

Alouette Watershed Sockeye – Fish Passage Feasibility Project Year 5

COA-F22-F-3583-DCA

Prepared for:

Fish and Wildlife Compensation Program

Coastal Region

6911 Southpoint Drive, 11th Floor
Burnaby, BC V3N 4X8



Compilation report prepared and edited by:

Greta Borick-Cunningham
Alouette River Management Society
24959 Alouette Road, Maple Ridge, BC V4R 1R8

and

Megan Mathews
LGL Limited
environmental research associates
9768 Second Street, Sidney, BC V8L 3Y8

FINAL VERSION

November 15, 2022

This Project was funded by the Fish and Wildlife Compensation Program (FWCP). The FWCP is a partnership between BC Hydro, the Province of B.C., Fisheries and Oceans Canada, First Nations, and public stakeholders to conserve and enhance fish and wildlife impacted by the construction of BC Hydro dams.

Acknowledgements

This project thanks the commitment of the 2021 Alouette River Salmonid Restoration Program committee members from BC Hydro: Katy Jay, Alf Leake, Jacqueline Chapman, and Cam Hiebert; Alouette River Management Society: Geoff Clayton, Cheryl Ashlie, Ken Stewart, Sophie Sparrow, Alexandra Holmes, and Greta Borick-Cunningham; BC Corrections: Chris McMillan, Lance DiSalvo; LGL Limited: Bob Bocking, Megan Mathews, and Elmar Plate; Fisheries and Oceans Canada: Murray Manson, Scott Ducharme, and Sandie Hollick-Kenyon; Leq'á:mel First Nation: Justin Laslo; and Ministry of Environment and Climate Change Strategy: Shannon Harris.

Thanks to Fisheries and Oceans Canada: Dr. Lyse Godbout, for age and genetic analysis.

Special thanks to the Fish and Wildlife Compensation Program's – Coastal Program (FWCP) Manager Julie Fournier for support during the 2021–2022 season and to FWCP Program Assistants, Melissa Fiel de Sousa and Lorraine Ens for assistance with navigating the FWCP Application and Reporting online portal.

www.fwcp.ca



Individual reports prepared by:

Activity 1

Adult Sockeye Enumeration (Task 4a)

“Alouette Adult Sockeye Enumeration, 2021 Return”

G. Borick-Cunningham
Alouette River Management Society
24959 Alouette Road, Maple Ridge, BC V4R 1R8

Activity 2

Sockeye Smolt Outmigration Enumeration (Task 4b)

“Evaluation of the Migration Success of Sockeye Salmon Smolts (Oncorhynchus nerka) from the Alouette Reservoir, 2021”

M.A. Mathews
LGL Limited
environmental research associates
9768 Second Street, Sidney, BC V8L 3Y8

Activity 3

Alouette–Stave Diversion Tunnel Entrainment (Task 7)

“Alouette Tunnel Entrainment Monitoring, April 9, 2021, to May 31, 2022”

E.M. Plate and W. Challenger
LGL Limited
environmental research associates
9768 Second Street, Sidney, BC V8L 3Y8

and

A.-M. Mueller, D. Degan, and J. Lazar
Aquacoustics LLC
Sterling, Alaska

Activity 4

Technical Review Memorandum – Alouette Watershed Salmon Restoration Project

“Operational Summary of, and Recommendations, Regarding: Sockeye Smolt Outmigration Enumeration; Alouette-Stave Tunnel Assessment of Sockeye/Kokanee Entrainment; and Preliminary Investigation of Factors Potentially Influencing Sockeye Smolt Migration. Technical Review Memorandum”

M. Mathews, E. Plate, and W. Challenger
LGL Limited
environmental research associates
9768 Second Street, Sidney, BC V8L 3Y8

This page left intentionally blank.

Table of Contents

Acknowledgements	i
Overview of the Alouette Watershed Sockeye – Fish Passage Feasibility Project.....	1
Background	1
References	6
Activity 1 Adult Sockeye Enumeration (Task 4a)	A1-1
Activity 2 Sockeye Smolt Outmigration Enumeration (Task 4b)	A2-1
Activity 3 Alouette–Stave Diversion Tunnel Entrainment (Task 7)	A3-1
Activity 4 Technical Review Memorandum – Alouette Watershed Salmon Restoration Project	A4-1

This page left intentionally blank.

Overview of the Alouette Watershed Sockeye – Fish Passage Feasibility Project

Sockeye Salmon restoration in the Alouette Watershed was identified as a key priority in the Fish and Wildlife Compensation Program (FWCP)'s Alouette River Watershed Action Plan (2017) and is of significant cultural importance to the Katzie First Nation. The recently renamed Alouette River Sockeye Reanadromization Project to the Alouette River Salmonid Restoration Program (ARSRP) is a joint initiative among BC Hydro, the Alouette River Management Society (ARMS), Leq'á:mel First Nation, BC Corrections, Fisheries and Oceans Canada (DFO), LGL Limited, and Ministry of Environment and Climate Change Strategy (ENV) to promote the restoration of anadromous Alouette salmonids, including *Oncorhynchus nerka*, and to investigate the feasibility of fish passage at the Alouette Dam. The ARSRP committee has been working to resolve uncertainties around feasibility of Sockeye Salmon restoration in the Alouette watershed for over 16 years and within the Fish Passage Decision Framework (FPDF) since 2008. Most recently, in 2020, the Committee updated the Terms of Reference and the 11-year Work Plan for the Program to encompass a wholistic approach to restoration of all salmonids in the Alouette watershed particularly above the Alouette Reservoir. The Alouette dam, located at the southern end of the reservoir, is owned and operated by BC Hydro, a crown corporation and is located in Maple Ridge, British Columbia.

Background

In 2016, after the ARSRP committee did not receive funding to run an experimental Sockeye Salmon hatchery, a workshop was held with senior Katzie First Nation representatives, DFO, BC Hydro, ENV, and political leads to reassess the Alouette fish passage plan. Attendees agreed that it was important to have the ENV's newly developed Kokanee/Sockeye Nerkid Model peer reviewed and to test the predictions from the Nerkid Model. Testing would involve: 1) releasing Kokanee and Sockeye hatchery fry into the reservoir; 2) smolt outmigration and adult returnee surveys would generate estimates of fry-to-smolt survival to inform density-dependence; and 3) smolt-to-adult success to inform smolting heritability assumptions. As a commitment from the July 2016 workshop, BC Hydro would coordinate the development of a long-term plan and help develop a subsequent FWCP funding application for the Sockeye hatchery for that year. DFO also requested that the Nerkid Model be provided to them for the basis of a review (Compass 2016, unpublished). On that basis, the ARSRP committee developed an 11-year plan which outlines the tasks to be implemented to address key knowledge gaps to Sockeye restoration and fish passage feasibility. The plan was originally presented to the Fish and Wildlife Compensation Program Board of Directors on September 19, 2016, by Debbie Miller representing Katzie First Nation, Greta Borick-Cunningham representing ARMS, and Dr. Brett Van Poorten representing the Ministry of Environment (MoE).

The 11-year plan included a formal scientific review of the Nerkid Model by DFO and the scientific community. Originally, the Canadian Science Advisory Secretariat was to review it, however, in 2019 due to capacity issues to review the Nerkid Model and Alouette Plan, the committee had to reconsider who would be able to do so. After discussion with ARSRP members, it was decided that BC Hydro would seek out an independent environmental research group to review the Model and

Plan. With instruction by the ARSRP committee, this independent consulting group, Ecofish Research Ltd, was engaged and funded by BC Hydro, to review the Model and the Plan as to how and to what extent both documents address any uncertainties identified in the eleven-year plan. The review investigated and reported on our overall plan including 1) the structure and findings of the Nerkid Model; 2) limits to the Kokanee and Sockeye production as estimated from estimates of available habitat and the Nerkid Model; and 3) calculations of genetic consequences of continued release of smolts and the hatchery program. The review focused on short-and long-term implications of Sockeye Salmon smolting for genetic and population integrity. This review of both the Nerkid Model and the Alouette Sockeye fish passage feasibility program should provide the outstanding answers to the questions of minimum viable populations for Sockeye in the Alouette Lake Reservoir and any potential “showstoppers” including genetic, biological, or disease issues that would exclude the implementation of an experimental Sockeye hatchery for short-term enhancement and for data to feed into the Nerkid Model. The tasks and schedule of the 11-year plan are summarized below.

Table 1 – Alouette River Salmonid Restoration Program Studies completed, on-going and planned until 2027.

Issue	Status	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Program Objectives																					
Management Objectives Related to Kokanee/Sockeye Production	I	✓	-	-	-	-	-	-	-	-	-	-	-	•	-	-	-	-	-	-	-
In Migration																					
Periodicity of Spawner Returns	C/O	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	•	•	•	•	•	•	•
Trap and Truck	C/O ¹	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	•	•	•	•	•	•	•
Stock Identity through Genetic Analysis	C/O	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	•	•	•	•	•	•	•
Smolt to Spawner (Ocean) Survival	O	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	•	•	•	•	•	•	•
Physical Barriers to In-Migration	n/a ²	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Escapement Level Allowing for Limited Fishery	n/a ³	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Spawning																					
Spawning Periodicity	C	-	-	-	-	-	-	-	-	-	✓	✓	-	-	-	-	-	-	-	-	-
Spawning Habitat Complete	C	-	-	-	-	-	-	-	-	-	✓	✓	-	-	-	-	-	-	-	-	-
Operational Impacts on Spawning	I	-	-	-	-	-	-	-	-	-	✓	✓	-	-	-	-	-	-	-	-	-
Egg to Fry Survival	I	-	-	-	-	-	-	-	-	-	✓	✓	-	-	-	-	-	-	-	-	-
Hybridization of Forms	I ⁴	-	-	-	-	-	-	-	-	-	-	-	-	-	•	•	•	•	•	•	•
Long Term Viability of Populations	I ⁵	-	-	-	-	-	-	-	-	-	✓	✓	✓	-	•	•	•	•	•	•	•
Rearing																					
Productive Capacity of Alouette Lake Reservoir	C/O ⁶	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	•	•	•	•	•	•	•
Powerhouse and Adit Gate Entrainment	O ⁷	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	?	?	?	?	?
Propensity for Anadromy	C/O ⁸	-	-	-	-	-	-	-	-	-	-	-	-	-	•	•	•	•	•	•	•
Viable Kokanee Fishery	C/O ⁶	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	•	•	•	•	•	•	•
Out Migration																					
Success of Spring Surface Release	C/O ⁹	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	•	•	•	•	•	•	•
Resiliency of Non-Anadromous Population	C/O ⁶	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	•	•	•	•	•	•	•
Should there be a Target Smolt Release?	I	-	-	-	-	-	-	-	-	-	-	-	-	-	•	•	•	•	•	•	•
Smolt Survival During Seaward Migration	I ¹⁰	-	-	-	-	-	-	-	-	-	-	-	-	-	?	?	?	?	?	?	?

C - Complete; I - Incomplete; O - Ongoing

✓ - Complete; • - Scheduled

¹ Need to determine program threshold (150-200/day?) and consider future plan when number of returns increase

² No formal assessment; no physical barriers assumed based on success of other species (Chum). May be formally assessed at a later date

³ Limited fishery not currently an objective. May be assessed if included as an objective

⁴ Clarify issue/objective and include in 11-year Plan

⁵ Nerkid model currently under review

⁶ Completed through Nutrient Program

⁷ Entrainment study began in 2021 and is ongoing

⁸ Success of re-anadromy assessed in 11-Year Plan

⁹ May assess success of pulse or increased flows

¹⁰ Tracking study required for assessment

In summary, from 2017 to 2020, the following tasks were planned, implemented, or shelved prior to the latest 2020 update to the Terms of Reference and broadening of scope to include all salmonid species in the Alouette system. For the purposes of the report, activities have been given task numbers for ease of reference. Task 3 “Hatchery Raising Fry” is currently on hold given it has not been endorsed by all key members of the watershed and the ARSRP.

Table 2 – Alouette Watershed Sockeye – Determination of Fish Passage Feasibility: (2017–2027) from October 2018.

Tasks in the Feasibility Plan		Phase 1		Phase 2						Phase 3		
		2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Task 1	Model & Plan Independent Review	✓	✓	✓								
Task 2	Spawning Habitat Assessment and Reproductive Behaviour	✓	✓									
	Kokanee Broodstock Collection	✗										
Task 3	Hatchery Raising Fry	✗										
Task 4	Adult and Smolt Enumeration	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Task 5	Acoustic Assessment of Density Dependence	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Task 6	Heritability of Smoltification						✓	✓	✓	✓	✓	✓
Task 7	Entrainment					✓	✓	✓				

- ✓ Task implemented for the given year
- ✓ Task implemented subject to other study result
- ✗ Task not approved for funding and did not proceed

Note: Table updated 15 Nov 2022

This report presents the work implemented for Year 5 of this 11-year plan. The goals for Year 5 were to:

1. Monitor and enumerate adult Sockeye Salmon returns to the ALLCO fish fence,
2. Monitor and enumerate juvenile Sockeye Salmon smolt outmigration at Mud Creek in the South Alouette River, and
3. Monitor for fish entrainment through the Alouette-Stave diversion tunnel.

The first two studies are necessary for the evaluation of heritability, long-term Sockeye projections and for eventual Fish and Wildlife Compensation Program (FWCP) endorsement. The third is a hydroacoustic research study of potential fish entrainment through the Alouette-Stave diversion tunnel; the design of this study was a component of the Year 4 Fish Passage Feasibility Project.

This final report is presented as a compilation of 4 individual reports from the completed work for Year 5. The first section presents the report for Task 4a – Alouette Adult Sockeye Enumeration; the second section presents the report for Task 4b – Sockeye Smolt Outmigration Enumeration; the third section is the Year 1 report of the hydroacoustic study of potential entrainment through the Alouette-Stave diversion tunnel, also referred to as Task 7 in the Alouette 11-year restoration plan; and the final section presents a technical memo on the operational summary and recommendations regarding the smolt enumeration, the entrainment study, and a preliminary investigation of factors potentially influencing smolt migration.

References

Alouette River Salmonid Restoration Program Committee, October 2020. Terms of Reference 2020.

Compass Resource Management, July 2016, unpublished minutes. Prepared for the Alouette River Sockeye Reanadromization Project committee.

Ecofish Research Ltd., July 31, 2019. Alouette River Sockeye Reanadromization Project (ARSRP) – Independent Review of the Nerkid Model and Risk Assessment.

Activity 1 Adult Sockeye Enumeration (Task 4a)

“Alouette Adult Sockeye Enumeration, 2021 Return”

G. Borick-Cunningham
Alouette River Management Society
24959 Alouette Road, Maple Ridge, BC V4R 1R8

This page left intentionally blank

**Alouette Adult Sockeye Enumeration
Final Report – 2021 Return**

**Year 5 – Alouette Watershed Sockeye
Fish Passage Feasibility Project**



COA-F22-F-3583-DCA

Prepared for:
Fish and Wildlife Compensation Program

Prepared by:
Greta Borick-Cunningham
Alouette River Management Society
24959 Alouette Road,
Maple Ridge, BC, V4R 1R8



Acknowledgements

This project was one of three funded activities of the Alouette River Salmonid Restoration Program committee's efforts for 2021–2022 to establish fish passage feasibility. Committee members include: Alouette River Management Society (ARMS), BC Corrections, BC Hydro (BCH), Department of Fisheries and Oceans (DFO), LGL Limited, Leq'á:mel First Nation, and Ministry of the Environment and Climate Change Strategy (ENV).

Our appreciation is extended to the following individuals for their commitment to the direct and related project work of the Alouette Adult Sockeye Enumeration: Ken Stewart, Alexandra Holmes, and Sophie Sparrow (ARMS); Megan Mathews, Elmar Plate, and Bob Bocking (LGL); Katy Jay, Alf Leake, and Jacqueline Chapman (BC Hydro); Lyse Godbout (Pacific Biological Station-DFO); Scott Ducharme (DFO).

Thank you to Chris McMillan and Lance DiSalvo (BC Corrections) for their dedication on the ALLCO trap and truck program to bring the returning adult Sockeye back to the Alouette Reservoir. Thanks also to Dennis Roberge (contractor) for monitoring the BC Hydro trap at the base of the Alouette dam during the adult enumeration study.

Gratitude to Geoff Clayton who continues to be an incomparable source of information and history on this work in the Alouette watershed.

From the Fish and Wildlife Compensation Program (FWCP), we thank Julie Fournier and Lorraine Ens for project coordination.

Special thanks to FWCP for funding this project and for its continued support of salmonid restoration in the Alouette Watershed.

Suggested citation: Borick-Cunningham, G. 2022. Alouette Adult Sockeye Enumeration, 2021 Return. Report prepared for FWCP – Coastal by the Alouette River Management Society, Maple Ridge, B.C.

The Alouette Watershed Sockeye-Fish Passage Feasibility Project for Year 5 was managed and delivered with the financial support from the Fish and Wildlife Compensation Program. www.fwcp.ca

Contents

Acknowledgements.....	A1-4
List of Tables	A1-6
List of Figures.....	A1-6
Executive Summary	A1-7
Introduction.....	A1-8
Objectives	A1-9
Study Area	A1-10
Methods	A1-10
Results	A1-13
Adult Sockeye Returns.....	A1-13
Fork Length	A1-14
Age Structure.....	A1-15
Genetic Sampling	A1-15
Smolt to Spawner Survival.....	A1-16
Discussion.....	A1-17
Adult Sockeye Returns.....	A1-17
Fork Length	A1-19
Age Structure.....	A1-21
Recommendations.....	A1-22
References.....	A1-23
Appendix 1.A – Alouette Project, Lyse Godbout – Pacific Biological Station	A1-25
Appendix 1.B – Photos of Returning Adult Sockeye Salmon – 2021	A1-27

List of Tables

Table 1.1 Estimated number of smolts leaving the Alouette Reservoir during the spring surface release, 2005–2021.....	A1-8
Table 1.2 Number of returned adult Sockeye to the Alouette Watershed, 2007-2021	A1-14
Table 1.3 Genetics and age class for Alouette adult Sockeye 2021	A1-16
Table 1.4 Alouette Sockeye brood survivals, 2005-2019	A1-17
Table 1.5 Average Sockeye salmon fork length measured, 2008-2021	A1-20
Table 1.6 Alouette adult Sockeye salmon age structure analysis, 2008-2021	A1-21

List of Figures

Figure 1.1 Map of Alouette Watershed and project location.....	A1-10
Figure 1.2 ALLCO fish hatchery fence	A1-11
Figure 1.3 First adult Sockeye salmon at ALLCO fish fence (August 8, 2021).....	A1-12
Figure 1.4 Last adult Sockeye salmon at ALLCO fish fence (October 21, 2021).....	A1-12
Figure 1.5 ALLCO Sockeye transport trailer	A1-13
Figure 1.6 Date of capture for each adult Sockeye salmon, 2021	A1-14
Figure 1.7 Fork length for all returning adult Sockeye, 2021.....	A1-15
Figure 1.8 Return dates for each adult Sockeye salmon - ALLCO fish fence, 2021.....	A1-18
Figure 1.9 Total number of Sockeye returned to the Alouette River, 2008-2021	A1-19
Figure 1.10 Total number of Sockeye salmon in each size class, 2008-2021	A1-20

Executive Summary

In order to assess the feasibility of anadromous Sockeye salmon (*Oncorhynchus nerka*) re-introduction into the Alouette Reservoir, studies are being conducted to determine the return success of *O. nerka* adults to the ALLCO Fish Fence. 2021 was the fifteenth year of monitoring Alouette adult Sockeye salmon. Fifteen years of monitoring includes the 2007 return.

Through BC Hydro's Alouette Project Water Use Plan (2009), a spring surface release from the Alouette Dam allowed for Sockeye smolts to migrate to the ocean. The first surface releases occurred in 2005 and in 2007 the first adult Sockeye returned to the Alouette Watershed. The 2021 Alouette Sockeye salmon run saw eight adults return between August 8 and October 21. All eight Sockeye were sampled at the ALLCO trap location, seven of which were successfully transported to Alouette Reservoir, one fish which arrived in October was mistakenly culled as a Chum salmon for egg-take. Fork length measurements were taken of all Sockeye salmon along with scale and tissue samples. The measurements indicated an average fork length of 56.8 cm.

The genetic sampling identified five of the eight adults originated from Alouette stock. The other three returning individuals were identified as Weaver stock. Between the smolt outmigration years of 2005-2018, the smolt to adult (return to the hatchery fish fence) survival of the Alouette Sockeye has ranged from a low of 0.02% in the 2013 smolt year to a high of 1.36% in the 2008 smolt year. (Bocking and Mathews, 2022 unpublished data).

Since 2007, up to and including the 2021 season, 454 adult Sockeye salmon have returned to the ALLCO fish fence, 388 of those have been successfully released into the Alouette Reservoir.

This project aligns with Fish and Wildlife Compensation Program's Alouette River Watershed Action Plan. (2020). The priority which is addressed are:

- Sub-objective 1 – ALU.RLR.SB.18.01 Conduct technical feasibility assessment, monitoring and/or species-based actions associated with Sockeye Salmon passage at Alouette Dam to support reintroduction to the Alouette system. Work must build upon the Alouette River Sockeye Re-Introduction Synthesis (13.ALU.02) and the Alouette Watershed Sockeye-fish passage Feasibility (COA-F18-F-2385). Proponents looking for an FWCP grant to evaluate opportunities to restore fish production above BC Hydro facilities that previously blocked fish passage are required to work through the Fish Passage Decision Framework (<http://fwcp.ca/fish-passage-decisionframework>).

Introduction

During the 2006 review of the Alouette Project Water Use Plan (AP-WUP), the consultative Alouette Monitoring Committee identified the restoration of an anadromous Sockeye salmon run as a key issue in the Alouette River system. Construction of the dam in the 1920’s impounded the reservoir and extirpated the Sockeye run soon after. As a means of re-establishing the stock, a spring surface release from the dam was integrated into the A-WUP. The testing of a specific surface release of $3 \text{ m}^3\text{s}^{-1}$ from April to June has facilitated Sockeye out-migration from the reservoir. Since 2005, smolts have successfully out-migrated through the spillway gate during the spring release and to the ocean via the Alouette River (Table 1.1, Mathews et al. 2022).

Table 1.1 Estimated number of smolts leaving the Alouette Reservoir during the spring surface release, 2005–2021.

Year of Smolt Migration	Estimated Abundance of Smolts
2005	7,900
2006	5,064
2007	62,915
2008	7,957
2009	3,704
2010	12,363
2011	30,729
2012	648
2013	5,385
2014	11,523
2015 ^A	583
2016	◇
2017	17,394
2018	31,643
2019 ^B	1
2020	1,473
2021	7,417

^ANote: 2015 season did not have the rotary screw trap in the collection site when BC Hydro had a controlled release of water due to storm events.

◇Note: 2016 season - The FWCP funding application was denied to run the rotary screw trap and therefore no smolts were enumerated.

^BNote: 2019 season - The opening of the Alouette Reservoir spillway gate was delayed due to low water levels within the reservoir; spillway flows began May 22, 38 days later than the typical start date of April 15.

The viability and authenticity of kokanee smolt “re-anadromization” is dependent on the stocks ability to adapt to saltwater conditions, to adopt behavioural strategies to compete and avoid predation in an ocean environment, and to recognize and return to their native lake/stream system to spawn (Gaboury & Bocking 2004). Through the original Alouette Adult Sockeye Enumeration monitoring program, Sockeye salmon returning to the Alouette River were collected, counted, aged, genetically tested, and released into Alouette Reservoir. In 2007, it was found that returning Sockeye salmon trapped at the ALLCO fish fence were genetically proven to be Alouette stock (Balcke, 2009).

The main purpose of the original seven-year Alouette Adult Sockeye Enumeration monitoring program, as funded under BC Hydro’s AP-WUP (2009), was to establish whether out-migrating Alouette Reservoir Kokanee/Sockeye smolts were capable of adapting to an anadromous existence. Adaptation is considered successful when Sockeye salmon return from the ocean environment to spawn in Alouette Reservoir (Godbout et al, 2015). Additionally, the original monitoring program sought to establish the timing and genetic structure of the returning Sockeye run and to assess whether ocean survival rates of returning re-anadromized Kokanee were comparable to that of Sockeye stocks found elsewhere. During the first three years of the program (2008-2010), the ALLCO hatchery fish fence was operated from April to December to determine the timing and volume of the run (Crowston & Borick-Cunningham, 2012). Based on the results of these efforts, the following eight years (2011-2018) had a shorter fence operation timeframe, which commenced mid-June through to early September. However, on 25 October 2018, one adult Sockeye salmon returned to the ALLCO fish fence. This adult Sockeye was not silver in colour like the earlier in-migrants were but green with red colouration. After discussion with BC Hydro staff, the trap at the base of the Alouette dam remained installed and continued to be monitored until the end of October. In 2019, 2020, and again 2021, ARMS and ALLCO hatchery staff continued to monitor the fish fence and trap for returning Sockeye until the end of October in case of any late arrivals. In 2021, tissue samples were collected from all Sockeye salmon in order to ensure that returning adults were Alouette stock and not strays from other nearby coastal systems.

Objectives

The Alouette River Salmonid Restoration Program committee (ARSRP) provides input to the larger project “Alouette Watershed Sockeye – Fish Passage Feasibility” and the Alouette River Management Society implements the Alouette Adult Sockeye Enumeration portion of this project. This enumeration monitor, as part of the larger ARSRP project, is funded through a Fish and Wildlife Compensation Program direct contribution agreement. This year would allow continued data collection on the number of adult Sockeye returning to the Alouette system and up to the ALLCO fish fence including completion of another year of genetic sampling. This continued sampling would reinforce the baseline data for Sockeye salmon as part of many years of ongoing efforts to return Sockeye adults back into the upper Alouette Watershed (Alouette River Watershed – Action Plan, 2020). This year would include the continuation to trap, enumerate, sample, and with the assistance of the BC Corrections supervisor and crew, transfer adult Sockeye into the Alouette Reservoir.

As discussed in Plate et al technical feasibility report (Oct 2014), there have been a variety of monitoring studies including the “Alouette Adult Sockeye Enumeration Monitor” (ALUMON#4) which contributed to many years of research and data collection about the genetics, parentage, and age of the Alouette adult Sockeye returns. These studies were compiled in 2013-2014, along with the Kokanee Outmigration Monitor (ALUMON#2) and others, into a technical feasibility report which synthesized all the research done up to that point on Alouette Sockeye and the process that needed to be taken to re-establish Sockeye in the Alouette Reservoir. This synthesis report outlined

and recommended various ways in which Sockeye salmon can be brought back to the reservoir and speaks to the importance of the ongoing adult enumeration and sampling which is a vital part of this future work. There has been further studies initiated and implemented by different members of the ARSRP committee since this synthesis report was written in 2013 by Plate et al. These additional studies have been incorporated into annual reports to the Fish and Wildlife Compensation Program (FWCP) since 2017.

Study Area

The South Alouette Watershed (144 km²), comprised of the South Alouette River and Alouette Reservoir, are located within the communities of Maple Ridge and Pitt Meadows (Figure 1.1). The site of the Alouette Adult Sockeye Enumeration monitor is approximately 7.5 km downstream from the Alouette Reservoir at the ALLCO Fish Hatchery operated by BC Corrections Fraser Regional Correctional Centre. The hatchery is well positioned to intercept all in-migrating adult Sockeye on their way back to the reservoir.

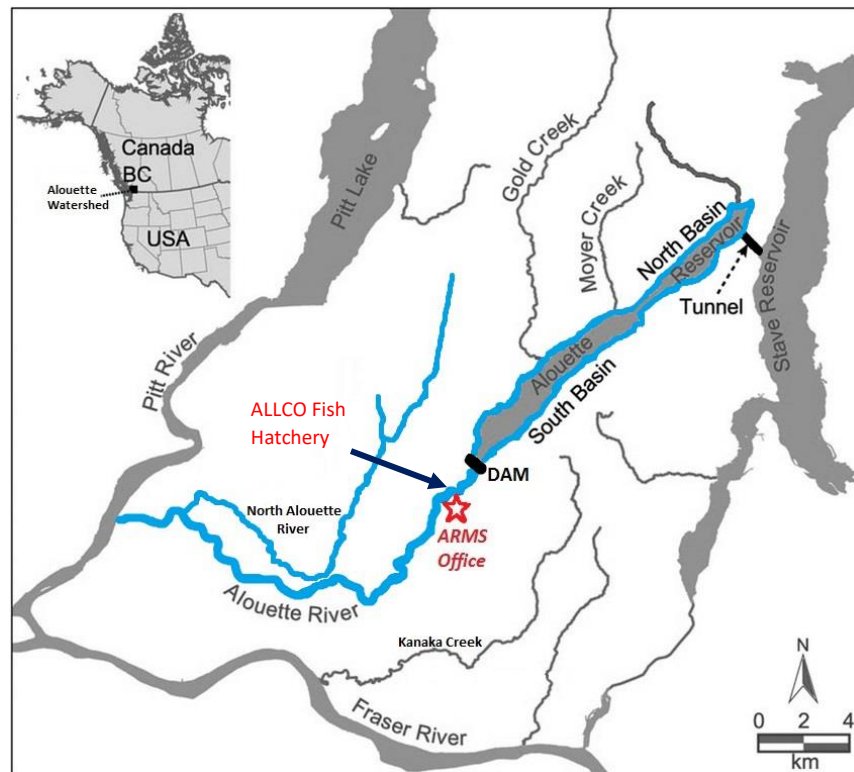


Figure 1.1 Map of Alouette Watershed and project location

Methods

From the first year of monitoring in 2008, the adult Sockeye run appeared to be a summer run, arriving in the Alouette Watershed in July and August (Balcke, 2009). Taking this into consideration, as well as the maintenance requirements, and downstream steelhead kelt passage, the Alouette Monitoring Committee decided that in both the 2009 and 2010 the ALLCO fish fence would be in operation between April and December, rather than year-round (Cruickshank, 2010).

The fish fence was designed to direct Sockeye and other salmon into the trap. In case of a failure at the fish fence, BC Hydro operated a trap at the low-level outlet of the Alouette Dam to catch any returning Sockeye that are not captured at the ALLCO fence (Figure 1.2).

From 2011 until 2018, the ALLCO fence was monitored from June 15 to early September for returning adult Sockeye. From 2019 to 2021, the fence was monitored from June 15 until late October (McMillan, C. pers. comm. Oct 2022). The BC Hydro fence and trap operations was installed on 15 June and closed on October 1, 2021. (Hiebert, C. pers. comm. Oct 2022)

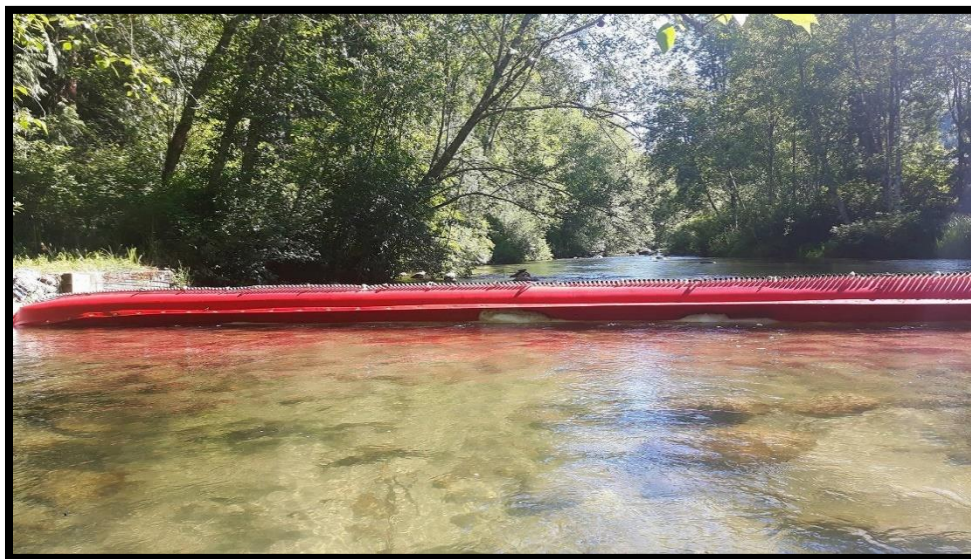


Figure 1.2 ALLCO fish hatchery fence

In 2021, Sockeye salmon sampling dates commenced on August 8 when the first adult arrived and completed on October 21 when the last adult arrived. For each returning Sockeye in 2021, the date of capture was recorded along with a unique ID assigned (Figures 1.3 and 1.4). Fork length was measured, and photos were taken of the left and right side and vent of each returning adult salmon.



Figure 1.3 First adult Sockeye salmon at ALLCO fish fence (August 8, 2021)



Figure 1.4 Last adult Sockeye salmon at ALLCO fish fence (October 21, 2021)

After samples were taken and the salmon were measured, the fish were transported via a specially designed trailer system to the Alouette Reservoir where they were released (Figure 1.5). Seven out of eight adult Sockeye were successfully transported to Alouette Reservoir in 2021.



Figure 1.5 ALLCO Sockeye transport trailer

The majority of returning Sockeye adults were in great health and strong swimmers when released into the reservoir. Several Sockeye salmon this year had large gashes from what appeared to be predation. Fork length measurements and photos were taken of all eight fish. In addition, scales were taken from the left and right side of each fish and an adipose fin clip was taken for analysis. The tissue and scale samples were sent to the Pacific Biological Station (Department of Fisheries and Oceans) laboratories in Nanaimo, B.C., for aging and genetic analysis.

Results

Adult Sockeye Returns

A total of eight Sockeye salmon returned to the Alouette Watershed during the 2021 run (Figure 1.6). Seven of the eight trapped salmon were successfully released into the Alouette reservoir, one was culled mistakenly during the Chum egg-take in October later in the season. The 2021 return of Sockeye salmon was the fifth lowest run on record out of fifteen years of monitoring at the ALLCO fish fence (Table 1.2). This is including 2007 when Sockeye returned for the first time to the fish fence in the Alouette River.

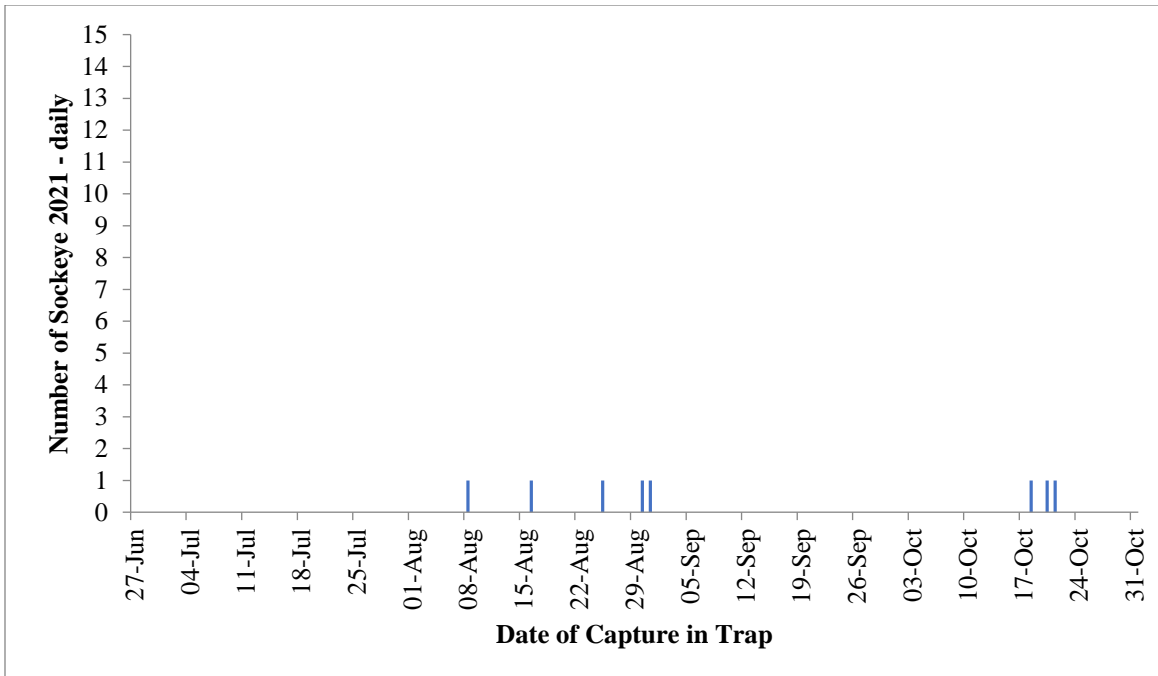


Figure 1.6 Date of capture for each adult Sockeye salmon, 2021

Table 1.2 Number of returned adult Sockeye to the Alouette Watershed, 2007-2021

Year of Adult Return	Number of Returned Adults	Number of Adults Released Alive into Alouette Reservoir
2007	38	5
2008	54	53
2009	45	43
2010	115	103
2011	11	8
2012	45	43
2013	10	7
2014	0	0
2015	4	0*
2016	6	6
2017	3	1
2018	15	15
2019	15	14
2020	85	83
2021	8	7
Totals	454	388

*Transported to the Alouette Sockeye Research Facility for holding

Fork Length

Fork length measurements were collected for all returning Sockeye (Figure 1.7). The fork length average for all returning fish was measured at 56.8 cm.

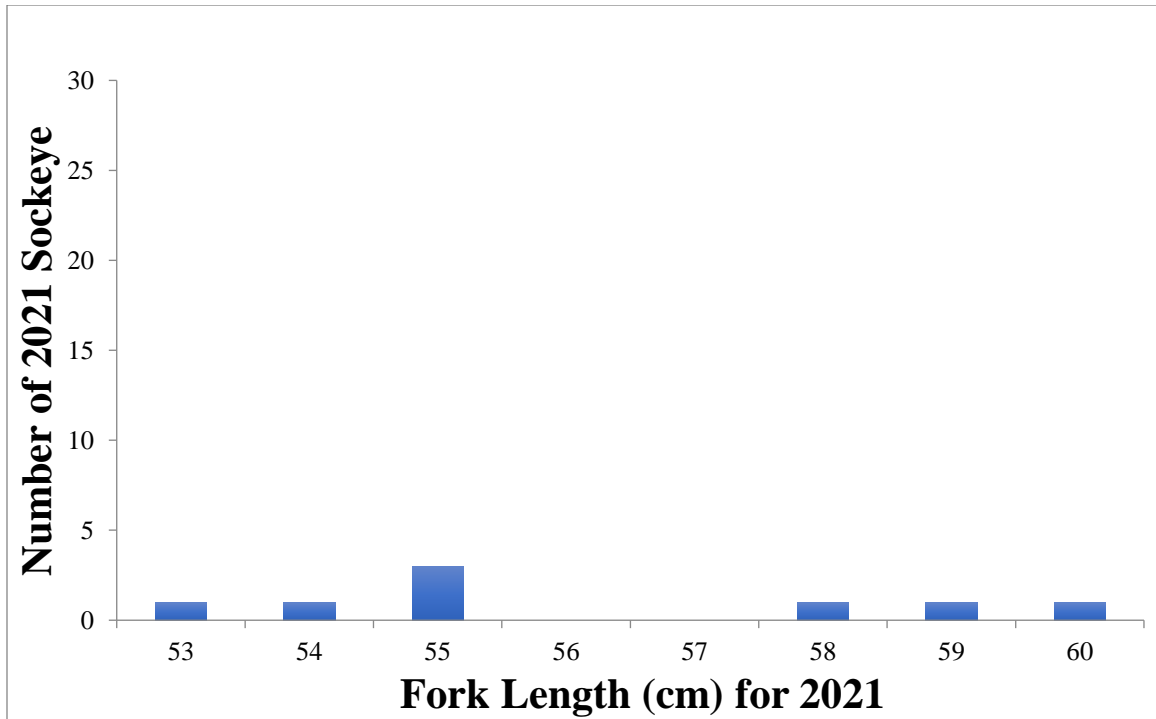


Figure 1.7 Fork length for all returning adult Sockeye, 2021

Age Structure

Scale samples were analyzed from seven of the eight to determine the 2021 run age structure. See Godbout, L. 2022. (Appendix 1.A). All adult Sockeye that returned to the ALLCO fish fence had scale samples taken for aging. All salmon were able to be aged, except one whose scales were upside down upon arriving at the laboratory. All salmon were classified under the Gilbert-Rich Age system. Four out of the five specimens that were sampled at the first return run were aged as 52, their brood year 2016. The three specimens in the second return run were aged at 42 under the Gilbert-Rich age system. This would make 2017 their brood year.

Genetic Sampling

Results from this analysis indicate that five of the returning adults to the ALLCO fish fence in 2021 were from the Alouette Reservoir and three of the returning adults were Weaver stock. Tissue samples were analyzed for DNA based on procedures described by Beacham et al. (2005) and used to determine the population of origin stock ID using 90 coast wide populations of Sockeye and Kokanee. The probability of an individual's belonging to a given population was calculated, and each individual was assigned to the population for which it had the highest marginal probability (Godbout, 2022 unpublished data).

Table 1.3 Genetics and age class for Alouette adult Sockeye 2021

Sockeye ID	Origin	Age of Sockeye (Gilbert-Rich Age)
1	Alouette (100%)	52
2	Alouette (100%)	UD
3	Alouette (100%)	52
4	Alouette (100%)	52
5	Alouette (100%)	52
6	Weaver (100%)	42
7	Weaver (100%)	42
8	Weaver (100%)	42

Gilbert-Rich and European age of the *O. nerka* caught in Alouette River in 2021. Mounted upside down (UD), unable to be read.

Smolt to Spawner Survival

Between the smolt outmigration years of 2005-2018, the smolt to adult (return to the hatchery fish fence) survival of the Alouette Sockeye has ranged from a low of 0.02% in the 2013 smolt year to a high of 1.36% in the 2008 smolt year. (Bocking and Mathews, 2022 unpublished data).

Smolt-to-spawner survival was calculated from age specific estimates of the number of smolts migrating out from the Alouette Lake Reservoir and the number of adults returned to the reservoir (Megan Mathews pers. comm.¹).

Table 1.4 Alouette Sockeye brood survivals, 2005-2019

Year of Smolt Migration	Survival (smolts:TRS)
2005	0.662%
2006	0.765%
2007	0.081%
2008	1.356%
2009	0.198%
2010	0.364%
2011	0.033%
2012	0.463%
2013	0.019%
2014	0.052%
2015	0.712%
2016	na
2017	0.054%
2018 ^a	0.273%
2019	na

^aSmolts: TRS is incomplete as some age classes have not yet returned.

Current marine survival rates (smolt–adult) being experienced by the Alouette River Sockeye (Table 1.4) are lower but in the same range as the Chilko Lake Sockeye which has seen marine survivals less than 3.5% since the 2007 return year and as low as 0.3% for the 2009 adult return year (2007 smolt year), respectively (Rensel et al. 2010). Survival rates for other Fraser River Sockeye stocks, and in particular the Pitt River and early summer run stock grouping are not available from Fisheries and Oceans Canada. However, survival rates for Cultus Lake Sockeye which has undergone a re-building effort have also been poor in recent years (CSAS 2010).

Discussion

Adult Sockeye Returns

The 2021 Alouette Sockeye run continues to demonstrate timing comparable to a summer run, arriving at the ALLCO fish hatchery trap location in July and August although this year it was a late start to the run with the first adult Sockeye arriving on August 8 (Figure 1.8).

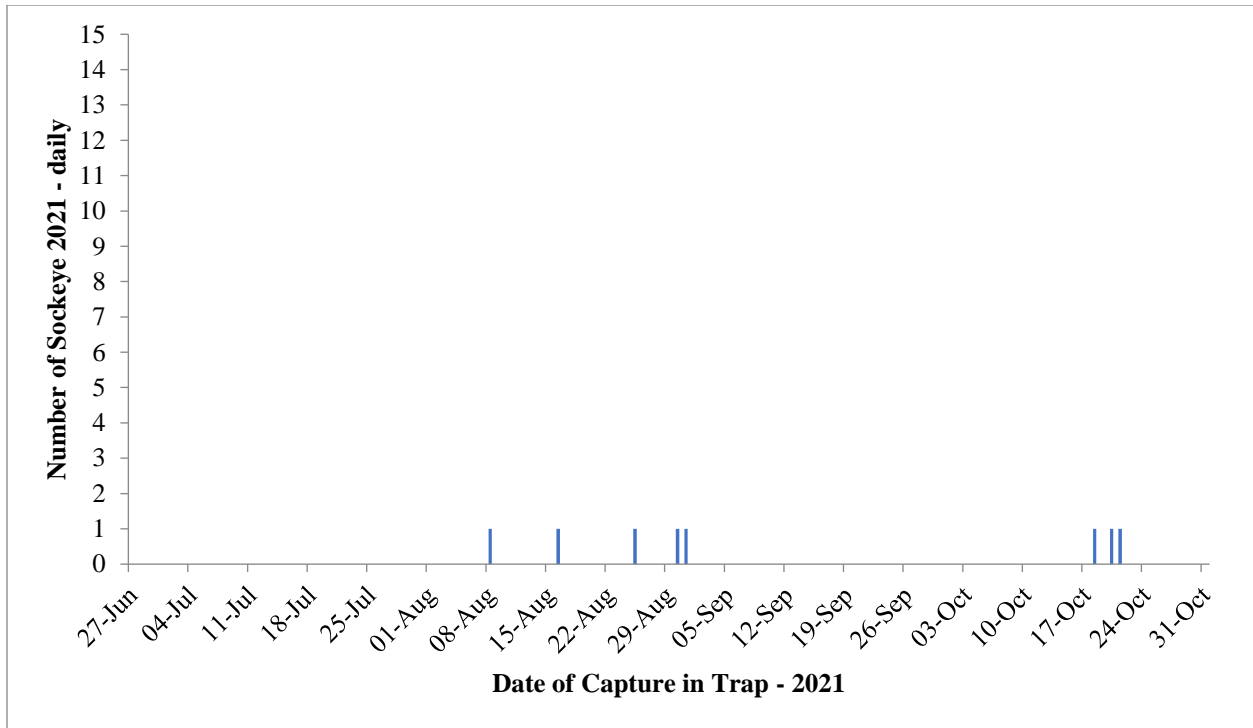


Figure 1.8 Return dates for each adult Sockeye salmon - ALLCO fish fence, 2021

This date is the second latest first day return since 2015 when the first Sockeye salmon arrived on August 10. In addition, since 2018 adult Sockeye salmon have also returned in mid-September and mid to late October. The Alouette Sockeye run from 2008-2021 has demonstrated peaks in the second week of July and again in the second week of August (Figure 1.9).

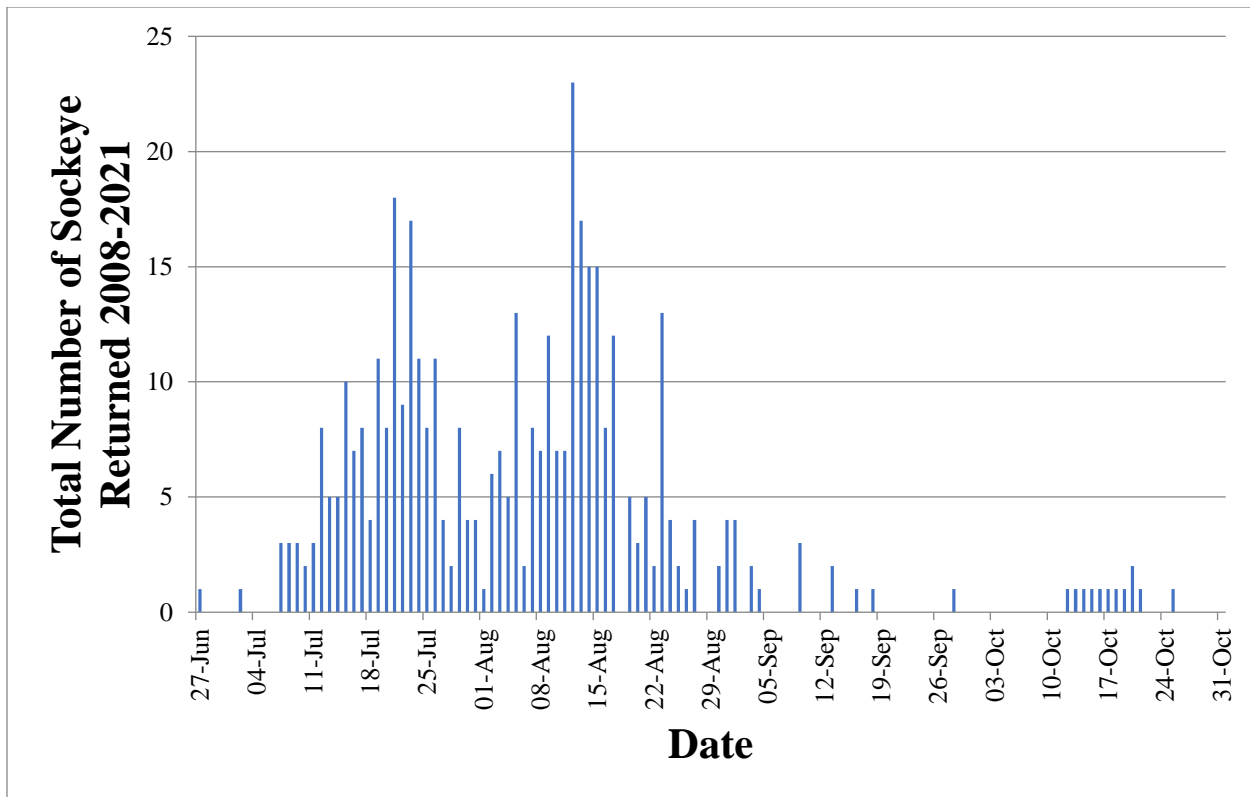


Figure 1.9 Total number of Sockeye returned to the Alouette River, 2008-2021

A total of 454 adult Sockeye returned to the ALLCO fish fence during the 2007–2021 runs, of which 388 have been successfully released back into the Alouette reservoir. Although the number of total adult Sockeye returns is low, the data shows that re-anadromization of Sockeye to the Alouette watershed is occurring regularly.

Fork Length

Measurements were collected for all eight 2021 returning Sockeye salmon. The average fork length measured in 2021 was 56.8 cm (Table 1.5). This average fork length represents the fifth smallest over the past fifteen years of monitoring.

Table 1.5 Average Sockeye salmon fork length measured, 2008-2021

Year of Adult Return	Number of Adults Measured	Average Fork Length (cm)
2008	54	59.3
2009	15	59.1
2010	115	58.1
2011	10	60.4
2012	42	57.8
2013	8	46.6
2014 ^a	0	0
2015	4	52.5
2016	6	60.1
2017	2	60.9
2018	15	55.6
2019	15	60.3
2020	85	53.7
2021	8	56.8

^aNo Sockeye returned to the ALLCO fence in 2014.

The two fork length size classes that represent the largest adult Sockeye returns in number are 56 cm (42 Sockeye) and 53 cm (41 Sockeye) and with 37 adults sized at 60 cm from 2008 to 2021 (Figure 1.10).

