Columbia River Project Water Use Plan

Lower Columbia River Fish Management Plan

Lower Columbia River Fish Stranding Assessment and Ramping Protocol

Implementation Year 16

Reference: CLBMON-42A

Annual Monitoring Summary (April 2022 to April 2023) and Water Use Plan Synthesis Report

Study Period: 2007 to 2023

WSP Canada Inc.
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Castlegar, BC

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REPORT

CLBMON-42: Lower Columbia River Fish Stranding Assessment and Ramping Protocol

Lower Columbia River and Kootenay River Fish Stranding Assessments: Annual Summary (April 2022 to April 2023) and Water Use Plan Synthesis Report

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Executive Summary

The Lower Columbia River Fish Stranding Assessment and Ramping Protocol (CLBMON-42) was implemented in 2007 as a component of BC Hydro's Water Use Plan for the Columbia River. Since the implementation of CLBMON-42, 16 years (2007/2008 to 2022/2023; study periods were 1 April to 1 April annually) of fish stranding assessments have been conducted in response to flow reductions from Hugh L. Keenleyside Dam/Arrow Lakes Generating Station (HLK/ALH) and Brilliant Dam and Brilliant Expansion Powerplant (BRD/X). This study adds to an additional seven years (2000 to 2006) of stranding assessments that were conducted after assessment procedures were standardized in 1999. These assessments were designed to collect fish stranding data to assess the impact of flow reductions and flow ramping rates (i.e., rate at which flow reductions occur) from Hugh L. Keenleyside Dam (HLK)[1] on the native fish species of the lower Columbia River. The objectives of this report are as follows: 1) summarize findings of fish stranding assessments during the 2022/2023 study year; and 2) conduct statistical analysis of the 23-year dataset of fish stranding assessments to address the monitoring program's management questions regarding operational and environmental factors that affect fish stranding.

The study area was the 56 km long portion of the lower Columbia River from HLK/ALH to the Canada/USA border and the lower 3 km of the Kootenay River from BRD/X to its confluence with the Columbia River. Once an operational flow reduction was planned, a fish stranding risk assessment was conducted following protocols established in *The Canadian Lower Columbia and Kootenay River: Fish Stranding Protocol* (Golder 2021a). The risk assessment was based on both current conditions (i.e., risk period, magnitude of flow reduction, resulting river stage, water temperature, and wetted history) as well as results of past stranding assessments stored in the Lower Columbia River Fish Stranding Database. The risk assessment included a query of the Lower Columbia River Fish Stranding Database to identify which sites out of 25 established stranding locations had the highest risk for fish stranding.

Fish stranding assessments occurred on the same day as an operational flow reduction from HLK/ALH or BRD/X. During each stranding assessment, a selection of 25 sites on the lower Columbia and Kootenay rivers was visited from high to low priority based on the ranking provided in the database query. In addition, sites were assessed from upstream to downstream following the stage recession. During each site assessment, the total number of new isolated pools or dewatered pools created as a result of the flow reduction was recorded. Pools were assessed for stranded fish using a method suitable to the size and depth of the pool, including backpack electrofishing, seine netting, or visual assessment. Fish were identified to species and life stage when possible, and the total number of live, dead, and salvaged fish from each site was recorded. All fish stranding assessment data, as well as discharge in the Columbia River, HLK/ALH, and BRD/X before and after the reduction were recorded for each reduction.

Results from the 2022/2023 study year indicated typical discharge in the Columbia and Kootenay rivers, and the number of stranding assessments, number of fish stranded, and species composition of stranded fish were similar to recent years.

[1] The CLBMON-42 monitoring program is specific to operations at HLK; however, this facility operates in association with Arrow Lakes Generating Station (ALH) and will be referred to as the combined operation of HLK/ALH. The management questions of the program will be presented as written in the CLBMON-42 Terms of Reference (BC Hydro 2007a).

During the 14 fish stranding assessments conducted during the 2022/2023 study year (1 April 2022 to 1 April 2023), a total of 6,856 fish were recorded as stranded, of which 56% were successfully salvaged and returned to the mainstem of the Columbia or Kootenay rivers, 35% were observed during salvage efforts but avoided capture, and 9% were mortalities. Of all stranded fish, 97% were young-of-year (YOY) or juvenile age class. Sportfish accounted for 45% of all stranded fish and included Mountain Whitefish, Rainbow Trout, and Kokanee. Non-sportfish accounted for 55% of stranded fish with Sucker spp. and Longnose Dace being the most abundant.

In the statistical analysis of the 23 years of fish stranding data, there was no evidence of an effect of ramping rate on the probability of stranding or the number of fish stranded. This suggests no difference in fish stranding risk within the range of operational ramping rates (1 to 5 kcfs/hr) currently used at HLK/ALH.

Although not in direct operational control, the length of time that habitat was inundated prior to a flow reduction, known as the wetted history, had a positive relationship with stranding probability and the number of fish stranded. The predicted mean number of fish stranded per site increased from 20 fish at 1 day of wetted history to 59 fish at 100 days, and 86 fish at 220 days. These results suggest that fish density in the near-shore area may increase with increased wetted history. This environmental variable should continue to be considered when planning fish assessments or salvage responses.

Physical habitat recontouring was conducted at six fish stranding sites on the lower Columbia between 2001 and 2014 to reduce the likelihood of fish stranding. Model predictions based on 23 years of data indicated a 12% reduction in the probability of stranding one or more fish, and a 69% reduction in the mean number of fish stranded, on average, after recontouring was conducted. This indicates that recontouring is an effective method to reduce the total number of fish stranded.

The effect of time of day (day versus night) and the implementation of a conditioning flow on fish stranding risk could not be determined during this study; however, previous studies from the lower Columbia River indicate that these likely do not have a strong effect on fish stranding.

These analyses improve understanding of factors that affect fish stranding in the lower Columbia River and support the fish stranding protocols currently being used.

Table ES1: Status of the management questions of CLBMON-42

Objective	Management Questions	Summary of Key Results
To assess the impact of flow reductions and flow ramping rates from HLK on the native species of the lower Columbia River.	MQ1: Is there a ramping rate (fast vs. slow, day vs. night) for flow reductions from HLK that reduces the number of fishes stranded (interstitially and pool) per flow reduction event in the summer and winter?	A statistical analysis conducted on the 23-year dataset of fish stranding assessments indicated little or no evidence of an effect of ramping rate within the range of operational ramping rates currently used at HLK/ALH on fish stranding in the lower Columbia River. Flow ramping studies conducted prior to CLBMON-42 also found no effect of ramping rate (Golder 2007; Irvine et al. 2009). Previous analysis indicated that time of day was not a strong predictor of fish stranding risk; however, few ramping experiments were conducted at night, and no stranding assessments were conducted at night. There is insufficient data to determine whether time of day is a significant predictor of the probability of fish stranding. Additional night-time ramping experiments, or night-time reduction events and stranding assessments would be required to balance the dataset and determine if there is any difference in the probability of fish stranding between day and night.
	MQ2: Does wetted history (length of time the habitat has been wetted prior to the flow reduction) influence the number of fishes stranded (interstitially and pool) per flow reduction event for flow reductions from HLK?	In a statistical analysis conducted on the 23-year dataset of fish stranding assessments in the lower Columbia and Kootenay Rivers, wetted history had a statistically significant positive effect on both the probability of stranding and the number of fish stranded. Modelling indicated that the predicted number of fish stranded increased from 20 fish at 1 day of wetted history to 59 fish at 100 days of wetted history. These findings were consistent with previous analyses conducted on lower Columbia and Kootenay River fish stranding assessment data (Golder 2020a; Golder and Poisson 2010; Irvine et al. 2014). This supports the idea that substrate that has been inundated for a longer period is more likely to strand fish if dewatered, compared to substrate that is inundated for a shorter period. Given these findings, wetted history is a key variable to consider when initiating a fish stranding assessment or a fish salvage in response to an operation flow reduction.
	MQ3: Can a conditioning flow (temporary, one step, flow reduction of approximately 2 hours to the final target dam discharge that occurs prior to the final flow change) from HLK reduce the stranding rate of fishes?	Experimental flow ramping studies conducted in the summers and winters of 2004, 2005 and 2006 (prior to CLBMON-42) indicated that the use of a conditioning flow reduction may reduce the incidence of pool stranding on the Columbia River; however, this relationship was not statistically significant, and the analysis was based on limited results and further conditioning flow experiments were recommended (Golder 2007; Irvine et al. 2009). Conditioning flow experiments have not been conducted under CLBMON-42. Uncertainty remains regarding the efficacy of a conditioning flow reducing the probability of stranding. Given the low number of experiments conducted, a definitive answer regarding whether a conditioning flow can reduce stranding rates cannot be determined.
	MQ4: Can physical habitat works (i.e., recontouring) reduce the incidence of fish stranding in high risk areas?	Six fish stranding sites on the lower Columbia River have been recontoured since 2000; one of which (Genelle Mainland [RUB]) underwent recontouring twice (first in 2003 and second in 2021). To assess the effectiveness of recontouring, a statistical analysis was conducted on the 23-year dataset of fish stranding assessments to model the probability of stranding and the number of fish stranded before vs. after recontouring. Results indicate a significant reduction in both the probability and the number of fish stranded after recontouring compared to before recontouring. These results agree with previous analyses (Golder 2020a; Golder and Poisson 2010; Irvine et al. 2014) and suggest that recontouring sites that pose a high stranding risk to fish is an effective mitigation strategy to reduce stranding risk.
	MQ5: Does the continued collection of stranding data, and upgrading of the lower Columbia River stranding protocol, limit the number of occurrences when stranding crews need to be deployed due to flow reductions from HLK?	Since the implementation of CLBMON-42 in 2007, the total number of HLK/ALH reduction events generally increased; however, the number of stranding assessments in response to HLK/ALH reductions was relatively constant over the same period, ranging from 8 to 15 assessments (median = 13 assessments, average = 12 assessments). While there has not been an observed decrease in the number of annual stranding assessments conducted in response to reduction events from HLK/ALH, a decrease in the response rate (i.e., the percent of yearly reduction events that are responded to with a stranding assessment) has been observed. Fish stranding risk is better understood due to updates to the stranding protocol (Golder 2021a) and the development of a predictive model of fish stranding risk (Dalgarno and Thorley 2023), both of which are used to determine fish stranding response, and guide fish stranding assessment effort to the highest risk locations.

Acronyms

ALH – Arrow Lakes Generating Station

BC ENV – BC Ministry of Environment and Climate Change

BRD/X – Brilliant Dam and Brilliant Expansion Powerplant

CDC – BC Conservation Data Center

CLBMON-42 – Lower Columbia River Fish Stranding Assessment and Ramping Protocol

COFAC – Columbia Operations Fish Advisory Committee

COSEWIC – Committee on the Status of Endangered Wildlife in Canada

CPC – Columbia Power Corporation

DFO – Fisheries and Oceans Canada

HLK – Hugh L. Keenleyside Dam

HLK/ALH – Hugh L. Keenleyside Dam and Arrow Lakes Generating Station

kcfs – thousands of cubic feet per second

LUB – Left upstream bank

MID – Mid-stream island

NRS – BC Hydro Natural Resource Specialist

QA/QC – Quality assurance and quality control

RUB – Right upstream bank

WUP – Water Use Plan

YOY – Young-of-year

ZIGLMM – zero-inflated generalized linear mixed model

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Note: Organizations and roles are presented for each individual at the time they contributed to the CLBMON-42. Organizations and roles for individuals may have changed over the duration of CLBMON-42.

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1.0 INTRODUCTION

1.1 Background

Fish stranding has been broadly recognized as a factor contributing to fish mortality. Fish can become stranded when water levels recede within the varial zone (the zone subject to seasonal inundation) of riverine habitats. When this occurs, fish can become stranded in habitats that are disconnected from the main channel (pool stranding) or become stranded between substrate particles in dewatered habitat (interstitial stranding).

Hydroelectric facilities have direct influences on water levels and can affect fish stranding downstream of their operations. The lower Columbia River water levels downstream of Hugh L. Keenleyside Dam and Arrow Lakes Generating Station (HLK/ALH) and the lower Kootenay River downstream of Brilliant Dam and Brilliant Expansion Powerplant (BRD/X) are influenced by the operations of these facilities.

Fish stranding was raised as an environmental issue associated with Hugh L. Keenleyside Dam (HLK) operations by regulatory agencies in the mid-1990’s, at which time, environmental monitoring began. Since the mid-1990’s, fish stranding assessments and flow ramping studies (Golder 2005, 2006, 2007) have been conducted, dam operations have been reviewed, flow smoothing (i.e., reductions in the magnitude and frequency of reductions) has occurred, and habitat recontouring of high risk fish stranding sites has been conducted. Over this same period, fish stranding assessment methods have been improved, standardized, and adapted to include Kootenay River operations (BRD/X).

The Lower Columbia River Fish Stranding Assessment and Ramping Protocol (CLBMON-42) monitoring program was implemented in 2007 as part of BC Hydro’s Water Use Plan (WUP) for the Columbia River (BC Hydro 2007). The primary objective of CLBMON-42 was to continue the collection of fish stranding data to assess the impact of flow reductions and flow ramping rates from HLK [2] on the native fish species of the lower Columbia River.

The approach to the monitoring program included three components:

- The continued collection of fish stranding data due to flow reduction events that occurred due to HLK/ALH (CLBMON-42[A]), and the subsequent establishment of a lower Columbia River stranding protocol;
- Conduct flow ramping studies designed to determine the effect of different flow reduction strategies on the stranding rates of fish; and
- Conduct physical habitat works in the form of gravel bar recontouring at locations where high rates of fish stranding occurs.

[2] The CLBMON-42 monitoring program is specific to operations at HLK; however, this facility operates in association with Arrow Lakes Generating Station (ALH) and will be referred to as the combined operation of HLK/ALH. The management questions of the program are presented as written in the CLBMON-42 Terms of Reference (BC Hydro 2007).

The monitoring program identified five management questions (BC Hydro 2007) which are as follows:

1) Is there a ramping rate (fast vs. slow, day vs. night) for flow reductions from HLK that reduces the number of fish stranded (interstitially and pool) per flow reduction event in the summer and winter?

2) Does wetted history (the length of time the habitat has been wetted prior to the flow reduction) influence the number of fish stranded (interstitially and pool) per flow reduction event for flow reductions from HLK?

3) Can a conditioning flow (a temporary, one step, flow reduction of approximately 2 hours to the final target dam discharge that occurs prior to the final flow change) from HLK reduce the stranding rate of fish?

4) Can physical habitat works (i.e., re-contouring) reduce the incidence of fish stranding in high risk areas?

5) Does the continued collection of stranding data, and upgrading of the lower Columbia River stranding protocol, limit the number of occurrences when stranding crews need to be deployed due to flow reductions from HLK?

Since the implementation of CLBMON-42 there have been 16 years (2007/2008 to 2022/2023; study period of 1 April to 1 April annually) of annual fish stranding assessments conducted on the lower Columbia and Kootenay rivers due to flow reduction events from HLK/ALH and BRD/X. This data adds to 7 years (2000 to 2006) of fish stranding assessments that have been conducted in response to flow reduction events from HLK/ALH and BRD[3] after stranding assessment methods were standardized in 1999. Collectively, there is a 23-year dataset to assess the impact of flow reductions and flow ramping rates.

Additional components that have been undertaken as part of CLBMON-42 include the following:

- In 2010, a literature review, and data analysis was conducted on fish stranding assessment data collected between 1999 and 2009 from the lower Columbia and Kootenay rivers (Golder and Poisson 2010) to identify variables influencing fish stranding during flow reductions and to provide recommendations on best management practices to minimize fish stranding on the lower Columbia River.

- In 2011, the results of Golder and Poisson (2010) were used to develop a stranding protocol entitled, *The Canadian Lower Columbia River: Risk Assessment and Response Strategy* (Golder 2011). This document fulfilled the need identified by the Columbia Operations Fisheries Advisory Committee (COFAC), Fisheries and Oceans Canada (DFO), BC Ministry of Environment and Climate Change (BC ENV) and the Comptroller of Water Rights for a comprehensive process and protocol to address the risks of fish stranding associated with flow reductions from hydroelectric facilities on the lower Columbia and Kootenay rivers. The protocol established the roles and responsibilities pertaining to flow reductions for owners and operators of hydroelectric facilities on the lower Columbia and Kootenay rivers and outlined the protocols for conducting fish stranding assessments.

[3] Construction of the Brilliant Dam Expansion Generating Station (BRDX) was completed in 2007. Prior to 2007 stranding assessments were conducted in response to flow reductions from BRD.

- In 2020, an analysis was conducted on a 20-year dataset (7 years [2000 to 2006] prior to CLBMON-42 and 13 years [2007/2008 to 2019/2020] during CLBMON-42) of fish stranding assessments conducted on the Lower Columbia and Kootenay rivers in response to flow reductions from HLK/ALH and BRD/X operations to address CLBMON-42's management questions (Golder 2020a).
- In 2021, the results of Golder (2020a), and a subsequent analysis to evaluate cut-off variables for high versus low stranding risk were incorporated into a draft update to the stranding protocol (Golder 2021a).
- In 2023, an analysis of the fish stranding assessment data was conducted to develop a predictive model of fish stranding risk (Dalgarno and Thorley 2023).
- Physical habitat recontouring was conducted at high risk stranding sites to reduce fish stranding in the following years:
  - 2021 – Recontouring occurred at Genelle Mainland (LUB). This site was previously recontoured in 2003.
  - 2015 – Recontouring occurred at Lions Head (RUB).
  - Fall 2012 / spring 2013 – recontouring occurred at Fort Shepherd Launch (RUB) by Columbia Power Corporation (CPC) as a component of CPC Owner's Commitment #39 (CPC 2011).
  - 2002 – Recontouring occurred at Norns Creek Fan (RUB)
  - 2001 – Recontouring occurred at Millennium Park (LUB) and Genelle Lower Cobble Island (MID)

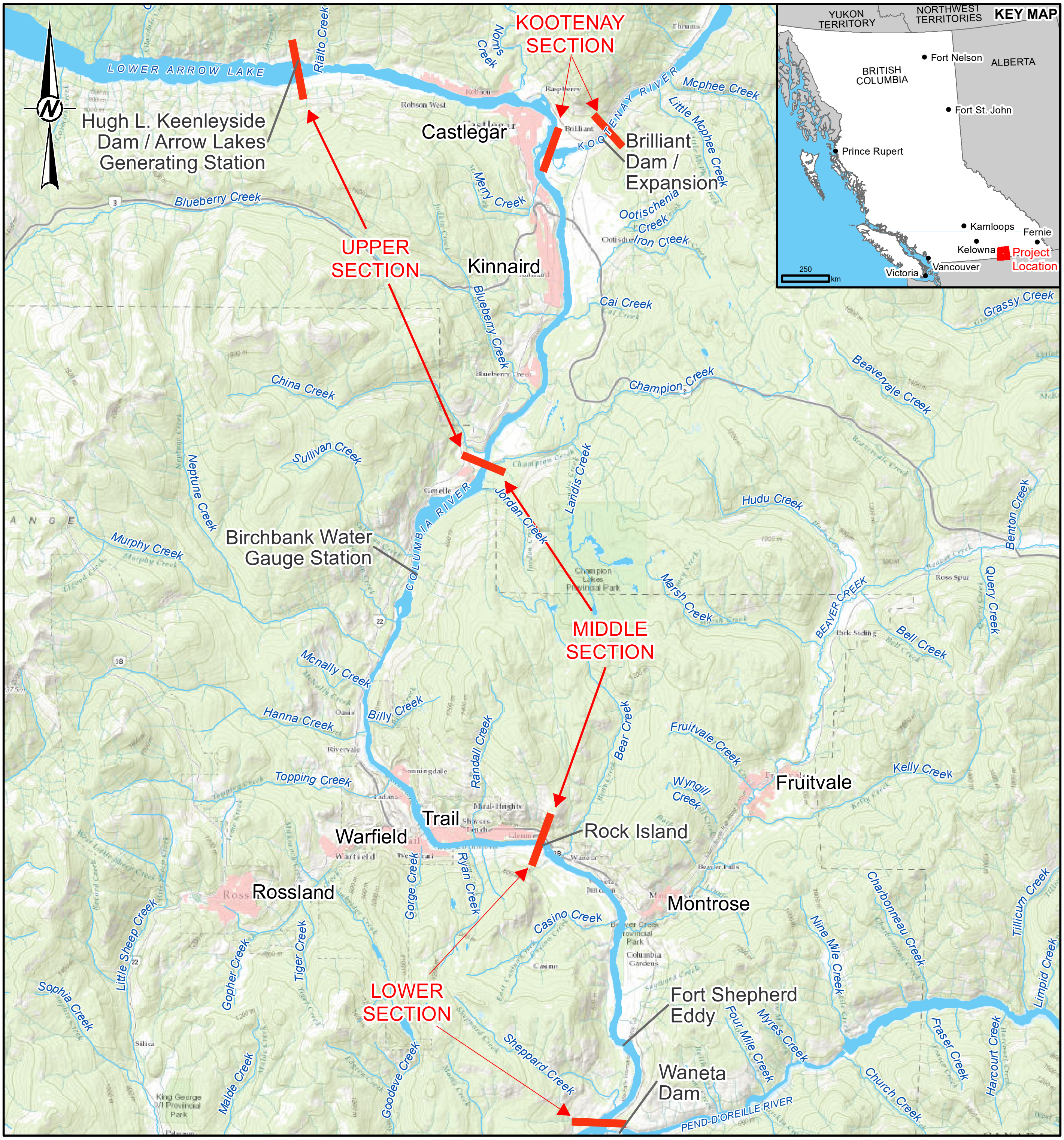
Although flow ramping studies were identified as a key component of the monitoring program, experimental flow ramping studies were not conducted as part of CLBMON-42. Flow ramping studies on the lower Columbia and Kootenay rivers downstream of HLK/ALH and BRD/X were conducted prior to CLBMON-42 in the summers and winters of 2004, 2005, and 2006 (Golder 2005, 2006, 2007; Irvine et al. 2009). In 2008, a power analysis was conducted on the existing ramping experiment data and presented to COFAC to provide an indication of how many more ramping experiments would be required to get an acceptable level of statistical power of 0.8 (Peterman 1990) for the experimental variables of conditioning reduction, ramping rate, and time of day (Irvine 2008). To determine if these variables had a statistically significant effect on fish stranding, the effect size from the altered operations would have to be greater than 50% and many more experiments would be required. In response to these findings, COFAC members determined it was the best use of resources to analyse the stranding assessment data to see what factors may influence fish stranding before proceeding with further ramping experiments.

1.2 Scope and Objectives

The present report summarizes the findings of Year 16 (1 April 2022 to 1 April 2023) of the lower Columbia River and Kootenay River Fish Stranding Assessments (CLBMON-42[A]) conducted in response to operational flow reductions at HLK/ALH and BRD/X. In addition, this report provides a statistical analysis of the 23-year dataset of fish stranding assessments conducted on the lower Columbia and Kootenay rivers due to flow reductions from HLK/ALH and BRD/X to address the management questions of the monitoring program.

1.3 Study Area

The study area encompassed the approximately 56 km long section of the lower Columbia River from HLK/ALH to the Canada/USA border and included the lower Kootenay River (approximately 2.8 km) from BRD/X to the Columbia River confluence (Figure 1). The Columbia River study area is further delineated into the upper section (which includes the 25 km of river between HLK/ALH and Genelle), middle section (which includes the 18 km between Genelle and Rock Island downstream of Trail), and lower section (which includes the 13 km between Rock Island downstream of Trail to the Canada/USA border). Stranding assessments were conducted at pre-determined stranding sites (Appendix A) on the lower Columbia and Kootenay rivers.



LEGEND

- WATERCOURSE
- WATERBODY
- RESIDENTIAL AREA

0 5 10

1:200,000 KILOMETERS

REFERENCES

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CLIENT
BC HYDRO

PROJECT
LOWER COLUMBIA RIVER (CLBMON#42[A]) AND KOOTENAY RIVER FISH STRANDING ASSESSMENTS

TITLE
STUDY AREA OVERVIEW

CONSULTANT

YYYY-MM-DD	2024-01-26
DESIGNED	KL
PREPARED	JG
REVIEWED	KL
APPROVED	DF

PROJECT NO.	PHASE	REV.	FIGURE
21508219	2022.5	0	1

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2.0 METHODS

As part of the CLBMON-42 program, *The Canadian Lower Columbia River: Risk Assessment and Response Strategy* (Golder 2011) was developed with the primary objective to mitigate the effects of flow reductions from HLK/ALH and BRD/X on native fish species through flow reduction planning. This document outlines the roles and responsibilities pertaining to flow reductions for owners and operators of hydroelectric facilities on the lower Columbia and Kootenay rivers. In addition, it outlines the standardized protocols for conducting fish stranding risk assessments, and field-based fish stranding assessments. In 2021, this protocol was updated based on the findings of Golder (2020a) and was re-titled *The Canadian Lower Columbia and Kootenay River: Fish Stranding Protocol* (Golder 2021a). This document currently exists as a living document which continues to be updated based on results of fish stranding assessments and input from the Columbia Operations Fish Advisory Committee (COFAC) members. During the present study period, the protocols described in *The Canadian Lower Columbia and Kootenay River: Fish Stranding Protocol* (Golder 2021a) were followed and are summarized below.
In addition, a predictive model of fish stranding risk was developed in 2023 using historical data from previous stranding assessments in the lower Columbia and Kootenay rivers (Dalgarno and Thorley 2023). This model was also used by BC Hydro as source of information when assessing risk and planning assessments, in addition to the approach summarized below in Section 2.1.

