 AND OLDER)
- AGE - 1
- AGE - 0

BASE DATA

- MAJOR ROAD
- ROAD - LOCAL
- WATERCOURSE
- WATERBODY



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GEO-REFERENCED VISUAL ENUMERATION SURVEY 2021

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MOUNTAIN WHITEFISH

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LEGEND

- PLACE NAME
- RIVER KILOMETRE POSTS
- RIVER CENTRELINE

MOUNTAIN WHITEFISH OBSERVATION

- ADULT (AGE - 2 AND OLDER)
- AGE - 1
- AGE - 0

BASE DATA

- HIGHWAY
- MAJOR ROAD
- ROAD - LOCAL
- WATERCOURSE
- WATERBODY

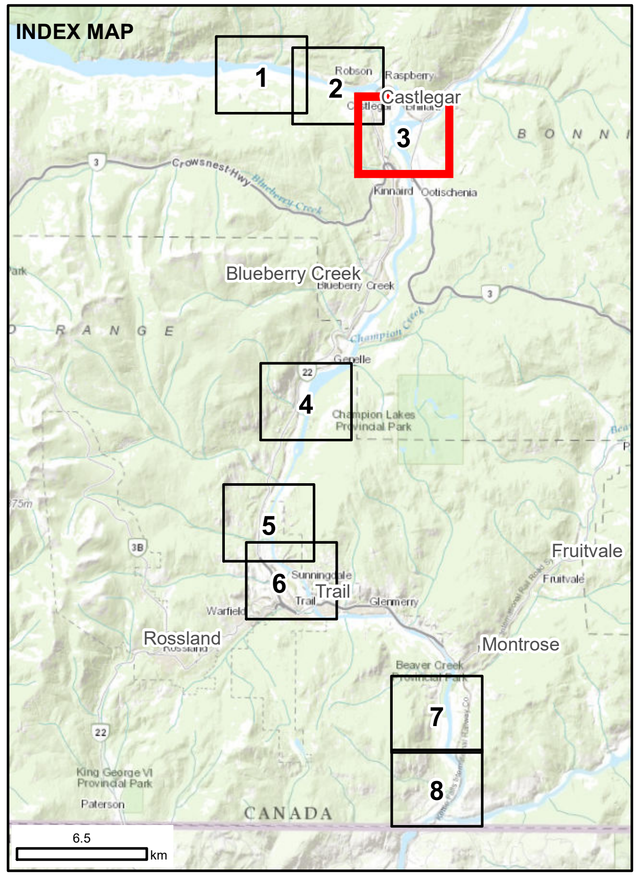

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FIGURE H1
3 OF 8

LEGEND

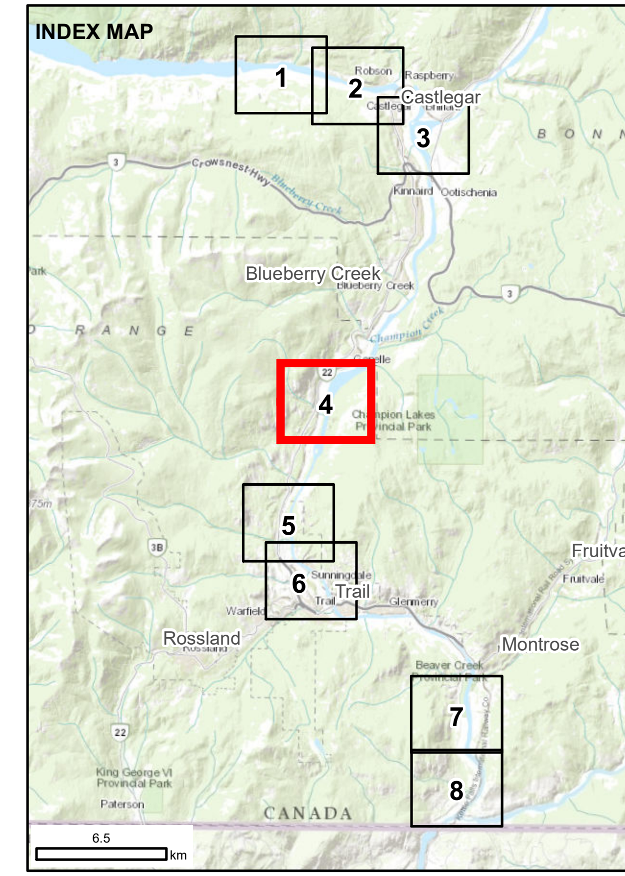
- PLACE NAME
- RIVER KILOMETRE POSTS
- RIVER CENTRELINE

MOUNTAIN WHITEFISH OBSERVATION

- ADULT (AGE - 2 AND OLDER)
- AGE - 1

BASE DATA

- HIGHWAY
- ROAD - LOCAL
- WATERCOURSE
- WATERBODY



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LEGEND

- PLACE NAME
- RIVER KILOMETRE POSTS
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MOUNTAIN WHITEFISH OBSERVATION

- ADULT (AGE - 2 AND OLDER)

BASE DATA

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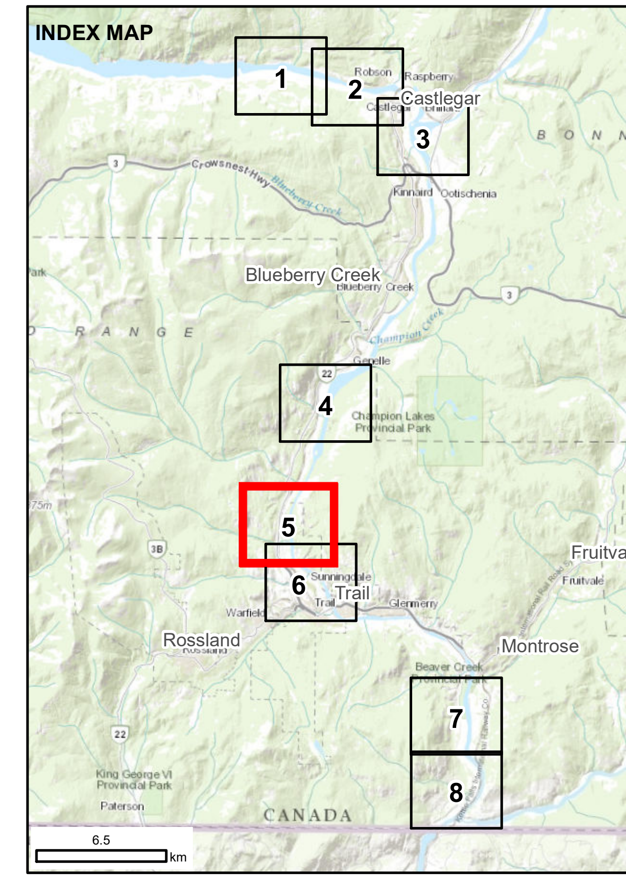
- ROAD - LOCAL
- WATERCOURSE
- WATERBODY



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MOUNTAIN WHITEFISH

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FIGURE H1
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LEGEND

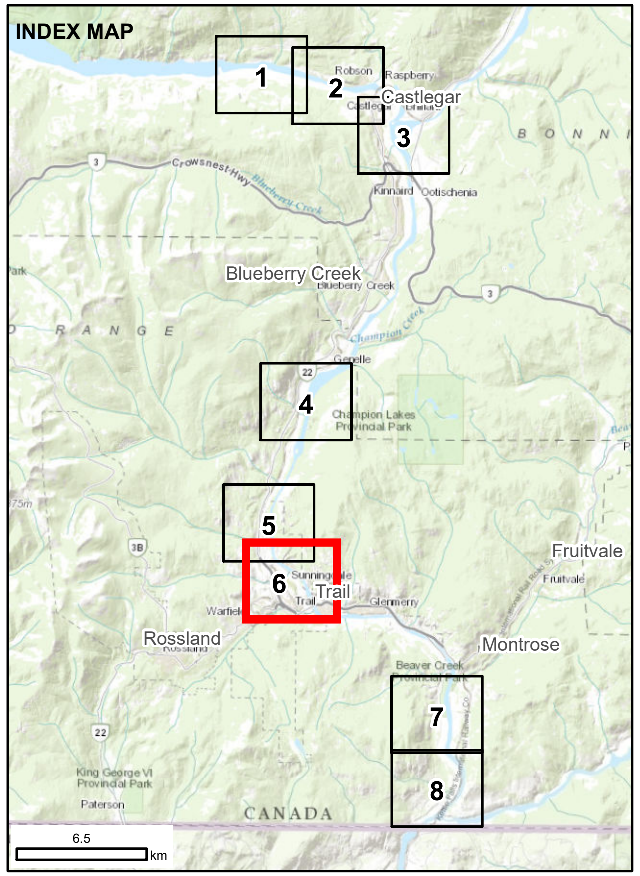
- PLACE NAME
- RIVER KILOMETRE POSTS
- RIVER CENTRELINE

MOUNTAIN WHITEFISH OBSERVATION

- ADULT (AGE - 2 AND OLDER)
- AGE - 1

BASE DATA

- HIGHWAY
- MAJOR ROAD
- ROAD - LOCAL
- WATERCOURSE
- WATERBODY



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LOWER COLUMBIA RIVER
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LEGEND

- PLACE NAME
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- RIVER CENTRELINE