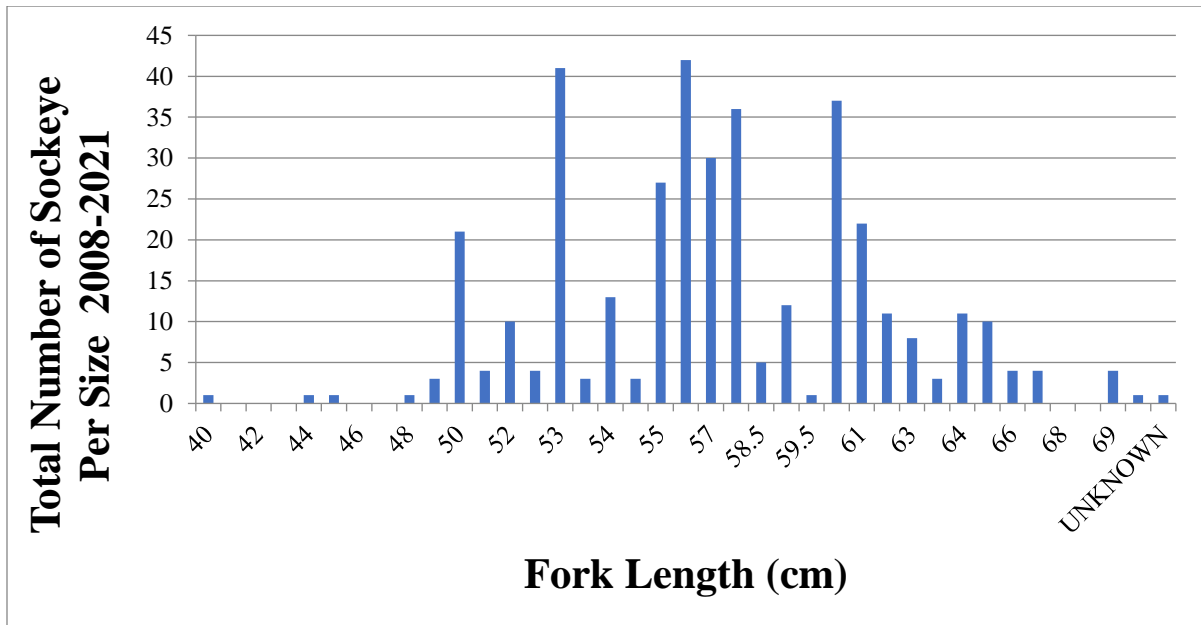


Figure 1.10 Total number of Sockeye salmon in each size class, 2008-2021

Age Structure

The age class analysis completed by the Pacific Biological Station (Fisheries and Oceans Canada) for the 2021 season showed that the returning adult Sockeye salmon were represented by two age classes (Appendix 1.A – Godbout, 2022 unpublished data).

The overall number of sampled Sockeye count for 2008 to 2021 was 286. The majority (57%) of these sampled returning spawners were age 42 years fish. Seven other age classes have been identified for the Alouette Sockeye, representing the remaining 43% of the fish sampled (Table 1.6).

Table 1.6 Alouette adult Sockeye salmon age structure analysis, 2008-2021

Year (# of sampled)	Age Class (Gilbert Rich Scale)									
	2 years in ocean	3.2	4.2	4.3	5.2	5.3	5.4	6.2	6.3	6.4
2008 (53)			19 (36%)	1 (2%)	14 (26%)	19 (36%)				
2009 (11)			7 (63%)			4 (36%)				
2010 (68)			36 (53%)		3 (4%)	13 (19%)	1 (1%)			15 (22%)
2011 (6)			3 (50%)			1 (17%)			2 (33%)	
2012 (29)			20 (69%)			8 (28%)				1(3%)
2013 ^a (4)			2 (50%)			2 (50%)				
2014 ^b (0)										
2015 (4)		1 (25%)	1 (25%)		1 (25%)	1 (25%)				
2016 ^c (6)	2 (33%)		4 (67%)							
2017 (3)						1(33%)				2 (66%)
2018 (13)			7 (54%)			5 (38%)				1 (7%)
2019 (13)			5 (38%)		7 (54%)			1 (8%)		
2020 (69)			55 (80%)		3 (4%)	11 (16%)				
2021 (7)			3 (43%)		4 (57%)					
Total (286)	2 (0.7%)	1 (0.3%)	162 (57.0%)	1 (0.3%)	32 (11.0%)	65 (22.7%)	1 (0.3%)	1 (0.3%)	2 (0.7%)	19 (6.6%)

^a Of the four fish sampled in 2013 only two were successfully aged at 4.2, the other two samples were hypothesized to be age 5.3.

^b No adult Sockeye returned to the Allco fish fence in 2014.

^c Due to sampling error, only partial reading could be taken in 2016.

^d Due to sampling error, 1 sample unable to be identified in 2021.

Recommendations

- 1) To ensure the beginning of the Sockeye run is captured, the ALLCO fish fence should continue to operate and monitored for adult Sockeye salmon from June 15 each year until October 31.
- 2) Sockeye salmon should continue to be caught and sampled by trained ARMS staff.
 - a. Sampling will continue in 2022 as per 2021, with fork length, scale and adipose fin tissue taken for all returning Sockeye. Fork length measurements will continue to be taken and ensure future scale samples are obtained from the correct location above the lateral line on the fish body, correctly placed in the sample booklets, and not taken near scars.
- 3) Due to the number of Sockeye captured below the dam in 2020, the BC Hydro trap should operate from June 15 until Thanksgiving weekend.
 - a. This date allows for any late returns of adult Sockeye salmon and seeks to avoid the chance of trapping any incoming Chum, Coho, and Chinook adults that have been allowed to pass the ALLCO fish fence.
- 4) All adult Sockeye will continue to be transported to the Alouette Reservoir, unless there are pre-spawn mortalities, which would then be sent as soon as possible to the Pacific Biological Station in Nanaimo, B.C. for fresh sampling.
 - a. If this is not possible the fish will be frozen and shipped at the end of the Sockeye run, if needed.

References

- Alouette Project Water Use Plan. April 15, 2009. Revised for Acceptance for the Water Comptroller of Water Rights. Prepared by BC Hydro.
- Alouette River Watershed Action Plan Final. November 14, 2017. Administrative Update July 21, 2020. Prepared by Fish and Wildlife Compensation Program.
- Balcke, A. 2009. *Alouette Adult Sockeye Enumeration: 2008*. Report prepared for BC Hydro. Report prepared by the Alouette River Management Society, Maple Ridge, BC.
- Beacham, T.D., Candy, J.R., McIntosh, B., MacConnachie, C., Tabata, A., Kaukinen, K., Deng, L., Miller, K.M., Withler, R.E., & Varnavskaya, N. 2005. *Estimation of Stock Composition and Individual Identification of Sockeye Salmon on a Pacific Rim Basis Using Microsatellite and Major Histocompatibility Complex Variation*. Transactions of the American Fisheries Society 134(5): 1124–1146. <https://doi.org/10.1577/T05-005.1>.
- Bocking, R.C. 2022. *Alouette Sockeye Brood Survivals* [Unpublished data]. LGL Limited, Sidney, BC.
- Crowston, A., & Borick-Cunningham, G. 2012. *Alouette Adult Sockeye Enumeration: 2011*. Report prepared for BC Hydro. Report prepared by the Alouette River Management Society, Maple Ridge, BC.
- Cruickshank, A. 2010. *Alouette Adult Sockeye Enumeration: 2009*. Report prepared for BC Hydro. Report prepared by the Alouette River Management Society, Maple Ridge, BC.
- CSAS (Canadian Science Advisory Secretariat). 2010. Assessment of Cultus Lake Sockeye Salmon in British Columbia in 2009 and evaluation of recent recovery activities. Canadian Science Advisory Secretariat Science Advisory Report 2010/056: 7 p.
- Gaboury, M.N., & Bocking, R.C. 2004. Feasibility of reintroducing Sockeye and other species of Pacific Salmon in the Alouette Reservoir, BC.
- Godbout, L. 2022. Alouette Lake parental analysis – 2021. Conservation Biology, Stream, 29C, Coquitlam, Alouette River, 2021/0417, Sockeye. [Unpublished data]
- Godbout, L., & Wood, C. 2015. Experimental release of hatchery-reared sea-run kokanee into Alouette Reservoir to evaluate the feasibility of re-establishing Sockeye salmon. Supplement of Information.
- Mathews, M.A. 2022. ARMS Alouette report tables from LGL Limited. October 2022. [Unpublished]
- Mathews, M.A. 2022. *Evaluation of the migration success of Sockeye Salmon smolts (Oncorhynchus nerka) from the Alouette Reservoir, 2021*. Report prepared for BC Hydro. Report prepared by LGL Limited, Sidney, BC.

- Plate, E.M., Mathews, M.A., & Bocking, R.C. 2014. Technical feasibility and recommendations for Alouette Lake Sockeye Salmon re-establishment above the Alouette Dam. October 2014.
- Rensel, J.E. Jack, Haigh, N., & Tynan, T.J. 2010. Fraser River Sockeye Salmon marine survival decline and harmful blooms of *Heterosigma akashiwo*. *Harmful Algae* 10(1): 98–115. <https://doi.org/10.1016/j.hal.2010.07.005>.

Appendix 1.A – Alouette Project, Lyse Godbout – Pacific Biological Station

ALOUETTE LAKE PARENTAL ANALYSIS - 2021, 2021, Lyse Godbout, Conservation Biology, Stream, 29C, Coquitlam, ALOUETTE RIVER, 2021/0417, Sockeye

Containers:	75316
Sample Type:	RESEARCH SURVEY
Gear:	Other Trap
Sample Dates:	2021-08-04 to 2021-08-04

Total Aged: 88% **Partially Aged: 12%** **Unageable: 12%**

Age Distribution:						
	Species	European	Gilbert-Rich	Brood Yr.	Frequency	Percent
	Sockeye	13	52	2016	4	57.1%
	Sockeye	12	42	2017	3	42.9%
Total:					7	100.0%

Partial Ages:			
Total:			0 0.0%

No Ages:						
	Species		UD	Upside Down scale		
	Sockeye		UD	Upside Down scale	1	100.0%
Total:					1	100.0%

	Specimen Label	Species	Reading Method	Container Label	Container Address	Gilbert-Rich Age	European Age	Part/No Age Code	Sample Start Date	Sample End Date	Site
1	S0001	Sockeye	Scales	75316	1	52	13		2021-08-04	2021-08-04	ALOUETTE RIVER
2	S0002	Sockeye	Scales	75316	2			UD	2021-08-04	2021-08-04	ALOUETTE RIVER
3	S0003	Sockeye	Scales	75316	3	52	13		2021-08-04	2021-08-04	ALOUETTE RIVER
4	S0004	Sockeye	Scales	75316	4	52	13		2021-08-04	2021-08-04	ALOUETTE RIVER
5	S0005	Sockeye	Scales	75316	5	52	13		2021-08-04	2021-08-04	ALOUETTE RIVER
6	S0006	Sockeye	Scales	75316	6	42	12		2021-08-04	2021-08-04	ALOUETTE RIVER
7	S0007	Sockeye	Scales	75316	7	42	12		2021-08-04	2021-08-04	ALOUETTE RIVER
8	S0008	Sockeye	Scales	75316	8	42	12		2021-08-04	2021-08-04	ALOUETTE RIVER

Appendix 1.B – Photos of Returning Adult Sockeye Salmon – 2021

Fish #1 – 75316



Fish #2 – 7316



Fish #3 – 7316



Fish #4 – 7316



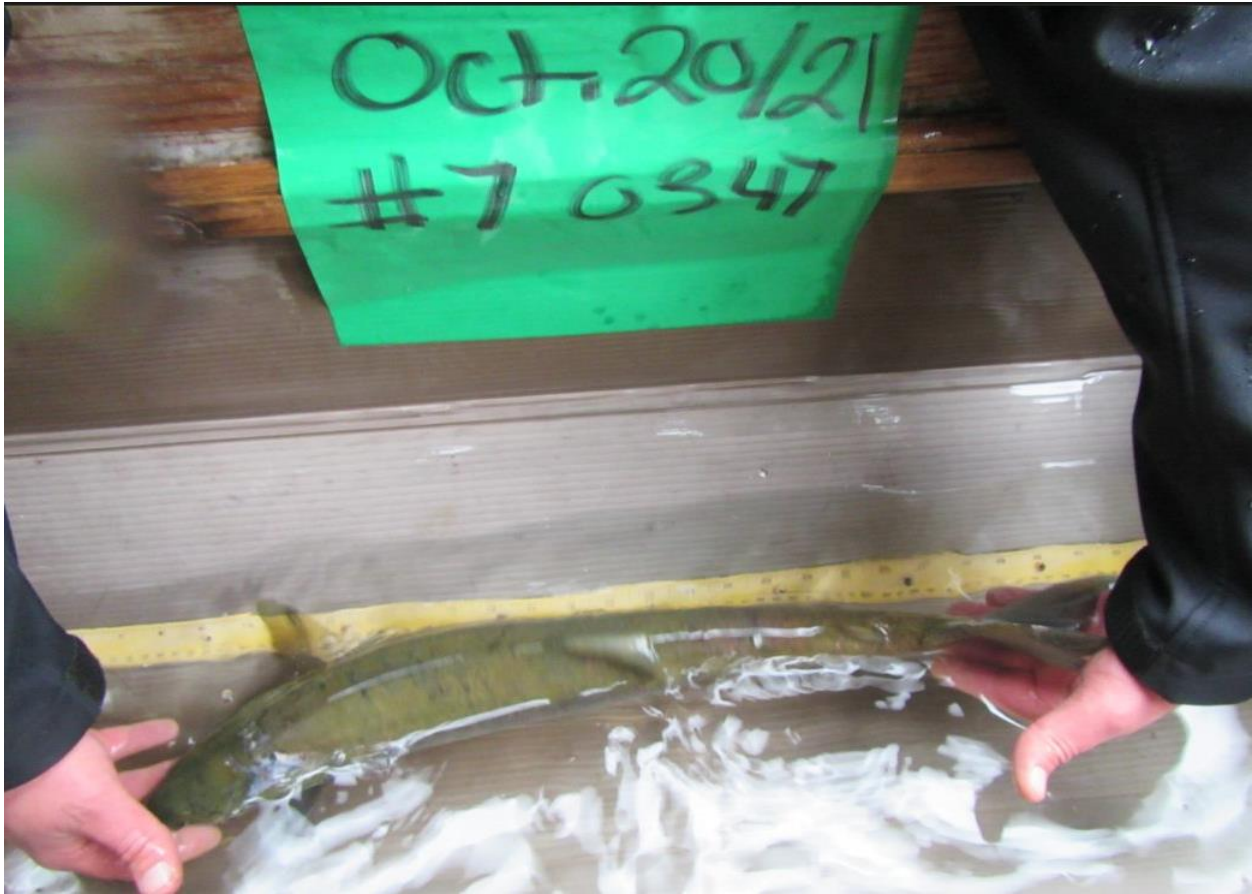
Fish #5 – 7316



Fish #6 – 7316



Fish #7 – 7316



Fish #8 – 7316



Activity 2

Sockeye Smolt Outmigration Enumeration (Task 4b)

“Evaluation of the Migration Success of Sockeye Salmon Smolts (Oncorhynchus nerka) from the Alouette Reservoir, 2021”

M.A. Mathews
LGL Limited
environmental research associates
9768 Second Street, Sidney, BC V8L 3Y8

This page left intentionally blank

Evaluation of the Migration Success of Sockeye Salmon Smolts (*Oncorhynchus nerka*) from the Alouette Reservoir, 2021



Prepared for:

FWCP – Coastal
11th Floor-6911 Southpoint Drive
Burnaby, BC V3N 6X8

Reference: COA-F22-F-3583-DCA



Prepared by:

M. A. Mathews

LGL Limited
environmental research associates
9768 Second Street
Sidney, BC V8L 3Y8

October 2022

**EVALUATION OF THE MIGRATION SUCCESS OF SOCKEYE SALMON SMOLTS
(*ONCORHYNCHUS NERKA*) FROM THE ALOUETTE RESERVOIR, 2021**

Prepared by:

M. A. Mathews

**LGL Limited
environmental research associates
9768 Second Street
Sidney, BC V8L 3Y8**

Prepared for:

**FWCP – Coastal
11th Floor-6911 Southpoint Drive
Burnaby, BC V3N 6X8**

Reference: COA-F22-F-3583-DCA

12 October 2022

EXECUTIVE SUMMARY

To assess the feasibility of anadromous Sockeye Salmon (*Oncorhynchus nerka*) re-introduction into the Alouette Reservoir, studies are being conducted to determine the migration success of Sockeye Salmon smolts from the reservoir; 2021 was the sixteenth year of study of juvenile salmon migration from the Alouette Reservoir (no study occurred in 2016). Abundance estimates of Sockeye Salmon smolts migrating from the reservoir have ranged from 583 (95% CI: 300–865) in 2015 to 62,423 (95% CI: 47,936–76,910) in 2007.

The Mud Creek rotary screw trap (RST) was operated from 14 April to 2 June 2021, which covered the typical timing of the Sockeye Salmon smolt migration from the Alouette Reservoir. In total, 1,800 smolts were captured, 1,503 of which were lower caudal clipped and released below the Alouette Dam, and 364 clipped fish were recaptured. Using an unbiased pooled Petersen equation for a single sampling site, an estimated 7,417 Sockeye Salmon smolts (95% CI: 6,631–8,203) migrated from the Alouette Reservoir between 14 April and 1 June. This was the ninth highest estimate in all sixteen study years.

Average daily spillway flows from the Alouette Reservoir to the South Alouette River during the Sockeye Salmon smolt migration were considerably higher than past years and ranged from 8.5 to 10.1 m³/s; the peak of which occurred on 28 May. The peak daily catch of 215 smolts occurred on 1 May.

A randomly chosen subsample of Sockeye Salmon smolts captured at the Mud Creek RST in 2021 were sampled for length, weight, age (scales), and genetics (fin tissue). These fish (<100 mm FL) averaged 80.5 mm FL (range: 65–98 mm FL; n = 767) and 4.7 g (range: 2.5–8.6 g; n = 767). Eighty-six percent of randomly sampled Sockeye Salmon smolts analysed for age (all lengths) were Age-1 smolts, 12% were Age-2, and 2% were Age-3. Genetic samples will be stored by Fisheries and Oceans Canada (DFO) for future potential Alouette watershed genetic studies. Other species captured were counted and released, including 149 adipose clipped Coho Salmon (*O. kisutch*) smolts and 12 adipose clipped steelhead (*O. mykiss*, i.e., anadromous Rainbow Trout).

The high spillway flows from the reservoir to the South Alouette River presented many logistical and safety challenges for both the crew and animals captured. Recommendations regarding RST operation during high flows are discussed.

ACKNOWLEDGEMENTS

The cooperation of many people was essential in meeting the objectives of this study. We are grateful to Katzie Development Limited Partnership (KDLP) for conducting the field work; in particular, Burgess Pierre and Lo Sylvester, and to Denise Horvath and Curtis Chapman for helping with project logistics. We are grateful to Greta Borick-Cunningham of the Alouette River Management Society (ARMS) for her assistance throughout the smolt monitoring program, as well as her overall project management and leadership of the greater 'Alouette Watershed Sockeye Fish Passage Feasibility – Year 5' project. From BC Hydro, we thank Katy Jay, Alf Leake, and Jacqueline Chapman for project assistance as well as technical review, and Cam Hiebert for project coordination and logistics management. From the Fish and Wildlife Compensation Program (FWCP), we thank Julie Fournier and Lorraine Ens for project coordination. From LGL Limited, Shane Johnson, Elmar Plate, Cam Noble, Cam McCulloch, and Ian Clevenger assisted with field work. Jason Smith, Bob Bocking, and Elmar Plate assisted as technical advisors, Dave Robichaud conducted statistical analyses, Naira Johnson and Anita Blakley assisted with safety management, Jason Smith and Dave Robichaud edited the final report, and Dawn Keller formatted and edited the final report. Report photos courtesy of KDLP and LGL. We appreciate BC Hydro altering their operational procedures at the Alouette Dam to accommodate the needs of this study.

Funding for this project was provided by the Fish and Wildlife Compensation Program – Coastal; special thanks to the FWCP.



Suggested citation:

Mathews, M.A. 2022. Evaluation of the migration success of Sockeye Salmon smolts (*Oncorhynchus nerka*) from the Alouette Reservoir, 2021. Report prepared for the FWCP – Coastal, Burnaby, B.C., by LGL Limited, Sidney, B.C. FWCP Reference No. COA-F22-F-3583-DCA.

TABLE OF CONTENTS

EXECUTIVE SUMMARY	A2-5
ACKNOWLEDGEMENTS.....	A2-6
LIST OF TABLES.....	A2-8
LIST OF FIGURES.....	A2-8
LIST OF PHOTOS	A2-9
LIST OF APPENDICES	A2-9
LIST OF ABBREVIATIONS	A2-10
INTRODUCTION.....	A2-11
Project Objectives.....	A2-18
METHODS.....	A2-18
Study Area.....	A2-18
BC Hydro Operations	A2-18
Fish Capture and Sampling	A2-19
Statistical Analyses.....	A2-20
Abundance Estimate.....	A2-20
Fish Lengths, Weights, and Condition Factors	A2-21
RESULTS.....	A2-22
BC Hydro Operations	A2-22
Fishing Effort and Physical Conditions.....	A2-22
Fish Capture and Sampling	A2-24
Sockeye Salmon Smolts	A2-24
Other Species.....	A2-33
DISCUSSION.....	A2-33
BC Hydro Operations	A2-33
Trapping Operations	A2-33
Abundance Estimate.....	A2-34
Run Timing	A2-34
Biosamples.....	A2-35
RECOMMENDATIONS	A2-38
REFERENCES	A2-40
APPENDICES	A2-43

LIST OF TABLES

Table 2.1.	Total catch at the Mud Creek rotary screw trap and the corresponding population estimates of Sockeye Salmon smolts migrating from the Alouette Reservoir, 2005–2021.	A2-14
Table 2.2.	Daily catch of Sockeye Salmon smolts in the Mud Creek rotary screw trap, 2021.	A2-26
Table 2.3.	Total estimated Sockeye Salmon smolt migration from the Alouette Reservoir, 2021.	A2-28
Table 2.4.	Mean length of Sockeye Salmon less than 100 mm FL (random samples only), 2005–2021.	A2-30
Table 2.5.	Mean weights of Sockeye Salmon smolts less than 100 mm FL (random samples only), 2005–2021.	A2-32
Table 2.6.	Age composition and length at age results for Sockeye smolts sampled at the Mud Creek rotary screw trap, 2013–2015, 2017–2018, and 2020–2021.	A2-37

LIST OF FIGURES

Figure 2.1.	Map of the Alouette Watershed showing local communities and features. ...	A2-12
Figure 2.2.	Map of the South Alouette River and location of the Mud Creek rotary screw trap in 2021.	A2-15
Figure 2.3.	Run timing of the Sockeye Salmon smolts at the Mud Creek rotary screw trap, 2005–2021.	A2-16
Figure 2.4.	Comparison of flows at the Alouette Dam spillway gate during the Sockeye Salmon smolt migration period, 2005–2021.	A2-23
Figure 2.5.	Daily discharge (m ³ /s) at WSC Station No. 08MH005 and spillway flows from the Alouette Reservoir, 13 April–15 June 2021.	A2-23
Figure 2.6.	Daily catch of Sockeye Salmon smolts at the Mud Creek rotary screw trap in 2021 in comparison to the maximum, mean, and minimum catches of the previous fourteen study years.	A2-28
Figure 2.7.	Length frequency distribution of Sockeye Salmon smolts measuring less than 100 mm FL (top panel), and 100 mm FL or greater (bottom panel), captured in the Mud Creek rotary screw trap operated in the South Alouette River (random samples), 2014–2021.	A2-29
Figure 2.8.	Length–weight relationship of Sockeye Salmon smolts migrating from the South Alouette Reservoir, 2021.	A2-30
Figure 2.9.	Comparison of mean fork length (top), weight (middle), and condition factors (bottom) across sampling years for Sockeye Salmon smolts (<100 mm FL) captured at the Mud Creek RST, 2005–2021.	A2-31

Figure 2.10. Comparison of the average length of Sockeye Salmon smolts measuring less than 100 mm FL and the estimated abundance of Sockeye Salmon (all sizes) that migrated from the South Alouette Reservoir, 2005–2021.A2-32

Figure 2.11. Comparison of daily catch of Sockeye Salmon smolts captured at the Mud Creek rotary screw trap and spillway flows from the Alouette Reservoir, 2021.A2-35

LIST OF PHOTOS

Photo 2.1. Mud Creek rotary screw trap, 12 May 2021.....A2-20

LIST OF APPENDICES

Appendix 2.A. Distributions of marks applied and numbers of recaptures, by date, at the Mud Creek rotary screw trap, 2021, where the recaptures have been lagged by 0 to 8 days.A2-44

Appendix 2.B. Correlation coefficients between daily numbers of marks applied and recaptures at the Mud Creek rotary screw trap, 2021, as a function of the number of days of lag applied to the recapture data.....A2-45

Appendix 2.C. Effect of assumed lag time on the final Petersen population estimate.A2-46

Appendix 2.D. Physical data collected at the Mud Creek rotary screw trap site, 2021.....A2-47

Appendix 2.E. Catch of non-target species at the Mud Creek rotary screw trap, 2021.....A2-48

LIST OF ABBREVIATIONS

ANOVA	analysis of variance
ARMS	Alouette River Management Society
ARSRP	Alouette River Salmon Re-anadromization Project
BC / B.C.	British Columbia
BCRP	Bridge Coastal Restoration Program
CI	confidence interval
DFO	Fisheries and Oceans Canada
FL	fork length
FWCP	Fish and Wildlife Compensation Program
HSD	honestly significant difference
IPT	inclined plane trap
KDLP	Katzie Development Limited Partnership
LGL	LGL Limited
NGO	non-governmental organization
RST	rotary screw trap
sp.	species (singular)
spp.	species (plural)
VIE	visible implant elastomer
WSC	Water Survey of Canada
WUP CC	Water Use Plan Consultative Committee
WUP	Water Use Plan

INTRODUCTION

Numerous interested parties in the Alouette Watershed, including government agencies, the Katzie First Nation, stewardship groups, environmental non-governmental organizations (NGOs), and concerned citizens have a vision of restoring historic salmon (*Oncorhynchus* spp.) runs above the Alouette Dam at the outlet of the Alouette Reservoir (Figure 2.1). Among other things, salmon re-introduction to the Alouette Reservoir hinges on determining whether enough juvenile salmonids (smolts) will exit over the dam at the south end of the Alouette Reservoir or through the diversion to Stave Lake at the north end of the Alouette Reservoir.

In 2002, LGL Limited (Sidney, B.C.) developed a framework for evaluating fish passage issues in the Bridge-Coastal hydro operating area (Bocking and Gaboury 2002). Following this, the Bridge Coastal Restoration Program (BCRP) sponsored an evaluation of the feasibility of restoring anadromous fish passage into the Alouette Reservoir (Gaboury and Bocking 2004). Numerous recommendations were made for future studies to address the fish-passage question at the Alouette Reservoir.

To address the issue of whether smolts would exit over the Alouette Dam or through the diversion to Stave Lake, the BCRP sponsored a study in 2005 that monitored the migration of Coho Salmon (*O. kisutch*) smolts out of the Alouette Reservoir and down the South Alouette River using unique colours of visible implant elastomer (VIE) tags during a test surface release of approximately 3 m³/s from the Alouette Dam (Baxter and Bocking 2006). Estimated migration success rates of Coho Salmon smolts to the lower Alouette River ranged from 79% for fish released at the spillway to 31–38% for fish released in the reservoir.

This study also yielded an unexpected but exciting result. While the surface release flow from the reservoir was occurring, kokanee / Sockeye Salmon (*O. nerka*) smolts were captured in the rotary screw trap (RST) operated at the Mud Creek site, approximately 1.5 km downstream from the reservoir (Baxter and Bocking 2006). Given the Alouette River Sockeye Salmon population had been considered extirpated as a result of the construction of the Alouette low level dam in the 1920s (Plate et al. 2104), this smolt migration was unexpected and prompted the Water Use Plan Consultative Committee (WUP CC) to recommend that the surface release occur annually. An abundance estimate of *O. nerka* was determined to be 7,900 smolts based on mark-recapture and a Coho trap efficiency rate.

A subsample of the Sockeye Salmon smolts that were counted in 2005 were implanted with acoustic tags for subsequent detection in listening arrays in the lower Fraser, Juan de Fuca Strait, and Strait of Georgia as a component of the Pacific Ocean Salmon Tracking or POST program. POST acoustic tracking of 19 *O. nerka* smolts determined a detection rate of 15.8% at the mouth of the Fraser River and 5.3% in Juan de Fuca Strait (Kintama Research Corporation 2005); clearly indicating that the smolts were migrating in the ocean.

In 2006, a study was conducted to monitor steelhead (*O. mykiss*, i.e., anadromous Rainbow Trout) smolt migration success out of the Alouette Reservoir and down the South Alouette River using both VIE tags and adipose fin clips (Humble et al. 2006). The estimated migration

success rate to the lower Alouette River was only 5.8% for steelhead smolts released in the reservoir. This low success rate was believed to be, at least in part, related to the delayed opening of the spillway gate due to low water levels in the reservoir. The 2006 project also provided a second year of Sockeye Salmon passage with an estimated 5,064 fish migrating from the reservoir during the surface release flow of approximately 3 m³/s. The 2005 and 2006 study results indicated that Sockeye Salmon smolts were successfully migrating from the Alouette Reservoir and there was the potential for adult Sockeye Salmon to return as early as 2007.

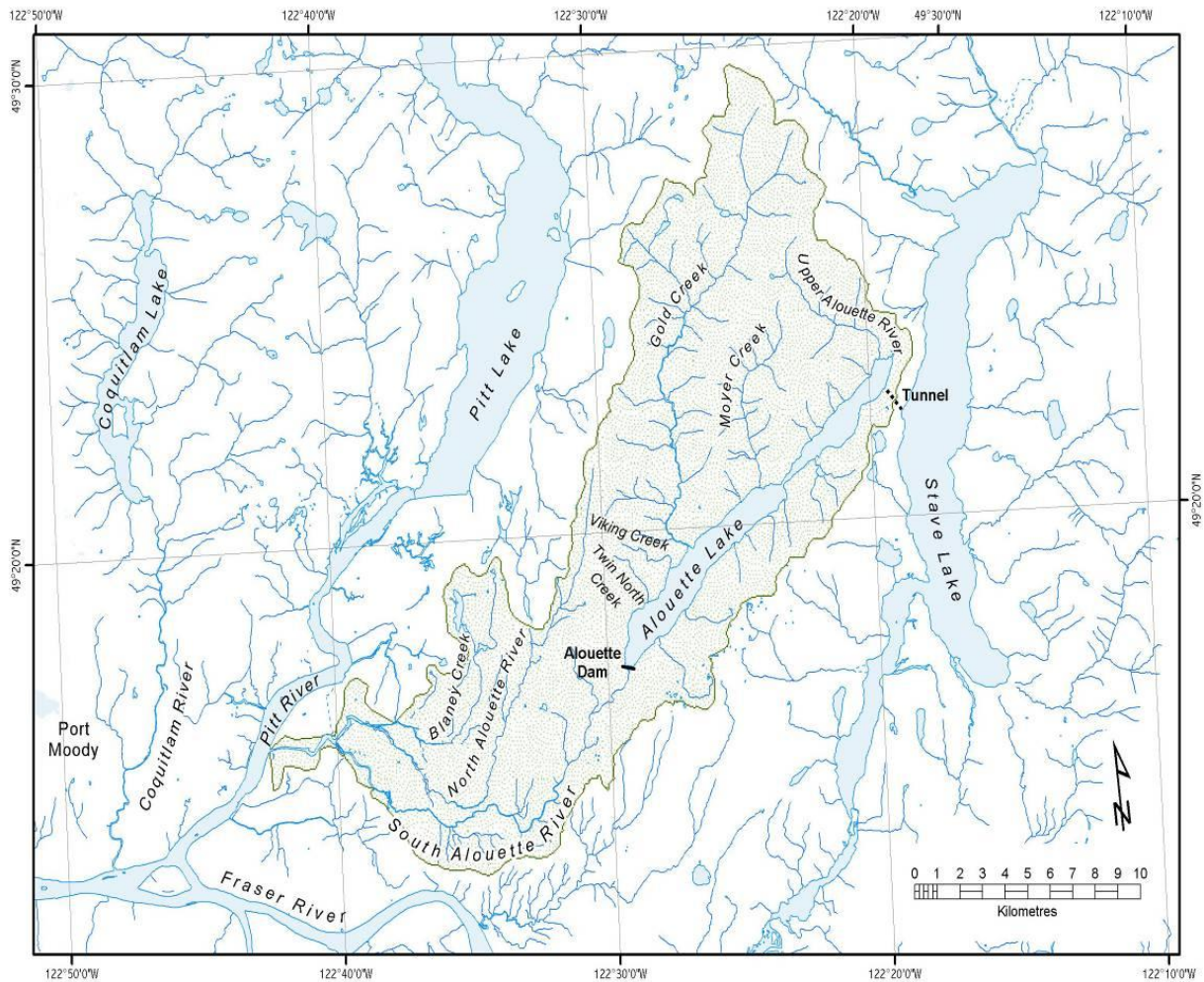


Figure 2.1. Map of the Alouette Watershed showing local communities and features.

To assess the feasibility of Sockeye Salmon re-introduction into the Alouette Reservoir, the 2007 smolt study was conducted to determine the volitional migration success of Sockeye Salmon from the reservoir during the surface release flow of approximately 3 m³/s. In 2007, a total of 7,787 Sockeye Salmon were captured in the Mud Creek RST, located 1.5 km downstream of the Alouette Dam (Figure 2.2). An estimated 62,423 (95% CI: 47,936–76,910) Sockeye Salmon emigrated from the Alouette Reservoir that year (Mathews and Bocking 2007) and remains the

highest estimate to date¹. Supported by the previous three years of results, and as part of the Alouette Project Water Use Plan (BC Hydro 2009), surface release flows were scheduled to continue annually with the desired outcome of re-establishing a Sockeye Salmon run. In 2008, 3,224 Sockeye Salmon smolts were captured at Mud Creek from 15 April to 26 May. The total 2008 migration was estimated to be 7,957 fish; this included a mark-recapture estimate of 7,412 fish (95% CI: 6,381–8,442) passing Mud Creek from 21 April to 8 May, plus an additional 545 fish (estimate based on trap efficiency) that passed outside of the marking period (Mathews and Bocking 2009). In 2009, 1,247 Sockeye Salmon were captured in the RST, yielding a total estimate of 3,704 (95% CI: 3,250–4,157) for the period of 21 April to 28 May (Mathews and Bocking 2010).

In 2010, two sites were to be used for the mark-recapture study. The Mud Creek RST was initially intended to operate as the recapture site. Two inclined plane traps (IPTs) located approximately 500 m upstream from the RST were intended to operate as the marking site. The IPTs were also to be used as a safe and effective trapping method during the flush. However, despite numerous modifications to the IPTs and the trapping site, they were not successful at capturing Sockeye Salmon smolts and were removed in early May. Fortunately, the RST operated as both the mark and recapture sites (as in previous years) and was used effectively during the 2010 flush period.

Table 2.1 summarizes total catch, population estimates and trap efficiencies annually; details regarding individual years can be found in annual reports (Mathews and Bocking 2011; Mathews et al. 2012–2016; Mathews and Smith 2018–2021). Note, due to unseasonably low water levels in the Alouette Reservoir in 2019, BC Hydro was unable to provide the spring surface release of 3 m³/s until 22 May. As a result of this 37-day delay from the preferred spring release timing, and despite operating the Mud Creek RST from 11 April to 15 June in 2019, no live Sockeye Salmon smolts were captured and thus no abundance estimate was generated (Mathews and Smith 2020).

In the summer and fall of 2021, eight adult Sockeye Salmon returned to the Allco Hatchery fence (A. Holmes, Alouette River Management Society, pers. comm.). Adult Sockeye Salmon have returned to the South Alouette River since 2007 and returns in previous years have ranged from zero (2014) to 115 migrants (2010) (Smith 2021).

Fourteen years of adult returns, along with the continued smolt migration, lend support to the feasibility that a South Alouette River Sockeye Salmon run, extirpated since the mid-1920s following the impoundment of the reservoir, could be re-established.

¹ Abundance estimates presented in this report for the 2007–2017 studies do not correspond to those found in earlier annual reports (see Mathews and Smith [2019] for more details).

Table 2.1. Total catch at the Mud Creek rotary screw trap and the corresponding population estimates of Sockeye Salmon smolts migrating from the Alouette Reservoir, 2005–2021.

Year	Total Catch	Abundance Estimate (N)	Lower 95% CL	Upper 95% CL	Trap Efficiency (%)
2005	3,310	7,900	-	-	42.0
2006	1,757	5,064	-	-	35.0
2007	7,787	62,423	47,936	76,910	12.2
2008	3,224	7,957	-	-	40.3
2009	1,247	3,704	3,250	4,157	33.4
2010	4,600	12,363	-	-	37.2
2011	8,525	30,729	29,221	32,238	27.7
2012	83	648	268	1,028	11.3
2013	1,032	5,385	4,556	6,214	18.8
2014	2,787	11,523	10,531	12,514	24.1
2015	94	583	300	865	14.9
2016 ^a	-	-	-	-	-
2017	3,100	17,394	15,247	19,541	17.8
2018	7,071	31,643	29,537	33,750	22.3
2019 ^b	1	0	-	-	-
2020	181	1,473	876	2,070	11.8
2021	1,800	7,417	6,631	8,203	24.2

^a Sockeye Salmon enumeration did not occur in 2016.

^b A single Sockeye Salmon (degraded mort) was captured on 13 April 2019.

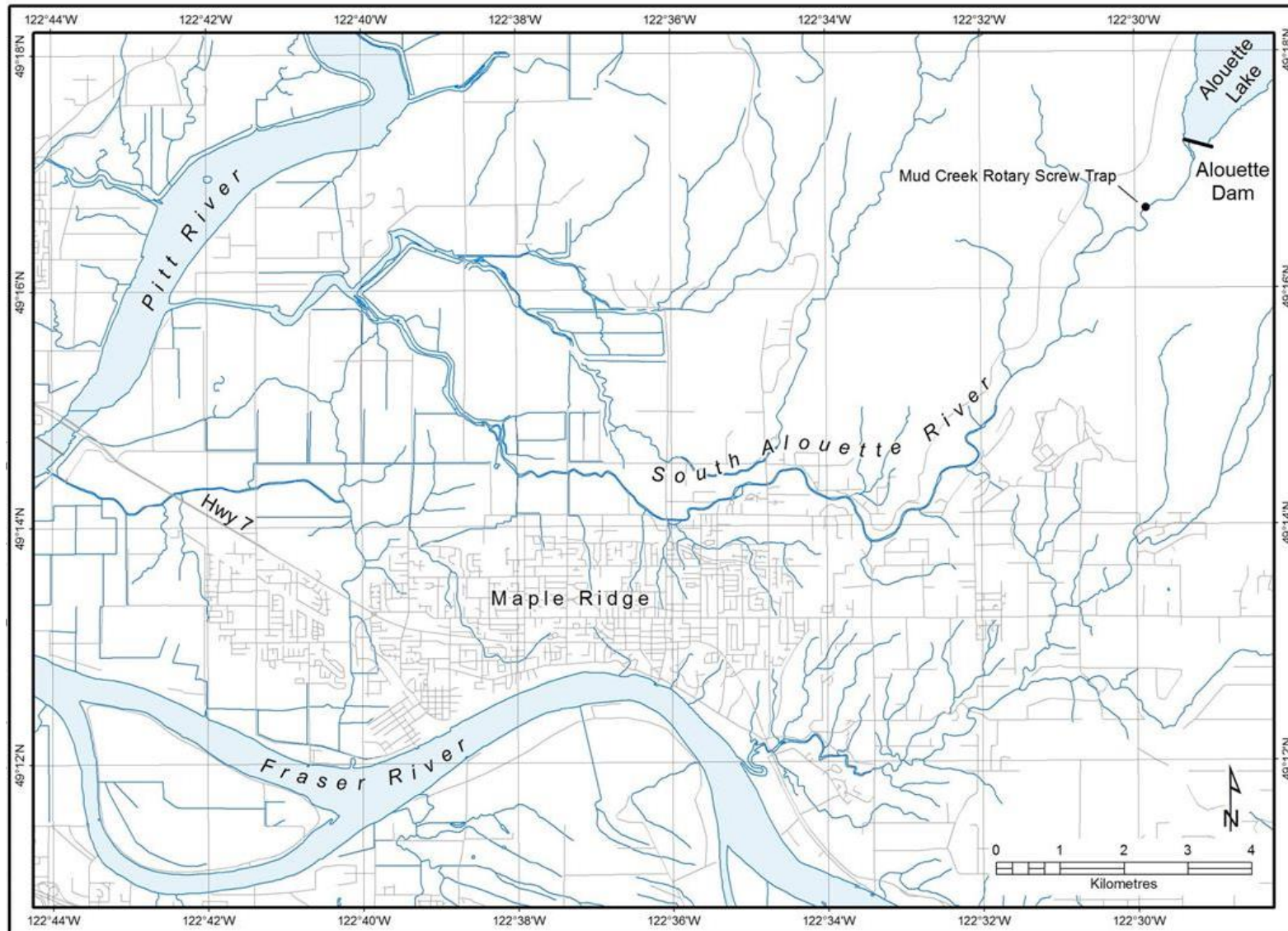


Figure 2.2. Map of the South Alouette River and location of the Mud Creek rotary screw trap in 2021.

The revised Alouette Water License issued in April 2009 confirmed that the surface release and associated Sockeye Salmon out-migration enumeration would be conducted through 2014. Due to run-timing uncertainty, it was proposed that the surface release be done for a period of 8 weeks each year. Annual monitoring would continue to identify the typical start, duration, and peak of the outmigration in hopes of shortening the duration of the surface release and reducing the corresponding flood risks. Although the migration timing has remained relatively consistent during the 13 years of full-season monitoring (2007–2020, excluding 2016), there have been differences in peak timing and duration. The 2011 migration continued through the first week of June, which was approximately a week later than the 2007, 2009, and 2017 migrations, and 2 weeks later than in 2008, 2010, 2012, 2013, 2014, 2015, and 2020, while the 2018 migration was the shortest duration of all full seasons monitored (35 days). The peak of the 2009 migration occurred in the latter half of May, while the peaks in 2007, 2008, 2010, 2013, 2014, 2018, and 2020 occurred in late April. The 2010 migration also began with high catches immediately once the spillway was opened in mid-April. Peak catches in 2015 occurred shortly after the opening of the spillway, peak catches in 2017 occurred 1 day following the peak spillway flow, and peak catches in 2012 occurred on the same date as 2011 (14 May); however, daily catches were extremely low in both 2012 and 2015 hence not readily comparable to previous years (Figure 2.3). Subsequent years of monitoring are, therefore, beneficial to help to improve our understanding of the timing of the run.

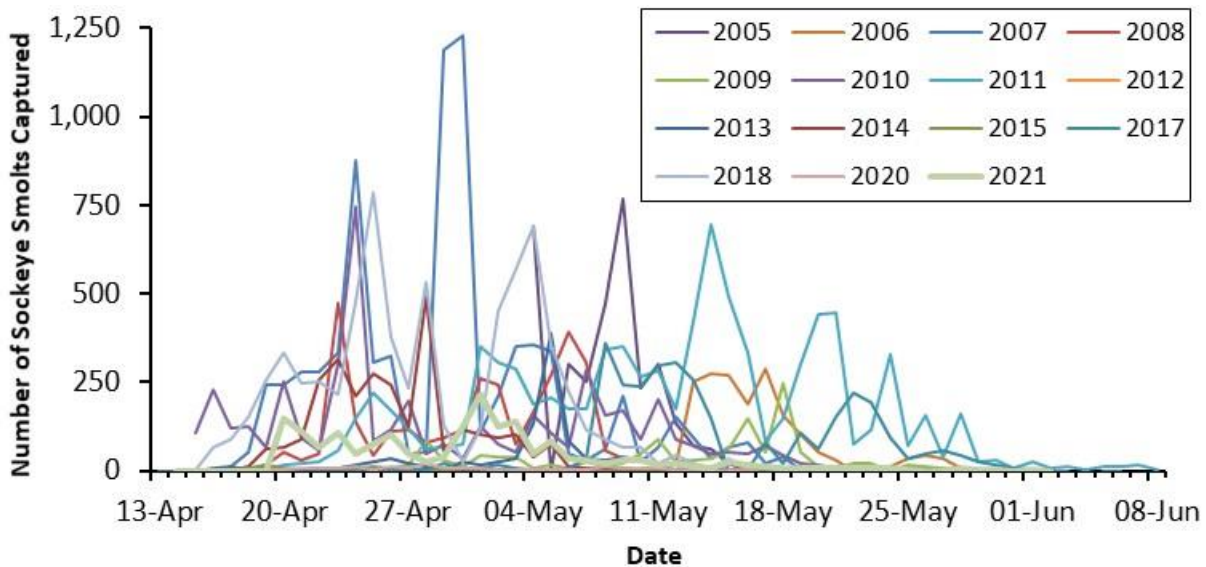


Figure 2.3. Run timing of the Sockeye Salmon smolts at the Mud Creek rotary screw trap, 2005–2021.

To address the uncertainty of whether the current magnitude of release is sufficient to promote migration among all seaward smolts, an experimental post-surface release flush was proposed for every second year of monitoring to determine if a doubling of flows for 7 days could induce additional migrants to move out of the reservoir. The first year of flush was attempted in 2009 and was scheduled for 7 days at the tail end of the migration. However, once flows reached a maximum of 6.5 m³/s, the integrity of the RST and safety of the crew and fish captured became

a concern, so the flush was terminated after only 3 days. As a result, it was proposed that a flush occur again in 2010 with an alternative gear type (e.g., IPTs) that could be operated safely during high flows. However, as discussed earlier, the IPTs were not effective at capturing Sockeye Salmon smolts, so operational modifications were made to the RST so that it could operate safely and effectively during the 7-day flush period. No increases in Sockeye Salmon catches were observed at the Mud Creek RST during the 2010 and 2011 post-surface release flush periods. In 2014, four modified pulse flows (i.e., an increase to approximately 4.5 m³/s for 24 hours) occurred in place of a post-surface release flush to see if there was a corresponding increase in the number of out-migrating juveniles in response to the pulses; no increase was observed. In 2020, there was a very small increase in catches during the 7-day pulse flow from mid-late May, indicating the higher pulse flows may have encouraged a small pulse of smolts to migrate.

The 2014 study was the final year of the Kokanee Out-Migration (ALUMON#2) project funded through the Alouette Water Use Plan (WUP) Monitoring Program. This monitoring program successfully addressed the three management questions originally proposed in the WUP terms of reference. First, this monitoring program showed that a surface release of at least 3 m³/s from the Alouette Dam (obtained through the spillway gate) was adequate to promote the downstream migration of Sockeye Salmon smolts out of the Alouette Reservoir. In each year of study, Sockeye Salmon catches at the Mud Creek RST showed a distinct start, peak, and end, which is a characteristic pattern for out-migrating Sockeye Salmon smolts. Second, this monitoring program revealed that a post-surface release flush of 6–9 m³/s, lasting 7 days following the tail end of the out-migration period, did not appear to encourage more smolts to leave the system. Flush events (2009, 2010, and 2011) and pulse flows (2014) did not yield an increase in Sockeye Salmon catches at the Mud Creek RST. And third, this monitoring program appeared to show that a surface-release period from mid-April to early June promotes the out-migration of all Sockeye Salmon smolts that are prepared to leave the system.

Although the WUP CC management questions were answered with the completion of the monitoring program (ALUMON#2), the Alouette River Sockeye Re-anadromization Project (ARSRP; now known as the Alouette River Salmon Re-anadromization Project) Committee recommended continued annual monitoring of smolt outmigration at Mud Creek as this was deemed critical to the question of re-establishing a self-sustaining population of Alouette Reservoir Sockeye Salmon. Given this recommendation, a successful application for the Fish and Wildlife Compensation Program (FWCP) funding was completed in 2015 and the annual monitoring continued. However, in 2016, the FWCP funds were not awarded and hence no smolt migration monitoring occurred. From 2017 to 2021, smolt out-migration monitoring has been included as a component of the Alouette Watershed Sockeye Fish Passage Feasibility Project that has been successfully awarded funds annually by the FWCP.

Project Objectives

Specific objectives for the 2021 study year were to:

- 1) Operate a rotary screw trap (1.8 m diameter) safely and continuously from 15 April to approximately early June (or when the migration ceases) during high spillway flows at the Mud Creek site located 1.5 km downstream from the Alouette Dam;
- 2) Inspect all Sockeye Salmon smolts captured for a mark, and apply marks to all unmarked Sockeye Salmon smolts captured up to a specified daily target (dependent on random or target samples);
- 3) Transport all marked fish to the plunge pool located immediately downstream of the Alouette Dam and release (on a daily basis);
- 4) Collect biosamples from a subset of individual Sockeye Salmon smolts captured, including length, weight, scales (for ageing), and a tissue sample (fin clip for genetic analysis);
- 5) Enumerate and collect length information from all adipose clipped Coho Salmon smolts captured in the RST; and
- 6) Enumerate and release all other fish species captured in the RST.

METHODS

Study Area

The Alouette Reservoir is located 11 km northeast of Maple Ridge in southwest British Columbia (Figure 2.1). The Alouette River watershed is a relatively small system (144 km²) that arises in the Coastal Mountains of Golden Ears Provincial Park, approximately 50 km northeast of Vancouver, B.C. The upper watershed flows into an impounded reservoir known as Alouette Lake. At the reservoir's river outlet, the South Alouette River flows for 21 km before entering the Pitt River near Pitt Meadows; and the Pitt River, in turn, flows south into the Fraser River at Douglas Island.

Present fish resources within the Alouette Reservoir include Sockeye Salmon and kokanee (*O. nerka*), Rainbow Trout (*O. mykiss*), Bull Trout (*Salvelinus confluentus*), Cutthroat Trout (*O. clarkii clarkii*), Lake Trout (*Salvelinus namaycush*), Three-spined Stickleback (*Gasterosteus aculeatus*), sculpin (*Cottus* sp.), Northern Pikeminnow (*Ptycheilus oregonensis*), Peamouth (*Mylocheilus caurinus*), Bridgelip Sucker (*Catostomus columbianus*), Largescale Sucker (*C. macrocheilus*), and Redside Shiner (*Richardsonius balteatus*; Wilson et al. 2003).

BC Hydro Operations

Spillway flows began at the typical spring surface release of approximately 3 m³/s on 15 April then increased to a range of 8.5–10.1 m³/s from 19 April to 2 June. Once the smolt migration ceased flows were decreased back down to approximately 3 m³/s until 15 June. Alouette flows diverted to the Stave Reservoir via the adit gate during the RST operational period ranged from 5.50 to 49.03 m³/s.

Fish Capture and Sampling

All fish for this study were captured at the Mud Creek RST, located on the South Alouette River approximately 1.5 km downstream of the Alouette Dam (Figure 2.2; Photo 2.1). The Mud Creek RST was checked two to three times daily (an extra check occurred when debris levels were high). Each morning, crews enumerated all species of fish in the holding box. Unmarked non-target fish were enumerated to species and released downstream of the trap. All adipose clipped Coho Salmon smolts captured were enumerated and measured for fork length (FL) prior to release downstream of the RST. Each evening, crews checked the RST for debris and ensured that all fish in the holding box were healthy. On days when debris levels were high or a rain event occurred, crews checked the RST in the afternoon and again in the evening just prior to dusk. All fish captured after the morning check were processed the following morning.

Up to a daily maximum of 150 randomly chosen Sockeye Salmon smolts were marked with a lower caudal fin clip. If the random sample did not produce ten large fish (≥ 100 mm FL), then additional target samples were to be collected until this goal was reached (up to a maximum of 10 fish per day). All target fish were to receive an adipose fin clip instead of a lower caudal fin clip. All marked fish were held in recovery buckets that were placed in the RST live tank for several hours prior to release. Marked fish were then released into the plunge pool below the dam during the evening on the day they were marked which allowed adequate time for recovery (note fish captured and marked on 20 April were released 21 April due to logistical issues).

The first 40 randomly chosen Sockeye Salmon smolts each day, as well as any target samples of large fish, were measured for fork length (to the nearest millimetre) and weighed (to the nearest tenth of a gram). Fish scales were collected from the first 10 randomly chosen Sockeye Salmon smolts each day, and from all target samples. Scales were sent to the Fisheries and Oceans Canada (DFO) Pacific Biological Station (Nanaimo, B.C.) for ageing. Genetic samples (fin tissue) were collected from the first 40 randomly chosen Sockeye Salmon each day and from all target samples. Genetic samples were sent to the DFO Pacific Biological Station for future potential Alouette watershed genetic studies at a later date.