2.1 Fish Stranding Risk Assessment

When an operational flow reduction from HLK/ALH or BRD/X was proposed, a BC Hydro local Natural Resource Specialist (NRS) conducted a fish stranding risk assessment with input from the WSP (formerly Golder Associates Ltd.) Stranding Assessment Supervisor to determine the appropriate response (i.e., whether to conduct a field-based fish stranding assessment or not). The fish stranding risk assessment process is illustrated in Figure 2 and described below.

The first step in the risk assessment process was to review three variables which are known to affect the severity of fish stranding in the lower Columbia and Kootenay rivers.

- **Variable 1. Reduction Timing:**

  Fish stranding risk (i.e., the probability of stranding) differs based on the time of year when flow reductions occur (Golder 2020a). A year is divided into two fish stranding risk periods; the High Risk period occurs from 1 June to 30 September and the Low Risk period occurs between 1 October and 30 May (Golder 2021a).

- **Variable 2. River Stage:**

  The river stage is defined as the water level in the Columbia River. The discharge at the Water Survey of Canada's Birchbank hydrometric station (Station Number 08NE049; Birchbank) is used as an indicator of river stage for the Lower Columbia and Kootenay rivers. The Birchbank station is located downstream of HLK/ALH and BRD/X facilities and therefore reflects adjustments in flow from all operations. During the risk assessment process, the current discharge at Birchbank and the expected discharge at Birchbank after a proposed flow reduction (i.e., resultant discharge) are considered. If the resultant Birchbank discharge is equal to or below 60 kcfs (thousands of cubic feet per second), then fish stranding risk is greater than if the resulting Birchbank discharge is above 60 kcfs (Golder 2021a).

- **Variable 3. Wetted History:**

  The wetted history is defined as the number of days that habitat is inundated with water before dewatering. Substrate that is inundated for a longer period is more likely to strand fish when dewatered, compared to substrate that has been inundated for a shorter period (Golder 2020a). A statistical analysis conducted to determine an appropriate High Risk versus Low Risk cut-off determined that a wetted history of less than 30 days was considered Low Risk for stranding and a wetted history of greater than or equal to 30 days was considered High Risk for stranding (Golder 2021a).

Once the above variables were defined, the next step in the risk assessment process was to conduct a query of the Lower Columbia River Fish Stranding Database (the database), which stores data from previous fish stranding assessments conducted on the lower Columbia and Kootenay rivers. The database query requires the user to provide the following inputs:

- The current discharge at Birchbank (in kcfs);
- The expected resultant discharge at Birchbank after the proposed flow reduction (in kcfs);
- The current water temperature at Birchbank (in Celsius);
- The date of the proposed reduction; and
- The facility responsible for the proposed reduction (HLK/ALH, BRD/X, or a combined reduction from both facilities).

The database query output provides a fish stranding concern category for each of the 25 established stranding sites on the lower Columbia and Kootenay rivers downstream of HLK/ALH and BRD/X (Appendix A) based on previous fish stranding assessment data (year 2000 to present). The concern categories and their definitions are as follows:

- No Pools – Isolated pools (pools no longer connected to the mainstem of the Columbia or Kootenay rivers) have not been identified during previous assessments;
- Reconnaissance – Fewer than five stranding assessments have been conducted since 2000;
- Minimal Effect – Less than 200 fish (regardless of life stage) have been stranded during each previous reduction and a species at risk has never been stranded during previous reductions; and
- Effect – Greater than or equal to 200 fish (regardless of life stage) have been stranded during any previous reduction, or greater than or equal to one species at risk has been stranded during a previous reduction.

In addition to the database query output, the NRS also reviews the historic fish stranding summary table (Table 9), which identifies maximum and average number of stranded fish per reduction event by site, risk period, and discharge. This table is updated annually and provides an important visual tool to estimate expected fish stranding risk for a proposed reduction event. Predicted fish stranding from the model described in Dalgarno and Thorley (2023), based on the magnitude of reduction, river stage, and time of year, is also considered when assessing risk at this stage in the assessment.

After determining the variables of timing, river stage and wetted history and reviewing results of previous stranding assessments (i.e., the database query output, the historic fish stranding summary table, and the predictive model of fish stranding risk [Dalgarno and Thorley 2023]), the NRS decided whether or not a field-based stranding assessment should be conducted in response to the proposed flow reduction.

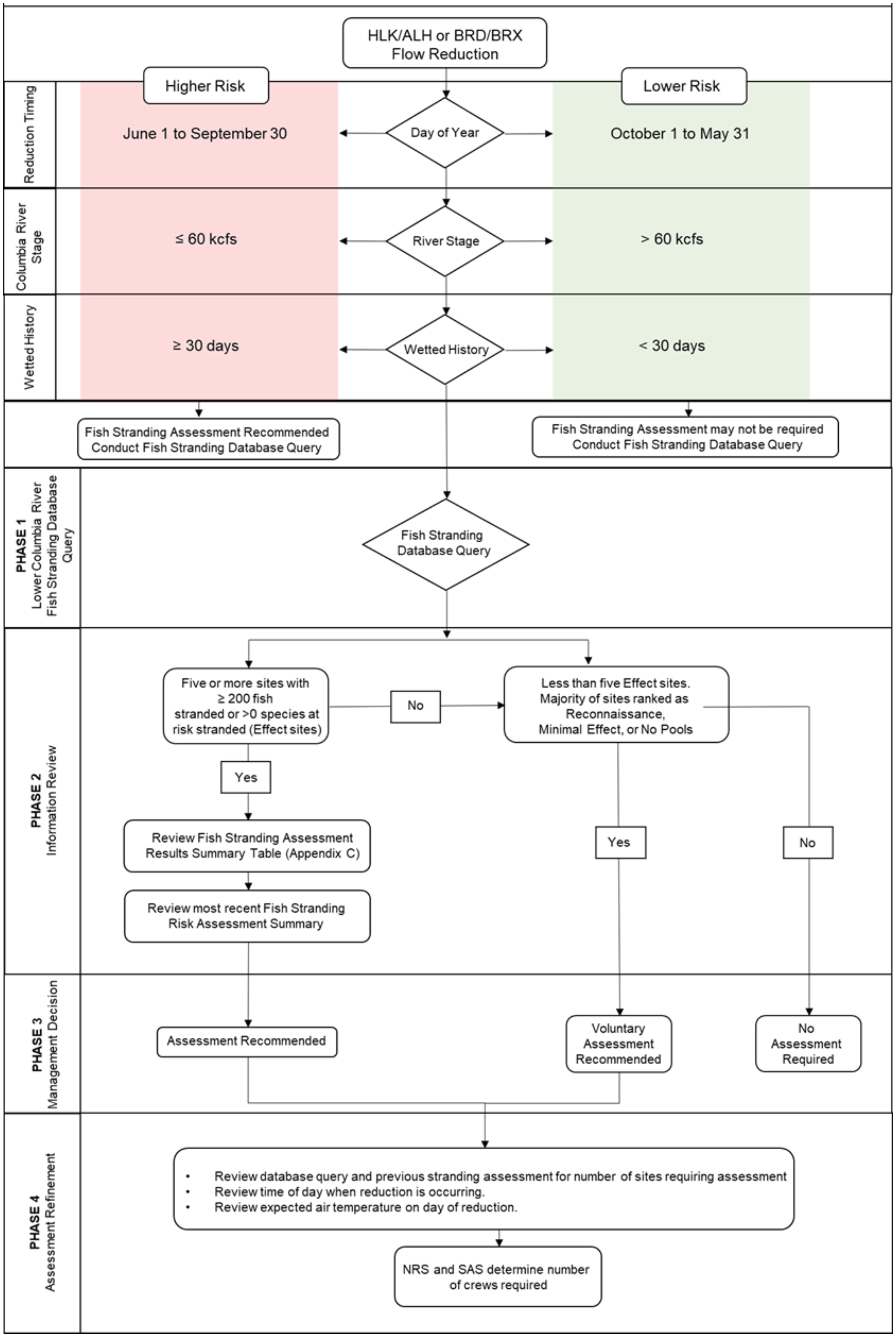

Figure 2: Fish Stranding Risk Assessment Process (Golder 2021a).

2.2 Fish Stranding Assessment and Salvage Methods

Fish stranding assessments were typically conducted by a single, two-person crew. However, for some reduction events a second two-person crews was deployed due to higher risk of fish becoming stranded and to facilitate greater effort to salvage stranded fish.

Fish stranding assessments occurred on the same day as an operational flow reduction from HLK/ALH or BRD/X. During each stranding assessment, a selection of 25 sites on the lower Columbia and Kootenay rivers (Appendix A) was visited from high to low priority based on the ranking provided in the database query. Stranding assessment crews arrived at the first stranding site no later than one hour after the final staged reduction from HLK/ALH or BRD/X. Throughout the day, site assessments were conducted from upstream to downstream following the stage recession. This standardized order of site assessment helped ensure that sites were not assessed prior to the effects of the flow reduction reaching the site. Sites where an ‘Effect’ ranking was assigned were considered the highest priority to assess by the crew, followed by ‘Reconnaissance’ sites. If time permitted, ‘Minimal Effect’ and/or ‘No Pools’ sites were assessed to confirm that the site ranking identified by the database query were correct.

At each site, the field crew conducted the following activities:

1) Habitat variables were recorded at each site to classify available fish habitat, characterize the stranding mechanisms present (i.e., pool stranding or interstitial stranding), and characterize general site conditions (Table 1).
2) A broad scale search of the dewatered area was conducted. The total number of new isolated pools (pools no longer connected to the mainstem of the Columbia or Kootenay river) and dewatered pools that were present due to the current flow reduction were recorded. Pools isolated during previous reduction events were noted in the comments but were not included in the tally for total pools formed due to the current reduction event.
3) Each new isolated pool was inspected for stranded fish and crews attempted to salvage all fish present in pools using Smith-Root™ model 12-B POW or LR24 backpack electrofishers (Smith-Root, Vancouver, WA, USA), dipnets, or beach seines, depending on conditions. Backpack electrofishing was conducted with one crew member operating the electrofisher and one crew member netting fish. All captured fish were transferred to 20 L buckets filled with water. The effort and number of pools sampled was recorded at each site depending on the method used for fish capture. Captured fish from previously isolated pools (i.e., previous reduction events), were recorded but were not included in the tally for total number of fish stranded during the current reduction event. Instead, these fish were retroactively assigned to the reduction event that caused their stranding and were entered into the database in this manner.
4) Interstitial stranding areas (i.e., habitat amongst dewatered substrate) were also assessed for stranded fish. The total interstitial area searched (in m^2) was recorded.
5) Captured fish were identified to species when possible and assigned to one of the following life stages; egg, YOY, juvenile, or adult. The total number of live stranded fish (including those observed during sampling, but not captured), dead fish, and salvaged fish were recorded for each species and life stage. The stranding mechanism (i.e., pool stranding or interstitial stranding) for each fish was recorded. If the number of stranded fish was more than approximately 200 individuals, the total number of fish stranded was estimated, and a subsample of these fish were captured and identified to species to expedite the fish salvage process.
6) Fish length measurements were collected from up to 30 individuals of each species captured during each stranding assessment. Total length was measured for sculpin species and fork length was measured for all other species.

7) All salvaged fish were returned to the main channel of the Columbia or Kootenay rivers.
8) Representative photographs were taken to document current conditions. Photographs of representative fish species were also taken, when possible.
9) Invasive species captured during stranding assessments were euthanized and removed from the system as per permit requirements.

Table 1: Habitat variables recorded at each stranding site as part of the Lower Columbia River and Kootenay River Fish Stranding Assessments, 2022/2023.

Variable	Description
Site Names	Name of stranding site
Date	The date the site was sampled
Time	Arrival time on site
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 0.1°C)
Conductivity	Water conductivity at the time of sampling (to the nearest 10 µS/cm)
Estimated Vertical Drop	The estimated change in water level due to the current flow reduction
Slope	Estimated slope percent of dewatered area at site (less than or greater than 4%)
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); Fog
Instream Cover Type	Interstices, Woody Debris, Aquatic Vegetation, or Terrestrial Vegetation (percent of 100)
Substrate	Boulder, Cobble, Gravel, Sand (percent of 100)
New Pools Present	Total number of new pools isolated due to the current reduction
New Pools Sampled	Total number of new pools assessed for presence of stranded fish
Dewatered Pools	Total number of dewatered pools due to the current reduction
Interstitial Area Sampled	Estimated area of interstitial (i.e., dewatered substrate) sampled for stranded fish (m^2)
Electrofisher Model	The model of electrofisher used during sampling
Volts	The voltage (V) used during sampling
Frequency	The frequency (Hz) used during sampling
Pulse Width	The pulse width (ms) used during sampling
Crew	The field crew that conducted the sampling
Sample Comments	Any additional comments regarding the stranding site or sampling conditions
Future Flow Reduction Problems	Identify whether new stranding pools will form if water level were to drop another 0.5 m
Photographs	Representative photographs documenting site conditions or fish species captured.

2.3 Data Analysis

Results of fish stranding assessments conducted during the present study period (1 April 2022 to 1 April 2023) have been tabulated and summarized and are presented in Sections 3.1 to 3.5. Methodology of the statistical analysis on the 23-year dataset of fish stranding assessments to address the management questions of the monitoring program are described below.

2.3.1 Data

All data from fish stranding assessments conducted prior to and during CLBMON-42 are stored in the Lower Columbia River Fish Stranding Database in Microsoft Access format. All fish stranding assessment data were entered into the database under a unique reduction event number and each reduction event was identified as occurring due to a flow reduction at HLK/ALH, BRD/X, or a flow reduction from both facilities. In addition, flow data from the Birchbank hydrometric station, HLK/ALH, and BRD/X were entered into the database for each reduction. The flow data for Birchbank were entered as daily maximum and minimum discharge (to the nearest hour) in kcfs on the day of each flow reduction. Flow data for HLK/ALH and BRD/X were entered as baseflow (in kcfs) before and after the flow reduction and includes number of ramps (i.e., individual drops in flow per reduction) and average ramping rate (total flow reduction divided by number of ramps) as identified by the facility responsible for the flow reduction.

Data were used in statistical analyses to address the effects of ramping rate, wetted history, and physical habitat recontouring on fish stranding to address management question #1, #2, and #4, as described in detail in Sections 0 and 2.3.3.

Data from the Lower Columbia River Fish Stranding Database were not used to address the effectiveness of using a conditioning flow (management question #3) to reduce fish stranding. A conditioning flow is an experimental flow regime which creates a short term (1–2 hour) flow reduction approximately 24 hours prior to a normal operational flow reduction. During CLBMON-42, conditioning flows were not conducted; therefore, the fish stranding data from the database is not adequate to answer the effect of a conditioning flow on fish stranding. For this report, this management question was assessed based on data and analysis associated with flow ramping experiments in the summers and winters of 2004, 2005, and 2006 (Golder 2005, 2006, 2007; Irvine et al. 2009).

Data from the Lower Columbia River Fish Stranding Database were used to address whether the continued collection of fish stranding data and upgrading of the lower Columbia River stranding protocol reduced the frequency that stranding crews were deployed in response to HLK/ALH reduction events (management question #5). A statistical analysis was not deemed necessary to assess this management question. Instead, the annual number of reduction events and stranding assessments conducted as a result of flow changes at HLK/ALH were plotted and visually assessed.

2.3.2 Data Quality Assurance/Quality Control and Compilation

As stranding survey methods were standardized in 1999, only data from 1999 to 2023 were considered for inclusion in analyses; however, data from 1999 were incomplete for several variables and reduction events. As such, the entire 1999 study year was ultimately excluded from all analyses. Analyses included data from reduction events that occurred between January 2000 and March 2023 resulting from changes in discharge at HLK/ALH, BRD/X, or both facilities. Although the management questions are specifically directed at flows from HLK, the addition of reduction events from BRD/X in each analysis allowed for a larger dataset of environmental and operational variables that may influence fish stranding in the lower Columbia and Kootenay rivers.

Prior to analysis, Quality Assurance/Quality Control (QA/QC) of the 23-year dataset described above was conducted, including exploratory plotting and checks on maximum and minimum values. During QA/QC, some stranding sites were omitted from analyses due to their small sample size (i.e., few site visits). In addition, some reduction events were omitted from analyses due to missing data for key variables (i.e., ramping rate or discharge), or because some aspect of the reduction event resulted in incompatible data.

Between 2000 and 2023, reduction events occurred on a single day or occurred over multiple consecutive days. For multi-day reduction events, stranding assessments were conducted on each day of the reduction event or only one assessment was conducted on the final day of the reduction event. Beginning in 2018, each day of multi-day reductions was entered in the database as a separate reduction event. Because the number of reduction days and assessment days were not always the same between reduction events from 2000 to 2023, the unit of observation was the reduction event (rather than the individual reduction date). To compile the data by reduction event, the number of stranded fish was summed across all survey dates and reduction dates associated with the reduction event. Similarly, the minimum and maximum discharge at Birchbank was summarized to describe the entire range of discharges observed across all reduction days, where applicable.

For five of the six sites where physical habitat recontouring was conducted, fish stranding assessments were conducted both before and after the recontouring event, which allowed the effectiveness of recontouring to reduce fish stranding to be assessed following a before/after study design. The Genelle Lower Cobble Island (MID) site was recontoured in 2001; however, it was excluded from analyses because stranding assessment data for this site was limited to visual surveys conducted from the opposite river bank, due to access limitations (i.e., boat access only).

After QA/QC and data compilation, the total sample size of the datasets used to address the effects of ramping rate, wetted history, and physical habitat recontouring on fish stranding are described in Table 2.

Table 2: Datasets used to address the effects of ramping rate, wetted history, and physical habitat recontouring on fish stranding.

Variable Tested	Number of Site Visits	Total Number of Reduction Events (number per facility responsible for reduction event)	Number of Sites
Ramping Rate and Wetted History	2,856	345 (282 from HLK/ALH, 34 from BRD/X, 29 from both)	24
Physical Habitat Recontouring	1,084	336 (276 from HLK/ALH, 31 from BRD/X, 29 from both)	5

2.3.3 Statistical Analysis

The statistical models were updated and refined from a previous analysis of the dataset that was conducted after the last scheduled year (2019/2020) of monitoring under the WUP (Golder 2020a). As with the previous analysis, a two-stage, generalized linear mixed hurdle model was used to analyze fish stranding data in the lower Columbia and Kootenay rivers. The hurdle model contained two components – one component that described the non-zero counts of stranded fish (conditional model), which was used to assess the severity of stranding (i.e., the number of fish), and one component that described the probability of zero versus non-zero counts of stranded fish (zero-inflation model), which was used to assess the probability of stranding. The conditional model assumed a negative binomial distribution to describe the non-zero counts of fish. The zero-inflation model was equivalent to a logistic regression to predict whether or not one or more stranded fish were observed during a site visit. The hurdle model was used due to its suitability for modelling count data (i.e., the number of fish stranded) that have many zeroes and a large variability in the counts (Brooks et al. 2017; Zuur et al. 2009,).

Two models were used, one to assess the effects of ramping rate (management question #1) and wetted history (management question #2), and the second to assess the effects of physical habitat recontouring (management question #4). Two separate models were required because only five of the sites had recontouring conducted, which resulted in a smaller sample size for that analysis. In both models, the response variable was the number of fish stranded (all life stages and species combined) and the unit of observation was each site visit during each reduction event. Site and year were included as random effects in both models. The predictor variables of primary interest to the management questions were ramping rate, wetted history, and physical habitat recontouring (second model only); other variables thought to influence stranding, based on previous analyses, were also included as predictor variables and are detailed below.

For each of the two models, a candidate model was constructed using all of the predictor variables listed below. This model was then assessed for modelling assumptions and plots of residuals versus individual predictors were used to identify lack of fit that required changes to model specification. The initial model was then adjusted to resolve residual patterns, usually via the use of natural cubic spline smoothers instead of linear predictors, or increasing the degrees of freedom of existing splines, where nonlinear patterns were observed in the residuals.

The candidate predictor variables were as follows:

- **Ramping rate** describes the rate at which discharge was reduced for each reduction event. For multi-day reductions, the average values for all reduction days were used. Ramping rates in the database were obtained from BC Hydro prior to the reduction event, which were then used in the analysis, instead of the realized rate of change in discharge at Birchbank because they are more closely linked to operational strategies. Ramping rates are reported as change in kcfs per hour, instead of metric units (m^3/s per hour), to align with conventions used by dam operators and established protocols for ramping rates.
- **Wetted history** is defined as the number of days that habitat had been inundated with water before dewatering. Wetted history was calculated for each reduction event as the number of days prior to the reduction date that discharge was above the minimum discharge reached for that event. Discharge values from Birchbank were used to calculate wetted history because this station is downstream of the confluence of the Columbia and Kootenay rivers, and therefore represents changes in the river level resulting from discharge changes at both HLK/ALH and BRD/X. The values of minimum discharge at Birchbank were extracted from the LCR Fish Stranding Database, and the dates for the previous date of lower discharge were obtained from hourly discharge data for Birchbank from BC Hydro's Columbia Basin Hydrological database.

Wetted history was capped at 365 days, such that all values greater than 365 were assigned a value of 365. This was done because low sample sizes of long wetted histories (up to 5,684 days), combined with highly variable counts of fish at long wetted histories, influenced model fit. The rationale for the maximum value of 365 days was that re-colonization of habitat was expected to occur within one year of re-watering.

- **Recontouring** was a predictor variable with values of “Before” or “After”, based on when physical habitat recontouring was conducted at the site. This variable was only used in the recontouring model that only included sites where physical habitat recontouring was conducted (see below).
- **Magnitude of reduction** was calculated as the difference between the maximum and minimum discharge at Birchbank for each reduction event, as provided in the Lower Columbia River Fish Stranding Database. The Birchbank station provided a more complete discharge dataset than data from HLK/ALH or BRD/X, which both had more periods with missing discharge data. Minimum and maximum values at Birchbank that were recorded in the database were typically the minimum and maximum value during each 24-hour period of the reduction day. In some cases, if the discharge subsequently increased after the discharge reduction, the values in the database are the minimum and maximum preceding and following the reduction event, not including subsequent changes in discharge on the same day.
- **Minimum discharge** of the Columbia River at Birchbank after the reduction event was obtained from the Lower Columbia River Fish Stranding Database. Minimum discharge was used as an indicator of river stage.
- **Load shaping** is defined as within-day variation in discharge due to changes in generation at a hydroelectric facility to meet changes in power demand. In the study area, load shaping can occur at BRD/X but does not occur at HLK/ALH. Load shaping was a binary categorical variable to indicate whether load shaping occurred on the reduction day. For multi-day reduction events, if load shaping occurred on any of the days within the reduction event, the reduction event was considered to have had load shaping.
- **River kilometre** for each site was obtained from the Lower Columbia River Fish Stranding Database and was included in the model to account for attenuation in the risk of stranding with increasing distance downstream from the dams. This variable was removed from the model of recontouring, since only five sites (and hence five river kilometre values) had recontouring data.
- **Day of year** was included to account for seasonal differences in stranding risk.

The fixed effects included in the final models, including the degrees of freedom of the natural cubic splines, are detailed in Table 3. All continuous predictor variables were standardized by subtracting their mean and dividing by their standard deviation. Interactions between the predictor variables were not included in the model.

Table 3: Variables used as fixed effects in the final model of wetted history and ramping rate and the final model of recontouring effect.

