Alouette Watershed Sockeye-Fish Passage Feasibility Project Year 1

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Prepared for:

Fish and Wildlife Compensation Program

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Overview of the Alouette Watershed Sockeye – Fish Passage Feasibility Project

Sockeye restoration in the Alouette Watershed was identified as a key priority in FWCP's Alouette Salmonid Action Plan, and is of significant cultural importance to the Katzie First Nation. The Alouette River Sockeye Reanadromization Program (ARSRP) is a joint initiative among the Katzie First Nation, the Alouette River Management Society (ARMS), BC Hydro, Ministry of Environment and Climate Change (MOE), Fisheries and Oceans Canada (DFO), and local stakeholders that works to promote the re-establishment of anadromous Alouette Sockeye and investigate the feasibility of fish passage at the Alouette Dam. The ARSRP committee has been working to resolve uncertainties around feasibility of Sockeye restoration in the Alouette watershed for over 14 years and within the Fish Passage Decision Framework (FPDF) since 2008. The dam is owned and operated by BC Hydro, a crown corporation and is in Maple Ridge, British Columbia.

After the ARSRP group failed to receive funding in 2016 for an experimental Sockeye hatchery, a workshop was held with senior Katzie First Nation representatives, DFO, BC Hydro, MOE and political leads to reassess the Alouette fish passage plan. Attendees agreed that it was important to have the MOE's newly developed Kokanee/Sockeye Nerkid Model peer reviewed and to test the predictions from the Nerkid Model. Testing would involve: releasing Kokanee and Sockeye hatchery fry into the reservoir; smolt outmigration and adult returnee surveys would generate estimates of fry-to-smolt survival to inform density-dependence, and 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. The DFO also requested that the Nerkid Model be provided to them for the basis of a review (Compass, 2016 unpublished).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 eleven-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 MOE.

The eleven-year plan included a formal scientific review of the Nerkid Model by DFO and the scientific community. To address any uncertainties identified in the eleven-year plan, the ARSRP will be reviewed by the Canadian Science Advisory Secretariat (CSAS). The review will investigate and report 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 will focus on short-and long-term implications of Sockeye smolting for genetic and population integrity. However, the experimental Sockeye hatchery was not approved for funding by the FWCP for Year 1 so this work was not initiated, instead the CSAS review of both the Nerkid Model and the

Alouette Sockeye fish passage feasibility program would need to 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 eleven-year plan are summarized below.

Alouette Watershed Sockeye – Determination of Fish Passage Feasibility: (2017 – 2027 Overall Plan)

		Phase 1		Phase 2						Phase 3		
Tasks in the Feasibility Plan		2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Task 1	Model Peer/CSAS Review	✓	✓									
Task 2	Spawner habitat mapping and spawner behaviour	✓	✓									
	Kokanee broodstock collection	✓	✓	✔	✔	✔	✔					
	Spawner habitat use									✔	✔	
Task 3	Hatchery Fry Release			✔	✔	✔	✔	✔				
Task 4a and 4b	Adult and Smolt Enumeration	✓	✓	✔	✔	✔	✔	✔	✔	✔	✔	✔
Task 5	Acoustic Assessment of Density Dependence	✓	✓	✔	✔	✔	✔	✔	✔	✔	✔	✔
Task 6	Heritability assessment and restoration projections			✔	✔	✔	✔	✔	✔	✔	✔	✔

✓ Task to be implemented for the given year with appropriate FWCP funding

✔ Task implemented subject to other study result

This report presents the work implemented for Year 1 of this eleven-year plan. The goals for Year 1 were to:

1. Undertake a peer review and a formal DFO review of the ARSRP program and review MOE's Nerkid Model to determine if it can accurately forecast Sockeye restoration feasibility;
2. Raise fry at the Alouette Sockeye Hatchery to test heritability; *(not approved for funding so did not run in 2017)*
3. Monitor adult returns and juvenile outmigration necessary for the evaluation of heritability and for eventual Fish and Wildlife Compensation Program (FWCP) endorsement;
4. Determine the availability of spawner habitat to confirm it can support a self-sustaining population.

This report is presented as a compilation of 4 individual summary/reports from the eleven-year plan. The first section is Task 1 - Peer review and CSAS review of Nerkid Model, the second section presents Task 2 – Spawning Habitat Assessment and Kokanee Spawner Behaviour; the third section presents Task 4a – Adult Sockeye Enumeration; and the final section presents Task 4b – Outmigrating Kokanee Smolt Enumeration.

Acknowledgements

Special thanks to FWCP- Coastal's Program Manager Julie Fournier for her assistance and guidance throughout the 2017-2018 season and to FWCP Program Assistant, Lorraine Ens for her help with navigating the new FWCP Application and Reporting online portal.

And finally, thank you to David Cunningham for his infinite patience and amazing formatting skills.

References:

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

Alouette Watershed Sockeye – Determination of Fish Passage Feasibility (2017 – 2027 Overall Plan) pg 10. Prepared for the Fish and Wildlife Compensation Program, September 2016

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TASK 1 – CANADIAN SCIENTIFIC ADVISORY SECRETARIAT (CSAS) REVIEW OF SOCKEYE RESPONSE MODEL AND ALOUETTE PROGRAM -

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Project Leads for the CSAS Review met with the Science Coordinator for the Secretariat. The Project Initiation Document (PID) has been reviewed and is being edited in order to modify and amalgamate similar Project Objectives of the review. This will reduce the number of Objectives and reduce the scale of the review and the number of individuals that will be required to engage. Once complete, the PID will become the foundation for the Terms of Reference for the review. A list of technical experts, both inside and outside of DFO, has been identified to participate in each of the review components.

The major challenge for the review is the workload and time constraints on DFO Science to engage in a timely manner. Ongoing pressures from other Program Sectors and significant salmon conservation pressures throughout Pacific Region put a strain on available Science Branch resources. DFO understands the importance of this work to the Alouette Recovery Program, and operational staff continue to work with Dr. Selbie to move this Review forwards.

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TASK 2 - ALOUETTE RESERVOIR *ONCORHYNCHUS NERKA* SPAWNING BEHAVIOUR AND HABITAT STUDY, 2017

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This project was completed by the University of British Columbia (UBC) in partnership with the Ministry of Environment and Climate Change Strategy, and through a Memorandum of Understanding with the Alouette River Management Society (ARMS). Sincerest gratitude is extended to the staff within MOE and FLNRO – particularly Craig Mount, Don Philip, Robin Munroe, Julie Scott-Ashe and Joshua Chan – for all of their efforts in ensuring that the spatial analysis and GIS component of the project was successfully delivered within our required timeline. Their time and dedication were above and beyond the typical level of in-kind support and truly reflects the value in multi-agency partnerships.

Successful delivery of the program would not have been possible without the collaboration and support of many great people:

- Jennifer Sarchuk and Heather Vainionpaa (British Columbia Conservation Foundation) – field assistance during habitat mapping program, general support and positive attitudes
- Melanie Kuzyk (UBC) – volunteer field assistance during habitat mapping program
- Bob Secord and Kevin Gould (BCCF) – boat operations and gillnetting
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- Andrew Lotto (UBC) – help with logistics, thoughtful suggestions, and field assistance
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- Byron Woods and Don Philip (MOE) – GIS support and spatial analysis
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- Greta Borick-Cunningham and Ken Stewart (ARMS) – flexibility with funding arrangements; Greta for taking on the extra administrative requirements
- Trevor Davies and Tyler Weir (FLNRO) – helping to secure additional project funding, administration and support
- Denise Heron, Regina Florence, Debbie Miller, Katzie Development Limited Partnership – project support and administration
- Kerry Baird, British Columbia Conservation Foundation – contract management
- Greg Andrusak (FLNRO), Andy Morris (FLNRO), Theresa Godin (FFSBC), Elmar Plate (LGL) – sharing their knowledge and experience.

Thank you to Dr. Scott Hinch (University of British Columbia) for welcoming me into his lab as a graduate student and for his supervision, guidance with project development and all the support that goes along with being a graduate supervisor. Thanks are also extended to Dr. Daniel Selbie (Fisheries and Oceans Canada) for his mentorship, commitment and support for this project.

The support from the Ministry of Environment and Climate Change Strategy, specifically Manjit Kerr-Upal and Dr. Brett Van Poorten, both with the Conservation Science Section, is greatly appreciated. And finally thank you to Shannon Harris; her persistence and support over countless phone calls and meetings meant sacrificing time from her other projects to ensure this project was a success. This project would not have been possible without her dedication; it is truly appreciated.

Executive Summary

This report covers Year 1 (2017) of the Alouette watershed fish passage feasibility plan Task 2; the focus of which is Sockeye and Kokanee (*Oncorhynchus nerka*) spawning behaviour (timing, site selection, etc.) and habitat (existing conditions, capacity, potential constraints). Due to the difficult nature of assessing spawning habitat and behaviour in deep water, we proposed a two-pronged approach over a multi-year period: (1) habitat mapping based on well-established procedures using underwater video and photographic imaging in concert with GIS analysis; and (2) spawner surveys based on methods for the study of lake spawning fishes using short-set gillnetting and remote operated vehicle (ROV) surveys to validate data. All depth data from the field were corrected to a reference surface elevation of 125 m GSC based on day-end reservoir elevations; only corrected depths are reported.

Quadrat sample points taken using a drop camera system established the distribution of substrate composition (size and embeddedness) within the reservoir; Thiessen polygons were created for each point mathematically identifying areas of similar habitat. Spatial analyses estimated 48 ha of potentially suitable spawning habitat for Sockeye and Kokanee in Alouette Reservoir out of a total of 688 ha with the 10-80 m depth range; this is considered an overestimate and should be viewed with caution. We recommend collection of additional quadrat points in key locations to provide the resolution required for a more reliable estimate of capacity; while this could be done with current data, the level of uncertainty surrounding estimates would reduce their significance. Initial results suggest that spawning habitat would not be the limiting for Sockeye and Kokanee in the reservoir.

Kokanee were the primary species caught during short-set gillnet surveys (1,754 individuals); of which, approximately 70% were successfully released back into the reservoir. Impacts to the Alouette Bull Trout population was minimized with 3 mortalities out of a total of 38 individuals captured as bycatch. The Kokanee spawning timing window was defined as October to the end of December (with a very limited number into January); peak spawning time was during November, as indicated by maturity data and the presence of females on the spawning grounds. Ripe males entered spawning grounds early in addition to a small number of silver females. Significant numbers of females in spawning condition did not appear until November. The sex ratio of males to females was greater than 2:1 overall; either the Alouette spawning population was male biased or males were more susceptible to sampling gear due to greater movement on spawning grounds.

Kokanee spawners were captured generally between depths of 15 m and 70 m confirming the Alouette stock are a deep lake spawning population. Evidence of nest digging activity was the only type of spawning behaviour found. A total of three primary and four secondary spawning sites were identified in a spatially clumped distribution. All three primary spawning areas were on the east shore of the south basin. Two sites (Area A and E) were in gravel lakebed habitat, while the other site (Area B) was in mixed sand and granule gravel (i.e. 2-4 mm size class) substrate embedded with fine sediment (classified as fine lakebed). Area B was not characteristic of typical spawning habitat for Sockeye and Kokanee. The four secondary spawning sites (Areas C, D, F and G) were all located on the west shore; three sites were in the south basin and associated with tributary stream outlets (i.e. Twin North Creek, Gold Creek, Moyer Creek), while the fourth site was at the south end of the north basin on a small alluvial fan. Area G at Gold Creek was the only site with gravel lakebed; the other secondary spawning sites consisted of

fine lakebed (Area C and F) and coarse lakebed (Area G) habitats. Spawning activity was limited in the north basin despite the availability of gravel lakebed within the known spawning depth range.

Results suggest that substrate size and embeddedness criteria alone were not consistent predictors of actual spawning habitat selection by Kokanee in Alouette Reservoir. While spawning was confirmed in a range of habitats, spawning success does not imply incubation success; at this stage, incubation success across habitat types remains unknown, as it was not within the scope of this task. Initial results highlight how assumptions based on current literature for stream and shallow lake spawning Sockeye and Kokanee populations may not be appropriate for the Alouette stock; they also highlight the importance of multi-year studies that capture the natural variability in a system. Future work should focus on collecting new physical and chemical environmental data in addition to increased densities of quadrat points on substrate composition; this will allow us to refine the definition and estimates of suitable spawning habitat, as well as inform on the underlying mechanisms for site selection in deep water spawners.

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1. Introduction

In the late 1920s, the Alouette River was dammed to create the Alouette Reservoir, a storage reservoir used for hydroelectric power generation in the neighbouring Stave system. At that time, there was no consideration for fish passage, and so all anadromous salmonids were cut off from upstream habitats. Sockeye Salmon (*Oncorhynchus nerka*) persisted in the reservoir as its resident form, Kokanee.

The Alouette River Sockeye Reanadromization Project (ARSRP) is a collaborative initiative of the Katzie First Nation, federal and provincial agencies, and local stakeholders. The objective of the ARSRP is to promote re-establishment of anadromous Sockeye in the Alouette watershed and determine feasibility of fish passage at the Alouette Dam in accordance with the Fish Passage Decision Framework (the 'Framework'; Fish, Wildlife and Hydro Policy Committee 2016). Sockeye restoration means: the population is Alouette stock; the annual run size meets agency requirements for a minimum viable population; and the population is self-sustaining (i.e. no long-term hatchery intervention). To help set priorities and guide decision making, agencies need biological evidence to guide the restoration of viable anadromous salmon populations above the dam. The 'Framework' requires fish passage feasibility proposals to include:

- Profiles for their target species (current populations, distribution in the watershed, migration timing, habitat requirements, etc.);
- Assessment of existing and potential habitat (spawning, rearing, overwintering) above and below the dam (location, type, quantity, quality, capacity);
- Discussion of attainable restoration goals and potential constraints;
- Possible effects on resident fish (ecological, genetic, disease, etc.);
- Assessment of biological benefits and risks.

This report is for Task 2 in the Alouette fish passage feasibility plan, the focus of which is Sockeye and Kokanee spawning behaviour and habitat in the reservoir.

1.1 Goals and Objectives

Of the diverse range of reproductive behaviours exhibited by Sockeye and Kokanee salmon (e.g. Burgner 1991, McPhail 2007), the Alouette stock are a deep-water lake spawning population – a rare ecotype with only a few known populations world-wide (Moreira and Taylor 2015). In Lake Saiko, Japan, the deep spawning population are considered a separate species (*Oncorhynchus kawamurae*) from sympatric stream spawning Kokanee (Nakabo *et al*. 2011). Due to the relative difficulty in observing fish and collecting data in deep water (i.e. 20-70 m), there is limited information on their spawning behaviour and habitats. Previous work focused on evaluating salmonid spawning habitat potential in tributaries. Additional work involving Alouette Sockeye tracking suggested both forms of *O. nerka* used deep-water areas in the reservoir during spawning and confirmed at least one spawning location (Plate and Bocking 2010, 2011, 2013). Building on previous work, the goals for Task 2 are to answer key questions on existing reservoir habitat conditions; spawning behaviour, habitat selection and timing; potential interactions between anadromous and resident fish; and potential constraints on the population. Thus, this task directly informs the establishment of stock and habitat profiles for Alouette *O. nerka*. Establishing attainable restoration goals and determining how they can achieved are critical to the ARSRP. While limnological data from the Alouette Reservoir Nutrient Restoration Program can help to identify rearing habitat capacity and potential constraints in that regard, data from Task 2 will help identify spawning habitat capacity and potential constraints. Additionally, findings of this study will help inform the objectives and targets to be set by the agencies. Task 2 directly addresses three number one priority actions outlined in the Alouette River Watershed Action Plan (2017), including: Action 1 – Develop a current habitat assessment map; Action 2 – Conduct a limiting factors analysis in the upper watershed including Alouette Lake and its tributaries; and Action 18 – Conduct technical feasibility assessments, monitoring and/or species-based actions associated with Sockeye Salmon passage at Alouette Dam to support re-introduction to the Alouette system.

Task 2 involves three components conducted over a multi-year period: (1) reservoir habitat mapping, (2) spawner surveys, and (3) reporting (annual data reports and a final synthesis report). A multi-year approach to capture data on spawning habitat and behaviour is based on previous work on Alouette Sockeye showing considerable variability in behaviour from year to year (Plate and Bocking 2013).

Objectives for Task 2 Year 1 include:

a. Provide an estimate of potential spawning habitat within the reservoir using a habitat mapping approach.

b. Define the spawning timing window and describe general spawning behaviour and habitat selection.

This summary report presents initial results from Task 2 in 2017 (Year 1).

2. Study Area

Alouette Reservoir is located at 49.3335°N and 122.4182°W approximately 60 km northeast of Vancouver, British Columbia, within the traditional territory of the Katzie and Kwantlen First Nations (FWCP 2017) (Figure 2-1). Alouette Reservoir is a monomictic, oligotrophic lake with two distinct basins connected by a narrow section. The reservoir has a maximum length of 17 km, a maximum depth of 152 m, and mean depth of 78 m. At full pool, the reservoir is 1,666 ha. In addition to Sockeye and Kokanee, known fish species in Alouette Reservoir include: Rainbow Trout (*Oncorhynchus mykiss*), Cutthroat Trout (*Oncorhynchus clarkii clarkii)*, Bull Trout (*Salvelinus confluentus*), Redside Shiner (*Richardsonius balteatus*), Peamouth Chub (*Mylocheilus caurinus*), Northern Pikeminnow (*Ptychocheilus oregonensis*), Threespine Stickleback (*Gasterosteus aculeatus*), sucker (*Catostomus* spp.) and sculpin (*Cottus* spp.). Lake Trout (*Salvelinus namaycush)* were introduced to the reservoir (1960s and 1980s); it is unknown whether they have persisted.

Originally, the area consisted of two smaller lakes joined by section of river. In 1920s, the Alouette River was dammed to create a storage reservoir for hydroelectric power generation. The dam is located at the south end of the reservoir, and is equipped with a gated spillway, an overflow weir, and a gated low-level outlet. At the north end of the reservoir, a 1.0 km long gated tunnel diverts water into the neighbouring Stave Reservoir where power is generated. Alouette Reservoir operations are guided by the Water Use Plan (BC Hydro 2009). Reservoir elevations range between a maximum of 125.51 m GSC (Geodetic Survey of Canada) at full pool and minimum of 112.6 m GSC allowing for a maximum drawdown of 12.91 m. However, elevations below 116 m GSC result in turbidity issues, so the reservoir is typically maintained above 116 m (BC Hydro 2009). From June 15 to Labour Day, water levels are held ≥122.5 m GSC for recreational purposes. From Labour Day until September 15, a short shoulder season allows water levels to drop to 121.25 m before resuming standard operations (BC Hydro 2009). All inflow into the reservoir is uncontrolled. Outflow is managed either through the tunnel into Stave Reservoir, the dam low-level outlet into the Alouette River, and/or the dam spillway and overflow weir to the Alouette River. Under their water license, BC Hydro is required to maintain an average base flow of 2.6 $m^3 \cdot s^{-1}$ into the Alouette River. Because this is typically achieved using the low-level outlet, base flows may range from 1.52 to 2.97 $m^3 \cdot s^{-1}$ depending on the reservoir elevation and resulting head pressure. From April 15 to June 14, the dam spillway is opened to allow the outmigration of juvenile *O. nerka* from the reservoir into the Alouette River.