Photo 2.1. Mud Creek rotary screw trap, 12 May 2021.

Statistical Analyses

Abundance Estimate

An unbiased pooled Petersen equation for a single sampling site (Volkhardt et al. 2007) was used to estimate the number of Sockeye Salmon migrating from the reservoir:

$$N = U \cdot \frac{M+1}{R+1}, \quad (1)$$

where

U = total number of unmarked fish caught in second sample,

M = number of fish caught, marked, and released in first sample,

N = population estimate, and

R = number of recaptures in the second sample (i.e., fish that were marked and released in the first sample).

The variance, standard error, and approximate 95% confidence interval (CI) for the abundance estimate (N) were calculated as follows:

$$CI = N \pm 1.96 * \text{Standard error} \quad (2)$$

where

$$\text{Standard error} = \sqrt{\text{Variance of } N} \quad (3)$$

and

$$\text{Variance of } N = \frac{(M+1) \cdot (U+R+1) \cdot (M-R) \cdot U}{(R+1)^2 \cdot (R+2)} \quad (4)$$

Since a single mark was used for the duration of the field season, there was no direct way to determine average travel times. In past years, a 2-day lag from release to recapture was assumed. This year, the peak date for marks-applied (1 May) was separated by 4 days from the peak date for recaptures (5 May), and a series of correlation analyses between the marks-applied and lagged recapture time series (Appendix 2.A) showed the highest correlation at a lag of 4 days (Appendix 2.B). Nevertheless, at least some fish had 1-day travel times (first marks were released 21 April, recaptures occurred 22 April). Lag times and travel times do not directly impact the Petersen equation, since the calculations were performed on the final counts, pooled over the entire study period.

Due to debris issues, there were 3 days when the RST was not fully functional, hence an estimate was made of what the unmarked catch might have been had the trap functioned (average of the previous and subsequent days' catches). The debris issues also complicated the Petersen estimation, because marks released prior to the trap malfunction (and which passed the trap while it was compromised) were not provided a fair opportunity to be recaptured. To avoid underestimation of trap effectiveness, we excluded from the analyses any fish that were marked and released 1 day previous, and marks detected on the day of. It could be argued that we should instead have ignored marks released 2 days prior (given assumed travel times from previous years), or 4 days prior (based on the correlation analysis in Appendix 2.B). A sensitivity analysis revealed that the impact of this adjustment was insensitive to the number of days selected (Appendix 2.C).

Fish Lengths, Weights, and Condition Factors

The lengths, weights, and condition factors of randomly chosen 1-year-old Sockeye Salmon smolts (i.e., fish considered to have over-wintered for 1 year in the Alouette Reservoir) were compared by year of monitoring using analysis of variance (ANOVA). Length-at-age data from 2005 to 2010 (Mathews and Bocking 2011) indicated that 1-year-old fish were 100 mm FL or less, thus bigger fish were excluded from the length and weight analyses. When ANOVA results were statistically significant, Tukey's honestly significant difference (HSD) post-hoc multiple comparison was used to assess pairwise differences.

RESULTS

BC Hydro Operations

The Alouette Dam spillway gate was opened on 15 April 2021 at 1105 hours and remained open until 15 June at 1211 hours. The average daily releases from the spillway gate ranged from 3.22 to 3.75 m³/s (minimum measured from the first full day of spilling from the crest gate) until 19 April when hydro operations were modified to allow for higher spillway flows during the smolt outmigration period (Figure 2.4). During this period, the average daily releases from the spillway gate ranged from 8.5 to 10.1 m³/s. Once the smolt migration ceased the spillway gate was partially closed (3 June) and flows again ranged from 3.1 to 3.4 m³/s until the spring surface release was complete on 15 June. The low-level outlet gate was closed from 15 April to 15 June. Alouette flows diverted to the Stave Reservoir via the adit gate during the RST operational period (14 April to 2 June) ranged from 5.50 to 49.03 m³/s.

Fishing Effort and Physical Conditions

The Mud Creek RST was installed and operational on 14 April (approximately 1700 hours). A minor stoppage occurred the morning of 20 April (1.80 h) and another stoppage occurred later that night or during the early morning of 21 April as the RST was found clogged with debris upon arrival for the morning check on 21 April. Following this the RST operated continuously until 2 June (1040 hours). Water temperature, water depth, RST rotational speed, and general weather conditions were recorded daily each morning from 15 April to 2 June (Appendix 2.D). Water temperature was measured using a hand-held thermometer. Daily discharge of the South Alouette River was recorded at the Water Survey of Canada (WSC) Station No. 08MH005 (approximately 10 km downstream of the Mud Creek RST site) and ranged from 2.90 to 11.67 m³/s (mean = 7.97 m³/s) between 14 April and 2 June (Figure 2.5).

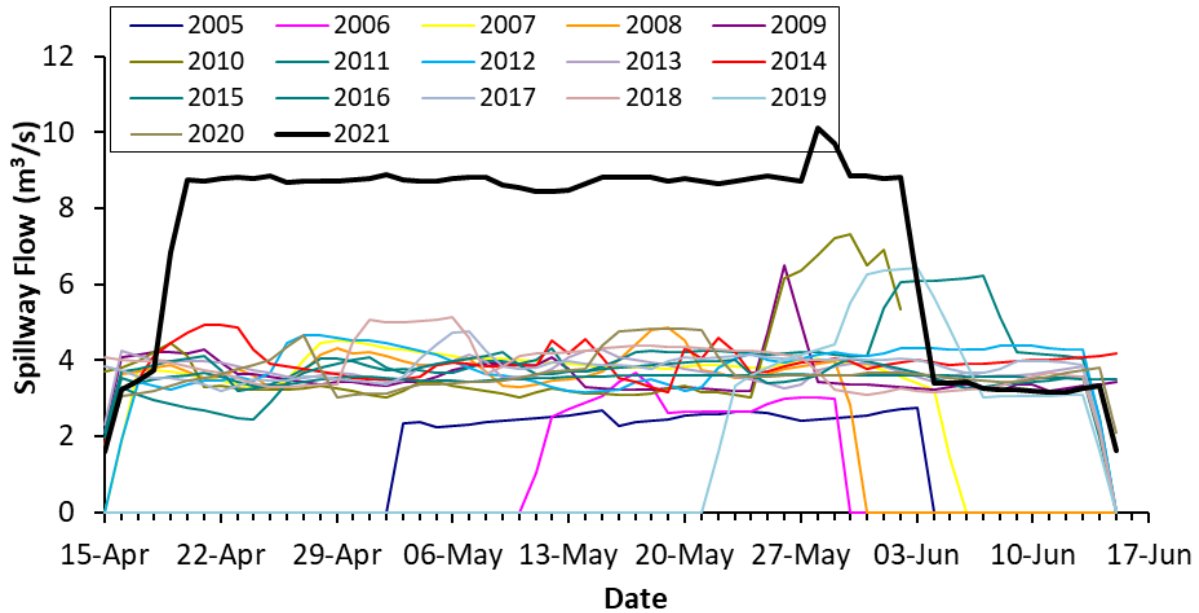


Figure 2.4. Comparison of flows at the Alouette Dam spillway gate during the Sockeye Salmon smolt migration period, 2005–2021.

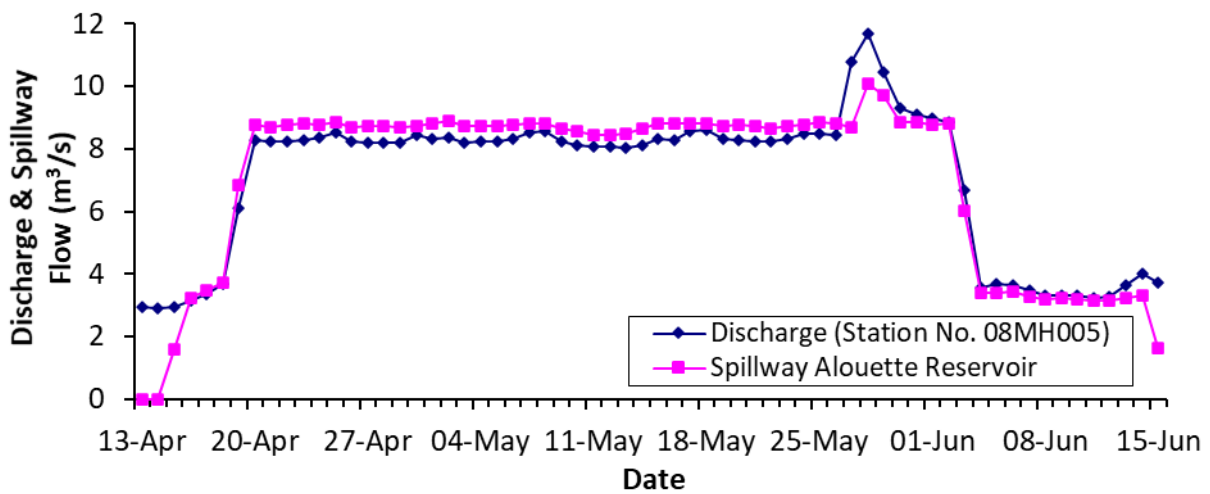


Figure 2.5. Daily discharge (m³/s) at WSC Station No. 08MH005 and spillway flows from the Alouette Reservoir, 13 April–15 June 2021. The WSC station is located on the mainstem South Alouette River at the 232nd Street bridge (discharge data from WSC website [accessed November 2021]: https://wateroffice.ec.gc.ca/search/real_time_e.html).

Fish Capture and Sampling

Sockeye Salmon Smolts

Substantial debris in the RST on 21 April resulted in several degraded mortalities, hence an estimate was done on site by the crew of both mortalities and live fish released quickly among the debris.

Also, on 25 April, 13 May, and 19 May, debris interference in the RST holding tank allowed fish to escape (visually observed by the crew), therefore the total tally counted from the holding tank was known to be low, hence the daily catch was estimated based on the average of the previous and subsequent days' catches. The analysis excluded the number of marks released the day previous ($n = 68$), and the marks detected on the day of ($n = 2$), given that the compromised fishing did not provide a real opportunity to recapture the marks released the day before. Given these operational issues the unmarked catch of 1,800 smolts includes the 3 days of estimated catches.

From 14 April to 2 June 2021, 1,721 unmarked Sockeye Salmon smolts were captured in the Mud Creek RST (Table 2.2). An additional 79 smolts were estimated and added to the unmarked catch for the 3 days when the RST was not fully functional, resulting in a total catch of 1,800 smolts (Figure 2.6). The peak catch of 215 smolts occurred on 1 May. The first smolt was captured on 20 April and the last on 1 June, a migration duration of 43 days.

A total of 1,571 Sockeye Salmon smolts were marked (lower caudal clipped) and released below the dam, however 68 smolts marked on the days prior to the 3 days when the RST was not fully functional were excluded from the estimate, resulting in 1,503 ('M') marks released (Table 2.3). A total of 1,800 unmarked smolts ('U') captured at the Mud Creek RST were examined for marks and considered available for recapture, and 364 ('R') lower caudal clipped smolts recaptured were included in the estimate (366 total recaptures: Table 2.2).

A total of 823 unmarked Sockeye Salmon smolts captured were measured for fork length and weighed. Of these, 308 were scale-sampled and had fin tissue collected for potential genetic studies. The lengths of smolts sampled ranged from 65 to 255 mm FL (mean = 86.6 mm FL; $n = 823$; Figure 2.7). The largest number of Sockeye Salmon smolts were in the 76–80 mm FL ($n = 286$) size class, the second largest size class was 81–85 mm FL ($n = 265$). The weights of Sockeye Salmon sampled ranged from 2.5 to 126.0 g and averaged 8.3 g ($n = 823$). Figure 2.8 displays a length–weight relationship established for the 2021 Sockeye Salmon smolts migrating from the Alouette Reservoir.

Of those Sockeye Salmon measuring less than 100 mm FL (i.e., fish considered to have over-wintered for 1 year in the Alouette Reservoir), mean lengths varied significantly among years ($F_{14, 7,813} = 497.7$, $P < 0.0001$; Table 2.4.). Post-hoc pairwise comparisons revealed a complex pattern of differences among years (Figure 2.9, where years that are not connected by the same letter are significantly different). Mean lengths in 2021 were significantly smaller than those in 2010, 2013, and 2017, and significantly longer than those in 2005, 2008, 2009, 2011,

2014, 2015, and 2018. The average length of Sockeye Salmon smolts measuring less than 100 mm FL and the estimated abundance of Sockeye Salmon (all sizes) that migrated from the South Alouette Reservoir were also compared (Figure 2.10). There was no apparent relationship between smolt size and abundance.

The average weight of 1-year-old Sockeye Salmon smolts varied significantly among study years (F12, 7,101 = 577.2, $P < 0.0001$; Table 2.5). Post-hoc pairwise comparisons revealed a complex pattern of differences among years (Figure 2.9). Mean weights in 2021 were significantly lower than those in 2010, 2013, 2017, and 2020; and significantly heavier than those in 2006, 2009, 2011, 2014, 2015, and 2018. Note that weights were not measured in 2005 or 2008.

The average condition factor varied significantly among study years (F12, 7,101 = 121.2, $P < 0.0001$). Results of the post-hoc pairwise comparisons between years are shown in Figure 2.9, where years that are not connected by the same letter are significantly different. Mean condition factor in 2021 was among the highest recorded to date, and was significantly better than in 2009–2014, and 2018.

Table 2.2. Daily catch of Sockeye Salmon smolts in the Mud Creek rotary screw trap, 2021.

Date	Mud Creek	
	Unmarked	Clip Recaptures
14-Apr	0	0
15-Apr	0	0
16-Apr	0	0
17-Apr	0	0
18-Apr	0	0
19-Apr	0	0
20-Apr	145	0
21-Apr ^a	110	0
22-Apr	67	7
23-Apr	105	1
24-Apr	49	7
25-Apr ^b	8	1
26-Apr	101	3
27-Apr	47	11
28-Apr	27	16
29-Apr	40	10
30-Apr	123	27
01-May	215	25
02-May	124	33
03-May	136	22
04-May	49	28
05-May	82	42
06-May	35	23
07-May	28	20
08-May	20	19
09-May	29	1
10-May	28	2
11-May	16	0
12-May	19	6
13-May ^b	5	1
14-May	8	3
15-May	25	5

Table 2.2. Continued.

Date	Mud Creek	
	Unmarked	Clip Recaptures
16-May	14	14
17-May	11	7
18-May	7	6
19-May ^b	4	0
20-May	8	9
21-May	7	7
22-May	7	4
23-May	5	2
24-May	5	2
25-May	1	1
26-May	0	0
27-May	0	0
28-May	5	1
29-May	3	0
30-May	2	0
31-May	0	0
01-Jun	1	0
02-Jun	0	0
Total	1,721	366

^a Total unmarked catch includes mortality estimate due to debris event.

^b RST not fully functional due to debris.

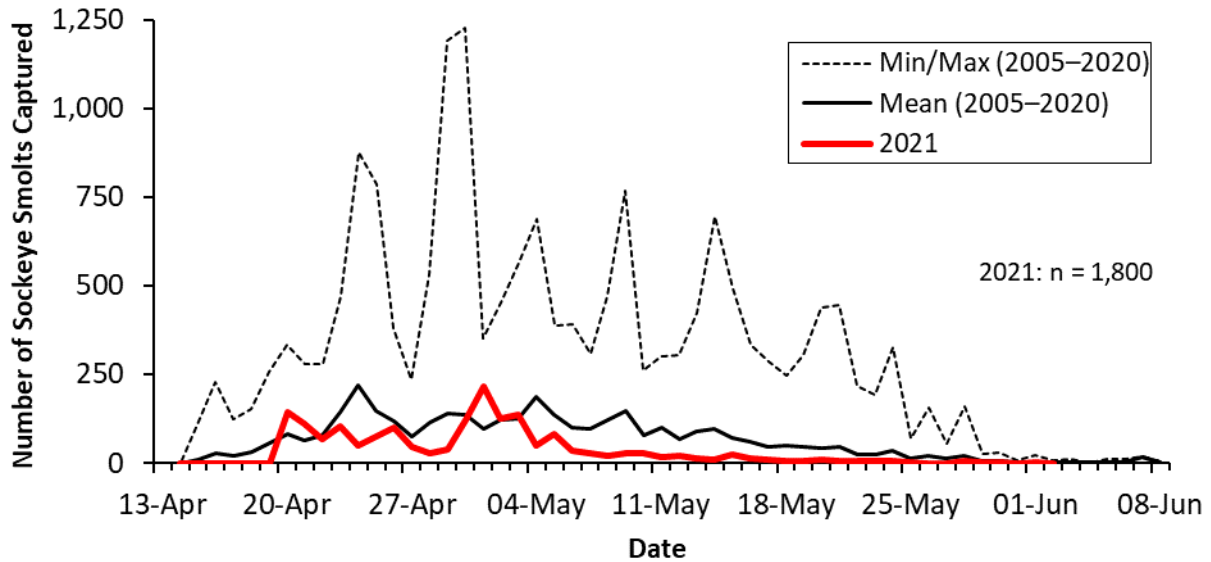


Figure 2.6. Daily catch of Sockeye Salmon smolts at the Mud Creek rotary screw trap in 2021 in comparison to the maximum, mean, and minimum catches of the previous fourteen study years.

Table 2.3. Total estimated Sockeye Salmon smolt migration from the Alouette Reservoir, 2021.

Sockeye Passage at Mud Creek:

No. Sockeye Clipped and Released Below Dam ('M')	1,503
No. Sockeye Unmarked Fish ('U')	1,800
No. Sockeye Recaptures ('R')	364
Estimated Sockeye Passage (14 April–1 June 2021) ('N')	7,417
95% Confidence Interval	6,631–8,203
Trap Efficiency (%)	24.2

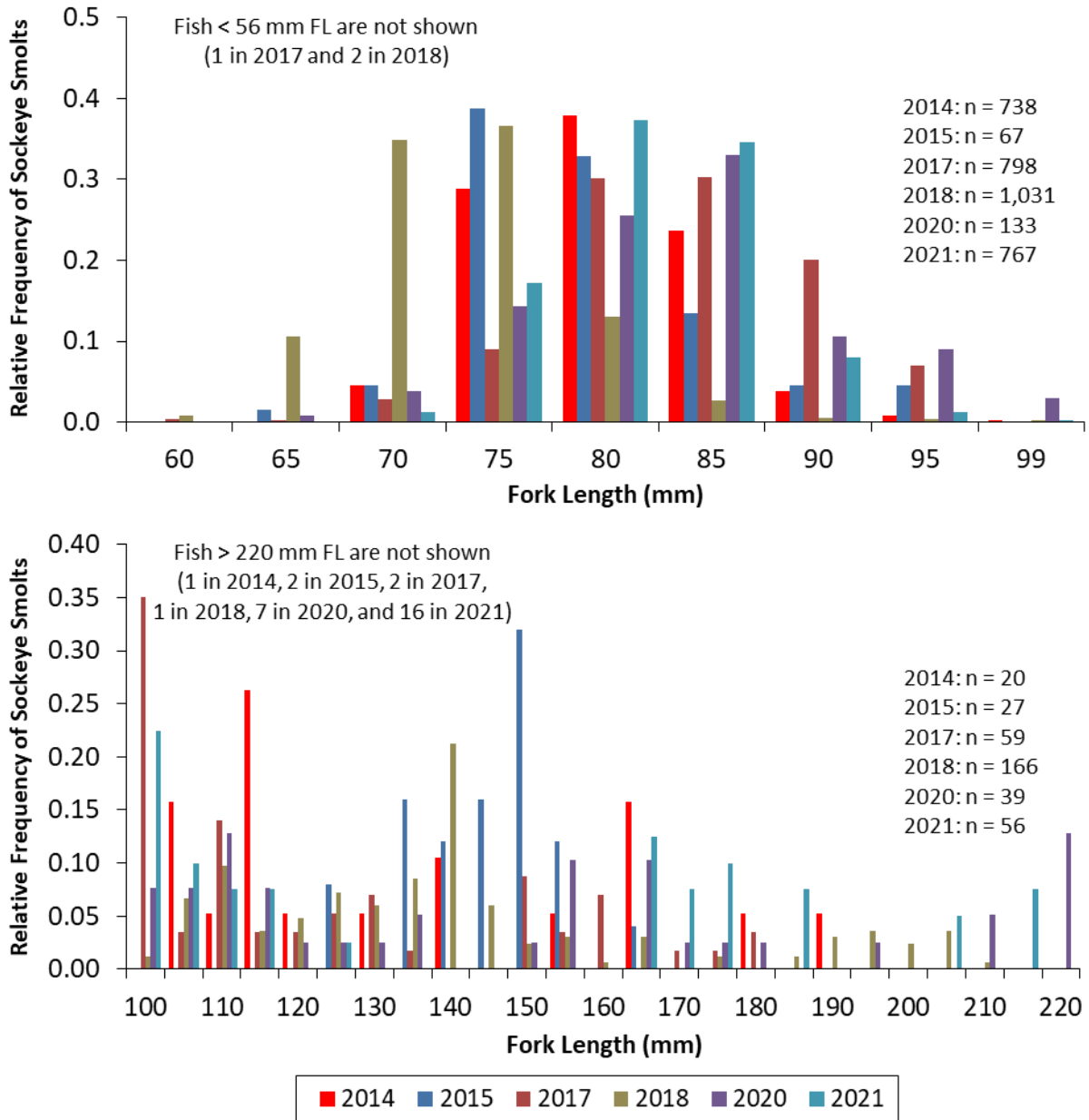


Figure 2.7. Length frequency distribution of Sockeye Salmon smolts measuring less than 100 mm FL (top panel), and 100 mm FL or greater (bottom panel), captured in the Mud Creek rotary screw trap operated in the South Alouette River (random samples), 2014–2021.

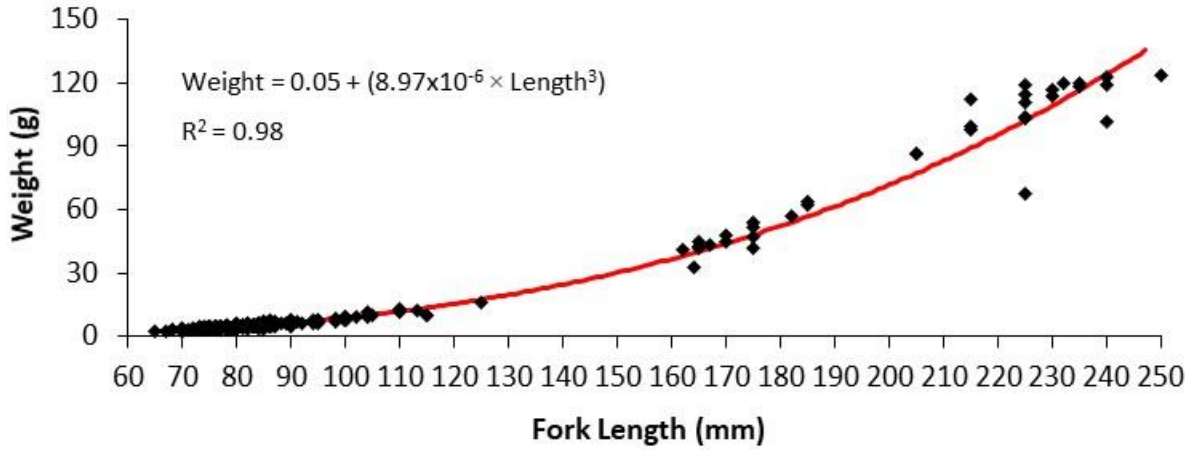


Figure 2.8. Length–weight relationship of Sockeye Salmon smolts migrating from the South Alouette Reservoir, 2021.

Table 2.4. Mean length of Sockeye Salmon less than 100 mm FL (random samples only), 2005–2021.

Year	Mean FL		
	(mm)	SE	n
2005	78.6	0.35	233
2006	79.5	0.54	97
2007	80.8	0.38	198
2008	71.2	0.25	447
2009	75.0	0.24	489
2010	83.2	0.20	708
2011	72.4	0.13	1,618
2012	79.9	0.84	40
2013	85.6	0.25	464
2014	78.1	0.20	738
2015	77.8	0.65	67
2017	83.7	0.19	798
2018	71.4	0.17	1,031
2020	81.6	0.46	133
2021	80.5	0.19	767

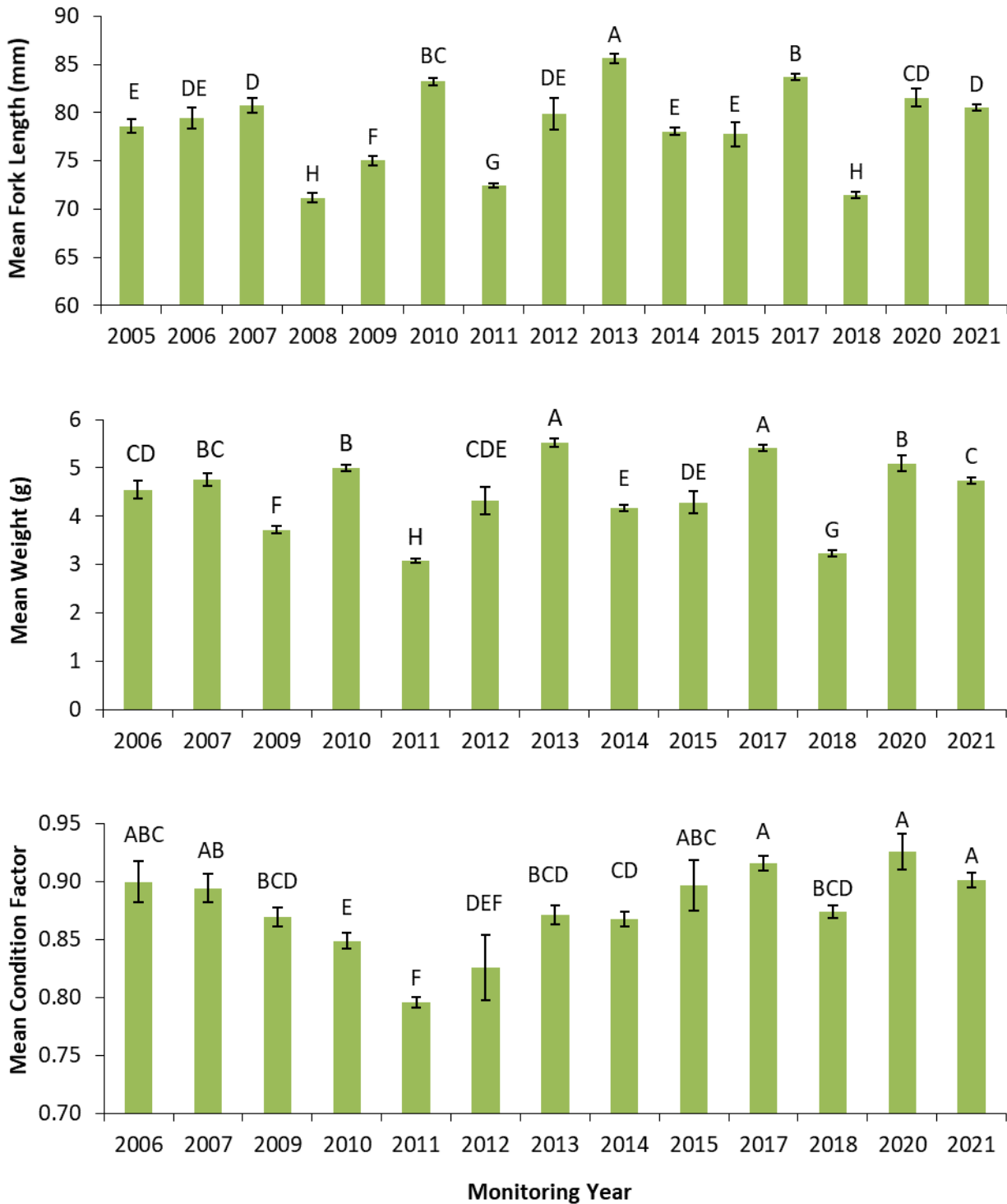


Figure 2.9. Comparison of mean fork length (top), weight (middle), and condition factors (bottom) across sampling years for Sockeye Salmon smolts (<100 mm FL) captured at the Mud Creek RST, 2005–2021.

Letters indicate results of the post-hoc pairwise comparisons between years, where years that are not connected by the same letter are significantly different.

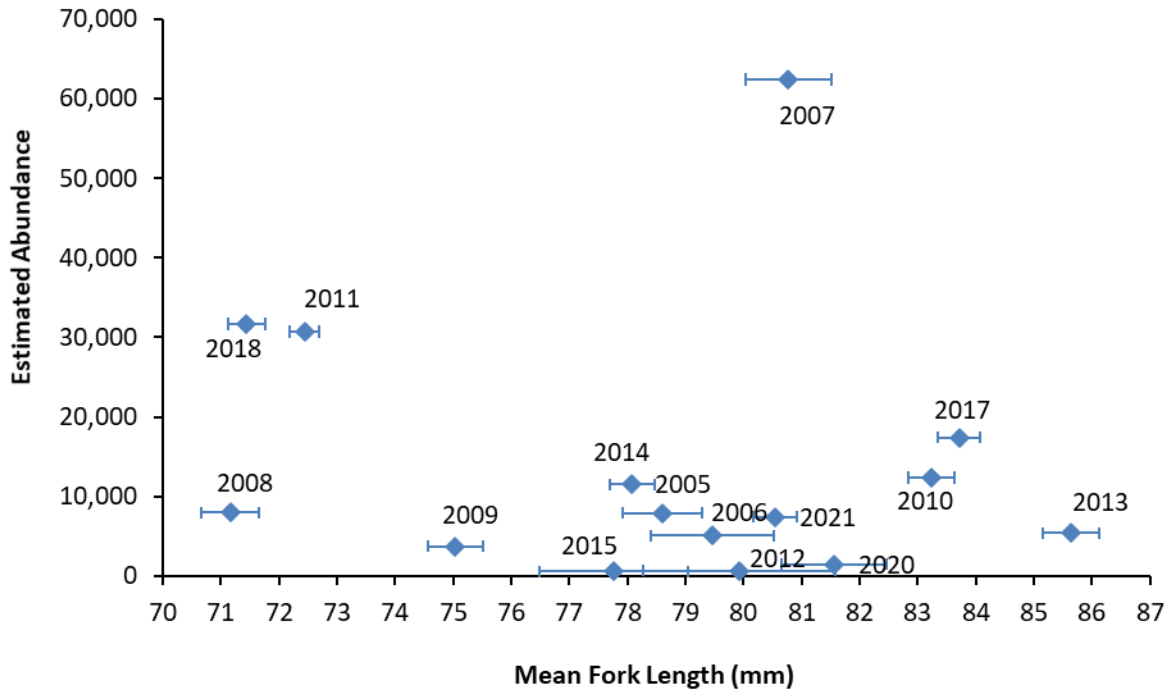


Figure 2.10. Comparison of the average length of Sockeye Salmon smolts measuring less than 100 mm FL and the estimated abundance of Sockeye Salmon (all sizes) that migrated from the South Alouette Reservoir, 2005–2021.

Labels beside the data points indicate the study year.

Table 2.5. Mean weights of Sockeye Salmon smolts less than 100 mm FL (random samples only), 2005–2021.

Year	Mean Wt (g)	SE	n
2006	4.6	0.09	97
2007	4.8	0.07	198
2009	3.7	0.04	489
2010	5.0	0.04	684
2011	3.1	0.02	1,618
2012	4.3	0.15	40
2013	5.5	0.04	464
2014	4.2	0.03	738
2015	4.3	0.11	67
2017	5.4	0.03	789
2018	3.2	0.03	1,030
2020	5.1	0.08	133
2021	4.7	0.03	767

Other Species

In total, 149 adipose clipped Coho Salmon smolts were captured from 27 April to 1 June (Appendix 2.E); fork lengths of these fish ranged from 80 to 200 mm. These smolts were released as fry into the Alouette Reservoir in May 2020. Upon request from DFO, timing and fork length data was collected.

In addition to wild steelhead, a total of 12 adipose clipped steelhead were captured from 25 April to 12 May. These fish were released as smolts in late spring in the lower South Alouette River and are assumed to be residuals that did not leave the system and instead moved to the upper reaches of the river.

See Appendix 2.E for all non-target species catch data.

DISCUSSION

BC Hydro Operations

Average daily spillway gate flows to the South Alouette River in 2021 differed from those observed in past monitoring years (i.e., 2007 and later) for most of the smolt migration period. On 19 April, flows increased to 8.5–10.1 m³/s until the smolt migration ceased, at which point (3 June) BC Hydro partially closed the spillway gate to decrease flows to 3.1–3.4 m³/s until the spring surface release was complete on 15 June (Figure 2.4). The opening of the spillway gate on 15 April was typical of most years, as were flows to the Stave Reservoir via the adit gate (5.50 to 49.03 m³/s).

Trapping Operations

Apart from the stoppage issues experienced on 20–21 April due to heavy debris, the Mud Creek RST operated consistently from 14 April until 2 June. However, the high flows presented many challenges for the safe and effective operation of the RST and had some detrimental effects to trap operations.

In addition to increased safety risks for the crew to operate the RST, the mortality rate of Sockeye Salmon smolts and other fish species increased (one debris event caused a significant fish kill in the beginning of the season), and many Sockeye Salmon smolts were significantly descaled. Four juvenile bird mortalities occurred (we assume they were unable to avoid the RST while floating in the heavy flow) and the RST experienced increased wear and tear that required many field repairs. The high flows also led to heavy debris loads throughout the season which were difficult to predict. The 2021 flow range of 8.5–10.1 m³/s was at the maximum range of safe operation for the crew, fish, and RST.

In addition to causing mortalities, debris issues affected the collection of catch data and the accuracy of the population estimate in the following ways:

- Some mortalities were damaged to the point that determining daily catches was not feasible;
- Debris buildup within the fish holding tank forced the water level within the tank to rise, which in turn allowed for fish to escape above the screen at the back of the tank, hence some catch was lost, and daily totals were affected; and
- In these instances when the RST was not fully functional, an estimate was made of what the unmarked catch might have been had the trap functioned. The analysis ignored the number of marks released the day previous, and the marks detected on the day of, given that the compromised fishing did not provide a real opportunity to recapture the marks released the day before.

Abundance Estimate

The South Alouette River Sockeye Salmon smolt migration at Mud Creek was estimated to be 7,417 (95% CI: 6,631–8,203) fish for the period of 14 April to 1 June 2021. This was the ninth highest estimate of the sixteen study years (Table 2.1).

The total catch of 1,800 smolts was also the ninth highest, or eighth lowest, catch of all years. The 2021 Mud Creek RST capture efficiency of 24.2% was very close to the 2005–2020 median of 23.2% (range: 11.3–42.0%), even with the increased spillway flows (Table 2.1; Figure 2.6).

Research is currently ongoing on whether hydro operations can affect Sockeye Salmon smolt outmigration abundances.

Run Timing

The 43-day duration (20 April–1 June) of the 2021 Alouette Reservoir Sockeye Salmon smolt migration was the sixth longest of all full seasons monitored (2007–2020, range: 35–51 days; Figure 2.3; Figure 2.6). The start and peak dates for the 2005 and 2006 migrations were not comparable to those from 2007 to 2020 because the spillway was opened much later in those years (3 May 2005 and 11 May 2006), and presumably after the onset of the Sockeye Salmon smolt migrations.

The first Sockeye Salmon smolt captured in 2021 was on 20 April, immediately following the increase of spillway flows (morning after the first night of high flows). The onset of the run began with a catch of 145 smolts, indicating the spillway opening was timed well with the onset of the migration. This large immediate catch differs from past years when the onset of the run typically began with a very small catch, often a single smolt; 2010 was the only other exception to this (n = 108 on 15 April). The onset of the 2021 out-migration was the latest of all full seasons monitored (past migrations began from 15–19 April). The peak catch of migrants occurred on 1 May (n = 215) and the second largest peak occurred on 20 April, the first day of migration (n = 145; Figure 2.11). The midpoint of catches occurred on 1 May.

The end date of the 2021 migration was 1 June. Of the 15 study years since 2005, 11 had end dates that were 1–13 days earlier than observed in 2021, two had the same end date, and one had an end date 7 days later. Based on all years of monitoring, the target spill period from mid-April to mid-June (as effected from 2007 to 2021) appears to cover the bulk of the smolt migration window.

Spillway flows appear to affect the timing of smolt migration and research is ongoing to investigate this further.

The run timing of the Alouette Reservoir Sockeye Salmon smolt migration is comparable to the nearby Coquitlam Reservoir Sockeye Salmon smolt migration timing; the main 2021 outmigration period in Coquitlam River coincided with the main average outmigration period for the Alouette Reservoir. In 2021, the first Coquitlam Sockeye smolt was captured on 18 April, the last fish was captured on 30 May, and the peak catch of 115 smolts occurred on 10 May 2021 (Mathews and Plate 2022).

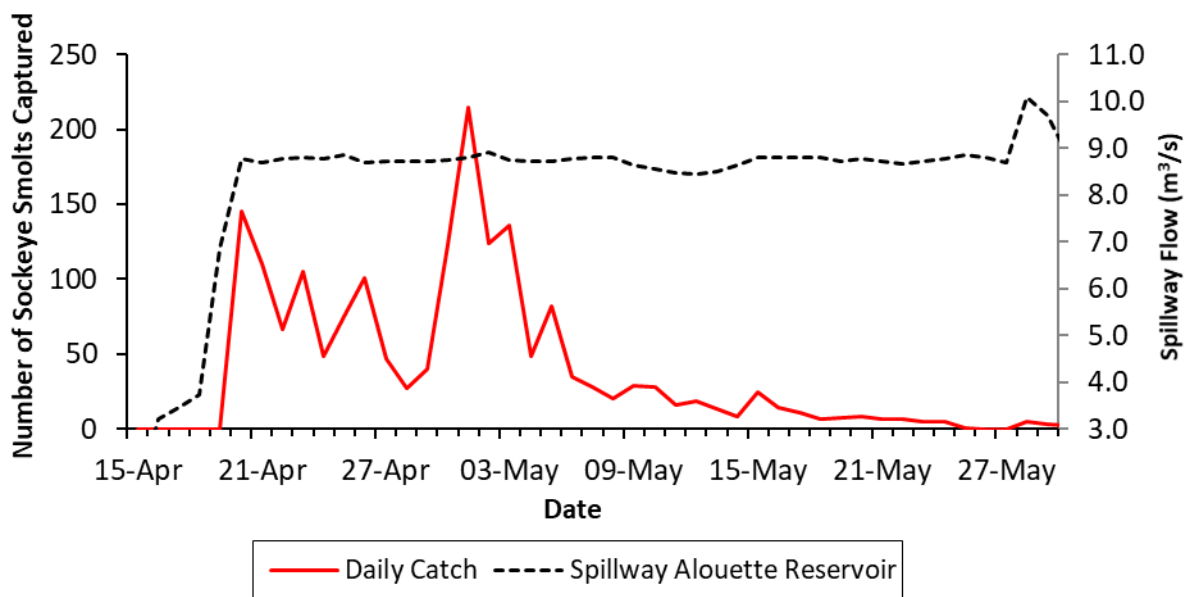


Figure 2.11. Comparison of daily catch of Sockeye Salmon smolts captured at the Mud Creek rotary screw trap and spillway flows from the Alouette Reservoir, 2021.

Biosamples

Mean fork length of smaller Sockeye Salmon smolts (<100 mm FL) captured at the Mud Creek RST has varied from a low of 71.2 mm FL in 2008 to a high of 85.6 mm FL in 2013 (Table 2.4.). The mean fork length of smaller fish observed in 2021 (80.5 mm FL; n = 767) was the sixth largest observed in fifteen study years. In 2020, the greatest number of fish were in the 76–80 and 81–85 mm FL size classes (Figure 2.7). Size classes comprising the largest number of Sockeye Salmon (<100 mm FL) have varied over the years: 66–70 (2008), 71–75 (2009, 2011, 2012, 2015, 2018), 76–80 (2005, 2006, 2014, 2012; equal numbers of fish measured in 2012

were in both the latter two size classes), and 81–85 mm FL (2007, 2010, 2013, 2017, 2020). The smallest Sockeye Salmon sampled in 2021 measured 65 mm FL, while the largest fish measured 255 mm FL. Fifty-six large Sockeye Salmon smolts (≥ 100 mm FL) were captured in 2021, which represented 6.8% of all 823 fish caught (Figure 2.7).

The mean weight of small Sockeye Salmon smolts (< 100 mm FL) sampled in 2021 (4.7 g; $n = 767$) was the sixth largest in 13 years of weight data (Table 2.5). Condition factor was compared across all years with length and weight data (except for 2005 and 2008). The mean condition factor of the 2021 Sockeye Salmon smolts was 0.90 ($n = 767$), which was the third highest condition factor among years and statistically similar to those in 2006, 2007, 2015, 2017, and 2020 (Figure 2.9).

The majority (86%) of randomly sampled Sockeye smolts caught at the Mud Creek RST in 2021 were Age-1 smolts (i.e., deposited as eggs in the Fall of 2019, emerged as fry in the Spring of 2020, and spent 1 year rearing in the lake prior to out-migrating in 2021; Table 2.6). Age-1 smolts also made up the majority (68–99%) of random samples in 2013, 2014, 2015, 2017, 2018, and 2020. The average length of Age-1 smolts in 2021 was 82 mm FL (range: 65–104 mm FL), while Age-1 smolts averaged 72–85 mm FL (range: 60–131 mm FL) in previous years. Age-2 smolts have been captured in all years (1–27% of random samples) and ranged in length from 80 to 215 mm FL. Three-year-old fish comprised 0–9% of randomly sampled fish across years and ranged from 100–247 mm FL.

Genetic analysis has not been done thus far on the 2021 Sockeye Salmon smolt samples. At this time genetic analysis is not proposed but samples are collected annually given fin tissue is readily available from the mark recapture study and can be stored and analyzed for genetic studies at a later date. Results of past genetic analysis of the Alouette Reservoir Sockeye Salmon population, including smolt samples collected at the Mud Creek RST during past study years, can be found in Godbout et al. (2011, 2013, 2014).

Table 2.6. Age composition and length at age results for Sockeye smolts sampled at the Mud Creek rotary screw trap, 2013–2015, 2017–2018, and 2020–2021.

Year	Number of Fish				Length at Age (mm FL)								
	(%)			n	Age-1			Age-2			Age-3		
	Age-1	Age-2	Age-3		Min	Max	Avg	Min	Max	Avg	Min	Max	Avg
	<u>Random Samples</u>												
2013	139 (88)	4 (3)	15 (9)	158	73	96	85	95	103	98	100	146	133
2014	210 (94)	12 (5)	1 (0)	223	67	95	78	96	165	118	247	247	247
2015	62 (70)	24 (27)	3 (3)	88	64	94	78	95	162	141	225	231	228
2017	86 (99)	1 (1)	0 (0)	87	60	115	84	180	180	180	-	-	-
2018	271 (78)	64 (18)	13 (4)	348	60	106	72	90	173	131	185	241	197
2020	106 (68)	38 (24)	13 (8)	157	64	131	81	80	210	119	161	240	218
2021 ^a	226 (86)	31 (12)	5 (2)	262	65	104	82	83	215	132	205	232	220

^a Length at age averages of Age-1 and Age-2 fish do not include all fish aged due to data discrepancies.

Size and age results from the nearby Coquitlam Reservoir Sockeye Salmon smolt migration are comparable to the Alouette Reservoir. The mean fork length of smolts captured migrating from the Coquitlam Reservoir in 2021 was 88 mm and 67% of all smolts measured were in the 81–90 mm length bin while the remaining smolts comprised the 91–100 mm, 71–80 mm, and 101–110 mm length bins; Mathews and Plate (2022) assume only one age class of Sockeye Salmon smolts, likely Age 1+ fish, out-migrated in 2021.

RECOMMENDATIONS

The 'Alouette Watershed Sockeye Fish Passage Feasibility' project is now directly awarded annually to the Alouette River Management Society by the FWCP and includes a financial contribution from BC Hydro. The Sockeye Salmon smolt monitoring program remains a component of the overall project. LGL Limited and KDLP will continue monitoring the Sockeye smolt migration from the Alouette Reservoir in the spring of 2022 as a component of Task 4 of the Sockeye Fish Passage Feasibility proposal.

Regardless of flow conditions, and similar to recent monitoring years, we propose the following recommendations to monitor the Sockeye Salmon smolt migration from the Alouette Reservoir in 2022:

- 1) Operate a rotary screw trap (1.8 m diameter) continuously from 15 April to approximately early June at the Mud Creek site located 1.5 km downstream from the Alouette Dam;
- 2) Inspect all Sockeye Salmon captured for a mark, and apply marks to all unmarked Sockeye smolts captured up to a specified daily target (dependent on random or target samples);
- 3) Transport all marked fish to the plunge pool located immediately downstream of the Alouette Dam and release (on a daily basis);
- 4) Collect biosamples from a subset of individual Sockeye Salmon smolts captured, including length, weight, scales (for ageing), and a tissue sample (fin clip for genetic analysis);
- 5) Use an unbiased pooled Petersen equation for a single sampling site to determine the population estimate of migrating Sockeye Salmon smolts; and
- 6) Record the number of all other fish captured.

Based on our experiences during 2021, and should high flows be required in future monitoring years, we propose these additional recommendations:

- 1) Given the many difficulties experienced at flows from 8.5 to 10.1 m³/s in 2021, we do not recommend exceeding this flow range in future years with the current RST setup at Mud Creek. Contrary, if continuing with the current RST setup we recommend decreasing flows to 8.5 m³/s or less to reduce fish damage and mortalities;
- 2) If high flows continue in future years, we recommend flushing (ideally using pulses) the reservoir of debris prior to trapping to avoid heavy debris causing fish kills. Flush flows could occur several weeks earlier than the typical start timing of the smolt outmigration to prevent enticing smolts to begin outmigrating early and risk missing fish counts prior to trapping. Trapping could be conducted on all days when flush flows are not occurring to determine if the early flush flows result in an early outmigration;
- 3) If high flows continue in future years, we recommend monitoring the level of descaling of Sockeye Salmon smolts and tracking mortality rates to quantify the effects;

- 4) If high flows continue in future years, we recommend making structural modifications to the holding tank to mitigate for damage to fish, such as adding a removable baffle to provide fish a reprieve from heavy flows; and for other wildlife, adding an accessible platform above the water surface in the live tank to provide trapped animals with a way to exit the water;
- 5) If high flows continue in future years, we recommend the installation of an instream log deflector to divert birds (and other species) and large debris away from the RST to prevent bycatch mortalities and reduce debris load in the RST. The log deflector system could be anchored to the left bank and would be placed far enough upstream from the RST to avoid displacing smolts close to the water surface; and
- 6) If high flows continue in future years, to mitigate for crew safety during operations we recommend installing handrails on the RST to help prevent crew from accidentally falling into the RST drum, as well as an additional safety line from shore to aid in egress should someone fall into the water downstream of the RST (a rope anchored to shore and lightly tethered to the back of the RST to act as a pendulum back into shore).

REFERENCES

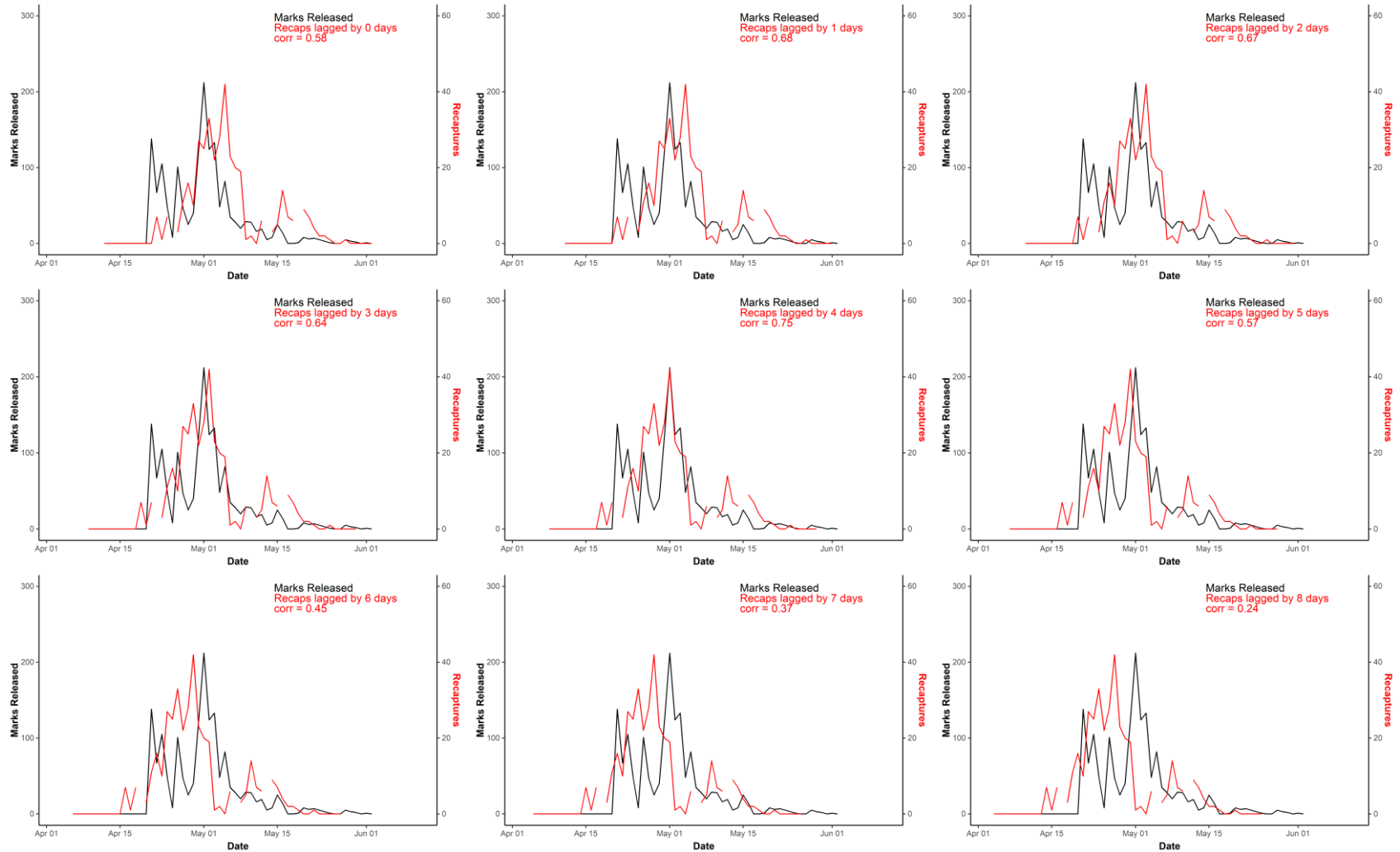
- Baxter, B.E., and R.C. Bocking. 2006. Field trials to assess Coho smolt migration success through the Alouette Reservoir, 2005. Report prepared for BC Hydro Bridge Coastal Fish and Wildlife Restoration Program by LGL Limited, Sidney, B.C. BCRP Report No. 05.AI.02.
- BC Hydro. 2009. Alouette Project Water Use Plan (April 15, 2009). Revised for Acceptance for the Comptroller of Water Rights. Report prepared by BC Hydro Generation Resource Management.
- Bocking, R.C., and M.N. Gaboury. 2002. Framework for the evaluation of restoring historic passage for anadromous fish at BC Hydro Bridge-Coastal Generation Area dams. Report prepared for Bridge-Coastal Fish and Wildlife Restoration Program.
- Gaboury, M.N., and R.C. Bocking. 2004. Feasibility of reintroducing Sockeye and other species of Pacific salmon in the Alouette Reservoir, B.C. Report prepared for Alouette River Management Society, Maple Ridge, B.C.
- Godbout, L., C.C. Wood, R.E. Withler, S. Latham, R.J. Nelson, L. Wetzel, R. Barnett-Johnson, M.J. Grove, A.K. Schmitt, and K.D. McKeegan. 2011. Sockeye Salmon (*Oncorhynchus nerka*) return after an absence of nearly 90 years: a case of reversion to anadromy. *Canadian Journal of Fisheries and Aquatic Sciences* 68(9):1590–1602.
- Godbout, L., C.C. Wood, R.E. Withler, D. Menard, and A. Ogden. 2013. Assessment of smolt production from anadromous *O. nerka* transferred into the Alouette Reservoir: brood years 2008–2010. Prepared for BC Hydro Bridge Coastal Restoration Program, Burnaby, B.C., by Fisheries and Oceans Canada, Pacific Biological Station, Nanaimo, B.C.
- Godbout, L., C.C. Wood, R. Withler, M. O'Brien, and D. Menard. 2014. Assessment of smolt production from anadromous *O. nerka* transferred into the Alouette Reservoir: brood years 2008–2012. Prepared for BC Hydro Bridge Coastal Restoration Program, Burnaby, B.C., by Fisheries and Oceans Canada, Pacific Biological Station, Nanaimo, B.C.
- Humble, S.R., A.C. Blakley, and R.C. Bocking. 2006. Field trials to assess steelhead smolt migration success through the Alouette Reservoir, 2006. Report prepared for BC Hydro Bridge Coastal Restoration Program by LGL Limited, Sidney, B.C.
- Kintama Research Corporation. 2005. Pacific Ocean Shelf Tracking Project (POST): Results from the Acoustic Tracking Study on Survival of Columbia River Salmon. Annual Report to the Bonneville Power Administration. Contract No. 2003-114-00, Grant No. 00021107.
- Mathews, M.A., and R.C. Bocking. 2007. Evaluation of the migration success of *O. nerka* (kokanee / Sockeye) from the Alouette Reservoir, 2007. Report prepared for BC Hydro Bridge Coastal Restoration Program by LGL Limited, Sidney, B.C.
- Mathews, M.A., and R.C. Bocking. 2009. Evaluation of the migration success of *O. nerka* (kokanee / Sockeye) from the Alouette Reservoir, 2008. Report prepared for BC Hydro Water License Requirements by LGL Limited, Sidney, B.C.