Variable	Model of Wetted History and Ramping Rate		Model of Recontouring	
	Logistic Component	Count Component	Logistic Component	Count Component
Ramping rate	Spline (df = 2)	Spline (df = 2)	Linear effect	Linear effect
Wetted history	Spline (df = 2)	Spline (df = 2)	Spline (df = 2)	Spline (df = 2)
Recontouring	Not included		Categorical effect	Categorical effect
Magnitude of reduction	Spline (df = 2)	Spline (df = 2)	Spline (df = 2)	Spline (df = 2)
Minimum discharge	Spline (df = 4)	Spline (df = 4)	Spline (df = 5)	Spline (df = 5)
Load shaping	Categorical effect	Categorical effect	Categorical effect	Categorical effect
River kilometre	Linear effect	Linear effect	Not included	
Day of year	Spline (df = 5)	Spline (df = 5)	Spline (df = 5)	Spline (df = 5)

df = degrees of freedom

Statistical significance of the effect of predictor variables on the conditional model and on the zero-inflation model was assessed using type II *P* values (Langsrud 2003). Effect size was assessed using plots of the predicted values of the response variable versus one of the predictor variables, while holding other continuous predictor variables at their mean values and categorical variables at their reference values (i.e., “Before” for recontouring and “No” for load shaping). These “population-level” predictions from the fitted model are predictions with the random effects of site and year set to zero, which represents the predictions for an average site and an average year. For the analysis of recontouring, effect size was assessed using random-level predictions for each site.

Models were fit using the package glmmTMB (Brooks et al. 2017) in the statistical environment R (R Core Team 2023). Model diagnostics included checks of model assumptions including linearity of effects, homoscedasticity, and normality of residual errors. Plots of residuals versus predicted values and residuals versus predictor variables were created to look for residual trends that would indicate poor model fit. All of these checks used simulated residuals produced using the DHARMa package (Hartig 2020) in R.

The management questions were addressed based on trends in the data, and the effect sizes and statistical significance from the models. Where possible, supporting information from other studies was considered when assessing the effects of environmental variables on fish stranding. Modelling results are presented in Section 3.6 and conclusions based on the modelling and other supporting information are provided for each management question in Section 4.0.

3.0 RESULTS

3.1 Operational Overview 2022/2023

During the present study period (1 April 2022 to 1 April 2023), the discharge in the Columbia River at Birchbank ranged from 24.5 kcfs on 31 March 2023 to 155.7 kcfs on 25 June 2022 (Figure 3). Discharge generally increased from April to July and from October to January and decreased from July to October and from January to April, following typical flow patterns observed in previous years. Discharge in the Columbia River was higher than the long-term (2000 to 2022) average for most of the present study period's High Risk stranding period (1 June to 30 September). Furthermore, discharge during the present study period was lower than the long-term average from January to April and reached historical lows in January and March (Figure 3).

The mean hourly discharge from HLK/ALH ranged from 10.0 kcfs on 14 April 2022 to 95.6 kcfs on 6 August 2022. (Figure 3). During the High Risk stranding period, discharge from HLK/ALH generally increased through June and July, then operational discharge reductions began in August. During the Low Risk stranding period, discharge reductions from HLK/ALH were intermittently dispersed.

The mean hourly discharge from BRD/X ranged from 8.8 kcfs on 7 October 2022 to 102.0 kcfs on 14 June 2022 (Figure 3). Discharge from BRD/X was similar to previous years (Golder 2020b, 2021b, 2022), and generally followed the same seasonal pattern as unregulated systems. This was partly due to the limited capacity of BRD/X to store water upstream compared to HLK/ALH. During the High Risk stranding period, discharge from BRD/X exhibited a steady decline from mid-June to the end of September, decreasing from approximately 100 kcfs to 10 kcfs over this period.

Kootenay River system operations can be more dynamic in certain situations due to the need to meet system load requirements. Load factoring at BRD/X shapes average daily inflows into peak discharge during the high load hours (typically 0600 to 2200 hrs) and minimum discharge during low load hours (typically 2200 to 0600 hrs). This can occur when Kootenay River inflows are between 18 and 43 kcfs. Flow reductions associated with load factoring were not considered individual reduction events.

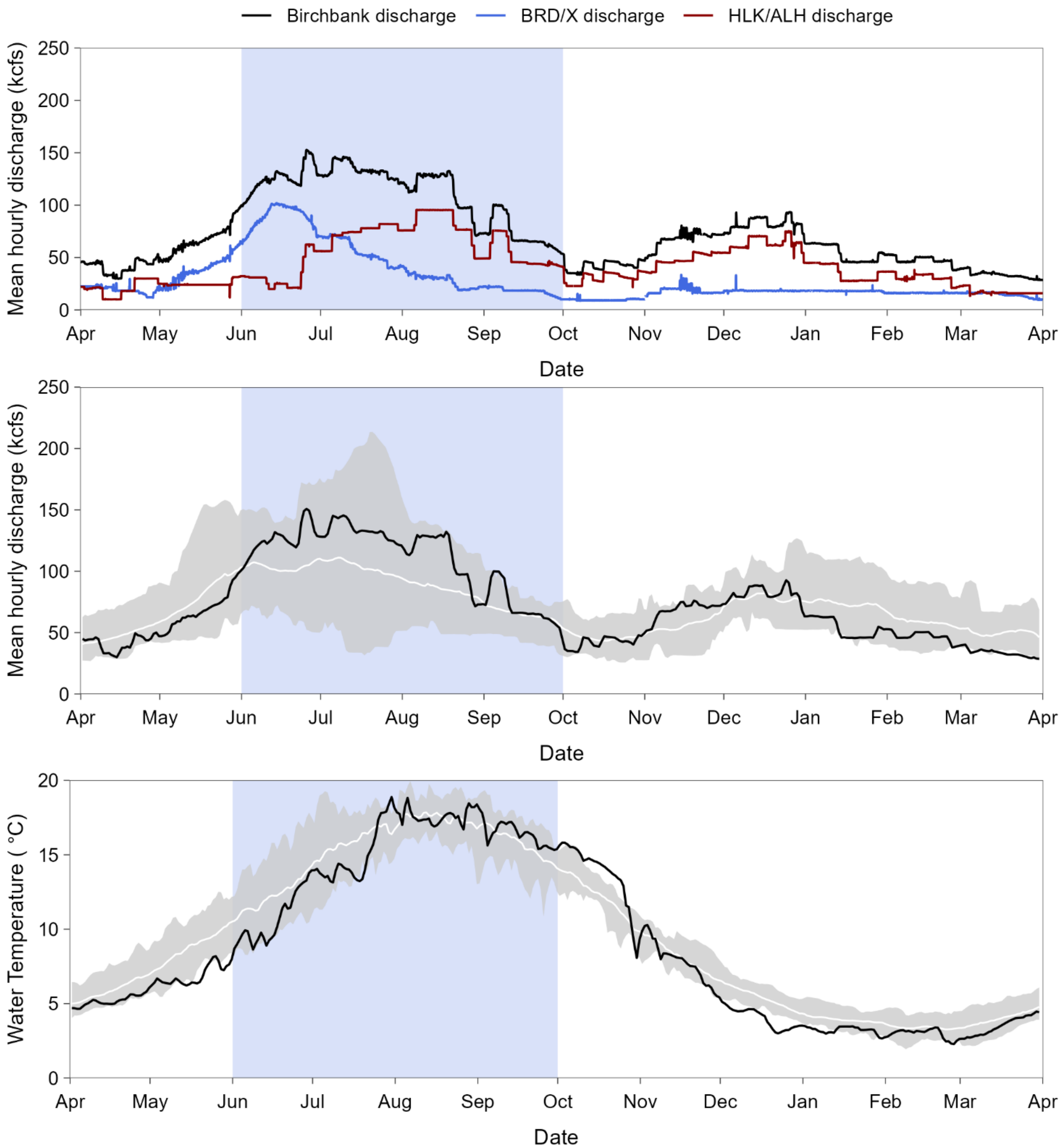

Figure 3: Mean hourly discharge at HLK/ALH, BRD/X, and Birchbank station 1 April 2022 to 1 April 2023 (top panel). Mean hourly discharge at Birchbank station 1 April 2022 to 1 April 2022 with historical range (2000 to 2022; grey shaded area) and mean (white line) (middle panel). Mean hourly water temperature at Birchbank station 1 April 2022 to 1 April 2023 with historical range (2006 to 2022; grey shaded area) and mean (white line) (bottom panel). Blue shaded area represents the High Risk stranding period (1 June to 30 September). Data provided by Water Survey of Canada and BC Hydro's Columbia Basin Hydrological Database.

3.2 Reduction Events and Fish Stranding Assessments

During the 2022/2023 study period, there were a total of 45 operational flow reduction events; 30 occurred at HLK/ALH, 14 occurred at BRD/X, and 1 occurred at both facilities on the same day (Table 4; Figure 4). A total of 12 reductions events occurred during the High Risk period, while the remaining 33 occurred during the Low Risk period. The reduction events from HLK/ALH and BRD/X corresponded to reductions in discharge in the Columbia River at Birchbank that ranged from 0.7 to 22.6 kcfs (Table 4). All reduction events occurred on a single day, except for RE2022-22 which occurred over a two-day period.

The magnitude of flow reduction for each reduction event at HLK/ALH ranged from 0.8 to 15.0 kcfs (Table 4). All reduction events from HLK/ALH were carried out with a maximum ramping rate of 5 kcfs/hr. For example, if the planned reduction had a total magnitude of 15 kcfs, then the reduction would be conducted as 3 reductions of 5 kcfs, separated by an hour between each reduction. All reduction events at HLK/ALH were implemented to fulfill Columbia River Treaty Coordination Agreements.

The magnitude of flow reduction for each reduction event at BRD/X ranged from 0.5 to 4.0 kcfs (Table 4).

During the 2022/2023 study period, there were more recorded reduction events than in previous study periods (Figure 4). This was due in part to small (1-2 kcfs) reduction events at BRD/X in 2022/2023. In 2022/2023 fish stranding assessments were conducted for 14 of the 45 reduction events (Table 4) resulting in a response rate (percent of total reduction events that initiated a stranding assessment) of 31%. The response rate during the present study period was lower than most previous study periods but similar to the 2021/2022 study period (Figure 4). Since the 2016/2017 study period, the number of reduction events has generally increased, and the number of conducted stranding assessments has generally decreased (Figure 4).

When looking strictly at HLK/ALH reduction events, the total number of HLK/ALH reduction events generally increased between the 2007/2008 study period and the 2022/2023 study period; however, the number of stranding assessments in response to HLK/ALH reductions was relatively constant over the same period, ranging from 8 to 15 assessments (median = 13, average = 12; Figure 5). Stranding assessments conducted in response to BRD/X reduction events ranged from 0 to 8 assessments (median = 1, average = 2; Figure 6).

Table 4: Summary of Reduction Events from HLK/ALH and BRD/X 1 April 2022 to 1 April 2023.

Reduction Event Number	Reduction Date	Risk Period	Stranding Survey Conducted?	Facility Responsible for Reduction	Magnitude of Facility Reduction (kcfs)	Magnitude of Birchbank Reduction (kcfs)	Maximum Birchbank Discharge (kcfs)	Minimum Birchbank Discharge (kcfs)	Birchbank Average Ramping Rate (kcfs/hr)	Number of Fish Stranded [a]
RE2022-13	2-Apr-22	Low	No	HLK	1.0	2.2	45.6	43.4	0.3	-
RE2022-14	9-Apr-22		Yes	HLK	10.7	11.4	44.8	33.4	0.5	2,790
RE2022-15	13-Apr-22		Yes	BRD	3.3	2.8	34.1	31.3	0.4	90
RE2022-16	23-Apr-22		No	BRD	2.0	2.1	49.1	47.0	0.4	-
RE2022-17	30-Apr-22		Yes	HLK	5.0	7.8	53.0	45.2	0.9	14
RE2022-18	10-Jun-22	High	No	HLK	5.0	6.7	128.2	121.5	0.9	-
RE2022-19	11-Jun-22		No	HLK	5.0	5.3	126.1	120.8	1.1	-
RE2022-20	18-Jun-22		No	HLK	4.0	5.3	129.3	124.0	0.5	-
RE2022-21	28-Jun-22		No	HLK	6.5	11.7	150.4	138.8	0.5	-
RE2022-22	20-Aug-22		No	Both	15.0	22.6	129.6	107.0	1.0	-
	21-Aug-22		No	Both	3.0	7.8	107.7	99.9	0.4	-
RE2022-23	27-Aug-22		Yes	HLK	14.9	15.9	98.2	82.3	1.0	339
RE2022-24	28-Aug-22		Yes	HLK	12.3	12.7	83.0	70.3	0.9	632
RE2022-25	8-Sep-22		No	BRD	3.5	4.2	99.2	95.0	0.3	-
RE2022-26	9-Sep-22		No	HLK	5.0	4.6	95.7	91.1	0.4	-
RE2022-27	10-Sep-22		Yes	HLK	15.0	16.6	91.5	74.9	1.3	57
RE2022-28	11-Sep-22		Yes	HLK	9.8	9.9	75.2	65.3	0.7	85
RE2022-29	17-Sep-22		No	HLK	1.5	1.1	65.7	64.6	0.3	-
RE2022-30	1-Oct-22	Low	Yes	HLK	15.0	14.8	53.0	38.1	0.9	1,069
RE2022-31	2-Oct-22		Yes	HLK	3.2	2.8	38.1	35.3	0.4	143
RE2022-32	6-Oct-22		No	BRD	1.0	2.2	36.4	34.1	0.4	-
RE2022-33	12-Oct-22		Yes	HLK	5.0	5.3	44.5	39.2	0.4	721
RE2022-34	22-Oct-22		Yes	HLK	1.6	2.5	45.2	42.7	0.2	0
RE2022-35	2-Dec-22		No	BRD	4.0	1.8	74.2	72.4	1.5	-
RE2022-36	17-Dec-22		No	HLK	8.9	9.9	89.0	79.1	0.8	-
RE2022-37	26-Dec-22		No	HLK	10.1	10.6	93.6	83.0	1.9	-
RE2022-38	27-Dec-22		No	HLK	10	12.4	84.4	72.0	1.0	-
RE2022-39	30-Dec-22		No	HLK	9.0	9.9	82.6	72.7	0.5	-
RE2022-40	31-Dec-22		Yes	HLK	8.9	9.9	73.1	63.2	0.7	2
RE2023-01	6-Jan-23		No	HLK	1.0	1.1	63.9	62.9	0.1	-
RE2023-02	13-Jan-23		No	HLK	8.0	8.5	62.5	54.0	0.7	-
RE2023-03	14-Jan-23		Yes	HLK	8.2	8.1	54.0	45.9	0.5	162
RE2023-04	30-Jan-23		No	BRD	2.0	2.8	55.1	52.3	0.1	-
RE2023-05	4-Feb-23		No	HLK	6.7	6.7	52.3	45.6	0.6	-
RE2023-06	18-Feb-23		No	HLK	4.0	4.6	50.5	45.9	0.4	-
RE2023-07	25-Feb-23		No	HLK	10.0	9.9	47.7	37.8	0.9	-
RE2023-08	4-Mar-23		Yes	HLK	10.2	7.4	40.3	32.9	1.0	752
RE2023-09	15-Mar-23		No	BRD	1.0	1.0	34.6	33.6	0.1	-
RE2023-10	16-Mar-23		No	BRD	0.5	0.9	34.1	33.2	0.1	-
RE2023-11	17-Mar-23		No	BRD	0.5	0.9	33.7	32.8	0.1	-
RE2023-12	18-Mar-23		No	HLK	0.8	1.1	33.1	32.0	0.1	-
RE2023-13	23-Mar-23		No	BRD	1.0	1.0	32.5	31.5	0.1	-
RE2023-14	24-Mar-23		No	BRD	0.6	0.8	31.9	31.0	0.1	-
RE2023-15	25-Mar-23		No	BRD	0.5	0.7	31.3	30.7	0.0	-
RE2023-16	26-Mar-23		No	BRD	1.5	1.4	30.8	29.4	0.1	-
RE2023-17	28-Mar-23		No	BRD	0.9	0.7	29.5	28.8	0.1	-

Notes

[a] When fish stranded during a previous reduction event were encountered, these fish were assigned to the reduction event that caused the stranding.

Birchbank Gauge Station flow data provided by Water Survey of Canada Birchbank Guage Station No. 08NE049. Accessed on 15 August 2023 at: https://wateroffice.ec.gc.ca/report/real_time_e.html?stn=08NE049

BRD/X and HLK/ALH flow data provided by BC Hydro's Columbia Basin Hydrological Database.

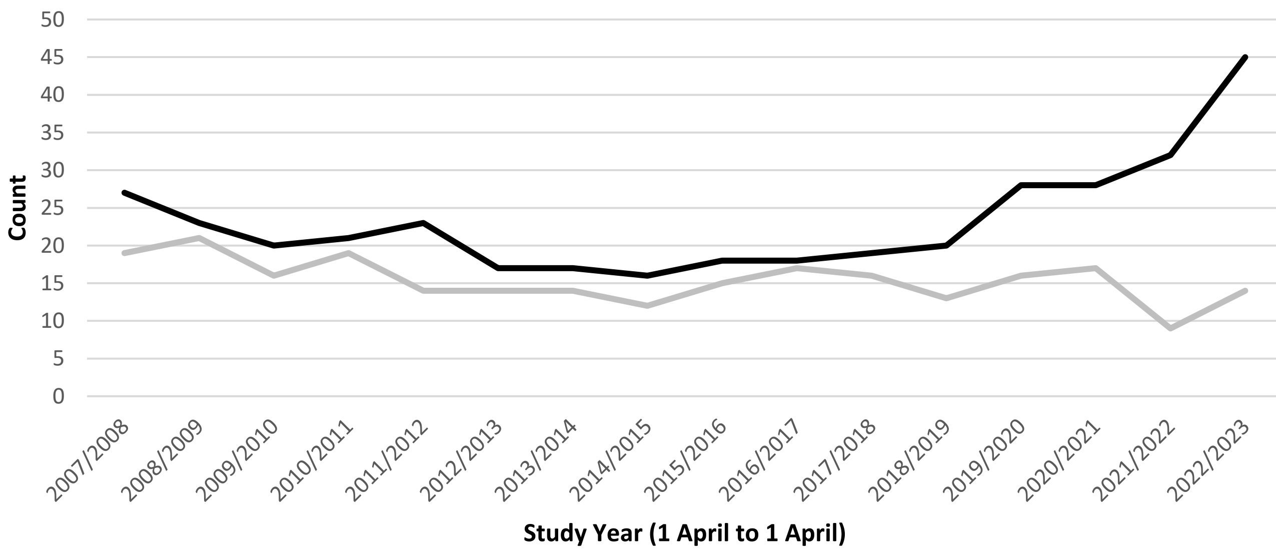

Figure 4: Count of annual reduction events (black line) and stranding assessments (grey line) conducted during each study period of the Lower Columbia River and Kootenay River Fish Stranding Assessments, 2007/2008 to 2022/2023. The figure includes reduction events from HLK/ALH, BRD/X, and both facilities.

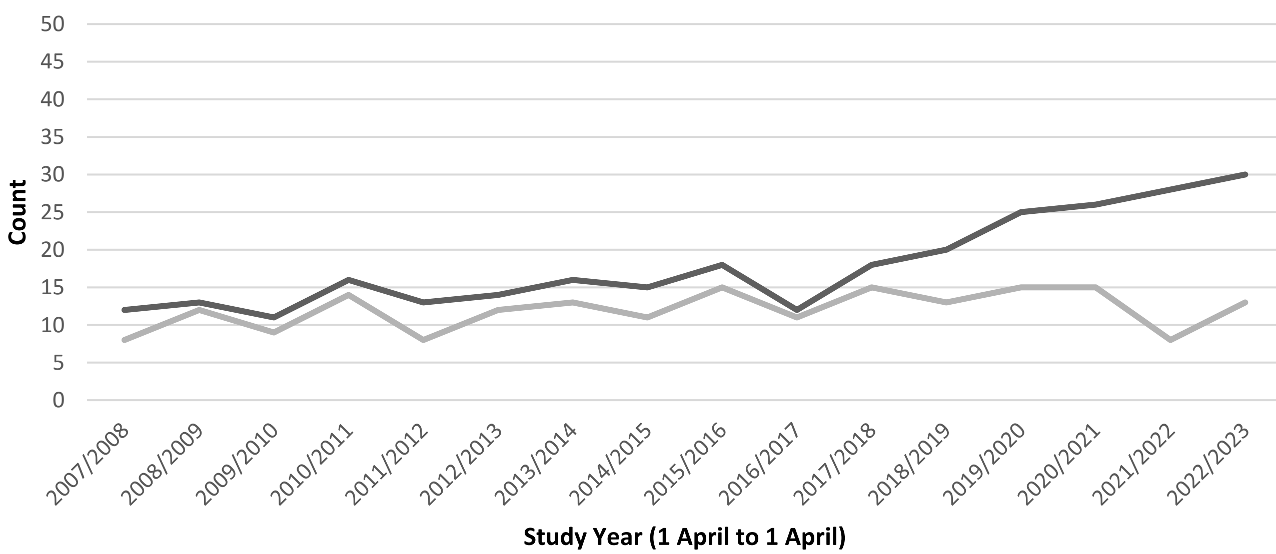

Figure 5: Count of annual reduction events (black line) and stranding assessments (grey line) conducted during each study period of the Lower Columbia River and Kootenay River Fish Stranding Assessments, 2007/2008 to 2022/2023. The figure includes only reduction events from HLK/ALH and stranding assessments conducted in response to reduction events from HLK/ALH.

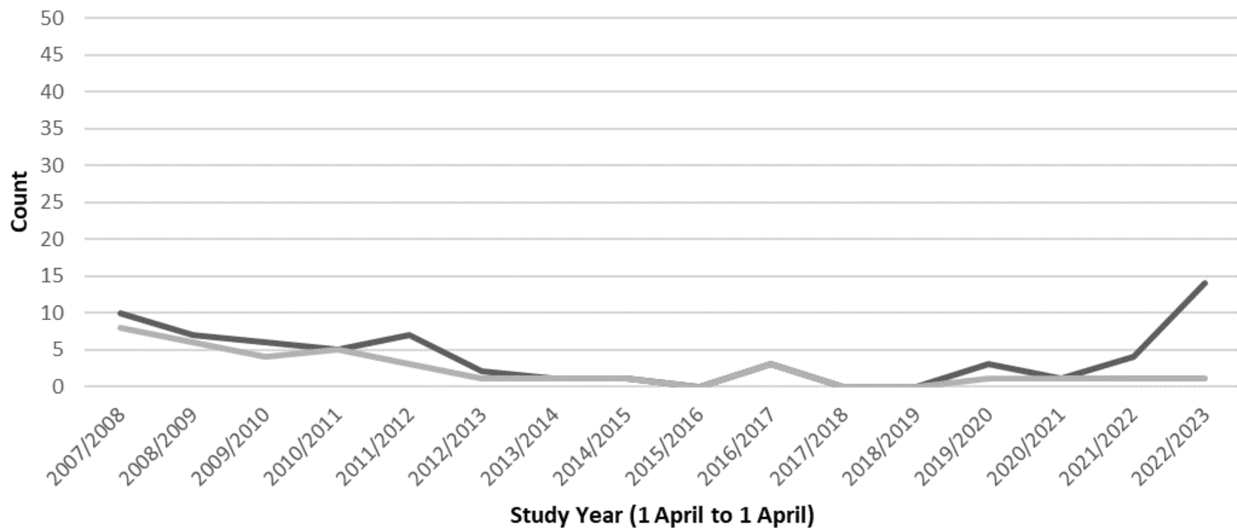

Figure 6: Count of annual reduction events (black line) and stranding assessments (grey line) conducted during each study period of the Lower Columbia River and Kootenay River Fish Stranding Assessments, 2007/2008 to 2022/2023. The figure includes only reduction events from BRD/X and stranding assessments conducted in response to reduction events from BRD/X.

As in previous years, sites ranked as ‘Effect’ sites in the database queries were prioritized during stranding assessments since these sites were most likely to strand fish.

Of the 97 site assessments conducted in 2022/2023, the database queries ranked 73 sites (75%) as ‘Effect’ sites, 19 sites (20%) as ‘Reconnaissance’ sites, and 5 sites (5%) as ‘Minimal Effect’ sites (Table 5). Sites ranked as ‘No Pools’ were not assessed because stranded fish are most encountered in isolated pools as opposed to de-watered substrate (Golder 2021b, 2022). To provide an evaluation of the database query (Section 2.1), Table 5 identifies each database query site designation and categorizes each into the ‘Effect’, ‘Minimal Effect’ or ‘No Pools’ ranking based on the results from site assessments conducted during the present study period. Overall, 97 sites assessments resulted in 14 sites (14%) that met the ‘Effect’ designation, 63 sites (65%) met the ‘Minimal Effect’ designation, and 20 sites (21%) met the ‘No Pools’ designation. The database queries predict stranding risk by assigning a concern category based on the most severe historical site visit (Section 2.1). As this is a conservative approach, there is expected to be variation between pre-survey predictions and collected data and the assigned site ranking from the collected data is expected to be lower than the predicted concern category in many cases.