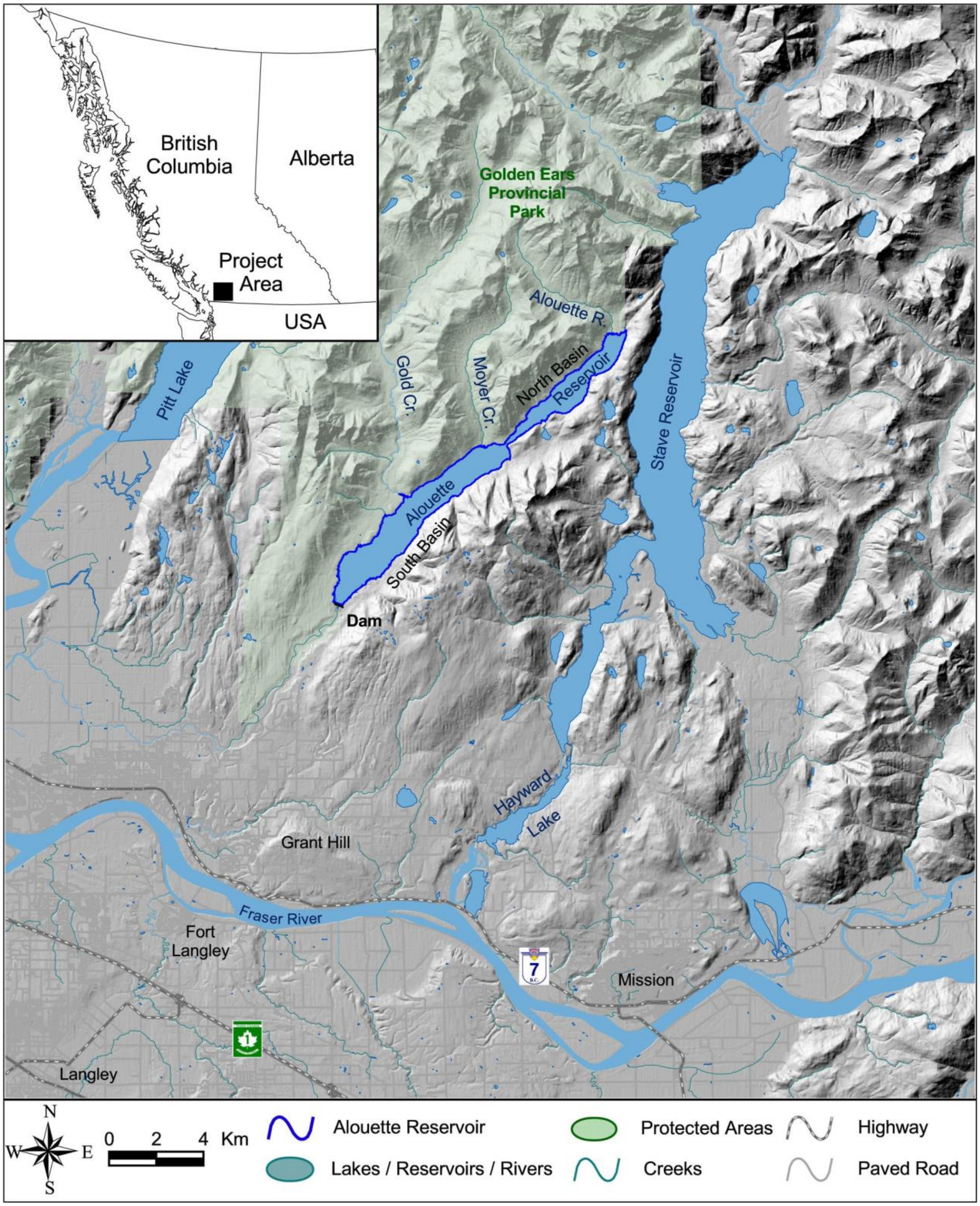

Figure 2-1 Location of Alouette Reservoir, British Columbia.

3. Methodology

Due to the difficult nature of assessing spawning habitat and behaviour in deep water, our approach combined a number of complimentary methods established in the literature (Fitzsimmons 1994, Morris and Caverly 2004, Coggan *et al*. 2007, Barton and Dux 2013). Methods consisted of habitat mapping based on well-established procedures (e.g. seafloor habitat mapping) using underwater video and photographic imaging in concert with GIS analysis. Spawner surveys were based on methods for the study of lake spawning fishes (e.g. Lake Trout spawning, previous work on deep spawning Kokanee within the Seton-Anderson system) using short-set gillnetting and remote operated vehicle (ROV) surveys to then validate netting data.

3.1 Reservoir Habitat Mapping

A reconnaissance trip to test BC Hydro's remote operated vehicle or ROV (VideoRay Pro 4 PS 300SE) for mapping purposes was conducted on May 1-2, 2017. During the reconnaissance survey, it was determined that the ROV would not be suitable for the collection of detailed spatial data, as required for the mapping component. The primary concern was its inability to give accurate location data in terms of X, Y coordinates. The ROV would be suitable for general assessment of spawning habitat following spawner surveys.

The Ministry of Environment and Climate Change Strategy provided an underwater drop camera system that was upgraded and used for the collection of habitat data (Figure 3-1). The drop camera system consisted of a Shark Marine SV-DSP-Z2 Camera and SV-Q10K Underwater Light (250 or 500 W halogen bulb) mounted to a weighted lowering frame with a 0.25 m^2 quadrat (measuring 0.5 m by 0.5 m with 1 mm, 1 cm, and 5 cm scale references). The camera and light were controlled (zoom, focus, light intensity etc.) at the surface using a Shark Marine SV-SC-120VL Surface Console equipped with SV-GPS-OV1 Global Positioning System (GPS) Overlay and external GPS receiver. The GPS system recorded the surface location of drop-camera and overlaid the position onto the recorded imagery. The camera was white balanced using a solid white corrugated plastic sheet mounted to the lowering frame at a depth of approximately 10 m prior to data collection after each time the camera system was shut down. The camera system was powered with a portable 2000 W generator. Imagery was recorded onto a miniDV disc in the field and subsequently transferred to a digital video file. Quadrat depths were recorded from a marked line attached to the lowering frame, corrected for the height of the frame itself to represent the bottom depth. Each quadrat location made up one data point. Field work was conducted in late June and early July, during which approximately 250 data points were collected with information on reservoir substrate. Due to summer bloom conditions, the water clarity prohibited the collection of imagery at depths less than approximately 20 m. Substrate data were collected from depths of approximately 20-95 m, as well as shoreline areas within the drawdown zone. Concentration of data points was balanced between suspected spawning locations (based on previous work) and other areas of the reservoir. Specifically, information contained in McKusker *et al*. (2003) and Plate and Bocking (2013) was used to identify potential spawning locations, so their extents could be determined.

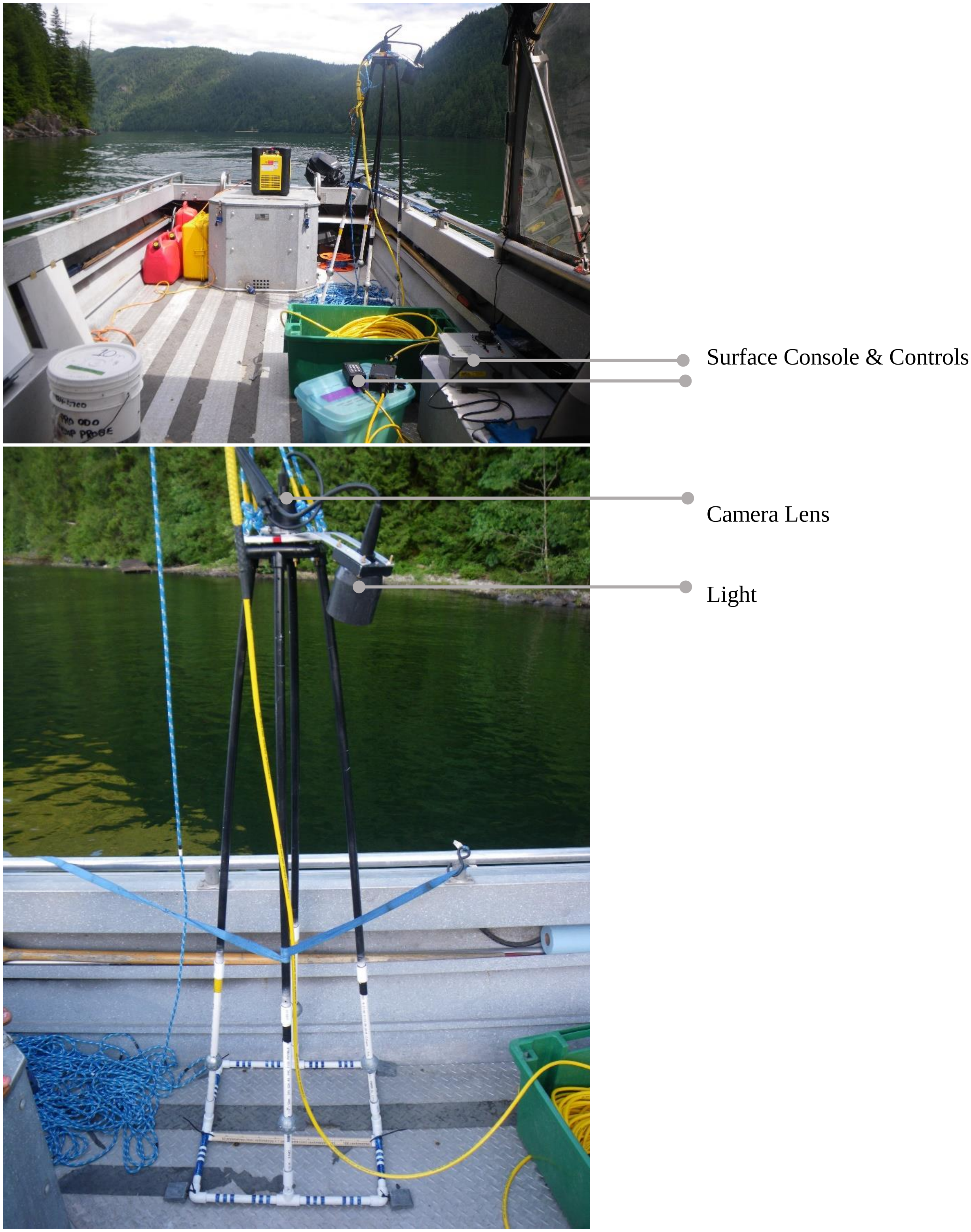

Figure 3-1 Underwater drop camera system used for collection of substrate data on Alouette Reservoir; bottom image shows downward looking camera lens and light mounted to the weighted lowering frame and 0.25 m² quadrat.

Substrate size was classified based on Wentworth (1922) and RISC (2001); see Appendix A for details. Data on embeddedness, the degree to which rock pieces are buried in fine sediments or to which fine sediments fill the interstitial spaces between rock pieces, and cover of small woody debris, large woody debris and aquatic macrophytes were recorded.

Appendix B contains details on how these other habitat variables were classified.

3.2 Spawner Surveys

3.2.1 Gillnet Surveys

Spawner surveys were conducted from September 11, 2017 to January 22, 2018. Surveys involved nearshore gillnetting using sinking nets set at depths from approximately 5-70 m. Two different net types were used:

- modified seven-panel RISC nets (RISC 1997) with mesh sizes: 25 mm, 89 mm, 51 mm, 76 mm, 38 mm, 64 mm, 32 mm (1”, 3.5”, 2”, 3”, 1.5”, 2.5”, 1.25”), which are referred to as RISC nets throughout this report; and
- seven-panel nets consisting entirely of 51 mm (2”) mesh, which are referred to as all 2” mesh nets in the text of this report and as “IN” in figures (as per RISC 2008).

Each panel measured 2.44 m by 15.24 m resulting in overall dimensions of 2.44 m by 106.68 m. At each station, a gang of two nets of the same type were set perpendicular to shore with the lead line on the lake bottom. The gang was anchored to shore and at depth. Start times were recorded once a set was complete (i.e. when the deep anchor line was dropped). It consistently took 5 minutes to set a gang; this was the elapsed time from anchoring the first net to shore to dropping the deep anchor line at the end of the second net. Times were also recorded at the beginning and end of net retrieval. Set times were calculated from the start time to the beginning of net retrieval; while total soak time was calculated from the beginning of a set to the end of retrieval (i.e. once the nets were completely out of the water; this represented maximum possible net encounter time for fish). Set times were typically 15 minutes for the 51 mm mesh nets and 30 minutes for the RISC nets. Short set times were meant to minimize fish mortalities. The 51 mm nets and RISC nets were set at neighbouring stations for comparison of catch size and efficiency.

A recovery tank was kept onboard for assessment and recovery of fish; it consisted of a pale blue, insulated 250 L fish tote equipped with an aerator and a YSI Pro ODO meter to assess temperature and dissolved oxygen. Lake water was pumped into the tank from a depth of 1-2 m and replaced as needed to maintain water quality. During September when temperatures in Alouette Reservoir were above optimal, water was retrieved from Gold Creek and cooled with ice packs contained in a plastic bag. An opaque lid was used to fully or partially cover the tank from the sun.

Handling of fish was minimized. Captured Kokanee were removed and placed in a net suspended at the top of the recovery tank. Each individual was immediately assessed for sex, spawning condition, marked/tagged and then put into the main portion of the recovery tank until they could be released alive back into the reservoir. Bycatch of non-target species was recorded and individuals were generally immediately released into the reservoir as they did not require assessment. Individuals that were in poor condition were euthanized and kept for further sampling; all net mortalities were also kept for further sampling. Catch was tracked for each panel of each net along with the corresponding mesh size.

Canadian Council on Animal Care guidelines were followed in the handling of fish during field programs (CCAC 2005). To eliminate the risk of pathogen transfer, all sampling equipment was disinfected with Peroxiguard according to Provincial fish health standards.

3.2.2 Remote Operated Vehicle (ROV) Surveys

Once spawning activity in the reservoir had declined, winter ROV surveys were conducted to look for evidence of spawning (e.g. redds, gravel areas that had been cleaned of fine sediment) and confirm physical habitat characteristics as a means to validate gillnet data. ROV surveys involved video recording transects perpendicular to shore from depths of approximately 5 m to 80 m at gillnetting areas. To establish a point of reference for observers in the field and allow a more accurate assessment of substrate size, a scale bar in 1 cm increments was recorded directly in front of the ROV camera and at 0.5 m away (Figure 3-2).

ROV surveys were scheduled for December 5-8, 2017. Field work was successfully conducted on December 5, but unfortunately, on December 6, the ROV malfunctioned and the work was delayed until it could be repaired. Additional surveys were carried out on February 20 and 21, 2018; again, field work had to be cut short, this time due to inclement weather resulting in safety concerns (i.e. snow and icy conditions). Despite these challenges, at least one ROV transect covering depths from 5-45 m was completed at each gillnetting area.

Figure 3-2 Remote operated vehicle (ROV) imagery with scale bar reference points; bottom scale bar is in 1-centimeter increments and top scale bar is in 1-inch increments.

3.3 Analysis

A desktop review of habitat imagery was completed following field collection. All quadrat, ROV and gillnet depths were corrected to the reference surface elevation of 125 m GSC based on day-end reservoir elevations provided by BC Hydro. Habitat data were analyzed in Esri ArcGIS 10.3. Attributes including substrate characterization and embeddedness were used to classify quadrat points into general habitat types. Gravel lakebed, where gravel was >10% of substrate and embeddedness was <80% (may or may not include components of cobble, sand, fine or organic materials), defined the "suitable" category and was used to estimate potential spawning habitat area. Although areas with that degree of embedded substrate would generally not be considered suitable for salmonid spawning, Burgner (1991) noted for lake spawning *O. nerka* that the physical act digging of redds removes accumulated fine sediments. So, we assumed that if an area had appropriately-sized substrate and was not completely covered by fine sediment, it may offer potential spawning habitat. All other habitat types were defined as "unsuitable"; these included fine, coarse and bedrock lakebed where there was no gravel component or where embeddedness was >80%. Thiessen polygons were created for each quadrat point mathematically identifying areas of like habitat. Polygons were restricted between bathymetry contours of -10 m to -80 m (with the 0 m reference elevation at 125 m GSC representing the reservoir surface at full pool). We assumed that substrate beyond 80 m depth would consist of a deep layer of fine sediment and be unsuitable for *O. nerka* spawning. And although quadrat data were limited to corrected depths of 20 m to 93 m, we assumed habitat characteristics between 10 m and 20 m would be similar as generally observed from ROV surveys. Furthermore, current data on Alouette *O. nerka* spawning suggest spawning is unlikely in shallow littoral areas or beyond 80 m depth.

The total area of suitable spawning habitat polygons was calculated for the reservoir. Spawning habitat capacity can be estimated using a standard density of 1 female per 2 m^2 for Sockeye populations (Burgner 1991). As well, lakeshore spawning Sockeye in Iliamna Lake (a large oligotrophic lake in Alaska) have been observed spawning up to 30 m deep and exhibited maximum sustained densities of 1 female per 1.7 m^2 on spawning grounds (Adkinson *et al*. 2014), and so we felt the standard given by Burgner (1991) would be appropriate for Alouette Sockeye. Estimated spawning habitat capacity can also be calculated using 1 female per 0.6 m^2 which is similar to the size of Kokanee spawning territories observed by Foote (1990) in Kootenay Lake and is consistent with the spawning capacity assessment for Coquitlam Reservoir (Gaboury and Murray 2006).

Spawner survey sampling sites were determined using a stratified design based on reservoir habitat mapping data. Habitats were stratified into suitable and unsuitable spawning areas as described above. The unsuitable habitat category was further stratified into fine and coarse lakebed types. Fine lakebed was where fine sediment was >80% and or embeddedness was >80%. Coarse lakebed was where cobble and or boulder substrate was >10% and where gravel substrate was not a primary component (<10%) of the aggregate; these would include: cobble, boulder cobble, cobble boulder, and boulder aggregates (see Appendix A for more details). Coarse lakebed had embeddedness values <80%. A total of twelve gillnetting stations were originally selected; five were in suitable habitat and seven were in unsuitable habitat (four in fine lakebed areas and three in coarse lakebed areas). Two of these sites were subsequently removed after initial sampling proved challenging; both sites mapped to be coarse lakebed types leaving a total of five sample locations in suitable habitat and five in unsuitable habitat (Figure 4-4), only one of which was in coarse lakebed.