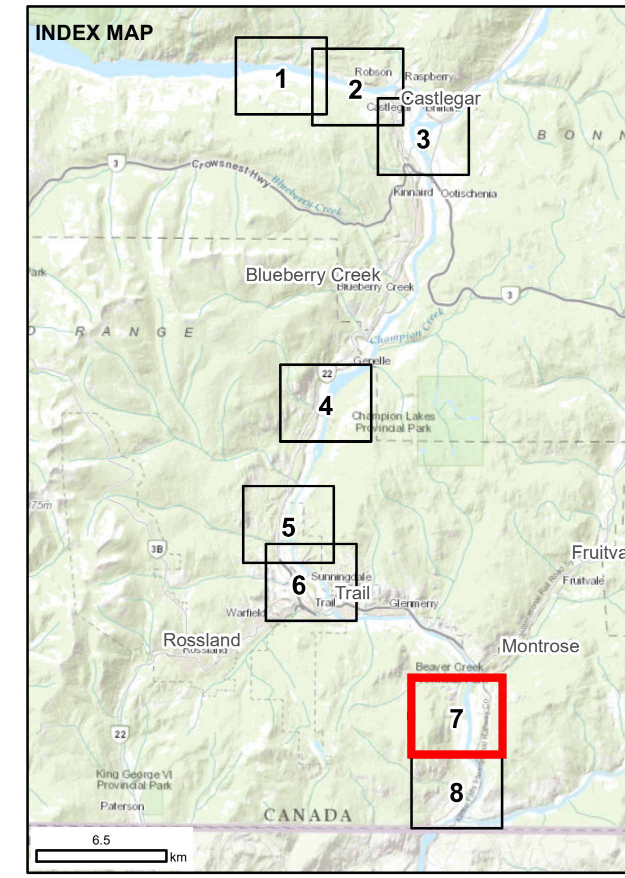
MOUNTAIN WHITEFISH OBSERVATION

- ADULT (AGE - 2 AND OLDER)
- AGE - 1

BASE DATA

- HIGHWAY
- ROAD - LOCAL
- WATERCOURSE
- WATERBODY

INDEX MAP



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DATUM: NAD83 PROJECTION: UTM ZONE 11

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SCALE 1:15,000 METRES

PROJECT

LOWER COLUMBIA RIVER
GEO-REFERENCED VISUAL ENUMERATION SURVEY 2021

TITLE

MOUNTAIN WHITEFISH

wsp

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LEGEND

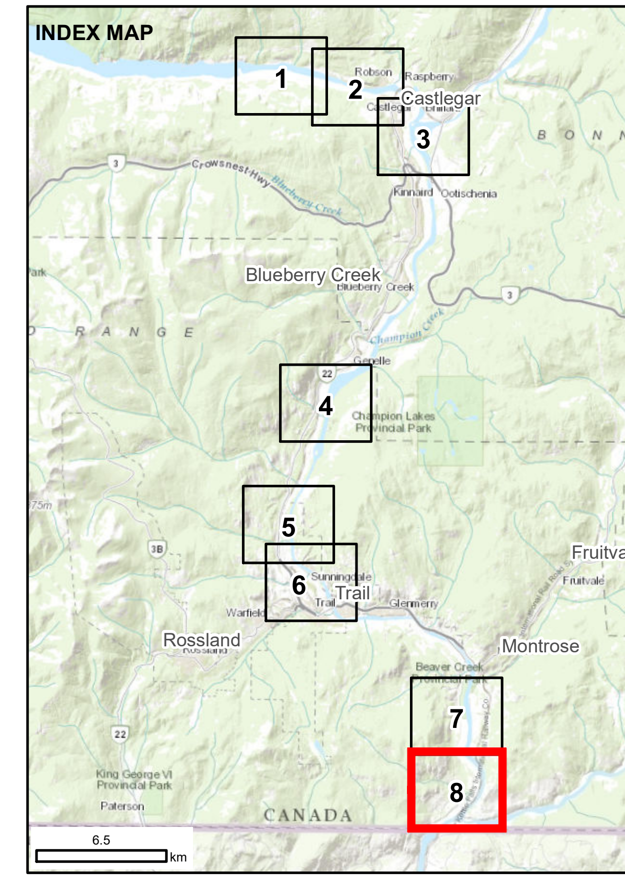
- PLACE NAME
- RIVER KILOMETRE POSTS
- RIVER CENTRELINE

MOUNTAIN WHITEFISH OBSERVATION

- ADULT (AGE - 2 AND OLDER)
- AGE - 1
- AGE - 0

BASE DATA

- HIGHWAY
- MAJOR ROAD
- ROAD - LOCAL
- WATERCOURSE
- WATERBODY



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DATUM: NAD83 PROJECTION: UTM ZONE 11

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SCALE 1:15,000 METRES

PROJECT

LOWER COLUMBIA RIVER
GEO-REFERENCED VISUAL ENUMERATION SURVEY 2021

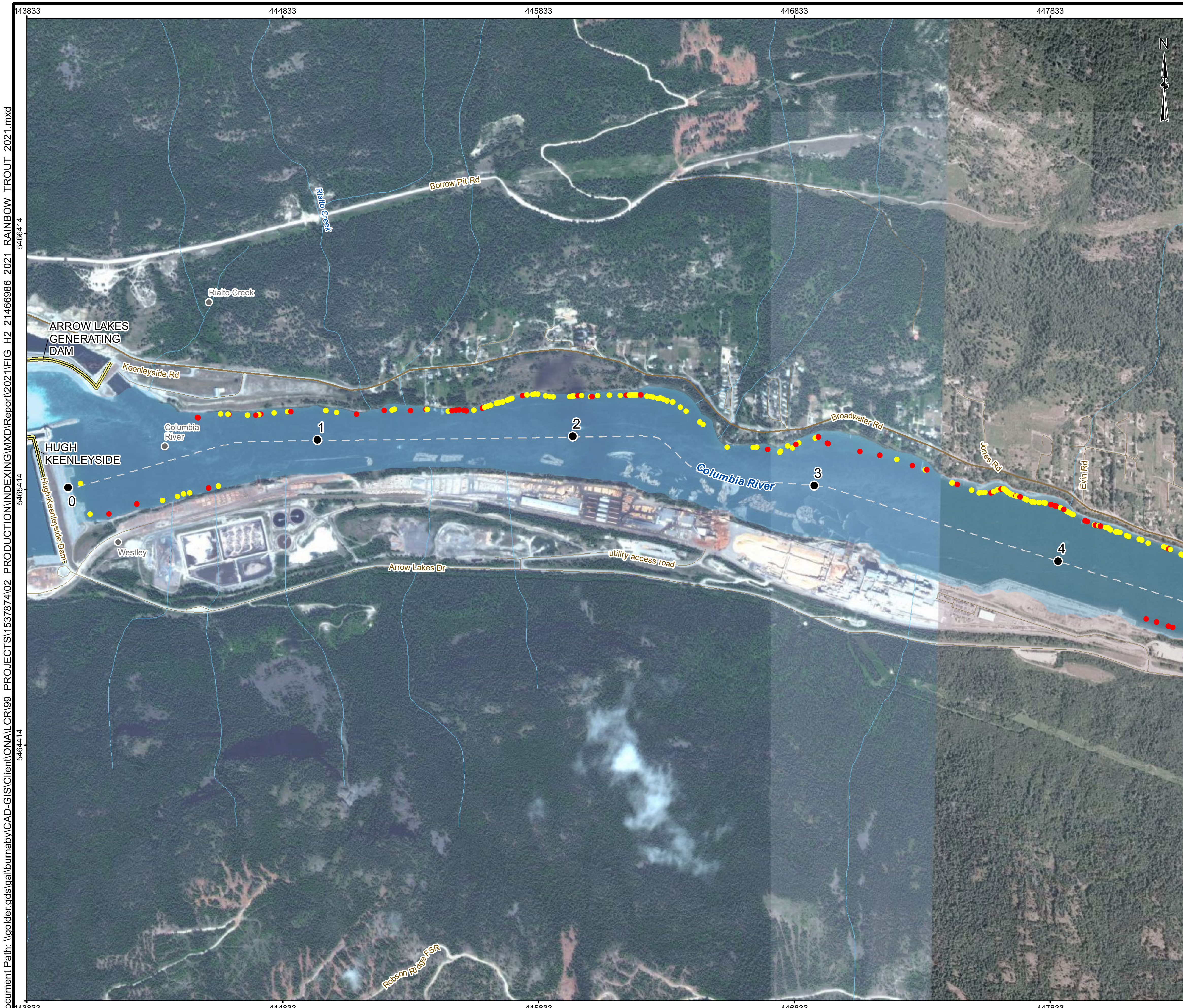
TITLE

MOUNTAIN WHITEFISH

PROJECT		21466986-2021	FILE No.
DESIGN	DR	2022-05-31	SCALE AS SHOWN REV. 0
GIS	JG	2022-05-31	FIGURE H1
CHECK	DR	2022-05-31	8 OF 8
REVIEW	SR	2022-05-31	

Document Path: \\golder.gds\gal\burnaby\CAD-GIS\Client\ONALCR\99_PROJECTS\1537874\02_PRODUCTION\INDEXING\MXD\Report\2021\FIG_H1_21466986_2021_MOUNTAIN_WHITEFISH_2021.mxd

Document Path: \\golder.gds\gal\burnaby\CAD-GIS\Client\ONALCR\99_PROJECTS\1537874\02_PRODUCTION\INDEXING\MXD\Report\2021\FIG_H2_21466986_2021_RAINBOW_TROUT_2021.mxd