Five ‘Minimal Effect’ sites were randomly selected to be assessed in 2022/2023 to verify the Database query designation: Norns Creek Fan (RUB) and Fort Shepherd Launch (RUB, RE2022-27), CPR Island (MID, RE2022-33), and Tin Cup Rapids (RUB) and Zuckerberg Island (LUB; RE2023-08). Fort Shepherd Launch [RUB]) was the only one which met the ‘Minimal Effect’ criteria. No pools or stranded fish were found at Norns Creek Fan (RUB) and CPR Island (MID). Tin Cup Rapids (RUB) and Zuckerberg Island (LUB) were identified as ‘Effect’ sites because a single Shorthead Sculpin (a species of concern as identified by the BC Conservation Data Centre [CDC] and the Committee on the Status of Endangered Wildlife in Canada [COSEWIC]) was stranded at Tin Cup Rapids (RUB) and 638 stranded fish were identified at Zuckerberg Island (LUB).

Table 5: Comparison of site designations from database queries and site designations based on results of fish stranding assessments, 1 April 2022 to 1 April 2023.

Predicted Site Designation from Database Query (Section 2.1)	Observed Site Designation Based on Results of Stranding Assessments			Total (% of total)
	Effect [a]	Minimal Effect [b]	No Pools [c]	
Effect [a]	12	52	9	73 (75%)
Reconnaissance	0	10	9	19 (20%)
Minimal Effect [b]	2	1	2	5 (5%)
Total (% of total)	**14 (14%)**	**63 (65%)**	**20 (21%)**	**97 (100%)**

[a] ≥ 200 fish or ≥ 1 species of concern stranded.
[b] < 200 fish stranded and no species of concern stranded.
[c] No fish stranded and no isolated pools identified.

In 2022/2023, 20 out of 25 stranding sites were assessed at least once over the 14 fish stranding assessments (Table 6). Five sites (Kinnaird Rapids [RUB], Blueberry Creek D/S [LUB], Sandbar Eddy [LUB], Birchbank Snye [LUB], and Korpack [LUB]) were not assessed because field crews were limited by time constraints (i.e., field crews focused on ‘Effect’ sites and did not have time to assess lower priority sites).

The sites most frequently assessed (>10 assessments) were Genelle Mainland (LUB), Kootenay River (RUB), and Norns Creek Fan (RUB). All three sites are locations where fish stranding commonly occurs and are ranked as ‘Effect’ sites in database queries through a variety of discharge levels. Genelle was also an area to monitor the effectiveness of the physical habitat recontouring completed in March 2021[4].

In general, sites in the Upper Section and Kootenay Section of the study area (Figure 1) were more frequently assessed than sites in the Middle and Lower Sections, because they were usually ranked as ‘Effect’ sites in the database query. Furthermore, crews could not begin assessments at sites in the Lower Section of the Columbia River until the reduction reached those sites, limiting the number of sites that could be assessed in the Lower Section during a typical 10-hour field day. The stage reduction generally reaches Norns Creek Fan (RUB) within 1-2 hours, Genelle Mainland (LUB) within 6 hours, and Fort Shepherd Launch (RUB) within 10 hours (Golder 2021a).

3.3 Fish Encountered During 2022/2023 Stranding Assessments

Stranded fish were identified during all stranding assessments conducted in response to flow reduction events except for RE2022-34. During the 14 fish stranding assessments conducted, a total of 6,856 fish were recorded as stranded (Table 6). This total includes 512 fish that were identified in isolated pools that had formed during a previous reduction event. The total number of fish observed or captured during each stranding assessment ranged from 0 to 2,790 (Table 4). Pool stranding accounted for 95% of all fish stranded, while the remaining 5% were stranded interstitially within dewatered substrate.

[4] This involved filling in depressions where isolated pools commonly formed and grading the substrate.

In 2022/2023, 16% of the total stranded fish were stranded during the High Risk period (1 June to 30 September) and 84% of fish were stranded during the Low Risk period (1 October to 31 May). As there were stranding assessments conducted for 4 reduction events in the High Risk period and 11 reduction events in the Low Risk period, the average number of fish stranded per reduction event when an assessment was conducted was 278 fish/event during the High Risk period and 574 fish/event during the Low Risk period. In previous years, a greater number of fish were stranded during the High Risk period compared to the Low Risk Period (Golder 2017, 2018, 2019, 2020b, 2021b, 2022). During the High Risk period, larval and YOY fish are known to inhabit near shore habitat, and the risk of stranding is elevated (Golder and Poisson 2010, Golder 2020a).

The majority (59%) of stranded fish were found in pools and dewatered substrate located at Genelle Mainland (LUB) and Norns Creek Fan (RUB) (Table 6). Genelle Mainland (LUB) has been one of the top three site, in terms of total fish stranded during the previous six years (Golder 2017, 2018, 2019, 2020b, 2021b, 2022). At Norns Creek Fan (RUB), the majority of observed fish stranding (2,181 of 2,465 fish stranded in 2022/2023) occurred during a single reduction event on April 9, 2023 and 2,150 of these 2,181 fish were YOY Mountain Whitefish.

Other sites where relatively large numbers (i.e., hundreds) of fish were stranded in 2022/2023 were CPR Island (MID), Millennium Park (LUB), Tin Cup Rapids (RUB), Kootenay River (RUB), Zuckerberg Island (LUB), and Blueberry Creek (LUB). Large numbers of fish have been observed at these sites in many previous years. Sites that were assessed in 2022/2023 but where stranded fish were not recorded included Waterloo Eddy (RUB), Gyro Park (RUB), Casino Road Bridge U/S (LUB), Casino Road Bridge D/S (LUB), and Bear Creek (RUB) (Table 6).

Table 6: Count of site assessments and fish stranded by site during reduction events, 1 April 2022 to 1 April 2023.

Site [a]	Number of Site Assessments	Number of Fish Stranded	% of Total Stranded Fish	% Stranded during High Risk Period [b]	Median and Range of Fish Stranded per Assessment
Lions Head (RUB) [c]	6	133	1.9	0.0	0 (0 – 128)
Norns Creek Fan (RUB)	11	2,465	36.0	<1.0	14 (0 – 2181)
CPR Island (MID) [d]	5	299	4.4	0.0	10 (0 – 205)
Millennium Park (LUB) [e]	4	251	3.7	0.0	1.5 (0 – 248)
Tin Cup Rapids (RUB)	8	391	5.7	73.7	25 (0 – 203)
Kootenay River (LUB)	6	19	<1.0	0.0	0.5 (0 – 12)
Kootenay River (RUB)	11	540	7.9	0.0	6 (0 – 286)
Zuckerberg Island (LUB)	5	673	9.8	0.0	17 (0 – 638)
Waterloo U/S (RUB)	2	34	<1.0	0.0	17 (0 – 34)
Waterloo Eddy (RUB)	1	0	0.0	0.0	0 (0 – 0)
Blueberry Creek (LUB)	4	338	4.9	100.0	4 (0 – 330)
Genelle Mainland (LUB)	12	1,558	22.7	28.5	41.5 (0 – 684)
Gyro Park (RUB)	1	0	0.0	0.0	0 (0 – 0)
Gyro Boat Launch (RUB)	6	48	<1.0	0.0	0 (0 – 48)
Trail Bridge (RUB)	4	8	<1.0	0.0	0 (0 – 8)
Casino Road Bridge U/S (LUB)	1	0	0.0	0.0	0 (0 – 0)
Casino Road Bridge D/S (LUB)	1	0	0.0	0.0	0 (0 – 0)
Bear Creek (RUB)	6	0	0.0	0.0	0 (0 – 0)
Beaver Creek (RUB)	1	72	1.1	0.0	72 (72 – 72)
Fort Shepherd Launch (RUB)	3	27	<1.0	100.0	0 (0 – 27)
Total	**98**	**6,856**	**100**	**16.2**	**0 (0 – 2,790)**

[a] Sites ordered from upstream to downstream; Appendix A; Figures A1 through A11.
[b] High Risk Period = 1 June to 30 September.
[c] RUB = right bank as viewed facing upstream
[d] MID = island in mid-channel
[e] LUB = left bank as viewed facing upstream

3.3.1 Sportfish

Sportfish accounted for 45% of all fish stranded in 2022/2023 (Table 7). Of these, the majority (77%) were Mountain Whitefish encountered at Lions Head (RUB), Norns Creek Fan (RUB), and Genelle Mainland (LUB). Of all Mountain Whitefish stranded, all but one were Young-of-Year (YOY) that were encountered in the month of April, which aligns with the timing of fry emergence (McPhail 2007). Mountain Whitefish are known to spawn in Norns Creek and in the Columbia River near Genelle (Golder 2014), so it is not unexpected to encounter newly emerged fry in the shallow near-shore habitat of Lions Head (RUB), Norns Creek Fan (RUB) and Genelle Mainland (LUB) in the early spring months.

A total of 499 stranded Rainbow Trout were encountered during the present study period, all of which were identified as either YOY or juvenile age class. The highest numbers of stranded Rainbow Trout were found at Tin Cup Rapids (RUB) (*n* = 243) and CPR Island (MID) (*n* = 185). These sites are characterized by coarse substrate (i.e., cobble and boulder), which provides shelter and adequate rearing habitat preferred by Rainbow Trout (McPhail 2007). Less than 50 stranded Rainbow Trout were encountered at all other sites. During the 2022/2023 period, approximately equal numbers of stranded Rainbow Trout were encountered during the High Risk period (*n* = 231) and the Low Risk Period (*n* = 268). Historically, between 2000 and 2023, 80% of all stranded Rainbow Trout occurred during the High Risk period. The peak spawning period for Rainbow Trout typically occurs within the first two weeks of May (Thorley et. al. 2017), with emergence occurring approximately 4 to 6 weeks later depending on water temperature (McPhail 2007). Therefore, greater numbers of YOY Rainbow Trout are to be expected within near-shore habitats vulnerable to dewatering during the summer months as opposed to the winter months.

A total of 216 stranded Kokanee were encountered, all of which were YOY. Kokanee were observed at Norns Creek Fan (RUB) and Genelle Mainland (LUB) on 9 and 13 April 2022. Since 2000, Kokanee have been encountered relatively infrequently during fish stranding assessments, compared to Mountain Whitefish and Rainbow Trout. In total, 602 Kokanee have been encountered between 2000 and 2023, with 99% of encounters occurring in the months of March, April, May, and June. The highest number of encounters occurred at Genelle Mainland (LUB) (*n* = 334) and Lions Head (RUB) (*n* = 227), suggesting that these locations provide adequate rearing habitat for newly emerged Kokanee.

No other sportfish were encountered during the 2022/2023 study period; however, Bull Trout were recorded during previous study years.

3.3.2 Non-sportfish

Non-sportfish accounted for 55% of all fish stranded (Table 7). Of all non-sportfish species stranded, YOY and juvenile sucker species (*Catostomus spp*.) were the most common, representing 24% of all fish stranded. Sucker species often represent the highest number of stranded fish during yearly stranding assessments (Golder 2016, 2017, 2018, 2020b, 2021b, 2022). Of all stranded sucker species, 84% were found at Genelle Mainland (LUB), Kootenay River (RUB), and Zuckerberg Island (LUB) combined; however, sucker species are ubiquitous throughout the lower Columbia and Kootenay rivers and were found at 15 of the 20 sites assessed in 2022/2023. During the present study period, 77% of sucker species were stranded during March or October.

Longnose Dace (*Rhinichthys cataractae*) were the second most abundant non-sportfish species stranded (Table 7), with the majority of these individuals stranded at Blueberry Creek (LUB) and Genelle Mainland (LUB). Sculpin species are commonly observed during stranding assessments on the lower Columbia and Kootenay rivers. Of sculpin species stranded during the 2022/2023 study year, Torrent Sculpin (*Cottus rhotheus*) had the greatest relative abundance, followed by Prickly Sculpin (*Cottus asper*), Slimy Sculpin (*Cottus cognatus*), Columbia Sculpin (*Cottus hubbsi*), and Shorthead Sculpin (*Cottus confusus*) (Table 7).

3.3.3 Unidentified Fish

A total of 43 fish could not be identified to species during stranding assessments in 2022/2023, and a further 143 fish were unidentified sculpin species. The majority of unidentified fish (*n* = 29) were YOY that were too small to identify the species. The remaining unidentified fish (*n* = 14) were YOY or juvenile life stages that were visually observed but were not captured; therefore, identification to species was not possible.

Of the total number of stranded sculpin not identified to species, all were identified as juveniles life stage. Of those measured, most (93 of 98) had total lengths that were 45 mm or less. Due to the small size of juvenile sculpin species and widespread interspecific hybridization common in the Kootenay region (McPhail 2007), field identification of juvenile sculpin to the species level is challenging.

3.3.4 Exotic Fish Species

Exotic species (i.e., not native to the lower Columbia and Kootenay rivers) stranded during the present study period were Common Carp (*Cyprinus carpio*) and Tench (*Tinca tinca*) (Table 7).

Of the 148 Common Carp captured in the 2022/2023 study year, one was captured at Genelle Mainland (LUB) during RE2022-23 (27 August 2022) and the remainder were captured at Kootenay (RUB) during RE2022-30 and RE2022-31 (1–2 October 2022). All Common Carp encountered were juveniles. Since 2000, a total of 286 Common Carp have been identified during fish stranding assessments, with the greatest number (*n* = 215) occurring at Kootenay River (RUB). Common Carp have also been found at Genelle Mainland (LUB), Gyro Boat Launch (RUB), and Beaver Creek (RUB).

One adult Tench was captured at Kootenay River (RUB) during RE2022-14 (9 April 2022) and 29 juvenile Tench were captured at this site during RE2022-30 (1 October 2022). Since 2000, a total of 35 Tench were captured during fish stranding assessments.

All stranded exotic species fish were euthanized as per Scientific Fish Collection Permit (Permit No. CB22-698348) conditions.

Table 7: Summary of fish species captured or observed during fish stranding assessments, 1 April 2022 to 1 April 2023.

Species		Total Stranded	% of Total Stranded	% Stranded during High Risk Period [a]	Total Mortalities	Total Salvaged	Species Classification
Sportfish	Mountain Whitefish	2,367	34.5	<1.0	71	470	CDC [b] – Yellow
	Rainbow Trout	499	7.3	46.3	78	283	CDC – Yellow
	Kokanee	216	3.2	0.0	13	183	
Non-Sportfish	Sucker species	1,642	23.9	14.3	92	1,411	N/A [c]
	Longnose Dace	568	8.3	93.0	53	446	CDC – Yellow
	Torrent Sculpin	403	5.9	3.5	129	274	CDC – Yellow
	Redside Shiner	323	4.7	2.5	30	285	CDC – Yellow
	Northern Pikeminnow	278	4.1	3.3	100	168	CDC – Yellow
	Sculpin species	143	2.1	26.6	9	122	N/A [d]
	Peamouth	79	1.2	0.0	3	76	CDC – Yellow
	Umatilla Dace	50	<1.0	2.0	4	46	SARA – Schedule 3 Special Concern COSEWIC – Threatened CDC – Red
	Unidentified	43	<1.0	90.7	1	38	N/A
	Largescale Sucker	31	<1.0	6.5	0	31	CDC – Yellow
	Prickly Sculpin	16	<1.0	6.25	2	14	CDC – Yellow
	Slimy Sculpin	14	<1.0	28.6	0	14	CDC – Yellow
	Columbia Sculpin	3	<1.0	33.3	1	2	SARA [e] – Schedule 1 Special Concern COSEWIC [f] – Special Concern CDC – Blue
	Shorthead Sculpin	2	<1.0	50.0	0	2	SARA – Schedule 1 Special Concern COSEWIC – Special Concern CDC - Blue
	Longnose Sucker	1	<1.0	100.0	0	1	CDC - Yellow
Exotic Fish	Common Carp	148	2.2	<1.0	2	0	CDC – Exotic
	Tench	30	<1.0	0.0	0	0	CDC – Exotic
Total		**6,856**	**100.0**	**16.2**	**588**	**3,866**	

[a] High Risk Period = 1 June to 30 September.
[b] BC Conservation Data Centre (CDC); Red = indigenous species or subspecies that have, or are candidates for, Extirpated, Endangered, or Threatened status in British Columbia; Blue = any indigenous species or subspecies considered to be of Special Concern in British Columbia. Yellow = species that are apparently secure and not at risk of extinction. Exotic = species that have been moved beyond their natural range because of human activity. (BC Conservation Data Centre 2023).
[c] No Sucker species are listed as species of concern in the Columbia and Kootenay rivers.
[d] Sculpin species may be species of concern under the classification system listed.
[e] Species at Risk Act (SARA); Species that were designated at risk by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) before the creation of the *Species at Risk Act* must be reassessed according to the new criteria of the Act before they can be added to Schedule 1. These species are listed on Schedules 2 and 3 and are not yet officially protected under SARA (COSEWIC 2010).
[f] Committee on the Status of Endangered Wildlife in Canada (COSEWIC 2010).

3.3.5 Species of Concern

Umatilla Dace (*Rhinichthys umatilla*), Columbia Sculpin (*Cottus hubbsi*), Shorthead Sculpin (*Cottus confusus*), and White Sturgeon (*Acipenser transmontanus*) are species of concern in the study area (i.e., designated at risk by COSEWIC [5] and/or the CDC [6]). Umatilla Dace, Columbia Sculpin, and Shorthead Sculpin have been documented during previous study years (Golder 2016, 2017, 2018, 2019, 2020b, 2021b, 2022). White Sturgeon have never been identified during lower Columbia River and Kootenay River fish stranding assessments. In 2022/2023, Umatilla Dace, Columbia Sculpin, and Shorthead Sculpin were stranded.

The majority of Umatilla Dace stranded (41 of 50 individuals) were encountered at Beaver Creek (RUB) during RE2022-14 on 9 April 2022. Of the 50 Umatilla Dace stranded, 92% were successfully salvaged and returned to the mainstem of the Columbia or Kootenay River and the other 8% (*n* = 4) were mortalities. Since 2000, a total of 2,610 Umatilla Dace have been identified during fish stranding assessments, with 94% stranded during the Low Risk period. In particular, the highest numbers of stranded Umatilla Dace have occurred in February (*n* = 733) and March (*n* = 1,081) (Figure 7). These findings suggest that the summer months do not pose a higher stranding risk for Umatilla Dace, as opposed to other taxa (e.g., Sucker species and Redside Shiner). Based on studies in the Slocan River, Umatilla Dace likely spawn from early July to mid-September (AMEC 2014). Only sparse information is available regarding Umatilla Dace preferred spawning habitat, but adults may congregate in deeper water to spawn. Upon emergence, YOY and juveniles use shallow habitat for rearing throughout the fall, winter, and spring. In a study conducted by R.L. & L. Environmental Services Ltd. (1995), YOY Umatilla Dace were recorded in the mainstem Columbia River in shallow nearshore areas throughout the year and juveniles (age 1+) were abundant in nearshore areas in the summer, but then moved to deeper water during the fall. Since 2000, data indicate that there are certain stranding sites that are more likely to strand Umatilla Dace. The highest numbers of stranded Umatilla Dace have been found at Kootenay River (LUB; *n* = 675), Kootenay River (RUB; *n* = 511), Gyro Boat Launch (RUB; *n* = 430), and Bear Creek (RUB; *n* = 402) (Figure 8).

During the present study period, three Columbia Sculpin were recorded during stranding surveys, of which two were salvaged and one was a mortality. Two Shorthead Sculpin were recorded during stranding surveys and both were salvaged. Since 2000, there have been a total of 3,690 Columbia Sculpin and 1,530 Shorthead Sculpin found stranded during fish stranding assessments on the Lower Columbia River.

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[5] https://www.cosewic.ca/index.php/en-ca/

[6] https://www2.gov.bc.ca/gov/content/environment/plants-animals-ecosystems/conservation-data-centre/explore-cdc-data

Table 8: Summary of Species of Concern identified during stranding assessments, 1 April 2022 to 1 April 2023.

Site [a]	Total Number of Assessments	Number of Site Assessments with Species of Concern	Number of Fish Stranded	% Stranded during High Risk Period [b]
Umatilla Dace (SARA: Schedule 3 Special Concern, COSEWIC: Threatened, CDC: Red)				
Tin Cup Rapids (RUB)	8	2	2	50.0
Kootenay River (RUB)	12	2	6	0.0
Genelle Mainland (LUB)	12	1	1	0.0
Beaver Creek (RUB)	1	1	41	0.0
Columbia Sculpin (SARA: Schedule 1 Special Concern, COSEWIC: Special Concern, CDC: Blue)				
Millennium Park (LUB)	4	1	1	0.0
Tin Cup Rapids (RUB)	8	2	2	50.0
Shorthead Sculpin (SARA: Schedule 1 Special Concern, COSEWIC: Special Concern, CDC: Blue)				
Tin Cup Rapids (RUB)	8	2	2	50.0
Total			**55**	**5.5**

[a] Appendix A; Figures A1 through A11.
[b] High Risk period = 1 June to 30 September.

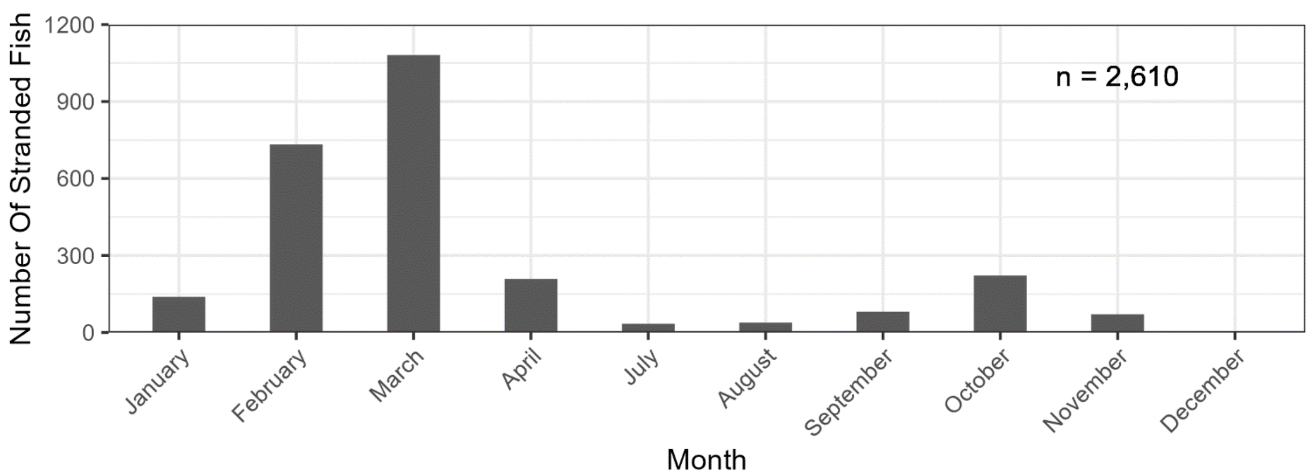

Figure 7: Number of Umatilla Dace stranded by Month from 1 January 2000 to 1 April 2023.

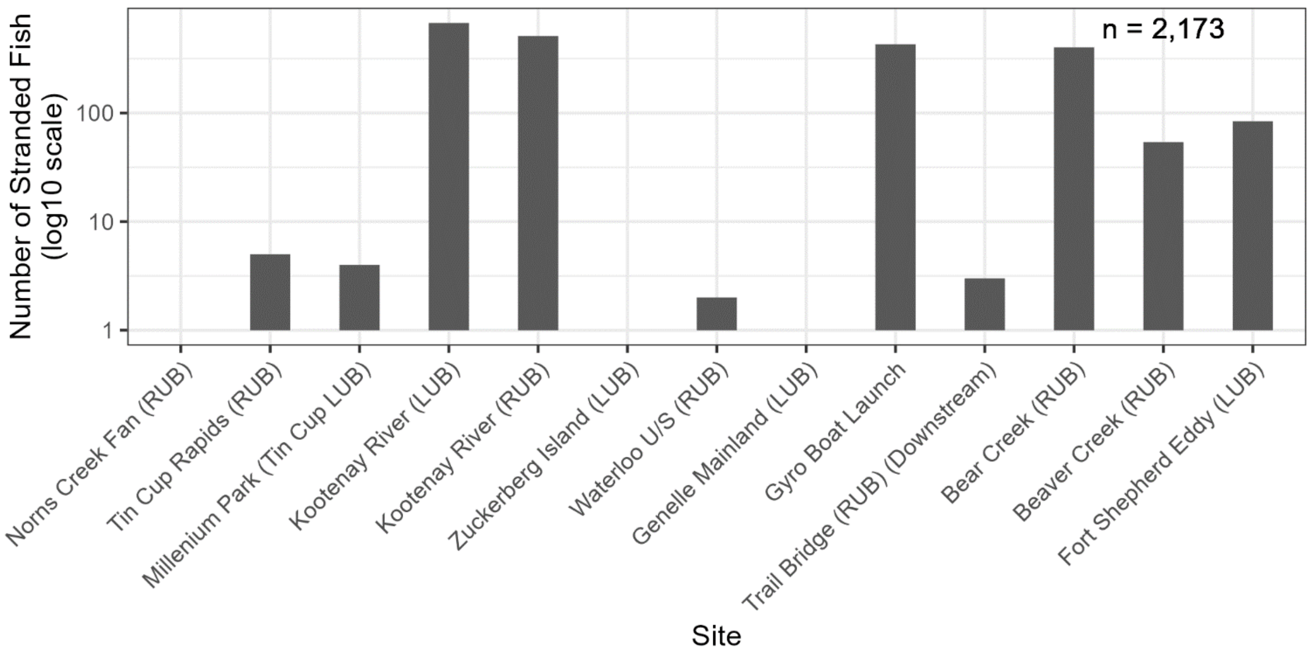

Figure 8: Number of Umatilla Dace stranded by site from 1 January 2000 to 1 April 2023. Sites ordered from upstream to downstream. Figure does not include Umatilla Dace that were stranded at Lions Head (RUB), Genelle Mainland (LUB), and Fort Shepherd Launch (LUB) before the most recent recontouring at these sites.