- Mathews, M.A., and R.C. Bocking. 2010. Evaluation of the migration success of *O. nerka* (kokanee / Sockeye) from the Alouette Reservoir, 2009. Report prepared for BC Hydro Water License Requirements by LGL Limited, Sidney, B.C.
- Mathews, M.A., and R.C. Bocking. 2011. Evaluation of the migration success of *O. nerka* (kokanee / Sockeye) from the Alouette Reservoir, 2010. Report prepared for BC Hydro Water License Requirements by LGL Limited, Sidney, B.C.
- Mathews, M.A., and E. Plate. 2022. Monitoring of 2021 Coquitlam Sockeye Salmon smolt outmigration. Report prepared for the Fish and Wildlife Compensation Program, Burnaby, B.C., by LGL Limited, Sidney, B.C. FWCP Reference No. COA-F22-F-3584-DCA.
- Mathews, M.A., and J.J. Smith. 2018. Evaluation of the migration success of *O. nerka* (kokanee / Sockeye) from the Alouette Reservoir, 2017. Report prepared for the FWCP – Coastal, Burnaby, B.C., by LGL Limited, Sidney, B.C. *In*: G. Borick-Cunningham (editor), Alouette Watershed Sockeye-Fish Passage Feasibility Project Year 1. Fish and Wildlife Compensation Program – Coastal Region. FWCP Reference No. COA-F18-F-2385.
- Mathews, M.A., and J.J. Smith. 2019. Evaluation of the migration success of *O. nerka* (kokanee / Sockeye) from the Alouette Reservoir, 2018. Report prepared for the FWCP – Coastal, Burnaby, B.C., by LGL Limited, Sidney, B.C. *In*: G. Borick-Cunningham (editor), Alouette Watershed Sockeye-Fish Passage Feasibility Project Year 2. Fish and Wildlife Compensation Program – Coastal Region. FWCP Reference No. COA-F19-F-2683.
- Mathews, M.A., and J.J. Smith. 2020. Evaluation of the migration success of *O. nerka* (kokanee / Sockeye) from the Alouette Reservoir, 2019. Report prepared for the FWCP – Coastal, Burnaby, B.C., by LGL Limited, Sidney, B.C. *In*: G. Borick-Cunningham (editor), Alouette Watershed Sockeye-Fish Passage Feasibility Project Year 3. Fish and Wildlife Compensation Program – Coastal Region. FWCP Reference No. COA-F20-F-3072.
- Mathews, M.A., and J.J. Smith. 2021. Evaluation of the migration success of *O. nerka* (kokanee / Sockeye) from the Alouette Reservoir, 2020. Report prepared for the FWCP – Coastal, Burnaby, B.C., by LGL Limited, Sidney, B.C. *In*: G. Borick-Cunningham (editor), Alouette Watershed Sockeye-Fish Passage Feasibility Project Year 4. Fish and Wildlife Compensation Program – Coastal Region. FWCP Reference No. COA-F21-F-3365-DCA.
- Mathews, M.A., J.J. Smith, and R.C. Bocking. 2012. Evaluation of the migration success of *O. nerka* (kokanee / Sockeye) from the Alouette Reservoir, 2011. Report prepared for BC Hydro Water License Requirements by LGL Limited, Sidney, B.C.
- Mathews, M.A., J.J. Smith, and R.C. Bocking. 2013. Evaluation of the migration success of *O. nerka* (kokanee / Sockeye) from the Alouette Reservoir, 2012. Report prepared for BC Hydro Water License Requirements by LGL Limited, Sidney, B.C.
- Mathews, M.A., J.J. Smith, and R.C. Bocking. 2014. Evaluation of the migration success of *O. nerka* (kokanee / Sockeye) from the Alouette Reservoir, 2013. Report prepared for BC Hydro Water License Requirements by LGL Limited, Sidney, B.C.

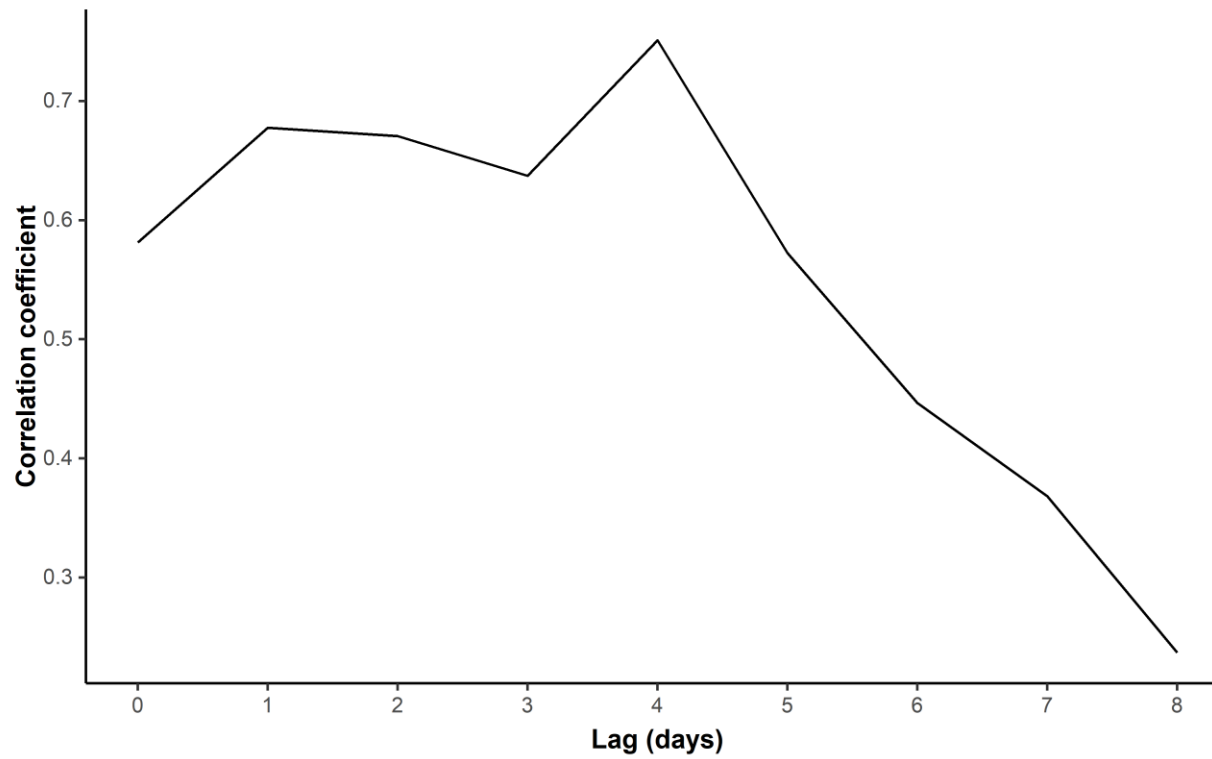
- Mathews, M.A., J.J. Smith, and R.C. Bocking. 2015. Evaluation of the migration success of *O. nerka* (kokanee / Sockeye) from the Alouette Reservoir, 2014. Report prepared for BC Hydro Water License Requirements by LGL Limited, Sidney, B.C.
- Mathews, M.A., J.J. Smith, and R.C. Bocking. 2016. Evaluation of the migration success of *O. nerka* (kokanee / Sockeye) from the Alouette Reservoir, 2015. Report prepared for the FWCP – Coastal, Burnaby, B.C., by LGL Limited, Sidney, B.C. FWCP Reference No. 16.ALU.01.
- Plate, E., M. Mathews, and R. Bocking. 2014. Technical Feasibility and Recommendations for Alouette Lake Sockeye Salmon Re-Establishment above the Alouette Dam. Report prepared for the FWCP – Coastal, Burnaby, B.C., by LGL Limited, Sidney, B.C.
- Smith, S. 2021. Alouette adult Sockeye enumeration monitor, 2020. Report prepared for the FWCP – Coastal, by the Alouette River Management Society, Maple Ridge, B.C. *In*: G. Borick-Cunningham (editor), Alouette Watershed Sockeye-Fish Passage Feasibility Project Year 4. Fish and Wildlife Compensation Program – Coastal Region. FWCP Reference No. COA-F21-F-3365-DCA.
- Volkhardt, G.C., S.L. Johnson, B.A. Miller, T.E. Nickelson, and D.E. Seiler. 2007. Rotary screw traps and inclined plane screen traps. Pages 235–266 *in* D.H. Johnson, B.M. Shrier, J.S. O’Neal, J.A. Knutzen, X. Augerot, T.A. O’Neil, and T.N. Pearsons (editors), Salmonid field protocols handbook: techniques for assessing status and trends in salmon and trout populations. American Fisheries Society, Bethesda, Md.
- Wilson, G., K. Ashley, M. McCusker, R. Land, J. Stockner, G. Scholten, D. Dolecki, and D. Sebastian. 2003. The Alouette Reservoir Fertilization Project: years 2000 and 2001 experiment, whole reservoir fertilization. Fisheries Project Report No. RD 99 2003. Ministry of Water, Land & Air Protection, Aquatic Ecosystem Section, Province of B.C.
- WSC (Water Survey of Canada). 2021. Water Survey of Canada [Internet]. Gatineau, Q.C.: Government of Canada, Environment Canada; [modified 16 November 2021; accessed November 2021]. Available from: https://wateroffice.ec.gc.ca/search/real_time_e.html.

APPENDICES

Appendix 2.A. Distributions of marks applied and numbers of recaptures, by date, at the Mud Creek rotary screw trap, 2021, where the recaptures have been lagged by 0 to 8 days.



Appendix 2.B. Correlation coefficients between daily numbers of marks applied and recaptures at the Mud Creek rotary screw trap, 2021, as a function of the number of days of lag applied to the recapture data.



Appendix 2.C. Effect of assumed lag time on the final Petersen population estimate.

	Lag (days) Assumed for Trap-efficiency Adjustments				No Adjustment Made
	1	2	3	4	
No. Sockeye Clipped and Released Below Dam (M)	1,503	1,450	1,462	1,379	1,571
No. Sockeye Unmarked (U)	1,800	1,800	1,800	1,800	1,800
No. Sockeye Recaptures (R)	364	364	364	364	366
Trap Efficiency (m/M)	24.2%	25.1%	24.9%	26.4%	23.3%
Estimated Sockeye Passage (N)	7,417	7,156	7,215	6,805	7,710
Lower CI	6,631	6,401	6,453	6,093	6,890
Upper CI	8,203	7,910	7,977	7,518	8,530

Appendix 2.D. Physical data collected at the Mud Creek rotary screw trap site, 2021.

Date	Water Temp (°C) ^a	Weather Conditions	RST Speed (RPM)	Water Depth (m)	Date	Water Temp (°C) ^a	Weather Conditions	RST Speed (RPM)	Water Depth (m)
15-Apr		sunny	7	0.24	10-May		sunny	11	0.43
16-Apr		sunny	7	0.25	11-May		sunny	9	0.43
17-Apr		sunny	7	0.25	12-May		cloudy	9	0.43
18-Apr		sunny	7	0.30	13-May		sunny	9	0.43
19-Apr		sunny	8	0.30	14-May		sunny	9	0.43
20-Apr		sunny	8.5	0.45	15-May		sunny	9	0.43
21-Apr		sunny	10	0.47	16-May		sunny	10	0.45
22-Apr	7.5	sunny	9	0.45	17-May		cloudy/rain	10	0.45
23-Apr	7	cloudy	10	0.47	18-May		cloudy/rain	10	0.47
24-Apr	9	cloudy/rain	10	0.47	19-May		cloudy/rain	10	0.45
25-Apr	10	cloudy/rain	10	0.45	20-May		sunny	10	0.45
26-Apr	9	cloudy	10	0.45	21-May		sunny	10	0.43
27-Apr	9	cloudy	10	0.45	22-May		sunny	10	0.45
28-Apr	9	cloudy	10	0.45	23-May		cloudy	10	0.45
29-Apr	9	cloudy	10	0.45	24-May		rain	10	0.45
30-Apr	9	cloudy/rain	10	0.45	25-May		sun/cloud/rain	10	0.45
01-May	9	cloudy/sun	10	0.45	26-May		cloudy	10	0.45
02-May	8	sunny	10	0.45	27-May		rain	10	0.45
03-May	8	cloudy	10	0.45	28-May		rain	10	0.47
04-May	10	cloudy	10	0.45	29-May		sunny	10	0.50
05-May	10	cloudy	10	0.45	30-May		cloudy	10	0.47
06-May	10	cloudy	10	0.44	31-May		sun/cloud/rain	10	0.45
07-May	10	cloudy	10	0.45	01-Jun	12	sunny	9	0.45
08-May	9	cloudy	10	0.45	02-Jun	11	sunny	10	0.45
09-May	10	sunny	10	0.43					

^a Note some water temperature data is missing due to equipment failures.

Appendix 2.E. Catch of non-target species at the Mud Creek rotary screw trap, 2021.

Date	Total Catch (# Fish)																		
	Chum Fry	Chinook/ Coho Fry (<70 mm)	Chinook Parr/Smolt (>70 mm)	Coho Parr/Smolt (>70 mm)	Coho Adipose Clipped (>70 mm)	Steelhead (<90 mm)	Steelhead (>90 mm)	Steelhead Adipose Clipped (>90 mm)	Bull Trout	Cutthroat Trout	Dace Spp.	Sculpin Spp.	Stickle-back	Red-side Shiner	Northern Pikeminnow	Peamouth Chub	Sucker Spp.	Lamprey	
15-Apr	1,086	8										3	1				2	1	
16-Apr	2,539	48										5			1				
17-Apr	2,625	60				3					2							1	
18-Apr	3,168	68				1			1						1	1			
19-Apr	3,120	118	1			1						1			1				
20-Apr	10,990	167				6						2	1		5		1	3	
21-Apr ^a																			
22-Apr	1,255	5				1	2					1							
23-Apr	620	10					1					1							
24-Apr	500	3					7				1	3						2	
25-Apr	190	6					3	1				2							
26-Apr	746	4		2				2				3			2				
27-Apr	1,194	6	10	4	2		3	2				2						2	
28-Apr	786	14	6	15	1		6				1				1				
29-Apr	450	50	2	6	1		4	2					1		5				
30-Apr	900	100	1	5	1		4	2					1		2				
01-May	300	3	1	3			3	0							2				
02-May	300	50	1	4	1		5					2							
03-May	345	245	1	12	4		1					1	1						
04-May	500	200		24	2		7	1				2							
05-May	300	300	2	44			3	1					1		1				
06-May	100	50		24	1		4				2	2	10	2	9			2	
07-May	50	200		45			2					2	7		2				
08-May	45	40		24			4					1	1		1				
09-May	50	10		23	6							4							
10-May	10	4	1	12	11		1				1	3	1	1					
11-May	50	30		9	5							6							
12-May		200		9	7			1				2							

Appendix 2.E. Continued.

Date	Total Catch (# Fish)																	
	Chum Fry	Chinook/ Coho Fry (<70 mm)	Chinook Parr/Smolt (>70 mm)	Coho Parr/Smolt (>70 mm)	Coho Adipose Clipped (>70 mm)	Steelhead (<90 mm)	Steelhead (>90 mm)	Steelhead Adipose Clipped (>90 mm)	Bull Trout	Cutthroat Trout	Dace Spp.	Sculpin Spp.	Stickle-back	Red-side Shiner	Northern Pikeminnow	Peamouth Chub	Sucker Spp.	Lamprey
13-May		50		24	7							2	4		1			1
14-May				22	9						1		4	1	2			
15-May				9	5		1					2	2		0			1
16-May				12	8							6	2		2			
17-May				20	9							9						
18-May				28	8		1					4	2		2			
19-May				0	1												1	
20-May				14	11							7	2					1
21-May			1	15	8		1					4	10		4			2
22-May					6							7	4					
23-May				12	4							7	1					
24-May				14	5							6			3			
25-May				7	4							11	2		2			
26-May ^b				4	4					1					4			
27-May				4	1						2		1		4			
28-May	100			20	6								2		2			
29-May				5	2							14	4		1			1
30-May ^c				6	4					1	2	6	3	1				
31-May				15	3						2	6						
01-Jun				2	2						4	6	15		2			
02-Jun				4							2	4			1			
Totals	32,319	2,049	27	502	149	1	74	12	1	2	23	147	82	6	63	1	5	16

^a Due to debris event, non target fish were quickly released and not counted.

^b Two invasive Weather Loach (*Misgurnus anguillicaudatus*) were captured.

^c One invasive Weather Loach was captured.

This page left intentionally blank

Activity 3

Alouette–Stave Diversion Tunnel Entrainment (Task 7)

“Alouette Tunnel Entrainment Monitoring, April 9, 2021, to May 31, 2022”

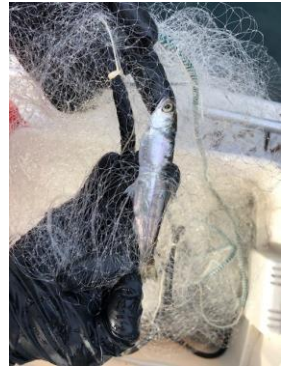
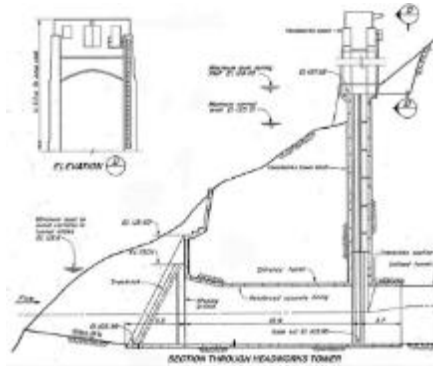
E.M. Plate and W. Challenger
LGL Limited
environmental research associates
9768 Second Street, Sidney, BC V8L 3Y8

and

A.-M. Mueller, D. Degan, and J. Lazar
Aquacoustics LLC
Sterling, Alaska

This page left intentionally blank

Alouette Tunnel Entrainment Monitoring, April 9, 2021, to May 31, 2022



Final Data Report

Prepared for:

FWCP – Coastal
11th Floor-6911 Southpoint Drive
Burnaby, BC V3N 6X8

Reference: COA-F22-F-3583-DCA



Prepared by:

Elmar M. Plate¹, Ph.D., and Wendell Challenger¹, Ph.D.

and

Anna-Maria Mueller², Ph.D.

Don Degan², M.Sc.

Jeff Lazar²

¹LGL Limited environmental research associates

²Aquacoustics LLC

Technical Contact: Elmar Plate, PhD
 eplate@lgl.com, 1.250.588.5735

October 2022



**ALOUETTE TUNNEL ENTRAINMENT MONITORING,
APRIL 9, 2021, TO MAY 31, 2022**

FINAL DATA REPORT

Prepared by:

Elmar M. Plate, Ph.D., and Wendell Challenger, Ph.D.

**LGL Limited
environmental research associates
9768 Second Street
Sidney, BC V8L 3Y8**

and

Anna-Maria Mueller, Ph.D.

Don Degan, M.Sc.

Jeff Lazar

**Aquacoustics LLC
Sterling, Alaska**

Prepared for:

**FWCP – Coastal
11th Floor-6911 Southpoint Drive
Burnaby, BC V3N 6X8**

Reference: COA-F22-F-3583-DCA

October 2022

Suggested citation:

Plate, E.M., W. Challenger, A.-M. Mueller, D. Degan, and J. Lazar. 2022. Alouette Tunnel entrainment monitoring, April 9, 2021, to May 31, 2022. Final data report. Unpublished report for BC Hydro Generations, Water License Requirements, Burnaby, B.C., by LGL Limited environmental research associates, Sidney, B.C., and Aquacoustics LLC, Sterling, Alaska. 66 pp.

Cover photos:

From left to right: Hydroacoustic transducer deployment frame, hydroacoustic transducers on rotator motors, drawing of Alouette Tunnel, and Sockeye Salmon (*Oncorhynchus nerka*) in gillnet. Photos © Elmar Plate, LGL Limited.

© 2022 BC Hydro.

No part of this publication may be reproduced, stored in a retrieval system, or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording, or otherwise, without prior permission from BC Hydro, Burnaby, B.C.

EXECUTIVE SUMMARY

To address a remaining uncertainty around the re-establishment of a self-sustaining Sockeye Salmon population, the Alouette River Salmon Restoration Program (ARSRP) Committee requested a study evaluating potential entrainment of Sockeye Salmon through the Tunnel into Stave Reservoir (herein referred to as the “Tunnel”). The concern over entrainment of juvenile Sockeye Salmon through the Tunnel was based on the high Tunnel discharges ranging from 5–50 m³/s when compared to the typical lower spillway flows into the Alouette River (3–5 m³/s) over Alouette Dam spillway in spring to facilitate juvenile Sockeye Salmon outmigration.

A hydroacoustic split-beam system was installed between April 9, 2021, and May 31, 2022, with transducers pointing in front of the Tunnel entrance to determine fish numbers, fish sizes, fish depths, and fish swimming directions in proximity to the Tunnel entrance. Initial hydroacoustic target numbers were first expanded by the coverage of the hydroacoustic cone in relation to the Tunnel entrance area and then reduced by filtering for applicable depths (in front of Tunnel entrance), swimming direction and swimming behaviour in front of the Tunnel entrance. The final number of potentially entrained Sockeye Salmon was then determined based on the filtered counts and the frequency and size of Sockeye Salmon in the gillnet sets positioned in close vicinity to the Tunnel entrance and which were used for fish species identification. Fish size of Sockeye Salmon was used to calculate the likelihood of entrainment given the current velocities at the entrance and the size dependent ability of juvenile Sockeye Salmon to escape this current.

After filtering for depth, direction, species and size, the number of Sockeye Salmon potentially entrained in the entrance to the Tunnel was estimated to be low from for the study period from April 9, 2021– May 25 in 2021 and 2022, the periods when > 95% of Sockeye smolts left the Alouette Reservoir over the Alouette Dam spillway in these two years. For both years combined, an estimated 100% (N = 17,957) of all Sockeye smolts left the reservoir over the Alouette Dam spillway while an estimated 0% of Sockeye smolts were likely entrained through the Tunnel.

In addition, the total number of Sockeye Salmon in all size classes potentially entrained over the whole study period was estimated at 2,499 fish (± SE of 971 fish) or 1.15%, while the number of likely entrained Sockeye was 816 fish (± SE of 367 fish) or 0.38% of the Sockeye population estimated at 216,807 fish on March 9, 2022. These percentages have to be seen in light of the ever-changing population size. Within these low numbers, the majority of Sockeye Salmon were entrained in summer and fall and in the length bin sizes from 101–180 mm, representing Age 2+ Sockeye Salmon.

In 2021 and 2022, the numbers of entrained targets were very low for the period preceding the last week of May. From May 22, 2021, onwards, the number of filtered targets increased by more than two orders of magnitude over the next two weeks. The same increase was not observed in 2022 when numbers of filtered targets stayed low until May 31, 2022, the end of the reporting period for this report. Based on the low number of Sockeye Salmon and the high number of Peamouth Chub in the gillnet catches, it was assumed that most of the 2021 increase in targets, detected from middle of May onwards were Peamouth Chub. This assumption was supported by literature reported Peamouth Chub behaviour at that time of year and visual observation of large numbers of juvenile Peamouth Chub at the edge of the Tunnel vortex just below the reservoir surface.

Table 3.1 lists the interim findings from this study with respect to several management questions posed by BC Hydro and the ARSRP Committee. In general, based on these interim findings, it can be concluded

that no Sockeye Salmon smolts were entrained through the Tunnel during the spring Sockeye outmigration periods in 2021 and 2022.

In addition to the stationary hydroacoustic monitoring covering the Tunnel entrance, a roving hydroacoustic survey covering transects throughout Alouette Reservoir was conducted on March 9, 2022. In this survey, the general fish distribution throughout Alouette Reservoir, and the potential congregation of fish in the Age 1+ Sockeye Salmon length class of from 30–80 mm in the Alouette North Basin and close to the Tunnel entrance were investigated. The survey showed that mainly Sockeye Salmon (species determined through gillnet sets) of all length classes were found in the highest abundances in the north portion of the South Basin and in the lowest abundances in the North Basin and close to the Tunnel. This was the first roving hydroacoustic survey carried out in the spring in Alouette Reservoir, but the resulting population estimate was well within the range of estimates based on previous BCMOE summer and fall population estimates. The fish distribution comparison between BCMOE summer–fall and our early 2022 spring surveys suggested that fish are leaving the North Basin for the South Basin in the winter or early spring. The spring hydroacoustic survey results also suggest that Age 1+ Sockeye smolts do not actively migrate northward towards the Tunnel entrance to leave the reservoir and corroborate the findings of low Sockeye Salmon numbers in front of the Tunnel entrance during the outmigration period in April and May of 2021 and 2022.

Table 3.1 Summary of management questions and key interim findings.

Management Questions (MQs)	Summary of Key Interim Findings
<p>MQ1: How do overall Alouette hydro operations influence outmigration of Sockeye smolts?</p>	<p><i>Summary</i> Based on the summaries for MQs 2–5, discharge through the Stave Tunnel (on the reservoir north end) appears to have a negligible effect on outmigration of Sockeye smolts through the Alouette River (on the reservoir south end) while discharge rates over the Alouette Dam spillway (on the reservoir south end and directly feeding the lower Alouette River) are suggested to be in a range of 3–5 m²/s, with no increase in outmigration observed for discharges > 5 m²/s. Discharges through the low level outlets (LLOs) in the Alouette Dam on the southern end of the reservoir feeding directly into the lower Alouette River are fairly constant for most of the year when the spillway is closed and are therefore not believed to be affecting Sockeye smolt outmigration into the lower Alouette River. During years when only the LLOs are open but the spillway is closed, Sockeye smolt outmigration is close to zero fish.</p>
<p>MQ2: Does decreasing flows through the Tunnel result in lower entrainment of <i>O. nerka</i>?</p>	<p><i>Summary</i> No evidence was found that decreases in Tunnel discharge resulted in lower Tunnel entrainment.</p>
<p>MQ3: Does decreasing flows through the Tunnel result in higher Sockeye Salmon migration over the Alouette dam spillway?</p>	<p><i>Summary</i> No evidence was found that Tunnel discharges affect Sockeye Salmon outmigration over the Alouette spillway.</p>
<p>MQ4: Does increasing flows down the Alouette dam spillway result in lower Tunnel entrainment of <i>O. nerka</i>?</p>	<p><i>Summary</i> There is no evidence that spillway discharges affect Tunnel entrainment; the rate of Sockeye Salmon Tunnel entrainment was observed to be very low.</p>
<p>MQ5: Does increasing flows down the Alouette dam spillway result in higher Sockeye Salmon outmigration into the Alouette River downstream of the dam?</p>	<p><i>Summary</i> The detailed analysis of this management question was not addressed in this study and report but instead analyzed for many years by Dr. Wendell Challenger (LGL Limited) and results will be presented in a report that is currently being prepared.</p>

ACKNOWLEDGEMENTS

The authors express their appreciation to the following individuals for their assistance in coordinating and conducting this study:

Alf Leake, Katy Jay, Dr. Jacqueline Chapman, and Cam Hiebert with BC Hydro were essential as logistical and administrative supports for this study. The Alouette River Management Society (ARMS) and the Alouette River Salmon Restoration Program (ARSRP) Committee Members guided the project objectives and goals in the project planning and execution phase.

We gratefully acknowledge that funding for this study was provided by the Fish and Wildlife Compensation Program and BC Hydro to the Alouette River Management Society under guidance of Greta Borick-Cunningham. We are also grateful for receiving data of previous roving hydroacoustic surveys and Sockeye population estimates by the Aquatic Ecosystem Branch of the Province of BC through Shannon Harris (Limnology Specialist).

List of Contributors:

LGL Limited environmental research associates

Elmar Plate, Ph.D. (Technical Lead, Project Manager, and Primary Report Author)

Wendell Challenger, Ph.D. (Report Co-Author and Report Reviewer)

Megan Mathews, M.Sc., R.P.Bio (Co-Project Manager and Report Reviewer)

Shane Johnson B.Sc. (Field Biologist)

Annie Chalifour, Ph.D., R.P.Bio (Field Biologist)

Julio Novoa, M.Sc. (GIS Work)

Robert Bocking, M.R.M., R.P.Bio (Report Reviewer and Senior Advisor)

Aquacoustics LLC

Anna-Maria Mueller, Ph.D. (Hydroacoustic Data Analysis)

Don Degan, M.Sc. (Hydroacoustic Data Analysis, Technical Advisor)

Jeff Lazar (Hydroacoustic Data Analysis)

Katzie Development Limited Partnership (KDLP)

Lo Sylvester (Field Technician)

Burgess Pierre (Field Technician)

Jessie Pauls (Field Technician)

George Vosper (Field Technician)

Curtis Chapman (Field Technician)

Denise Horvath (Operations Manager)

Courtney Jaquemot (Field Technician Manager)

TABLE OF CONTENTS

EXECUTIVE SUMMARY	A3-6
ACKNOWLEDGEMENTS.....	A3-9
LIST OF TABLES.....	A3-12
LIST OF FIGURES.....	A3-13
LIST OF ABBREVIATIONS	A3-15
1 BACKGROUND AND INTRODUCTION	A3-16
2 GOAL, RESEARCH QUESTION, MANAGEMENT QUESTIONS, AND DECISION PATHWAY	A3-17
2.1 Goal	A3-17
2.2 Research Question.....	A3-17
2.3 Management Questions.....	A3-17
3 STUDY AREA.....	A3-18
3.1 Alouette Watershed and Reservoir.....	A3-18
4 METHODS.....	A3-19
4.1 Site Details and Experimental Set-Up	A3-19
4.2 Split-Beam Array Settings and Data Storage	A3-23
4.3 Field Schedule	A3-24
4.4 Gillnets Sets.....	A3-25
4.5 Hydroacoustic Data Analysis	A3-26
4.6 Lake Acoustic Survey	A3-29
4.7 Acoustic Doppler Current Profiler (ADCP) Measurements	A3-32
5 RESULTS	A3-32
5.1 Filters Applied – Tunnel Hydroacoustic Monitoring.....	A3-32
5.2 Tunnel Current Velocity and Discharge	A3-32
5.3 Net Catches, Fish Species Composition, and Hydroacoustic Target Length Distributions...	A3-34
5.4 Fish Depth Distribution.....	A3-39
5.5 Fish Target Swimming Direction.....	A3-41
5.6 Sockeye Salmon Entrainment by Time of Year and Time of Day	A3-42
5.7 Reservoir Elevation and Entrainment	A3-49
5.8 Sockeye Salmon Tunnel Entrainment and Sockeye Smolt Outmigration over the Alouette Dam Spillway	A3-51
5.9 Tunnel Discharge and Sockeye Smolt Outmigration over the Alouette Dam Spillway	A3-52
5.10 Alouette Dam Spillway Discharge and Tunnel Entrainment of Sockeye Salmon	A3-52
5.11 Results of the Reservoir Hydroacoustic Survey	A3-55

6	DISCUSSION.....	A3-73
6.1	Net Catches, Fish Species Composition, and Hydroacoustic Target Length Distributions...	A3-73
6.2	Is the Net Catch Species Composition Representing the Hydroacoustic Target Species Composition?	A3-73
6.3	Fish Target Depth Distribution	A3-74
6.4	Fish Target Swimming Direction.....	A3-74
6.5	Filters Applied	A3-75
6.6	Sockeye Salmon Entrainment by Season and Time of Day	A3-75
6.7	Tunnel Current Velocity and Entrainment	A3-76
6.8	Reservoir Elevation and Entrainment	A3-76
6.9	Sockeye Salmon Tunnel Entrainment as a Proportion of Sockeye Smolt Outmigrating over the Spillway and with Regards to the whole Sockeye Population.....	A3-76
6.10	Tunnel Discharge and Sockeye Smolt Outmigration over the Alouette Dam Spillway	A3-76
6.11	Alouette Dam Spillway Discharge and Tunnel Entrainment of Sockeye Salmon	A3-77
6.12	Reservoir Survey Results and Total Entrainment as a Proportion of the Spring 2022 Sockeye Population	A3-77
6.13	Modelled versus Measured Tunnel Entrance Current Speeds and Implications for Entrainment	A3-78
6.14	Framework for a Decision-Making Pathway based on Level of Impact to Outmigration over the Spillway and into Alouette River	A3-78
6.15	Conclusion and Recommendations.....	A3-80
	REFERENCES.....	A3-81

LIST OF TABLES

Table 3.1	Summary of management questions and key interim findings.	A3-8
Table 3.2	Summary table of filters used to arrive at Sockeye Salmon entrainment numbers by seasons and size groups as a percentage of the total Alouette Reservoir fish population	A3-44
Table 3.3	Proportion of Age 1+ Sockeye Salmon smolts that were leaving Alouette Reservoir in 2021 and 2022 over the Alouette Dam spillway or were entrained through the Tunnel.....	A3-51
Table 3.4	Vertical distribution of fish in size class 0 (30–80 mm) along the long axis of the reservoir	A3-57
Table 3.5	Vertical distribution of fish in size class 1 (80–120 mm) along the long axis of the reservoir	A3-59
Table 3.6	Vertical distribution of fish in size class 2 (121–250 mm) along the long axis of the reservoir	A3-62
Table 3.7	Summary of population estimates for the spring 2022 roving survey compared to BCMOE data collected from 1998–2020	A3-67
Table 3.8	Proportion of Sockeye of all age classes in Alouette Reservoir that were entrained over the 14 months study period.....	A3-68
Table 3.9	Population estimates for fish size class 0 (0–80 mm), by basin and 5 m depth strata, starting at 5 m depth down to the lake bottom or maximum range, derived from down-looking acoustic data.....	A3-69
Table 3.10	Population estimates for fish size class 1 (80–120 mm), by basin and 5 m depth strata, starting at 5 m depth down to the lake bottom or maximum range, derived from down-looking acoustic data.....	A3-70
Table 3.11	Population estimates for fish size class 1 (121–250 mm), by basin and 5 m depth strata, starting at 5 m depth down to the lake bottom or maximum range, derived from down-looking acoustic data.....	A3-71
Table 3.12	Population estimate for fish near surface (0.6–5.0 m depth) derived from side-looking acoustic data.	A3-72
Table 3.13	Decision-making framework leading to next steps based on level of impact to outmigration over the spillway and into Alouette River.	A3-79

LIST OF FIGURES

Figure 3.1	Map of the Alouette Watershed showing local aquatic features.....	A3-19
Figure 3.2	Transducer deployment frame (left panel), automatic brake trailer winch (centre panel) used to lower and lift the transducer deployment frame to optimally cover the Tunnel entrance and keep the transducers immersed, and complete set-up with solar panels.....	A3-20
Figure 3.3	Transducer deployment frame detail (left panel) showing transducer attachment with rotator motors installed.	A3-20
Figure 3.4	Section through Headworks Tower intake showing details of the trash rack.....	A3-21
Figure 3.5	Sections through the Headworks Tower showing the dimensions of the Tunnel entrance at the trash rack (7 m high x 6.65 m wide), the Tunnel behind the trash rack (5.02 m high x 4.57 m wide) and the entrance area to the Tunnel with a concrete bottom and sidewalls that the transducers were pointing at.....	A3-22
Figure 3.6	Biosonics DT-X Extreme Autonomous Portable Scientific Echosounder surface unit and two 6° angle split-beam transducers.....	A3-24
Figure 3.7	Average fork lengths versus net mesh size for fish caught in freshwater lakes in British Columbia.....	A3-25
Figure 3.8	Side-looking beam geometry for transducer mounted at 0.6 m depth, tilted 5.5° down from horizontal.....	A3-30
Figure 3.9	Results of the February 17, 2022, ADCP measurements in front of the Tunnel entrance (top panel) with highest current velocities measured at 0.805 m/s (deep red) right in front of the Tunnel entrance at a discharge of 27 m ³ /s through the Tunnel.....	A3-33
Figure 3.10	Gillnet catch by sampling date from April 9, 2021–May 31, 2022 (total N = 184).	A3-34
Figure 3.11	Fish species composition in gillnet catch by season.....	A3-35
Figure 3.12	Fish species and size composition in gillnet catch by season.....	A3-36
Figure 3.13	Percentage of Sockeye Salmon in gillnet catch from April 9, 2021–May 31, 2022 (total N = 44) by season.	A3-37
Figure 3.14	Gillnet catch (A) from April 9, 2021–May 31, 2022 (N = 184) showing all fish species by length bins. Panel B is showing the fish target counts detected in the same length bins and Panel C shows the expanded fish target count in the same length bins.	A3-38
Figure 3.15	Fish target depth frequencies by seasons and entrainment risk.....	A3-40
Figure 3.16	Targets moving towards Tunnel entrance.....	A3-41
Figure 3.17.	Estimates of total likely and potential entrainment under different filtering assumptions.....	A3-43
Figure 3.18	Fish target (filtered by depth and swimming direction) distribution frequency by day, night, and twilight for different study periods.....	A3-45
Figure 3.19	Number of fish targets (top panel) coloured by entrainment likelihood and average daily Tunnel discharge (bottom panel) from April 9–July 9, 2021.....	A3-47
Figure 3.20	Number of fish targets (top panel) coloured by entrainment likelihood and average daily Tunnel discharge (bottom panel) from September 17,	

	2021–May 31, 2022. Entrainment was not monitored from November 13, 2021–January 31, 2022 (grey shaded area).....	A3-48
Figure 3.21	Reservoir elevation and number of filtered fish targets by date from April 9–July 9, 2021 (top panel), and from September 17, 2021–May 31, 2022 (bottom panel).....	A3-50
Figure 3.22	Average daily Tunnel discharge (m ³ /s) and daily catch of Sockeye Salmon in the RST operated in the Alouette River below Alouette Dam in 2021 (top panel) and 2022 (bottom panel).....	A3-53
Figure 3.23	Spillway flow and filtered fish detected at the Tunnel from April 9–July 9, 2021 (top panel), and from September 17, 2021–May 31, 2022 (bottom panel).....	A3-54
Figure 3.24	Geographic distribution of fish in size class 0 (30–80 mm) derived from down-looking acoustic data (depth > 5 m).....	A3-56
Figure 3.25	Geographic distribution of fish in size class 1 (80–120 mm) derived from down-looking acoustic data (depth > 5 m).....	A3-58
Figure 3.26	Geographic distribution of fish in size class 2 (121–250 mm) derived from down-looking acoustic data (depth > 5 m).....	A3-61
Figure 3.27	Geographic location of fish > 250 mm (2 individuals) derived from down-looking acoustic data (depth > 5 m).	A3-63
Figure 3.28	Geographic distribution of fish near surface (0.6–5.0 m depth) derived from side-looking acoustic data.	A3-64
Figure 3.29	Fish target density in N/ha for the south basin (Transect 8–4) and the north basin (Transect 3–1) of Alouette Reservoir survey transects.	A3-66

LIST OF ABBREVIATIONS

ADCP	acoustic Doppler current profiler
ARMS	Alouette River Management Society
ARSRP	Alouette River Salmon Restoration Program Project
BC / B.C.	British Columbia
BCMOE	BC Ministry of Environment
CI	confidence interval
FWCP	Fish and Wildlife Compensation Program
KDLP	Katzie Development Limited Partnership
LGL	LGL Limited
LLO	low level outlet
masl	meters above sea level
MQ	Management Questions
RIC	Resource Inventory Committee
ROV	remotely operated vehicle
RST	rotary screw trap
SE	standard error
STDEV	standard deviation

1 BACKGROUND AND INTRODUCTION

Katzie First Nation: Peter Pierre (Katzie Elder and Medicine Man), as recorded by Diamond Jenness in the 1955 book “The Faith of a Coast Salish Indian” stated that:

“Swaneset (a mythical Katzie leader) assured Katzie people an abundance of Sockeye for the coming generations. Since that time Katzie people have fished Sockeye and other salmon species from a variety of fishing stations and seasonal villages along the Fraser, Pitt, and Alouette rivers.”

Based on this account, the Katzie First Nation has always been tied to Sockeye Salmon that could be harvested in the Fraser, the Pitt and the Alouette Rivers. In addition, Katzie people fished for Coho, Chum, and Pink salmon, and Steelhead in the South and North Alouette rivers.

Starting in the late 1800s, logging occurred in the watershed, and in 1926 Alouette Dam and Alouette–Stave Tunnel (“Tunnel”) were built creating one reservoir out of two lakes and cutting off access for Sockeye, Chinook, Coho, and Chum salmon to spawning habitat in the tributaries to Alouette Reservoir as well as the reservoir itself. As a consequence, Alouette River Sockeye, Chinook, Coho, and Chum salmon were extirpated above the dam (Driver and Spurgeon 1998). In addition, the flows into the Alouette River below the dam were very low until 1971 when minimum flows of 5% of annual average were implemented. In 1996, the Alouette Water Use Plan implemented a new minimum flow of 20% of annual average, and in 2002 the restoration of salmon above the Alouette Dam was suggested, the feasibility of which was assessed in 2004 (Gaboury and Bocking 2004). The outcome of the feasibility study concluded that despite uncertainties that needed to be resolved, no serious impediments to the reintroduction of Sockeye and Coho salmon, and Steelhead existed.

As an unexpected outcome of a spillway passage survival study for Coho Salmon in the spring of 2005, Sockeye smolts left the reservoir in large numbers and Sockeye Salmon re-introduction was suggested as a focus of the Alouette River Salmon Restoration Program (ARSRP). Since its inception, the ARSRP has been composed of the Alouette River Management Society (ARMS), BC Hydro, First Nations, Fisheries and Oceans Canada, and BC Ministry of Environment and Climate Change Strategy. The ARSRP has the goal to restore and enhance salmonid species historically native to the Alouette Watershed.

To address uncertainties around the re-establishment of a self-sustaining Sockeye Salmon population, since 2005, the ARSRP has implemented a number of studies to resolve uncertainties prior to moving forward with a permanent fish passage solution. One of the studies, and the subject of this study, is to evaluate potential entrainment of Sockeye Salmon through the Tunnel into Stave Reservoir. Tunnel entrainment was identified as a key remaining uncertainty that needed to be addressed before developing a final restoration plan for endorsement by the Fish and Wildlife Compensation Program (FWCP) Board (Step 5 of Fish Passage Decision Framework).

The hypothesis of significant entrainment of juvenile Sockeye Salmon through the Tunnel was based on the high Tunnel discharges ranging from 5–50 m³/s, which is considerably higher than the typical and year-round flows into the Alouette River (3–5 m³/s) through the low-level outlet (LLO) and in spring over the Alouette Dam spillway (3–5 m³/s). In general, juvenile Alouette Sockeye Salmon should be genetically predisposed to choose a southern direction to leave the reservoir following the ancestral Sockeye Salmon outmigration route, but if migration to the Tunnel for active outmigration exists, it would be expected to occur for mainly Age 1+ (those that spent 1 full year in the reservoir after emergence) smolts during the spring migration period. In addition, since juvenile Sockeye Salmon are distributed throughout the reservoir in the summer and fall it is also possible that Sockeye Salmon could be in proximity to the Tunnel and when encountering high Tunnel discharges may become passively entrainment as 0+ juveniles (those that spent less than 1 full year in the reservoir after emergence).

Older age classes and larger fish are more likely to withstand the Tunnel entrance velocities and swim out of the Tunnel suction zone.

In this study, a hydroacoustic array was installed to monitor fish presence and swimming direction in front of the Tunnel entrance throughout all seasons and discharges. Gillnet sets were also conducted within 30 m of the Tunnel entrance as a species verification method. The resulting hydroacoustic data were also used to analyze fish length for age class determination and to relate to the lengths of fish in the gillnet catch.

2 GOAL, RESEARCH QUESTION, MANAGEMENT QUESTIONS, AND DECISION PATHWAY

2.1 Goal

This study, in combination with the annual enumeration of Sockeye smolts over the Alouette Dam spillway and into the Alouette River, and an analysis of environmental and reservoir operational factors (e.g., spillway and Tunnel discharges, reservoir elevations, juvenile Sockeye Salmon abundance in reservoir) that may influence Sockeye smoltification, is intended to aid in the identification of measures that could be taken to encourage Sockeye smolting and emigration from the Alouette reservoir over the spillway and into the Lower Alouette River and from there into the Fraser River and ocean.

Given the constraints of marine survival and resulting adult Sockeye Salmon returns to the Alouette, it is a general goal of all Alouette Reservoir salmon restoration studies to assess ways to optimize outmigration of Sockeye Salmon from the reservoir.

2.2 Research Question

The main research question of this study is:

- What proportion of the Alouette reservoir Sockeye Salmon population is volitionally and/or passively entrained at the Tunnel?

The seasonal timing of entrainment numbers and peaks, in combination with swimming direction towards the Tunnel, and direct behavioral observations, may indicate whether the fish are passively entrained or volitionally leave the reservoir using the Tunnel.

2.3 Management Questions

The main management question that is being addressed in this study is:

- How do overall Alouette hydro operations influence outmigration of Sockeye smolts?

Specifically, BC Hydro and the ARSRP are trying to answer the following questions:

- Does decreasing flows through the Tunnel result in lower entrainment of Sockeye Salmon?
- Does decreasing flows through the Tunnel result in higher Sockeye Salmon migration over the Alouette dam spillway?
- Does increasing flows down the Alouette dam spillway in spring result in lower Tunnel entrainment of Sockeye Salmon?
- Does increasing flows down the Alouette dam spillway in spring result in higher Sockeye Salmon outmigration into the Alouette River downstream of the dam?

Through the completion of a roving acoustic survey throughout Alouette Reservoir completed in March 2022, the following additional question was addressed:

- Are juvenile Sockeye (Age 1+) abundances higher in the north basin of the reservoir and in the vicinity of the Tunnel entrance in the spring, suggesting a propensity for actively migrating through the Tunnel or being passively entrained?

In summary, the following study components were included to address the above management questions:

- Estimate entrainment of Sockeye Salmon as a proportion of Sockeye smolts outmigrating to the Alouette River below the dam;
- Estimate the number of Sockeye Salmon smolts outmigrating to the Alouette River in comparison to previous years (outmigration study, Mathews 2022) and at higher spillway and Tunnel flows (this study); and
- Evaluate Sockeye Salmon distribution throughout the reservoir prior to the typical outmigration period from April to May.

3 STUDY AREA

3.1 Alouette Watershed and Reservoir

The Alouette River watershed is a relatively small system that arises in the Coastal Mountains of Golden Ears Provincial Park, approximately 50 km northeast of Vancouver, British Columbia (Figure 3.1). The watershed's 202 km² drainage area ranges in elevation from 120 to 1,800 m (FWCP 2011), and the upper watershed flows into an impounded reservoir known as Alouette Reservoir, located in east Maple Ridge in southwest B.C. The reservoir is comprised of two basins, the smaller north basin, and the larger south basin (originally two separate lakes [BCRP 2000]); the basins are connected through a narrow section approximately 9 km upstream from the dam. The reservoir is 1,656 ha in area with a maximum depth of 152 m at full pool, a combined length of approximately 17 km and an average (of the two basins) maximum width of approximately 1.4 km (Andrusak and Irvine 2013). At the reservoir's dam outlet in its southwest corner, the South Alouette River flows for 21 km before entering the Pitt River near Pitt Meadows, and the Pitt River, in turn, flows south into the Fraser River at Douglas Island. The focus of the stationary entrainment monitoring was a Tunnel that drains out of the northeast corner of the north basin into Stave Reservoir. In addition, the roving hydroacoustic survey covered all of the reservoir on regular transects for a general fish distribution and abundance assessment.

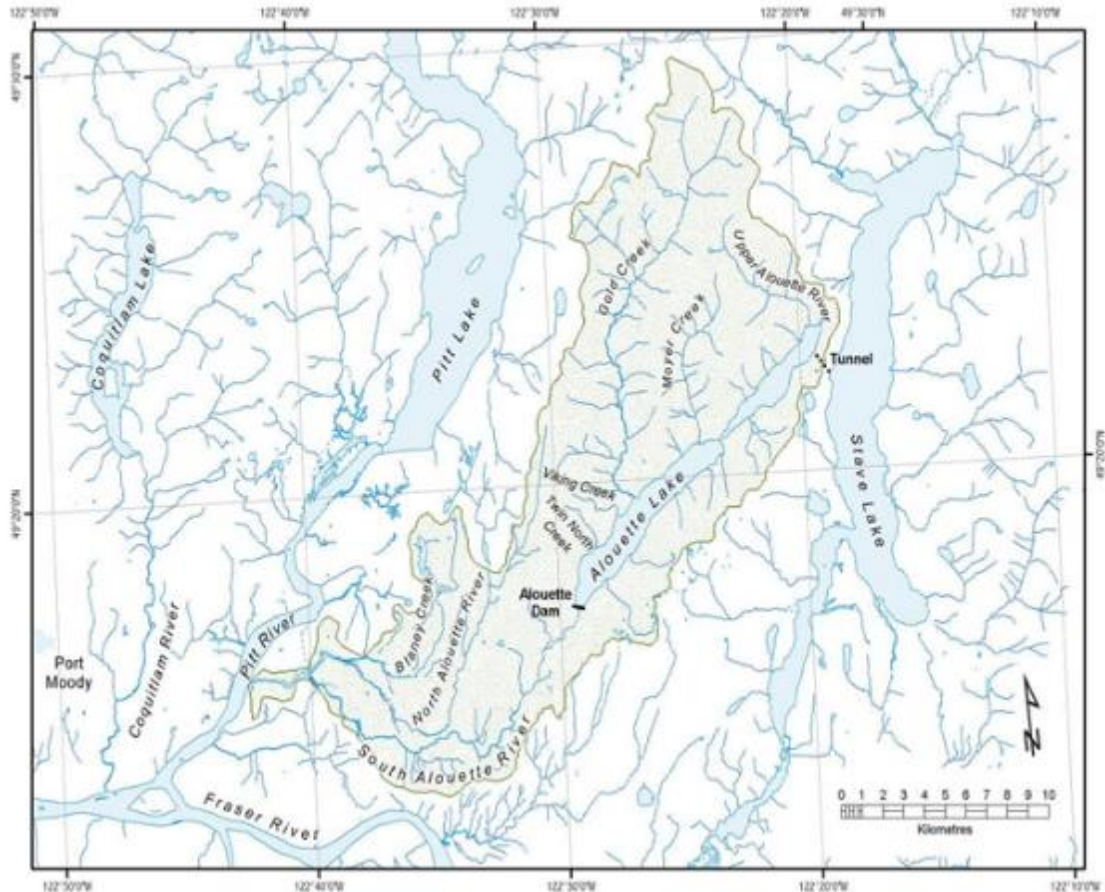


Figure 3.1 Map of the Alouette Watershed showing local aquatic features (Source: Mathews 2021).