LEGEND

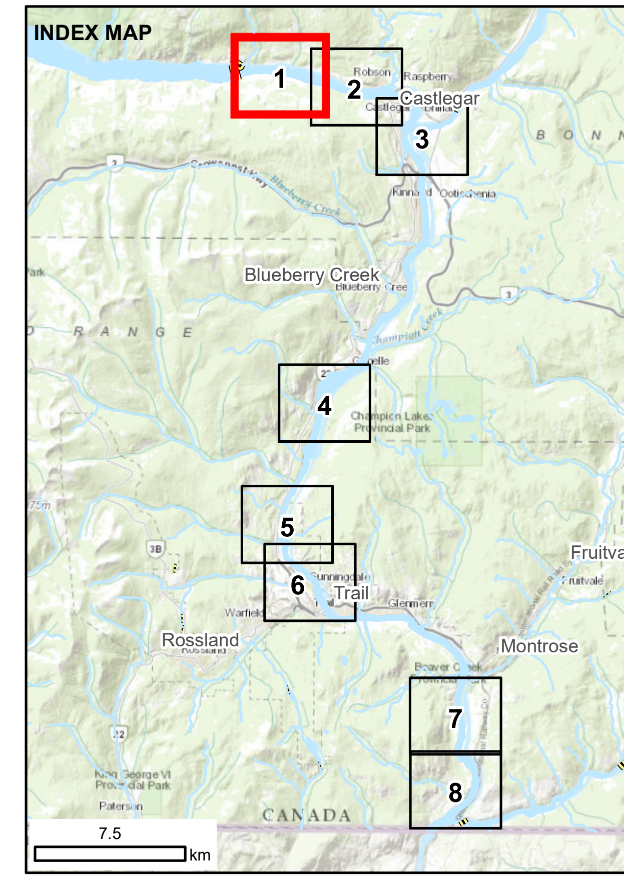
- PLACE NAME
- RIVER KILOMETRE POSTS
- RIVER CENTRELINE

RAINBOW TROUT OBSERVATION

- ADULT (AGE - 2 AND OLDER)
- AGE - 1
- AGE - 0

BASE DATA

- MAJOR ROAD
- ROAD - LOCAL
- DAM
- WATERCOURSE
- WATERBODY



REFERENCE

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DATUM: NAD83 PROJECTION: UTM ZONE 11

300 0 300

SCALE 1:15,000 METRES

PROJECT

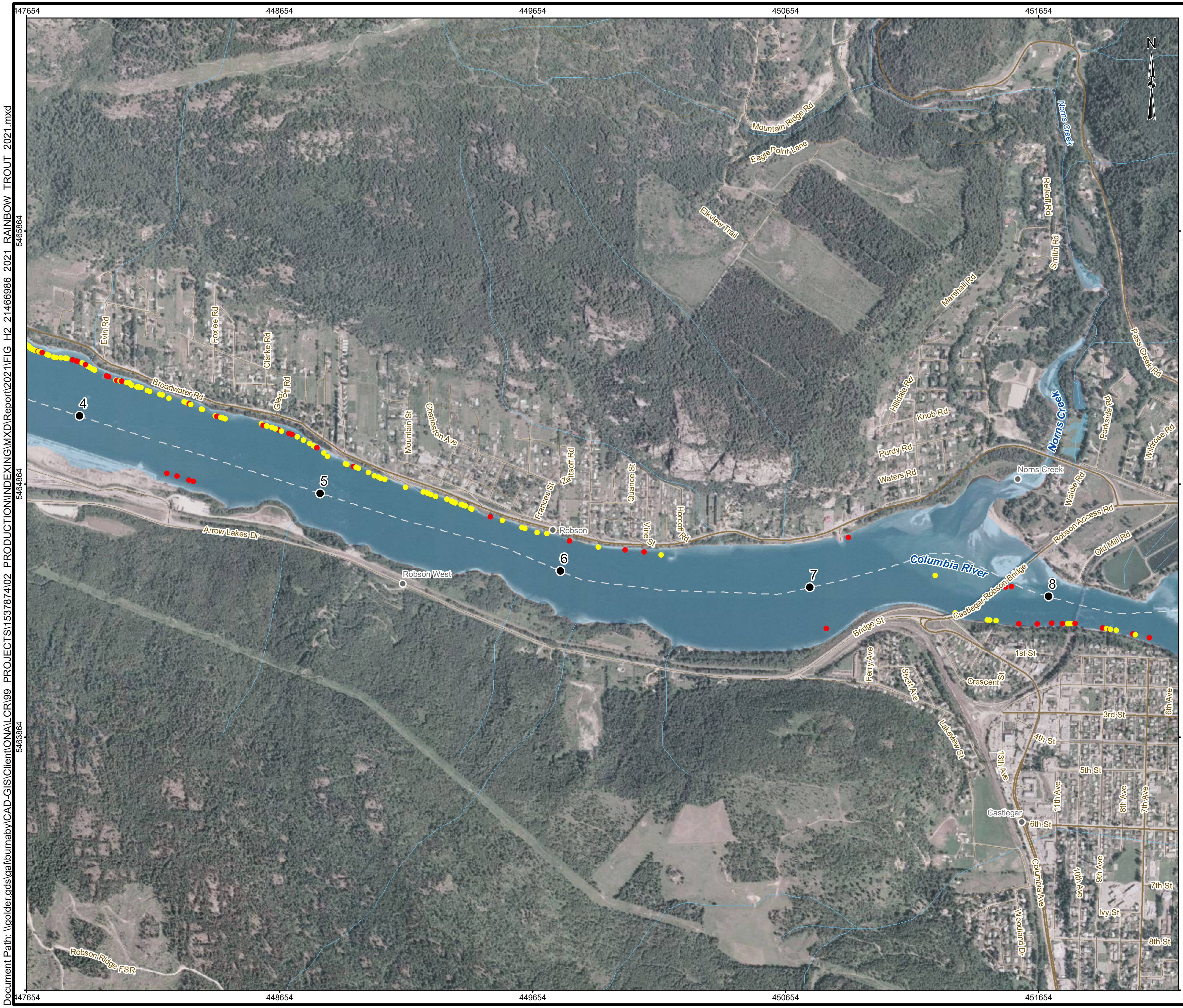
LOWER COLUMBIA RIVER
GEO-REFERENCED VISUAL ENUMERATION SURVEY 2021

TITLE

RAINBOW TROUT

wsp

PROJECT	21466986-2021		FILE No.	
DESIGN	DR	2022-05-31	SCALE AS SHOWN	REV. 0
GIS	JG	2022-05-31	FIGURE H2	
CHECK	DR	2022-05-31	1 OF 8	
REVIEW	SR	2022-05-31		



LEGEND

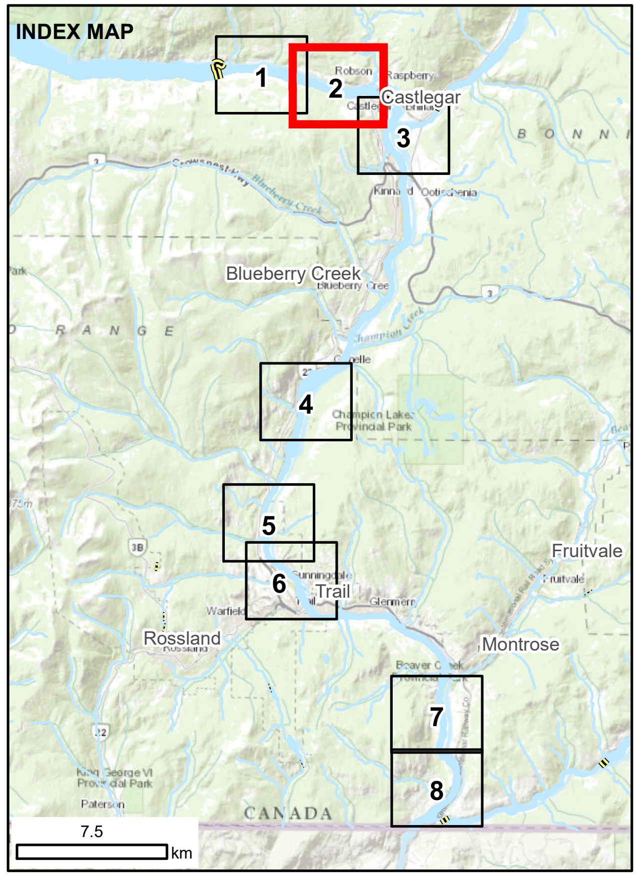
- PLACE NAME
- RIVER KILOMETRE POSTS
- RIVER CENTRELINE

RAINBOW TROUT OBSERVATION

- ADULT (AGE - 2 AND OLDER)
- AGE - 1
- AGE - 0

BASE DATA

- MAJOR ROAD
- ROAD - LOCAL
- WATERCOURSE
- WATERBODY



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DATUM: NAD83 PROJECTION: UTM ZONE 11

300 0 300

SCALE 1:15,000 METRES

PROJECT

LOWER COLUMBIA RIVER
GEO-REFERENCED VISUAL ENUMERATION SURVEY 2021

TITLE

RAINBOW TROUT

PROJECT		21466986-2021	FILE No.	
DESIGN	DR	2022-05-31	SCALE AS SHOWN	REV. 0
GIS	JG	2022-05-31	**FIGURE H2**	
CHECK	DR	2022-05-31	**2 OF 8**	
REVIEW	SR	2022-05-31		