3.4 Historic Fish Stranding Summary

The results of fish stranding assessments conducted between January 2000 and 1 April 2023 are summarized by site, risk period (High vs. Low), and resultant Birchbank discharge (classified into 10 kcfs ranges) in Table 9. Effect sites (sites where 200 or more fish have been stranded during a single reduction event) and sites where species of concern (i.e., Columbia Sculpin, Shorthead Sculpin, and Umatilla Dace) have been previously stranded are also identified. In addition, the average number of fish stranded per reduction event are also presented. Table 9 can be used by BC Hydro during the risk assessment process (Section 2.1) to determine if a proposed reduction event has occurred historically at a given time of year, and which sites are most likely to have a risk of stranding based on the historical fish stranding data.

Tin Cup Rapids (RUB) should remain a focus of stranding surveys during the High Risk period since this site is identified as an Effect site at all recorded Birchbank discharge ranges (30 to ≥120 kcfs) except between 40 and 50 kcfs (Table 9). As discussed in Section 3.3.1, the characteristics of this site result in a stranding risk to juvenile Rainbow Trout during the summer months. In addition, species of concern have been stranded at Tin Cup Rapids (RUB) during the High Risk and Low Risk periods. Between 2006 and 2023, a total of 26 individuals of species of concern have been stranded at Tin Cup Rapids (RUB) including Columbia Sculpin (*n* = 18), Umatilla Dace (*n* = 5), and Shorthead Sculpin (*n* = 3). Most years, 1 to 2 individuals of species of concern are encountered at Tin Cup Rapids (RUB), with the highest number of species of concern stranded in 2015 (*n* = 10) and 2022 (*n* = 4).

Historically, Genelle Mainland (LUB) stranded a high number of fish during the High Risk period and was identified as an Effect site at all Birchbank discharges ranging from 30 to 100 kcfs (Golder 2020b). Since recontouring was conducted in 2021, there have been three reduction events at Genelle Mainland (LUB) during the High Risk period that resulted in more than 200 fish stranded each time (Table 9), indicating that Genelle Mainland (LUB) still poses a stranding risk during the High Risk period.

Other sites identified as Effect sites at three or more Birchbank discharge ranges during the High Risk period include Norns Creek Fan (RUB), Kootenay River (RUB), Blueberry Creek (LUB), and Gyro Park Boat Launch (RUB) (Table 9). These sites were identified as Effect sites during the High Risk Period at discharge ranges between 30 and 110 kcfs.

During the Low Risk period, sites in the Kootenay River and in the Columbia River upstream of the Kootenay River confluence pose a higher risk of stranding, in terms of the number of fish stranded, compared to sites downstream of the Kootenay River confluence (Table 9). In addition, species of concern have been stranded at all sites in the Kootenay River and in the Columbia River upstream of the Kootenay River confluence during the Low Risk period. Gyro Boat Launch (RUB) was identified as an Effect site and Umatilla Dace have been stranded when Birchbank discharges were between 30 and 70 kcfs during the Low Risk period (Table 9). Overall, there is a greater occurrence of species of concern during the Low Risk period than during the High Risk period. Stranding risk during the Low Risk period appears to decrease sharply when discharge is greater than 70 kcfs; however, this finding is based on a low number of site assessments.

Table 9: Summary of fish stranded by site, risk period and discharge on the lower Columbia and Kootenay rivers due to reduction events at HLK/ALH and BRD/X, 1 January 2000 to 1 April 2023

Observed Effect — Columbia River

Risk Period	Resultant Birchbank Discharge (kcfs)	Lions Head (RUB) [a]			Norns Creek Fan (RUB) [a]			CPR Island (MID)			Tin Cup Rapids (RUB)			Millennium Park (LUB) [a]		
		# of Fish Max.	# of Fish Avg.	# of RE	# of Fish Max.	# of Fish Avg.	# of RE	# of Fish Max.	# of Fish Avg.	# of RE	# of Fish Max.	# of Fish Avg.	# of RE	# of Fish Max.	# of Fish Avg.	# of RE
High Risk (1 June to 30 September)	≤30															
	≥30 to <40	8	8	1	455	228	2	60	22	3	13500	4508	3	38	19	2
	≥40 to <50	0	0	1	312	125	6	191	84	6	76	19	4	15	15	1
	≥50 to <60	17	5	4	150	29	16	112	30	4	253	51	14	17	3	7
	≥60 to <70	5	1	5	423	66	30	0	0	6	258	14	28	34	3	10
	≥70 to <80	8	1	12	56	7	17	0	0	2	219	27	18	0	0	12
	≥80 to <90	No Pools			88	6	17	No Pools			203	14	20	24	2	16
	≥90 to <100	2	1	4	12	2	12	0	0	5	563	120	14	26	2	11
	≥100 to <110	50	50	1	2	1	3	2	2	1	10307	2579	4	7521	1893	4
	≥110 to <120				No Pools			No Pools			1500	536	4	60	20	3
	≥120				No Pools			No Pools			1200	406	4	100	56	2
Low Risk (1 October to 31 May)	≤30	7	7	1	46	22	5	6	3	2	68	44	4	6	3	5
	≥30 to <40	953	86	14	5071	205	46	289	33	20	228	14	29	358	40	32
	≥40 to <50	201	22	11	623	42	51	337	23	37	117	13	40	526	40	28
	≥50 to <60	33	6	8	146	16	32	20	3	18	86	4	25	601	33	23
	≥60 to <70	177	23	8	700	42	35	16	2	18	11	1	34	2	0	24
	≥70 to <80	1	0	3	79	5	15	2	0	6	3	0	15	8	1	16
	≥80 to <90	No Pools			0	0	2	No Pools			1	0	3	0	0	3
	≥90 to <100				0	0	1	0	0	1	0	0	1	0	0	1
	≥100 to <110															
	≥110 to <120				No Pools			No Pools								
	≥120				No Pools			No Pools			0	0	1	0	0	1

Observed Effect — Kootenay River

Risk Period	Resultant Birchbank Discharge (kcfs)	Kootenay River (LUB)			Kootenay River (RUB)		
		# of Fish Max.	# of Fish Avg.	# of RE	# of Fish Max.	# of Fish Avg.	# of RE
High Risk (1 June to 30 September)	≤30						
	≥30 to <40	129	76	2	641	160	4
	≥40 to <50	94	28	5	81	31	8
	≥50 to <60	58	5	14	3901	257	18
	≥60 to <70	3172	126	32	5737	212	30
	≥70 to <80	1	0	11	35	3	15
	≥80 to <90	No Pools			12	2	10
	≥90 to <100	No Pools			No Pools		
	≥100 to <110	No Pools			No Pools		
	≥110 to <120	No Pools			No Pools		
	≥120	No Pools			0	0	2
Low Risk (1 October to 31 May)	≤30	0	0	2	382	146	5
	≥30 to <40	286	16	27	1168	59	42
	≥40 to <50	517	50	50	1450	112	63
	≥50 to <60	193	17	34	2839	122	37
	≥60 to <70	122	10	46	529	14	50
	≥70 to <80	0	0	14	10	1	17
	≥80 to <90	No Pools			0	0	4
	≥90 to <100	No Pools			No Pools		
	≥100 to <110	No Pools			No Pools		
	≥110 to <120	No Pools			No Pools		
	≥120	No Pools			0	0	1

Observed Effect — Columbia River

Risk Period	Resultant Birchbank Discharge (kcfs)	Zuckerberg Island (LUB)			Kinnaird Rapids (RUB)			Waterloo U/S (RUB)			Waterloo Eddy (RUB)			Blueberry Creek (LUB)			Blueberry Creek D/S (LUB)		
		# of Fish Max.	# of Fish Avg.	# of RE	# of Fish Max.	# of Fish Avg.	# of RE	# of Fish Max.	# of Fish Avg.	# of RE	# of Fish Max.	# of Fish Avg.	# of RE	# of Fish Max.	# of Fish Avg.	# of RE	# of Fish Max.	# of Fish Avg.	# of RE
High Risk (1 June to 30 September)	≤30													No Pools					
	≥30 to <40	620	221	3	No Pools						0	0	1	0	0	1			
	≥40 to <50	0	0	1				13	13	1				4505	4505	1			
	≥50 to <60	18	5	6	0	0	1	0	0	1	No Pools			0	0	3			
	≥60 to <70	55	4	14	0	0	1	No Pools			No Pools			1	0	7	No Pools		
	≥70 to <80	48	4	12	No Pools									1299	128	14	No Pools		
	≥80 to <90	0	0	14	No Pools			No Pools						269	38	12			
	≥90 to <100	No Pools			No Pools						No Pools			No Pools					
	≥100 to <110	0	0	3										0	0	2			
	≥110 to <120	No Pools			No Pools									0	0	2			
	≥120	0	0	1										0	0	2			
Low Risk (1 October to 31 May)	≤30	5	2	3	1	1	2							No Pools					
	≥30 to <40	638	33	30	No Pools			34	13	3				0	0	2	0	0	1
	≥40 to <50	298	26	37	2	1	3	24	8	3	0	0	3	0	0	5	0	0	1
	≥50 to <60	7	1	31	10	3	4				No Pools			152	30	5			
	≥60 to <70	109	4	32	0	0	8	No Pools			No Pools			1	0	8	No Pools		
	≥70 to <80	1	0	18	No Pools									0	0	5	No Pools		
	≥80 to <90	0	0	3	No Pools			No Pools						0	0	2			
	≥90 to <100	No Pools			No Pools						No Pools			No Pools					
	≥100 to <110																		
	≥110 to <120	No Pools			No Pools														
	≥120	0	0	1															

Observed Effect — Columbia River (continued)

Risk Period	Resultant Birchbank Discharge (kcfs)	Sandbar Eddy (LUB)			Genelle Mainland (LUB) [a]			Birchbank Snye (LUB)			Gyro Park (RUB)			Gyro Boat Launch (RUB)			Trail Bridge (RUB)		
		# of Fish Max.	# of Fish Avg.	# of RE	# of Fish Max.	# of Fish Avg.	# of RE	# of Fish Max.	# of Fish Avg.	# of RE	# of Fish Max.	# of Fish Avg.	# of RE	# of Fish Max.	# of Fish Avg.	# of RE	# of Fish Max.	# of Fish Avg.	# of RE
High Risk (1 June to 30 September)	≤30																		
	≥30 to <40													152	152	1			
	≥40 to <50				5	5	1				0	0	1	464	95	5			
	≥50 to <60				0	0	1							0	0	5	0	0	3
	≥60 to <70				333	197	2							0	0	4			
	≥70 to <80				225	88	3							0	0	8	No Pools		
	≥80 to <90	No Pools			268	202	2	No Pools						500	71	11	No Pools		
	≥90 to <100													500	120	6	No Pools		
	≥100 to <110													500	250	2			
	≥110 to <120													No Pools			No Pools		
	≥120													No Pools			No Pools		
Low Risk (1 October to 31 May)	≤30													0	0	3	2	1	2
	≥30 to <40				684	223	5	0	0	1				2024	216	19	20	5	14
	≥40 to <50				1	0	4				0	0	1	658	65	39	30	4	12
	≥50 to <60							0	0	1				273	31	19	8	1	11
	≥60 to <70	0	0	1				2000	667	3	0	0	1	351	19	19	14	2	8
	≥70 to <80													0	0	5	No Pools		
	≥80 to <90	No Pools						No Pools						0	0	2	No Pools		
	≥90 to <100																No Pools		
	≥100 to <110																		
	≥110 to <120													No Pools			No Pools		
	≥120													No Pools			No Pools		

Observed Effect — Columbia River (continued)

Risk Period	Resultant Birchbank Discharge (kcfs)	Casino Road Bridge, Trail (U/S)			Casino Road Bridge, Trail (D/S)			Korpack (LUB)			Bear Creek (RUB)			Beaver Creek (RUB)			Fort Shepherd Launch (RUB) [a]		
		# of Fish Max.	# of Fish Avg.	# of RE	# of Fish Max.	# of Fish Avg.	# of RE	# of Fish Max.	# of Fish Avg.	# of RE	# of Fish Max.	# of Fish Avg.	# of RE	# of Fish Max.	# of Fish Avg.	# of RE	# of Fish Max.	# of Fish Avg.	# of RE
High Risk (1 June to 30 September)	≤30													No Pools					
	≥30 to <40				0	0	1							31	31	1			
	≥40 to <50				207	74	3				0	0	1				0	0	1
	≥50 to <60	0	0	4	11	5	4				0	0	5	358	96	4	0	0	2
	≥60 to <70	6	1	8	5	1	6	0	0	3	2030	232	14	21	4	7	2	1	5
	≥70 to <80	No Pools			0	0	4				57	9	11	21	3	10	27	3	10
	≥80 to <90	No Pools			No Pools			No Pools			0	0	6	62	10	6	134	22	6
	≥90 to <100	No Pools			No Pools						No Pools			251	55	6	No Pools		
	≥100 to <110																0	0	1
	≥110 to <120	No Pools			No Pools						No Pools			No Pools					
	≥120	No Pools			No Pools						No Pools			No Pools					
Low Risk (1 October to 31 May)	≤30	0	0	3	0	0	2				0	0	2	No Pools			0	0	1
	≥30 to <40	0	0	10	1	0	12	122	16	8	18	2	14	72	20	9	9	2	9
	≥40 to <50	4	0	11	2	0	10	0	0	4	2015	119	17	4	0	9	5	1	13
	≥50 to <60	0	0	15	21	1	21	0	0	5	2063	138	15	17	3	8	29	6	7
	≥60 to <70	1	0	19	3	0	23	0	0	3	2	0	20	4	1	7	46	7	7
	≥70 to <80	No Pools			0	0	7	No Pools			3	0	12	0	0	5	0	0	2
	≥80 to <90	No Pools			No Pools			No Pools			0	0	2	0	0	3	0	0	1
	≥90 to <100	No Pools			No Pools						No Pools						No Pools		
	≥100 to <110																		
	≥110 to <120	No Pools			No Pools						No Pools			No Pools					
	≥120	No Pools			No Pools						No Pools			No Pools					

Code	Description	Definition
	No Pools	Site has been previously surveyed; isolated pools have not been recorded.
	Minimal Effect	Site has been previously surveyed five or more times under similar flow conditions; isolated pools were observed and the maximum number of stranded fish during a single RE was less than 200.
	No Data or Insufficient Data	Site has been previously surveyed less than five times under similar flow conditions; isolated pools were observed and the maximum number of stranded fish during a single RE was less than 200.
	Effect	Site has been previously surveyed under similar flow conditions; the maximum number of fish stranded during a single RE was greater than or equal to 200.
	Unlikely Discharge Range	Birchbank discharge has not been recorded at these levels during the specified time period based on discharge data collected between 2000 and 2023.
	Species of Concern Were Stranded	During at least one stranding assessment under similar flow conditions species of concern (i.e., Columbia Sculpin, Shorthead Sculpin, or Umatilla Dace) were stranded.

Notes

RE = reduction event; Max. = maximum number of fish stranded during a single RE; Avg. = average number of fish stranded over all RE; RUB = right bank as viewed facing upstream; LUB = left bank as viewed facing upstream; MID = mid channel site.

When multiple day assessments were conducted for a single RE, the fish numbers for were summed.

Includes all stranding assessment data collected from the lower Columbia and Kootenay rivers from flow reductions at HLK/ALH and BRD/X between 1 January 2000 and 1 April 2023.

a. Sites have been physically recontoured. Data from pre-recontouring not included.

3.5 Summary of 2022/2023 Results

The main findings from fish stranding assessments conducted on the Lower Columbia and Kootenay rivers in response to flow reductions at HLK/ALH and BRD/X between 1 April 2022 and 1 April 2023 are:

- Discharge in the Columbia River at Birchbank was similar to previous study years and ranged from 24.5 kcfs to 155.7 kcfs.
- There were 45 operational flow reduction events; 30 from HLK/ALH, 14 from BRD/X, and 1 from both facilities on the same day. Stranding assessments were conducted for 14 of the 45 reduction events, resulting in a response rate of 31%.
- During the 14 fish stranding assessments conducted, 6,856 fish were recorded as stranded. Of these stranded fish, 56% were successfully salvaged and returned to the Columbia or Kootenay river, 35% were observed during salvage efforts but avoided capture, and 9% were mortalities. The majority of stranded fish (84%) were observed during the Low Risk period, contrary to previous years. Genelle Mainland (LUB) and Norns Creek Fan (RUB) accounted for 59% of all stranded fish identified.
- Sportfish accounted for 45% of all stranded fish and included YOY and juvenile Mountain Whitefish, Rainbow Trout, and Kokanee. Non-sportfish accounted for 55% of stranded fish with sucker spp. and Longnose Dace representing the highest abundance.
- Stranded exotic species included 148 Common Carp and 30 Tench. All exotic species encountered were euthanized and removed from the lower Columbia or Kootenay River as a requirement of the Scientific Fish Collection Permit.
- Stranded species of conservation concern included 50 Umatilla Dace, 3 Columbia Sculpin, and 2 Shorthead Sculpin. The majority (82%) of Umatilla Dace were stranded at Bear Creek (RUB) during the Low Risk period.

3.6 Statistical Analysis to Address Management Questions

To address this monitoring program’s management questions, statistical analysis was conducted using the 23-year dataset from fish stranding assessments conducted on the Lower Columbia and Kootenay rivers. A zero-inflated generalized linear mixed model (ZIGLMM) was used to assess the effects of ramping rate, wetted history, and physical habitat recontouring, while accounting for other covariates of fish stranding, and annual and site-to-site variation. A separate model was conducted for recontouring, because only some of the sites had physical works to recontour the habitat.

In the model used to assess ramping rate and wetted history, ramping rate was not a statistically significant predictor of the probability or number of fish stranded (Table 10) and ramping rate did not show any clear relationship with either the predicted or observed values fish of stranding (Figure 9). Wetted history had a statistically significant effect on both the probability of observing stranded fish and the number of fish stranded (Table 10). The predicted probability of observing stranded fish increased from 0.37 at 1 day of wetted history to 0.49 at 100 days wetted history and plateaued at 0.55 at approximately 200 days (top panel; Figure 10). The predicted number of fish stranded, based on the combined two components of the model, increased from 20 fish at 1 day of wetted history to 59 fish at 100 days, and peaked at 86 fish at 220 days (bottom panel;

Figure 10). The small decrease in the predicted number of fish stranded at wetted history greater than 220 days was likely related to smaller sample sizes and high variability at greater values of wetted history. These predictions are while holding all other predictor variables in the model at their mean values for continuous variables and at reference level for categorical variables.

Other predictor variables in the model used to assess ramping rate and wetted history were not directly related to management questions but were included to account for and improve understanding of other variables that may influence fish stranding. Magnitude of reduction was a statistically significant predictor of both the probability of stranding and the number of fish stranded (Table 10).The predicted mean probability of stranding one or more fish increased from 0.23 at a reduction of 28 m^3/s (approximately equivalent to 1 kcfs) to 0.59 at a reduction of 598 m^3/s (approximately 21 kcfs), but decreased at reductions greater than 598 m^3/s (top panel; Figure 11). Similarly, the predicted mean number of fish stranded, based on the combined two components of the model, increased from 32 fish at a reduction of 28 m^3/s to a peak of 55 fish at a reduction of 348 m^3/s, but then decreased at larger reductions (bottom panel; Figure 11).

There was a negative relationship between the number of fish stranded, in events where one or more fish were stranded (i.e., the conditional model), and the magnitude of reduction (middle panel; Figure 11). The negative relationship between magnitude of reduction and the conditional number of fish stranded was the opposite of the expected positive relationship and may be explained by the high variability and relatively small number of observations at very low and very high magnitudes of reduction. The unexpected greater conditional number of fish predicted at low magnitude reductions could also be partly explained by the lower river stage (minimum discharge) that were more common during small reductions, and the associated greater expected greater number of fish stranded at low discharges. As large magnitude reductions did not occur during low discharges, these variables are partly confounded when discharge is very low, which could mean that the model is less able to separate the effects of these two variables. Overall, the results from the combined model support the expected increase in number of fish stranded between low- and medium-sized reductions, with high uncertainty and a likely spurious negative relationship at higher magnitude reductions.

Minimum discharge was used as a proxy to assess the effect of river stage on fish stranding. Minimum discharge was a statistically significant predictor of both the probability of stranding and number of fish stranded (Table 10). The probability of observing stranded fish decreased little between 800 m^3/s (0.68) and 1200 m^3/s (0.69) but decreased to 0.17 at 2500 m^3/s (top panel; Figure 12). The combined model of probability and number of fish stranded suggested a non-linear relationship with minimum discharge. The predicted number of fish stranded increased from 155 fish at 800 m^3/s to a peak of 206 fish at 1100 m^3/s and decreased to 34 fish at 2000 m^3/s (bottom panel; Figure 12).

Day of year was included in the models to account for seasonal variation in stranding risk. Day of year was a statistically significant predictor of both the probability of stranding and number of fish stranded (Table 10). The probability of stranded fish peaked in mid-August, whereas the predicted number of fish stranded based on the combined model peaked in mid-July (Figure 13). Predictions of the number of fish stranded were highly uncertain between April and August (grey ribbon in bottom panel; Figure 13). Although the observed data suggested a second peak in fish stranding in late March and April, this was likely related to the values of other predictor variables during that time of year, not the time of year *per se*. For example, March and April often have relatively low minimum discharge (~1,000 to 1,300 m^3/s) and intermediate discharge reductions (between 200 and 450 m^3/s), both of which are associated with higher stranding counts (Figure 12 and Figure 11, respectively).

River kilometre was a statistically significant predictor of the probability of fish stranding but not the number of fish stranded (Table 10 and Figure 14). The predicted probability of stranding one or more fish decreased from 0.58 at river kilometre 7, which is near Norns Creek Fan (RUB), to 0.29 at river kilometre 47, which is near Beaver Creek (RUB).

Table 10: Statistical significance of predictor variables in the fish stranding model used to assess the effects of ramping rate and wetted history in the lower Columbia and Kootenay rivers, 2000 to 2023.

Predictor Variable	Effect on Probability of Stranding (Zero-Inflation Model)	Effect on Number of Fish Stranded (Conditional Model)
	P-Value	*P*-Value
Ramping Rate	0.070	0.400
Wetted History	**<0.001**	**0.002**
Magnitude of Reduction	**<0.001**	**0.020**
Minimum Discharge	**<0.001**	**0.003**
Day of Year	**<0.001**	**<0.001**
River Kilometre	**0.004**	0.900
Load Shaping	0.100	0.300

Note: Direction of the effect, estimated coefficients, and their uncertainty are not presented because many of the predictor variables were modelled as splines (i.e., ramping rate, wetted history, magnitude of reduction, minimum discharge, and day of year), which means that they had multiple coefficients per variable, which makes it not possible to interpret the standardized coefficients as effect sizes. Instead, effect size is presented in terms of the change in predicted values relative to each predictor variable, while holding other variables at their mean values (Figures 7 to 12). Variables significant at the 0.05 level are shown in **bold**.