Spawner survey data (net set and individual fish data) were entered into csv files and analyzed in R version 3.4.2 (R Core Team 2017) using R Studio version 1.1.423 (RStudio Team 2016) and the packages "dplyr" (Wickham *et al*. 2017), "doBy" (Højsgaard and Halekoh 2016), and "ggplot2" (Wickham 2009). Catch-per-unit-effort (CPUE) was calculated based on the number of individuals caught per 100 m^2 of net per hour, so comparisons of catch rates could easily be made regardless of net size configuration. Effort was classified into two categories based on net set time and total soak time; CPUE was calculated for each time accordingly.

For simplification, the following RISC standard codes for fish names were used in tables and figures: Kokanee (KO), Bull Trout (BT), Rainbow Trout (RB), Cutthroat Trout (CT), Peamouth Chub (PCC), Northern Pikeminnow (NSC), Redside Shiner (RSC), sucker spp. (SU), sculpin spp. (CC), and crayfish (CR). The code NFC (no fish caught) was used in place of a species name to track net sets with no captures.

4. Results

4.1 Reservoir Habitat Mapping

Select drop camera images taken during Alouette Reservoir habitat mapping surveys are shown to provide examples of substrate classification terms (Figure 4-1 and Figure 4-2; see Appendix A for details). Quadrat sample points established the distribution of substrate types within the reservoir from depths of 20-93 m. Spatial analyses of quadrat data resulted in an estimate of 48 ha of potential suitable spawning habitat for Sockeye and Kokanee in Alouette Reservoir out of a total of 688 ha within the 10-80 m in depth band (Figure 4-3). Based on the current density of quadrat points, this is considered an overestimate and should be viewed with caution. The mathematical model extrapolates substrate types based on information at each point and the points nearest to it; thus, in instances where neighbouring points were not within close range, the area gets extrapolated beyond the likely bounds of the actual habitat type. Additional quadrat points in key areas (now that we know more about where fish are spawning; Section 4.2) will provide the resolution required for a more reliable estimate of capacity.

In the south basin, suitable spawning habitat was generally confined to alluvial fans on the east shore, as well as an area on the west shore north of Gold Creek. The widest distribution of potential spawning habitat was found in the north basin associated with alluvial fans on the west shore in addition to bay areas on the east shore. Spawner surveys areas were selected based on habitat mapping results using a stratified design and are shown in Figure 4-4. Using different spawning densities for Sockeye and Kokanee (Section 3.3), spawning habitat capacity in the reservoir can be grossly estimated; however, due to the limitations of current habitat estimates (as described above), we feel it would be prudent to first complete and refine the mapping component.

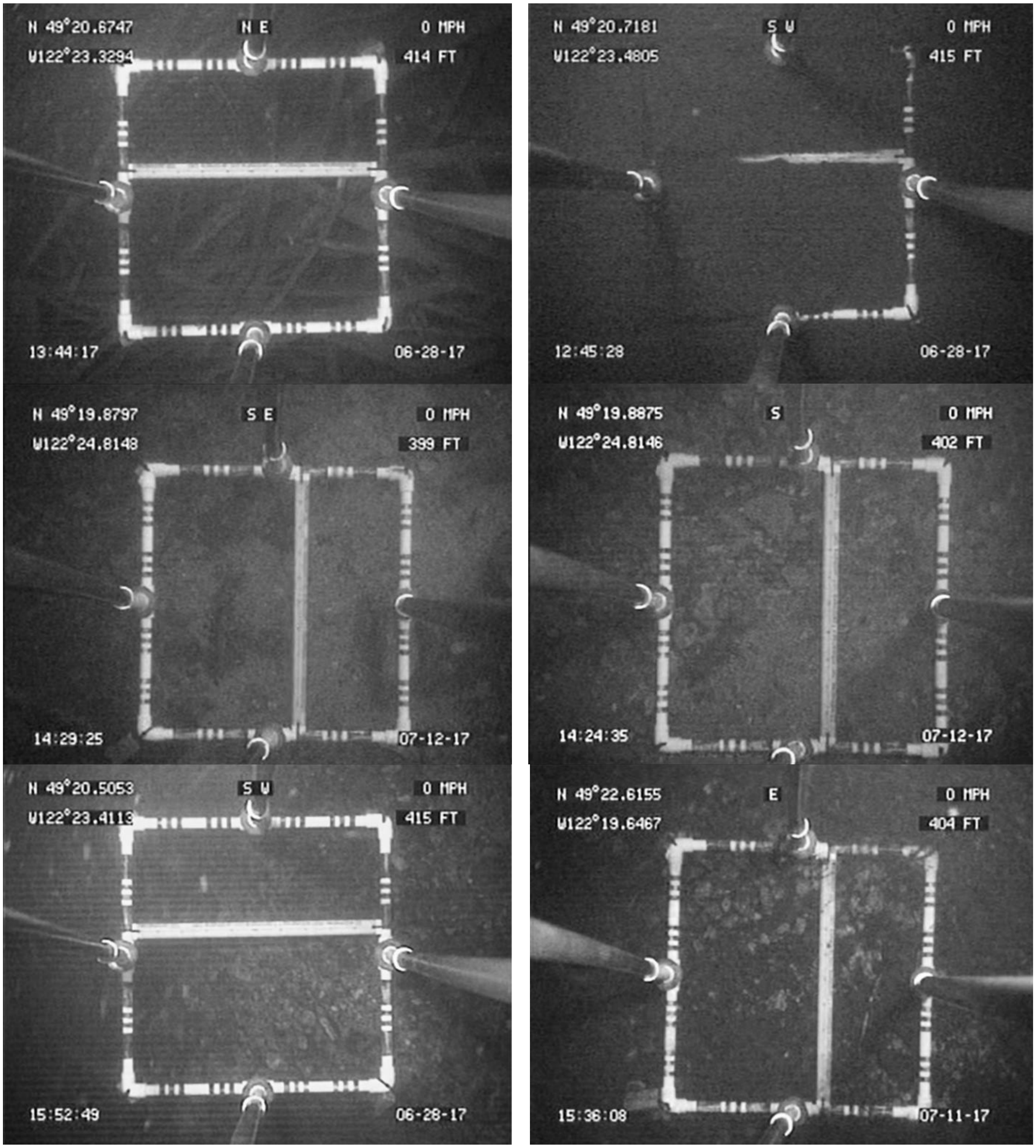

Figure 4-1 Drop camera quadrat imagery (stills taken from video recordings and presented in greyscale) showing examples of substrate classifications; aggregates from left to right, top to bottom are: organic (small woody debris > 80%), fine, sand, sandy gravel, gravel, organic gravel.

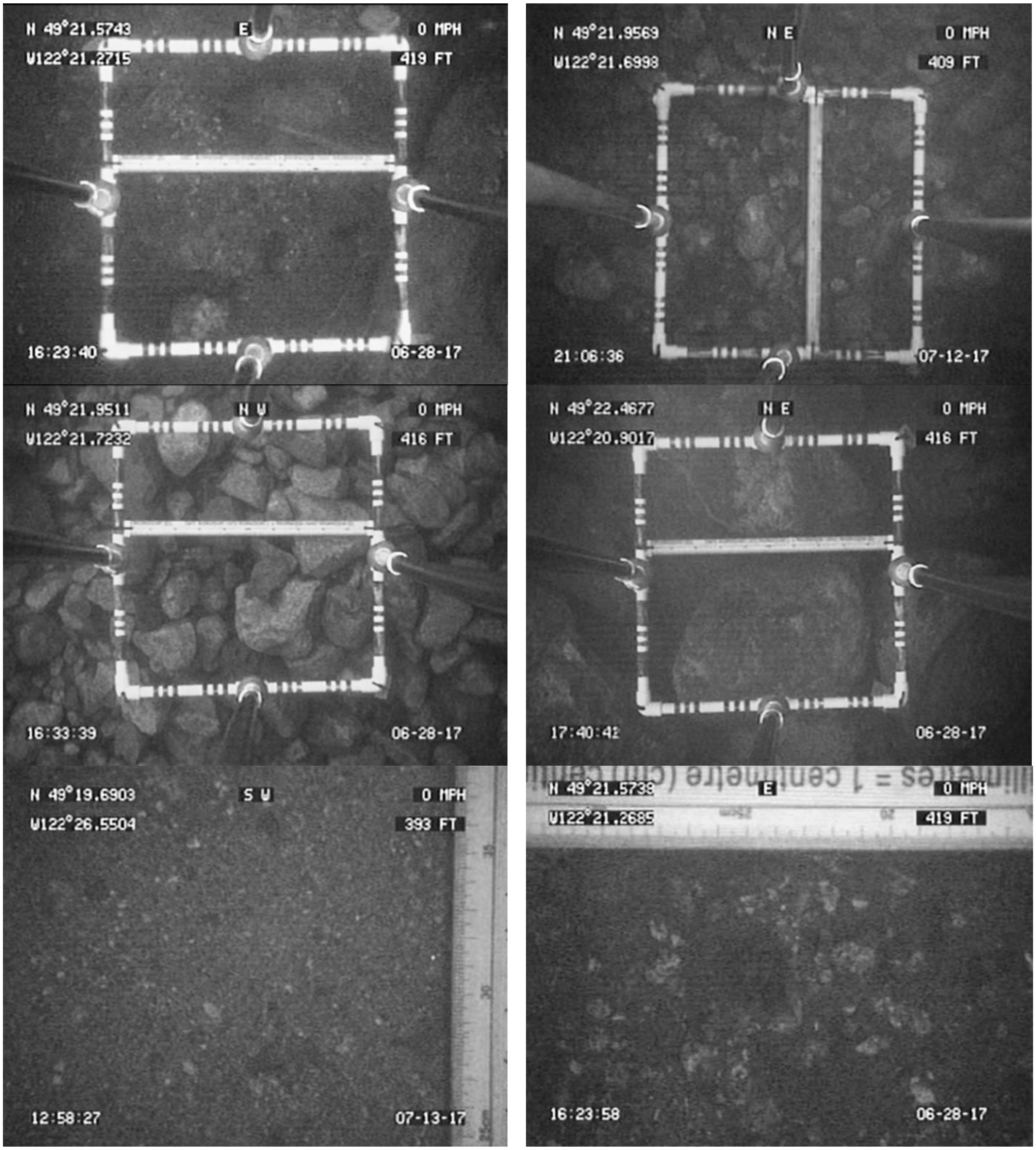

Figure 4-2 Drop camera quadrat imagery (stills taken from video recordings and presented in greyscale) showing examples of substrate classifications and zoom capabilities allowing users to differentiate among smaller grain sizes; aggregates from left to right, top to bottom are: gravel (granule and pebble classes, < 10% cobble), cobble gravel, cobble, boulder, zoom of sand and granule gravel, zoom of granule and pebble gravel.

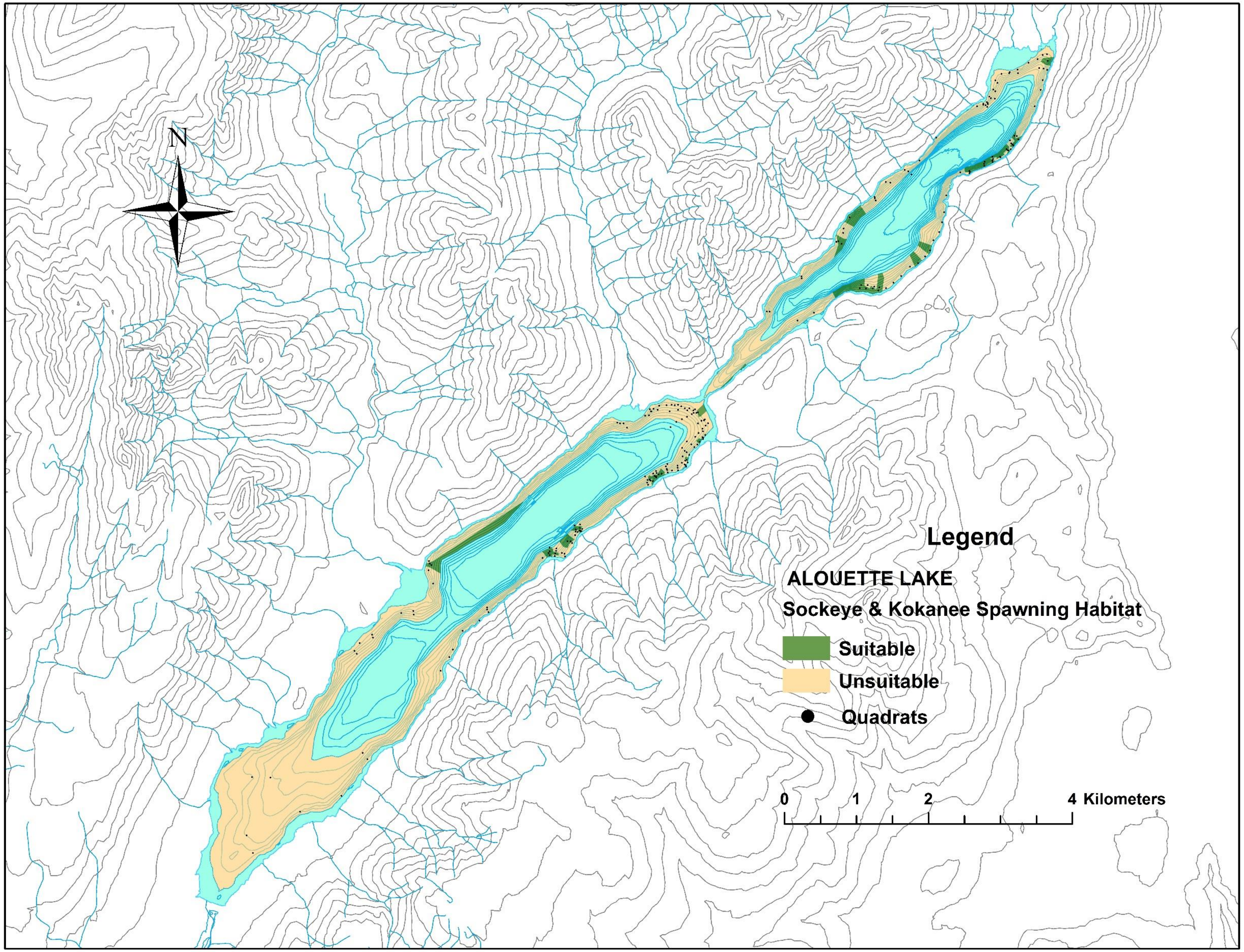

Figure 4-3 Habitat suitability map showing areas of potentially suitable and unsuitable spawning habitat for Sockeye and Kokanee within Alouette Reservoir, BC, at depths of 10-80 m. Habitat suitability polygons were generated from quadrat point data using substrate size and embeddedness attributes as classifiers. Bathymetry contours represent 10 m depth intervals based on a reference surface elevation of 125 m GSC. Topography contours represent 100 m elevations.

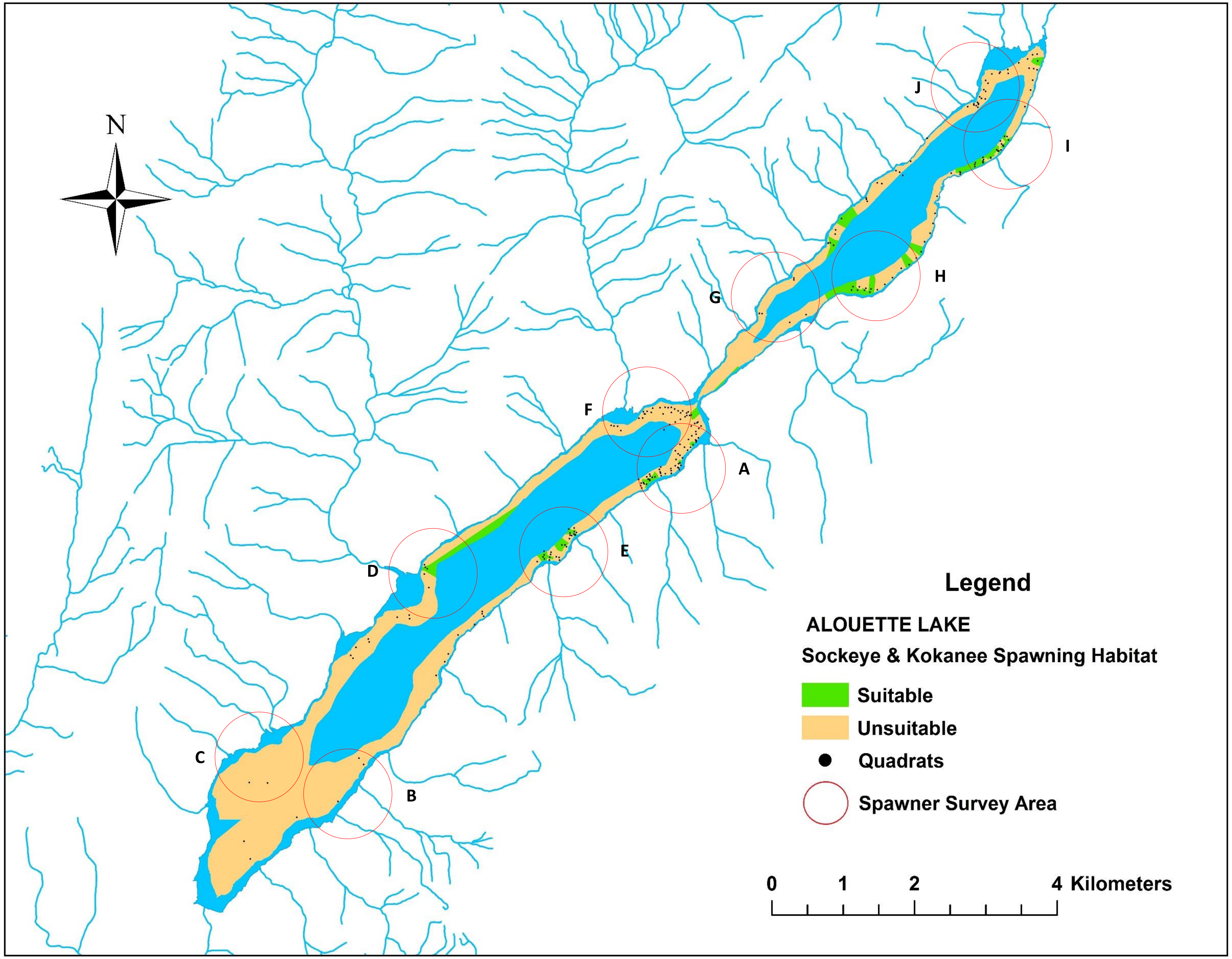

Figure 4-4 Habitat suitability map showing locations and identification of spawner survey areas (i.e. gillnet areas) for Sockeye and Kokanee within Alouette Reservoir, BC.