Document Path: \\golder.gds\gal\burnaby\CAD-GIS\Client\ONAL\CR\99_PROJECTS\1537874\02_PRODUCTION\INDEXING\MXD\Report\2021\FIG_H2_21466986_2021_RAINBOW_TROUT_2021.mxd

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LEGEND

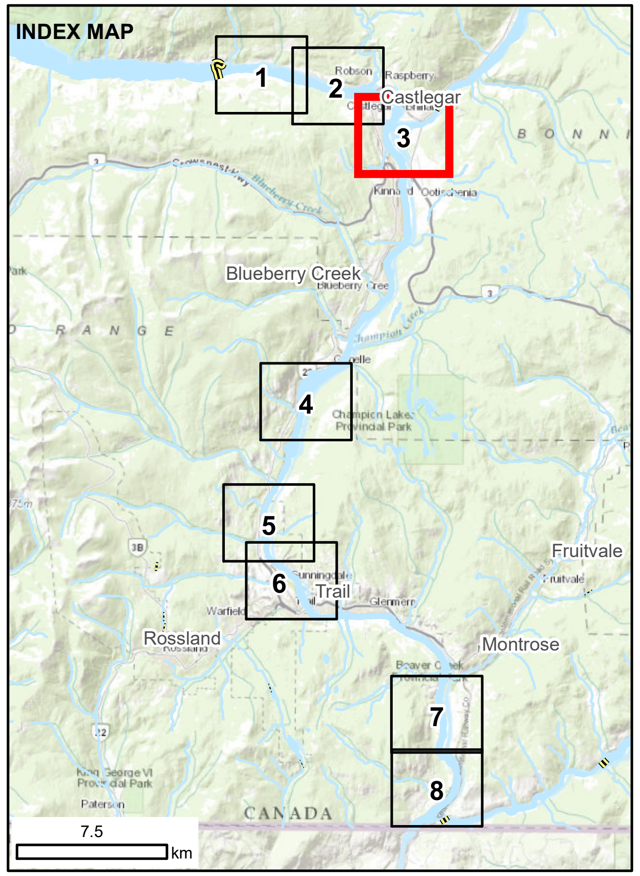
- PLACE NAME
- RIVER KILOMETRE POSTS
- RIVER CENTRELINE

RAINBOW TROUT OBSERVATION

- ADULT (AGE - 2 AND OLDER)
- AGE - 1
- AGE - 0

BASE DATA

- HIGHWAY
- MAJOR ROAD
- ROAD - LOCAL
- DAM
- WATERCOURSE
- WATERBODY



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DATUM: NAD83 PROJECTION: UTM ZONE 11

300 0 300

SCALE 1:15,000 METRES

PROJECT

LOWER COLUMBIA RIVER
GEO-REFERENCED VISUAL ENUMERATION SURVEY 2021

TITLE

RAINBOW TROUT

wsp

PROJECT		21466986-2021	FILE No.	
DESIGN	DR	2022-05-31	SCALE AS SHOWN	REV. 0
GIS	JG	2022-05-31	FIGURE H2 3 OF 8	
CHECK	DR	2022-05-31		
REVIEW	SR	2022-05-31		

LEGEND

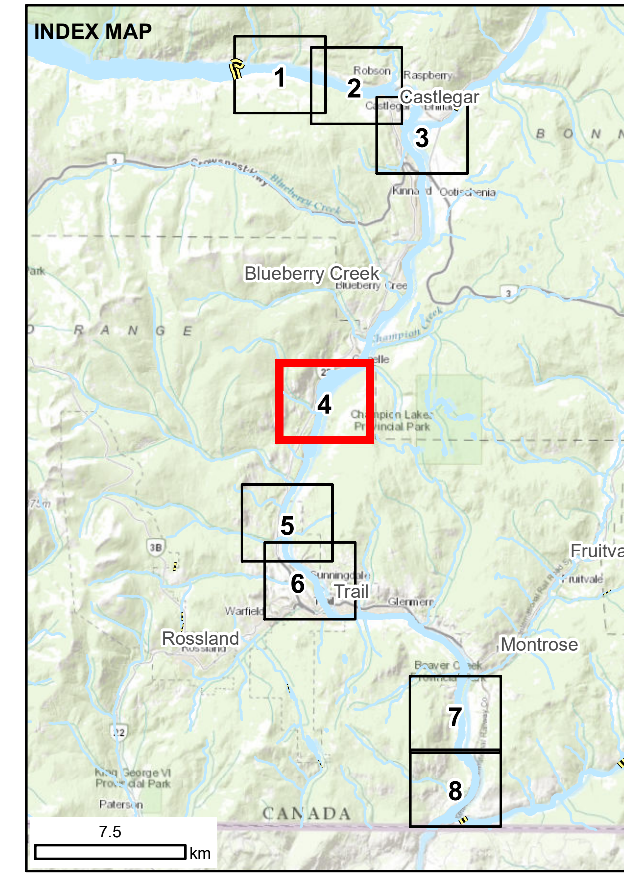
- PLACE NAME
- RIVER KILOMETRE POSTS
- RIVER CENTRELINE

RAINBOW TROUT OBSERVATION

- ADULT (AGE - 2 AND OLDER)
- AGE - 1
- AGE - 0

BASE DATA

- HIGHWAY
- ROAD - LOCAL
- WATERCOURSE
- WATERBODY



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DATUM: NAD83 PROJECTION: UTM ZONE 11

300 0 300

SCALE 1:15,000 METRES

PROJECT

LOWER COLUMBIA RIVER
GEO-REFERENCED VISUAL ENUMERATION SURVEY 2021

TITLE

RAINBOW TROUT

wsp

PROJECT	21466986-2021		FILE No.
DESIGN	DR	2022-05-31	SCALE AS SHOWN — REV. 0
GIS	JG	2022-05-31	**FIGURE H2**
CHECK	DR	2022-05-31	**4 OF 8**
REVIEW	SR	2022-05-31	

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LEGEND

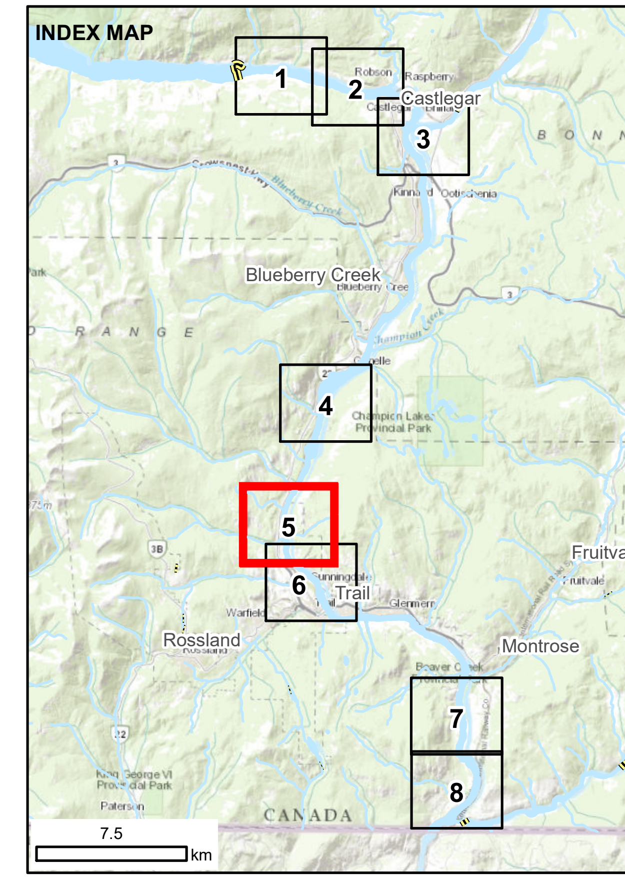
- PLACE NAME
- RIVER KILOMETRE POSTS
- RIVER CENTRELINE

RAINBOW TROUT OBSERVATION

- ADULT (AGE - 2 AND OLDER)
- AGE - 1
- AGE - 0

BASE DATA

- HIGHWAY
- ROAD - LOCAL
- WATERCOURSE
- WATERBODY



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DATUM: NAD83 PROJECTION: UTM ZONE 11

300 0 300

SCALE 1:15,000 METRES

PROJECT

LOWER COLUMBIA RIVER
GEO-REFERENCED VISUAL ENUMERATION SURVEY 2021

TITLE

RAINBOW TROUT

PROJECT	21466986-2021		FILE No.
DESIGN	DR	2022-05-31	SCALE AS SHOWN / REV. 0
GIS	JG	2022-05-31	FIGURE H2
CHECK	DR	2022-05-31	5 OF 8
REVIEW	SR	2022-05-31	