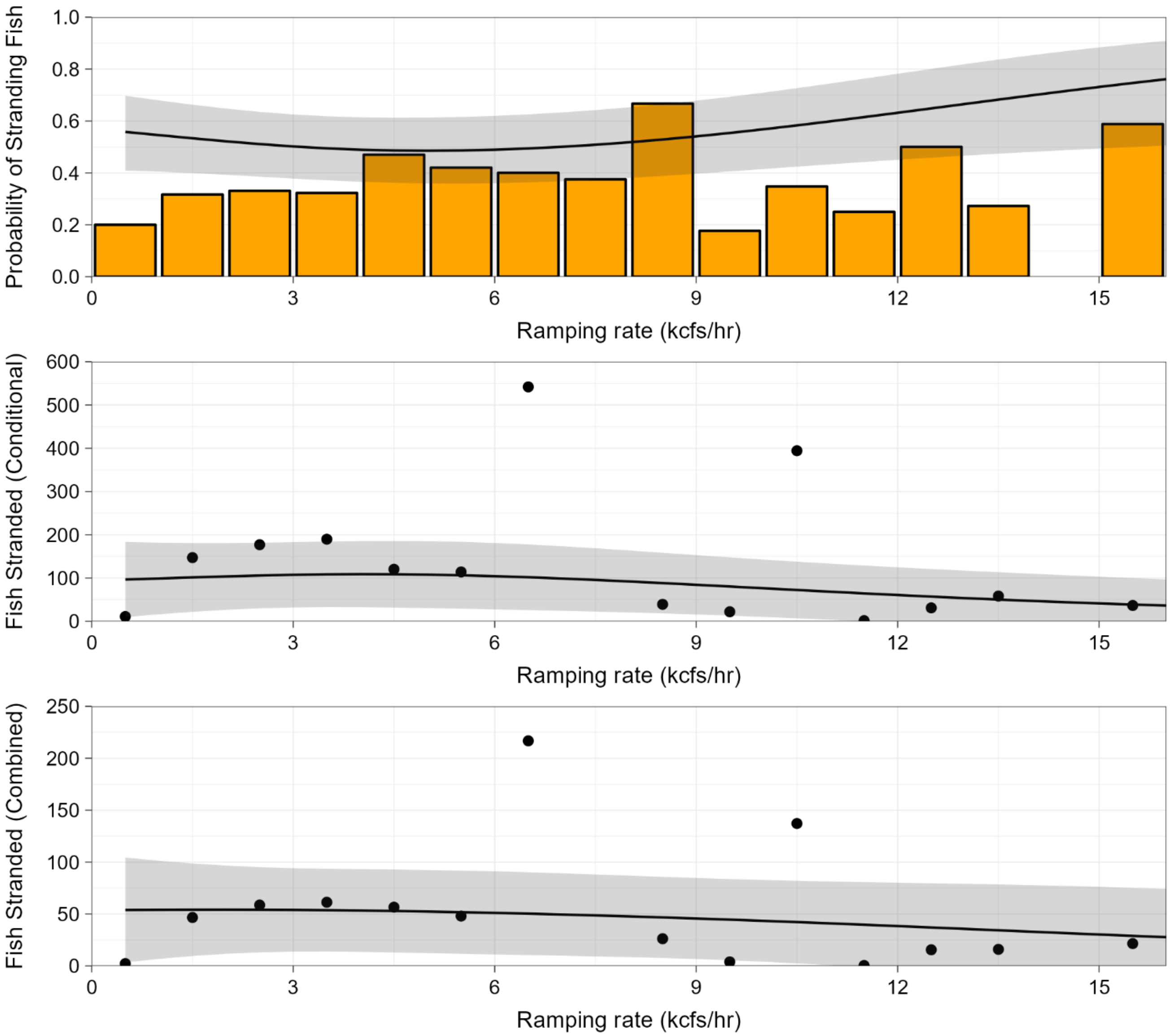

Figure 9: Predicted fish stranding versus ramping rate in the lower Columbia and Kootenay rivers, 2000 to 2023. Orange bars and black points are the mean values of the observed data by 1 kcfs/hr bins of ramping rate. Black line is the mean prediction and grey ribbon is the approximate 95% confidence interval. Ramping rate was not a statistically significant predictor of either the probability of stranding fish or the number of fish stranded.

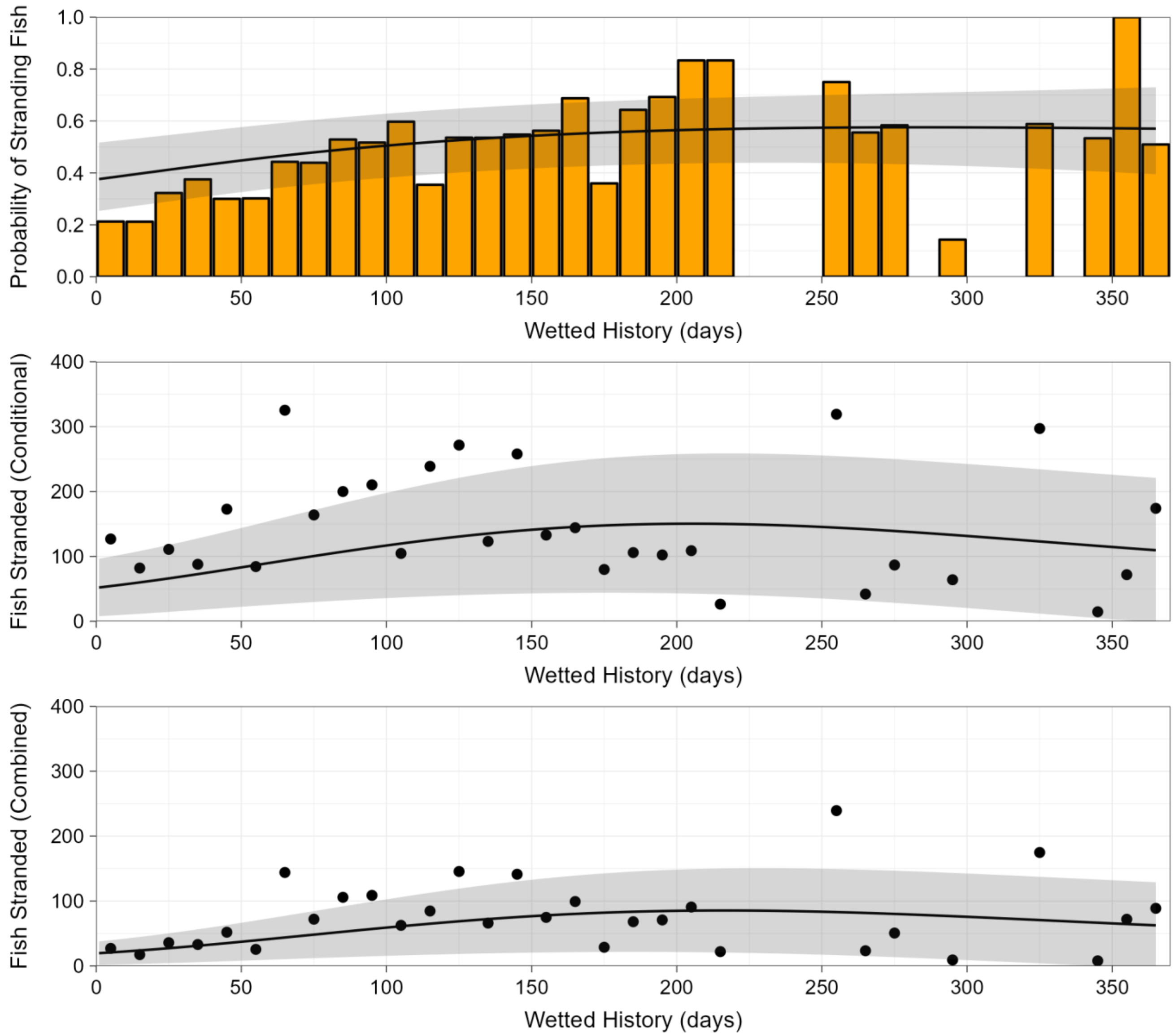

Figure 10: Predicted fish stranding versus wetted history in the lower Columbia and Kootenay rivers, 2000 to 2023. Orange bars and black points are the mean values of the observed data by 10-day bins of wetted history. Black line is the mean prediction and grey ribbon is the approximate 95% confidence interval.

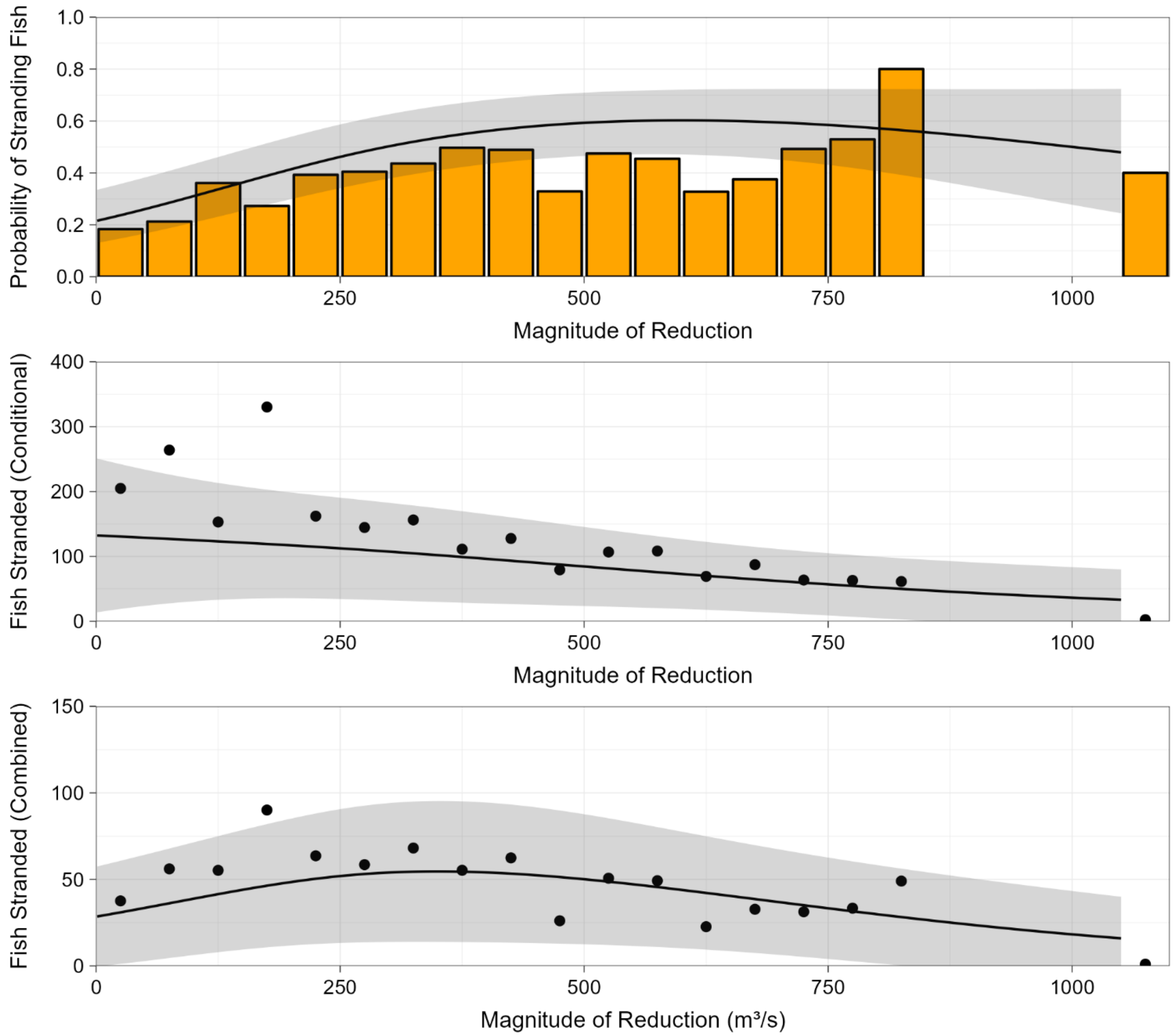

Figure 11: Predicted fish stranding versus magnitude of discharge reduction in the lower Columbia and Kootenay rivers, 2000 to 2023. Orange bars and black points are the mean values of the observed data by 50 m³/s bins of magnitude of reduction. Black line is the mean prediction and grey ribbon is the approximate 95% confidence interval.

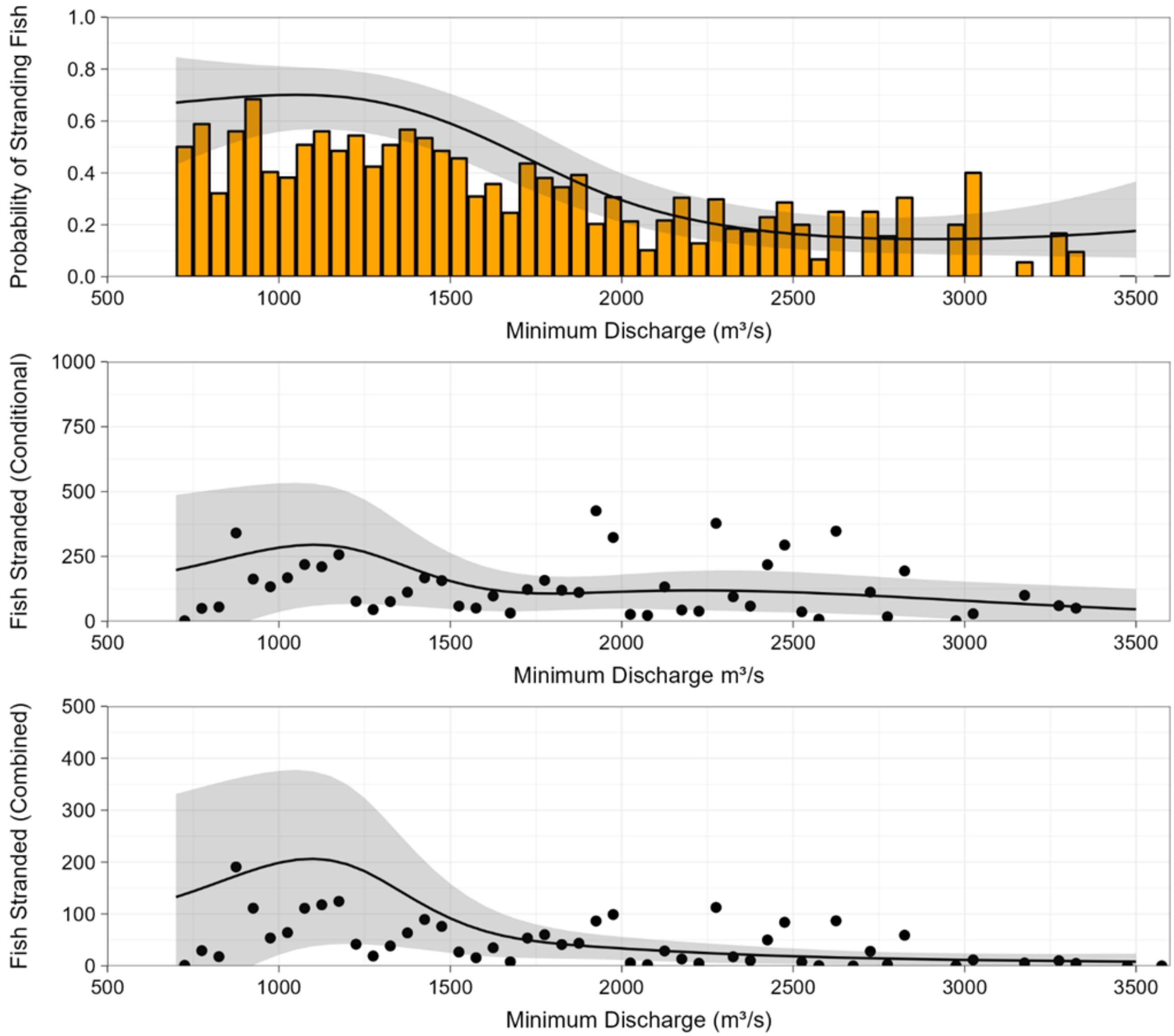

Figure 12: Predicted fish stranding versus minimum discharge reached during the reduction in the lower Columbia and Kootenay rivers, 2000 to 2023. Orange bars and black points are the mean values of the observed data by 50 m³/s bins of minimum discharge. Black line is the mean prediction and grey ribbon is the approximate 95% confidence interval.

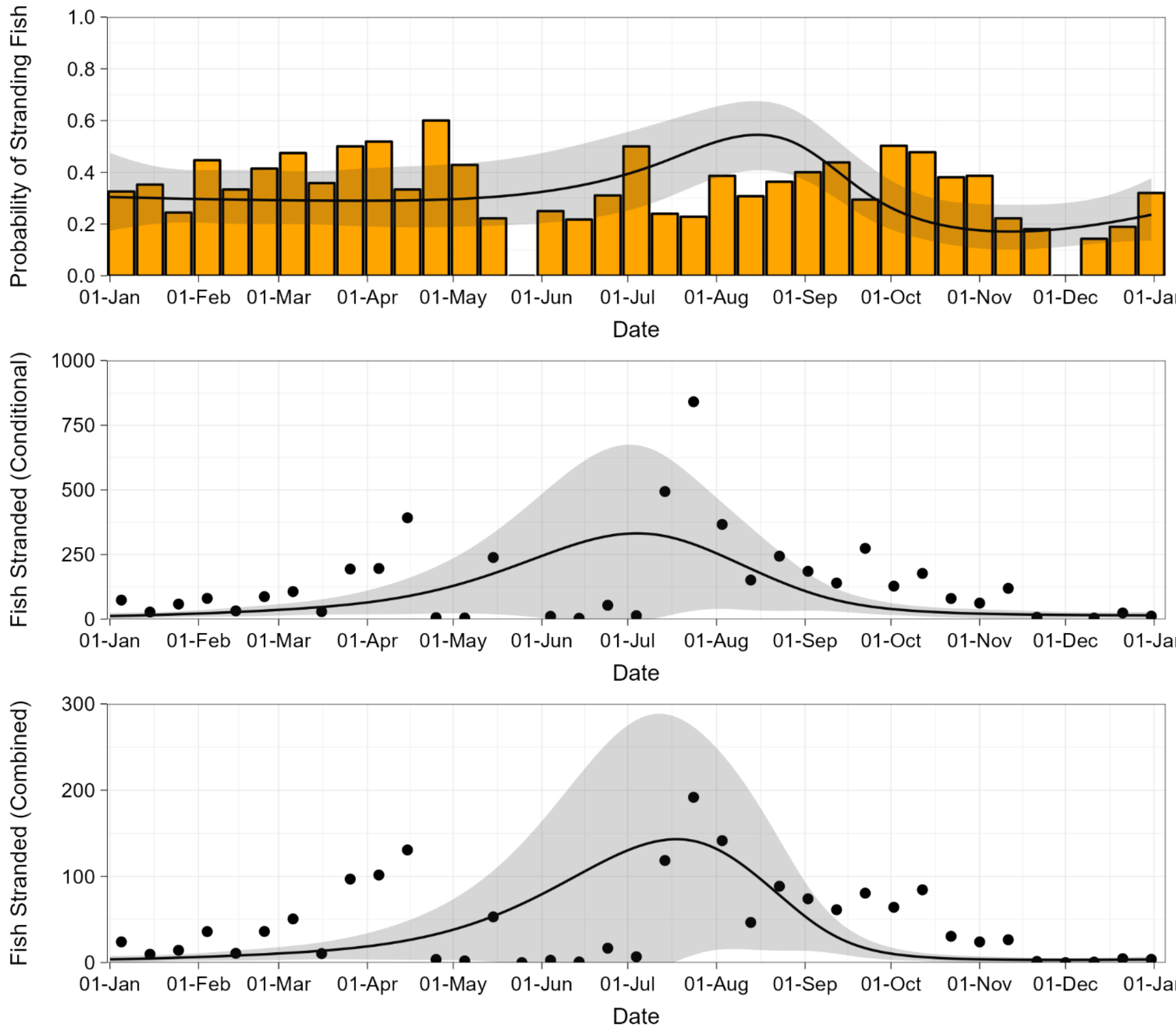

Figure 13: Predicted fish stranding versus day of year in the lower Columbia and Kootenay rivers, 2000 to 2023. Orange bars and black points are the mean values of the observed data by 10-day bins. Black line is the mean prediction and grey ribbon is the approximate 95% confidence interval.

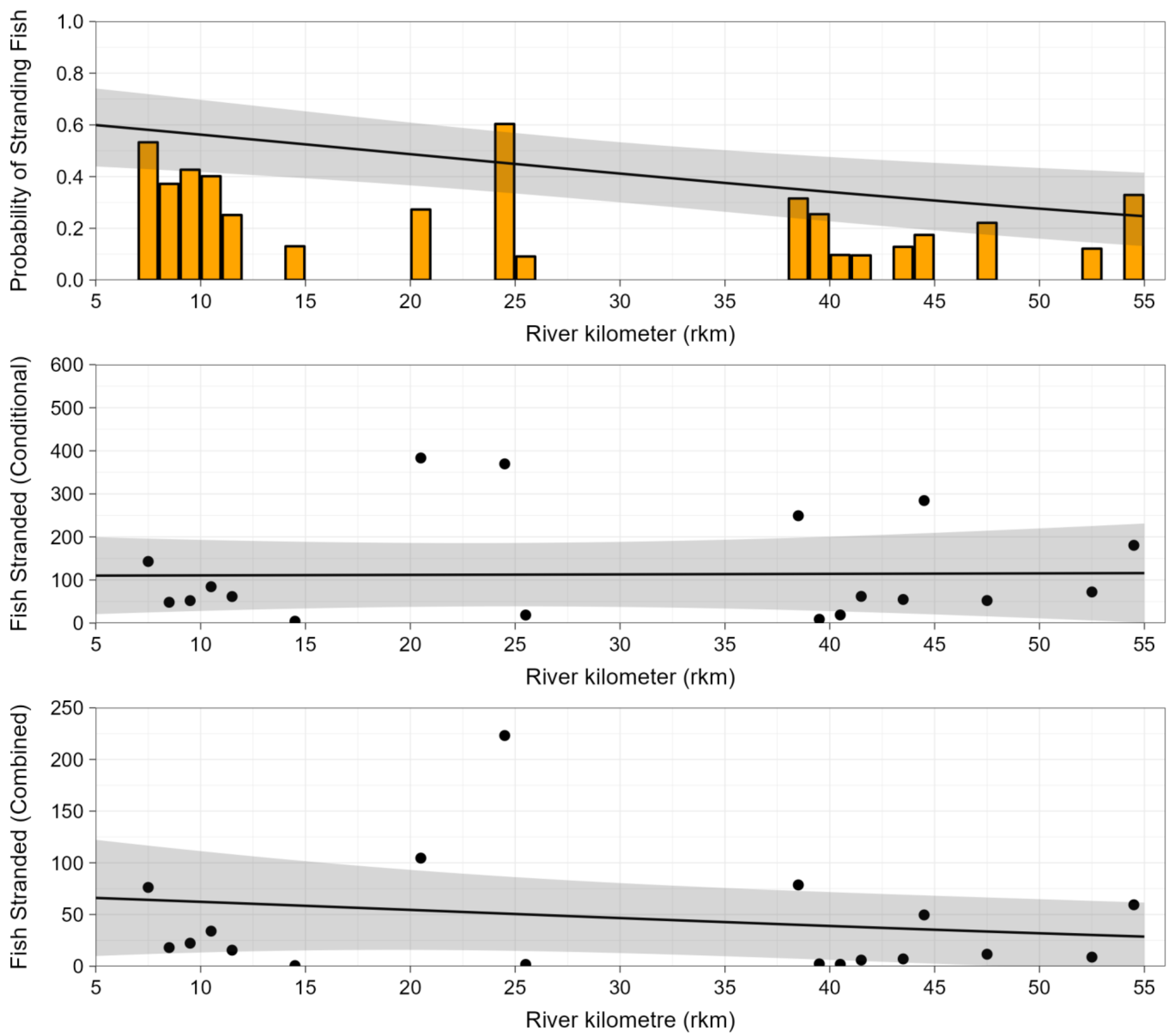

Figure 14: Predicted fish stranding versus river kilometre in the lower Columbia and Kootenay rivers, 2000 to 2023. Orange bars and black points are the mean values of the observed data by 1 km bins. Black line is the mean prediction and grey ribbon is the approximate 95% confidence interval.

In the model used to assess physical habitat recontouring, the effect of recontouring was statistically significant for both the probability of stranding fish and the number of fish stranded (Table 11). The predicted probability and number of fish stranded was greater before recontouring than after recontouring at all five sites, but the size of the difference varied among sites (Figure 15). In terms of the predicted probability of stranding, the effect of recontouring was larger at Millenium Park (LUB), Lions Head (RUB), and Fort Shepherd Launch (RUB), where the probability of stranding fish decreased by 13% to 16% after recontouring, and smaller at Genelle Mainland (LUB) and Norns Creek Fan (RUB), where the probability decreased by 7% after recontouring (top panel; Figure 15). In terms of the predicted number of fish stranded based on the combined two components of the model, the largest positive effect occurred at Genelle Mainland (LUB), where the predicted mean number of fish based on the combined model was 1,323 fish before recontouring and 418 fish after recontouring (bottom panel; Figure 15). In comparison, at the site with the smallest effect of recontouring as an absolute difference in the number of stranded fish, Lions Head (RUB), the predicted mean number of stranded fish decreased from 133 fish before recontouring to 40 fish after recontouring. When the effect of recontouring was calculated as a percent change relative to the predicted number of fish stranded before recontouring, the effect of recontouring was similar among sites, ranging from 68% to 72% fewer fish stranded after recontouring than before.