4 METHODS

4.1 Site Details and Experimental Set-Up

The hydroacoustic transducers were attached to the end of an aluminum deployment frame (10 m long x 3 m wide) (Figure 3.2, left panel) that was fabricated for this project in parts and assembled in the field. The transducers were fastened to the outside corners of the frame onto the end of two aluminum poles (2 m long) that were aiming vertically at a 90° angle to the frame pointing downwards. The end of the poles were outfitted with a vertical and a horizontal pivoting arrangement allowing for fine adjustment of the transducer angle in relation to the Tunnel entrance (Figure 3.3, left panel).

The frame with attached transducers was moved into deployment position by resting the frame end on an inflatable boat for support. Once the reservoir end of the frame was moved out into the reservoir, the land end was attached to two pivoting assemblies with base plates that were attached to the bedrock and concrete with expanding rock bolts.

The whole frame could be lowered and lifted by using a (2,500 lb) magnetic brake trailer winch that was connected via steal cable to the frame at the reservoir end. The trailer winch was fastened to a walkway on the Tunnel Headworks Tower at an elevation of 127.95 meters above sea level (masl) visible on Figure 3.2 (centre panel).



Figure 3.2 Transducer deployment frame (left panel), automatic brake trailer winch (centre panel) used to lower and lift the transducer deployment frame to optimally cover the Tunnel entrance and keep the transducers immersed, and complete set-up with solar panels.

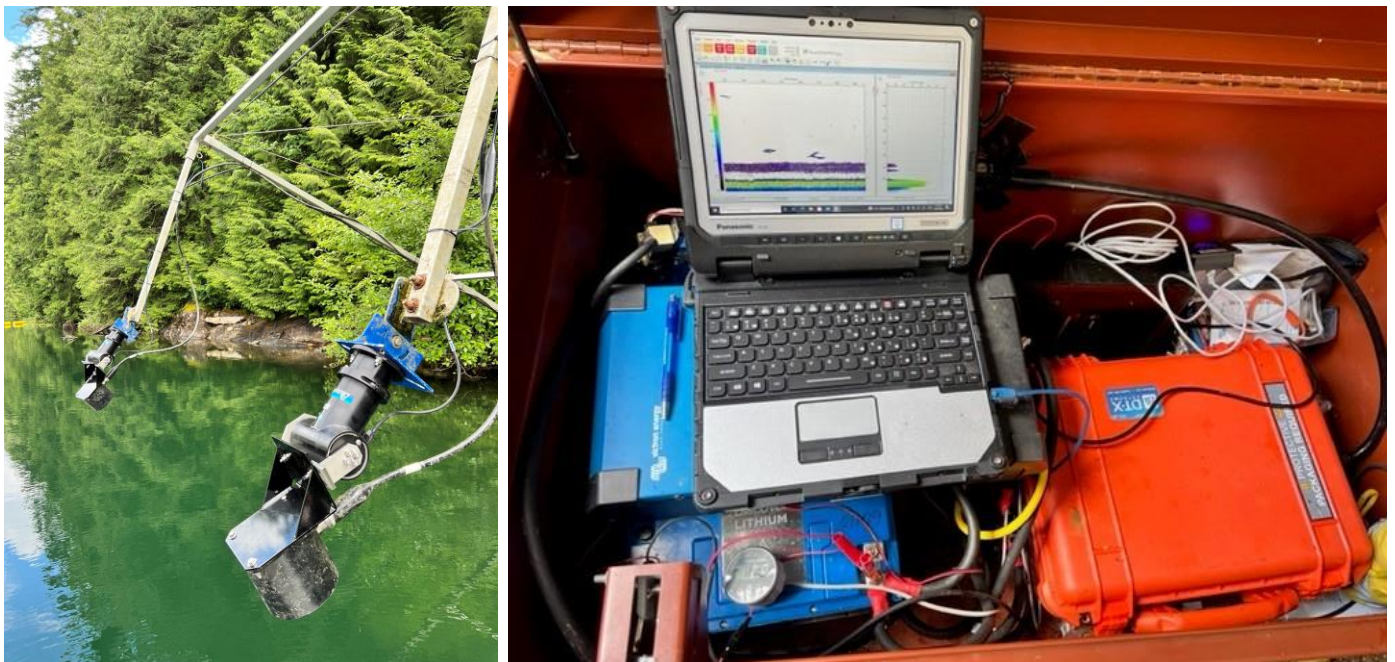


Figure 3.3 Transducer deployment frame detail (left panel) showing transducer attachment with rotator motors installed. Without motors, transducers could still be set to one angle by tightening screws on blue plates. Equipment tote set-up (right panel) with laptop running Biosonics Visual Acquisition software and recording fish target, lithium batteries and charger (under laptop) and Biosonics DTx sonar unit to the right with incoming transducer cables.

Initially two transducers were pointing in front of the Tunnel entrance with minimal overlap to ensure best entrance coverage from April 9–21, 2021 (Figure 3.4). Based on needed adjustments for signal noise reduction, only one transducer was used from April 22, 2021–May 31, 2022, or the end of the study period. The transducer was aligned with the Tunnel entrance to achieve a minimal gap of > 0.5 m by setting the transducer angle and position to be aiming about 1 degree away from the upper Tunnel metal bar as guide during initial fine tuning.

Figure 3.5 shows details and dimensions of the Tunnel Headworks Tower components such as the tunnel (5.59 m high x 5.12 m wide) and the gate lift assembly.

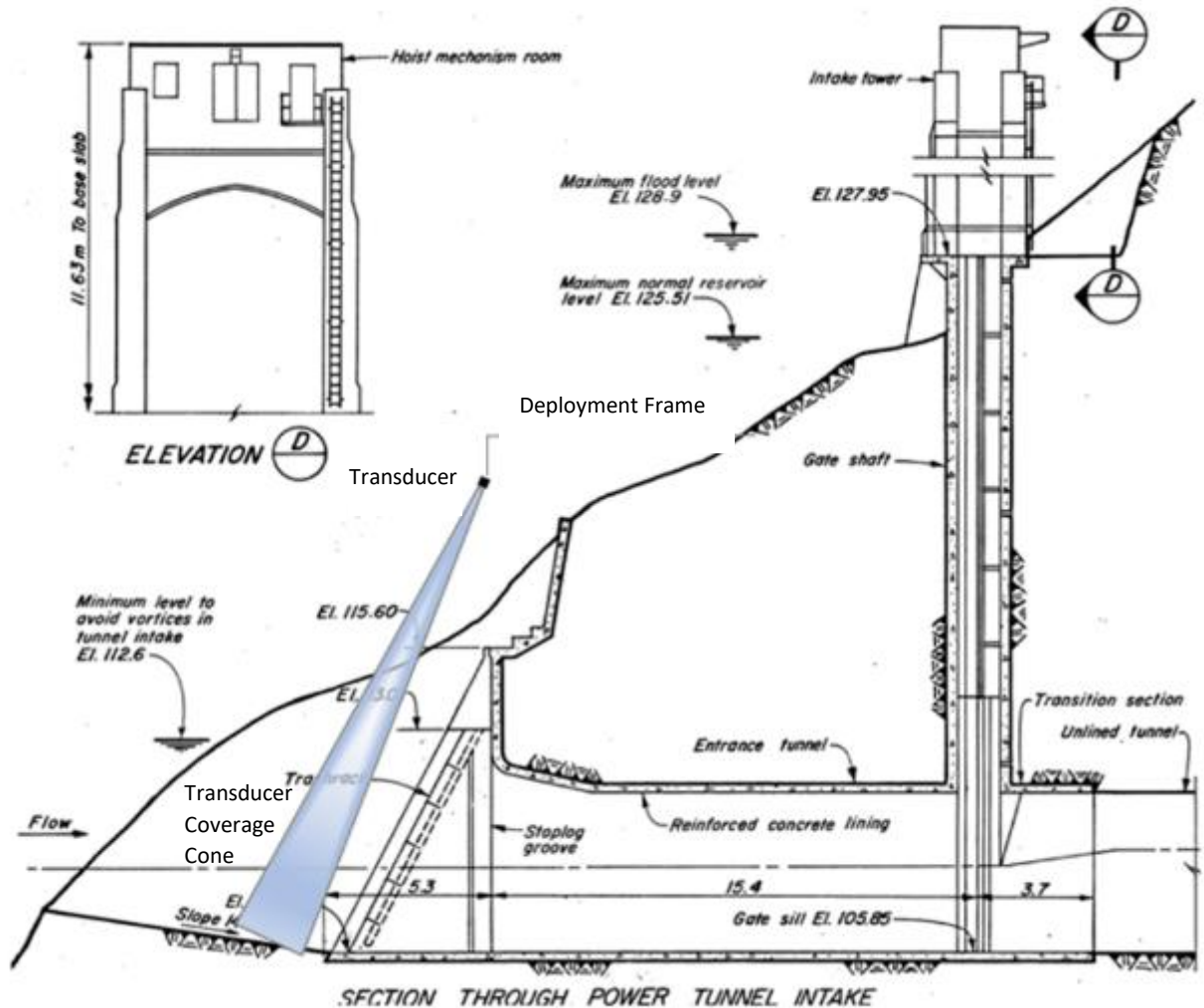


Figure 3.4 Section through Headworks Tower intake showing details of the trash rack; all elevations in masl (Source: BC Hydro with additions by LGL Limited).

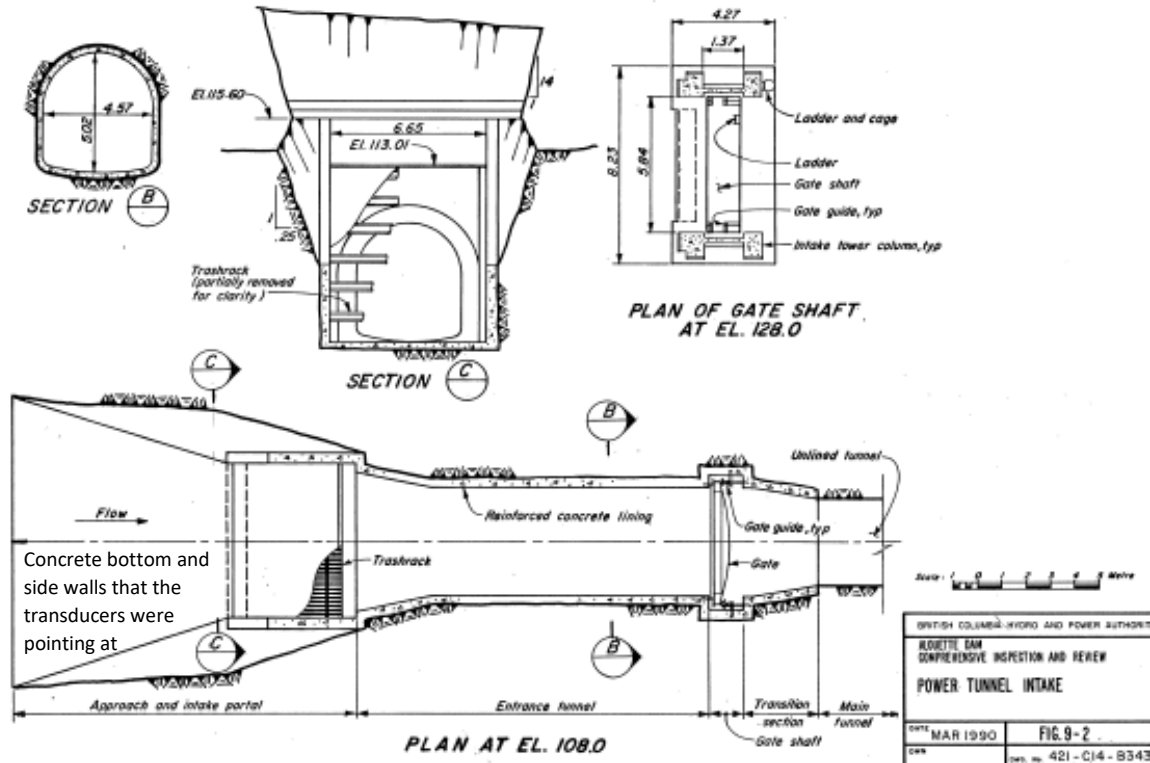


Figure 3.5 Sections through the Headworks Tower showing the dimensions of the Tunnel entrance at the trash rack (7 m high x 6.65 m wide), the Tunnel behind the trash rack (5.02 m high x 4.57 m wide) and the entrance area to the Tunnel with a concrete bottom and sidewalls that the transducers were pointing at (Source: BC Hydro).

The system was powered by a generator charged battery bank using the following equipment:

- Initially two alternating 1000W Honda generators (Model: Honda EA 1000i) for charging. The Honda 1000i generators were replaced in June 2022 by one 2200W Honda generator (Model: Honda 2200i);
- A fuel tank with generator fuel cap connection that allowed for up to 36 hours of continuous charging (Model: IPI BERGS 1 Extended Run Fuel System and Tank);
- A battery bank consisting initially of four 6V lead-acid batteries (Model: GRP GC2, 232 AH, 140 R/C [75A], 474 R/C [25A]) connected in a series/parallel arrangement to achieve 464 Ampere Hours @ 12V at 100% discharge and 232 Ampere Hours at the recommended maximum of 50% discharge. For the period From September 17–November 14, 2022, a total of eight batteries of the same type were installed and a doubling of Ampere Hours was achieved;
- For this period, the batteries were charged with a 40A and generator driven charger (Model: Trucharge2, 12V, 40A CHG, three bank parallel version);
- Also, for this period and to protect the batteries from damaging discharges below 12.1 V, a voltage limiter was installed that cut power to the Biosonics DTx, and the Panasonic Toughbook laptop computer off at 12.1 V;
- In addition, two solar panels with a combined charging power of 360W were installed in September 2021 to support battery charging.

On November 14, 2021, an atmospheric river led to enormous flooding and damage in the Lower Mainland of British Columbia, and the water level in Alouette Reservoir rose to levels not experienced since its construction in 1926. Unfortunately, the high reservoir levels also submerged and destroyed the stationary hydroacoustic sonar, laptop computer and power system deployed for this study, and all of the specific hydroacoustic equipment had to be re-ordered and re-built. The newly built equipment was re-installed at a higher elevation out of the potential flooding zone and monitoring was re-started on January 31, 2022, with the following changes to the power system:

- Generator: 2200W Honda generator (Model: Honda 2200i);
- Generator Run Time Extension Tank: IPI BERGS 1 Extended Run Fuel System and Tank;
- Battery Charger: One charger (Victron Energy MultiPlus Compact 12/2000/80-50 120V);
- Batteries: Three lithium-ion batteries (Lithium Blue 12.8 V 2560 Watt 200 AH); and
- Solar Panels: Two solar panels (340-HQ-120) connected to a solar power distributor (Victron SmartSolar MPPT 100/30).

The new power system based on lithium-ion batteries and their charger provided 600 Ampere Hours at the recommended maximum discharge of 100% and added practicality through smart phone Apps that provided wireless and Bluetooth-based voltage, charging status and battery health checks. Inherently lithium-ion batteries can also be drawn down to > 12 V without damage to the battery and thus a voltage limiter was not necessary. The new system provided reliable operational times of nine days and therefore the period of time between site visits for downloads and maintenance was extended to seven days.

4.2 Split-Beam Array Settings and Data Storage

While two systems were used and installed due to the flooding loss, the system specification and models were identical. A Biosonics DT-X Extreme Autonomous Portable Scientific Echosounder surface unit (Figure 3.6) was used with two 30 m cables connected to two 6° angle split-beam Biosonics transducers.

The system was operated with the following settings controlled by the proprietary Biosonics Visual Acquisition Software (Version 6.4) installed on Panasonic Toughbook (Model: CF-VEK33):

- Power: -10 dB
- Ping Duration: 0.2 ms
- Ping Rate: 10 pings/s for each transducer
- Data Collection Threshold: -80 dB for recording and -60 dB for viewing
- Start Range: 1 m
- End Range: 17 m (depth + 1 m)
- Calibration Correction: 0 dB based on calibration with standardized sphere
- Temperature: Set to the same level as ambient water temperature
- pH: Set to 7
- Disabled (unchecked): “Bottom Detection”, “Echo Detection” and “Track Detection”
- File Duration: 30 min



Figure 3.6 Biosonics DT-X Extreme Autonomous Portable Scientific Echosounder surface unit and two 6° angle split-beam transducers (Source: Biosonics website).

The system was initially operated using two transducers from April 9–21, 2021, but noise level and interference between transducer signals pinging into the concrete and rock dominated the Tunnel entrance area and was too high to allow for the determination of fish swimming direction. Hence from April 22, 2021, on, only one transducer pinged at a time. This resulted in a marked reduction in signal noise and allowed for the important analysis of target directionality.

In addition to the flooding outage from November 14, 2021–January 31, 2022, the system was shut down from July 14–September 17, 2021, when the adit gate of Tunnel was closed or operated at discharges of $< 1 \text{ m}^3/\text{s}$.

All data were stored on two external hard drives with a capacity of $> 500 \text{ MB}$ that were exchanged during every field visit. Therefore, potential data loss was limited to a maximum period between site visits. During each site visit, data were also backed up onto an additional external hard drive that was not left in the field, and again to a secondary office based hard drive.

4.3 Field Schedule

The system was regularly visited for data downloads and generator re-fuelling at intervals of 2–7 days between April 9 and July 13, 2021 (until the summer closure), and again following the summer closure from September 17, 2021, to November 14, 2021, when the system was flooded and destroyed. After the re-start on January 31, 2022, and based on the new lithium-ion-based power supply, the site was visited once per week for download and maintenance and an additional field visit was added every second week for gill net sets to identify species composition of the hydroacoustic targets. During these site visits, gillnet sets were conducted for 24h except when access was blocked, and nets had to be left for up to 48 h. For 2021 and 2022, the project contract required entrainment monitoring coverage of 100% for the month of April (coinciding with high Sockeye smolt migration numbers over the Alouette Dam), 80% for the month of May (coinciding with high Sockeye smolt migration numbers over the Alouette Dam for the first half of the month) and 60% for the rest of the year when water was discharged through the Tunnel.

In 2021, entrainment monitoring was stopped from July 6–September 17, coincidental with the summer stoppage of Tunnel discharge.

4.4 Gillnets Sets

Gillnetting was required to identify the species composition of hydroacoustic fish targets and collect biological information from the fish species present in the vicinity of the Tunnel entrance in accordance with Resource Inventory Committee (RIC) standards (BC Fisheries Information Services Branch 2001). These data were used to estimate species composition of the hydroacoustic targets. The gill nets had a total length of 90 m (composed of six 15 m panels) and a height of 2.4–3.6 m and were attached to a buoy on one end and the Tunnel exclusion boom on the other end via 10 m long ropes, thus fishing at depths of 10.0–12.4 or 13.6 m or the Tunnel entrance depth. All nets were set at 45° angle to shore and in water depths (distance between surface and reservoir bottom) of 15–30 m for 24–48 h. Gillnet sampling effort was therefore focused on the pelagic zone of the reservoir on one end and the littoral zone of the shore end to cover the widest possible species variety without touching the bottom directly.

Nets were constructed of double knotted, transparent-green monofilament mesh and consisted of five panels measuring 15 m x 3.6 m long each with thread diameters ranging from 0.2 to 0.25mm, and mesh sizes of 12, 88, 50, 25 and 18 mm. The five panels were strung together in a "gang" to form a net 75 m long and 3.6 m deep. The net type was chosen given other studies conducted in British Columbia (Hamley 1972; Plate 2007) indicated a favorable relationship between these particular mesh sizes and the length ranges of fish being targeted (Figure 3.7). A 12 mm minimum mesh size is expected to catch fish with a minimum fork length of 40 mm, and thus could catch all age classes of Sockeye Salmon as well as other fish species.

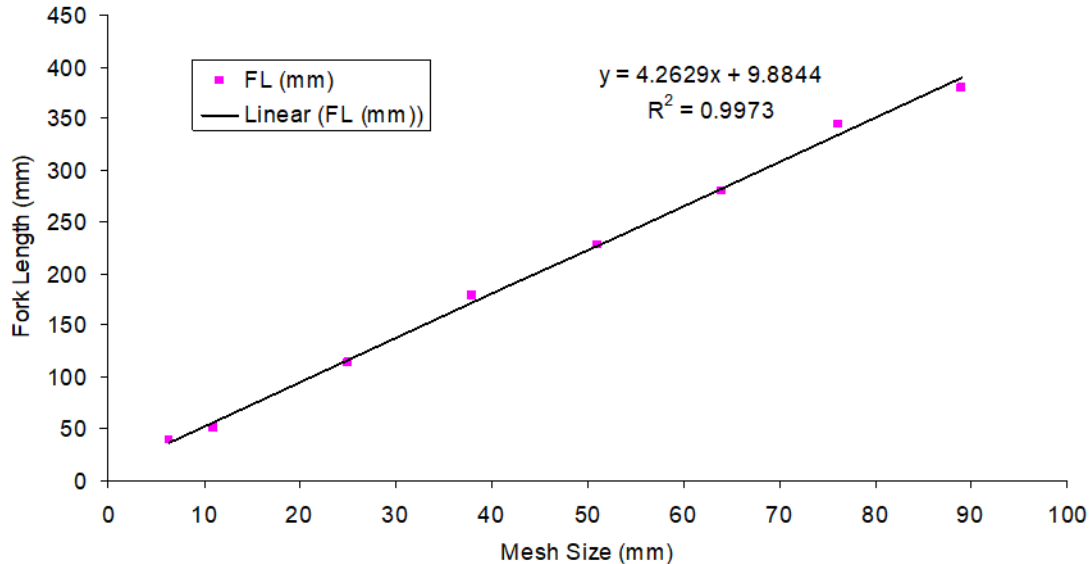


Figure 3.7 Average fork lengths versus net mesh size for fish caught in freshwater lakes in British Columbia (data from: Hamley 1972; Plate 2007).

4.5 Hydroacoustic Data Analysis

The acoustic data were analyzed in *Echoview* software (Version 9), with a -60 dB threshold imposed on the compensated target strength of single target echo detections. Fish echo traces were tracked with *Echoview's* fish tracking algorithm, which tracks systematic movement of individual targets. The purpose of tracking is to group each series of echoes that has been returned by an individual fish over a series of pings. The tracking results are used to determine the number, acoustic size, and trajectories of the fish detected in the beam. Tracking accuracy was visually judged based on the coherence of angle colors (indicating movement towards or away from the intake) and edited accordingly. Fish moving through the beam typically leave a solid echo trace that progresses through the corresponding angle color spectrum. The echogram pattern of entrained air (e.g., vortices) is typically more amorphous.

Tracking results were exported from *Echoview* in the form of spreadsheet csv files, 1 record per track, i.e., fish, with the fields *Fish_ID*, *date*, *time*, *range*, *TS_mean*, and *direction_horizontal* (additional fields are exported but not used in this analysis). Spreadsheets from multiple *EV* files were concatenated into a single *Excel* worksheet covering the entire analysis period.

Unit of measurement are provided in brackets after each factor where appropriate. For each fish, the following derived fields were calculated in *Excel* as follows:

Fish length (cm) is the estimated fish length based on an empirical relationship between physical and acoustic size of fish described by Love (1971):

$$L = 30.48 \times 10^{(TS+35.65)/19.1}$$

where

L = estimated fish length (cm)

TS = fish target signal strength (dB)

Vertical distance from transducer (m) is calculated as a function of fish range and transducer depression and slew angle:

$$\Delta Z = R \times \cos(90 - \gamma) \times \cos(\delta)$$

where

ΔZ = fish vertical distance from transducer (m)

γ = depression angle of transducer (0° = horizontal; 90° straight down)

δ = slew angle of transducer (0° = straight down)

Fish elevation (m) is the transducer elevation (m) minus the vertical distance of the fish from the transducer (m):

$$Z_{fish} = Z_{transducer} - \Delta Z$$

where

Z_{fish} = fish elevation (m)

$Z_{transducer}$ = transducer elevation (m)

ΔZ = fish vertical distance from transducer (m)

γ = depression angle of transducer (0° = horizontal; 90° straight down)

δ = slew angle of transducer (0° = straight down)

Elevation filter (Boolean; 0 or 1): 1 indicates fish is considered a potential candidate for entrainment based on its elevation, 0 indicates it is not:

If $Z_{fish} < 114$: 1

Else: 0

where

Z_{fish} = fish elevation (m)

A threshold of 114.1 m represents the top of the Tunnel entrance.

Direction filter (Boolean; 0 or 1): 1 indicates fish is considered a potential candidate for entrainment based on its direction of movement, 0 indicates it is not:

If $135 > Direction_horizontal > 225$: 1

Else: 0

where

$Direction_horizontal$ = horizontal component of fish trajectory, based on phase measurement (splitbeam angle of first and last echo in fish track) ($0^\circ = 360^\circ$ = away from Tunnel intake; 180° = towards Tunnel intake)

A directional threshold between 135 and 225.1 was chosen based on the direction of swimming in the direction of the Tunnel entrance relative to the transducer mounting direction.

TS threshold differential (Decibel [dB]) is the fish target strength (dB) minus the analysis threshold (dB):

$$\Delta TS = TS - Threshold$$

where

ΔTS = TS threshold differential

TS = fish target strength (dB)

$Threshold$ = analysis threshold (dB) imposed on the compensated target strength of single target echo detections (here: -60 dB)

An analysis threshold of -60 dB represents the best compromise between the filtering of background noise and target detection.

Effective beam width (degrees) is the beam width over which a fish of the given size TS (dB) would be detected at the given range R (m), based on approximate beam pattern of 7° circular BioSonics transducer:

$$\epsilon_{TS,R} = 2 \times a \times \Delta TS^b$$

where

$\epsilon_{TS,R}$ = effective beam width (degrees) of fish of size TS at range R

ΔTS = TS threshold differential

a = constant based on approximate beam pattern of 7° circular BioSonics transducer

b = constant based on approximate beam pattern of 7° circular BioSonics transducer

Effective beam width (m) is derived from the effective beam width (degrees) using:

$$E_{TS,R} = 2 \times R \times \tan \frac{\epsilon_{TS,R}}{2}$$

where

$E_{TS,R}$ = effective beam width (m) of fish of size TS at range R

$\epsilon_{TS,R}$ = effective beam width (degrees) of fish of size TS at range R

ΔTS = TS threshold differential

Fish count expanded to the intake width (#) is the number of fish estimated to be present across the entire intake width (6.65 m) for the size range of the detected fish, (smaller fish have a greater expansion factor than larger fish) given the effective beam width (m) for the given fish at the given range:

$$F_{expanded} = \frac{6.65}{E_{TS,R}}$$

where

$F_{expanded}$ = fish count expanded to the intake width

$E_{TS,R}$ = effective beam width (m) of fish of size TS at range R

Critical water velocity filter (Boolean; 0 or 1): was used to determine whether fish would be overwhelmed by Tunnel velocity at the Tunnel entrance and was determined as:

If $U_{crit} < V_{tunnel}$: 1

Else: 0

where

$U_{crit} = 6 \times BL$ is the critical swim speed determined as 6 times the fish target body length measured in metres (BL); and

$V_{tunnel} = D/33.5$ is the water velocity at the Tunnel entrance, determined as the Tunnel discharge cms (D) divided by the area of the Tunnel entrance (m^2).

The critical water velocity represents the water velocity at which Sockeye Salmon swimming ability would be overwhelmed by the water velocity at the Tunnel entrance. The U_{crit} of 6 represents an intermediate value between the 60-minute critical swim speeds (i.e., 4.5–5.0 body lengths per second for 10–20 cm fish) and the maximum sprint speed (i.e., 12–15 body lengths per second for 10–20 cm fish) (Webb 1995).

Fish records were first filtered to retain only those that met the criteria for the elevation and direction filters, these were termed “potential entrainment” and represent fish at the correct depth and heading toward the Tunnel entrance. Potentially entrained records were further filtered by the critical water velocity filter to determine “likely entrainment” which were potentially entrained fish that would have been overwhelmed by the water velocity at the Tunnel entrance at the time of detection. The expanded fish counts of the filtered dataset were then summarized to provide estimates of potential and likely entrained fish by date and hour, length frequency distribution by date, cumulative vertical distribution, and other miscellaneous information.

4.6 Lake Acoustic Survey

A roving hydroacoustic survey was conducted on Alouette Reservoir to determine Sockeye Salmon distribution throughout the reservoir before the typical annual smolt outmigration period, with a focus on the Age 1+ size class. The survey was conducted on March 9, 2022, starting after sunset and completed at 12:00 midnight, using a BioSonics DTX system multiplexing between two 6.8° circular 201 kHz splitbeam transducers. Both transducers were deployed at 0.6 m depth, one aimed vertically for down-looking data collection (5 m depth and below), and the other one aimed nearly horizontal, approximately 5° down from horizontal, for side-looking data (< 5.0 m depth and above).

Data Collection Parameters

- Boat Speed: 1.8 m/s
- Ping Rate: 4 pings/s on each transducer
- Transmit Power Reduction Level: -10 (to reduce noise)
- Threshold: -80 dB
- Range: Transects 1–4: 2–60 m; transects 5–8: 2–70 m
- Alouette Reservoir Pool Elevation at Time of Survey: 121.0 masl

Data Analysis Methods

The data were analyzed in Echoview software (Version 12), with a -70 dB threshold imposed on the compensated target strength of single target echo detections. In addition, single target echo detections were filtered to retain only detections with a maximum beam compensation of 15 dB. This created a uniform effective beam angle of 10° for fish > 30 mm. Without this restriction, the abundance of larger fish would be overestimated because larger targets can be detected further off axis.

Fish densities can be calculated from mobile acoustic data using one of three methods: echo integration, target tracking, or echo counting (MacLennan and Simmonds 1992). If fish densities are low enough to resolve individual fish, target tracking is generally the preferred method because it requires relatively few assumptions and provides, in addition to abundance estimates, descriptive information (e.g., size) for each fish detection. The fish densities observed in this survey were sufficiently low to be analyzed with target tracking.

In the down-looking dataset, bottom echoes were tracked with Echoview's Best bottom candidate algorithm. The resulting bottom line was reviewed and manually edited as necessary to exclude bottom echoes from the subsequent analysis.

Fish echo traces were tracked on the single target detection echogram with Echoview's fish tracking algorithm, which tracks systematic relative movement (here primarily boat movement) of the target. The minimum number of hits criterion for tracking was 2 echoes. Given the boat speed (1.8 m/s), ping rate (4 pings/s), effective beam size (10°) and minimum hit criterion, fish were tracked effectively at ranges > 5 m (i.e., each fish > 30 mm should be detected over a minimum of 3 consecutive pings).

Fish densities for near surface fish (0.6 m–5.0 m depth) were derived from the range interval 21–27 m of the side-looking dataset (Figure 3.8). Side-looking data for Transects 1, 1.5, and 2 were not processed because of unstable transducer aim.

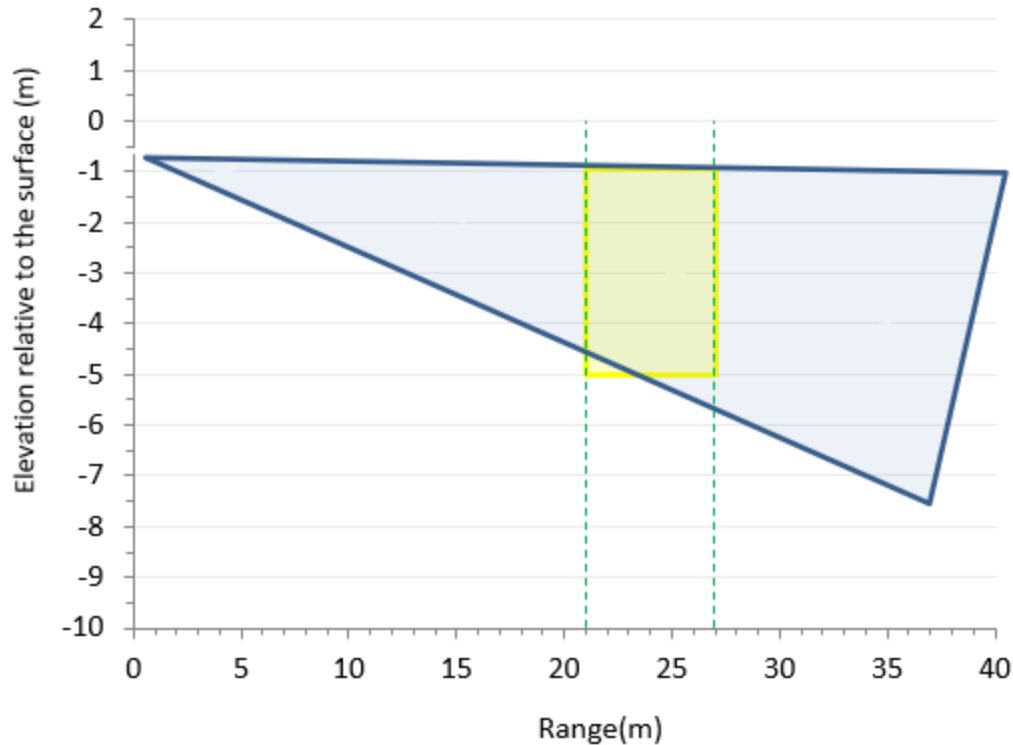


Figure 3.8 Side-looking beam geometry for transducer mounted at 0.6 m depth, tilted 5.5° down from horizontal. The blue triangle approximates the coverage of the effective 10° beam width. The dashed green lines indicate the range interval that was processed for estimating fish densities in the top depth stratum (0.6 m–5.0 m depth; yellow rectangle).

The purpose of fish tracking is to group each series of echoes that has been returned by an individual fish over a series of pings. The tracking results are used to determine the total number of individual fish detected, their spatial distribution, and, with down-looking data, the acoustic size estimate of each individual.

Side-looking mobile data does not provide meaningful fish size estimates because of the random aspect angle at which fish are being encountered, and thus highly variable target strength.

The accuracy of the tracking results was visually checked during data analysis in an angle echogram. As the boat moves over a stationary fish, the fish’s echo trace progresses through the spectrum of angle colors, providing good visual separation from the echo traces of nearby fish.

For down-looking data, the length of each individual fish was estimated based on the mean target strength over its track. Target strength is a measure of the proportion of the sound energy reflected from a target, relative to the transmitted energy. The acoustic size of each fish was converted to an estimate of physical fish length (mm), based on the empirical relationship for dorsal aspect described by Love (1971), here for 201 kHz:

$$L = 30.48 \times 10^{(TS+35.45)/19.1}$$

where

L = estimated fish length (cm)

TS = target strength (dB)

To compensate for the increase in the acoustic sample volume as a function of range (beam spreading with range), each fish track was normalized to the number of fish one would have expected to detect if the beam had been 1 m wide, regardless of range. The normalization to a uniform 1 m wide swath width was achieved by weighting each detected fish track by the ratio between 1 and the beam diameter at the range where the fish was detected (i.e., a fish detected where the effective 10° beam is 1 m wide counts as 1, where the beam is only 0.5 m wide as 2, where the beam is 2 m wide as 0.5):

$$W_f = \frac{1}{2 \times R \times \tan\left(\frac{B}{2}\right)}$$

where

W_f = weighted fish count

R = range of fish from the transducer (m)

B = effective beam angle (here: 10°)

Without this normalization, the abundance of deeper fish would be overestimated, as the sample volume increases with range.

The fish tracking results were binned in to 4 size classes, roughly representing Sockeye Salmon age classes in the reservoir:

- Size Class 0: < 80 mm (Age 0+ Sockeye, based on Age 1+ RST catch size minus 2 months of estimated growth)
- Size Class 1: 80–120 mm (Sockeye age classes 1+ and 2+ based on netting results ageing results of previous studies)
- Size Class 2: 121–250 mm (Sockeye age classes 2+ to 4+ including all spawners for the year based on netting and ageing results of previous studies)
- Size Class 3: > 250 mm (fish other than Sockeye Salmon, likely Northern Pikeminnow, Cutthroat Trout, Rainbow Trout, or Bull Trout)

Fish density (fish/ha) estimates were calculated for size classes 0, 1 and 2. Only 2 fish tracks fell into size class 3 (> 250 mm), too few to calculate meaningful density estimates for this class. Estimates were calculated for 250 m intervals (used for mapping the geographic distribution) and for entire transects (used for the tables showing the vertical distribution along the long axis of the lake and for developing population estimates). Density estimates for intervals were derived from the sum of weighted fish counts (tracks), divided by the length of the interval (in most cases 250 m, except the truncated last, and sometimes first, interval in each transect), multiplied by 10,000 to convert m² to ha. Transect estimates were calculated for each vertical depth stratum. Here the sum of weighted fish counts was divided by the length of the transect in the given depth stratum (i.e., shorter in depth strata that included the lake bottom).

Population estimates were computed for size classes 0, 1, and 2 for each 5 m depth stratum of down-looking data, and any size for side-looking data representing the near surface layer from 0.6 m to 5.0 m depth. Separate estimates were provided for the south and north basin of the lake. The estimates were derived from the average fish density in each depth stratum, multiplied by the estimated lake area at that depth. Estimates of lake area by depth were taken from Appendix F, Alouette Reservoir Habitat Areas (ha), in Harris et al. (2010). Confidence intervals for the population estimates were generated with bootstrap analysis with 1,000 samples (Simstat Version 2.6.8).

For side-looking data, fish density and population estimates were computed analogous to the method used for down-looking data. Note, for side-looking data, the relationship between acoustic and physical size is too variable due to the highly variable fish aspect angle to provide meaningful estimates of physical fish size. This prevents parsing side-looking estimates by size class. Also, no population estimate was generated for near surface fish in the South Basin because the first 3 transects could not be processed because of unstable transducer aim.

4.7 Acoustic Doppler Current Profiler (ADCP) Measurements

Water current speeds in the vicinity of the Tunnel were calculated by dividing the Tunnel entrance area ($\sim 25 \text{ m}^2$) by the discharge in m^3/s to arrive at a discharge velocity in m/s . While discharge velocity at the Tunnel entrance can be directly calculated, velocities at distance need to be calculated by assuming an increasing area that is affected by Tunnel suction with increasing distance from the Tunnel entrance. For example, it was assumed that the 25 m^2 area that is affected by suction at 0 m will increase to 36 m^2 at 1 m distance and current velocity decreases accordingly. These modelled current speeds were ground-truthed through measurements with an acoustic Doppler current profiler (ADCP) at the Tunnel entrance in Alouette Reservoir on February 17, 2022.

The ADCP used was a Teledyne Workhorse Sentinel with the following specifications:

- Frequency: 600 kHz
- Velocity Accuracy: $\pm 0.3 \text{ cm}/\text{s}$
- Ping Rate: 2 Hz
- Beam Angle: 20°
- Depth Rating: 200 m
- Communications: Serial RS-422

The ADCP was operated using Teledyne RD Instruments Win River II Version 2.23.00.01 software.

The ADCP was mounted on a boat facing downward at a depth of 0.5 m and the boat was moved across the Tunnel entrance back and forth for 4–6 times, parallel to shore while measurements were taken.

5 RESULTS

5.1 Filters Applied – Tunnel Hydroacoustic Monitoring

The large number of fish detected was filtered by Sockeye Salmon net catch percentage depth in front of the Tunnel (Figure 3.15), and swimming direction (Figure 3.16) for each analysis period to estimate the filtered target numbers.

5.2 Tunnel Current Velocity and Discharge

Current velocity at the Tunnel entrance was determined to assess passive entrainment potential for Sockeye Salmon of all size classes. The top panel of Figure 3.9 shows results of ADCP measurements carried out on February 17, 2022, at a discharge of $27 \text{ m}^3/\text{s}$ in front of the Tunnel entrance compared to the current velocities modelled in preparation of this study (bottom panel).

The highest current velocities were repeatedly measured at $0.805 \text{ m}/\text{s}$ at a discharge of $27 \text{ m}^3/\text{s}$ while the modelled current velocities at a discharge of $27 \text{ m}^3/\text{s}$ and between 0–1 m distance from the Tunnel entrance were estimated to be between $0.6\text{--}1.0 \text{ m}/\text{s}$. Therefore, the measured current velocities were right in the range of the modelled velocities and the model can be assumed to be accurately predicting field measurements.

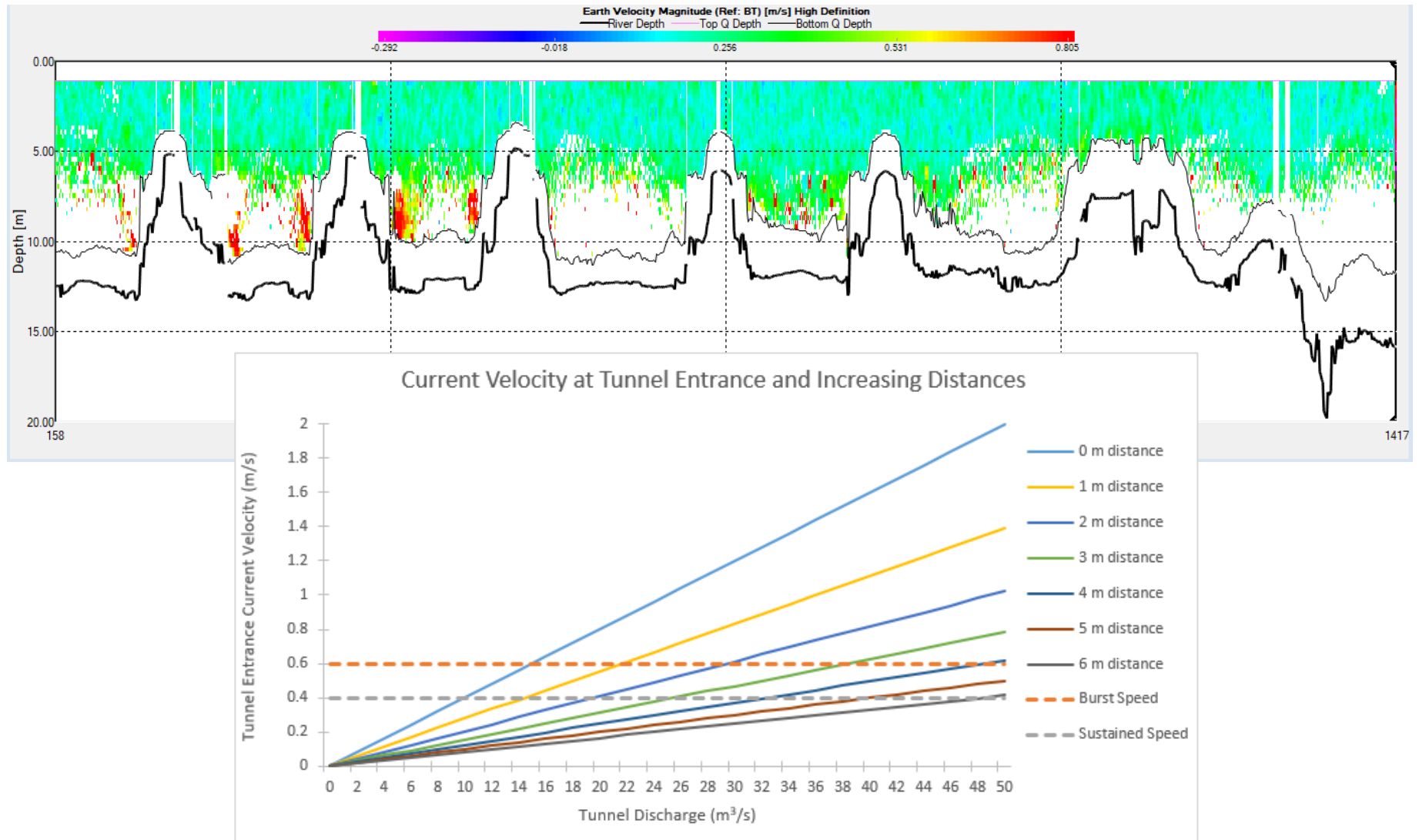


Figure 3.9 Results of the February 17, 2022, ADCP measurements in front of the Tunnel entrance (top panel) with highest current velocities measured at 0.805 m/s (deep red) right in front of the Tunnel entrance at a discharge of 27 m³/s through the Tunnel. Results of the current velocities modelled (bottom panel) in preparation of this study.

5.3 Net Catches, Fish Species Composition, and Hydroacoustic Target Length Distributions

Gillnet catches were generally low in April and early May of 2021 with a total of ten fish caught over three dates (Figure 3.10). For the last two set dates on May 22 and June 22 of 2021, the catch increased to 72. In the fall of 2021, gillnet catches for October 14 increased to the highest set catch of 51 fish before decreasing to 17 fish on October 28 before the equipment was damaged by the November 13, 2021, rapid reservoir elevation rise. After re-deployment on January 31, 2022, catches were generally low with eight, six and five fish caught on February 10 and 28 and March 3, respectively (Figure 3.10).

Throughout the 2021–2022 study period, gillnet catches were mainly composed of Northern Pikeminnow (NPM; *Ptychocheilus oregonensis*), Peamouth Chub (PM; *Mylocheilus caurinus*) and Sockeye Salmon (SO; *Oncorhynchus nerka*) (Figure 3.11). In addition, Large Scale Sucker (LSS; *Catostomus macrocheilus*) were caught rarely and limited to when the net touched the bottom. Three-Spined Stickleback (*Gasterosteus aculeatus*) were also caught in very low numbers throughout the year, few Cutthroat Trout (*Oncorhynchus clarkii*), and one Cutthroat/Rainbow (*Oncorhynchus mykiss*) Trout hybrid rounded out the catch. Catch composition changed by season. In winter, the catch was mostly composed of Sockeye Salmon, during the migration period in spring (March to May) of Peamouth Chub, in summer of Peamouth Chub and Northern Pikeminnow, and in the fall, most of the catch was composed of Northern Pikeminnow and Sockeye Salmon (Figure 3.11).

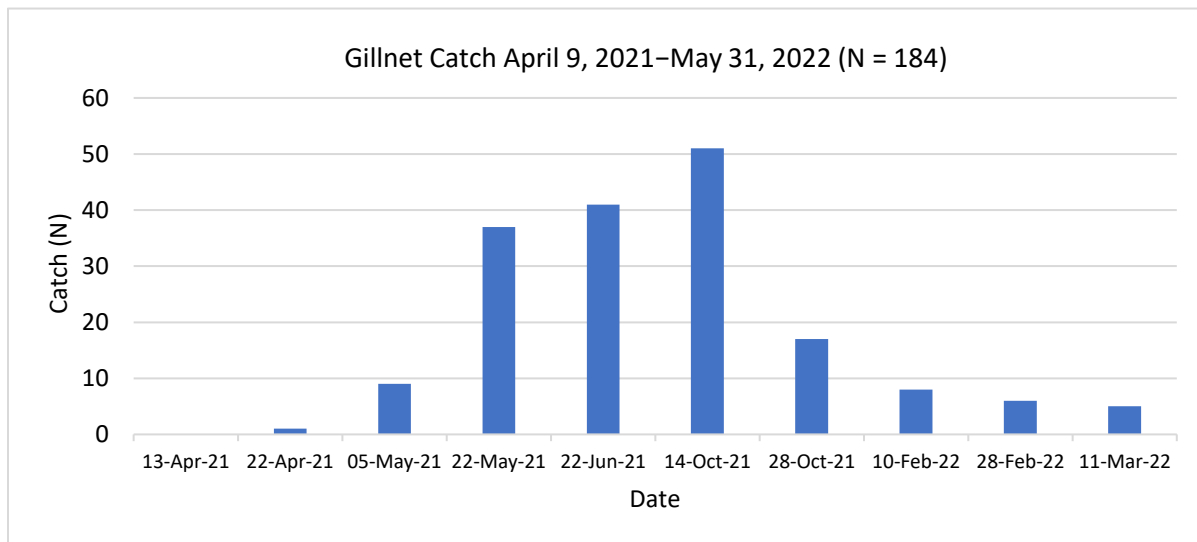


Figure 3.10 Gillnet catch by sampling date from April 9, 2021–May 31, 2022 (total N = 184).

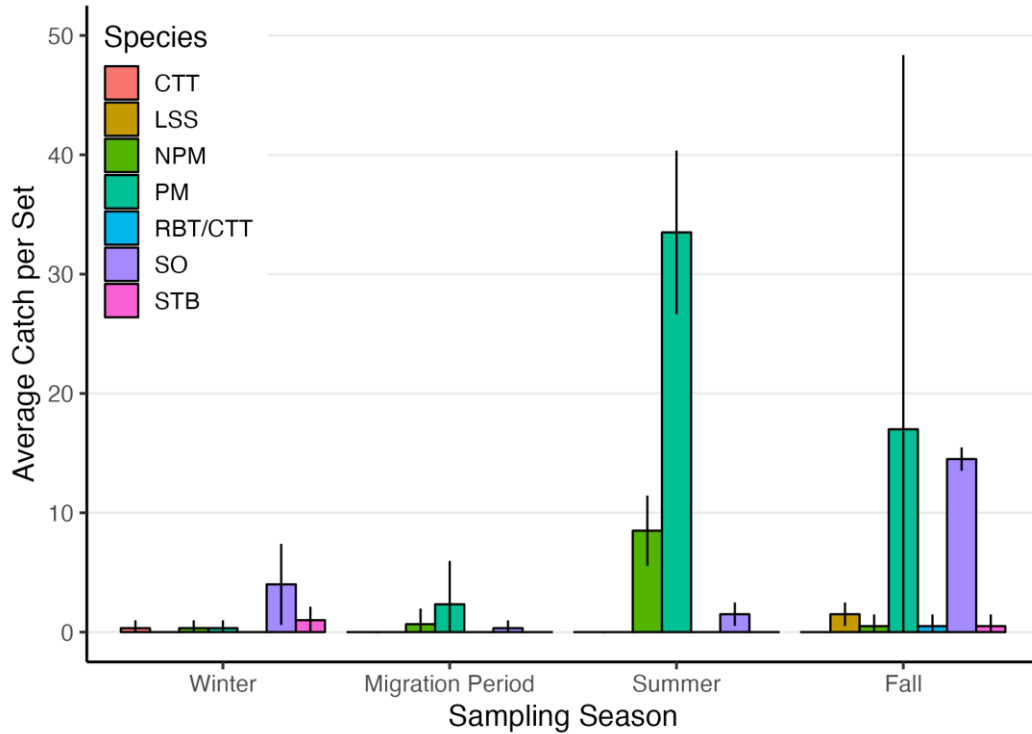


Figure 3.11 Fish species composition in gillnet catch by season (NPM = Northern Pikeminnow, PM = Peamouth, SO = Sockeye Salmon, LSS = Large Scale Sucker, RBT/CTT = Rainbow/Cutthroat Trout Hybrid, CTT = Cutthroat Trout, STB = Stickleback).

When looking at the size composition of the different species throughout the seasons, small Sockeye Salmon (< 100 mm) that would have a higher likelihood of entrainment when compared with larger Sockeye Salmon were rarely detected during any season (Figure 3.12) with no fish detected in that size class during the migration period. The majority of small fish (< 100 mm) were Three-Spined Stickleback in the winter and Peamouth Chub during the migration period and in summer and fall (Figure 3.12). Fish > 100 mm were mostly composed of Sockeye Salmon in the winter and Peamouth Chub for all other seasons.