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LEGEND

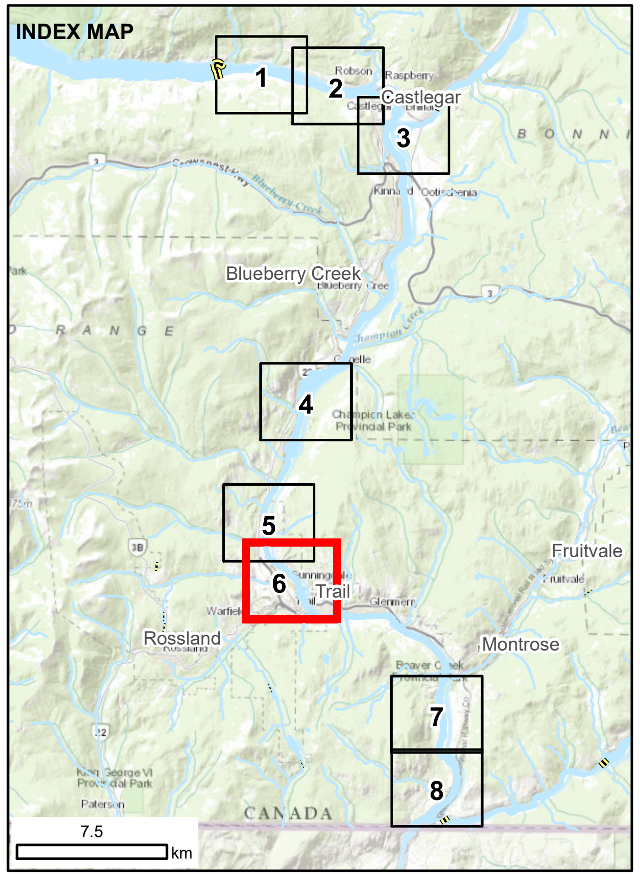
- PLACE NAME
- RIVER KILOMETRE POSTS
- RIVER CENTRELINE

RAINBOW TROUT OBSERVATION

- ADULT (AGE - 2 AND OLDER)
- AGE - 1
- AGE - 0

BASE DATA

- HIGHWAY
- MAJOR ROAD
- ROAD - LOCAL
- WATERCOURSE
- WATERBODY



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DATUM: NAD83 PROJECTION: UTM ZONE 11

300 0 300

SCALE 1:15,000 METRES

PROJECT

LOWER COLUMBIA RIVER
GEO-REFERENCED VISUAL ENUMERATION SURVEY 2021

TITLE

RAINBOW TROUT

wsp

PROJECT	21466986-2021		FILE No.	
DESIGN	DR	2022-05-31	SCALE AS SHOWN	REV. 0
GIS	JG	2022-05-31	**FIGURE H2**	
CHECK	DR	2022-05-31	**6 OF 8**	
REVIEW	SR	2022-05-31		

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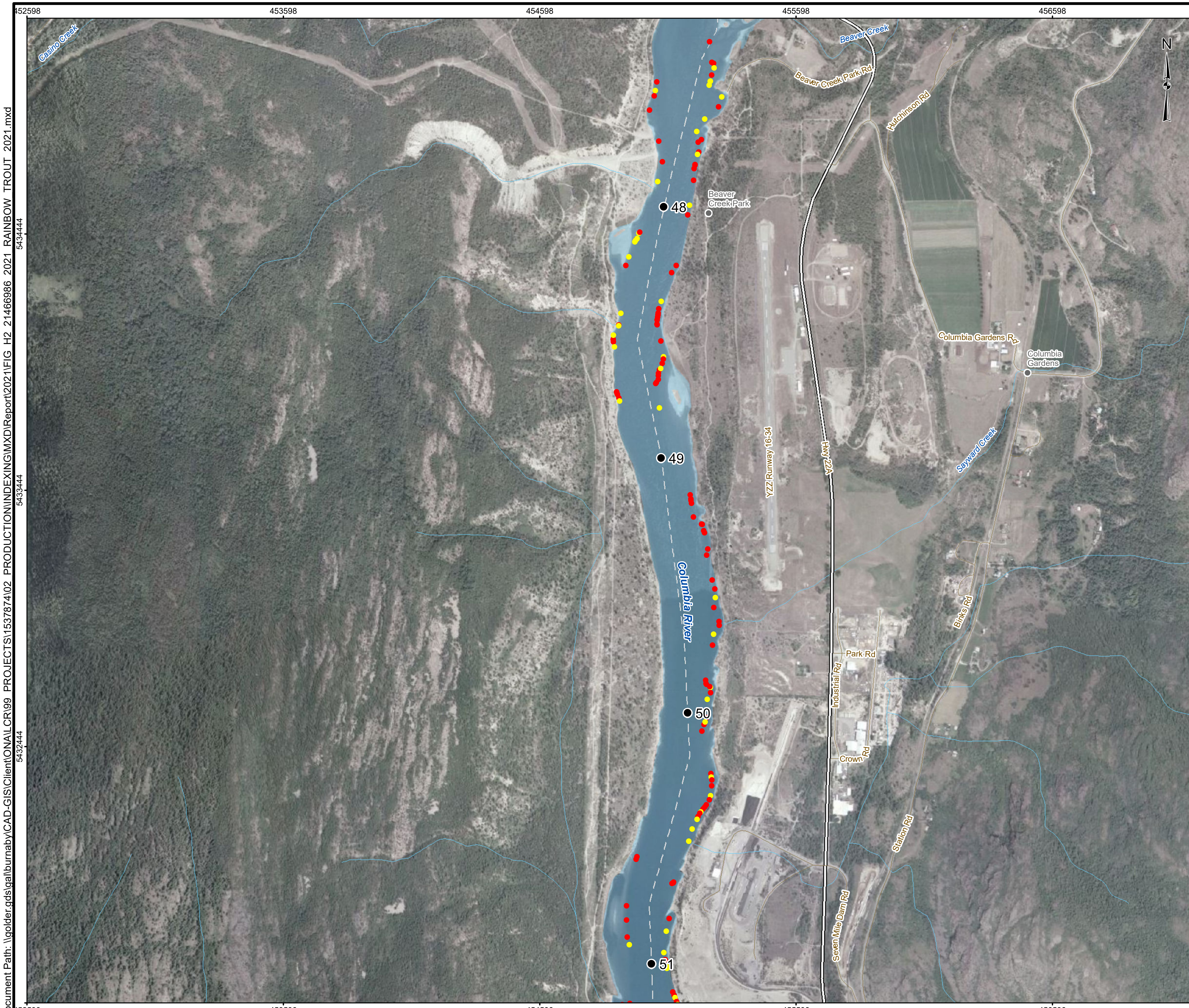


LEGEND

- PLACE NAME
- RIVER KILOMETRE POSTS
- RIVER CENTRELINE

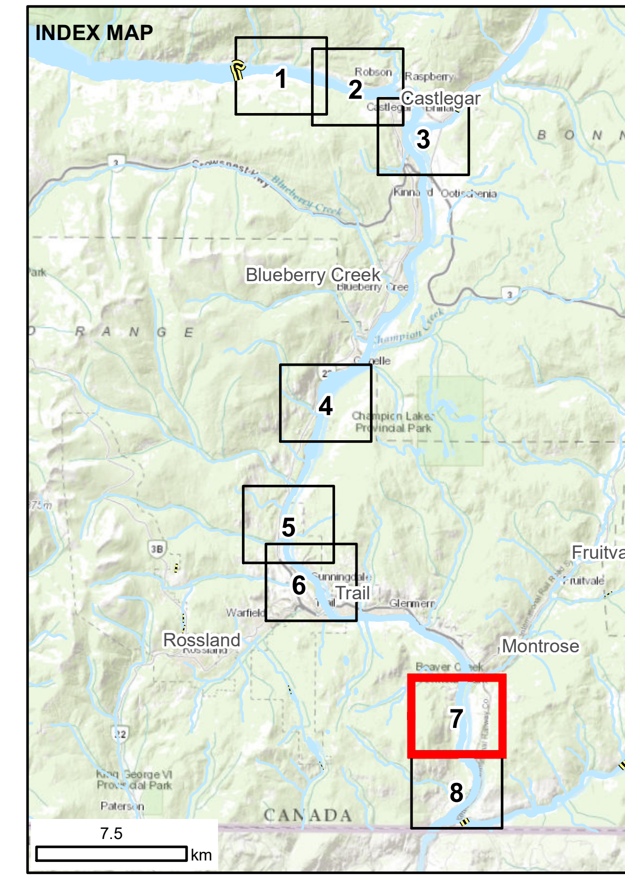
RAINBOW TROUT OBSERVATION

- ADULT (AGE - 2 AND OLDER)
- AGE - 1
- AGE - 0

BASE DATA

- HIGHWAY
- ROAD - LOCAL
- WATERCOURSE
- WATERBODY

INDEX MAP



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DATUM: NAD83 PROJECTION: UTM ZONE 11

300 0 300

SCALE 1:15,000 METRES

PROJECT

LOWER COLUMBIA RIVER
GEO-REFERENCED VISUAL ENUMERATION SURVEY 2021

TITLE

RAINBOW TROUT

wsp

PROJECT		21466986-2021	FILE No.	
DESIGN	DR	2022-05-31	SCALE AS SHOWN	REV. 0
GIS	JG	2022-05-31	FIGURE H2	
CHECK	DR	2022-05-31	7 OF 8	
REVIEW	SR	2022-05-31		