Population-level predictions were used to show the effect size of recontouring for an average site in an average year. The predicted probability of observing stranded fish was 0.83 (confidence interval: 0.69 to 0.91) before recontouring and 0.71 (confidence interval: 0.55 to 0.84) after recontouring. These estimates indicate that recontouring resulted in a 12% decrease, on average, in the probability of stranding one or more fish. The predicted mean number of fish stranded decreased from 281 fish (confidence interval: 0–589 fish) before recontouring to 86 fish (confidence interval: 0–173 fish) after recontouring, which represents a 69% reduction in predicted mean fish stranding.

In the model used to assess physical habitat recontouring, the effects of the other covariates in the model were similar to the model using the full dataset (i.e., all stranding sites) used to assess wetted history and ramping rate. The effects of wetted history, magnitude of reduction, minimum discharge, and day of year were statistically significant, but the effect of load shaping was not (Table 11). The direction and approximate size of these effects was similar to the full model (Figures 7 to 12), and therefore these results are not presented or discussed in detail.

Table 11: Statistical significance of predictor variables in the fish stranding model used to assess the effects of physical habitat recontouring in lower Columbia and Kootenay rivers, 2000 to 2023.

Predictor Variable	Effect on Probability of Stranding (Zero-Inflation Model)	Effect on Number of Fish Stranded (Conditional Model)
	***P*-Value**	***P*-Value**
Recontouring	**0.002**	**0.002**
Ramping Rate	0.100	0.400
Wetted History	**0.040**	**0.010**
Magnitude of Reduction	**<0.001**	0.700
Minimum Discharge	**<0.001**	**<0.001**
Day of Year	**<0.001**	**<0.001**
Load Shaping	0.300	0.200

Note: Direction of the effect, estimated coefficients, and their uncertainty are not presented because the continuous predictor variables were modelled as splines (i.e., ramping rate, wetted history, magnitude of reduction, minimum discharge, and day of year), which means that they had multiple coefficients per variable, which makes it not possible to interpret the standardized coefficients as effect sizes. Effect sizes in this model were similar to the effects of these variables in the model used to assess the effects of ramping rate and wetted history based on all stranding sites (Figures 7 to 12). Variables significant at the 0.05 level are shown in **bold**.

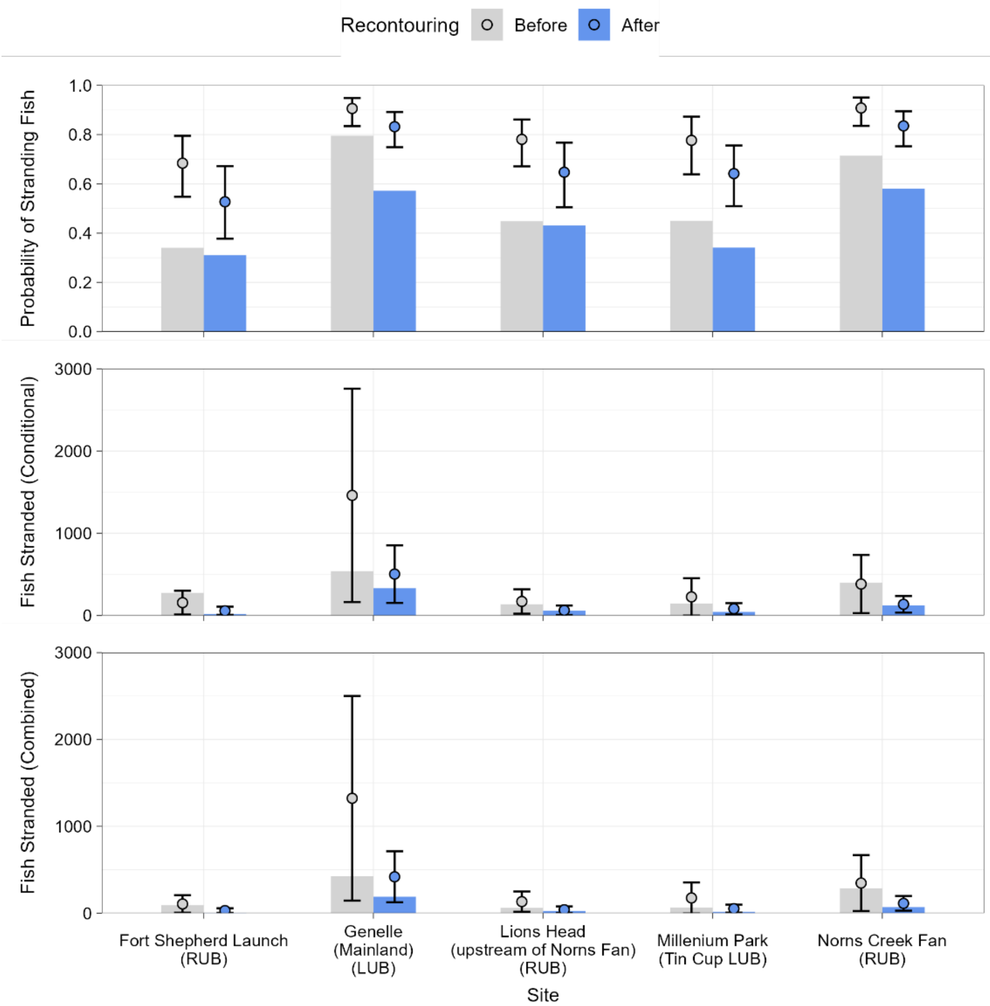

Figure 15: Predicted fish stranding before versus after recontouring by site in the lower Columbia and Kootenay rivers, 2000 to 2023. Points are predicted values and error bars are approximate 95% confidence intervals. Bars are the observed values from the data.

4.0 DISCUSSION

The Lower Columbia River and Kootenay River Fish Stranding Assessments (CLBMON-42[A]) were conducted between 1 April 2022 to 1 April 2023 in response to operational flow reductions at HLK/ALH and BRD/X, and the results are described above in Sections 3.1 to 3.5. In addition, a statistical analysis of the 23-year dataset of fish stranding assessment data was conducted to address the management questions of CLBMON-42. Results from the analysis and other supporting information are discussed in the sections below for each management question.

4.1 Management Question #1

"Is there a ramping rate (fast vs. slow, day vs. night) for flow reductions from HLK that reduces the number of fish stranded (interstitially and pool) per flow reduction event in the summer and winter?"

Based on 23 years of fish stranding assessments and experimental flow ramping studies conducted prior to CLBMON-42, ramping rate within the range of operational ramping rates currently used at HLK/ALH does not appear to influence fish stranding in the lower Columbia River.

Twenty-three years of data from fish stranding assessments were used to assess the effect of ramping rate on the number of fish stranded, using a statistical model that accounted for other variables that can influence stranding, such as magnitude of discharge reduction, day of year of reduction, and river stage. For this analysis, ramping rate was represented as the average ramping rate for each reduction as controlled by the hydroelectric facility responsible for the reduction. The majority of operational ramping rates per reduction were within the range of 1 to 10 kcfs/hr. The available data and modelling results suggest no effect of ramping rate on the likelihood or number of fish stranded (Table 10; Figure 9). These results agree with a previous analysis of lower Columbia River fish stranding assessments using data from 1999 to 2009 (Golder and Poisson 2010; Irvine et al. 2014). In this previous statistical analysis, ramping rate for each reduction was calculated as the rate of change in cm/hr as measured at Birchbank and did not have a statistically significant effect on stranding risk. In another recent analysis of the Lower Columbia River Fish Stranding Database to develop a predictive model of fish stranding, ramping rate was not an informative predictor of fish stranding and was therefore not included in the model (Dalgarno and Thorley 2023).

Experimental flow ramping studies also found no significant effect of ramping rate on fish stranding. Between 2004 and 2006, experimental flow ramping studies were conducted in the summer and winter on the Columbia and Kootenay rivers to assess the effect of flow ramping rate on the probability of pool and interstitial stranding of juvenile fishes (Golder 2005, 2006, 2007). Over the range of ramping rates tested (3.9 to 13.3 cm/hr for interstitial stranding experiments, and 7.4 to 35.3 cm/hr for pool stranding experiments as measured within test sites), ramping rate did not have a statistically significant effect on interstitial or pool stranding (Golder 2007). A subsequent statistical analysis conducted on the three years of experimental flow ramping data found that there was a trend of increased fish stranding frequency with increased ramping rates for pool stranding experiments, but the relationship was weak, and ramping rate was ranked low in terms of variable importance in the statistical models (Irvine et al. 2009). Similar results showing a lack of effect of ramping rate were reported in experimental flow ramping studies conducted in the lower Duncan River (Golder 2008).

As hypothesized by Golder and Poisson (2010), the lack of a detectable effect of ramping rates may be because of the relatively small range of ramping rates observed in the lower Columbia River, compared to studies elsewhere, where ramping rates were often much faster. In experimental studies, Salveit et. al. (2001) assessed ramping rates between 14 and 78 cm/hr and found a decrease in fish stranding when rates were slow (14-18 cm/hr). Although ramping rate was never a statistically significant predictor of fish stranding in studies in the lower Columbia River, the trend of increased fish stranding with increased ramping rate found during experimental ramping studies (Golder 2005) has resulted in hydroelectric facilities adopting relatively conservative operational ramping rates for reduction events to allow fish the greatest amount of time to leave the near-shore area prior to de-watering.

An additional component of this management question is the effect of time of day, specifically day versus night, on fish stranding. Some previous analyses have assessed the effect of time of day and reported a weak effect, but there have been few ramping experiments and no stranding assessments conducted at night. Therefore, the effect of time of day cannot be conclusively determined with the available data.

A statistical analysis of the fish stranding assessment data (1999 to 2009) on the lower Columbia River assessed whether time of day had an effect on the probability of stranding fish (Golder and Poisson 2010; Irvine et al. 2014). Four definitions of stranding levels were modelled with greater than or equal to 1, 50, 200, and 1,000 stranded fish required to constitute a stranding event. Based on the available data, the highest risk period for stranding was in the late afternoon. The relationship between time of day and fish stranding probability was significant only with the model that considered a stranding event to be equal to or greater than one fish; therefore, it was not considered to be a strong predictor of stranding risk (Golder and Poisson 2010; Irvine et al. 2014). Stranding assessments used for the Golder and Poisson (2010) and Irvine et al. (2014) analysis were all conducted during the day, which limits the ability to assess whether more fish strand during the day or night.

The effect of time of day (day versus night) on fish stranding was also tested in experimental flow ramping studies in the summer and winter in 2004 and 2005 on the Columbia and Kootenay rivers (Golder 2005, 2006). Results indicated a weak trend for interstitial stranding to occur more at night than during the day in winter (Golder 2005); however, a subsequent analysis conducted on all years of flow ramping studies revealed that time of day was not a statistically significant predictor for the probability of interstitial stranding in winter, or pool stranding in summer (Golder 2007; Irvine et al. 2009). The dataset for the analysis on all years of flow ramping studies was limited to seven experiments conducted at night and 65 experiments during the day. Other studies on the effect of time of day on juvenile fish stranding have provided conflicting results. In some studies, more fishes were stranded at night (e.g., Salveit et al. 2001) while other studies noted greater stranding occurring during daytime (e.g., Bradford et al. 1995).

Additional night-time ramping experiments, or night-time reduction events and stranding assessments would be required to determine if there is any difference in the probability of fish stranding between day and night.

4.2 Management Question #2

"Does wetted history (the length of time the habitat has been wetted prior to the flow reduction) influence the number of fish stranded (interstitially and pool) per flow reduction event for flow reductions from HLK?"

Based on 23 years of fish stranding assessments and experimental flow ramping studies conducted prior to CLBMON-42, wetted history does influence the number of fish stranded due to reduction events at HLK/ALH.

In the statistical analysis of the 23-year dataset of fish stranding assessments in the lower Columbia and Kootenay Rivers, wetted history had a statistically significant positive effect on both the probability of stranding and the number of fish stranded (Figure 10). This supports the idea that substrate that had been inundated for a longer period was more likely to strand fish if dewatered, compared to substrate that was inundated for a shorter period. The predicted probability of stranding fish increased from 0.37 at 1 day of wetted history to 0.49 at 100 days wetted history and plateaued at 0.55 at approximately 200 days. The predicted number of fish stranded per site, based on the full combined model, increased from 20 fish at 1 day of wetted history to 59 fish at 100 days, and peaked at 86 fish at 220 days (Figure 10). As there were 24 stranding sites included in the analysis, a difference of 66 fish per site between 1 and 220 days wetted history suggests a biological meaningful effect of wetted history on stranding risk.

These results are supported by a previous statistical analysis of the lower of the lower Columbia River fish stranding assessment data (Golder 2020a; Golder and Poisson 2010; Irvine et al. 2014). When a statistical analysis was conducted on the 1999 to 2009 dataset of the lower Columbia River fish stranding assessment data, results showed that wetted history had a statistically significant effect on the probability of fish stranding (Golder and Poisson 2010). In that statistical model, when stranding was defined as greater than or equal to one fish, the probability of stranding was 18% at 1 day and approximately 40% at 90 days of wetted history. Additionally, there was a statistically significant increase in the probability of stranding after a wetted history of greater than 10 days (approximately 30%) versus a wetted history of less than ten days (approximately 15%).

The effect of wetted history on fish stranding was also tested during three years (2004 and 2006) of experimental flow ramping studies on the lower Columbia and Kootenay rivers (Golder 2005, 2006, 2007). The experiments took place in the summer and winter of each year and assessed the effect of wetted history on the probability of pool and interstitial stranding. Irvine et. al. (2009) conducted a subsequent statistical analysis, on all years of experimental flow ramping studies to rank the effect of each tested variable (wetted history, time of day, natural fish density and conditioning flow) on interstitial and pool fish stranding risk. Wetted history ranked high in relative importance for fish stranding in pools, suggesting that the longer the varial zone is inundated with water prior to a flow reduction event, the greater likelihood more fish will strand as a result of the flow reduction.

4.3 Management Question #3

"Can a conditioning flow (a temporary, one step, flow reduction of approximately 2 hours to the final target dam discharge that occurs prior to the final flow change) from HLK reduce the stranding rate of fish?"

Due to limited conditioning flow experiments conducted the effect of this potential fish stranding mitigation measure cannot be determined.

A conditioning reduction is intended to create a 'learned' behaviour in fish inhabiting the varial zone. If a short-term (1–2 hour) flow reduction were to take place prior to the normal planned reduction, then fish inhabiting the varial zone may react with a flight response, leaving the near-shore area, thereby reducing overall fish density within the varial zone. If fish density was reduced in the varial zone due to the conditioning flow, this would expect to result in less fish stranding when the normal operational flow reduction follows.

The concept of a conditioning reduction and its potential as a fish stranding mitigation strategy was based on quantitative and qualitative observations that the number of fish in the near-shore area and the number of fish stranded both decreased through time on the Columbia and Kootenay River systems in the first phase of flow ramping experiments (Golder 2005). As a result of these observations, investigating the effect of a conditioning reduction on fish stranding in the lower Columbia and Kootenay rivers was the primary objective of flow ramping experiments conducted in the summer of 2006 downstream of HLK/ALH. Results of these experiments suggest that a conditioning flow appeared to reduce the incidence of pool stranding on the Columbia River (Golder 2007; Irvine et al. 2009); When the effects of the conditioning reduction as the single predictor variable were tested for significance using a quasibinomial distribution, the predicted value of the proportion of stranded fish in experiments without a conditioning reduction was 34.22% (95% CI: 23.4 to 46.2%), and the predicted value of the proportion of stranded fish with a conditioning reduction was 24.95% (95% CI: 11.6 to 45.52%) (Golder 2007). As these confidence levels overlap, the effect is not statistically significant. However, these results were based on a limited number of experiments and a recommendation was made that additional experiments be conducted to verify the results (Golder 2007; Irvine et al. 2009).

As part of CLBMON-42, additional flow ramping experiments were not conducted (see Section 1.0), and the 23-year dataset of fish stranding assessments does not provide the necessary data to answer this management question. The fish stranding assessments were conducted in response to normal operational flow reductions, and conditioning flows were not implemented at HLK/ALH as a fish stranding mitigation strategy.

To further clarify the preliminary results regarding the effects of a conditioning flow on the rate of fish stranding, additional ramping experiments would be required.

The value of implementing conditioning flows may require an assessment of the operational risk versus the biological rationale. The implementation of conditioning reductions would result in an extra reduction for every normal operational reduction, effectively doubling the number of total reductions. Although the preliminary data from summer ramping experiments in 2006 suggest that a conditioning flow may reduce fish stranding, there is also the possibility that a conditioning reduction may in itself cause significant mortality. The time from dewatering until death is variable but can be less than 30 minutes (Hessevik 2002). In observations made on the lower Duncan River during ramping experiments conducted in the fall of 2009, less than 10% survival was noted for juvenile Mountain Whitefish within an isolated pool that de-watered over the 30 minute conditioning flow reduction (Poisson and Golder 2010).

4.4 Management Question #4

“Can physical habitat works (i.e., recontouring) reduce the incidence of fish stranding in high risk areas?”

Physical habitat recontouring conducted at high risk stranding sites on the lower Columbia River has reduced incidences of fish stranding.

Physical habitat recontouring on the lower Columbia River has been conducted by using heavy equipment during periods of low river stage to remove or fill in potential stranding pools, decrease habitat cover, and increase channel slope. The intention of physical habitat recontouring is to minimize habitat features that may be conducive to fish stranding. Sites on the lower Columbia River where physical habitat recontouring was conducted to reduce stranding risk are listed in Section 1.1.

Twenty-three years of data from fish stranding surveys were used to assess the effect of recontouring on the number of fish stranded using a statistical model that accounted for other variables that can influence stranding, such as magnitude of discharge reduction, day of year of reduction, and river stage. Results of modelling indicate a substantial reduction in both the probability and number of fish stranded after recontouring at all five sites assessed. Model predictions indicated a 12% reduction in the probability of stranding one or more fish, and a 69% reduction in the mean number of fish stranded, on average, after recontouring. A separate analysis of the LCR fish stranding data was conducted recently to develop a predictive model of fish stranding and found that, on average (i.e., for a typical site), the expected mean number of fish stranded decreased from 62 before recontouring to 25 fish after recontouring (Dalgarno and Thorley 2023), which represents a 60% reduction in the number of fish stranded and is similar to the effect size from the analysis in this report (69%).

In 2010, an analysis of the fish stranding assessment data from 1999 to 2009 identified a significantly higher probability of a stranding event (identified as ≥200 stranded fish) occurring before recontouring (approximately 8%) compared to after recontouring (approximately 3%) (Golder and Poisson 2010; Irvine et al. 2014). This trend was also statistically significant when a stranding event was defined as greater than or equal to 1 fish, and greater than or equal to 50 fish.

All three analyses of the LCR stranding data indicated that physical habitat recontouring reduced overall fish stranding. Most of the recontouring at sites in the LCR occurred between 2001 and 2015, and Genelle Mainland (LUB) was recontoured a second time in 2021 after the initial recontouring in 2003. Overall, trends in the predicted number of fish stranded suggest a persistent reduction in stranding that has lasted for many years after physical habitat recontouring.

4.5 Management Question #5

"Does the continued collection of stranding data, and upgrading of the lower Columbia River stranding protocol, limit the number of occurrences when stranding crews need to be deployed due to flow reductions from HLK?"

Over the 16 years since CLBMON-42 was implemented, the number of annual stranding assessments conducted in response to reduction events from HLK/ALH was stable (Figure 5). The number of stranding assessments conducted in response to reduction events from HLK/ALH ranged from 8 to 15 assessments (median = 13, average = 12). In the 2022/2023 study year, 14 stranding assessments were conducted in response to reduction events implemented at HLK/ALH.

Another way to approach this management question is to look at annual fish stranding assessment response rates (i.e., the percent of yearly reduction events that are responded to with a stranding assessment). The response rate for HLK/ALH reduction events varied from 29% to 92% (median = 77%, average = 71%). In recent years (2020/2021, 2021/2022, and 2022/2023) the response rate was less than 60%. Part of the reason for the lower than typical response rate in recent years was an increase in the total number of annual HLK/ALH reduction events formally evaluated by BC Hydro and entered into the database, while the number of stranding assessments was relatively stable (Figure 5).

While the absolute number of stranding assessments conducted in response to reduction events from HLK/ALH did not decrease over the CLBMON-42 study, there have been a number of improvements to the process of deciding whether or not to conduct an assessment, and when assessments are conducted, where efforts are best directed to either fill in data gaps or prioritize fish salvage. In 2011, *The Canadian Lower Columbia River: Risk Assessment and Response Strategy* (Golder 2011) was developed, which provided a comprehensive process and protocol to address the risks of fish stranding associated with flow reductions from hydroelectric facilities on the lower Columbia and Kootenay rivers. For much of the CLBMON-42 program (2011 to 2021), this protocol was followed by BC Hydro and consultants when deciding whether a stranding assessment was warranted in response to flow reductions, and if an assessment was warranted, Golder (2011) identified standardized sampling protocols to be followed. In 2021, the protocol was updated (Golder 2021a) based on a statistical analysis on the 20-year dataset of fish stranding assessments (Golder 2020a). The statistical analysis provided an update on variables (e.g., wetted history, time of year, magnitude of reduction, and river stage) that affect both the probability of stranding and the number of fish stranded, and a change to high (≥30 days) vs. low (<30 days) stranding risk cut-offs for wetted history were adopted (Golder 2021a). Furthermore, in 2023, an analysis of the fish stranding assessment data was conducted to develop a predictive model of fish stranding risk (Dalgarno and Thorley 2023). Outputs from this model (in addition to the database query output described in Section 2.1) are now used to help identify where the greatest potential of fish stranding is expected to occur due to a proposed flow reduction from HLK/ALH or BRD/X. In turn, these outputs are used to guide fish stranding assessment effort at the highest risk locations.

4.6 Summary of Additional Findings

Additional predictor variables not directly related to the management questions of CLBMON-42 were also included in the statistical analyses to assess their potential effect on fish stranding in the lower Columbia River.

The magnitude of reduction was a significant predictor of both probability of stranding and predicted number of fish stranded; however, the trends were conflicting. There was a positive relationship between magnitude of reduction and probability of fish stranding (Figure 11). However, there was an unexpected negative relationship between the magnitude of reduction and the conditional number of fish stranded. This discrepancy may be explained by the high variability and relatively small number of observations at very low and very high magnitudes of reduction. Overall, the results from the combined two-components of the model support the expected increase in number of fish stranded between low- and medium-sized reductions, with high uncertainty and likely spurious negative relationship at higher magnitude reductions. Other analyses conducted on the lower Columbia River fish stranding assessment data also found an increased stranding risk with an increase in reduction magnitude (Golder and Poisson 2010; Irvine et al. 2014; Dalgarno and Thorley 2023).

Minimum discharge was included in analyses as a proxy to assess the effect of river stage on fish stranding. Model predictions indicated a non-linear effect of minimum discharge with a peak number of fish stranded at approximately 1100 m^3/s (Figure 12). This generally agreed with a recent predictive model of fish stranding in the lower Columbia River, which indicated increased numbers of fish stranded when the discharge at the start of the reduction was less than approximately 50 kcfs, which is equivalent to 1416 m^3/s (Dalgarno and Thorley 2023). Increased stranding at lower river stage may be a result of differences in the slope, channel shape, and substrate types at different elevations of the riverbed. A gently sloped shoreline is more likely to strand fish compared to a steep shoreline due to the greater physical area that becomes de-watered (Nagrodski et al. 2012). At low water levels, hundreds of small depressions in the substrate at some low-angle stranding sites (i.e., Lions Head [RUB]) have been observed to strand fish.

Day of year was included in the statistical models to account for seasonal variation in stranding risk. Day of year was a statistically significant predictor of both the probability of stranding and the number of fish stranded, with the predicted highest number of stranded fish occurring in mid-July. Although some studies of salmonids reported a greater incidence of standing during the winter months (Heggenes and Salveit 1990; Salveit et al. 2001), results from fish stranding assessments indicate that summer is the highest risk season for fish stranding on the lower Columbia River (Golder and Poisson 2010; Irvine et al. 2014). The increased risk of stranding in the summer is likely due to fish assemblage (i.e., greater numbers of young-of-year sucker spp., and Cyprinids) and increased fish density in varial zone during summer months. Although model predictions indicate the greatest stranding risk during summer, the observed data show many events with large numbers of stranded fish outside of this period, particularly during April to March and October to November. In addition, some species (e.g., Umatilla Dace) are more frequently stranded on the lower Columbia River during the winter months (Figure 7). These findings indicate that large stranding events can occur outside of the High Risk period, particularly if other variables, such as river stage, wetted history, and magnitude of reduction are conducive to fish stranding, and that the High Risk period does not pose a higher risk of stranding for all species.