4.2 Spawner Surveys

4.2.1 Gillnet Surveys

Kokanee were the dominant catch species. RISC nets caught less fish than the 2” mesh nets (Table 4-1). Although the percent of Kokanee relative to the total catch for each net type was similar, bycatch from the 2” mesh nets was biased by a single set in which 403 Peamouth Chub were caught. Bull Trout and non-game species (apart from Peamouth Chub) catch was greater in the RISC nets than in the 2” nets. Bull Trout were more likely to be captured in the larger mesh sizes (6 in 2.5”, 7 in 3”, 7 in 3.5”) of RISC nets relative to the all 2” mesh nets and smaller mesh sizes in the RISC nets (3 in 1.5”). The majority of the captured fish were released back into the reservoir alive. The mortality rate for Kokanee was approximately 20% (Table 4-2). For Bull Trout, the mortality rate was approximately 8% with 35 individuals released alive and 3 mortalities.

Table 4-1 Spawner survey catch by species and net type (all 2” mesh nets versus RISC nets, which consisted of seven different mesh sizes: 1”, 3.5”, 2”, 3”, 1.5”, 2.5”, 1.25”).

Species	All Nets		2” Nets	RISC Nets
	Frequency	% Frequency	Frequency	Frequency
BT	38	1.4	13	25
CC	6	0.2	2	4
CR	1	< 0.1	1	0
CT	14	0.5	9	5
KO	1754	64.1	1197	557
NSC	108	3.9	43	65
PCC	786	28.7	613	173
SU	29	1.1	8	21
Total	2736	100.0	1886	850

Table 4-2 Fate of fish caught in gillnets during spawner surveys. Fate categories include: E = escaped, R = released alive, M = mortality, S = sacrifice, S/M = sacrifice of likely mortality, and U = unknown.

Fate	All Catch		Kokanee	
	Frequency	% Frequency	Frequency	% Frequency
E	6	0.2	6	0.3
R	1753	64.1	1159	66.1
M	393	14.4	346	19.7
S	185	6.8	184	10.5
S/M	19	0.7	19	1.1
U	380	13.9	40	2.3
Total	2736	100.0	1754	100.0

Patterns between CPUE calculated based on net set times and total soak times were similar (Figure 4-5 and Figure 4-6); the major difference being that absolute values for CPUE based on total soak times were lower. Comparing CPUE for Kokanee only, CPUE was greater for 2” nets than RISC nets. CPUE peaked was generally in the month of November at all sampling areas. Areas A, B, and E had the greatest CPUE at 40-60 Kokanee per 100 m^2 of net per hour (Figure 4-5). CPUE in these areas was also sustained at high levels over a period of weeks. At Areas D, F and E, CPUE was less the 20 Kokanee per 100 m^2 of net per hour, and rates were not sustained over time. CPUE at Area C was similar. The remaining areas had low Kokanee catch throughout the sampling period.

The start depth for net stations ranged from 4-21 m with a mean depth of 11 m and median depth of 9 m. End depths for nets ranged from 22-129 m with a mean of 82 m and median of 77 m; shallower end depths were associated with areas in the south basin where the maximum lake depth was less than 80 m. Looking only at Kokanee in spawning condition (maturity classes M/SP, SP, SP/ST), catch depths based on the mid-point of each net panel ranged from 7 m to 105 m; most Kokanee were captured at depths between 15 m and 70 m (Figure 4-7).

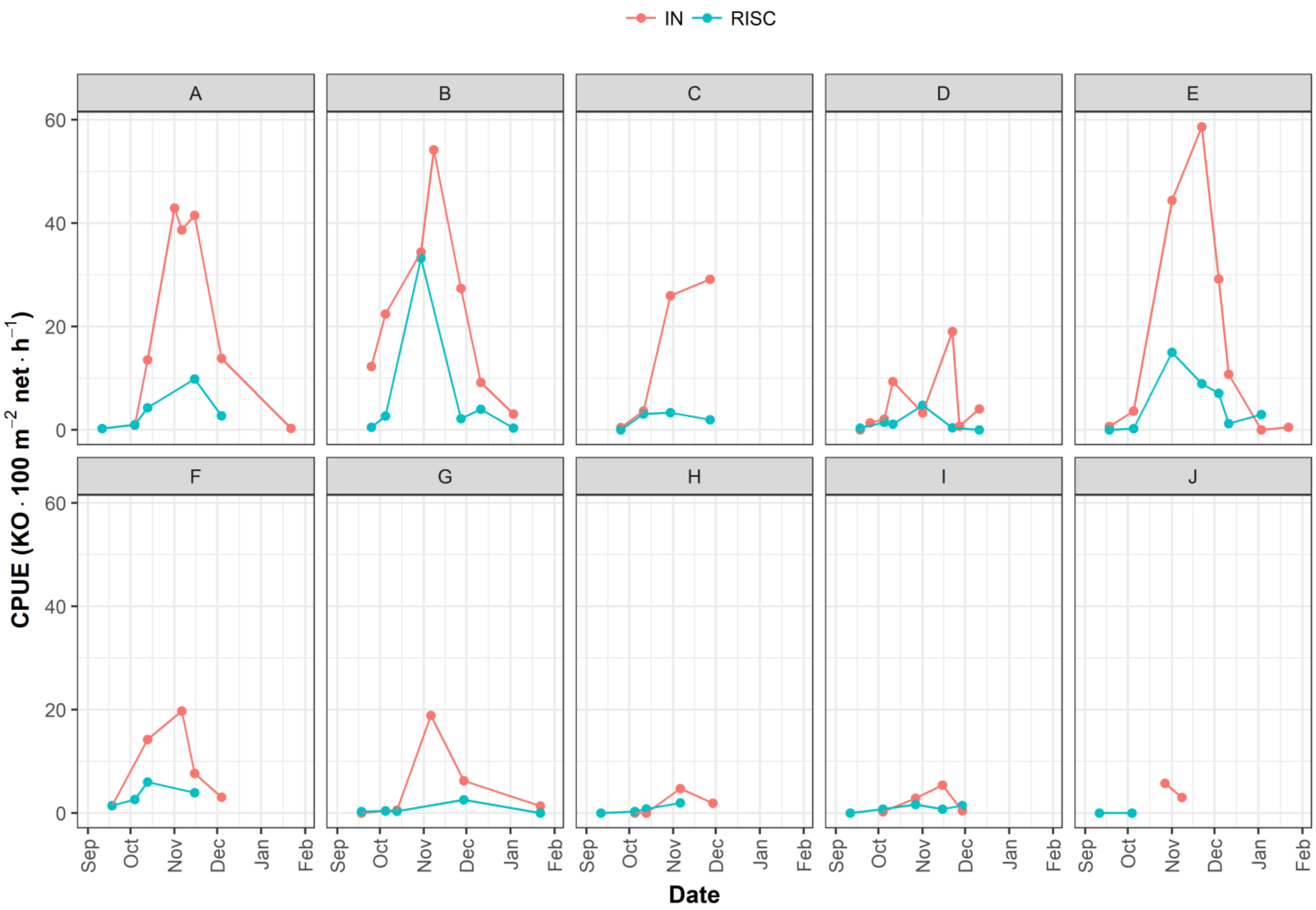

Figure 4-5 Catch-per-unit-effort CPUE) based on net set times (time elapsed from the end of net setting to the start of net retrieval; represents undisturbed net time) for Kokanee catch only; CPUE is shown according to sampling area (A-J) and net type (IN = all 2" mesh nets, RISC = standard variable mesh nets) for 2017-18 spawner surveys on Alouette Reservoir, BC.

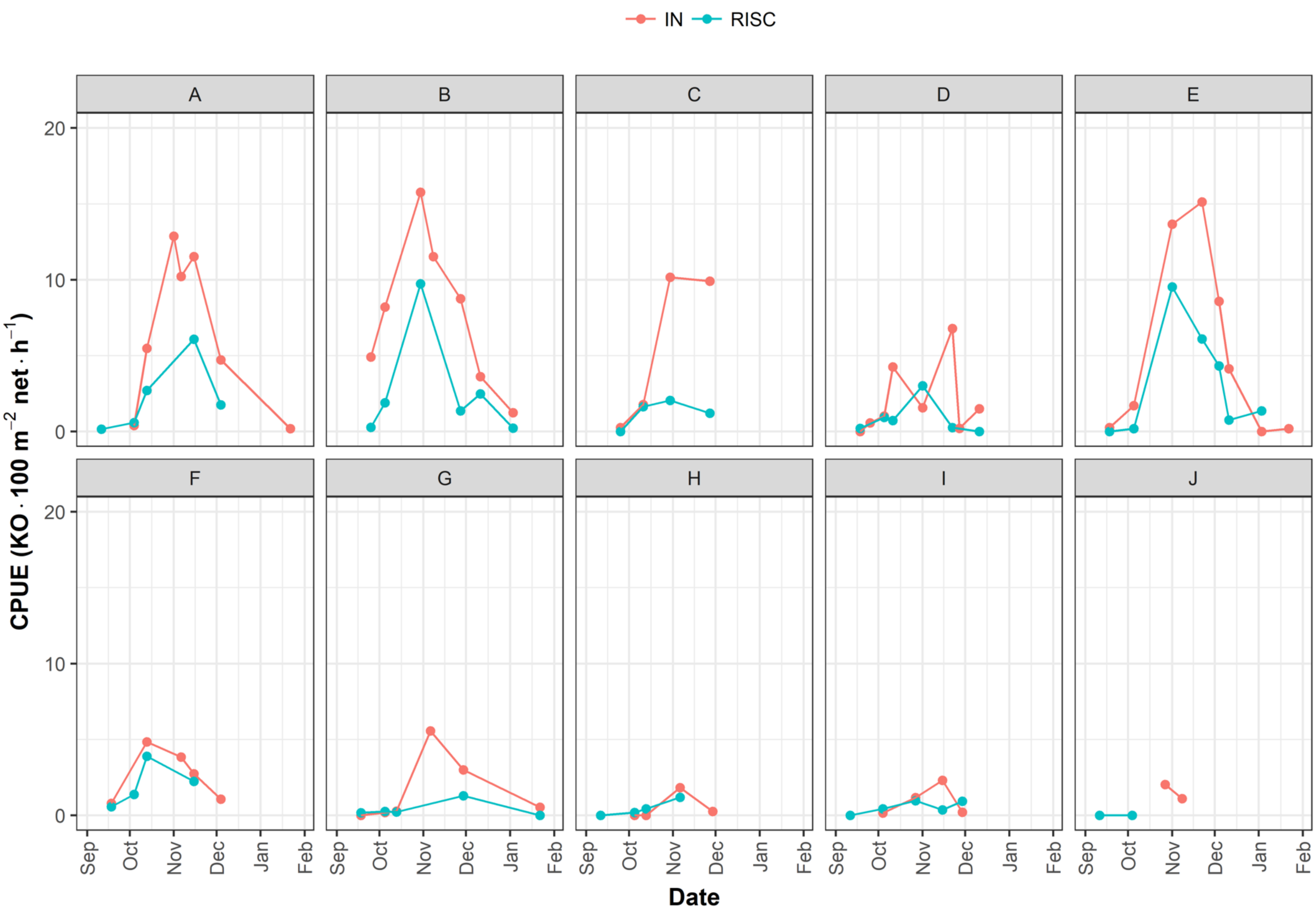

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Figure 4-6 Catch-per-unit effort (CPUE) based on total soak times (time elapsed from the start of net setting to the end of net retrieval; represents total possible fish encounter time) for Kokanee catch only; CPUE is shown according to sampling area (A-J) and net type (IN = all 2" mesh nets, RISC = standard variable mesh nets) for 2017-18 spawner surveys on Alouette Reservoir, BC.

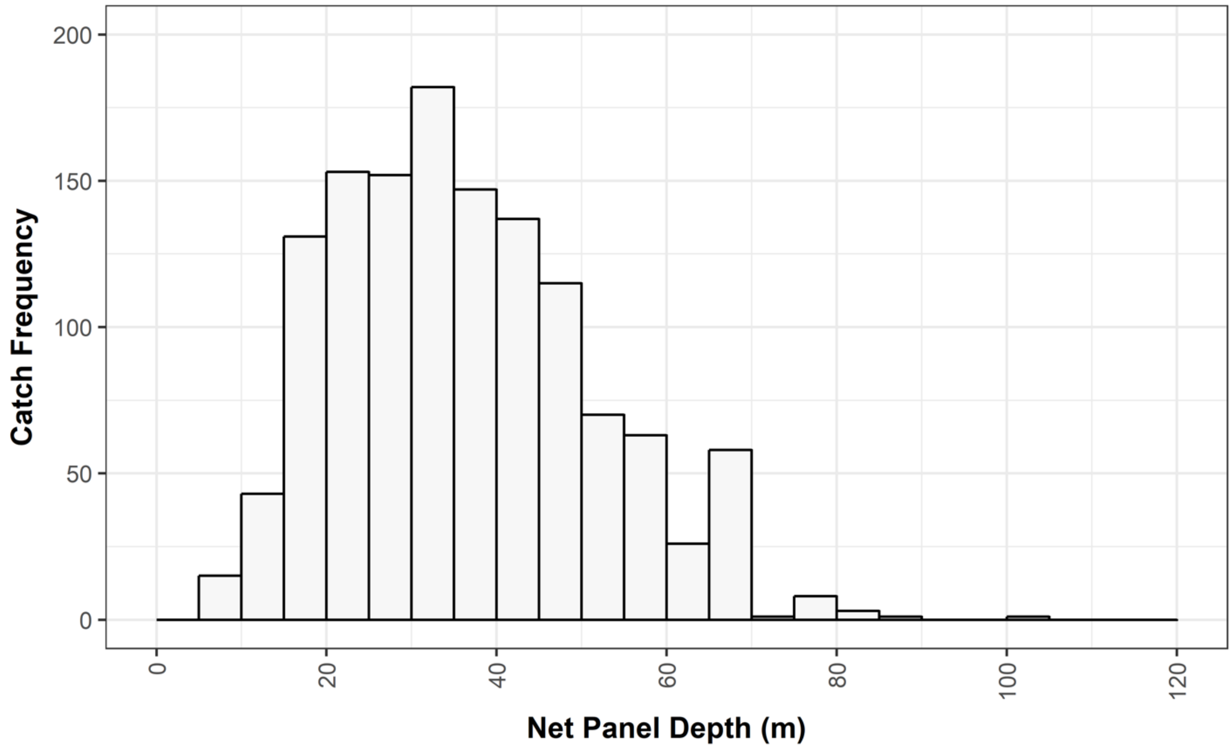

Figure 4-7 Catch frequency of spawning Kokanee by net panel depth (represented by the midpoint of each panel and corrected to a reference surface elevation of 125 m GSC) during spawner surveys on Alouette Reservoir, BC.

Kokanee caught in nearshore areas during the early part of the sampling period was biased towards males (Figure 4-8). Catch of female Kokanee did not increase until November (Figure 4-8). Even when greater numbers of females were captured (throughout November), catch remained male biased (Figure 4-8). Overall, the sex ratio of males to females was greater than 2:1 with a total of 1234 males and 447 females (32 unknown) captured.

During September, Kokanee caught in nearshore areas were still maturing or mature, and not yet spawning (Figure 4-9). Spawning Kokanee were caught in abundance from early October to mid-December with very few individuals in January. The majority of Kokanee in spawning condition were captured during the month of November (Figure 4-9).

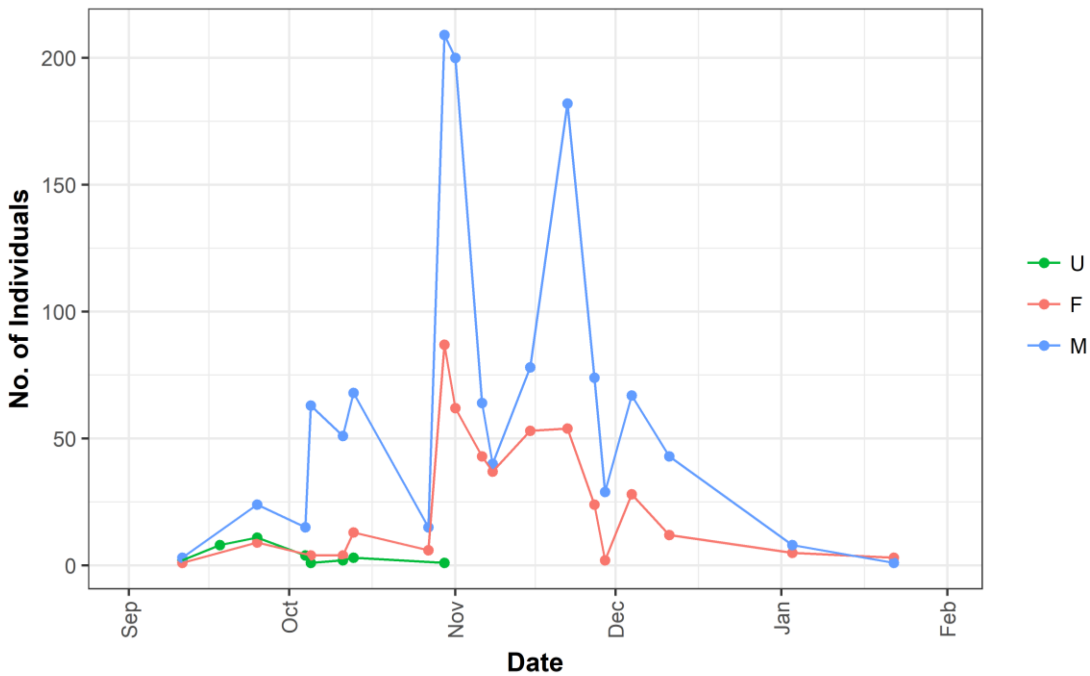

Figure 4-8 Number of Kokanee captured by sex during 2017-18 spawner surveys on Alouette Reservoir, BC. Sex is indicated by: U = undetermined, F = female, and M = male.

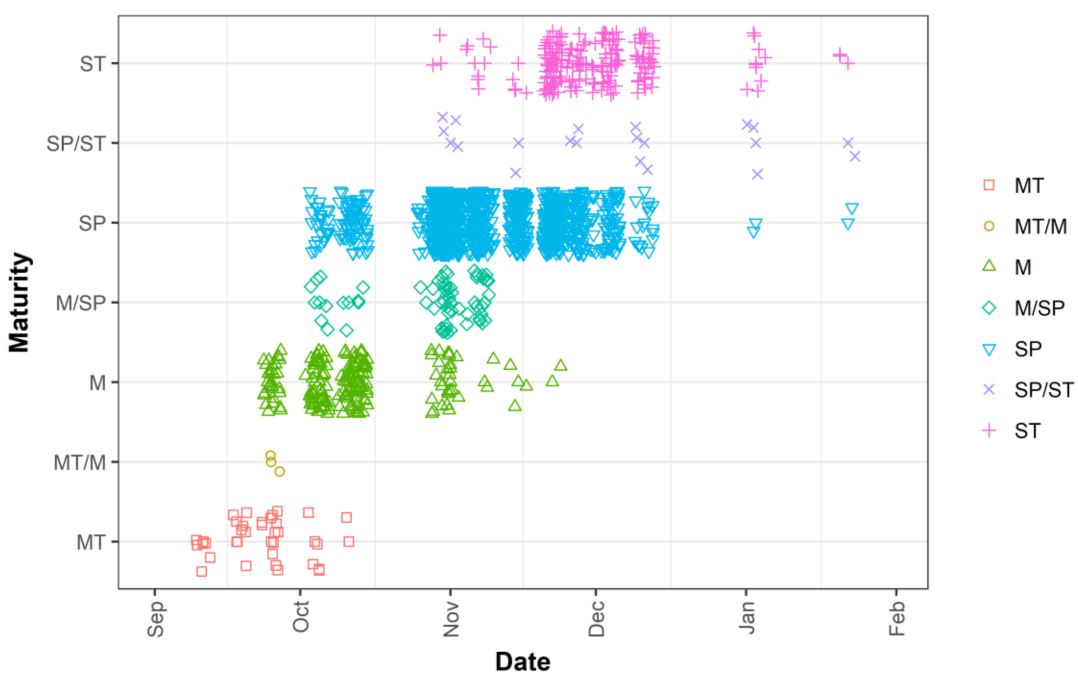

Figure 4-9 Maturity classification of Kokanee captured throughout 2017-18 spawner survey sampling period on Alouette Reservoir, BC. Maturity categories include: MT = maturing, M = mature, SP = spawning, and ST = spent; a slash indicates a fish that was very close to being in the next category.