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LEGEND

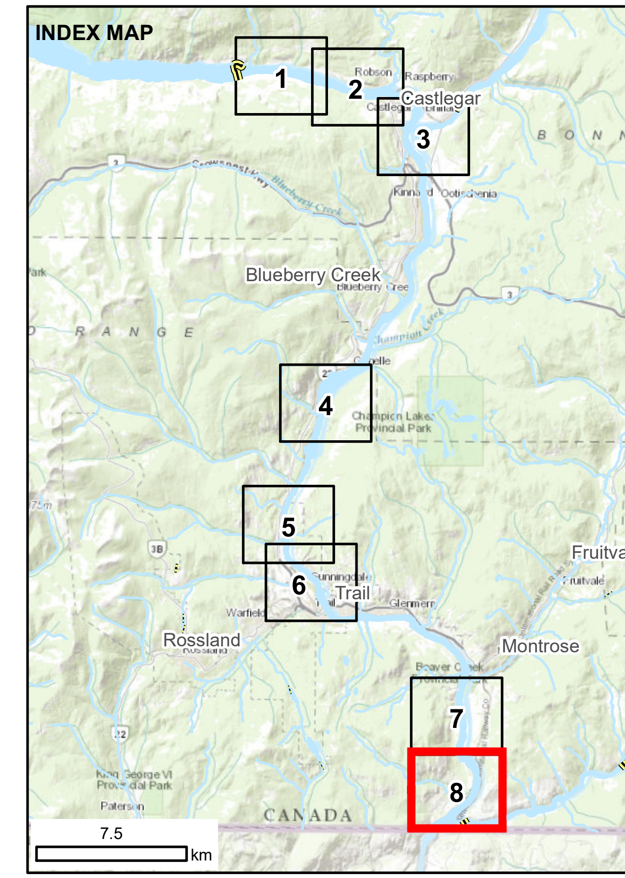
- PLACE NAME
- RIVER KILOMETRE POSTS
- RIVER CENTRELINE

RAINBOW TROUT OBSERVATION

- ADULT (AGE - 2 AND OLDER)
- AGE - 1
- AGE - 0

BASE DATA

- HIGHWAY
- MAJOR ROAD
- ROAD - LOCAL
- DAM
- WATERCOURSE
- WATERBODY



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DATUM: NAD83 PROJECTION: UTM ZONE 11

300 0 300

SCALE 1:15,000 METRES

PROJECT

LOWER COLUMBIA RIVER
GEO-REFERENCED VISUAL ENUMERATION SURVEY 2021

TITLE

RAINBOW TROUT

PROJECT	21466986-2021		FILE No.
DESIGN	DR	2022-05-31	SCALE AS SHOWN / REV. 0
GIS	JG	2022-05-31	FIGURE H2
CHECK	DR	2022-05-31	8 OF 8
REVIEW	SR	2022-05-31	

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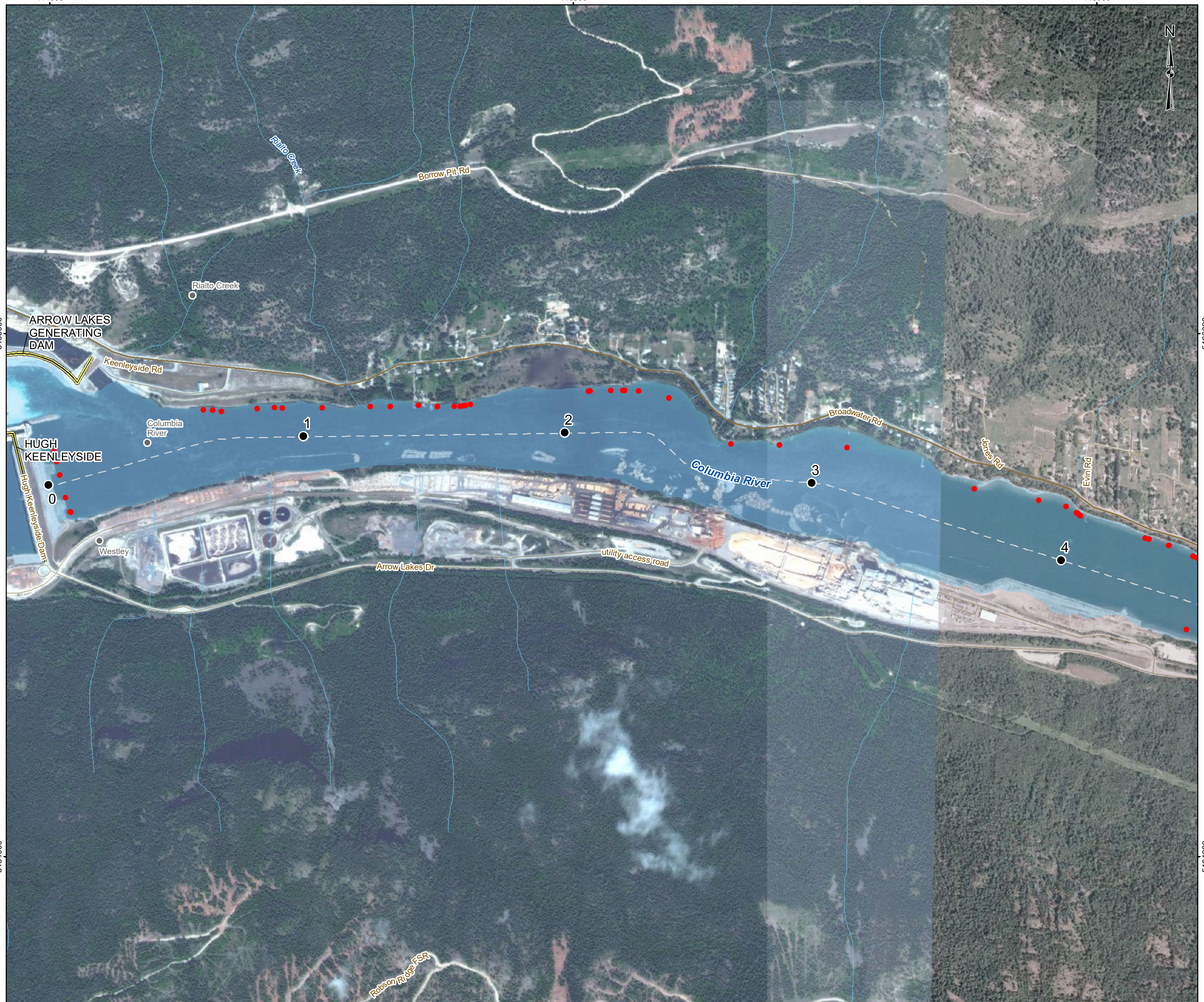


LEGEND

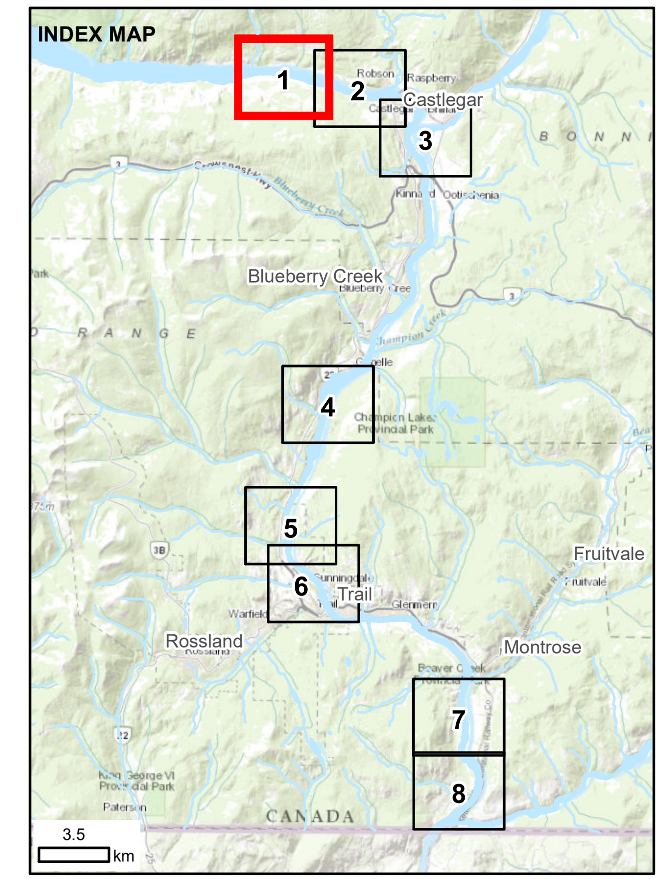
- PLACE NAME
- RIVER KILOMETRE POSTS
- RIVER CENTRELINE

WALLEYE OBSERVATION

- ADULT (AGE - 2 AND OLDER)
- AGE - 1
- AGE - 0

BASE DATA

- MAJOR ROAD
- ROAD - LOCAL
- DAM
- WATERCOURSE
- WATERBODY



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DATUM: NAD83 PROJECTION: UTM ZONE 11

300 0 300

SCALE 1:15,000 METRES

PROJECT

LOWER COLUMBIA RIVER
GEO-REFERENCED VISUAL ENUMERATION SURVEY 2021

TITLE

WALLEYE

PROJECT	21466986-2021		FILE No.
DESIGN	DR	2022-05-31	SCALE AS SHOWN / REV. 0
GIS	JG	2022-05-31	FIGURE H3
CHECK	DR	2022-05-31	1 OF 8
REVIEW	SR	2022-05-31	