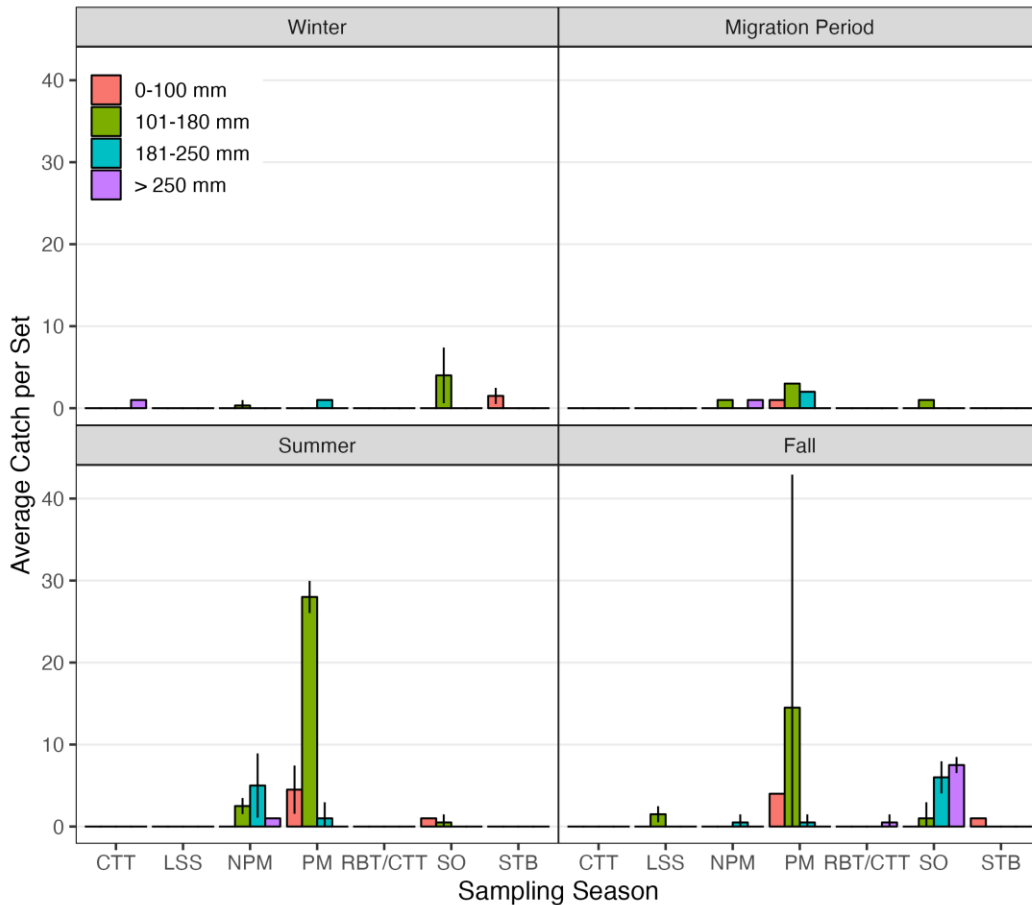


Figure 3.12 Fish species and size composition in gillnet catch by season (NPM = Northern Pikeminnow, PM = Peamouth, SO = Sockeye Salmon, LSS = Large Scale Sucker, RBT/CTT = Rainbow/Cutthroat Trout Hybrid, CTT = Cutthroat Trout, STB = Stickleback).

When looking at Sockeye Salmon (including spawners = red colour bars) in the catch, by season (Figure 3.13), the percentages increased from 4% and 3% in spring and summer, respectively, to 55% and 60% in fall and winter, respectively. When disregarding the Sockeye spawners captured in the gillnets (cyan colour bars) in October 2021, the average Sockeye fall catch frequency in the gillnet catch drops to 20%. While there is no evidence that the gillnet catch does not represent the composition of species that were detected in front of the Tunnel entrance for 90% of the year, there is reason to believe that Sockeye Salmon spawning in the area close to the Tunnel entrance do not get passively or volitionally entrained and this point will be elaborated on in the DISCUSSION section.

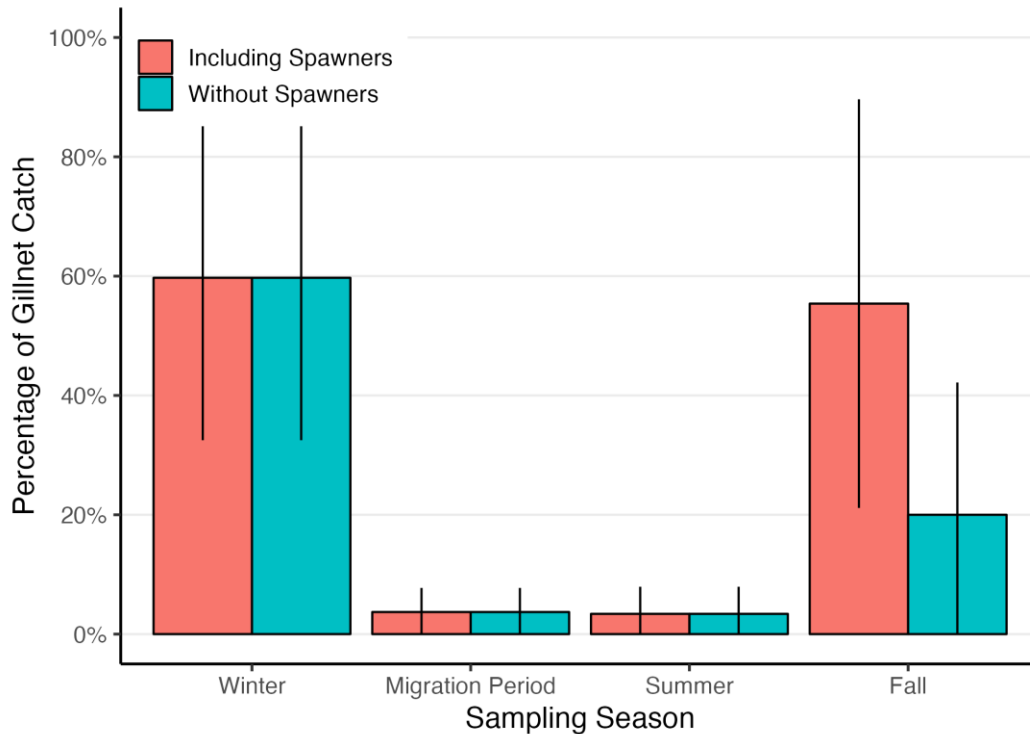


Figure 3.13 Percentage of Sockeye Salmon in gillnet catch from April 9, 2021–May 31, 2022 (total N = 44) by season.

As shown in Figure 3.14, the frequency of fish caught by species and distributed over five length bins (Panel A) was compared with count for filtered fish targets in the same five length bins (Panel B) and Panel C shows the expanded counts for fish in the same length bins. The expanded count is based on the assumption that a smaller fish will bounce back a weaker signal in the periphery of the conical hydroacoustic beam and consequently a small target in the peripheral beam is assigned a larger multiplier than a large target in the centre of the beam.

The length bin frequency pattern between the caught (Panel A) and detected targets (Panel B) was similar but the 0–50 mm length bin was under-represented in the catch because the net only catches fish to a minimum size of 50 mm while the hydroacoustic system detects target to a minimum of 30 mm.

Panels B and C also show entrainment likelihood in the categories “No Entrainment Risk” (above Tunnel elevation, wrong direction), “Potential Entrainment” (correct elevation and direction but fish size makes entrainment unlikely due to burst swim speeds exceeding Tunnel water velocity) and “Likely Entrainment” (correct elevation, direction and burst swim speeds under the Tunnel water velocity). Within these categories, most fish entrained fish can be found in the 0–50 mm and 50–100 mm length bins.

The discrepancy between the captured and detected fish for the small size bins is even more pronounced for the expanded count (Figure 3.14, Panel C).

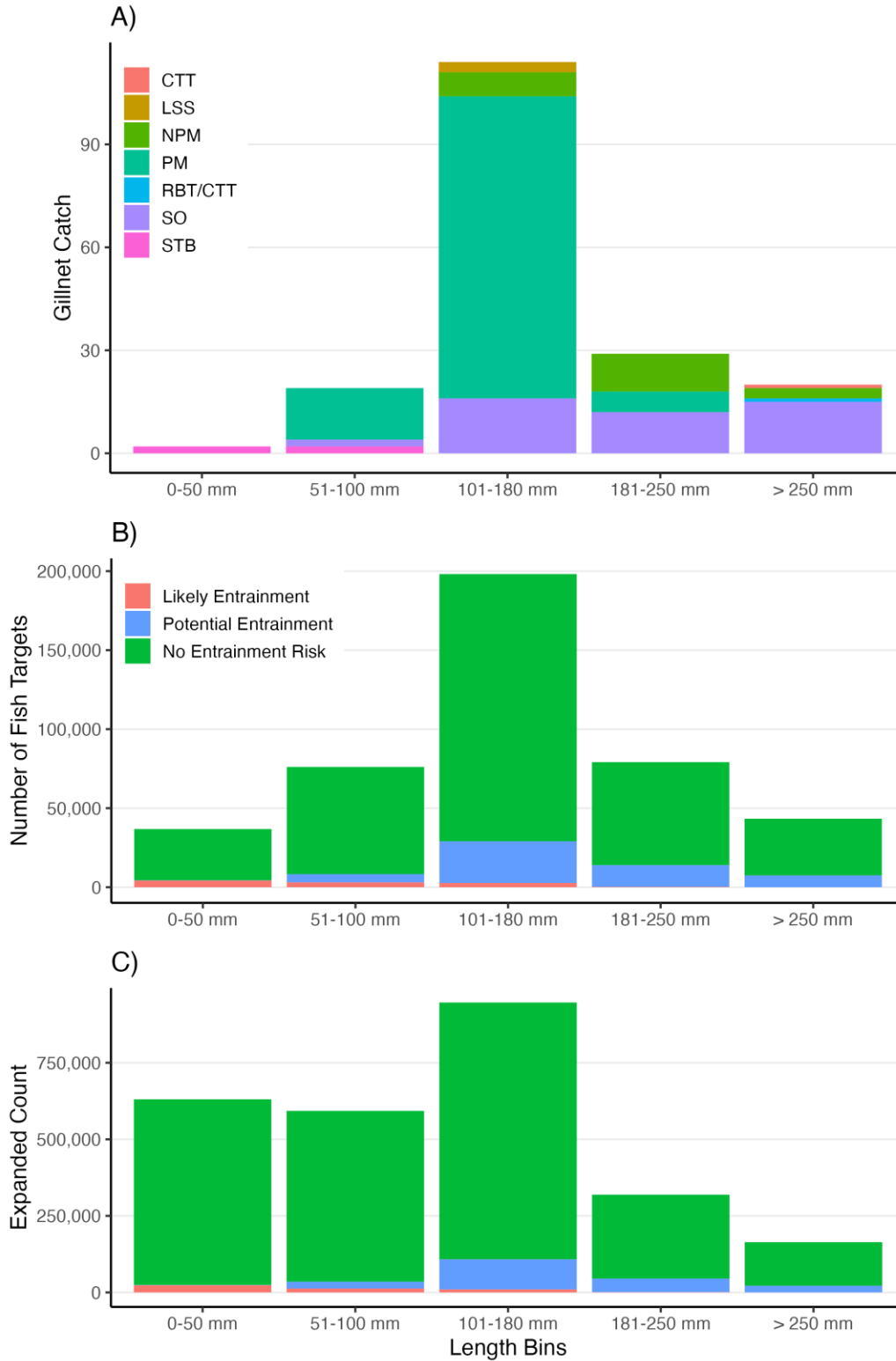


Figure 3.14 Gillnet catch (A) from April 9, 2021–May 31, 2022 (N = 184) showing all fish species by length bins. Panel B is showing the fish target counts detected in the same length bins and Panel C shows the expanded fish target count in the same length bins.

5.4 Fish Depth Distribution

The depth of fish targets was key to determining whether fish were detected above the Tunnel entrance (120–114 masl) or in front of the Tunnel entrance (113–106 masl) and was used as a filter for potential entrainment under the assumption that fish in the water column above the Tunnel entrance were unlikely to be entrained based on low current velocity (< 0.25 m/s) immediately above the Tunnel entrance as shown in Figure 3.9.

Overall, a total of 433,531 targets were detected and expanded to a total of 2,653,580 fish based on the size and angle dependent expansion factor. The depth detection pattern of these fish differed by season (Figure 3.15). In winter (top, left panel), > 99% of fish were detected above the Tunnel entrance, with the highest percentage at 116 masl. During the migration period (top, right panel), very few fish were detected in general and of those few fish, 87% were detected above the Tunnel entrance. For both, winter, and the migration period, very few fish were likely entrained (red bar colour; winter = 1.3%; migration period = 7%) and most fish had no entrainment risk (green bar colour; winter = 98.7%; migration period = 93%).

In summer (Figure 3.15, bottom, left panel), 59% of the fish were detected in the Tunnel entrance depth range below 114 masl and 12% those fish were potentially (blue bar colour) or likely entrained. For the fall period (bottom, right panel), similar to winter and the migration period, the majority of fish were detected above the Tunnel entrance. Different from winter and the migration period, a higher percentage (4.2%) of fish detected in front of the Tunnel were likely entrained in the fall.

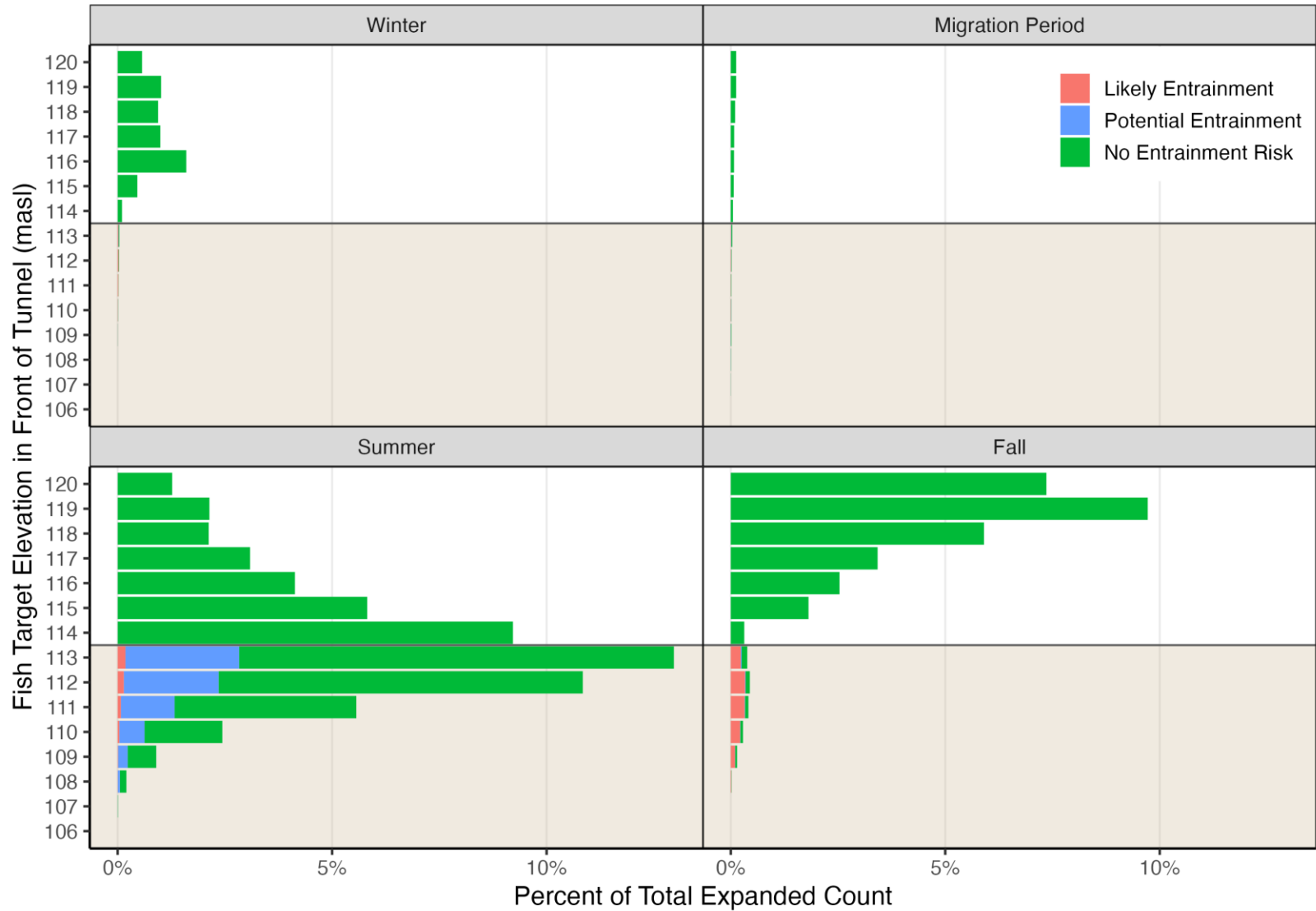


Figure 3.15 Fish target depth frequencies by seasons and entrainment risk.

5.5 Fish Target Swimming Direction

The total count of fish tracked moving in the direction of the Tunnel entrance (+/- 45° of the central axis pointing at the Tunnel entrance from the transducer cone) varied by season (Figure 3.16).

In winter (top, left panel) and during the migration period (top, right panel) very few targets were detected and the majority of those targets moved away from the Tunnel entrance. During these two periods none of the targets were in the “Likely Entrainment” category (red bar colour) of smaller fish.

In summer (bottom, left panel) and fall (bottom, right panel), the majority of targets were detected and a higher percentage of the targets (13%) was in the “Potential Entrainment” or “Likely Entrainment” categories.

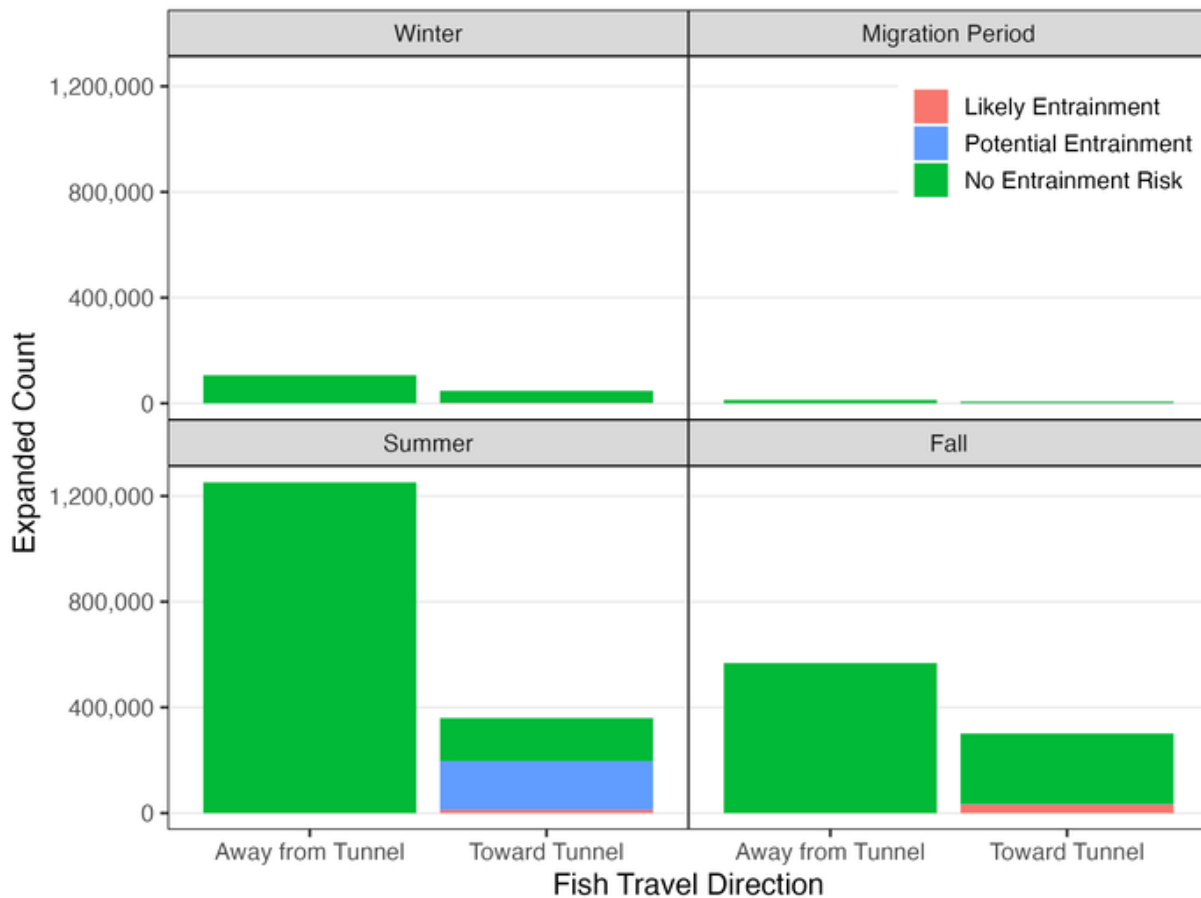


Figure 3.16 Targets moving towards Tunnel entrance.

5.6 Sockeye Salmon Entrainment by Time of Year and Time of Day

Table 3.2 summarizes the Sockeye Salmon entrainment numbers by season and size group. In total, 816 (SE ± 367 fish) Sockeye Salmon were likely entrained which represented 0.38% of the population estimate based on the March 9, 2022, roving hydroacoustic survey. Within this total number, entrainment varied by season and size bin.

In winter, a total of 1,522 filtered fish were detected but based on the Sockeye catch in the gillnet sets only 22 Sockeye Salmon (SE ± 5 fish) in the 101–180 mm size class were likely entrained. During the migration period, 751 filtered fish were detected, but based on the Sockeye catch in the gillnet sets no Sockeye Salmon were likely entrained. During the summer, 11,966 filtered fish were detected but based on the Sockeye catch in the gillnet sets only 274 (SE ± 112 fish) Sockeye Salmon in the 51–180 mm size bins were likely entrained. Finally, during the fall period, 31,470 filtered fish were detected and based on the Sockeye catches in the gillnets sets 632 Sockeye (SE ± 358) in the 101–181 mm size bin were likely entrained.

Entrainment calculations include uncertainty associated with the gillnet surveys used to determine species composition. Another source potential uncertainty is the elevation and horizontal direction filters used to determine fish targets that may be potentially entrained. To assess the potential impact of these filter choices a sensitivity analysis was conducted where the elevation filter was raised by one metre, or the horizontal direction filter was widened by 45 degrees (Figure 3.17). Overall, filter assumptions had a relatively small effect on the estimate of likely entrainment, but a larger effect on the estimate of potential entrainment. This is consistent with seasonal elevation distributions which featured primarily likely entrainment in the fall and a majority no entrainment risk or potential entrainment risk in the summer (Figure 3.15). Lower Tunnel velocities in the summer means relaxing filter parameters results in more targets being classified as potential entrainment, while higher Tunnel velocities in the fall combined with most fish targets being distributed higher in the water column resulted in only a small change to the estimate of likely entrainment (i.e., depth and direction consistent with entrainment with burst swim speed below current Tunnel water velocity).

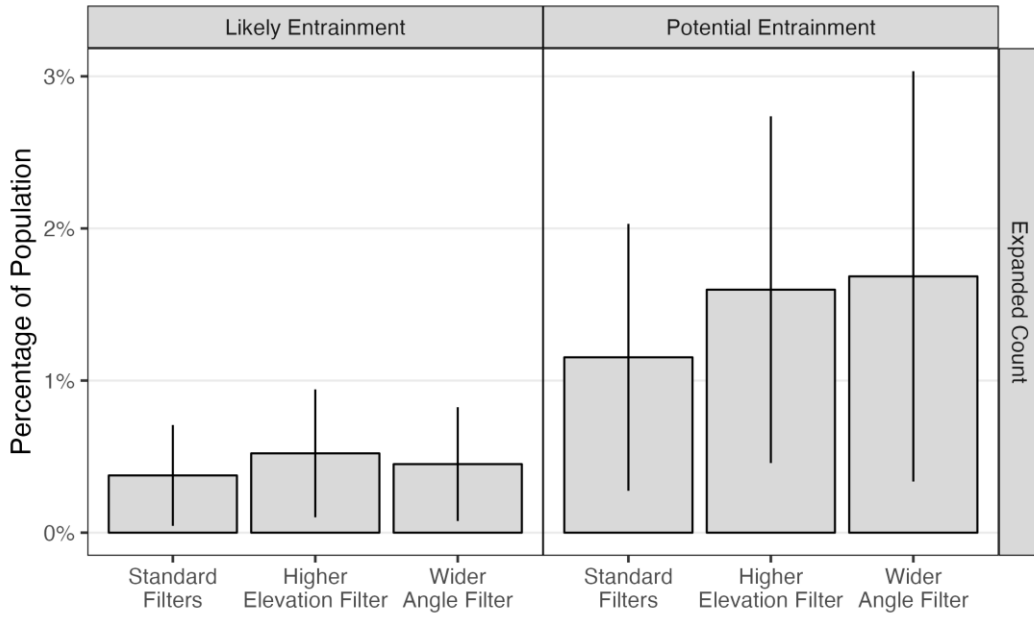


Figure 3.17. Estimates of total likely and potential entrainment under different filtering assumptions.

Table 3.2 Summary table of filters used to arrive at Sockeye Salmon entrainment numbers by seasons and size groups as a percentage of the total Alouette Reservoir fish population (as determined during the March 9, 2022, roving hydroacoustic survey).

Season	Size Bin	Gillnet Sockeye Catch		Acoustic Detections		All Data		Potential Sockeye Entrainment				Likely Sockeye Entrainment			
								Filtered by Depth and Direction		Final Expanded Estimates		Filtered by Depth, Direction, and Velocity		Final Expanded Estimates	
								Targets	Expanded	Total	SE	Targets	Expanded	Total	SE
Winter	0–50 mm	0.000	0.000	Feb 1, 2022	Apr 12, 2022	6,464	97,890	197	1,120	0	0	181	1,033	0.0	0.0
Winter	51–100 mm	0.000	0.000	Feb 1, 2022	Apr 12, 2022	4,339	41,177	123	539	0	0	103	453	0.0	0.0
Winter	101–180 mm	0.597	0.139	Feb 3, 2022	Apr 12, 2022	1,603	11,701	43	154	92	21	10	36	21.6	5.0
Winter	181–250 mm	0.000	0.000	Feb 4, 2022	Apr 12, 2022	278	1,823	9	30	0	0	0	0	0.0	0.0
Winter	> 250 mm	0.000	0.000	Feb 28, 2022	Apr 12, 2022	222	1,144	6	18	0	0	0	0	0.0	0.0
Migration	0–50 mm	0.000	0.000	Apr 24, 2021	May 15, 2022	730	11,209	106	599	0	0	95	543	0.0	0.0
Migration	51–100 mm	0.000	0.000	Apr 26, 2021	May 15, 2022	571	4,829	91	369	0	0	48	208	0.0	0.0
Migration	101–180 mm	0.056	0.037	Apr 22, 2021	May 14, 2022	381	2,120	72	228	13	8	0	0	0.0	0.0
Migration	181–250 mm	0.000	0.000	Apr 22, 2021	May 15, 2022	149	654	25	72	0	0	0	0	0.0	0.0
Migration	> 250 mm	0.000	0.000	Apr 24, 2021	May 15, 2022	197	768	29	80	0	0	0	0	0.0	0.0
Summer	0–50 mm	0.000	0.000	May 16, 2021	May 30, 2022	4,377	56,372	421	2,339	0	0	267	1,499	0.0	0.0
Summer	51–100 mm	0.023	0.016	May 16, 2021	May 30, 2022	53,034	330,993	6,082	25,982	599	414	911	3,899	89.9	62.1
Summer	101–180 mm	0.011	0.008	May 16, 2021	May 30, 2022	184,418	814,024	27,971	104,444	1,135	794	1720	6,599	71.7	50.2
Summer	181–250 mm	0.000	0.000	May 16, 2021	May 28, 2022	74,639	280,665	13,583	43,808	0	0	0	0	0.0	0.0
Summer	> 250 mm	0.000	0.000	May 16, 2021	May 23, 2022	38,338	129,052	7,051	20,528	0	0	0	0	0.0	0.0
Fall	0–50 mm	0.000	0.000	Sep 17, 2021	Nov 13, 2021	25,231	465,246	3,667	20,249	0	0	3667	20,249	0.0	0.0
Fall	51–100 mm	0.000	0.000	Sep 17, 2021	Nov 13, 2021	18,171	215,850	1,951	8,059	0	0	1951	8,059	0.0	0.0
Fall	101–180 mm	0.200	0.113	Sep 17, 2021	Nov 13, 2021	11,745	118,858	967	3,302	660	374	923	3,162	632.4	357.7
Fall	181–250 mm	Spawners Excluded		Sep 17, 2021	Nov 13, 2021	4,069	36,037								
Fall	> 250 mm	Spawners Excluded		Sep 17, 2021	Nov 13, 2021	4,575	33,168								
Total						433,531	2,653,580	Total Entrained Population Estimate		2,499	970.5	Total Entrained Population Estimate		815.7	366.6
								Percentage		1.15%		Percentage		0.38%	

Time of Day

The expanded count of fish targets detected during daytime, night and twilight periods was changing throughout the 13-month study period (Figure 3.18).

In winter and fall, the majority of expanded targets was detected during daytime while in summer > 90% of the targets were detected during daytime. During the migration period the number of expanded targets detected during daytime and night was similar.

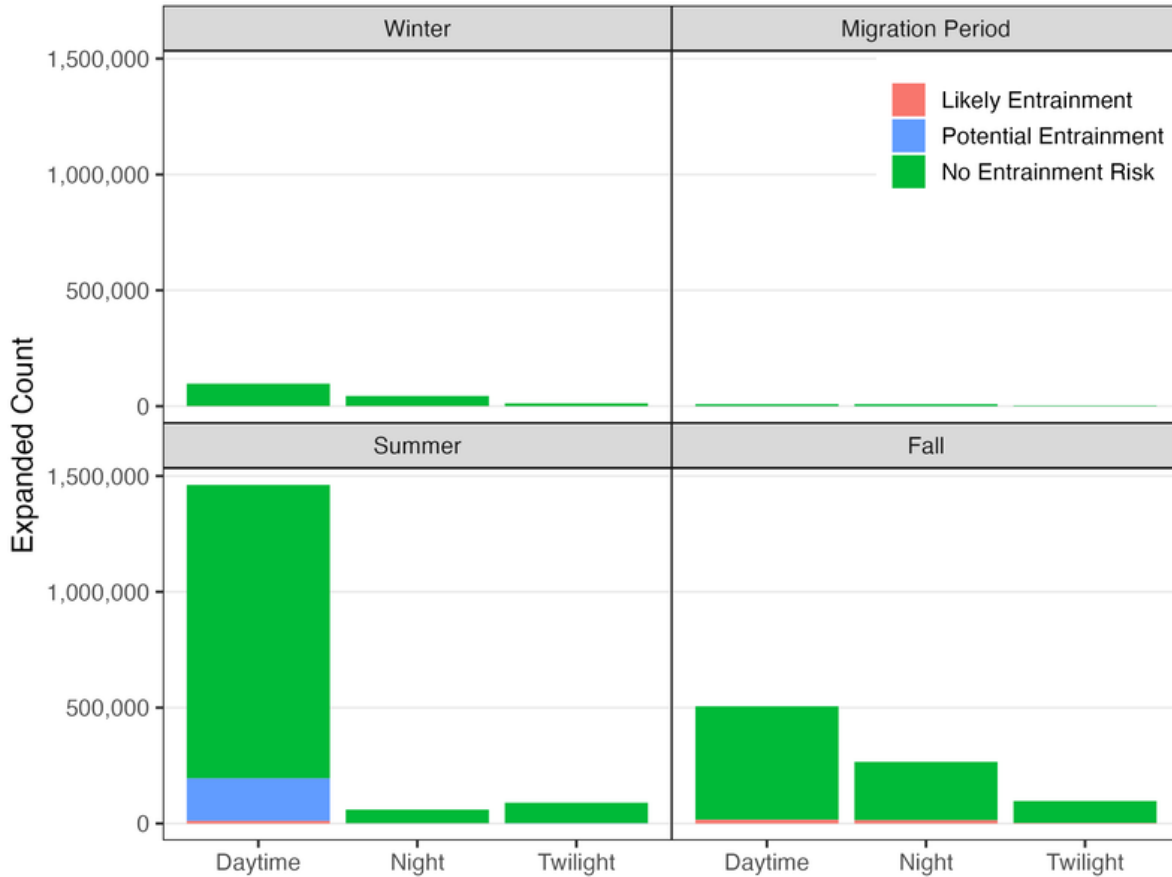


Figure 3.18 Fish target (filtered by depth and swimming direction) distribution frequency by day, night, and twilight for different study periods.

Tunnel discharge ranged widely from April 9, 2021–May 31, 2022. Minimum flows were generally between 5–6 m³/s while the maximum flows reached close to 50 m³/s (Figure 3.19, bottom panel). The exception was the period from July 5–9, 2021, when the Tunnel was closed to maintain summer reservoir elevations. For the period from September 17, 2021–May 31, 2022 (Figure 3.20, bottom panel), the Tunnel discharges were generally higher but no evidence was found of a relationship nor trend between total fish detections (Figure 3.19 and Figure 3.20, top panels) and Tunnel flows for either one of the periods.

Peaks in total fish target numbers around May 24 and June 29, 2021, coincided with low discharges while the peak on June 8 was preceded by a higher discharge (Figure 3.19, top panel).

All fall 2021 fish target peaks (Figure 3.20, top panel) coincided with high discharges because discharges were generally high during this period (Figure 3.20, bottom panel).

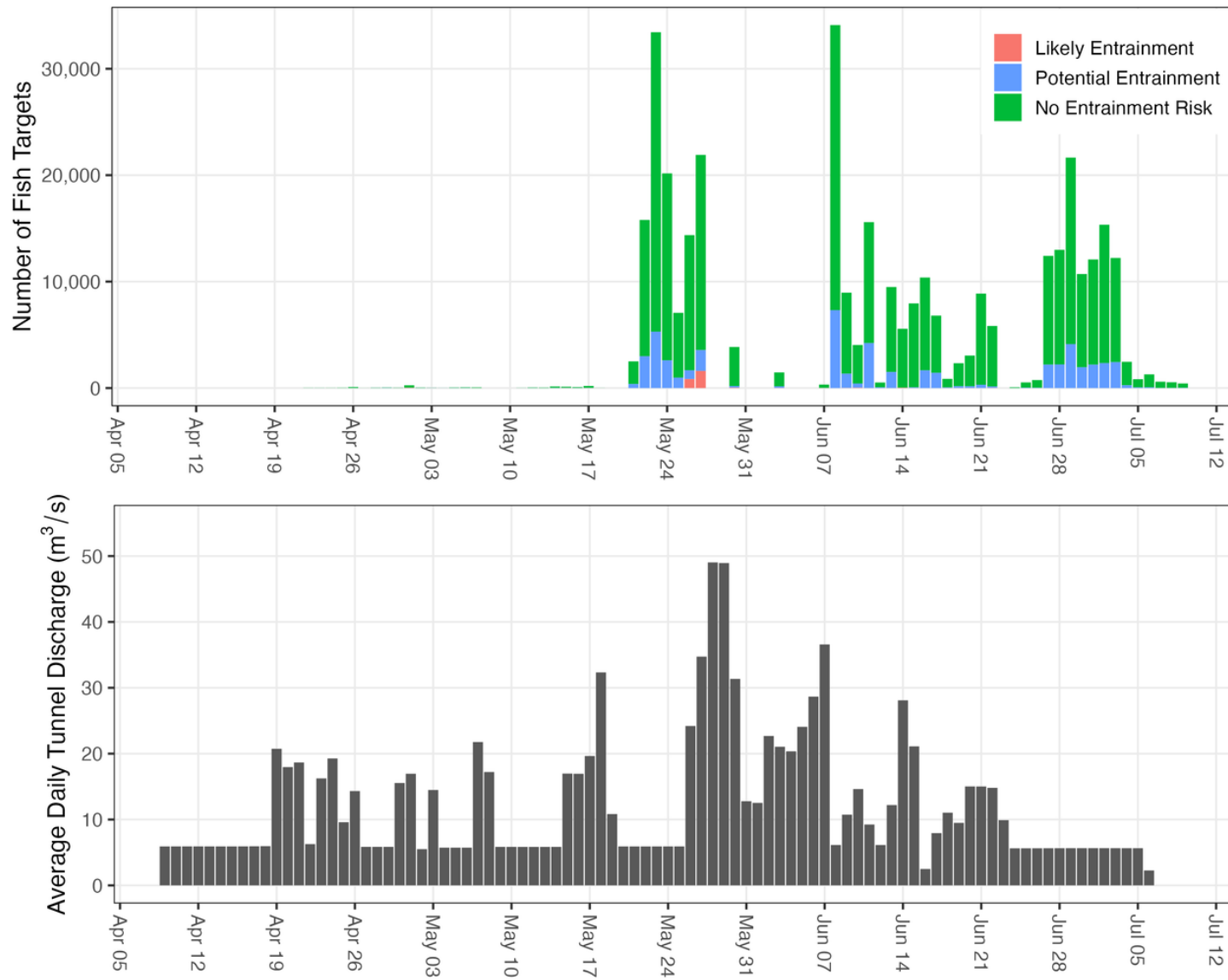


Figure 3.19 Number of fish targets (top panel) coloured by entrapment likelihood and average daily Tunnel discharge (bottom panel) from April 9–July 9, 2021.

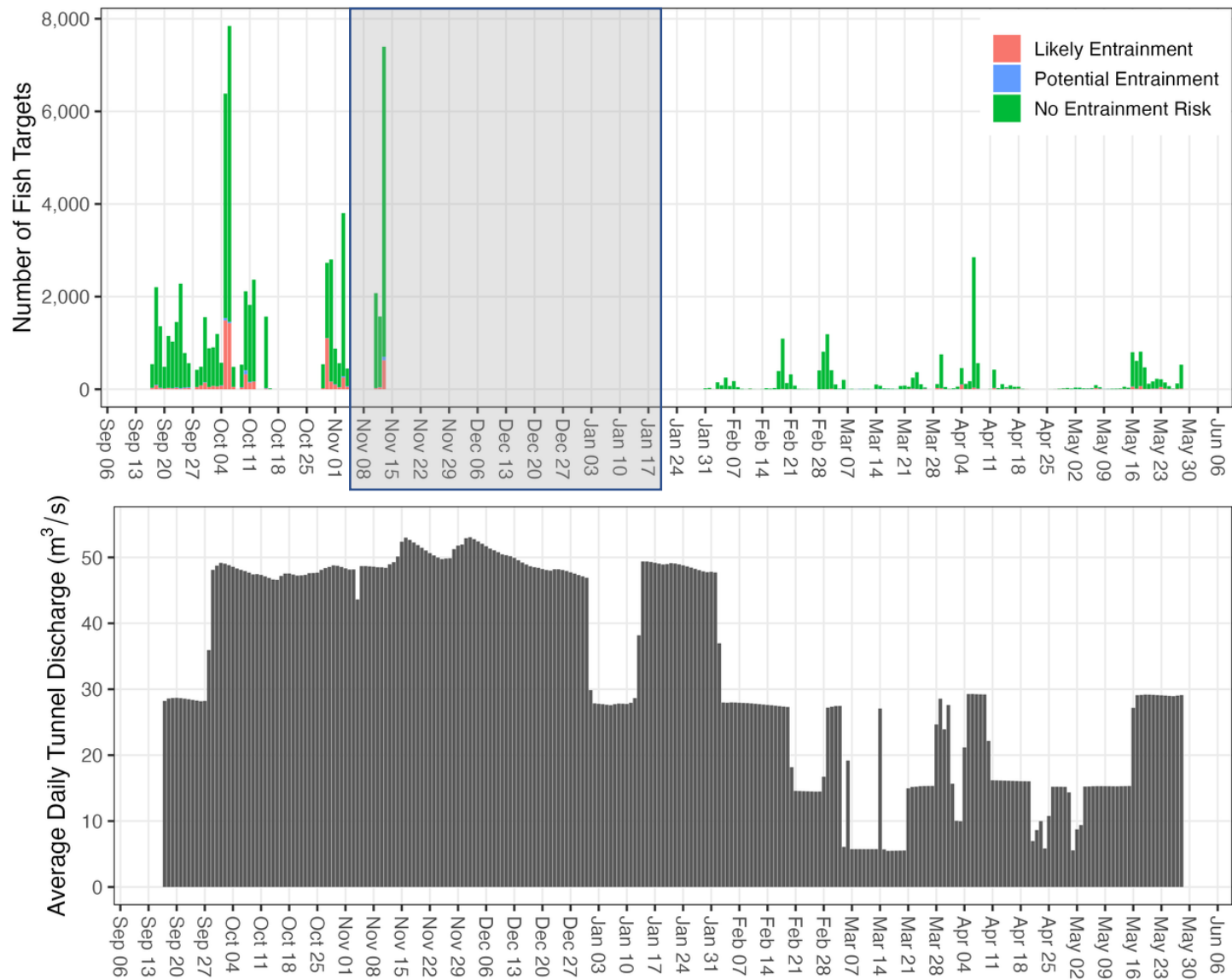


Figure 3.20 Number of fish targets (top panel) coloured by entrainment likelihood and average daily Tunnel discharge (bottom panel) from September 17, 2021–May 31, 2022. Entrainment was not monitored from November 13, 2021–January 31, 2022 (grey shaded area).

5.7 Reservoir Elevation and Entrainment

To assess the potential effect of reservoir elevation on fish (filtered by depth and direction) entrainment, these two factors were plotted in Figure 3.21. Reservoir elevation increased only slightly by 0.68 m from 122.10–122.78 masl from April 9–July 9, 2021, and even the notable increase in elevation from April 15–17 did not lead to a noticeable increase in filtered fish targets (Figure 3.21, top panel). The largest increase in fish targets subsequent to the large peak in numbers on May 21 occurred when reservoir elevations were stable.

For the period from September 17, 2021–May 31, 2022, reservoir levels fluctuated 3.4 m and therefore over a much higher range than observed for April to July, 2021 (Figure 3.21, bottom panel). During this period of higher reservoir level fluctuation, the highest numbers of filtered fish targets were detected during a rapid reservoir level increase on October 5, 2021, and during a rapid reservoir level decrease on October 21, 2021. Based on these findings it appears as if reservoir level increase and decreases can be associated with high number of targets in the Tunnel entrance. In addition, the lowest reservoir levels (120.3 m) observed on February 22, 2022, did not coincided with high numbers of targets in the Tunnel entrance even though it would result in fish holding in depths from 2–8 m closer to the Tunnel entrance. In contrast, on February 22, 2022, when reservoir elevation was low, very few total fish were detected (Figure 3.21, bottom panel).

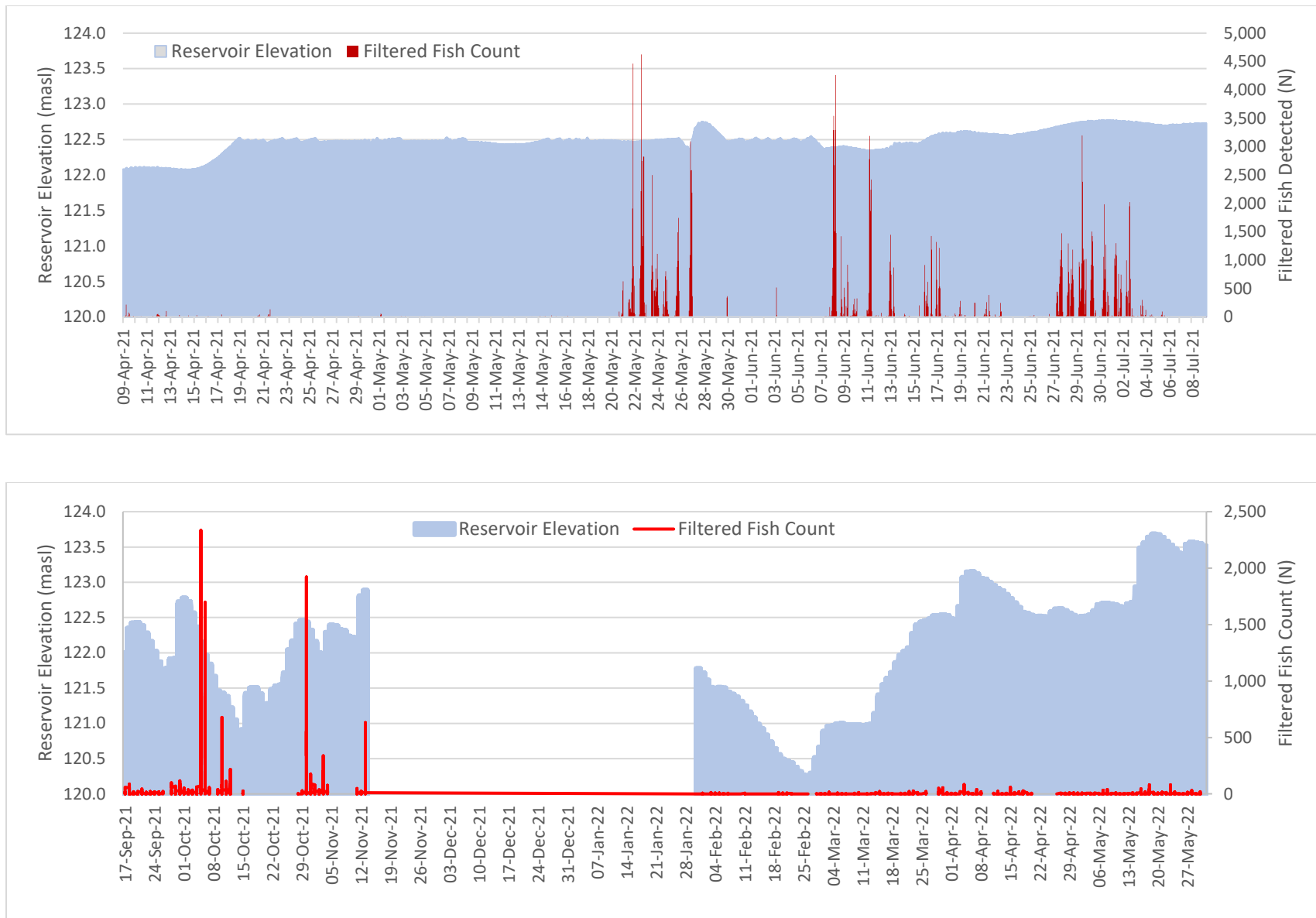


Figure 3.21 Reservoir elevation and number of filtered fish targets by date from April 9–July 9, 2021 (top panel), and from September 17, 2021–May 31, 2022 (bottom panel). Entrainment was not monitored from November 13, 2021–January 31, 2022.

5.8 Sockeye Salmon Tunnel Entrainment and Sockeye Smolt Outmigration over the Alouette Dam Spillway

As in previous years, a rotary screw trap (RST) was operated 1.5 km downstream of the Alouette Dam to enumerate the number of Sockeye Salmon smolts leaving the Alouette Reservoir over the Alouette Dam spillway and into the Alouette River. This is the route that allows Sockeye Salmon smolts to enter the marine environment and return as adults to the Alouette River. Entrainment through the Tunnel would not allow for outmigration into the ocean and any entrained Sockeye Salmon would be a loss of production and recruitment.

Between April 14 and May 25, 2021, an estimated 7,417 Sockeye Salmon smolts left the Alouette Reservoir over the spillway at the south end of the Reservoir and between April 14 and May 25, 2022, an estimated 10,871 Sockeye Salmon smolts left (Mathews et al. 2022).

At the north end of the Alouette Reservoir, no Sockeye Salmon in the size bin 0–100 mm were observed to be entrained in 2021 nor 2022, between April 14 and May 25, 2021. This ratio results in an estimate of 100% of Sockeye smolts leaving the reservoir through the Alouette River and 0% entrained through the Tunnel into Stave Reservoir (Table 3.3).

Table 3.3 Proportion of Age 1+ Sockeye Salmon smolts that were leaving Alouette Reservoir in 2021 and 2022 over the Alouette Dam spillway or were entrained through the Tunnel.

	2021 (± 95% Confidence Interval for RST)	2022 (± 95% Confidence Interval for RST)	2021 & 2022 Combined
RST Catch	7,076 (6,321–7,831)	10,664 (9,526–11,802)	17,440
Expanded Sockeye Smolt Targets Filtered by Length/Velocity, Direction and Depth	Both years combined 751		751
% of Sockeye in Gillnet Catch in the 0–100 mm Size Bin at Tunnel	0	0	0
Sockeye Assumed to be Entrainment	0	0	0
Sockeye Smolt Migrated Out	100%	100%	100%
Sockeye Smolt Entrained	0%	0%	0%

5.9 Tunnel Discharge and Sockeye Smolt Outmigration over the Alouette Dam Spillway

In 2021, the first small peak in Sockeye Salmon smolt RST catch was observed from April 19–21 and coincided with medium discharges from 17–21 m³/s through the Tunnel. In addition, the highest number of Sockeye Salmon smolts was caught on May 1 in the RST program preceded by an increase in Tunnel discharge from 6–17 m³/s (Figure 3.22, top panel).

Similarly, in 2022, the first small peak in Sockeye Salmon smolt catch at the RST was recorded from April 24–26 and coincided with medium Tunnel discharges from 11–15 m³/s, while the RST catch peak occurred again on May 1, coinciding with an increase of Tunnel discharge from 5–15 m³/s (Figure 3.22, bottom panel).

Therefore, no evidence was found for high Tunnel discharges at the reservoir north end to lure Sockeye Salmon smolts away from leaving the reservoir over the spillway on the south end.

5.10 Alouette Dam Spillway Discharge and Tunnel Entrainment of Sockeye Salmon

From April 9–July 9, 2021 (Figure 3.23, top panel), the largest increase in spillway discharge, from 3.2–8.7 m³/s, occurred between April 14–19 and coincided with a period of low filtered fish numbers detected at the Tunnel, while the largest increase in filtered fish targets at the Tunnel occurred from May 21–23, 2021, and coincided with a stable spillway discharge period (~8.7 m³/s).

From September 17, 2021–May 31, 2022 (Figure 3.23, bottom panel), the largest increase in spillway discharge, from 0–3.3 m³/s, occurred between April 13–14 and coincided with a period of regular low filtered fish target numbers detected at the Tunnel and no large increase in filtered fish targets at the Tunnel occurred for the rest of spillway discharge period until May 21, 2022, while the discharge also remained stable.