4.2.2 Remote Operated Vehicle (ROV) Surveys

Redds were observed in Area A up to 50 m deep. Area A was characterized by gravel, cobble gravel and gravelly cobble embedded from < 20% to 41-80% (Figure 4-10); these habitat types that would be classified as suitable for spawning. Gravels were typically in the size range of pebble gravel. In areas less than 17 m deep, organics (leaf litter) covered substrate. At depths greater than 35 m, embeddedness was primarily 41-80% and > 80% with localized areas of gravel free of fine sediment (i.e. embeddedness < 20%).

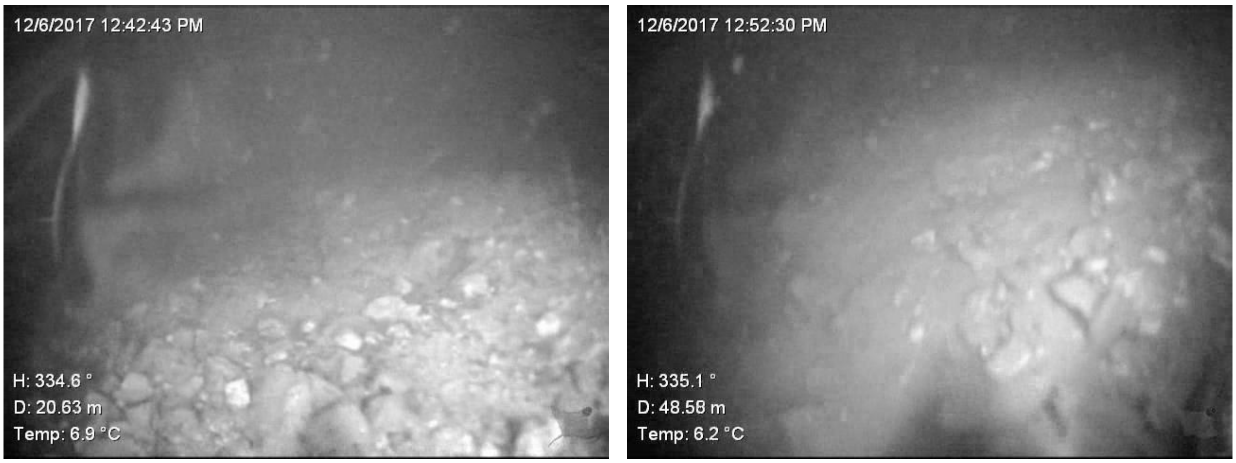

Figure 4-10 Remote operated vehicle (ROV) imagery showing example substrate types (gravel with embeddedness < 20% and 41-80%) in Area A of Alouette Reservoir, BC.

Redds were observed in Area B at depths from 25-40 m in mixed sand and granule gravel (2-4 mm) substrate embedded (> 80%) with fine sediment in most areas except for actual redd locations. Exact particle size differentiation at the scale of sand and granule gravel was difficult with the ROV. Additional habitat types observed at depths from 10-60 m in Area B included deep fine sediment (embeddedness > 80%) and embedded cobble (embeddedness 41-80% and > 80%). Habitat in Area B (Figure 4-11) would be classified as unsuitable spawning habitat.

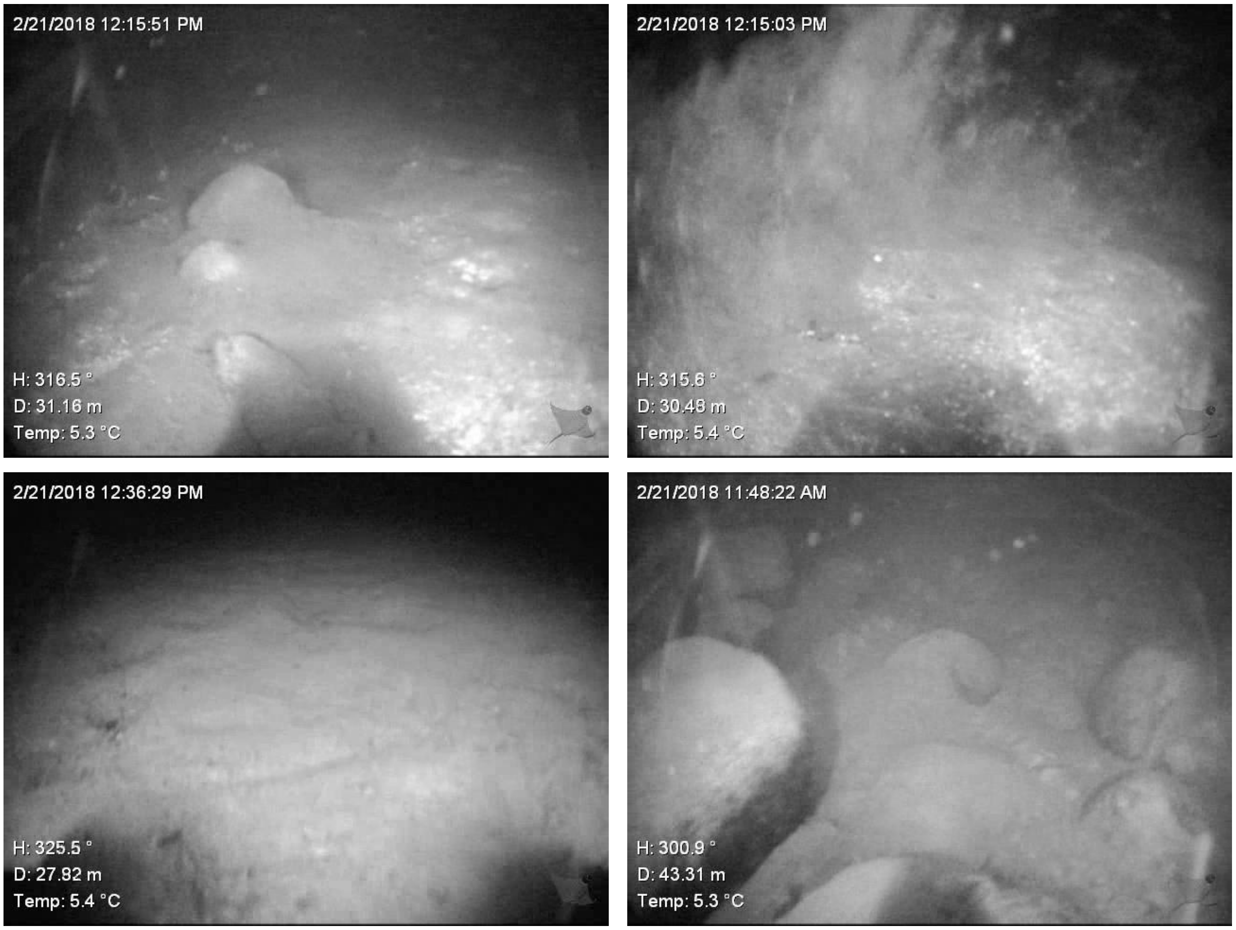

Figure 4-11 Remote operated vehicle (ROV) imagery showing example substrate types (from left to right, top to bottom: sand and granule gravel with embeddedness < 20% and > 80%, sand and granule gravel with embeddedness 21-40%, fine, cobble with embeddedness 41-80%) in Area B of Alouette Reservoir, BC.

ROV imagery in Area C (Figure 4-12) taken during the spring reconnaissance survey showed localized areas of sand (8-12 m) and gravelly sand (15-27 m) both of which were typically embedded (41-80% and > 80%) with fine sediment or were covered in organics (generally organics were limited to depths less than 15 m). Winter ROV surveys found only fine sediment (embeddedness > 80%) from depths of 20-60 m; spawning activity was not detected.

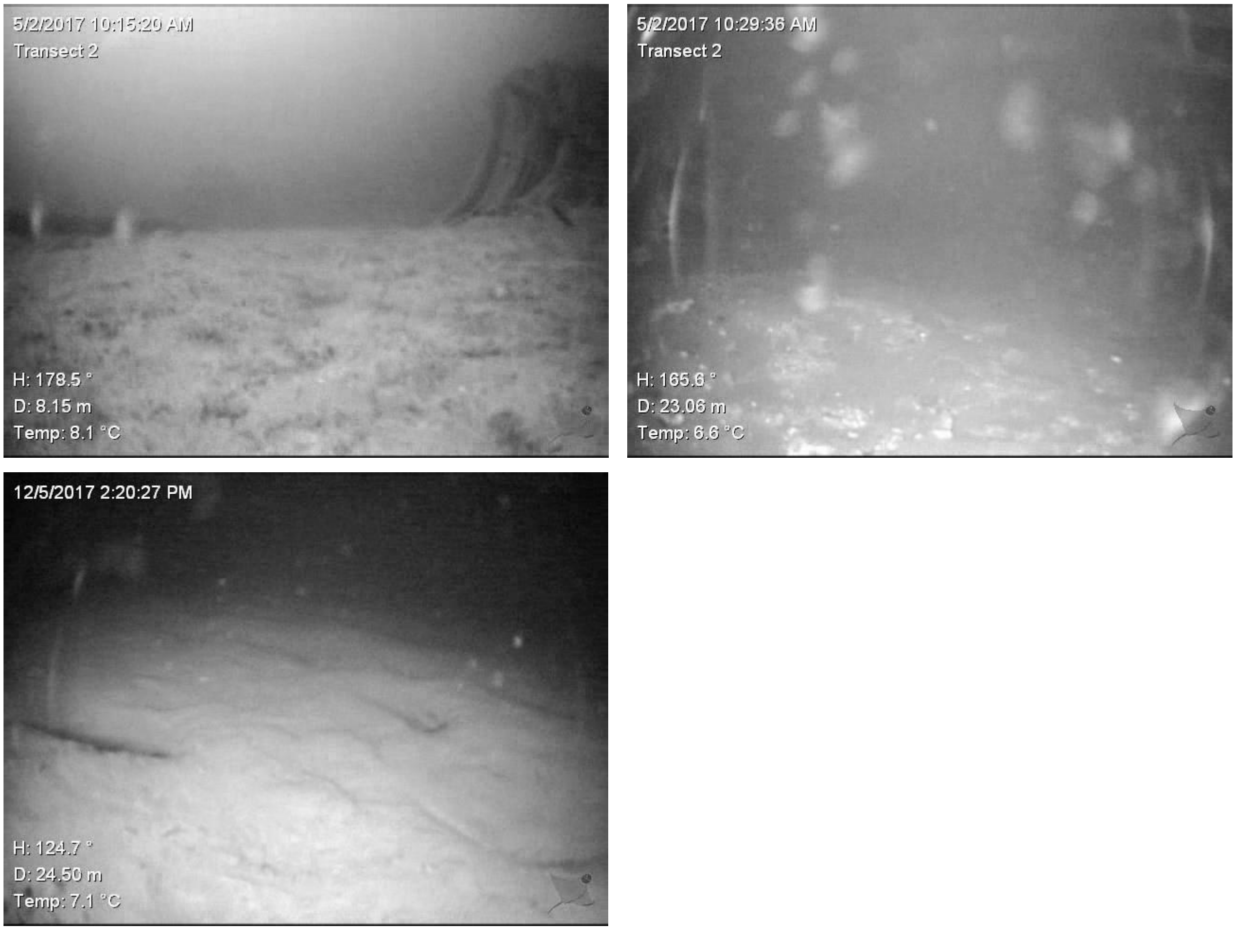

Figure 4-12 Remote operated vehicle (ROV) imagery showing example substrate types (from left to right, top to bottom: sand, gravelly sand with embeddedness 41-80% and > 80%, fine) in Area C of Alouette Reservoir, BC.

ROV imagery of Area D (Figure 4-13) showed organics and gravelly sand (embeddedness from < 20% to 41-80%); fine sediment (embeddedness > 80%) was observed beyond 12 m depth. Area D would be classified both as suitable and unsuitable spawning habitat.

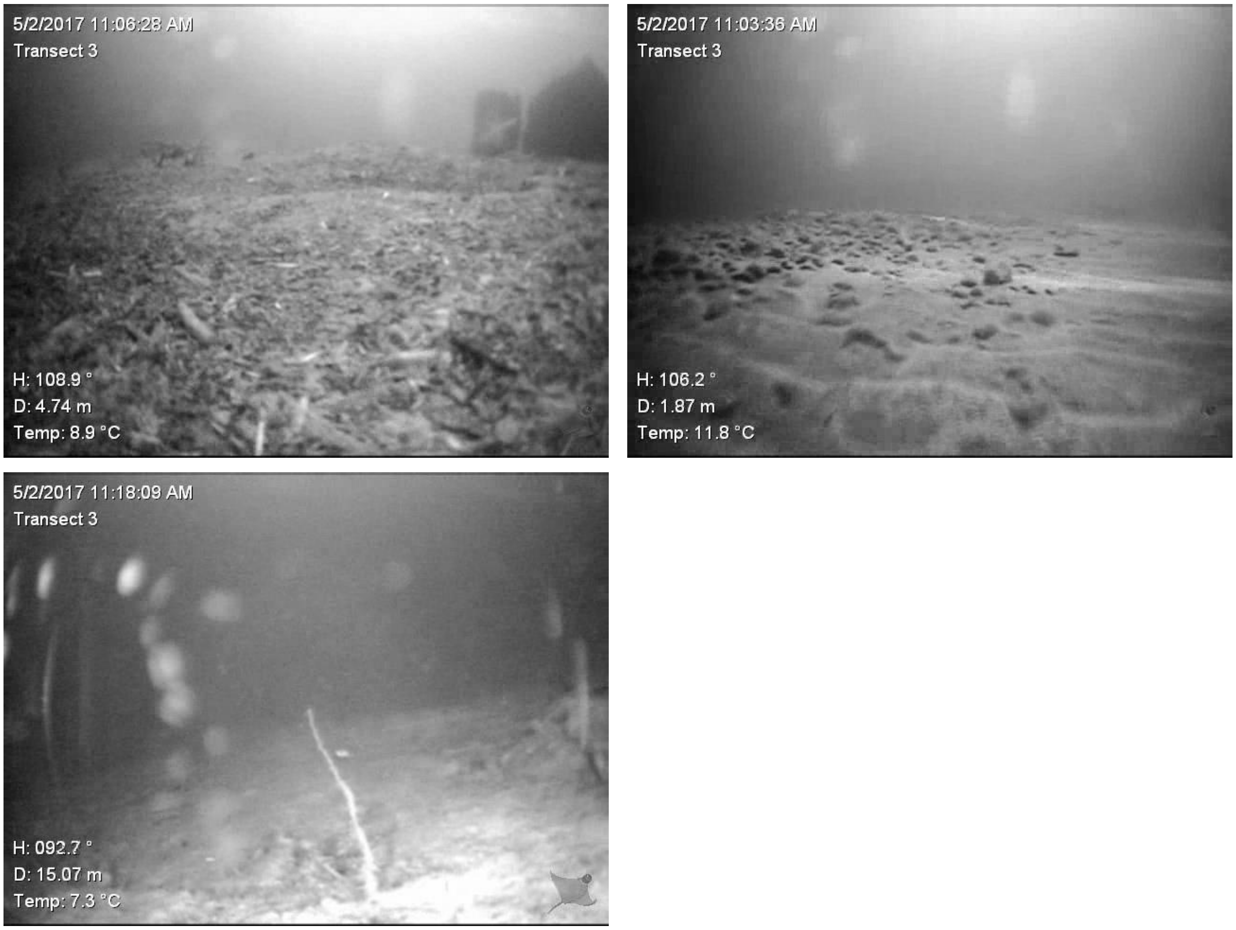

Figure 4-13 Remote operated vehicle (ROV) imagery showing example substrate types (from left to right, top to bottom: organic, gravelly sand, fine) in Area D of Alouette Reservoir, BC.

Redds were observed in Area E from 25-70 m in depth; live Kokanee were also observed in areas of clean (embeddedness < 20%) gravel (Figure 4-14). Generally, Area E offered extensive areas of pebble gravel with < 10% granule gravel and embeddedness < 20% and or 21-40%. In waters less than 10 m deep, organics (leaf litter) covered the substrate. Common aggregates observed throughout Area E were gravel, cobble gravel and gravelly cobble. Habitat from 20-76 m consisted of a matrix of common aggregates with embeddedness ranging from < 20% or 21-40% to 41-80% or > 80% (Figure 4-14); typically, embeddedness increased with depth. Where embeddedness was > 80%, the layer of fine sediment was relatively thin, as the ROV could touch down without sinking into a deep layer of fines. Overall, Area E would be classified as suitable spawning habitat.

Figure 4-14 Remote operated vehicle (ROV) imagery showing a Kokanee over gravel substrate (top left) as well as example substrate types (top right: gravel with embeddedness < 20%, bottom left: gravel with embeddedness 21-40% and 41-80%, bottom right: cobble gravel embeddedness > 80%) in Area E of Alouette Reservoir, BC.

Area F was classified as unsuitable spawning habitat. The dominant substrate in Area F was fine; isolated sites of cobble with embeddedness 41-80% and or > 80% were also observed (Figure 4-15). Small and large woody debris were present throughout the area. No evidence of spawning was detected.

Figure 4-15 Remote operated vehicle (ROV) imagery showing example substrate types (from left to right: cobble embeddedness > 80%, fine) in Area F of Alouette Reservoir, BC.

Redds were observed in Area G from 47-42 m (Figure 4-16), but evidence of spawning activity in the area was limited overall. Substrate in Area G was characterized by cobble gravel or cobble embedded with fine sediment from < 20% to > 80% depending on the specific location (Figure 4-16). Organic debris over finer substrate (possibly sand) was observed from 10-18 m; small and large woody debris were observed in abundance at all depths surveyed (up to 53 m).

Figure 4-16 Remote operated vehicle (ROV) imagery showing a cleaned redd (top left) as well as example substrate types (top right: cobble gravel with embeddedness 41-80%, bottom left: cobble with embeddedness 41-80%) in Area G of Alouette Reservoir, BC.