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LEGEND

- PLACE NAME
- RIVER KILOMETRE POSTS
- RIVER CENTRELINE

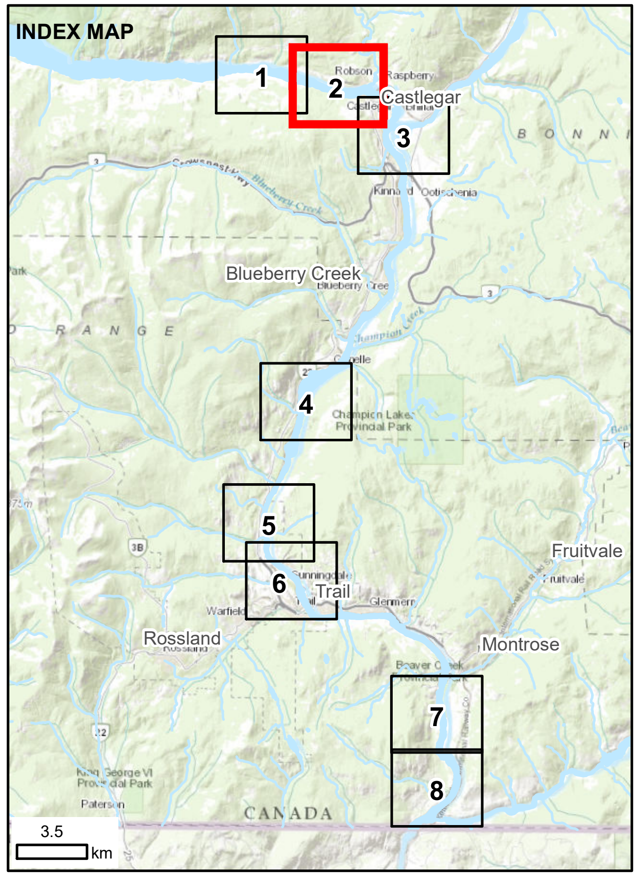
WALLEYE OBSERVATION

- ADULT (AGE - 2 AND OLDER)
- AGE - 1
- AGE - 0

BASE DATA

- MAJOR ROAD
- ROAD - LOCAL
- DAM
- WATERCOURSE
- WATERBODY

INDEX MAP



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DATUM: NAD83 PROJECTION: UTM ZONE 11

300 0 300

SCALE 1:15,000 METRES

PROJECT

LOWER COLUMBIA RIVER
GEO-REFERENCED VISUAL ENUMERATION SURVEY 2021

TITLE

WALLEYE

wsp

PROJECT	21466986-2021	FILE No.	
DESIGN	DR	2022-05-31	SCALE AS SHOWN / REV. 0
GIS	JG	2022-05-31	FIGURE H3 2 OF 8
CHECK	DR	2022-05-31	
REVIEW	SR	2022-05-31	

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LEGEND

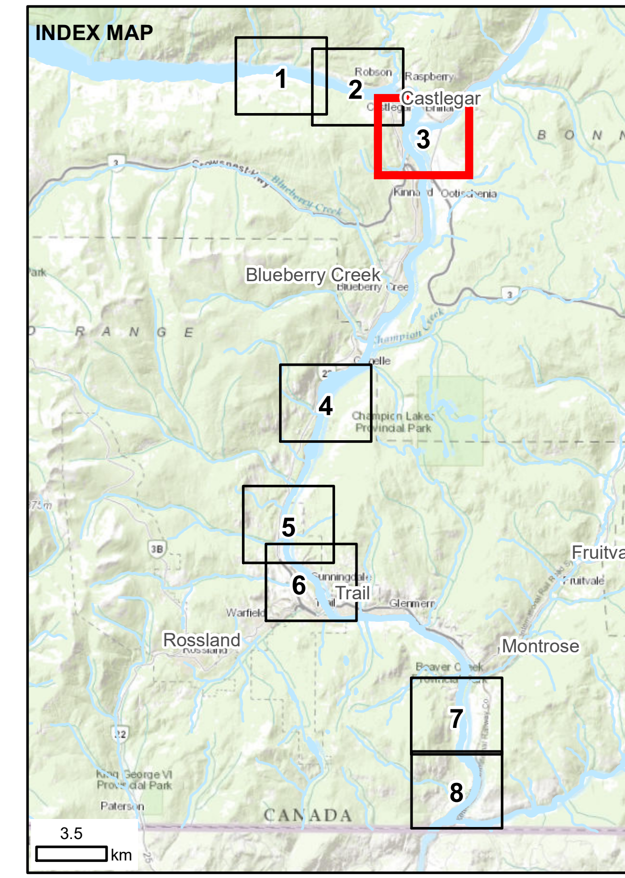
- PLACE NAME
- RIVER KILOMETRE POSTS
- RIVER CENTRELINE

WALLEYE OBSERVATION

- ADULT (AGE - 2 AND OLDER)
- AGE - 1
- AGE - 0

BASE DATA

- HIGHWAY
- MAJOR ROAD
- ROAD - LOCAL
- DAM
- WATERCOURSE
- WATERBODY



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DATUM: NAD83 PROJECTION: UTM ZONE 11

300 0 300

SCALE 1:15,000 METRES

PROJECT

LOWER COLUMBIA RIVER
GEO-REFERENCED VISUAL ENUMERATION SURVEY 2021

TITLE

WALLEYE

wsp

PROJECT	21466986-2021		FILE No.	
DESIGN	DR	2022-05-31	SCALE AS SHOWN	REV. 0
GIS	JG	2022-05-31	FIGURE H3	
CHECK	DR	2022-05-31	3 OF 8	
REVIEW	SR	2022-05-31		

Document Path: \\golder.gds\gal\burnaby\CAD-GIS\Client\ONALCR\99_PROJECTS\1537874\02_PRODUCTION\INDEXING\MXD\Report\2021\FIG_H3_21466986_2021_WALLEYE_2021.mxd

LEGEND

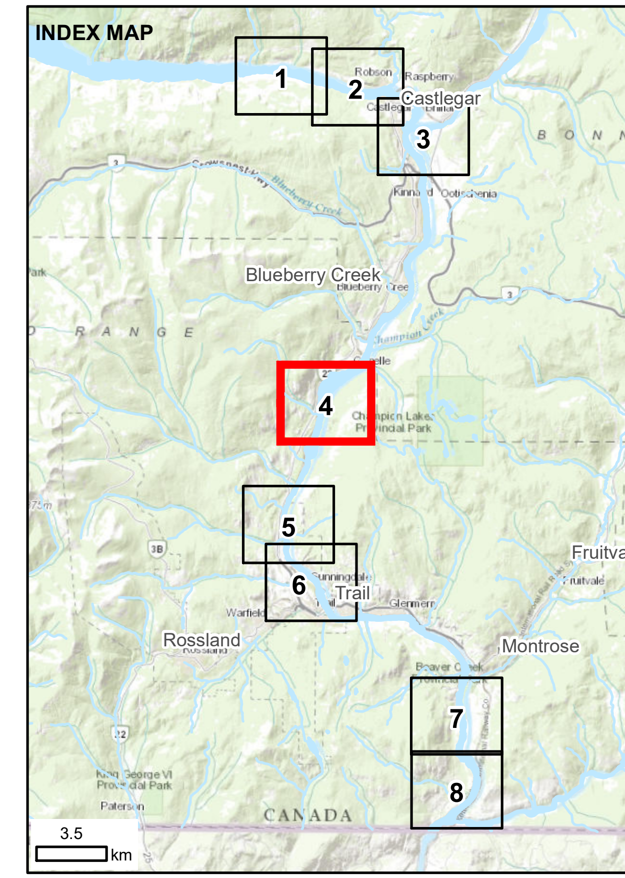
- PLACE NAME
- RIVER KILOMETRE POSTS
- RIVER CENTRELINE

WALLEYE OBSERVATION

- ADULT (AGE - 2 AND OLDER)
- AGE - 1
- AGE - 0

BASE DATA

- HIGHWAY
- ROAD - LOCAL
- DAM
- WATERCOURSE
- WATERBODY



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3. INDEX 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.

DATUM: NAD83 PROJECTION: UTM ZONE 11

300 0 300

SCALE 1:15,000 METRES

PROJECT

LOWER COLUMBIA RIVER
GEO-REFERENCED VISUAL ENUMERATION SURVEY 2021

TITLE

WALLEYE

PROJECT	21466986-2021	FILE No.	
DESIGN	DR	2022-05-31	SCALE AS SHOWN / REV. 0
GIS	JG	2022-05-31	FIGURE H3
CHECK	DR	2022-05-31	4 OF 8
REVIEW	SR	2022-05-31	

LEGEND

- PLACE NAME
- RIVER KILOMETRE POSTS
- RIVER CENTRELINE

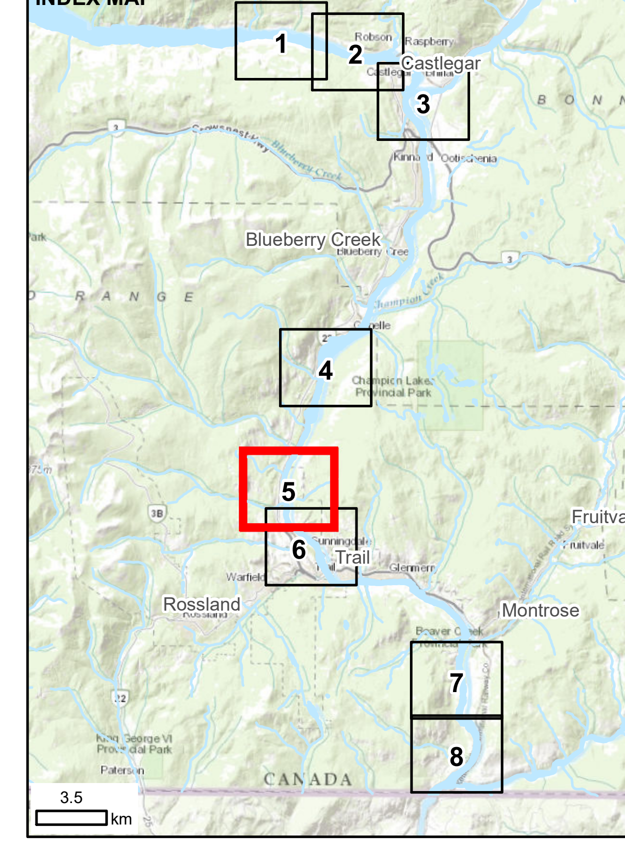
WALLEYE OBSERVATION

- ADULT (AGE - 2 AND OLDER)
- AGE - 1
- AGE - 0

BASE DATA

- HIGHWAY
- ROAD - LOCAL
- DAM
- WATERCOURSE
- WATERBODY

INDEX MAP



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DATUM: NAD83 PROJECTION: UTM ZONE 11