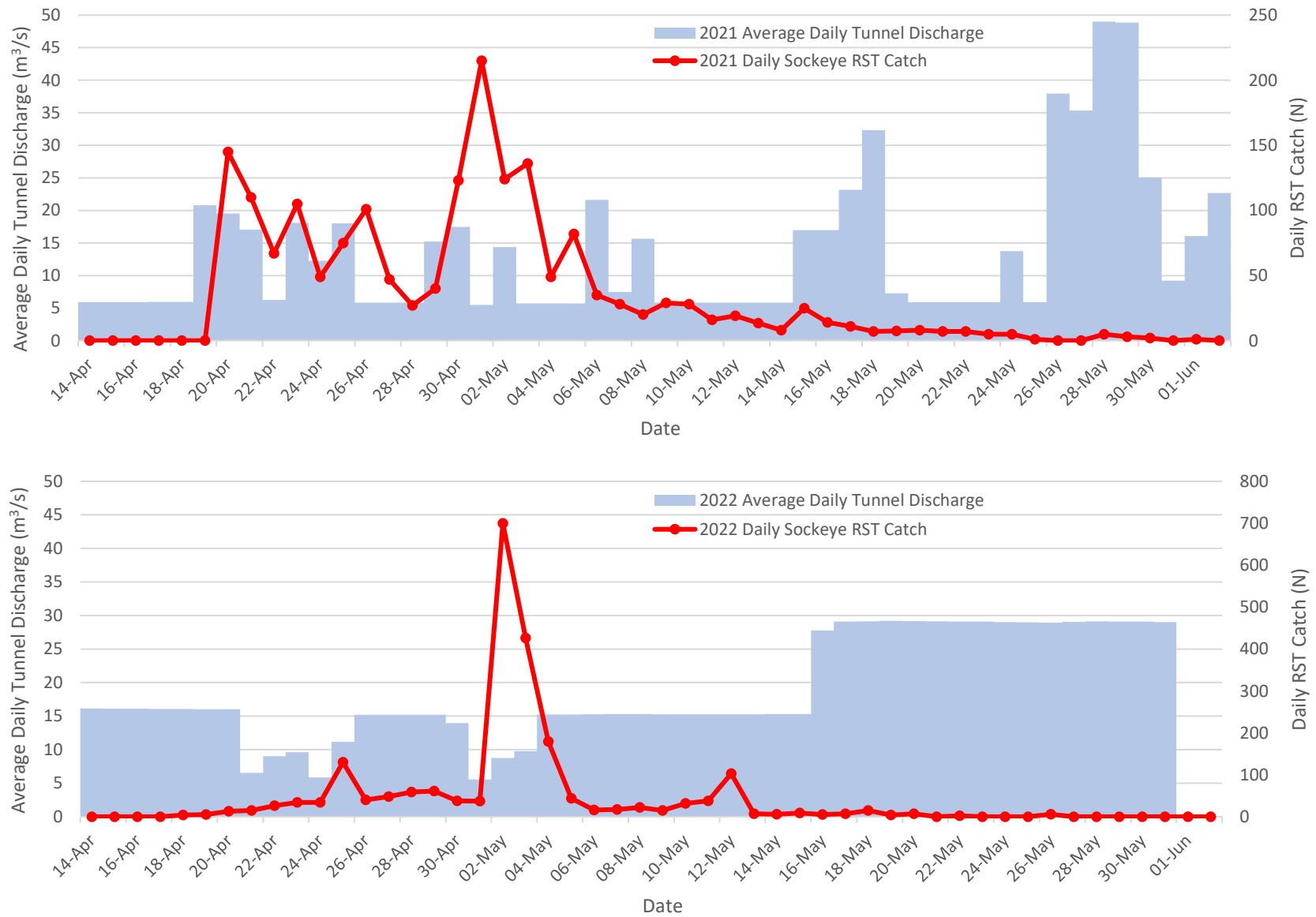


Figure 3.22 Average daily Tunnel discharge (m³/s) and daily catch of Sockeye Salmon in the RST operated in the Alouette River below Alouette Dam in 2021 (top panel) and 2022 (bottom panel).

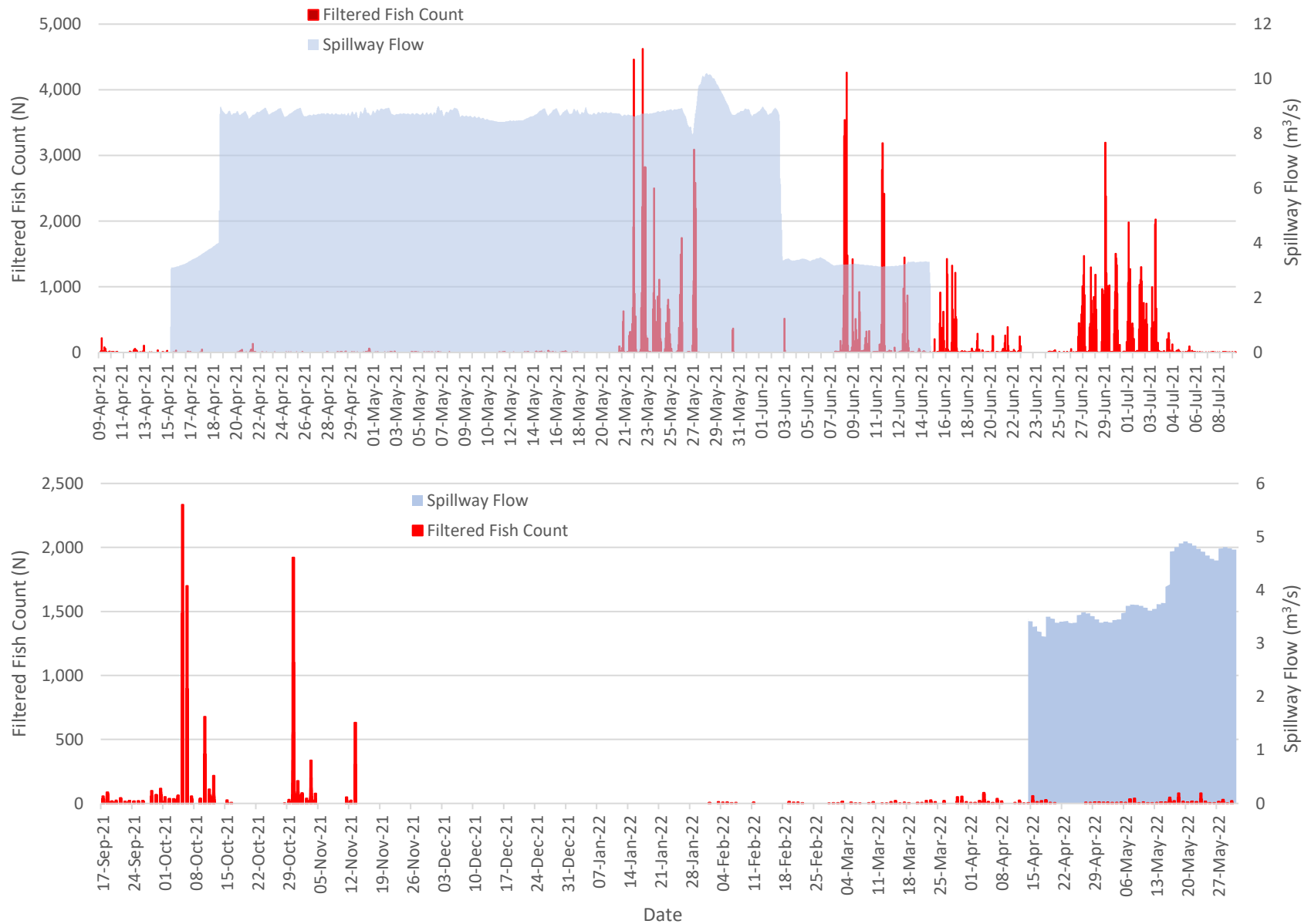


Figure 3.23 Spillway flow and filtered fish detected at the Tunnel from April 9–July 9, 2021 (top panel), and from September 17, 2021–May 31, 2022 (bottom panel).

5.11 Results of the Reservoir Hydroacoustic Survey

The hydroacoustic survey of the Alouette Reservoir was conducted after sunset on March 9, 2022, along 12 transects (Figure 3.24) starting from the north end of the reservoir and close to the Tunnel entrance and ending at the south end of the reservoir and close to the Golden Ears Park boat ramp. The transect labels were based on the conventions established as part of the annual BC Provincial Alouette Reservoir nutrient restoration program (Harris et al. 2010).

The results of the transect surveys were divided into the following four size groups of fish:

- Size Class 0: 30–80 mm, representing Age 1+ Sockeye Salmon (Age 0+ fry would likely not have emerged into open water at this time) that would be in preparation for smolting and leaving the reservoir in April and May if they have the desire to do so);
- Size Class 1: 80–120 mm, representing Age 2+ Sockeye Salmon;
- Size Class 2: 120–250 mm, representing Age 3+ and 4+ Sockeye Salmon that would likely spawn in 2022; and
- Size Class 3: > 250 mm, this size class would represent fish that are larger than Sockeye Salmon found in the reservoir and was not analyzed further since only two individual fish targets were detected in this length class.

Size Class 0, 30–80 mm (Age 1+ Sockeye)

This size class corresponds well with the average Age 1+ Sockeye Salmon smolt length of 78.6 mm caught in the Alouette RST from 2005–2022. Figure 3.24 shows the fish density distribution along the 12 transects for size class 0 (30–80 mm) and Table 3.4 shows the depth distribution for each transect. Age 1+ fish densities in the North Basin (average = 28.7 fish/ha) were much lower than in the South Basin (average = 152 fish/ha) (Figure 3.24) and fish depth distribution for this size group was also different between the two basins. In the North Basin, the 30–80 mm fish were mainly found in the depths ranges from 5–10 m and from 20–40 m, while in the South Basin fish this size occupied the depth ranges from 0–15 m and 20–55 m (Table 3.4).

The highest densities of 30–80 mm fish (231 fish/ha) were found at the north end of the South Basin along Transect 4 and at depths from 40–55 m (Table 3.4).

Size Class 1, 80–120 mm (Age 2+ Sockeye)

Figure 3.25 shows the fish density distribution along the 12 transects for size class 1 (80–120 mm) and Table 3.5 shows the depth distribution for each transect for the same length class. As for the Age 1+ fish, the Age 2+ fish densities in the North Basin (average = 2.5 fish/ha) were much lower than in the South Basin (average = 28.2 fish/ha) (Figure 3.25) and fish depth distribution was also different between the two basins. In the North Basin, the Age 2+ fish were mainly found from 15–20 m and from 35–40 m, while the Age 2+ fish in the South Basin mainly occupied the depths ranges from 5–10 m and 20–55 m (Table 3.5).

The highest fish densities (66.9 fish/ha) for the Age 2+ fish were found in the centre of the South Basin along Transect 6.5 close to mouth of Gold Creek and at depths from 5–15 m (Table 3.5).

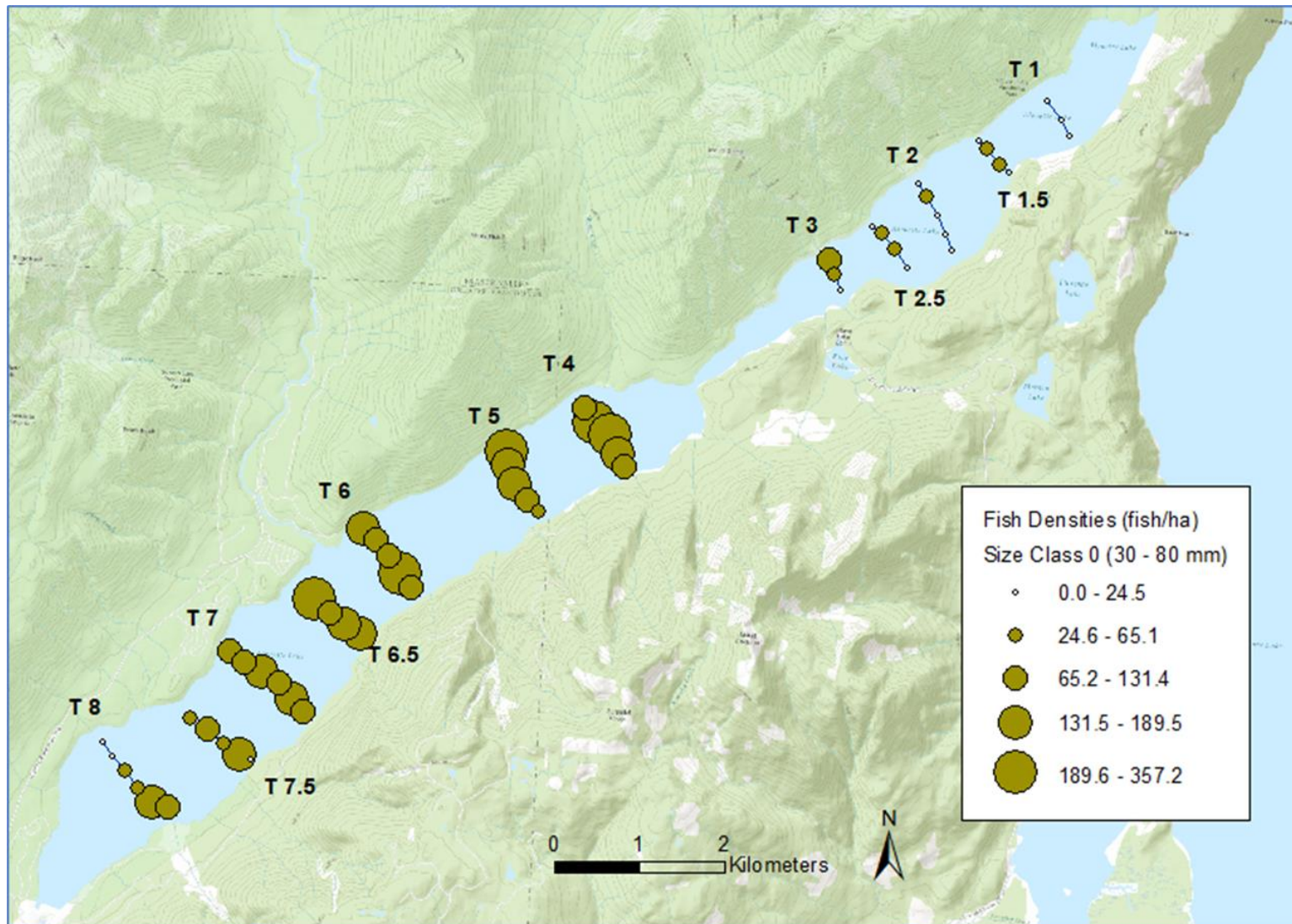


Figure 3.24 Geographic distribution of fish in size class 0 (30–80 mm) derived from down-looking acoustic data (depth > 5 m).

Table 3.4 Vertical distribution of fish in size class 0 (30–80 mm) along the long axis of the reservoir (colour coding: blue = low densities; white = medium densities; red = high densities).

Size 0 (30–80 mm) Fish Density (fish/ha area at depth) by Transect and Depth															
Transect (west to east)															
Depth Top (m)	South Average	South Basin							North Basin					North Average	
		8	7.5	7	6.5	6	5	4	3	2.5	2	1.5	1		
5	3.8	0.0	0.0	5.3	14.8	0.0	6.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	10.5	3.6	10.2	12.8	42.4	0.0	0.0	4.5	18.0	6.4	4.4	7.9	0.0	7.3	
15	7.8	4.9	3.8	8.0	15.9	0.0	7.1	15.0	0.0	5.0	0.0	0.0	0.0	1.0	
20	5.9	6.1	5.2	6.2	0.0	5.2	10.9	8.0	0.0	0.0	2.5	0.0	0.0	0.5	
25	12.9	9.4	15.5	10.0	9.3	8.5	18.0	19.5	8.4	8.1	4.2	0.0	0.0	4.1	
30	29.9	33.0	25.6	34.4	47.1	29.9	24.0	15.1	10.9	0.0	0.0	0.0	0.0	2.2	
35	20.4	12.4	11.5	21.7	36.6	27.1	15.3	18.1	6.8	8.3	3.1	11.3	0.0	5.9	
40	10.9	4.4	9.1	8.9	8.1	20.0	4.5	21.2	3.1	3.7	5.6	7.6	0.0	4.0	
45	15.8	0.0	5.5	14.4	13.2	23.3	17.5	36.4	3.0	3.2	3.8	0.0	0.0	2.0	
50	16.7	8.1	5.2	7.6	8.3	20.0	17.8	49.7	0.0	1.7	0.0	2.1	0.0	0.7	
55	17.3		0.0	2.7	2.8	33.1	20.6	44.6	2.8	1.6	0.0	0.0	0.0	0.9	
60	3.4		0.0	0.9	0.0	6.8	9.0								
65	0.4		1.2	0.0	0.0	1.0	0.0								
Total	152.1	81.9	92.8	132.9	198.4	174.8	151.6	232.1	53.0	37.9	23.5	28.8	0.0	28.7	

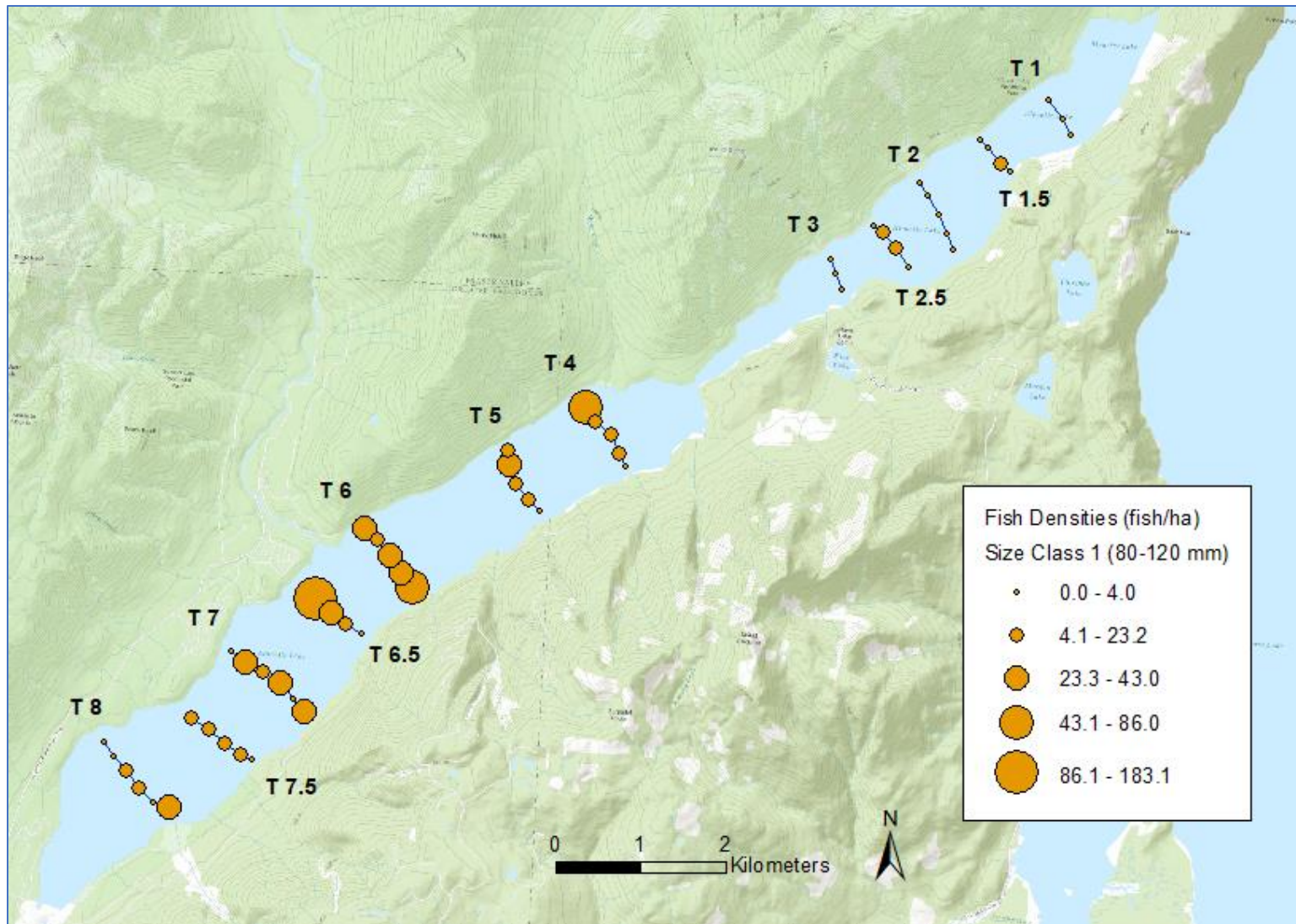


Figure 3.25 Geographic distribution of fish in size class 1 (80–120 mm) derived from down-looking acoustic data (depth > 5 m).

Table 3.5 Vertical distribution of fish in size class 1 (80–120 mm) along the long axis of the reservoir (colour coding: blue = low densities; white = medium densities; red = high densities).

Size 1 (80–120 mm) Fish Density (fish/ha area at depth) by Transect and Depth															
Transect (west to east)															
Depth Top (m)	South Average	South Basin								North Basin					North Average
		8	7.5	7	6.5	6	5	4	3	2.5	2	1.5	1		
5	1.1	0.0	0.0	0.0	7.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	5.4	3.6	0.0	3.9	21.3	4.0	0.0	5.2	0.0	0.0	0.0	0.0	0.0	0.0	
15	3.1	0.0	0.0	2.5	15.4	0.0	3.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.4	0.0	0.0	0.0	0.7	
25	1.8	2.0	0.0	1.6	2.4	2.0	2.2	2.2	0.0	0.0	0.0	0.0	0.0	0.0	
30	3.2	3.5	3.6	0.0	7.9	5.3	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	
35	4.0	4.0	5.2	2.6	1.9	7.6	5.0	1.6	0.0	0.0	0.0	0.0	0.0	0.0	
40	1.5	0.0	0.0	4.5	3.3	0.0	0.0	2.9	0.0	1.9	0.0	5.2	0.0	1.4	
45	2.6	0.0	4.0	2.0	3.0	3.7	0.0	5.2	0.0	0.0	0.0	0.0	0.0	0.0	
50	2.4	0.0	1.3	1.9	4.2	2.2	1.2	6.1	0.0	0.0	0.0	2.2	0.0	0.4	
55	2.5		1.2	2.8	0.0	5.3	2.3	3.5	0.0	0.0	0.0	0.0	0.0	0.0	
60	0.9		0.0	0.0	0.0	2.0	2.3								
65	0.6		0.0	0.0	0.0	1.9	1.1								
Total	28.2	13.0	15.4	21.8	66.9	33.9	18.0	28.6	0.0	5.3	0.0	7.4	0.0	2.5	

Size Class 2, 121–250 mm, Age 3+

Figure 3.26 shows the fish density distribution along the 12 transects for size class 2 (121–250 mm) and Table 3.6 shows the depth distribution for each transect for the same length class. As for the Age 1+ and 2+ fish, the Age 3+ fish densities in the North Basin (average = 4.5 fish/ha) were lower than in the South Basin (average = 20 fish/ha) (Figure 3.26) and fish depth distribution between the two basins were also quite different. In the North Basin, the Age 3+ fish were mainly found from 10–20 m, while the Age 3+ fish in the South Basin mainly occupied depths from 5–10 m (Table 3.6).

Similar to the highest fish densities for the Age 2+ fish, the highest fish densities (26 fish/ha) for the Age 3+ fish were found in the centre of the South Basin along Transect 6.5 close to the mouth of Gold Creek and at depths from 5–10 m (Table 3.6).

Size Class 3, > 250 mm

Figure 3.27 shows that the total of two fish > 260 mm were detected on Transect 6.5 close to the mouth of Gold Creek and in the centre of Alouette Reservoir. Since only two fish were detected, no further analysis was conducted for this size class.

Near Surface Fish Densities

Figure 3.28 shows the densities of fish detected at depths from 0.6–5.0 m. While densities for all other depths (5–70 m) were based on monitoring using a down-looking transducer, the surface densities were based on monitoring using a side-looking transducer. For the near surface layer, fish length distributions cannot be determined and only one depth stratum was imaged. During the survey of the first two Transects 1 and 1.5, windy conditions led to heavy boat movement and targets recorded through the side-looking transducer could not be analyzed.

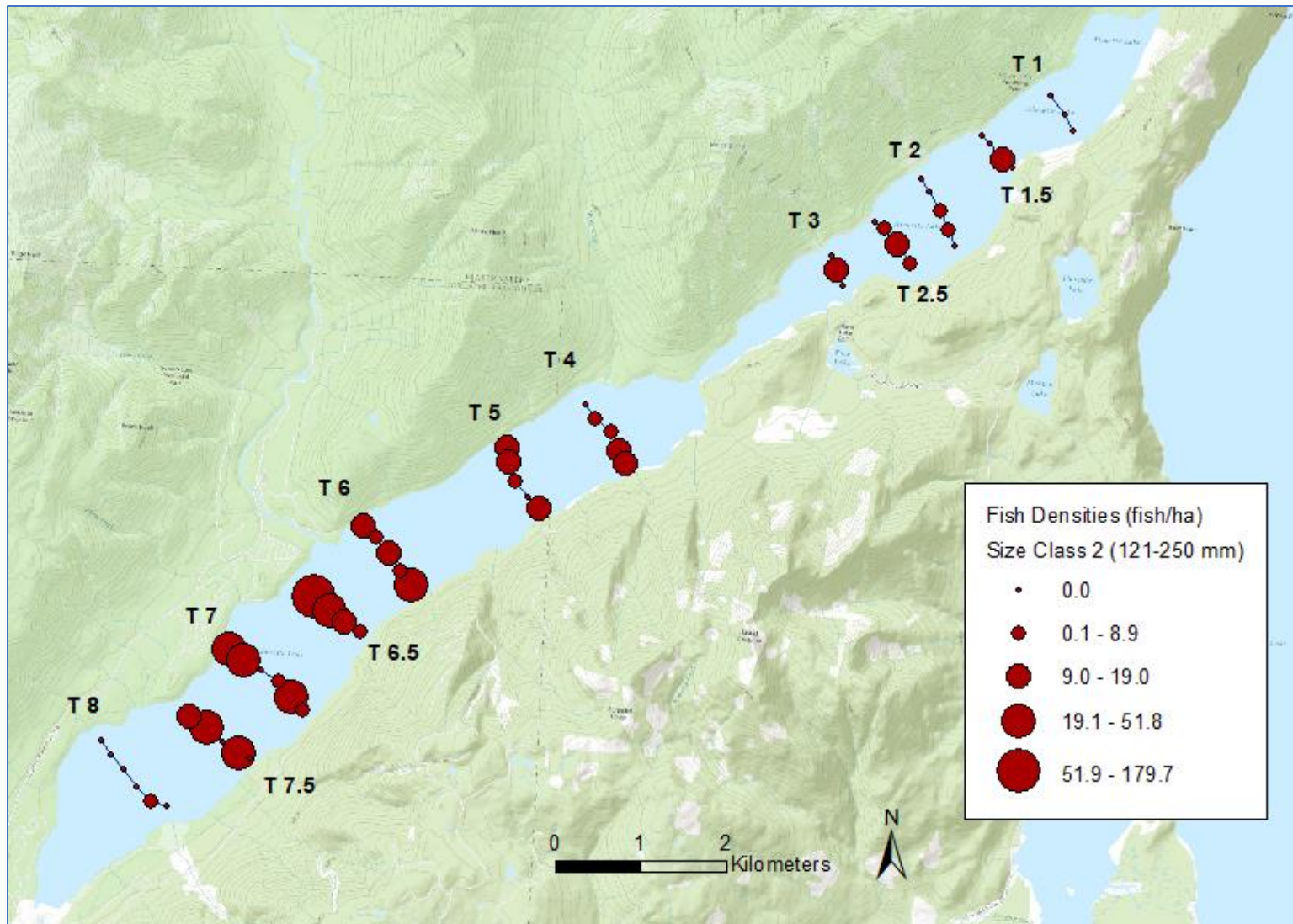


Figure 3.26 Geographic distribution of fish in size class 2 (121–250 mm) derived from down-looking acoustic data (depth > 5 m).

Table 3.6 Vertical distribution of fish in size class 2 (121–250 mm) along the long axis of the reservoir (colour coding: blue = low densities; white = medium densities; red = high densities).

Size 2 (121–250 mm) Fish Density (fish/ha area at depth) by Transect and Depth																
Transect (west to east)																
Depth Top (m)	South Average	South Basin								North Basin					North Average	
		8	7.5	7	6.5	6	5	4	3	2.5	2	1.5	1			
5	0.9	0.0	6.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	6.0	0.0	0.0	11.5	26.0	4.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15	2.8	0.0	3.8	0.0	15.6	0.0	0.0	0.0	0.0	0.0	5.2	0.0	0.0	0.0	0.0	1.0
20	0.8	0.0	0.0	0.0	3.2	2.6	0.0	0.0	0.0	5.1	0.0	0.0	0.0	0.0	0.0	1.0
25	0.4	0.0	0.0	0.0	2.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30	2.0	1.9	3.6	2.8	2.1	1.6	0.0	2.0	0.0	0.0	1.7	3.2	0.0	0.0	0.0	1.0
35	1.8	0.0	1.7	3.9	3.7	1.5	1.6	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.4
40	1.4	0.0	0.0	2.3	6.4	0.0	0.0	1.4	0.0	0.0	1.8	0.0	0.0	0.0	0.0	0.4
45	2.5	0.0	2.8	1.1	4.4	2.4	2.7	3.9	0.0	0.0	0.0	2.2	0.0	0.0	0.0	0.4
50	1.0	0.0	1.3	1.0	0.0	0.0	2.5	2.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
55	0.4		0.0	0.0	1.4	1.1	0.0	0.0	0.0	0.0	1.1	0.0	0.0	0.0	0.0	0.2
60	0.2		0.0	0.0	0.0	1.0	0.0									
65	0.0		0.0	0.0	0.0	0.0	0.0									
Total	20.0	1.9	19.6	22.4	65.2	14.4	6.9	9.9	5.1	9.0	2.8	5.4	0.0	0.0	0.0	4.5

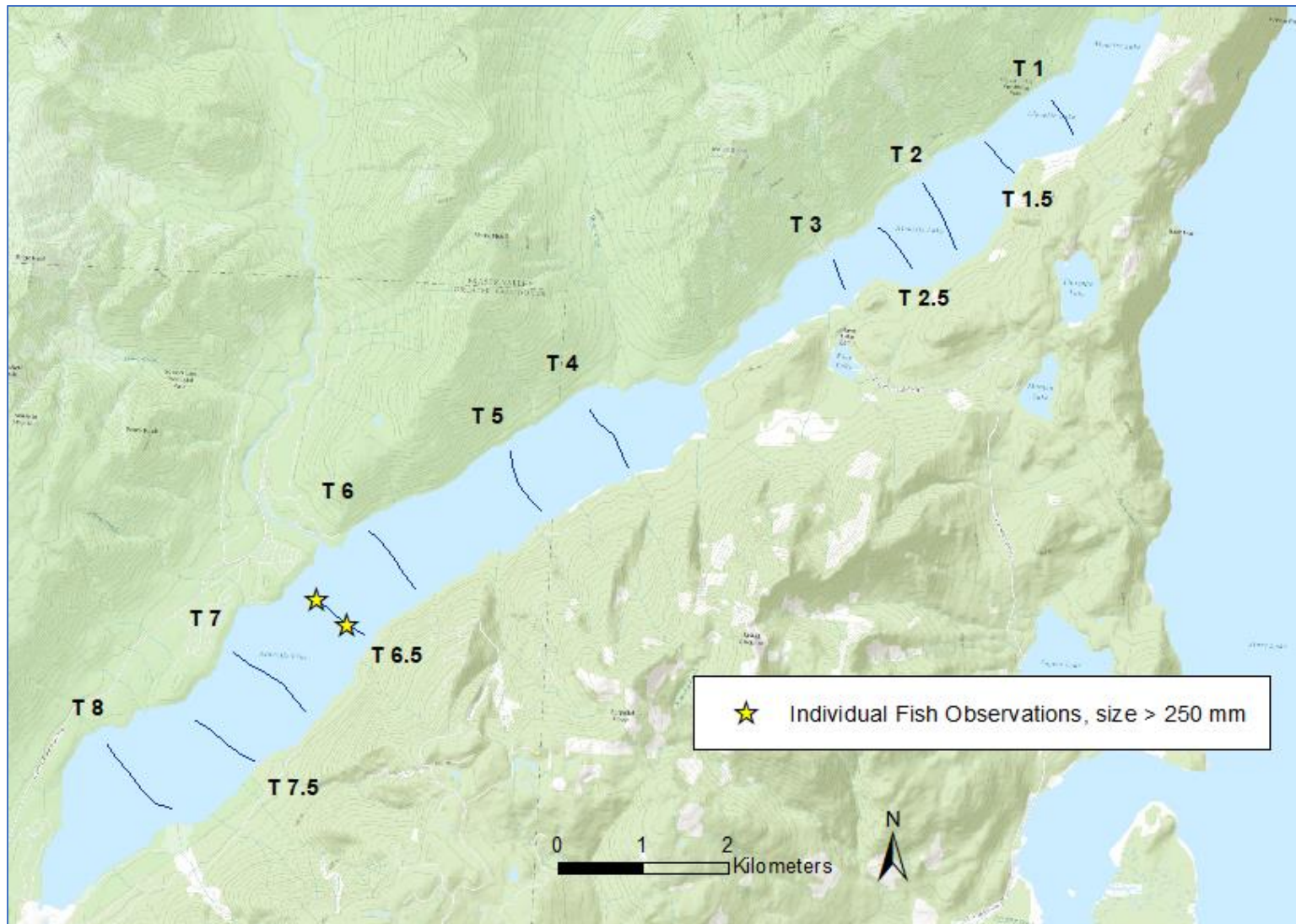


Figure 3.27 Geographic location of fish > 250 mm (2 individuals) derived from down-looking acoustic data (depth > 5 m).

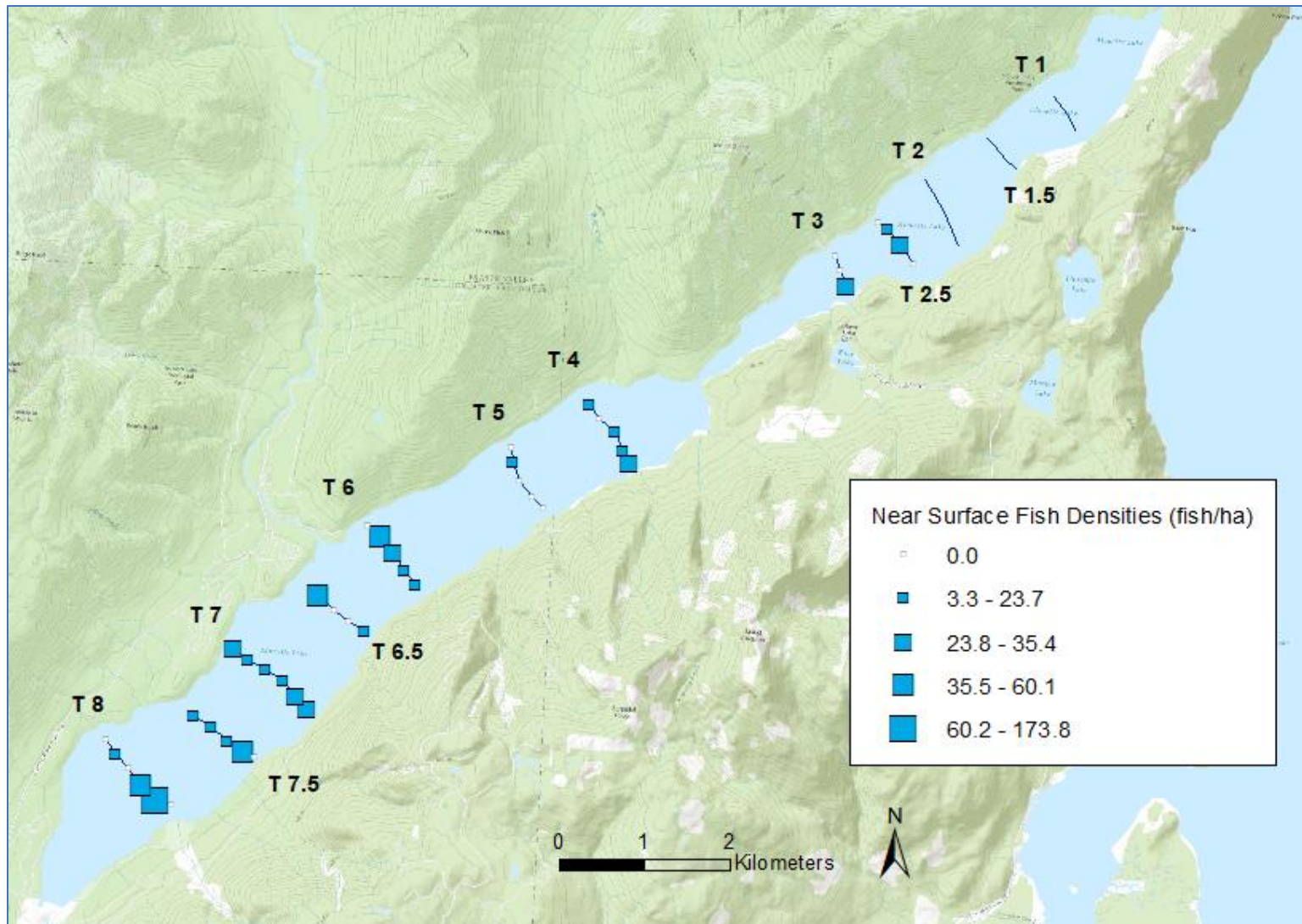


Figure 3.28 Geographic distribution of fish near surface (0.6–5.0 m depth) derived from side-looking acoustic data.

Comparison of 2022 Spring and BC MOE 1998 – 2018 Hydroacoustic Survey Results

The top panel of Figure 3.29 shows the hydroacoustic target density in fish/ha for Size Class 0 (30–80 mm, Age 1+ Sockeye) recorded during the spring 2022 survey. Target density for the Age 1+ Sockeye Salmon was highest on Transect 4 (232 fish/ha) at the north end of the South Basin and the lowest (24 fish/ha) on Transect 2 at the north end of the North Basin. The zero value for Transect 1 was based on boat rocking and resulting recording issues in stronger wind on this transect. The average densities for the South and North Basins were 152 fish/ha and 29 fish/ha, respectively.

For all age classes combined, the red bars in the bottom panel of Figure 3.29 are showing the 2022 spring survey results while the orange bars are showing the average target densities (\pm STDEV) from BCMOE summer and fall surveys carried out from 1998–2018. While the 2022 age class combined (200 fish/ha \pm STDEV 81 fish/ha) and the 1998–2018 average values (215 fish/ha \pm STDEV 79 fish/ha) for the South Basin are similar, the values for the North Basin are higher for the 2022 spring survey (45 fish/ha \pm STDEV 14 fish/ha) when compared with the 1998–2018 average values (157 fish/ha \pm STDEV 34 fish/ha).



Figure 3.29 Fish target density in N/ha for the south basin (Transect 8–4) and the north basin (Transect 3–1) of Alouette Reservoir survey transects. The top panel shows the 2022 spring survey results for Size Class 0 (30–80 mm, Age 1+) and the south basin and north basin averages (\pm STDEV). The bottom panel shows the results for all length classes combined for the 2022 spring survey (red bars) and the average for the fall and summer surveys carried out by the BC MOE between 1998–2018 (orange bars, \pm STDEV) (BCMOE data from: Scholten and Sebastian 2000; Squires et al. 2008; Harris et al. 2010; Hebert et al. 2015; Hebert et al. 2016; Vainionpaa et al. 2020).

Population Estimates

Population estimates were produced for each of the three size classes 0, 1, and 2, for all depths from 5–70 m based on the down-looking transducer readings, and for all size classes combined for the 0.6–5.0 m depth range based on the side-looking transducer readings.

A summary of the population estimates for all size classes and the 0.6–5.0 m depth range is provided in Table 3.7. The estimate for all fish detected in the Alouette Reservoir in March 2022 is 261,171 fish, of which 94.1% were detected in the North Basin while 5.9% were detected in the South Basin. For the surface (0.6–5.0 m) depth layer, no estimate was produced for the North Basin since targets could not be identified for Transects 1 and 1.5 and numbers were too low for Transects 2, 2.5, and 3. Based on species composition in gillnet catches carried out parallel to the roving survey approximately 216,807 of the total 261,171 targets detected were Sockeye Salmon. The estimated spring 2022 Sockeye population of 216,807 fish for the whole reservoir was similar to the BCMOE 1998–2018 average population estimate of 250,456 fish (\pm STDEV 68,304), while the distribution between the South and North Basins was different. In the 2022 spring survey, 94.1% and 5.9% of the fish were detected in the South and North Basin, respectively, while in the BCMOE summer and fall surveys 61% and 39% of the fish were detected in the South and North Basin, respectively.

For the 2021 summer, BCMOE estimated a total 299,052 Sockeye Salmon with 232,032 fish in the Age 0+ size class (data request to S. Harris BCMOE).

Table 3.7 Summary of population estimates for the spring 2022 roving survey compared to BCMOE data collected from 1998–2020 (BCMOE Data from: Scholten and Sebastian 2000; Squires et al. 2008; Harris et al. 2010; Hebert et al. 2015; Hebert et al. 2016; Vainionpaa et al. 2020; data request to S. Harris BCMOE).

Size Class (SC)	Pop. Estimate	% in North Basin	% in South Basin	Upper 95% CI Limit	Lower 95% CI Limit	% SO in Gillnet Catch	SO Estimate	BCMOE Average \pm STDEV
SC 0: 30–80 mm	181,427	7.2	92.8	284,395	99,076	90	163,284	167,088 \pm 56,713
SC 1: 80–120 mm	32,605	3.3	96.7	58,680	11,881	90	29,345	55,861 \pm 18,394
SC 2: 121–250 mm	24,206	9.5	90.5	47,907	4,845	90	21,785	27,506 \pm 20,292
Total 0.6–5.0 m	23,933	NA	100.0	36,146	13,859	10	2,993	
Total 2022 Spring Estimate	261,171	5.9	94.1	–	–		216,807	250,456 \pm 68,304 (39% NB, 61% SB)

Table 3.8 shows the estimated number of entrained Sockeye Salmon for the 14-month study period as a percentage of the spring 2022 population estimate. An estimated 5.2% of the population was entrained based on this comparison.

Table 3.8 Proportion of Sockeye of all age classes in Alouette Reservoir that were entrained over the 14 months study period.

	Filtered by Depth, Direction	% SO Gillnet Catch	Total SO
Apr 09–May 20, 2021	696	0.0413	29
May 21–Jul 09, 2021	195,704	0.0392	7,672
Sep 17–Oct 16, 2021	22,255	0.0540	1,202
Oct 17–Nov 13, 2021	11,483	0.0540	620
Jan 31–Feb 17, 2022	97	0.7000	68
Feb 18–Apr 20, 2022	2,014	0.6700	1,349
Apr 20–May 31, 2022	1,876	0.2000	375
Total Sockeye Entrained			11,315
Population Estimate	261,171	0.8300	216,807
Percentage of Population Entrained			5.2%

Details for the population estimates for all depth strata are provided in the tables on the following pages for size class 0 (Table 3.9), 1 (Table 3.10), 2 (Table 3.11), and 0.6–5.0 m depth range (Table 3.12).

Table 3.9 Population estimates for fish size class 0 (0–80 mm), by basin and 5 m depth strata, starting at 5 m depth down to the lake bottom or maximum range, derived from down-looking acoustic data.

Fish Size Class 0 (30 - 80 mm)																		
South Basin										North Basin					Alouette Lake Total			
Depth Top (m)	Area (ha)	Bootstrap Analysis 1,000 iterations			Population Estimate (# fish)			Area (ha)	Bootstrap Analysis 1,000 iterations			Population Estimate (# fish)			Lower Population Estimate	Upper Bound		
		Density (#fish/ha)	Lower Bound	Upper Bound	Lower Bound	Upper Bound	Density (#fish/ha)		Lower Bound	Upper Bound	Lower Bound	Upper Bound						
		Mean	95% CI	95% CI	Estimate	95% CI	95% CI		Mean	95% CI	95% CI	Estimate	95% CI	95% CI				
5	1,087	3.845	0.759	8.074	4,180	825	8,776	428	0.000	0.000	0.000	0	0	0				
10	1,061	10.502	3.112	22.099	11,416	3,383	24,022	402	7.319	2.453	12.937	3,133	1,050	5,537				
15	1,030	7.820	4.006	11.869	8,500	4,355	12,902	378	0.997	0.000	1.995	427	0	854				
20	978	5.940	3.641	7.904	6,457	3,958	8,592	366	0.492	0.000	0.984	211	0	421				
25	926	12.870	9.931	16.078	13,990	10,795	17,477	354	4.143	0.835	6.735	1,773	357	2,883				
30	874	29.871	23.174	36.904	32,470	25,190	40,115	342	2.187	0.000	4.374	936	0	1,872				
35	825	20.382	15.239	27.812	22,155	16,565	30,232	328	5.897	2.280	8.916	2,524	976	3,816				
40	790	10.907	6.412	16.258	11,856	6,970	17,672	309	4.007	1.851	6.039	1,715	792	2,585				
45	755	15.753	8.180	24.748	17,124	8,892	26,901	290	2.002	0.599	3.362	857	256	1,439				
50	755	16.665	8.552	31.800	18,115	9,296	34,567	290	0.745	0.000	1.411	319	0	604				
55	755	17.294	4.807	31.362	18,799	5,225	34,090	290	0.865	0.000	1.730	370	0	740				
60	755	3.351	0.176	6.787	3,643	191	7,377											
65	755	0.424	0.000	0.848	461	0	922											
Total					169,163	95,644	263,644	Total					12,264	3,432	20,751	181,427	99,076	284,395

Table 3.10 Population estimates for fish size class 1 (80–120 mm), by basin and 5 m depth strata, starting at 5 m depth down to the lake bottom or maximum range, derived from down-looking acoustic data.

Fish Size Class 1 (80 - 120 mm)																		
South Basin									North Basin						Alouette Lake Total			
Depth Top (m)	Area (ha)	Density (#fish/ha)			Population Estimate (# fish)			Area (ha)	Density (#fish/ha)			Population Estimate (# fish)			Population Estimate	Lower Bound	Upper Bound	
		Mean	95% CI	95% CI	Estimate	95% CI	95% CI		Mean	95% CI	95% CI	Estimate	95% CI	95% CI				
5	1,087	1.075	0.000	2.150	1,169	0	2,337	428	0.000	0.000	0.000	0	0	0				
10	1,061	5.409	1.855	11.678	5,880	2,016	12,694	402	0.000	0.000	0.000	0	0	0				
15	1,030	3.112	0.364	7.520	3,383	396	8,174	378	0.000	0.000	0.000	0	0	0				
20	978	0.000	0.000	0.000	0	0	0	366	0.677	0.000	1.354	290	0	580				
25	926	1.787	1.101	2.204	1,942	1,197	2,396	354	0.000	0.000	0.000	0	0	0				
30	874	3.184	1.524	5.283	3,461	1,657	5,743	342	0.000	0.000	0.000	0	0	0				
35	825	3.969	2.705	5.530	4,314	2,940	6,011	328	0.000	0.000	0.000	0	0	0				
40	790	1.532	0.000	2.808	1,665	0	3,052	309	1.429	0.000	3.138	612	0	1,343				
45	755	2.553	1.061	3.874	2,775	1,153	4,211	290	0.000	0.000	0.000	0	0	0				
50	755	2.417	1.076	4.165	2,627	1,170	4,527	290	0.435	0.000	0.870	186	0	372				
55	755	2.506	1.244	3.759	2,724	1,352	4,086	290	0.000	0.000	0.000	0	0	0				
60	755	0.857	0.000	1.713	932	0	1,862											
65	755	0.594	0.000	1.188	646	0	1,291											
Total					31,518	11,881	56,385	Total					1,088	0	2,295	32,605	11,881	58,680

Table 3.11 Population estimates for fish size class 1 (121–250 mm), by basin and 5 m depth strata, starting at 5 m depth down to the lake bottom or maximum range, derived from down-looking acoustic data.

Fish Size Class 2 (121-250 mm)																		
South Basin									North Basin						Alouette Lake Total			
Depth Top (m)	Area (ha)	Density (#fish/ha)			Population Estimate (# fish)			Area (ha)	Density (#fish/ha)			Population Estimate (# fish)			Population Estimate	Lower Bound	Upper Bound	
		Mean	95% CI	95% CI	Estimate	95% CI	95% CI		Mean	95% CI	95% CI	Estimate	95% CI	95% CI				
5	1,087	0.921	0.000	1.842	1,001	0	2,002	428	0.000	0.000	0.000	0	0	0				
10	1,061	5.973	0.619	13.393	6,493	673	14,558	402	0.000	0.000	0.000	0	0	0				
15	1,030	2.771	0.000	7.223	3,012	0	7,851	378	1.032	0.000	2.063	442	0	883				
20	978	0.816	0.000	1.717	887	0	1,866	366	1.958	0.000	2.055	838	0	880				
25	926	0.355	0.000	1.065	386	0	1,158	354	0.000	0.000	0.000	0	0	0				
30	874	1.986	1.186	2.709	2,159	1,289	2,945	342	0.979	0.000	1.958	419	0	838				
35	825	1.770	0.694	2.857	1,924	754	3,106	328	0.402	0.000	0.805	172	0	345				
40	790	1.442	0.202	3.272	1,567	220	3,557	309	0.356	0.000	0.712	152	0	305				
45	755	2.476	1.438	3.471	2,691	1,563	3,773	290	0.442	0.000	0.883	189	0	378				
50	755	1.040	0.318	1.764	1,130	346	1,917	290	0.000	0.000	0.000	0	0	0				
55	755	0.407	0.000	0.869	442	0	945	290	0.217	0.000	0.435	93	0	186				
60	755	0.191	0.000	0.382	208	0	415											
65	755	0.000	0.000	0.000	0	0	0											
Total					21,901	4,845	44,093	Total					2,305	0	3,814	24,206	4,845	47,907

Table 3.12 Population estimate for fish near surface (0.6–5.0 m depth) derived from side-looking acoustic data.

Any Size Fish Near Surface															
South Basin								North Basin							
Bootstrap Analysis 1,000 iterations								Bootstrap Analysis 1,000 iterations							
Depth	Stratum	Area (ha)	Density (#fish/ha)			Population Estimate (# fish)			Area (ha)	Density (#fish/ha)			Population Estimate (# fish)		
			Mean	95% CI	95% CI	Estimate	95% CI	95% CI		Mean	95% CI	95% CI	Estimate	95% CI	95% CI
0.6 - 5 m		1,103	21.698	12.565	32.771	23,933	13,859	36,146	443	not available					

6 DISCUSSION

6.1 Net Catches, Fish Species Composition, and Hydroacoustic Target Length Distributions

Eight fish species, namely, Sockeye Salmon, Peamouth Chub, Northern Pikeminnow, Largescale Sucker, Three-Spined Stickleback, Cutthroat Trout, Bull Trout, and a Cutthroat/Rainbow Trout hybrid, were caught in the gillnets set for this study at depths from 10.0–13.6 m at the Tunnel entrance.

At the 10.0–13.6 m depth, the net was fully overlapping with the Tunnel entrance but at a horizontal distance of about 20 m. Within the net catch, the percentage of Sockeye Salmon was highly variable throughout the year ranging from 4% and 3% during the migration period and summer to 60% in the winter and 20% in the fall (55% with spawners). Sockeye Salmon catch percentage in the gillnets was one of the filters used to filter the acoustic detections when estimating Sockeye Salmon entrainment. All fish caught other than the Sockeye Salmon in full spawning colours and releasing eggs and milt were used in the filtering process. Spawning Sockeye Salmon were not considered to be entrained but spawning in the gravel boulder substrate close to the Tunnel entrance, with the ability to easily avoid Tunnel suction based on their size (average length of 24 cm).

Although the net mesh sizes were specifically chosen to catch Sockeye Salmon of all age classes, fish > 50 mm or Age 0 Sockeye in the spring and summer could not be captured with the smallest mesh size while the net suitability for catching fish between 51–100 mm was proven by readily catching Peamouth Chub and Three-Spined Stickleback in this size bin. Therefore, it appeared that Sockeye Salmon of between 51–100 mm in length (Age 1+) did not tend to occur near to the Tunnel entrance and the likelihood of Age 1+ Sockeye Salmon entrainment was considered low.

Comparing the net catch length frequency distribution to the hydroacoustic fish target length frequency distribution showed good agreement between the two approaches for the higher length classes, but a higher percentage of fish targets < 100 mm was acoustically detected (87%) than gillnet caught (61%). This can be explained based on the high percentage of 0–50 mm fish detected as hydroacoustic targets but not caught with the smallest mesh size used. In addition, juvenile Peamouth Chub (< 10 cm) were visually observed holding in small numbers at the pelagic net set location 25–45 m from shore and in large numbers in the hydroacoustic recording location 8 m from shore in the littoral zone. Ideally, gillnets with an even smaller mesh size would have been set right in front of the Tunnel entrance and the hydroacoustic recording zone, but safety concerns and likely net loss made this location impossible to fish with a net.