ROV imagery in Area H (Figure 4-17) showed cobble gravel with < 20% embeddedness at depths less than 7 m and gravel substrate embedded < 20% at 37-40 m. Fine sediment (embeddedness > 80%) was present in surrounding areas. An abundance of small and large woody debris made ROV navigation and therefore lakebed observation difficult. No evidence of spawning activity was detected. The presence of clean gravel at depth resulted in the classification of this area as suitable spawning habitat.

Figure 4-17 Remote operated vehicle (ROV) imagery showing example substrate types (from left to right: gravel with embeddedness < 20%, fine) in Area H of Alouette Reservoir, BC.

ROV navigation in Area I was difficult due large quantities of small and large woody debris. Substrate types observed from 23-75 m included a mix of gravelly sand, cobble gravel, gravelly cobble, and cobble with varying degrees of embeddedness ranging from < 20% to > 80% (Figure 4-18). There was also a minor component of boulder (i.e. < 10%). Area I was classified as suitable spawning habitat. Clear evidence of spawning activity was not observed.

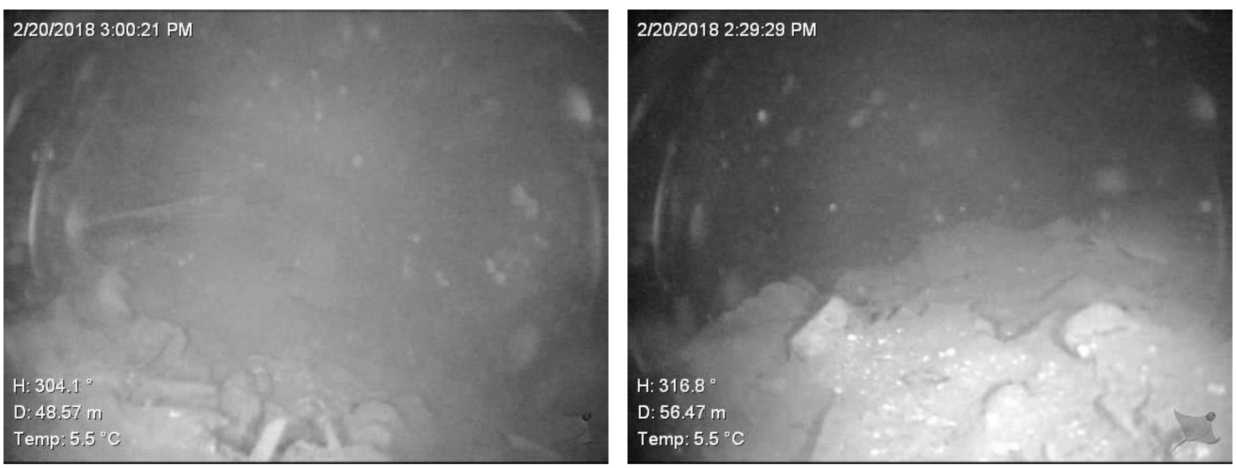

Figure 4-18 Remote operated vehicle (ROV) imagery showing example substrate types (from left to right: gravelly cobble with embeddedness 41-80%, cobble gravel with embeddedness 21-40%) in Area I of Alouette Reservoir, BC.

Area J was unsuitable spawning habitat. Gravelly sand and organics were observed at less than 18 m in depth; beyond 18 m was fine sediment (embeddedness > 80%) with < 10% boulder (Figure 4-19). No evidence of spawning activity was detected.

Figure 4-19 Remote operated vehicle (ROV) imagery showing example substrate types (from left to right: organic gravelly sand, fine) in Area J of Alouette Reservoir, BC.

ROV transects in areas within the north basin and Areas C and D did not meet the desired level of sampling intensity. In some locations the amount of large and small woody debris prevented the ROV operator from being able to stay close to the bottom and so sections of the transects were missed with additional neighbouring transects not able to be completed due to the shortened field session (see Section 3.2.2 for details). As a result, habitat could not be fully characterized and possible evidence of spawning activity may have been missed. Still, at least one ROV transect was completed in each area, and the results corroborated quadrat sample data.

5. Discussion

Reservoir spawning habitat

Depth results support our understanding that Alouette *O. nerka* are a deep spawning population. Lake spawning populations of Sockeye and Kokanee may exhibit nest digging or broadcast spawning behaviour. Broadcast spawning *O. nerka* act similarly to Lake Trout in that they spawn over large angular substrate in relatively shallow areas where circulation is driven by wind action (Burgner 1991, Fitzsimmons 1994, Shepherd 2000). Our study and previous work on the Alouette stock (McKusker *et al*. 2003, Plate and Bocking 2013) did not find any evidence of broadcast spawning; the only behaviour observed to date has been nest digging. Sockeye and Kokanee females typically dig their nests or redds in 10-25 mm gravel, though this varies depending on habitat availability and female body size (as females need to be able to move the gravels for nest excavation) (McPhail 2007). Substrate composition is also important for egg survival. Fine sediments (particularly substrate less 0.85 mm; i.e. medium sand grains and smaller as per Wentworth [1922]) that fill gravel interstitial spaces have a negative effect on egg survival (Irving and Bjornn 1984 as cited by Ford *et al*. 1995; Whitlock *et al*. 2015); this is largely attributed to a reduction in the intra-gravel flow required to ensure sufficient oxygen concentrations and for the removal of metabolic wastes during the alevin stage. We used substrate size and embeddedness (i.e. the degree to which fines fill interstitial spaces) as a way to identify potentially suitable spawning habitat in deep water areas of Alouette Reservoir. We then sampled areas of suitable and unsuitable habitat throughout the fall and winter to determine actual habitat selection by Alouette *O. nerka*. We chose this two-stage process, because the habitat requirements and site selection of lake spawning Sockeye and Kokanee have not been studied nearly to the same degree as those of stream spawning populations, and the discrepancy is even larger for deep spawning populations.

We found that substrate size and embeddedness criteria used to estimate habitat suitability were not consistent predictors of actual spawning habitat selected by Kokanee in Alouette Reservoir. Three areas – A, B, and E – were considered primary spawning sites; these locations were noted by high catch rates sustained over two or more sampling events (i.e. greater than a 1-week period) and confirmation of spawning activity. All primary spawning sites were located in the south basin on the east shore of the lake. Areas A and E were on alluvial fans with gravel lakebed at observed spawning depths and originally classified as suitable habitat. Interestingly, Area B was classified as unsuitable habitat as it did not have characteristics typically associated with Sockeye and Kokanee spawning. Although the shoreline was a series of smaller alluvial deposits, substrate at depths greater than 10 m was mixed sand and granule gravel substrate embedded with fine sediment. Actual redd locations did not have the same degree of fines as surrounding areas, which was likely a result of displacement of fines during nest digging activity.

Despite the inconsistencies with the literature, several lines of evidence support that Area B as well as Areas A and E are regular spawning locations. McKusker *et al*. (2003) identified all three of these areas as potential spawning sites; though this was based on observations in the littoral zone at depths shallower than what we observed in this study. Data from Alouette Sockeye tracking and ROV studies conducted by Plate and Bocking (2013) identified clusters of Sockeye in Areas A and B. The use of Area B, specifically, as a spawning location was somewhat confounded due to its proximity to the Sockeye release location and uncertainty as to whether an individual had died after release (Plate and Bocking 2010, 2011, 2013). Based on ROV video, Plate and Bocking (2013) confirmed spawning in Area A with evidence of spawning found in Area B. These findings highlight how assumptions based on current literature for stream and shallow lake spawning Sockeye and Kokanee populations may not be appropriate or accurate for the Alouette stock.

Data from our study identified four additional areas (C, D, F, and G) as possible secondary spawning locations; these areas had lower CPUE than at primary spawning sites and CPUE was not sustained. Spatially, secondary spawning locations were distributed along west shore of the south basin (Areas C, D and F) and southern-most end of the north basin (Area G). With the exception of Area G, all secondary spawning sites were near tributary stream outlets, including Twin North Creek (Area C), Gold Creek (Area D) and Moyer Creek (Area F). All areas except Area D (Gold Creek) were originally classified as unsuitable spawning habitat; specifically, Areas C and F were fine lakebed, while Area G was coarse lakebed. We were able to confirm localized spawning activity in Area G during ROV surveys. At the remaining secondary spawning locations, spawning activity was not confirmed. Although at least one ROV transect from 5-45 m was completed at each site in an effort to detect spawning activity, surveys would ideally involve multiple transects completed in a single area from depths of 5-80 m. Unfortunately, ROV surveys were only partially completed due to equipment failure and inclement weather resulting in safety concerns. Therefore, it is possible that spawning activity was occurring at Areas C, D and F, but was in low densities and simply not detected during winter ROV surveys.

Data indicated that Kokanee spawning was not occurring in remaining areas (H, I and J); all of which were all located in the north basin. Again, these results were counterintuitive, as habitat data suggested that spawning size gravels with relatively low embeddedness values (compared to confirmed spawning locations, e.g. Area B) were available at Areas H and I. Moreover, tracking data showed clusters of Sockeye at the north end of the north basin in multiple years and previous ROV surveys found some evidence of spawning (Plate and Bocking 2013). Our results emphasize the importance of multi-year studies that capture the natural variability in a natural system; a key finding also of Plate and Bocking's work (2010, 2011, 2013).

We know that *O. nerka* as a species exhibit a truly diverse range of reproductive behaviours. And yet with the wealth of literature on their life history and habitats, in some instances, such as the in the Stikine River system, these fish will spawn and rear in habitat that would be considered unsuitable for the species (Wood *et al*. 1987). Deep lake spawning, in general, could be considered in the same respect, as it is a rare among Sockeye and Kokanee populations. In the context of population restoration, the assumption is, if suitable spawning habitat is available then Sockeye and Kokanee will use it. Yet, we do not know if this will be the case. How Sockeye and Kokanee select spawning sites is complex. In their extensive review on spawning migrations, Bett and Hinch (2016) propose that salmonids use a hierarchical set of criteria to identify spawning grounds; in order of importance, these cues are: olfactory imprinting, the presence of conspecifics, and environmental variables such as substrate, flow, temperature, and dissolved oxygen. While Bett and Hinch (2016) note that the relative attractiveness of different environmental cues is not well studied, this strategy makes sense as a behavioural adaptation. The scale at which salmon act upon these cues has been shown to be remarkably fine scale (to the point of specific incubation units) in both lakes and streams (Stewart *et al*. 2003, Quinn *et al*. 2006). Still, lake spawning Sockeye exhibit greater variability in the final phase of their spawning migration than stream spawners (Young and Woody 2007), which may suggest a lower degree of site fidelity, and therefore greater relative importance of conspecifics and environmental factors as drivers of spawning habitat selection.

More importantly for Sockeye restoration is that spawning success does not equal incubation success. Experiments on incubation success at a gradient of used and unused sites by lake spawning Kokanee found that egg survival was highly variable within used spawning areas despite there being apparent suitable spawning habitat available in other areas (Whitlock *et al*. 2015). In Alouette Reservoir, we confirmed spawning in a range of habitat types, but egg survival and potential variability in survival across habitat types is unknown. Adequate dissolved oxygen levels are critical for successful incubation; and areas with large amounts of fine sediments typically have lower dissolved oxygen concentrations. In fact, spawning areas in Lake Pend Oreille with substrate entirely below 4 mm (i.e. granule gravel, sand, and fines; Appendix A) – as in Area B in Alouette Reservoir – reached threshold dissolved oxygen concentrations ($\leq 4\ mg \cdot L^{-1}$) during the incubation period and resulted in 0% survival (Whitlock *et al*. 2015).

For deep spawning populations, as with other lake spawners, it seems likely that areas with groundwater influence would be an important contributor to site selection and egg survival, and therefore should be included in the definition of suitable spawning habitat. In Iliamna Lake, beaches with suitable substrate but without upwelling were not used by lake spawning Sockeye; rather selected spawning areas had "coarse sand" substrate (actual size in mm undefined) and were heavily influenced by upwelling (Burgner 1991). The influence of groundwater on potential spawning areas is unknown and may account for the discrepancies in expected site selection. At the spawning depths observed in Alouette Reservoir, measuring groundwater influence directly would be difficult. This type of assessment would require divers for equipment installation and would be limited to depths less than 30 m (due to dive safety limitations). Modifications to standard mini-piezometers and stilling wells used in groundwater studies to determine hydraulic gradient (i.e. downwelling, upwelling) would also be required. Another possibility would be to use seepage meters to detect upwelling and rates; yet this method would require multiple dives to install and purge the instrument, and then to collect the samples. Seepage meters would also be limited to detecting upwelling only; and would not give any information on downwelling. Other variables such as temperature and conductivity could be used as proxies for detecting the possible influence of groundwater, as the physical and chemical properties should be different than lake water (Freeze and Cherry 1979, Wetzel 2001). Collection of detailed physical and chemical environmental data would allow us to refine the definition and estimates of potentially suitable spawning habitat within Alouette Reservoir, as well as inform us on the underlying mechanisms for site selection in deep water spawners.

Overall, spawning habitat selection by Alouette *O. nerka* may be attributed to fine-scale homing abilities (olfactory navigation based on imprinting to very specific sites), behavioural responses (presence of conspecifics, search for mates, etc.) and or environmental characteristics (physical and chemical characteristics of sites besides substrate composition that encourage or discourage use of some sites over others, such as groundwater). And while spawning site selection was investigated and the presence of redds were confirmed in a range of substrate compositions, differences in incubation success remains unknown.

At this stage, spatial analyses of potential suitable spawning habitat for Sockeye and Kokanee in Alouette Reservoir were considered too coarse to reliably assess capacity; while this could be done, the level of uncertainty surrounding estimates would reduce their significance. Based on substrate composition variables alone, first indications suggest that spawning habitat would not be the limiting factor for Sockeye and Kokanee in the reservoir. Answering this key question can be achieved by collecting additional data on substrate composition combined with new physical and chemical habitat variables.

Spawning timing and behaviour

Kokanee in various states of maturity (but that were expected to spawn during the sampling period) were present in nearshore areas from September though January. Peak spawning activity occurred in November, as indicated by maturity data and the presence of females on the spawning grounds. Ripe males arrived on the spawning grounds earlier than females, a reproductive tactic observed in many taxa, including *Oncorhynchus* (Morbey 2000, Morbey and Ydenberg 2001). Additionally, males were more abundant than females overall throughout the sampling period. There was a fraction of Kokanee caught early in the season (September and October) where sex could not be determined by external observation, and it is possible that these were generally maturing females. Early arriving “silver” females have been observed in other Kokanee populations, such as Meadow Creek in Kootenay Lake (Morbey and Guglielmo 2006). Early arrival and longer pre-spawn waiting times were more often exhibited by younger females when compared to the age of the general spawning population (Morbey and Guglielmo 2006). Even if these early arriving fish were "silver" females, males were still overrepresented in the catch. While the sex ratio of the Alouette spawning population may have been male biased, it is also possible that males were more vulnerable to sampling gear, as they demonstrate greater ranges of movement than females when on spawning grounds (Foote 1990).

In Seton and Anderson lakes and Lake Saiko, the carcasses of deep spawners commonly float to the surface following senescence (Morris and Caverly 2004, Nakabo *et al*. 2011). Observations of carcasses have been used as a coarse method of detecting spawning areas and timing (Morris and Caverly 2004). In Alouette Reservoir, however, we did not observe any spawner carcasses floating on reservoir surface or washed-up on shore throughout the sampling period. Neither did we observe any congregations of wildlife that would indicate the presence of carcasses. Furthermore, no carcasses were observed on the lake bottom during winter ROV surveys. And so, reliance on these types of observations for the detection of possible spawning areas or as indication of spawning timing would be inadequate in Alouette Reservoir.

Methods effectiveness – catch, bycatch, fate

A comparison of standard RISC nets to the all 2" mesh nets was undertaken to determine the efficacy of variable mesh nets (i.e. standard RISC nets) that are commonly used in other fisheries assessments for the study deep spawning populations. Overall, we found that CPUE for Kokanee in the RISC nets was consistently lower than in the all 2" mesh nets. As well, bycatch was greatest in RISC nets. Bull Trout bycatch was of interest given the South Coast British Columbia population is designated as a species of special concern (COSEWIC 2012). The Alouette Bull Trout population is also considered low enough to be closed to angling. Though Bull Trout only made up 1.4% of the total catch (38 individuals), Regional Biologists typically detect less than 50 individuals in the primary spawning stream (Gold Creek) during population assessments in any given year (Mike Willcox, FLNRO, pers. comm.). Mesh sizes ≥ 2.5" had greater capture frequencies of Bull Trout than mesh sizes at or below 2". Although the on-board mortality rate of Bull Trout was low (3 individuals), post-release stress and mortality was unknown. Any additional efforts that can reduce potential impacts on the Alouette Bull Trout population should be implemented.

The 2" mesh size was selected specifically to target Kokanee based on known selectively curves, as well as a test survey to determine which mesh size had the greatest incidence of Kokanee catch in Alouette Reservoir. Using a single mesh size meant catchability was equal along the entire length of each net gang and allowed us to determine approximate spawning depth based on the corresponding net panel depth. As results showed, the all 2" mesh nets had the greatest catch frequency and CPUE of Kokanee. Overall, the use of short-set gillnetting was an effective means of capturing deep-water spawning Kokanee and evaluating their reproductive behaviour.

Qualitatively, it was noted that the mortality rate for all fish species increased with increased water temperatures, net soak times, the severity or frequency of interactions with nets (e.g. interaction type – gilled, entangled, snagged; capture recurrence), as well as catch volume and the subsequent increase in processing time. It also appeared that Kokanee females were more sensitive to capture effects than males. As well, Kokanee not in spawning condition (i.e. immature, maturing or mature) were more susceptible to mortality. All of these observations are supported by the literature (Patterson *et al*. 2017, Teffer *et al*. 2017). Post-release mortality as a result of the project was unknown. Population assessments of Alouette Kokanee indicate that the abundance of individuals older than age-1 are greater than 60,000 individuals with a healthy recruitment of fry (Hebert *et al*. 2017); as such, we expect the population can handle incidental mortality as a result of the spawner survey program. To improve the immediate survival rate of the program, some small adjustments to the sampling methodology can be made (see Recommendations section); these improvements will be implemented in future years of the program.