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SCALE 1:15,000 METRES

PROJECT

LOWER COLUMBIA RIVER
GEO-REFERENCED VISUAL ENUMERATION SURVEY 2021

TITLE

WALLEYE

wsp

PROJECT	21466986-2021		FILE No.	
DESIGN	DR	2022-05-31	SCALE AS SHOWN	REV. 0
GIS	JG	2022-05-31	**FIGURE H3**	
CHECK	DR	2022-05-31	**5 OF 8**	
REVIEW	SR	2022-05-31		

Document Path: \\golder.gds\gal\burnaby\CAD-GIS\Client\ONALCR\99_PROJECTS\1537874\02_PRODUCTION\INDEXING\MXD\Report\2021\FIG_H3_21466986_2021_WALLEYE_2021.mxd

LEGEND

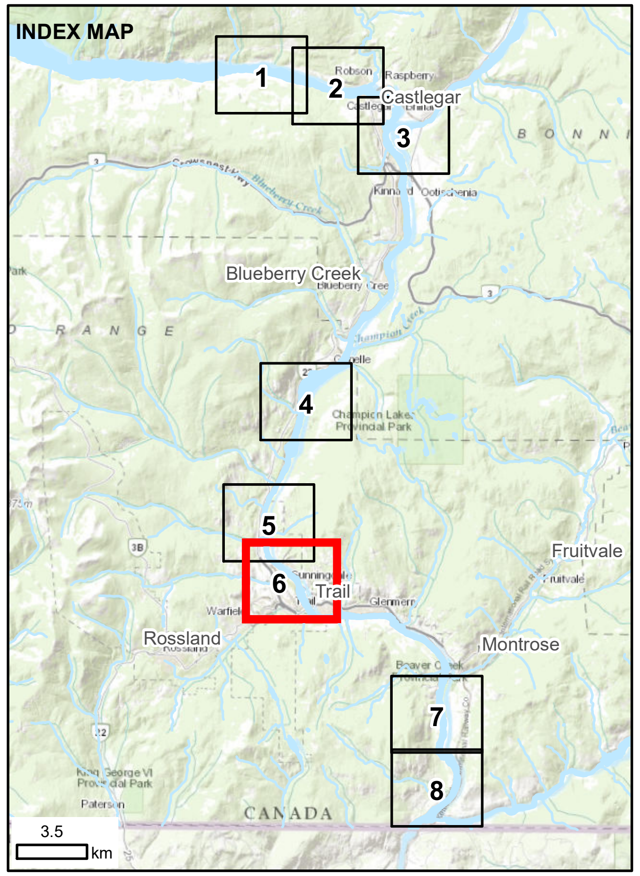
- PLACE NAME
- RIVER KILOMETRE POSTS
- RIVER CENTRELINE

WALLEYE OBSERVATION

- ADULT (AGE - 2 AND OLDER)
- AGE - 1
- AGE - 0

BASE DATA

- HIGHWAY
- MAJOR ROAD
- ROAD - LOCAL
- DAM
- WATERCOURSE
- WATERBODY



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PROJECT

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TITLE

WALLEYE

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GIS	JG	2022-05-31	FIGURE H3	
CHECK	DR	2022-05-31	6 OF 8	
REVIEW	SR	2022-05-31		

Document Path: \\golder.gds\gal\burnaby\CAD-GIS\Client\ONAL\CRI\99_PROJECTS\1537874\02_PRODUCTION\INDEXING\MXD\Report\2021\FIG_H3_21466986_2021_WALLEYE_2021.mxd

LEGEND

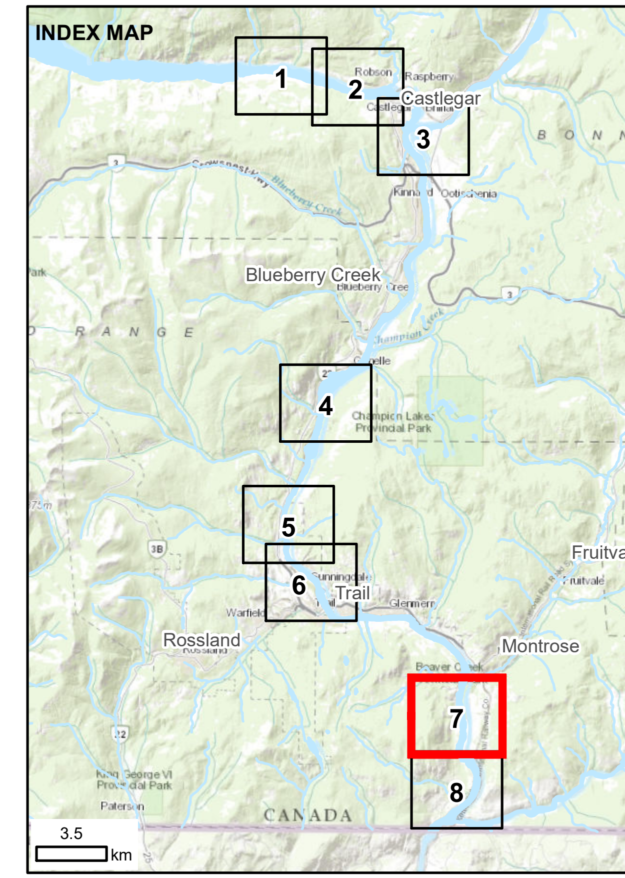
- PLACE NAME
- RIVER KILOMETRE POSTS
- RIVER CENTRELINE

WALLEYE OBSERVATION

- ADULT (AGE - 2 AND OLDER)
- AGE - 1
- AGE - 0

BASE DATA

- HIGHWAY
- ROAD - LOCAL
- DAM
- WATERCOURSE
- WATERBODY



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PROJECT

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GEO-REFERENCED VISUAL ENUMERATION SURVEY 2021

TITLE

WALLEYE

wsp

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GIS	JG	2022-05-31	FIGURE H3
CHECK	DR	2022-05-31	7 OF 8
REVIEW	SR	2022-05-31	

Document Path: \\golder.gds\gal\burnaby\CAD-GIS\Client\ONALCR\99_PROJECTS\1537874\02_PRODUCTION\INDEXING\MXD\Report\2021\FIG_H3_21466986_2021_WALLEYE_2021.mxd

LEGEND

- PLACE NAME
- RIVER KILOMETRE POSTS
- RIVER CENTRELINE

WALLEYE OBSERVATION

- ADULT (AGE - 2 AND OLDER)
- AGE - 1
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BASE DATA

- HIGHWAY
- MAJOR ROAD
- ROAD - LOCAL
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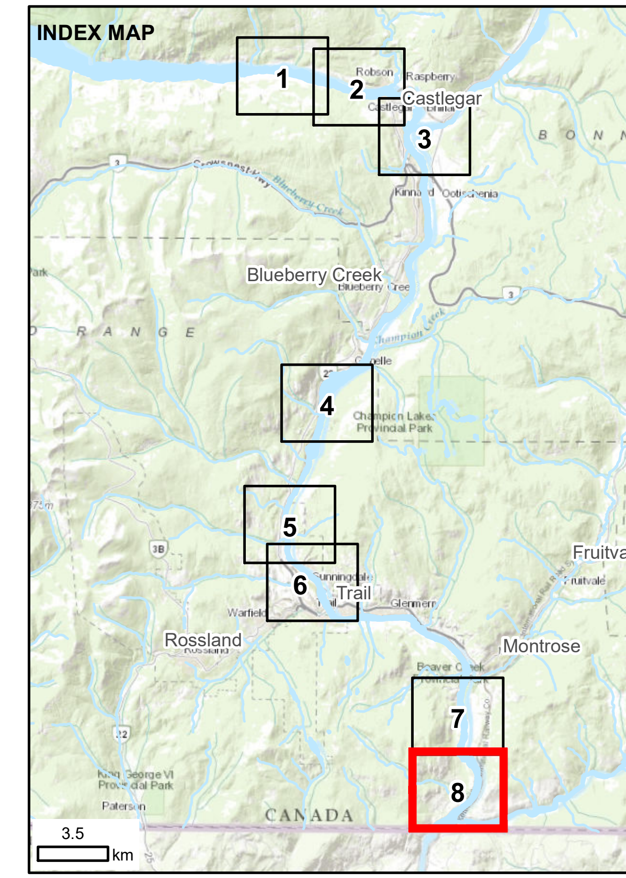

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REVIEW	SR	2022-05-31	

Document Path: \\golder.gds\gal\burnaby\CAD-GIS\Client\ONALCR\99_PROJECTS\1537874\02_PRODUCTION\INDEXING\MXD\Report\2021\FIG_H3_21466986_2021_WALLEYE_2021.mxd