6.2 Is the Net Catch Species Composition Representing the Hydroacoustic Target Species Composition?

The 20 m distance between the Tunnel entrance and the net set location leads us to believe that the net catch species composition is a reasonable estimate of the target species composition with the following comments:

- It was not possible to set the net right at the Tunnel entrance and therefore there will be slight differences based on species rearing habitat preferences. For example, Peamouth Chub prefer the littoral zone of bigger lakes but also occupy the fringes of the littoral zone where the nets were set. Therefore, the already high frequency of Peamouth Chub in the net catch likely was a slight underestimate of their occurrence closer to shore and as targets. The opposite is true for Sockeye Salmon that prefer the pelagic zone but are also found on the fringes of the littoral zone and were therefore likely slightly overestimated in their occurrence closer to shore and as targets.

- Specifically with regards to Sockeye Salmon, fish are leaving the pelagic zone for the littoral zone close to shore for two reasons, spawning in the fall or outmigration in April and May. Spawners are > 200 mm in length and have a much lower likelihood of passive entrainment based on their higher burst and continuous swimming speeds and would likely not be passively entrained unless they are in the immediate vicinity (> 1 m distance) of the Tunnel entrance and we know that the area within 1 m of the Tunnel entrance does not offer spawning habitat. This point will be further investigated with video recordings. With regards to outmigrating smolts, Sockeye Salmon of < 100 mm were never caught in the gillnet sets while fish of the same size belonging to other species were frequently caught. Therefore, Sockeye Salmon of < 100 mm do not appear to be holding anywhere close to the Tunnel entrance. The roving survey offered additional evidence for low Sockeye abundances in the North versus the South Basin in early spring.
- Visual observations were also used to estimate species composition in front of the Tunnel entrance and it was confirmed that all fish at the surface (visual observations from shore) and down to the Tunnel entrance depth (visual observations when using the ROV for site assessments) were non-salmonids reflecting the net catch species composition.

To conclude, there is no evidence that net catch does not represent the species composition at the Tunnel entrance aside from the Sockeye Salmon spawning period and video footage will be used to further investigate and inform this assumption.

6.3 Fish Target Depth Distribution

Acoustic detections were filtered by depth to determine potential entrainment targets, and the majority of fish filtered targets was detected above the Tunnel entrance in winter (> 99%) and during the migration period (87.5%) and in the fall (86%). For the summer period the picture changed and the majority (59%) of the filtered fish targets were found in front of the Tunnel entrance. When the percentage of fish above the Tunnel entrance was highest in the winter and during the migration period, very few Sockeye Salmon were likely entrained while the highest Sockeye entrainment likely occurred in the fall when slightly higher percentages of fish were holding in front of the Tunnel entrance and Sockeye catches in the gillnets were also higher.

During the summer period based on the net catch, most of the detected fish were Peamouth Chub, ranging in length from 8–22 cm. Peamouth Chub tend to generally rear in the littoral zone close to shore while exhibiting movements between shallower water during daytime and deeper water during night time (Macleod 1960). Macleod (1960) also found that this diurnal migration was observed to commence with onset of summer, following Peamouth Chub spawning in shallow water. This gives support to the assumption that the majority of observed hydroacoustic targets were Peamouth Chub. The large increase in fish target numbers was observed with the onset of summer in late May–early June 2021, when Peamouth Chub are expected to be more active within the monitored area. Prior to this, few targets were detected above the Tunnel entrance depth in 2021 and 2022.

6.4 Fish Target Swimming Direction

As another filter of fish targets, a determination of swimming direction towards the Tunnel entrance was applied. Of the targets detected within proximity of the Tunnel entrance, approximately 31% indicated a swimming direction or heading towards the Tunnel entrance. This was defined as a heading that was within 45° of the central axis pointing towards the Tunnel entrance (i.e., a combined range of 90°). This range represents one quarter or 25% of the possible 360° of the swimming headings around the transducer cone. If the swimming patterns were evenly distributed around the transducer cone, we would expect, by equal probability that 25% of all targets would be classified as heading in the direction

of the Tunnel entrance. The observed frequency of 31% was slightly higher than equal probability distribution indicating that entrainment is occurring at a low level. Nevertheless, of the 31% of fish that were swimming towards the Tunnel entrance, very few were likely Sockeye Salmon, based on all other filters including net catch composition and fish size based on the ability to swim out of the Tunnel current.

6.5 Filters Applied

The filters that were applied were potentially affected by sensitivities as follows:

- For the expansion factor to reflect the ratio between the cone coverage area and the Tunnel entrance area it was assumed that fish were entering the Tunnel entrance at an evenly distributed pattern and there was no reason to believe that this assumption was wrong. When the system was initially started, two transducers were operated side by side covering a larger area of the Tunnel entrance and target counts between the two transducers did not appear to differ.
- For the detection depth, it was assumed that fish to a distance of approximately 1 m above the upper edge of the Tunnel entrance were in the zone that was affected by current velocities similar to the velocities right in front of the Tunnel. This assumption is likely conservative since current speeds are more likely to be reduced at that distance.
- Swimming direction towards the Tunnel is likely an accurate measure with few confounding factors.
- The Sockeye Salmon percentage in the gillnet catch was affected by the approximate 20 m distance between the Tunnel entrance and the netting location and was discussed at length in a previous chapter (Chapter 6.2).
- Fish size as a measure for likelihood of entrainment based on the ability to swim out of the Tunnel suction was applied as the last filter and based on maximum and sustained swim speed of salmonids by size. This is likely a good proxy for risk of passive entrainment but obviously would not apply to volitional entrainment.

6.6 Sockeye Salmon Entrainment by Season and Time of Day

The Sockeye Salmon entrainment estimates throughout all seasons of the study period are summarized in Table 3.2 for all fish size bins and were generally low.

In winter, the expanded count for fish targets in the small bin sizes from 0–100 mm were relatively high but none of the Sockeye Salmon in the gillnets were in the same size target, while expanded count in the size bin from 101–181 mm was lower but some of the Sockeye caught were in the same length target resulting in a total estimate of 22 (\pm SE of 5 fish) entrained Sockeye in the Age 2+ length bin. A similar pattern of a mismatch between the expanded counts of targets in certain length bins and the size caught in the gillnet sets was found for all other seasons. For example, in summer and fall when the highest expanded target counts were detected in one bin size, Sockeye were caught in another bin size leading to low entrainment estimates.

This mismatch is likely based on the high number of non-Sockeye species in small bin sizes that are feeding in the Tunnel entrance while Sockeye appear to only be in the Tunnel vicinity at larger bin sizes.

The assumption that the high number of summer targets was based on Peamouth Chub was discussed in previous chapters.

Aside from these seasonal changes, the total number of 2,419 (\pm SE of 971 fish) potentially entrained and 816 (\pm SE of 367 fish) likely entrained Sockeye Salmon represents 1.15% and 0.38% of the total

Sockeye population. This finding suggests that Sockeye at any age do not get volitionally or passively entrained in high numbers through the Tunnel. This finding is also in line with the findings of the March 9, 2022, roving survey just before the annual Sockeye Age 1+ outmigration period demonstrating that very few Sockeye Salmon of all age classes but specifically Age 1+ can be detected in the North Basin of Alouette Reservoir close to the Tunnel.

In general, fish targets were detected in relatively even numbers during daytime and night in winter and during the migration period but in much higher numbers during daytime in summer and fall.

The general daytime preference for fish to hold in the Tunnel entrance area is again suggesting Peamouth Chub as the main species detected. Peamouth Chub typically rear in the pelagic zone and in depth similar to the Tunnel entrance depth, to feed on plankton during daytime and would therefore be detected as targets and migrate closer to shore and into shallower water where they could not be detected as targets anymore. Contrary, Sockeye Salmon targets would likely be mainly detected at night in the Tunnel entrance depth and migrate deeper during daytime where they could not be detected as targets anymore. In lake habitat, Sockeye Salmon typically migrate vertically to deeper depth below the thermocline during daytime and from there to shallower depth around and slightly above the thermocline at night (Levy 1989). If Sockeye Salmon were the main target species, more targets should be detected at night.

6.7 Tunnel Current Velocity and Entrainment

High fish target numbers were recorded in front of the Tunnel at very low discharges and very high discharges, and high discharges did not lead to higher target numbers or entrainment.

Based on the hydroacoustic results and the visual observations it appeared as if fish are attracted to the Tunnel entrance during discharge and leave the Tunnel entrance when discharge is stopped. At lower Tunnel discharges fish appear to be feeding in the discharge vortex since food items such as zooplankton are likely being drawn into the area by currents going towards the Tunnel entrance. This was further supported by visual observation of juvenile Peamouth Chub that were holding close to the surface and at the edge of the Tunnel entrance vortex while actively feeding.

6.8 Reservoir Elevation and Entrainment

Fluctuations in reservoir elevations did not appear to be connected to higher or lower entrained fish targets. Low entrainment was observed during high and low reservoir elevations and the same was true for periods with high entrainment. No connection can therefore be made between reservoir elevations and potential entrainment through the Tunnel at the range of elevations observed during the study period.

6.9 Sockeye Salmon Tunnel Entrainment as a Proportion of Sockeye Smolt Outmigrating over the Spillway and with Regards to the whole Sockeye Population

Tunnel entrainment of Sockeye Salmon was predicted to be 0 fish or 0% of the estimated 17,740 combined Sockeye smolts that migrated over the spillway into the Alouette River during 2021 and 2022. Sockeye Salmon entrainment through the Tunnel therefore appears to have had a negligible effect on Sockeye smolt outmigration into Alouette River during both years.

6.10 Tunnel Discharge and Sockeye Smolt Outmigration over the Alouette Dam Spillway

Tunnel discharge on the north end of the reservoir also appears to have a negligible effect on the outmigration of Sockeye smolts at the south end of the reservoir over the Alouette Dam spillway and into the Alouette River. Increases in Sockeye smolt outmigration numbers in the Alouette River were regularly

observed parallel to increases in discharges at the Tunnel. This association is in the opposite direction expected if Tunnel entrainment was impacting outmigration of Sockeye smolts at the Alouette spillway.

6.11 Alouette Dam Spillway Discharge and Tunnel Entrainment of Sockeye Salmon

Increases in Alouette Dam spillway discharge could divert Sockeye Salmon from migrating out through the Tunnel if Sockeye Salmon smolt entrainment or outmigration through the Tunnel was happening in large numbers and smolts would choose between the two options based on discharge.

However, entrainment or active migration through the Tunnel by Sockeye Salmon appears to be rare and therefore any changes to this small number, as a result of spillway discharge, would be hard to detect and likely not significant even if detectable. In addition, there was only one significant increase in spillway discharge during the smolt outmigration period from April 15–19, 2021, and that did not coincide with a decrease in Tunnel entrainment which was very low during this period. In conclusion, there is no evidence for an effect of spillway discharge on Tunnel entrainment in general and specifically of Sockeye Salmon.

6.12 Reservoir Survey Results and Total Entrainment as a Proportion of the Spring 2022 Sockeye Population

The average length of the Age 1+ Sockeye Salmon smolts in the RST catch in April and May is 78 mm and it was therefore assumed that the 30–80 mm length class detected at the beginning of March represented the Age 1+ fish well. The average density of Age 1+ (30–80 mm) Sockeye targets was more than five times higher in the South Basin (152 fish/ha) than the North Basin (29 fish/ha) and the highest densities of 232 fish/ha was found at the north end of the South Basin. For all other size classes, results were similar with much higher densities in the South Basin when compared to the North Basin.

Based on these results, there is no evidence that Sockeye smolts (Age 1+) purposefully migrate towards the Tunnel in March in preparation for outmigration. Contrary, when the spring survey results were compared to the summer and fall survey results provided by BCMOE, it appeared as if in early spring there are relatively fewer Age 1+ Sockeye in the North basin than in the South Basin than in summer and fall. In addition, and in support the 2022 spring survey methods, the population size of all Sockeye Salmon in the Alouette Reservoir in the spring of 2022 ($N = 216,807$) was comparable to and within the STDEV of the average summer and fall BCMOE observed from 1998–2018 ($262,171 \pm 68,304$).

When compared to the summer 2021, BCMOE estimate of a total 299,052 Sockeye Salmon with 232,032 fish in the Age 0+ size class (data request to S. Harris BCMOE), the spring 2022 total and Age 1+ 2022 estimates of 216,807 Sockeye with 181,427 fish in the Age 1+ size class were lower but in line with expected loss over the fall and winter periods.

The proportional distribution of the population between the South and the North Basins, similar to the average densities, showed 94.1% of the population to be in the South Basin in the spring of 2022 while an average of only 61% was found in the South Basin as part of the BCMOE 1998–2018 surveys.

For unknown reasons, Sockeye Salmon therefore appear to leave the North Basin during late fall and winter. One possible reason for this migration is more food in the South Basin in the winter during a time when food is scarce.

The estimated number of Sockeye Salmon that was entrained during the 14-month study period was 11,315 fish, representing approximately 5.2% of the total estimated March 9, 2022, Sockeye population

of 216,807 fish. This is likely a conservative estimate based on the fact that not all fish that were analyzed using filters were likely to be entrained. The 5.2% represent a small but sizeable proportion of the Sockeye population that is likely being passively entrained rather than volitionally leaving the reservoir, since very few entrained Sockeye targets were identified for the smolt outmigration period.

6.13 Modelled versus Measured Tunnel Entrance Current Speeds and Implications for Entrainment

The current speeds measured in the field by use of an ADCP were within the range of current speeds estimated through a simple mathematical formula as shown in Figure 3.9.

Most salmonids appear to have similar burst speed (short term, maximum swimming speed that can be sustained for seconds) of 0.5–0.7 m/s for juveniles at fork lengths of 50–100 mm, while the sustained maximum swimming speed (medium term, maximum swimming speed that can be sustained for minutes) is slightly lower at 0.3–0.5 m/s (Taylor and Foote 1991; Hawkins and Quinn 1996; Peake et al. 1997; Wolter and Arlinghaus 2003).

Figure 3.9 shows that all 50–100 mm fish would be entrained (percentage of blue line above the burst speed and sustained speed stippled lines) at the Tunnel entrance at discharges $> 16 \text{ m}^3/\text{s}$, while no fish would be entrained at the same discharge at 1 m (yellow line) from the Tunnel entrance. Even at the highest Tunnel discharges of $50 \text{ m}^3/\text{s}$ hardly a fish would be entrained at a 6 m distance from the Tunnel entrance (grey line).

Based on this, the area of passive entrainment for juvenile salmonids including Sockeye Salmon can be defined as a 3-dimensional space of approximately 6 m around the Tunnel entrance. Due to their higher burst and sustained swimming speeds, the area or volume of passive entrainment would be smaller for larger and adult salmonids including Sockeye Salmon.

At the most common discharges from $5\text{--}7 \text{ m}^3/\text{s}$ (Figure 3.19) and related current velocities of $< 0.3 \text{ m/s}$ at the Tunnel entrance, passive entrainment for salmonids of any size is not expected to occur based on the burst or sustained swimming speeds of $> 0.3 \text{ m/s}$.

6.14 Framework for a Decision-Making Pathway based on Level of Impact to Outmigration over the Spillway and into Alouette River

An initial decision framework was built to identify next steps based on the outcome of this study and specifically the potential findings of whether Sockeye Salmon entrainment is impacting outmigration over the spillway and to what extent. This decision framework is summarized in Table 3.13.

Based on the results of this study, Sockeye Salmon entrainment at the entrance of the Tunnel to Stave Reservoir was estimated to affect a maximum of 1.5% of the number of Sockeye smolts that are outmigrating over the Alouette Dam spillway into the Alouette River. Moreover, a total of 5.2% of the total Alouette Reservoir Sockeye population appeared to be entrained throughout the whole study period. Mitigative actions can be discussed based on these results.

Table 3.13 Decision-making framework leading to next steps based on level of impact to outmigration over the spillway and into Alouette River.

Degree of Impact to Outmigrating Sockeye Salmon to Alouette River	Recommended Management Action	Next Steps
None to limited impact to outmigration	No action	“Limited impact” threshold to be discussed
Limited to moderate impact to outmigration	Limited to moderate action (e.g., limited hatchery or operational changes)	“Moderate impact” threshold to be discussed
Moderate to high impact to outmigration	Moderate to extensive action (e.g., moderate or extensive suggestions for a hatchery program and operational changes)	“High impact” threshold to be discussed
Inconclusive results: large confidence intervals with reasonable likelihood of high entrainment	Additional study to reduce uncertainty and inform mitigation strategy	“Reasonable likelihood” threshold to be discussed
Inconclusive results: uncertain operational linkage	Conduct experiment(s) to test other mitigation options to inform mitigation strategy	N/A

6.15 Conclusion and Recommendations

Based on the findings of this study, we conclude that the use of hydroacoustics and gillnet sampling, combined with reported velocities at the Tunnel entrance, can provide defensible estimates of total fish and Sockeye Salmon entrainment which, based on the results of Year 1 of this study appeared to be low. Additional data collected in Year 2 of the study will further inform these conclusions and fill the 2021 winter entrainment knowledge gap from middle of November to end of January. To observe the behaviour of fish right in front of the Tunnel entrance trash rack, we recommend daytime video recordings for shorter periods coinciding with high numbers of entrained fish targets.

REFERENCES

- Andrusak, G.F., and R.L. Irvine. 2013. Alouette Kokanee Age Structure Analysis (ALUMON #6) – 2012. Year 5 of Alouette Project Water Use Plan Monitoring Plan #6. A Redfish Consulting Ltd. and Poisson Consulting Ltd. contract report. Prepared for and funded by BC Hydro under the Alouette Project Water Use Plan in partnership with the BC Ministry of Environment.
- BC Fisheries Information Services Branch. 2001. Reconnaissance (1:20000) Fish and Fish Habitat Inventory: Standards and Procedures. 170 pp. Available: <https://www2.gov.bc.ca/assets/gov/environment/natural-resource-stewardship/nr-laws-policy/risc/recce2c.pdf>.
- BCRP (Bridge Coastal Restoration Program). 2000. Strategic Plan, Volume 2, Watershed Plans, Chapter 6: Alouette River Watershed.
- Driver, J.C., and T.C. Spurgeon. 1998. The Alouette River and the Katzie First Nation. Prepared for BC Power and Hydro Authority (Environmental Services) and Katzie First Nation.
- FWCP (Fish and Wildlife Compensation Program). 2011. Alouette River Watershed Plan: Final Draft.
- Gaboury, M.N. and R.C. Bocking. 2004. Feasibility of reintroducing Sockeye and other species of Pacific salmon in the Alouette Reservoir, B.C. Prepared for Alouette River Management Society, Maple Ridge, B.C., by LGL Limited, Sidney, B.C.
- Hamley, J.M. 1972. Sampling with gillnets. *In*: Guidelines for sampling fish in inland waters. Edited by T. Backiel and R.L. Welcomme. EIFAC 1980 Technical Paper (33):176 p.
- Harris, S.L., H. Andrusak, G. Andrusak, D. Sebastian, G. Scholten, T. Weir, L. Vidmanic, E.J. Johnson, and N. Down. 2010. The Alouette Reservoir Nutrient Restoration Program, 2003–2008. Province of British Columbia, Ministry of Environment, Aquatic Ecosystem Protection Branch, Fisheries Project Report No. RD129.
- Hawkins, D.K., and T.P. Quinn. 1996. Critical swimming velocity and associated morphology of juvenile coastal cutthroat trout (*Oncorhynchus clarki clarki*), steelhead trout (*Oncorhynchus mykiss*), and their hybrids. Canadian Journal Fisheries Aquatic Sciences 53: 1487–1496. Available: <http://docs.streamnetlibrary.org/CoastalCutthroatData/sn600039.pdf>.
- Hebert, A.S., G.F. Andrusak, S.L. Harris, T. Weir, and L. Vidmanic. 2015. Alouette Reservoir Nutrient Restoration Project 5-year review, 2009–2013. Province of British Columbia, Ministry of Environment, Ecosystem Protection & Sustainability Branch, Fisheries Project Report No. RD150.
- Hebert, A.S., G.F. Andrusak, S.L. Harris, H. Andrusak, and G. Weir. 2016. Alouette Reservoir Nutrient Restoration Project, 2014–2015. Province of British Columbia, Ministry of Environment, Aquatic Ecosystem Protection & Sustainability Branch, Fisheries Project Report No. RD 154:59 pp.
- Levy, D.A. 1989. The selective advantage of diel vertical migration behavior in juvenile Sockeye Salmon and Kokanee (*Oncorhynchus nerka*). Ph.D. Thesis, University of British Columbia.
- Love, R.H. 1971. Dorsal-aspect target strength of an individual fish. The Journal of the Acoustical Society of America 49(3):816–823.
- MacLennan, D.N., and E.J. Simmonds. 1992. Fisheries Acoustics. Chapman and Hall, London, U.K. 325 pp.
- Macleod, J.C. 1960. The diurnal migration of Peamouth Chub (*Mylocheilus caurinus*) (Richardson) in Nicola Lake, British Columbia. M.Sc. Thesis, University of British Columbia. Available: <https://open.library.ubc.ca/media/download/pdf/831/1.0106390/1>.

- Mathews, M.A. 2021. Evaluation of the migration success of Sockeye Salmon smolts (*O. nerka*) from the Alouette Reservoir, 2021. Report prepared for the FWCP – Coastal, Burnaby, B.C., by LGL Limited, Sidney, B.C. FWCP Reference No. COA-F22-F-3583-DCA.
- Mathews, M.A. 2022. Evaluation of the migration success of Sockeye Salmon smolts (*Oncorhynchus nerka*) from the Alouette Reservoir, 2022. Report prepared for the FWCP – Coastal, Burnaby, B.C., by LGL Limited, Sidney, B.C.
- Peake, S.J., R.S. McKinley, and D.A. Scruton. 1997. Swimming performance of various freshwater Newfoundland salmonids relative to habitat selection and fishway design. *Journal of Fish Biology* 51(4):710–723. Available: https://www.researchgate.net/publication/230042509_Swimming_performance_of_various_freshwater_Newfoundland_salmonids_relative_to_habitat_selection_and_fishway_design.
- Plate, E.M. 2007. An investigation of the fish populations, zooplankton communities and fish diet in Red Bluff and Batchellor lakes in 2007. Prepared for the Gitga'at Development Corporation and Pacific Salmon Commission.
- Scholten, G., and D. Sebastian. 2000. Results of the 1999 hydroacoustic surveys in Alouette Reservoir. Province of British Columbia, Ministry of Fisheries, Stock Management Report No. 10:18 pp.
- Squires, M., E.-J. Johnson, D. Sebastian, G. Scholten, L. Vidmanic, J.E. Stockner, G. Andrusak, H. Andrusak, and E. Parkinson. 2008. Alouette Reservoir: Results of limnological Monitoring 2007 and assessment of fertilization effects on Kokanee 1998–2007. Province of British Columbia, Ministry of Environment, Biodiversity Branch Fisheries Technical Report 107:100 pp.
- Taylor, E.B., and C.J. Foote. 1991. Critical swimming velocities of juvenile sockeye salmon and kokanee, the anadromous and non-anadromous forms of *Oncorhynchus nerka* (Walbaum). *Journal of Fish Biology* 38(3):407–419. Available: https://www.researchgate.net/publication/230017456_Critical_swimming_velocities_of_juvenile_sockeye_salmon_and_kokanee_the_anadromous_and_non-anadromous_forms_of_Oncorhynchus_nerka_Walbaum.
- Vainionpaa, H.E., J.A. Sarchuk, H. Andrusak, and S.L. Harris. 2020. Alouette Reservoir Nutrient Restoration Project 5-Year Review, 2014–2018. Province of British Columbia, Ministry of Environment and Climate Change Strategy, Ecosystem Branch, Fisheries Project Report No. RD 168:116 pp.
- Webb, P.W. 1995. Locomotion. Pages 69–100 *in*: C. Groot, L. Margolis, and W.C. Clarke (editors). *Physiological ecology of Pacific Salmon*. UBC Press, Vancouver.
- Wolter, C., and R. Arlinghaus. 2003. Navigation impacts on freshwater fish assemblages: the ecological relevance of swimming performance. *Reviews in Fish Biology and Fisheries* 13:63–89. Available: https://www.ifishman.de/fileadmin/user_upload/Publikationen/HU_Berlin_Seite/Publikationen/2003/Wolter-Arlinghaus_review_2003.pdf.

Activity 4
Technical Review Memorandum –
Alouette Watershed Salmon Restoration Project

“Operational Summary of, and Recommendations, Regarding: Sockeye Smolt Outmigration Enumeration; Alouette-Stave Tunnel Assessment of Sockeye/Kokanee Entrainment; and Preliminary Investigation of Factors Potentially Influencing Sockeye Smolt Migration. Technical Review Memorandum”

M. Mathews, E. Plate, and W. Challenger
LGL Limited
environmental research associates
9768 Second Street, Sidney, BC V8L 3Y8

This page left intentionally blank

Technical Review Memorandum



CELEBRATING
50
YEARS

Prepared for:	Alouette River Salmon Restoration Program Committee (ARSRP) c/o Ken Stewart Chair of ARSRP Committee	Date:	19 November 2021
Prepared by:	LGL Limited Megan Mathews, MSc, RPBio Elmar Plate, PhD Wendell Challenger, PhD	Reviewed by:	Bob Bocking, MRM, RPBio
Memorandum Subject:	Operational Summary of, and Recommendations, regarding: <ul style="list-style-type: none">• Sockeye smolt outmigration enumeration• Alouette-Stave Tunnel Assessment of Sockeye/Kokanee Entrainment• Preliminary investigation of factors potentially influencing Sockeye smolt migration	Project Name:	Alouette Watershed Salmon Restoration Project

BACKGROUND

The Alouette River Salmon Restoration Project (ARSRP) is a collaboration between First Nations, Alouette River Management Society (ARMS), BC Hydro, Fisheries and Oceans Canada, Ministry of Environment and Climate Change Strategy, and local stakeholders, with the goal to meet First Nation and local community interests to restore and enhance salmonid species historically native to the Alouette Watershed, especially upstream of the Alouette Reservoir Dam. The ARSRP is currently addressing Step 3 and 4 of the BC Hydro Fish Passage Decision Framework, environmental feasibility studies (BC Hydro 2018). The 2021 “Sockeye Smolt Outmigration Enumeration” (from hereon the “Smolt Outmigration” project) and the “Alouette-Stave Tunnel Assessment of Sockeye Entrainment” (from hereon the “Tunnel” project) projects are studies being conducted in Year 5 of an updated 11-year plan (ARMS 2021).

OPERATIONAL SUMMARY AND RECOMMENDATIONS

LGL Limited has provided an operational summary of the 2021 projects and recommendations below for future years of studies of both the Smolt Outmigration and the Tunnel assessment. In addition, a preliminary investigation of factors influencing Sockeye smolt outmigration timing was conducted in 2021 and recommendations pertaining to further analysis are included. Detailed technical reports of the Smolt Outmigration and Tunnel Assessment projects will be provided in the coming months.

Sockeye Smolt Outmigration Enumeration

The annual Alouette Sockeye smolt enumeration project occurred at the Mud Creek site from 14 April to 2 June 2021 (see Mathews and Smith 2020 for description of methods). The 5 ft diameter rotary screw trap (RST) was again used for fish capture to conduct a mark-recapture experiment of the Sockeye smolts (*O. nerka*) leaving the Alouette Reservoir via the spillway to determine a population estimate of outmigrants (Figure 4.1, Figure 4.2), and to collect size, age, and genetic information from the outmigrants (Figure 4.3). In past years flows from the Alouette Reservoir over the spillway to the South Alouette River have typically ranged from 3.0–4.5 m³/s. However, in 2021 BC Hydro operated higher spillway flows of 8.5–10.1 m³/s to assess if increased flows from the reservoir would encourage a greater number of smolts to migrate.

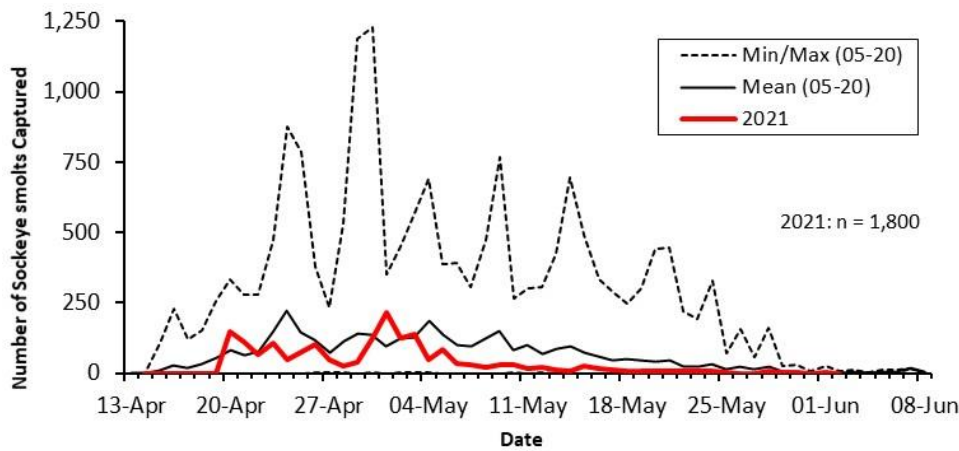


Figure 4.1 Daily catch of Sockeye smolts at the Mud Creek rotary screw trap in 2021 in comparison to the maximum, mean, and minimum catches of the previous fourteen study years.

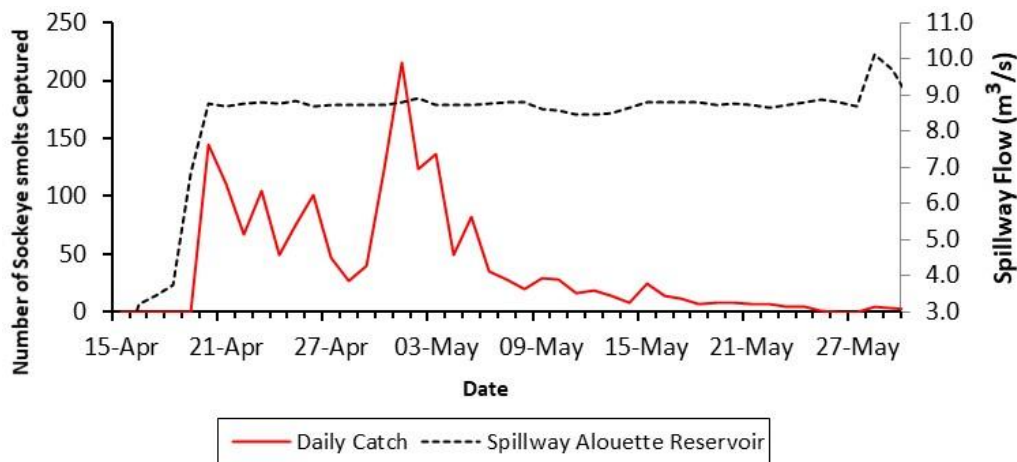


Figure 4.2 Comparison of daily catch of Sockeye smolts captured at the Mud Creek rotary screw trap and spillway flows from the Alouette Reservoir, 2021.

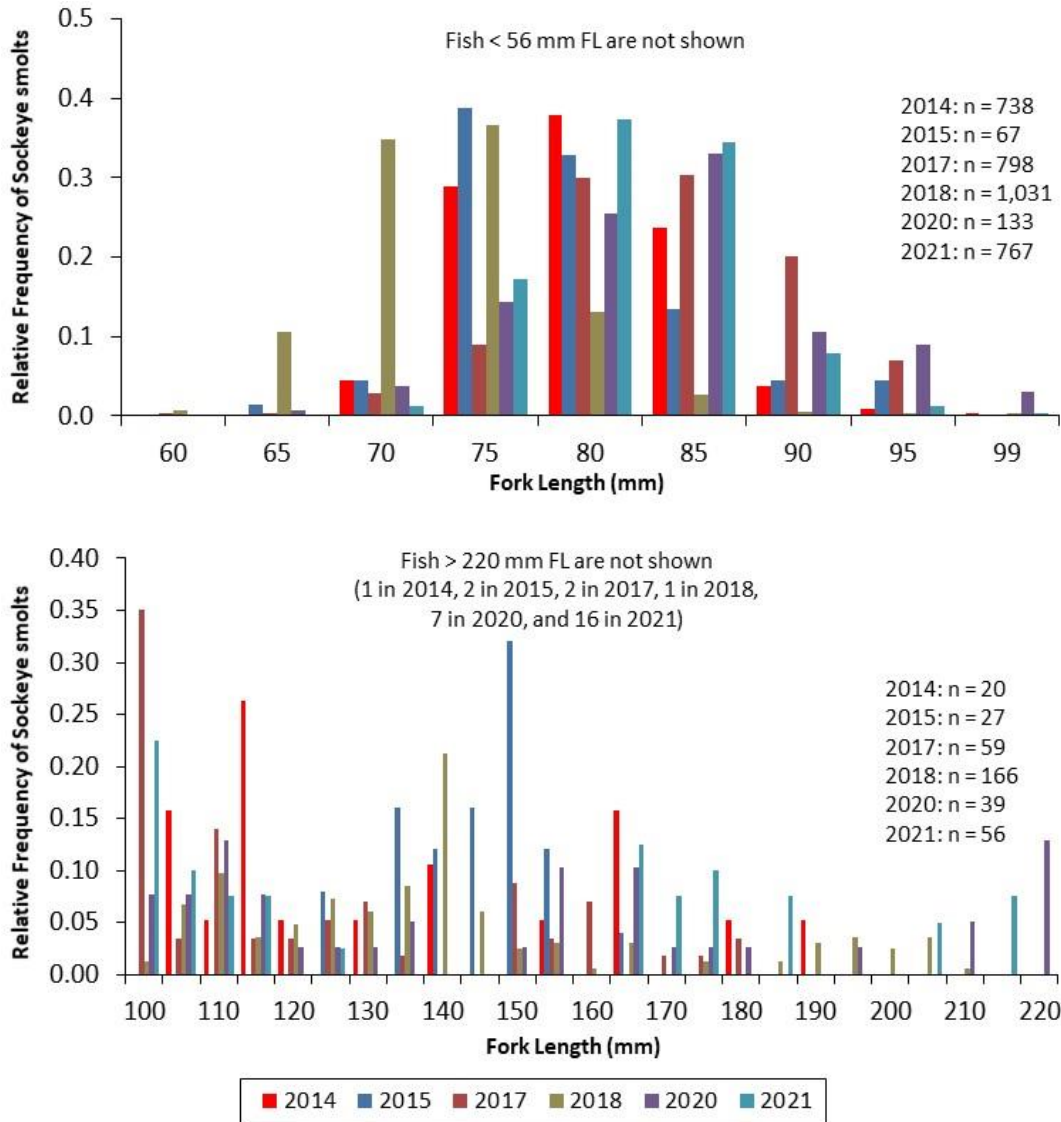


Figure 4.3 Length frequency distribution of Sockeye smolts measuring less than 100 mm FL (top panel), and 100 mm FL or greater (bottom panel), captured in the Mud Creek rotary screw trap operated in the South Alouette River (random samples), 2014–2021.

The increased spillway flows of 8.5–10.1 m³/s presented many challenges and had some detrimental effects to trap operations. In addition to increased safety risks for the crew to operate the rotary screw trap, the mortality rate of Sockeye smolts and other fish species increased (including other salmonids) and many Sockeye smolts were significantly descaled. Four juvenile bird mortalities occurred (we assume they were unable to avoid the RST while floating in the heavy flow) and the RST experienced increased wear and tear that required many field repairs. The high flows also led to heavy debris loads throughout the season which were difficult to predict. The 2021 flow range of 8.5–10.1 m³/s was at the maximum range of safe operation for the crew, fish, and RST.

In addition to causing mortalities (one debris event caused a significant fish kill in the beginning of the season), debris issues affected the collection of catch data in the following ways:

- Some mortalities were damaged to the point that determining daily catches was not feasible;
- Debris buildup within the fish holding tank forced the water level within the tank to rise, which in turn allowed for fish to escape above the screen at the back of the tank, hence some catch was lost, and daily totals were affected;
- In these instances when the RST was not fully functional, an estimate was made of what the unmarked catch might have been had the trap functioned. The analysis ignored the number of marks released the day previous, and the marks detected on the day of, given that the compromised fishing did not provide a real opportunity to recapture the marks released the day before; and
- Therefore, the debris issue did have a direct affect on catch data and the accuracy of the population estimate.

Below is a list of recommendations regarding project operations during high flows based on the operational experiences from 2021:

- Given the many difficulties experienced at flows from 8.5–10.1 m³/s, we do not recommend exceeding this flow range in future years with the current RST setup at Mud Creek. Contrary, if continuing with the current RST setup we recommend decreasing flows to 8.5 m³/s or less to prevent fish damage and mortalities.
- If high flows continue in future years, we recommend flushing (ideally using pulses) the reservoir of debris prior to trapping to avoid heavy debris causing fish kills (as occurred in the beginning of the 2021 trapping season). Flush flows could occur several weeks earlier than the typical start timing of the smolt outmigration to avoid missing fish prior to trapping. Trapping could be conducted on all days when flushing flows are not occurring to determine if the early flush flows result in an early outmigration.
- If an equivalent 2021 high flow range is continued by BC Hydro in future years, we recommend monitoring the level of descaling of Sockeye smolts and tracking mortality rates to quantify the effects.
- If high flows continue in future years, we recommend making structural modifications to the holding tank to mitigate for damage to fish, such as adding a removable baffle to provide fish a reprieve from heavy flows; and for other wildlife, adding an accessible platform above the water surface in the live tank to provide trapped animals with a way to exit the water.
- If high flows continue in future years, we recommend the installation of an instream log deflector to divert birds (and other species) and large debris away from the RST to prevent bycatch mortalities and reduce debris load in the RST. The log deflector system could be anchored to the River Left bank and would be placed far enough upstream from the RST to avoid displacing smolts close to the water surface.
- If high flows continue in future years, to mitigate for crew safety during operations we recommend the installation of handrails on the RST to help prevent crew from accidentally falling into the RST drum, as well as an additional safety line from shore to aid in egress should someone fall into the water downstream of the RST (a rope anchored to shore and lightly tethered to the back of the RST to act as a pendulum back into shore).

Alouette-Stave Tunnel Assessment of Sockeye Entrainment

The Alouette-Stave Tunnel Assessment of Sockeye Entrainment, or Tunnel project, was a new project for 2021. Based on field site visits and ROV deployment to investigate the site conditions in detail, we planned, designed and built an aluminum deployment frame that allowed for transducer placement just below the water surface, thus maximizing distance (11–16 m) to the tunnel entrance and related optimal sonar cone coverage. The aluminum deployment frame equipment was installed from 5–9 April 2021.

The sonar system (Biosonics DTx) recording number, length and swimming direction of fish located in the entrance to the Alouette-Stave Tunnel as well as the battery bank that the system uses as power source were installed in a metal work site tote (fastened to the Headworks Tower concrete wall). The charging generator and fuel assembly were installed in a separate work site tote next to it to avoid overheating of the hydroacoustic system based on generator operation.

Equipment deployment was challenging due to safety restrictions forbidding boat operations within the boomed area around the Tunnel entrance, combined with little space between the water's edge and the Tunnel Headworks Tower. We used an unmanned Zodiac style boat to float the weight of the 10 m x 3.5 m aluminum structure and the attached transducers, once assembled, into place and attach the other end of the structure to the pivoting assembly that fastened to bedrock using expanding rock anchors. The aluminum frame angle and connected transducer depth can be manipulated by a boat trailer winch attached to the Headworks Tower.

After initially planning for a generator fueled system, we added a battery bank, charged by the generator, to operate the DTx system on 12V DC power to reduce sonar signal noise. The generator connected to a fuel-extension tank can run for two consecutive days and charged the initial battery bank (72 hour run-time for 4 batteries) for a maximum system run time of five days. To extend the unmonitored run time even longer, we added two solar panels with a combined maximum charging voltage of 480V and doubled the battery bank size from the original 4 to 8 batteries. This combination of generator and solar charging of a much larger battery bank allows for unmaintained operations of approximately eight days or the planned period of time between maintenance visits.

Data recording started on 9 April, approximately 10 days before the first Sockeye catch in the Smolt Outmigration RST project was recorded. Initially two transducers were aiming in front of the tunnel entrance and from Day 1 on, fish targets and target strength (which can be translated into fish length) were reliably recorded. Nevertheless, due to high background noise levels in a rock and metal dominated environment, movement direction (most importantly towards or away from the trashrack) could not be reliably detected. This problem was addressed by recording with only one transducer and thus avoiding transducer pulse signal interference. Target signals were now clean enough to record fish target strength and movement direction and we were able to determine the percentage of fish that are moving towards the trashrack to be entrained out of the total number of targets detected. Based on this result, the deployment of a DIDSON/ARIS unit may only be necessary for a more detailed investigation of fish behaviour in front of the trashrack and in flow, rather than using DIDSON/ARIS for percentage entrainment calculations.

Detailed data analysis for this initial recording period showed that the number of fish targets was low for all of April and to the middle of May, the typical Sockeye smolt outmigration period (the period in 2021 when > 90% of smolts were captured at Mud Creek), while the number of Sockeye smolts leaving the reservoir through the Alouette River was within the range of previous years' catches (based on RST catch) for the same period. When the RST Sockeye catch at the Mud Creek site dropped in the middle of May, we observed a large increase of fish targets in the hydroacoustic array coinciding with a large increase of catch (non-Sockeye) in the nets set close to the tunnel entrance as a means to estimate species composition of the recorded targets. The two main minnow species caught in the nets were Peamouth Chub and Pikeminnow suggesting that the increase in hydroacoustically recorded fish targets was based on these two species. In addition to the high net catches of those two species, large numbers of juvenile Peamouth Chub, Pikeminnow and Redside Shiners were also observed visually from shore close to the tunnel entrance starting in mid-May along with increasing water temperatures.

From end of May until 14 July, data were downloaded and the generator was re-fuelled every four days while nets were set once every two weeks in June and July. On 9 July 2021, the Alouette Tunnel was closed to maintain the Water Use Plan ordered recreational reservoir elevation. To compare fish presence, abundance and movement direction in front of the tunnel when closed, hydroacoustic recording was maintained until 14 July when data collection was stopped.

The KDLP crew (consisting of Laurie Sylvester and Burgess Pierre) encountered generator problems that are now resolved. Initially generator 1 was replaced with generator 2 (both 1000W) but when generator 2 also failed a brand new 2200W generator 3 was purchased to replace generator 2. Generator 3 also showed unreliability but after excluding all other options, overheating appeared to be the most reasonable explanation for generator failure and air circulation holes were added to the generator job site tote. Since then, generator 3 ran reliably. Since generator 3 also produces twice the wattage of the previously used generators, it can be run on the energy savings mode which lowers running temperature while still providing sufficient power to charge the battery bank that powers the hydroacoustic sounder unit and the laptop computer. Approximately 10 hours are needed to charge the battery bank to provide power to the system for 120 hours. Therefore, shorter charging times do not lead to direct power failure but just shorten the time that the battery bank can provide power for. We lost short periods of recording due to continued generator problems but did not produce larger data gaps.

In addition to technical generator problems, the AC to DV converter fueling the battery charging unit and the PC that the hydroacoustic DTX unit is controlled by failed, causing short periods without hydroacoustic recording. The converter was not salvageable and was replaced by a new and higher-quality unit that is still in use.

Tunnel operations and hydroacoustic recording were re-started after September 7, 2021.

Based on our operational experience and data analysis to date we provide the following observations, issues and recommendations:

- When the Tunnel is running, the deployment of instruments is difficult due to the safety-based access restrictions;
- The actual behaviour of fish immediately (within 0.5 m of the Tunnel trash rack) in front of the tunnel is hard to determine. A video camera focal area is limited to a 2 m distance from the camera lens and will therefore only allow clear vision of the upper 1 m of the Tunnel entrance. Deployment of a camera immediately in front of the centre of the trash rack will lead to camera loss or damage and is therefore impractical;
- As was considered before project finalization for this year, we suggest deployment of a DIDSON unit to confirm direction of movement once we have determined current speeds as part of the ADCP deployment;
- There appears to be relatively good correlation between increases and decreases in net catches and observed changes to target numbers from the split beam acoustic devices;
- Net catches appear to also represent species composition well based on size representation in the net catch and the hydroacoustic targets;
- Winter access will be limited due to a combination of road steepness and loose surface material. Boat access will likely be needed for longer periods of time;
- For Year 2 of this project, we are recommending replacing the current lead-acid battery bank with a much more expensive lithium-ion battery bank to avoid slow battery deterioration due to discharges below 12V. Due to this phenomenon, the initial battery bank was destroyed but replaced for free with new batteries under warranty and we doubled the size of the battery bank at the same time. To avoid this deterioration for the new battery bank, we installed a voltage limiter that shuts the system down at 12.1V and re-starts once voltage is above this value. While the DTx unit and laptop computer are re-starting once charging is back above 12.1V, the Biosonics Visual Acquisition software does not start back automatically. We are currently trying to include the re-start of the software and DTx recording into the re-booting of the laptop for automatic re-starts. With a lithium-ion battery bank this problem would not need to be addressed since frequent discharging to below 12V would not damage the batteries;
- With a lithium-ion battery system installed in combination with the solar panels, the system maintenance visit intervals can likely be extended by 2–3 days between visits, resulting in 6 site visits/month including net sets during the 24/7 period from April to May and 4 visits/month for the rest of the year;
- As an added safety precaution to avoid hydroacoustic system damage based on transducers being operated outside of water, we are recommending installing a water sensor that would shut the system down when the reservoir falls below the level that exposes transducers to air;
- We are expecting that entrainment will be quantified by fish numbers, sizes and species as well as analysis of swimming direction throughout the 2021 fiscal year. Nevertheless, a second year of entrainment monitoring and analysis will add certainty to all parameters;
- We recommend conducting a pre-smolt reservoir acoustic survey to confirm distribution of sockeye juveniles across the entire reservoir in the February/March period; and
- Further analysis of factors that affect Sockeye abundance and distribution in the reservoir is needed and is elaborated on in the following section. The initial portion of this analysis is currently being conducted by Dr. Wendell Challenger and Bob Bocking of LGL and will be included as part of the 2021 fiscal year end report. Further analysis is likely needed as part of the 2022 fiscal year continuation of this project.

Exploratory Investigation

An exploratory investigation was conducted to examine the relationship, if any, between spillway discharge and Sockeye smolt migration. There was little variation in spillway discharge in most years, making comparisons to outmigration timing and abundance problematic. During years of similar spillway discharge there was a large variation in migration abundances, suggesting there is large natural variation, however underlying fry populations were not considered, which could be a critical explanatory fact. That said, the timing of spillway discharge showed some evidence of an effect on migration behaviour, with years where spillway discharge was delayed appearing to be associated with a stronger response to discharge (Figure 4.4). In order to better understand the critical factors driving Sockeye smolt outmigration future analyses will need to consider the underlying fry population (abundance, age, size, and distribution), individual characteristics (e.g., body size), and environmental factors (e.g., food availability, lake conditions [e.g., temperature, dissolved oxygen] and water management). Modifications to current water management practices may also be required to introduce additional variation in spillway timing and spillway discharge volumes. The low year-to-year variation in current spillway practices makes it difficult to elucidate the relationship, if any, between spillway discharge management and migration timing and abundances.

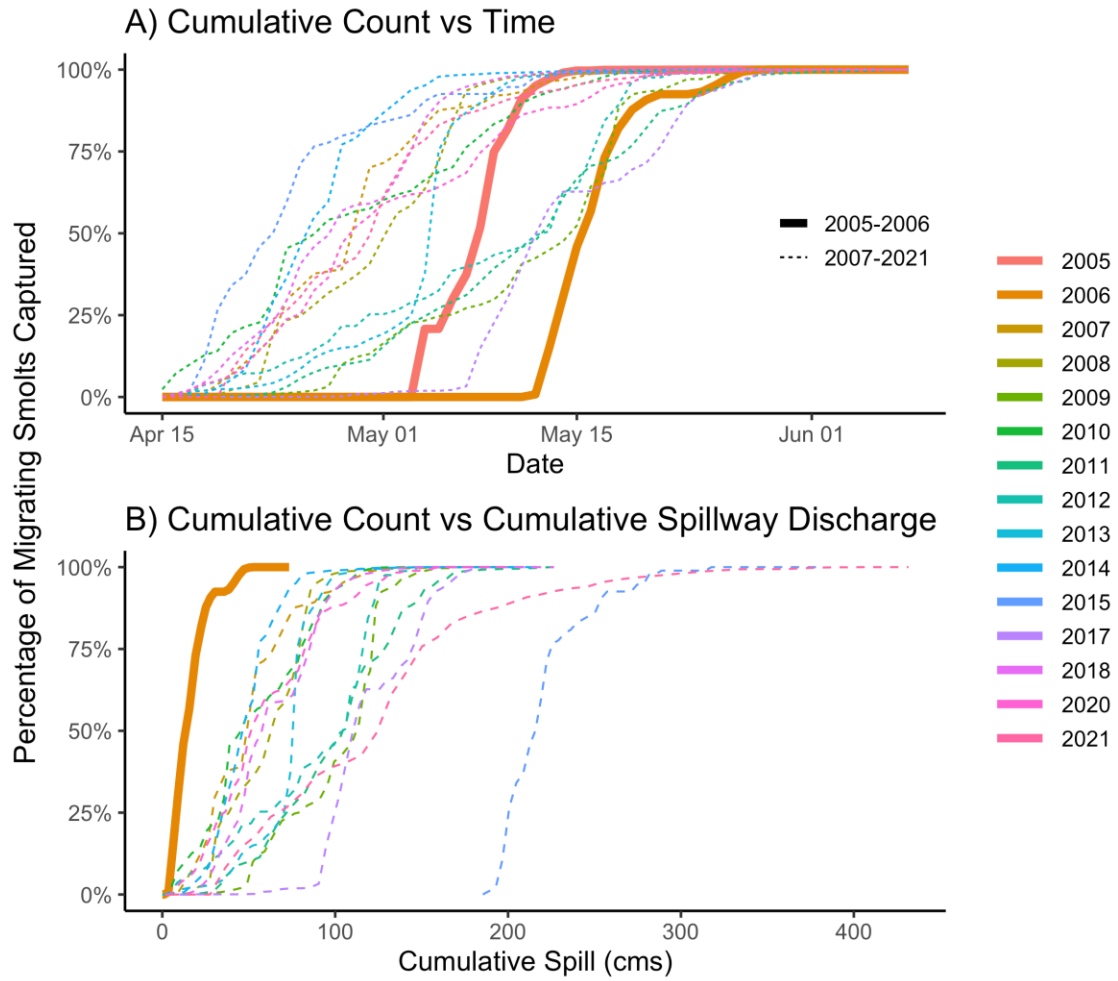


Figure 4.4. Comparison of cumulative smolts capture over time (A) and cumulative count to cumulative spillway discharge (B) from 15 April to 15 June. Thicker solid lines represented years that had a delay in spillway discharge (2005, 2006).

LITERATURE CITED

Alouette River Management Society (ARMS). 2021. Alouette Watershed Sockeye-Fish Passage Feasibility–Year 5. Proposal. Prepared for Fish and Wildlife Compensation Program, Burnaby, BC, by Alouette River Management Society, Maple Ridge, BC.

BC Hydro. 2018. Fish Passage Decision Framework for BC Hydro Facilities. Revision 2. Retrieved 02 November 2021 from <https://fwcp.ca/app/uploads/2019/06/Fish-Passage-Decision-Framework-Revision-2-Oct-31-2018.pdf>.

Mathews, M.A., and J.J. Smith. 2020. Evaluation of the migration success of *O. nerka* (Kokanee/Sockeye) smolts from the Alouette Reservoir, 2020. Report prepared for FWCP – Coastal by LGL Limited, Sidney, B.C.

—End of Report—