6. Recommendations

- Collect additional quadrat data to refine habitat maps and capacity estimates.
- Investigate additional environmental variables (e.g. temperature, dissolved oxygen, groundwater influence) in a more rigorous manner to refine definition of suitable spawning habitat and characterization of spawning habitat selection. This will also assist with evaluating incubation success and shed light on the mechanisms of habitat selection by deep water lake spawners.
- Repeat spawner survey program for at least one more year (to a maximum of three additional years to cover all cohorts based on a typical 4-year *O. nerka* life cycle) to demonstrate repeatability and allow generalization of results for the population. Considerable variability has been observed in the spawning behaviour of the Alouette stock from year-to-year. This is particularly true for Sockeye return timing (Alouette River Management Society, data on file) and summer-versus-fall Kokanee hydroacoustic data (Hebert *et al*. 2017), both of which may indicate variability in spawning timing window. As well as selection of spawning location as indicated from Sockeye tracking data (Plate and Bocking 2011, 2013).
- Continue approach of conducting spawner surveys once per week during the beginning and end phases of the spawning window, and twice per week during the main spawning period as means of efficient use of resources.
- Eliminate use of RISC nets to minimize bycatch and potential negative effects on at-risk Bull Trout population.
- Shorten net set time to reduce: total soak time, processing time, time and level of interaction fish have with the net, crowding in the recovery tank etc; all of which are aimed at reducing potential negative effects on Kokanee and bycatch. This will also allow for a greater number of sets in a typical field day and increase coverage of the reservoir.
- Eliminate marking of Kokanee using adipose clips to reduce handling time. Instead, tag all Kokanee using fine monofilament T-bar anchor tags to better track individuals throughout the program. This method is also faster than fin clipping, which will keep handling times low.
- Based on Task 2 Year 1 results, future experiments that involve broodstock collection and use of a hatchery should consider the following:

- Collection of Kokanee broodstock during mid-November using 2” mesh nets that are set for less than 10 minutes. Primary spawning locations best suited for broodstock collection were all on the east shore of the south basin, specifically Areas A, B, and E.
- Based on the initial assessment of the spawning window, adult Sockeye will require holding from their return time (as early as the first two weeks of July) to October (males) or November (females) and possibly longer depending on the individuals.

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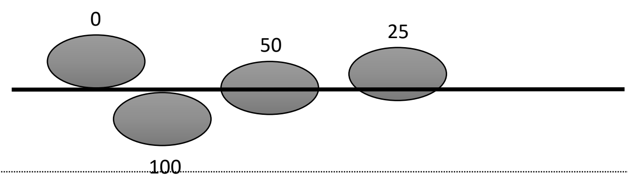
8. Appendices

Appendix A: Substrate classification system and terms

Code	Class	Size (mm)	Description
B	Boulder	> 256	Boulder
C	Cobble	64 to 256	Cobble
P	Pebble	4 to 64	Pebble gravel
G	Granule	2 to 4	Granule gravel
S	Sand	1/16 to 2	Sand (ranges from very coarse to very fine depending on size)
F	Fine	< 1/16	Silt / Clay / Fine organic sediments
O	Organic	Variable	Organic debris, wood, leaf litter
R	Bedrock	> 4000	Bedrock
A	Anthropogenic	Variable	Rip rap, concrete, infrastructure etc.

Terms	Aggregate
Boulder	Boulder > 80%
Cobble Boulder	Boulder > Cobble > 10%, Others < 10%
Boulder Cobble	Cobble > Boulder > 10%, Others < 10%
Cobble	Cobble > 80%
Gravelly Cobble	Cobble > Gravel > 10%, Others < 10%
Cobble Gravel	Gravel > Cobble > 10%, Others < 10%
Gravel	Gravel > 80%
Sandy Gravel	Gravel > Sand > 10%, Others < 10%
Gravelly Sand	Sand > Gravel > 10%, Others < 10%
Sand	Sand > 80%
Fine	Silt / Clay / Organic Fines > 80%
Embedded …	Fine > 10%
Organic	Organic > 80%
Organic …	Organic > 10% (organic debris on top of another substrate class)
… / …	Cannot discern dominant substrate class between two

Appendix B: Description of habitat mapping variables

Variable	Description
Embeddedness	Degree to which rock pieces are buried in fine sediments, or to which fine sediments fill the interstitial spaces between rock pieces; 0% = no fine sediments, 100% = rock pieces are completely covered or buried in fine sediment. 
Small Woody Debris (SWD)	Any woody debris with a diameter < 10 cm.
Large Woody Debris (LWD)	Woody material, including root wads, with a minimum diameter > 10 cm.
Macrophytes	Submergent, emergent or floating-leaf aquatic vegetation.

Code	Description (% cover)
0	0
1	1-20
2	21-40
3	41-80
4	> 80

Appendix C: Maturity classification codes and descriptions based on visual observation of fish life stage

Code*	Classification	Description
IM	Immature	Young individuals that have not yet reproduced, fish with undeveloped gonads
MT	Maturing	Ovaries and testes beginning to fill out and take up a large part of body cavity, eggs are distinguishable to naked eye
M	Mature	Fish in spawning colours, gonads at max size, body cavity feels full (especially females), roe or milt ***not*** produced if the body cavity is lightly squeezed
SP	Spawning	Fish in full spawning colours, eggs and milt are expelled from body when lightly squeezed (also referred to as gravid)
ST	Spent	Fish still in spawning colours, eggs or milt totally discharged, body cavity feels empty, genital opening inflamed, gonads empty except for a few residual eggs/sperm
R	Resting	Adult sized fish, spawning colours not as apparent, gonads are very small and eggs may not be visible to naked eye

* a slash (/) separating two different maturity codes (e.g. M/SP) indicates a fish that was very close to being in the next category (e.g. for M/SP a small amount of milt or 1-2 eggs expelled from body when a fish was lightly squeezed, but no more than that)

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TASK 4A - ALOUETTE ADULT SOCKEYE ENUMERATION, 2017

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This project task is part of the Alouette River Sockeye Reanadromization Project committee's efforts to establish fish passage over the Alouette Dam. The project task author would like to thank the current Committee members including: ARMS, BC Corrections - Allco Fish Hatchery, BC Hydro, Department of Fisheries and Oceans, City of Maple Ridge, Katzie First Nations, LGL Limited and Ministry of the Environment and Climate Change. Our appreciation and thanks is extended to the following individuals: Geoff Clayton, Ken Stewart, Cheryl Ashlie and Greta Borick-Cunningham (ARMS); Dr. Lyse Godbout and Christine MacWilliams (Pacific Biological Station-DFO); Bob Bocking, Megan Matthews, and Elmar Plate (LGL Limited); Shannon Harris and Dr. Brett Van Poorten (Ministry of the Environment and Climate Change); Ron MacLean and Mike Ilaender (BC Corrections - Allco Fish Hatchery); Allison Hebert (University of British Columbia, Masters student), Scott Ducharme, Michael Crowe, and Dave Nansen (Fisheries and Oceans Canada); Dr. Dan Selbie (Cultus Lake Research Facility – DFO), Brent Wilson, Alf Leake, and Alexis Hall (BC Hydro); Debbie Miller and Rick Bailey (Katzie First Nation).

ARMS would also like to acknowledge the Fish and Wildlife Compensation Program for funding this project for its first year as a multi-year project.

Executive Summary

Originally, through BC Hydro's Water Use Plan for the Alouette Watershed, a spring surface release from the Alouette Dam has allowed for Kokanee/Sockeye (*Oncorhynchus nerka*) smolts to migrate to the ocean from 2007 to 2017. The first surface releases occurred in 2005 and in 2007 the first adult Sockeye returned to the Alouette Watershed. The 2017 Alouette Sockeye salmon run saw three adults returning between July 25 and August 23, 2017. All three Sockeye were sampled at the Allco trap location, only one was successfully transported to Alouette Lake. Fork length measurements were taken of two Sockeye along with scale and tissue samples taken of all three. The measurements indicated an average fork length of 60.9cm.

The genetic sampling identified all adults originated from Alouette stock. Between the return years of 2005-2013, the smolt to adult (return to the hatchery fish fence) survival of the Alouette Sockeye has ranged from a low of 0.028% in the 2011 smolt year to a high of 1.34% in the 2008 smolt year. (Mathews, 2018 unpublished data).

Since 2007, up to and including the 2017 season, 331 adult Sockeye salmon have returned to the Allco fish fence, 269 of those have been successfully released into the reservoir.

This project aligns with BC Hydro's Fish and Wildlife Compensation Program's Alouette Watershed Coastal Action Plan and the Alouette Salmonid Action Plan (2011). The priorities which are addressed are:

> *Sub-objective 1 - Maximize the viability of anadromous salmonids. Compensation requires increasing present biological productivity to offset hydro development-related declines in productivity. There are myriad ways to compensate for fisheries impacts, and some work better for some species than others and some may be more suited to certain physical settings.*

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1. Introduction

During the 2006 review of the Alouette Water Use Plan (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 WUP. The testing of a specific surface release of $3m^3s^{-1}$ from April to June has indeed facilitated Kokanee/Sockeye out-migration from the reservoir. Since 2005, smolts have successfully outmigrated through the spillway gate during the spring release and to the ocean via the Alouette River (Table 1-1, Mathews et al. 2018 in press).

Table 1-1 Estimated number of smolts leaving the Alouette Reservoir during the spring surface release, 2005-2017.

Year of Smolt Migration	Estimated Abundance of Smolts
2005	7,900
2006	5,064
2007	62,923
2008	8,257
2009	4,287
2010	15,434
2011	35,542
2012	728
2013	6,179
2014	13,413
2015	677*
2016	- ◊
2017	18,633

* Note: 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 the FWCP funding application was denied to run the rotary screw trap and therefore no smolts were enumerated.

The viability and authenticity of Kokanee smolt "re-anadromization" is dependent on the stocks ability to adapt to salt water 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 returning to the Alouette River were collected, counted, aged, genetically tested and released into Alouette Lake. 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 Alouette Water Use Plan was to establish whether out-migrating Alouette Lake Reservoir Kokanee/Sockeye smolts were capable of adapting to an anadromous existence. Adaptation is considered successful when Sockeye return from the ocean environment to spawn in Alouette Lake. 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 (2011-2017) had a shorter fence operation timeframe, which commenced mid-June through to the fall. Tissue samples were also collected from all Sockeye in order to ensure that returning adults were Alouette stock and not strays from other nearby coastal systems.

2. Objectives

Since 2015, the task objectives were to continue the enumeration program as a bridging year between the Alouette Sockeye Adult Enumeration monitoring program (ALUMON#4) as funding by BC Hydro under its Alouette Water Use Plan had ended, and the upcoming timetable for the review of the Alouette and Stave Water Use Plans was still yet to be determined. This bridging year in 2015, and again in 2016, (funded by FWCP) allowed the continued data collection on the number of adult Sockeye returning to the Alouette system up to the Allco fish fence including completion of another year of genetic sampling. This continued sampling would reinforce the baseline data for Sockeye as part of many years of ongoing efforts to re-introduce Sockeye into the upper Alouette Watershed (Alouette Watershed – Salmonid Action Plan and Water Use Plan 2009). These bridging years included the continuation to trap, enumerate, sample, and with the assistance of the BC Corrections supervisor and crew, and to transfer Sockeye into the Alouette Reservoir. In 2017, the task of enumerating and sampling the adult sockeye returnees to the Allco fish fence was funded for the first year as part of a greater project for the Alouette Watershed Sockeye – Fish Passage Feasibility Plan (2017-2027).

As discussed in Plate et al technical feasibility report (Oct 2014), there have been a variety of monitoring studies including the Alouette Sockeye Adult Enumeration Monitor (ALUMON#4) which have 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 to date on Alouette Sockeye and the process needed to be taken to re-establish Sockeye in the Alouette Reservoir. This synthesis report outlines and recommends various ways in which Sockeye can be brought back to the reservoir including hatchery intervention and speaks to the importance of the ongoing adult enumeration and sampling which will be a vital part of this future work.

3. Study Area

The South Alouette Watershed (144 km^2), comprised of the South Alouette River and Alouette Lake Reservoir, are located within the communities of Maple Ridge and Pitt Meadows (Figure 3-1). The site of the Alouette Adult Sockeye Enumeration program is approximately 8 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 migrating adult Sockeye on their way back to the reservoir.

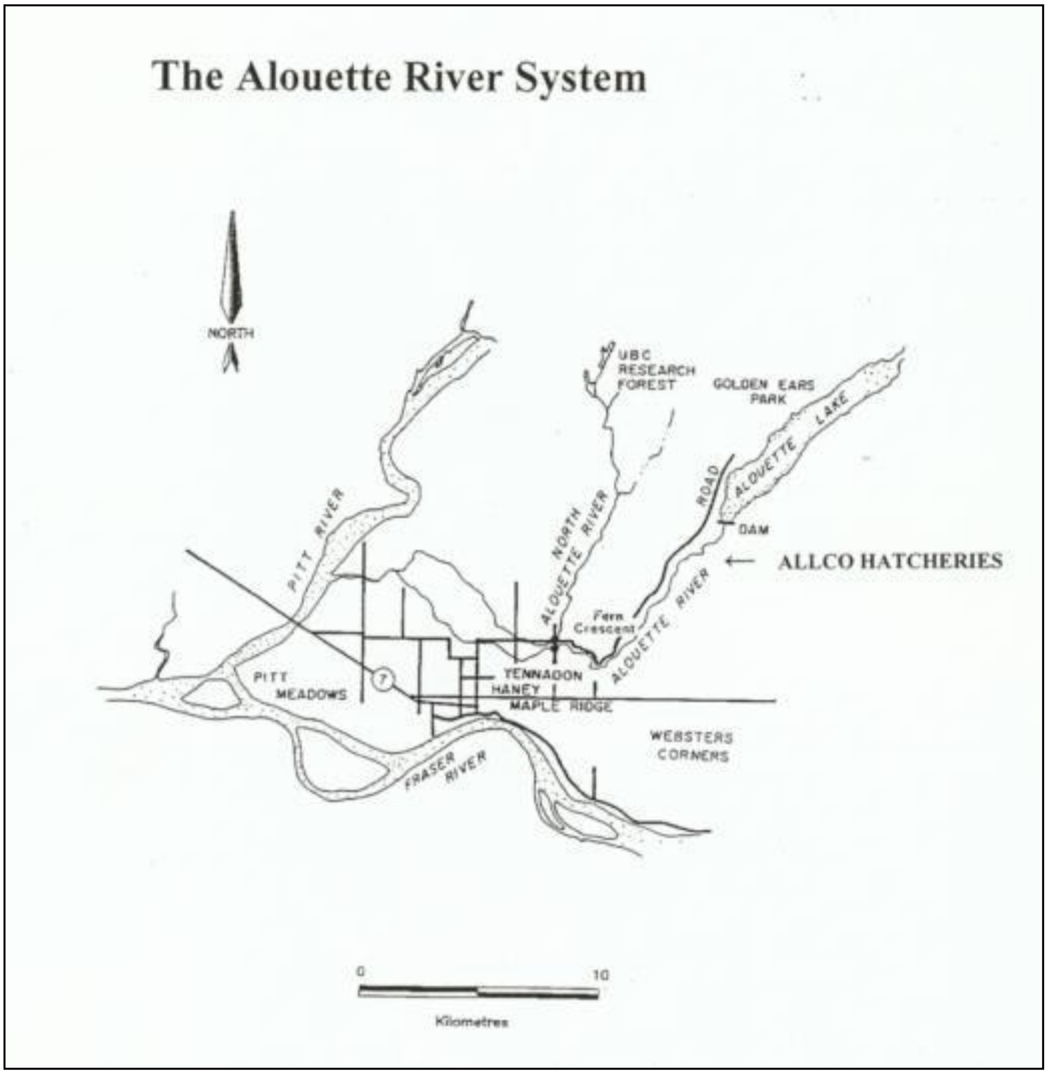

Figure 3-1 Map of the Alouette Watershed

4. 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 fence would be in operation between April and December, rather than year-round (Cruickshank, 2010). In 2011, the fence operation was shortened and the monitor began on June 15, 2011. In 2017, although the Allco fish fence (Figure 4-1) went up on June 15, returning Sockeye sampling dates commenced on July 25th when the first adult arrived and completed on August 23rd when the last adult arrived. The Allco fish fence remained in operation, following the Chum and Coho counts, into 2018 to enumerate the Alouette Steelhead run.

Figure 4-1 Allco Fish Hatchery fence, August 2017.

The fish fence was designed to direct Sockeye and other salmon into the trap, which was monitored daily in 2017 by BC Corrections staff and crew. In case of a failure at the Allco fish fence, BC Hydro operates a trap at the low-level outlet of the Alouette Dam to catch returning Sockeye that are not captured at the Allco fence. There were no fish reported in the Hydro trap in 2017.

Any adult Sockeye caught at the Allco trap, once sampled, are then transported by a specially designed tank and trailer system (Figure 4-2) and released into the Alouette Lake Reservoir.

Figure 4-2 Sockeye transport tanks, May 2014

For each returning Sockeye in 2017, the date of capture was recorded. Out of the three Sockeye two were prespawn mortalities. The first fish to return to the fence, on July 25th, was found on a rock just below the trap and was missing its head. It was sampled and preserved in a freezer for shipping to Pacific Biological Station (Figure 4-3). The second fish returned to the trap and was in very poor condition. As sampling materials were being prepared the Sockeye died in the trap. Samples were still collected and the fish was also packaged and preserved in the freezer until shipping to Pacific Biological Station (Figure 4-4). Additionally, fork length measurements and pictures were taken (Figure 4-5 to Figure 4-8). The tissue and scale samples were sent to the Pacific Biological Station (Department of Fisheries and Oceans) laboratories in Nanaimo, B.C. for genetic analysis.

Figure 4-3 Returning Sockeye photographed and dated – August 23, 2017

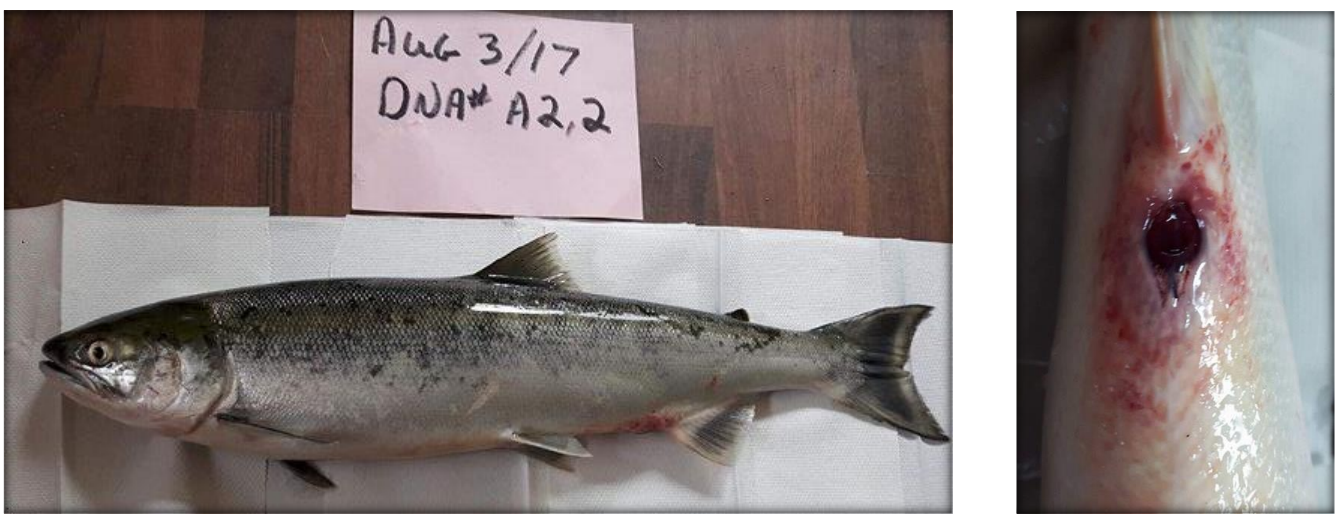

Figure 4-4 Returning Sockeye dated – August 3, 2017

Figure 4-5 Returning adult Sockeye photographed and dated – August 23, 2017

Figure 4-6 Returning Sockeye photographed for sex identification – August 23, 2017

Figure 4-7 Sampling Adult Sockeye (Left: DNA adipose punch, Right: Scale samples)

Figure 4-8 Measuring fork length at the Allco fish trap, August 23, 2017

5. Results

5.1 Adult Sockeye Returns

A total of three Sockeye returned to the Alouette Watershed during the 2017 run (Table 5-1). Ultimately, of the three Sockeye that were retained from the fish fence, two were dead and frozen for transport to

PBS and one was successfully released into the Alouette Reservoir. Two Sockeye were captured in the Allco fish fence trap and one was found just below the trap on a rock half eaten.