Relationships between the number of fish stranded and the predictor variables discussed above improve understanding of factors that affect fish stranding in the lower Columbia River and can be used to guide fish stranding assessments and protocols.

5.0 CONCLUSION

Results from the 2022/2023 study year of CLBMON-42 indicated fairly typical discharge in the Columbia and Kootenay rivers, and the number of stranding assessments completed, the number of fish stranded, and the species composition of stranded fish were all similar to recent previous years.

As 2022/2023 was the last year of fish stranding assessments conducted under the WUP, statistical analyses using 23 years of data were used to address CLBMON-42's management questions regarding operational controls and environmental factors that influence the number of fish stranded due to flow reductions from HLK. Results and supporting information from previous studies, such as experimental flow ramping studies conducted prior to CLBMON-42, were also used to address the management questions where possible.

Management Questions Conclusions

The statistical analyses resulted in the following conclusions, pertaining to the CLBMON-42 management questions:

- There was little evidence of an effect of ramping rate on the probability of stranding or the number of fish stranded. This suggests no difference in fish stranding risk within the range of operational ramping rates (1 to 5 kcfs/hr) currently used at HLK/ALH.
- Modelling results indicated that the longer the time period that habitat is underwater prior to an operational flow reduction, known as the wetted history, the greater the probability of stranding fish, and the greater the number of fish stranded. This finding suggests that fish density in the near-shore area, may increase with increased wetted history, and this environmental variable should continue to be considered when planning for a fish assessment or salvage response.
- Physical habitat recontouring conducted at high risk stranding sites on the lower Columbia River has been a long-lasting and effective method of reducing the number of fish stranded.
- The effect of time of day (day versus night) and implementation of a conditioning flow on fish stranding risk could not be determined during this study; however, previous studies from the lower Columbia River indicate that these likely do not have a strong effect on fish stranding.

Additional Findings

The statistical analyses conducted to address CLBMON-42's management questions also identified three additional predictor variables that influence fish stranding in the Columbia and Kootenay rivers:

- Magnitude of reduction - The results revealed an increase in the number of fish stranded between low- and medium-sized reductions, with high uncertainty and a likely spurious negative relationship at higher magnitude reductions.
- Minimum discharge - Minimum discharge was used as a proxy to assess the effect of river stage on fish stranding. Overall, the probability of stranding and the number of fish stranded was higher at low river stages, and lower at high river stages. The model predicted a peak in the number of fish stranded at a river stage of approximately 1100 m^3/s (~39 kcfs).
- Day of year - Day of year was included in the statistical models to account for seasonal variation in stranding risk. Overall, the probability of fish stranding and the number of fish stranded was higher during the summer months and lower during the winter months. The model predicted a peak in the number of fish stranded occurring near mid-July.

6.0 CLOSURE

We trust that this report meets your current requirements. If you have any further questions, please do not hesitate to contact the undersigned.

WSP Canada Inc.

Kevin Little
Senior Aquatics Biologist, BSc, RPBio

Dustin Ford
Senior Principal Scientist, BSc, RPBio

KL/DF/cmc

https://golderassociates.sharepoint.com/sites/157426/project files/5 technical work/2022_2023_report/21508219-003-r-rev0-2022_2023_lcr_stranding_&_wup 26jan_24.docx

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APPENDIX A

Site Maps

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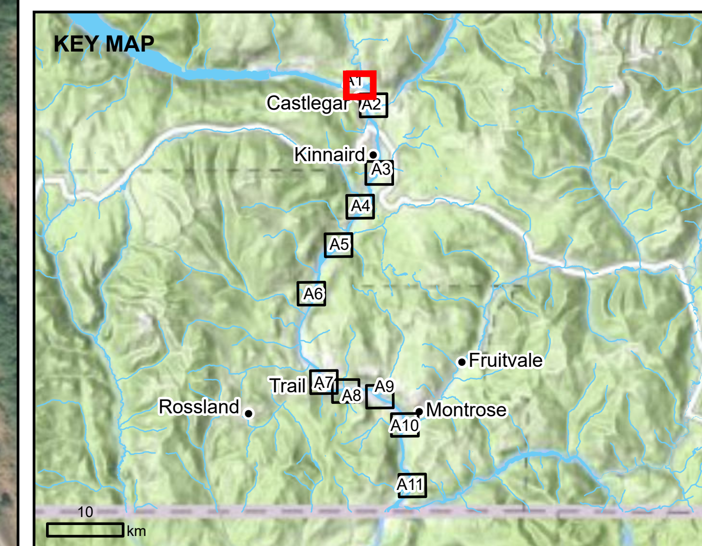
STRANDING SITE



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CLIENT
BC HYDRO

PROJECT
LOWER COLUMBIA RIVER (CLBMON#42[A]) AND KOOTENAY RIVER FISH STRANDING ASSESSMENTS

TITLE
STRANDING SITES: UPPER SECTION - COLUMBIA RIVER

CONSULTANT

wsp

YYYY-MM-DD	2024-01-26
DESIGN	KL
PREPARED	JG
REVIEW	KL
APPROVED	DF

PROJECT No.	PHASE	Rev.	FIGURE
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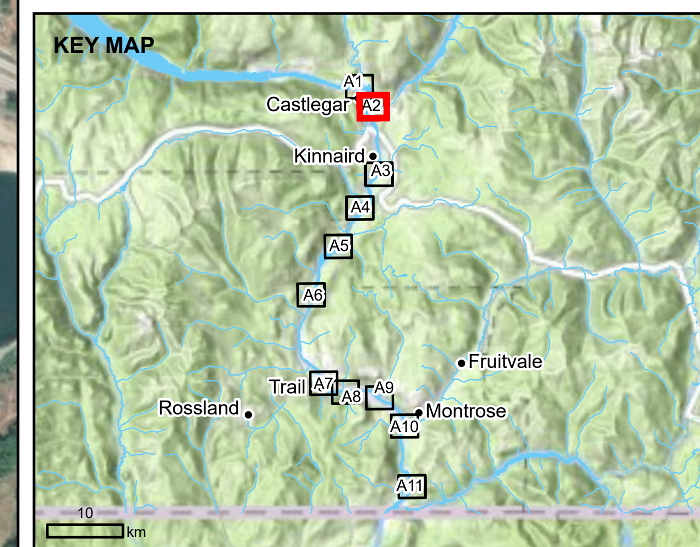

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CLIENT
BC HYDRO

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TITLE
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CONSULTANT

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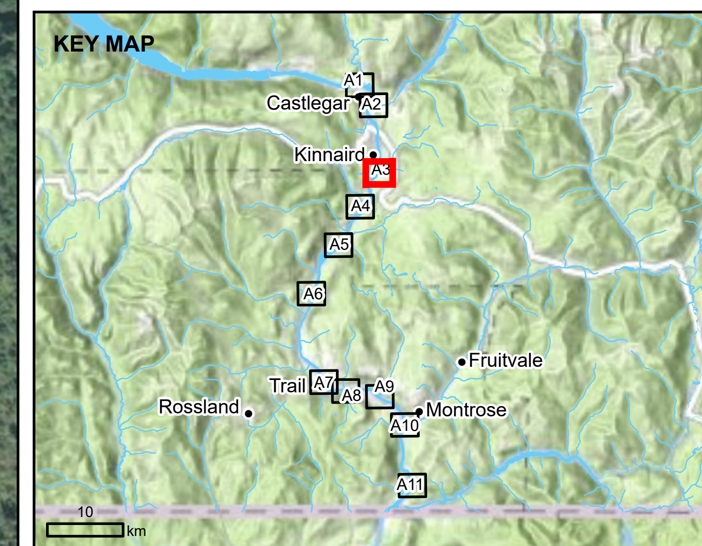

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BC HYDRO

PROJECT
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TITLE
STRANDING SITES: UPPER SECTION - COLUMBIA RIVER

CONSULTANT

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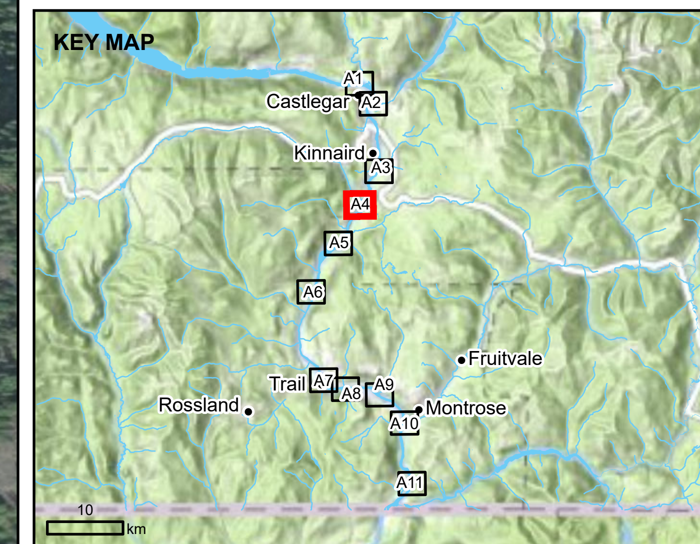

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PROJECT
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TITLE
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CONSULTANT

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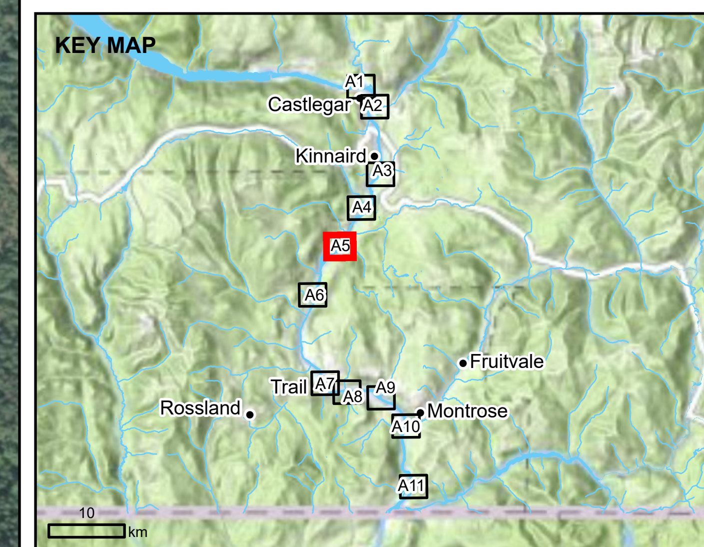

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CLIENT
BC HYDRO

PROJECT
LOWER COLUMBIA RIVER (CLBMON#42[A]) AND KOOTENAY RIVER FISH STRANDING ASSESSMENTS

TITLE
STRANDING SITES: MIDDLE SECTION - COLUMBIA RIVER

CONSULTANT
wsp

YYYY-MM-DD	2024-01-26
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PREPARED	JG
REVIEW	KL
APPROVED	DF

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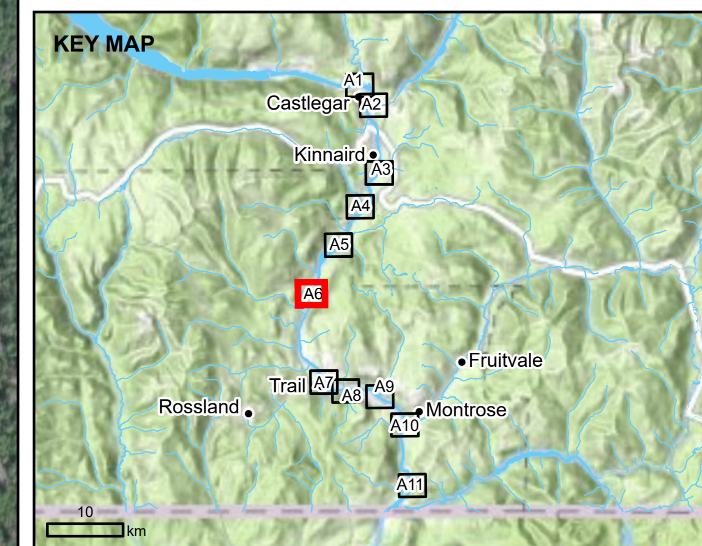

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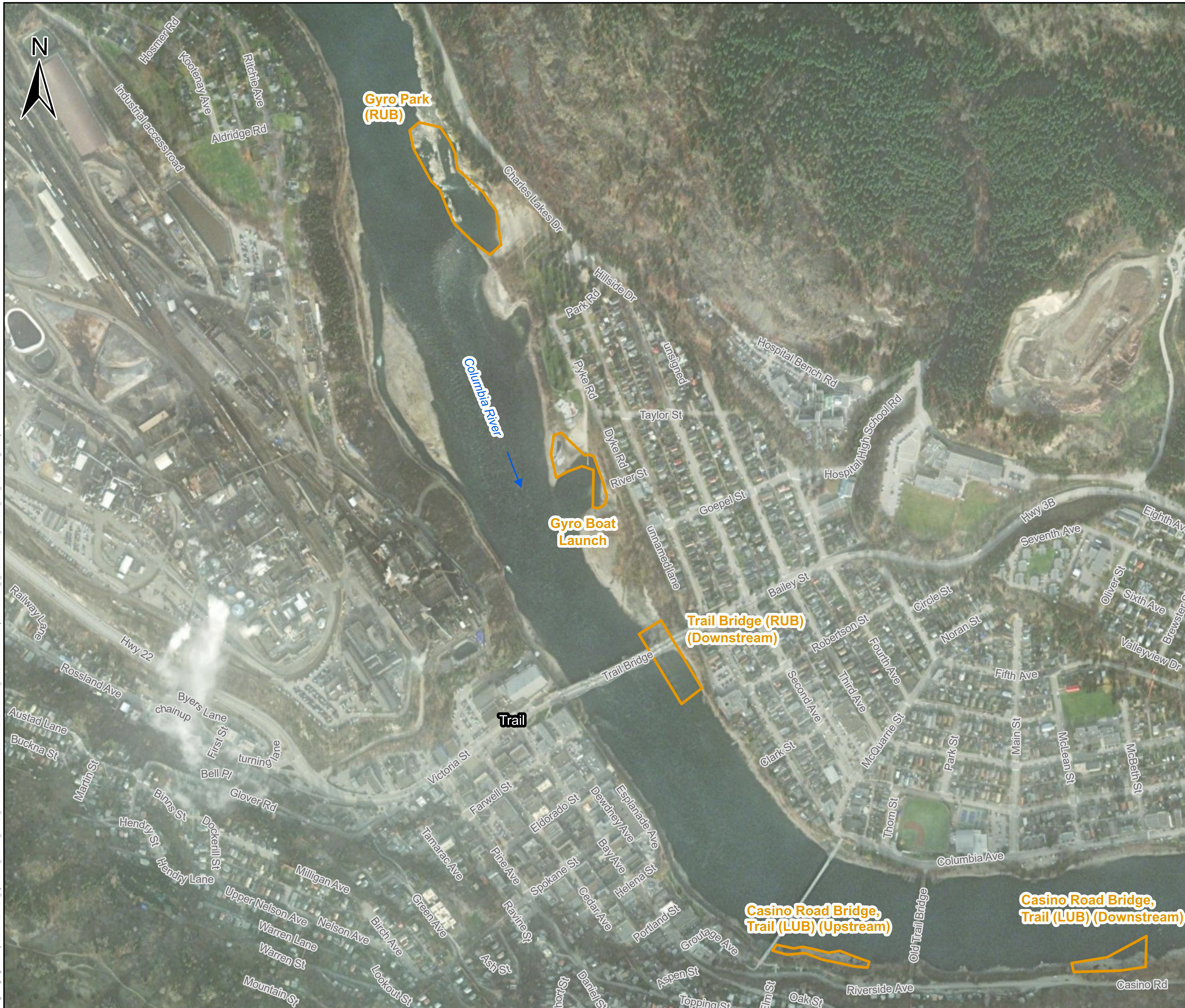

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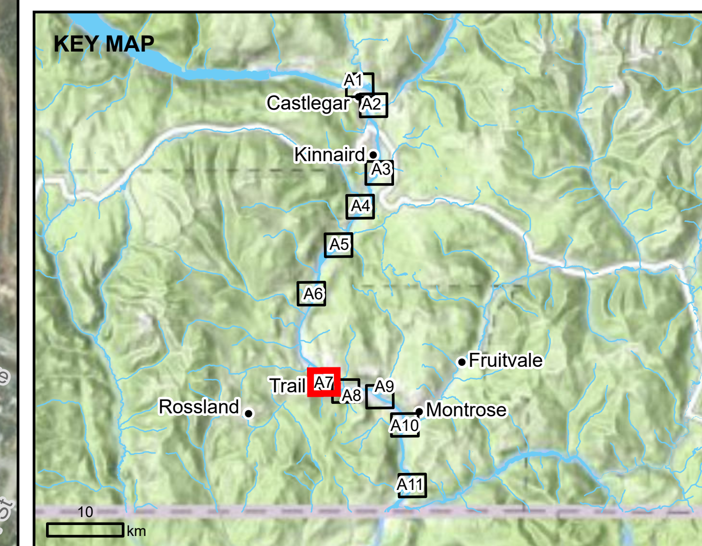

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TITLE
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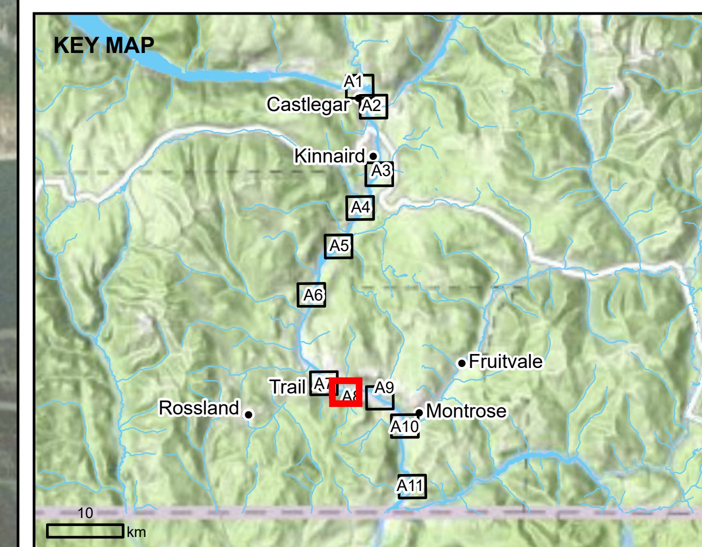

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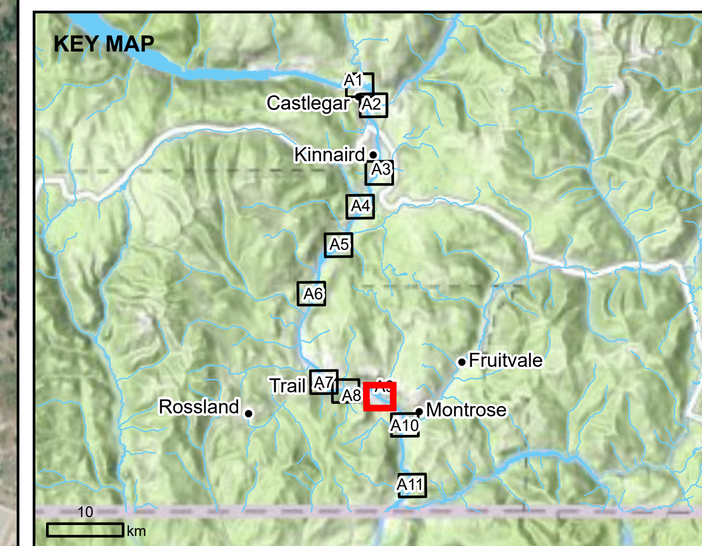

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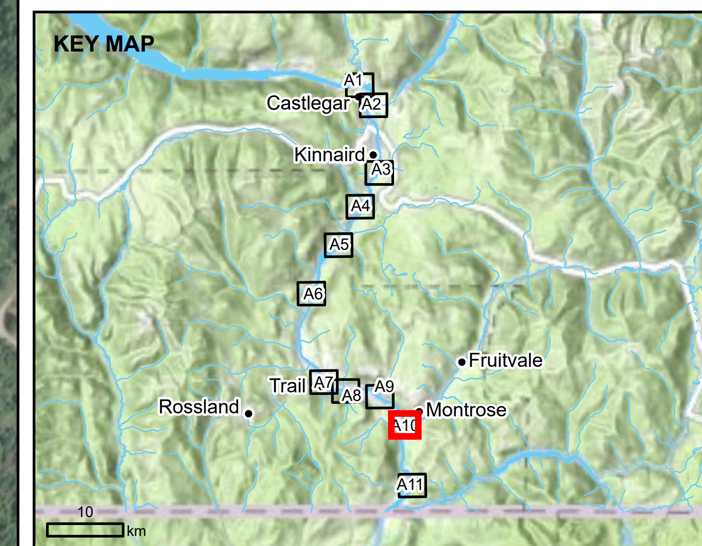
APPROVED	DF

PROJECT No.	PHASE	Rev.	FIGURE
21508219	2022.5	0	**A9**

LEGEND

STRANDING SITE



0 125 250

1:7,500 METRES

REFERENCE

1. BASE IMAGERY SOURCE: WORLD TOPO BASE: SOURCES: ESRI, HERE, DELORME, INCREMENT P CORP., NPS, NRCAN, ORDNANCE SURVEY, © OPENSTREETMAP CONTRIBUTORS, USGS, NGA, NASA, CGIAR, N ROBINSON, NCEAS, NLS, OS, NMA, GEODATASTYRELSEN, RIJKSWATERSTAAT, GSA, GEOLAND, FEMA, INTERMAP AND THE GIS USER COMMUNITY
WORLD IMAGERY: MAXAR
DATUM: NAD83 PROJECTION UTM 11

CLIENT
BC HYDRO

PROJECT
LOWER COLUMBIA RIVER (CLBMON#42[A]) AND KOOTENAY RIVER FISH STRANDING ASSESSMENTS

TITLE
LOWER SECTION - COLUMBIA RIVER

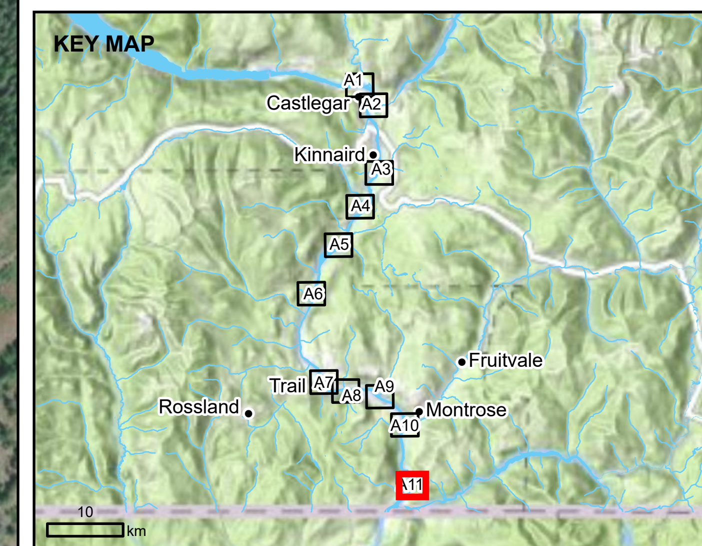
CONSULTANT

YYYY-MM-DD	2024-01-26
DESIGN	KL
PREPARED	JG
REVIEW	KL
APPROVED	DF

PROJECT No.	PHASE	Rev.	FIGURE
21508219	2022.5	0	A10

LEGEND

STRANDING SITE



0 125 250

1:7,500 METRES

REFERENCE

1. BASE IMAGERY SOURCE: WORLD TOPO BASE: SOURCES: ESRI, HERE, DELORME, INCREMENT P CORP., NPS, NRCAN, ORDNANCE SURVEY, © OPENSTREETMAP CONTRIBUTORS, USGS, NGA, NASA, CGIAR, N ROBINSON, NCEAS, NLS, OS, NMA, GEODATASTYRELSEN, RIJKSWATERSTAAT, GSA, GEOLAND, FEMA, INTERMAP AND THE GIS USER COMMUNITY
WORLD IMAGERY: MAXAR
DATUM: NAD83 PROJECTION UTM 11

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LOWER COLUMBIA RIVER (CLBMON#42[A]) AND KOOTENAY RIVER FISH STRANDING ASSESSMENTS

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CONSULTANT

YYYY-MM-DD	2024-01-26
DESIGN	KL
PREPARED	JG
REVIEW	KL
APPROVED	DF

PROJECT No.	PHASE	Rev.	FIGURE
21508219	2022.5	0	A11

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM:
25mm

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