Table 5-1 Number of returned adult Sockeye to the Alouette Watershed, 2007-2017

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
Totals	**331**	**269**

*Transported to the Alouette Sockeye Research Facility for holding

5.2 Fork Length

Fork length measurements were collected for two of the three returning Sockeye. The fork lengths for both fish were measured at 60.9cm.

5.3 Age Structure

Scale samples were analyzed from all three Sockeye to determine the 2017 run age structure. See Godbout, L. 2018. (Appendix A).

Table 5-2 Age class for Alouette Adult Sockeye 2017 (Godbout, L. et al 2018)

Sockeye ID	Origin	Age of Sockeye (Gilbert-Rich Age)
1	Alouette (100%)	6_4
2	Alouette (100%)	6_4
3	Alouette (99%)	5_3

5.4 Genetic Sampling

Results from this analysis indicate that all three of the returning adults to the Allco fish fence in 2017 were from the Alouette Lake Reservoir (Godbout, L. et al unpublished 2018). No parental analysis was performed on the 2017 samples.

5.5 Smolt to Spawner Survival

Smolt to spawner survival has ranged from a low of 0.028% to a high of 1.344% since 2005 to 2013 (see Table 4). 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 (B. Bocking and M. Mathews, LGL Limited, unpublished data, 2018).

Current marine survival rates (smolt – adult) being experienced by the Alouette River Sockeye (Table 5-3) 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).

Table 5-3 Alouette Sockeye brood survivals, 2005-2013

Year of Smolt Migration	Survival (smolts:TRS)
2005	0.532%
2006	0.750%
2007	0.081%
2008	1.344%
2009	0.218%
2010	0.292%
2011	0.028%
2012	0.412%
2013	0.032%

6. Discussion

6.1 Adult Sockeye Returns

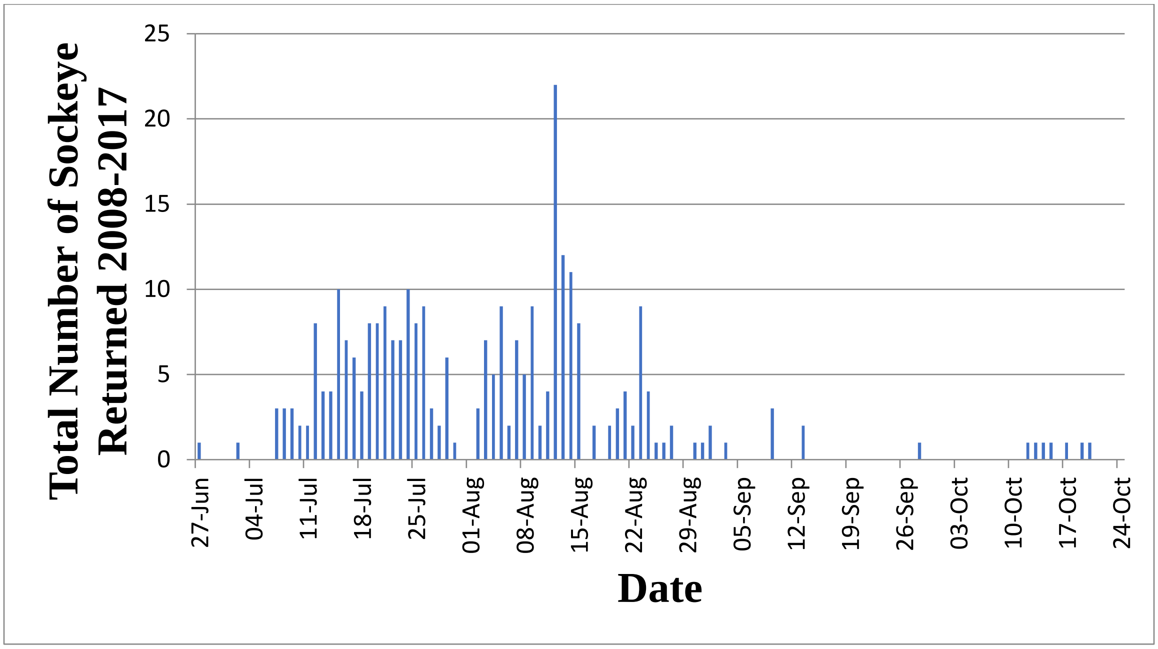

Figure 6-1 Total number of Sockeye returned to Alouette watershed 2008-2017 over the season.

The 2017 Alouette Sockeye run continues to demonstrate timing comparable to a summer run, arriving at the Allco Fish Hatchery trapping location in July and August (Figure 6-1). The peak of the Alouette Sockeye run for 2008-2017 is typically over the last week of July to the second week of August.

A total of 331 adult Sockeye returned to the Allco fish fence during the 2007–2017 runs, of which 269 have been successfully released back into the Alouette Lake Reservoir since 2007. Although the number of total adult Sockeye returns is low, the data shows that re-anadromization of Kokanee/Sockeye to the Alouette watershed is possible.

6.2 Fork Length

Measurements were collected for two of the three 2017 returning Sockeye. This represented a sample size which showed an decrease from the previous year in 2016 where six

Sockeye returned to the Allco fish fence. The average fork length measured in 2017 was 60.9 cm which is the largest average recorded. (

Table 6-1).

Table 6-1 Average Sockeye fork length, 2008-2017

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

a – No Sockeye returned to the Allco fence in 2014.

6.3 Age Structure

The age class analysis completed by the Pacific Biological Station (Fisheries and Oceans Canada) for the 2017 season showed that the returning adult Alouette Sockeye were represented by three fish in two age classes. (Appendix A Godbout. L (2017), unpublished data.)

The overall number of sampled Sockeye count for 2008 to 2017 was 184. The majority (50%) of these sampled returning spawners were age 4.2 years and 5.3 years fish (i.e. 26.5% were 2 years old and 10% were 3 years old when they left the Alouette Reservoir and then spent 2 years in the marine environment). Five other age classes have been identified for the Alouette Sockeye, representing 23.5% of the fish sampled (Table 6-2).

Table 6-2 Alouette adult Sockeye age structure analysis, 2008-2017

Year (% of sampled)				Age Class (Gilbert Rich Scale)					
	2 years in ocean	3.2	4.2	4.3	5.2	5.3	5.4	6.3	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						1(33%)			2 (66%)
Total (184)	**2 (1%)**	**1 (0.5%)**	**92 (50%)**	**1 (0.5%)**	**18 (10%)**	**49 (26.5%)**	**1 (0.5%)**	**2 (1%)**	**18 (10%)**

[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.

7. Recommendations

- To ensure the beginning of the Sockeye run is captured, the Allco fish fence should continue to operate from the middle of June each year.
- Sockeye should continue to be caught and sampled with the assistance of appropriately trained staff from ARMS to ensure proper data collection procedures are followed and clear pictures are taken.
- Sockeye sampling will continue in 2018 as per 2017, with fork length, scale and tissue samples taken for all returning Sockeye.

- All Sockeye will then be transported to the Alouette Reservoir in 2018, unless are prespawn mortalities, which would then be sent ASAP to PBS for fresh sampling.
    - If this is not possible the fish will be frozen and shipped at the end of the Sockeye run.
- Measures will continue to be taken to 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.

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9. Appendices

Appendix A

Dr. Lyse Godbout, Pacific Biological Station, Nanaimo (Fisheries and Oceans, 2018 unpublished data

Age, sex and stock identification

project	Stage	Species	Fish#	DNA Whatcom Sheet	Location	Gear	Date Caught
L. Godbout	adult	sockeye	1	A1 (1)	Alouette R.	Allco Fish Trap	July 25 2017
L. Godbout	adult	sockeye	2	A2 (2)	Alouette R.	Allco Fish Trap	August 3 2017
L. Godbout	adult	sockeye	3	A3 (3)	Alouette R.	Allco Fish Trap	August 23 2017

Fork length	Scale book No	Scale No	Gilbert-Rich age	European age	Sex	Prob of Alouette-kok
NA	75326	1,1,2,2	64	32	?	1.00
61.0	75326	3,3,4,4	64	32	female	1.00
61.0	75326	5,5,6,6	53	22	female	0.99

Appendix B

Christine MacWilliams, DVM – Preliminary Diagnostic Report, 2018, unpublished

PBS Case# 2018-022: Alouette River Sockeye; one intact adult carcass (A2) and one partial (anterior part of the fish was missing (A1), the whole head extending back into the abdominal cavity) were submitted to the lab on Feb 1, 2018. The intact carcass (Fish A2) was considered suitable for necropsy. The partial carcass (Fish A1) was rejected, as the internal organs were exposed and presumed to be contaminated.

<u>Gross findings:</u>

- unspawned female; carcass quality was poor; tissues were freezer burnt and appeared dehydrated; internal organs were unremarkable

<u>Cytology/Serology:</u>

Kidney impression smear stained with Diff Quik

- no bacteria or parasites were evident on the slide, however expected kidney cellular details were poor, suggesting diagnostic test results are unreliable

Kidney impression smear for direct fluorescent antibody test (DFAT) for *Renibacterium salmoninarum*

- negative

<u>Bacteriology</u> (on two culture media):

- negative for bacterial growth

<u>Virology:</u>

- negative for Infectious Hematopoietic Necrosis (**IHN**)

<u>Interpretation:</u>

There is no indication so far that infectious disease contributed to the pre-spawning death of this adult female Sockeye. However, carcass quality was poor, increasing the likelihood of inaccurate and/or false test results.

In the future, please submit freshly killed carcasses or recent morts (found dead, but still have pink gills and firm flesh), kept at refrigeration temperatures (5ºC – hard sided cooler with ice packs) and submitted within 48 hours of death. This sample preservation method will enable the broadest testing options and most reliable information on the health of the animal. If that's not possible, limit time in regular fridge-freezers as much as feasible; either delivering them to the diagnostic lab or transferring them to a colder freezer within a few days after freezing. If carcasses are to be frozen for long periods prior to lab submission, vacuum sealing and freezing at -80ºC will help maintain sample integrity.

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TASK 4B - EVALUATION OF THE MIGRATION SUCCESS OF *O. NERKA* (KOKANEE / SOCKEYE) FROM THE ALOUETTE RESERVOIR, 2017

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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 migration success of *O. nerka* smolts from the reservoir; 2017 was the twelfth year of study of juvenile salmon migration from the Alouette Reservoir (no study occurred in 2016). Estimates of *O. nerka* smolt migrations from the reservoir have ranged from 677 (95% CI: 394–959) in 2015 to 62,923 (95% CI: 48,436–77,410) in 2007.

The Mud Creek rotary screw trap (RST) was operated in 2017 during the typical timing of the *O. nerka* smolt migration from the Alouette Reservoir, from 12 April to 1 June. In total, 3,100 *O. nerka* smolts were captured, 1,239 of which were lower caudal clipped and released below the Alouette Dam, 3,320 fish were inspected for clips, and 220 clipped fish were recaptured. Using a pooled Petersen estimator, an estimated 18,633 *O. nerka* smolts (95% CI: 16,486–20,780) migrated from the Alouette Reservoir between 13 April and 30 May. This was the third highest estimate in all twelve years of studies. Average daily spillway flows to the South Alouette River during the *O. nerka* migration were maintained at similar levels to past years and ranged from 2.14−4.76 m^3/s. The peak catch of *O. nerka* smolts (358 migrants) occurred one day following the peak spillway flow, indicating the higher spillway flows may have encouraged the main pulse of migrants.

A subsample of *O. nerka* smolts captured at the Mud Creek RST in 2017 were sampled for length, weight, age (scales), and genetics (fin tissue). Randomly chosen *O. nerka* smolts (<100 mm FL) averaged 83.7 mm FL (range: 55–95 mm FL; n = 798) and 5.4 g (range: 1.8–9.3 g; n = 789); 99% of all randomly sampled smolts analyzed for age (all lengths) were Age 1 fish. Other species captured were counted and released.

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1. Introduction

Numerous interested parties in the Alouette Watershed, including government agencies, the Katzie First Nation, stewardship groups, environmental Non-Government 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 1-1). Among other things, salmon re-introduction to the Alouette Reservoir hinges on determining whether or not sufficient numbers of 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 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 ~3 m^3/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. The 2005 study also monitored the migration of Sockeye salmon (*O. nerka*; raised to a suitable size) that were tagged with acoustic transmitters for subsequent detection in listening arrays in the lower Fraser River, Juan de Fuca Strait, and Strait of Georgia. From the release location, the estimated migration success was 26% to the lower Fraser River detection array and 5.3% to the Juan de Fuca detection array. In 2005, an estimated 7,900 *O. nerka* also emigrated from the reservoir. This unexpected result prompted the Water Use Plan Consultative Committee (WUP CC) to recommend that the surface release occur annually.

In 2006, a study was conducted to monitor steelhead (*O. mykiss*) 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 *O. nerka* passage with an estimated 5,064 fish migrating from the reservoir during the surface release flow of ~3 m^3/s.

The 2005 and 2006 study results indicated that *O. nerka* smolts were successfully migrating from the Alouette Reservoir and there was the potential for adult Sockeye salmon to return as early as 2007.

In order 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 *O. nerka* from the reservoir during the surface release flow of ~3 m^3/s. In 2007, a total of 7,787 *O. nerka* were captured in the Mud Creek rotary screw trap (RST), located 1.5 km downstream of the Alouette Dam (Figure 1-2). An estimated 62,923 (95% CI: 48,436−77,410) *O. nerka* emigrated from the Alouette Reservoir that year (Mathews and Bocking 2007). 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 expectation of re-establishing a Sockeye salmon run. In 2008, 3,224 *O. nerka* were captured at Mud Creek from 15 April to 26 May. The total 2008 migration was estimated to be 8,257 fish; this included a mark-recapture estimate of 7,712 fish (95% CI: 6,682–8,742) 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 *O. nerka* were captured in the RST, yielding a total estimate of 4,287 (95% CI: 3,833–4,741) for the period of 21 April to 28 May (Mathews and Bocking 2010).

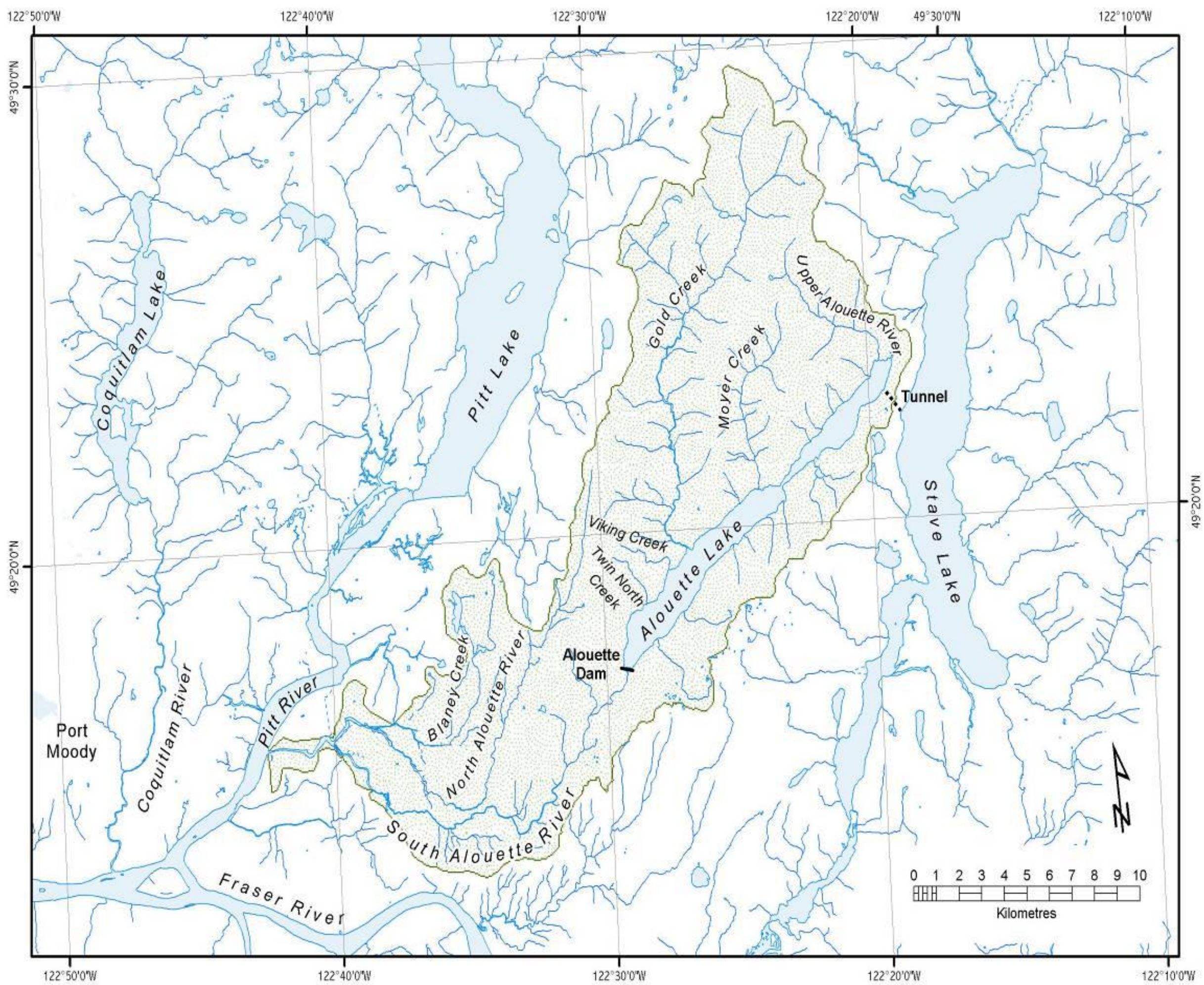

Figure 1-1 Map of the Alouette Watershed showing local communities and features.

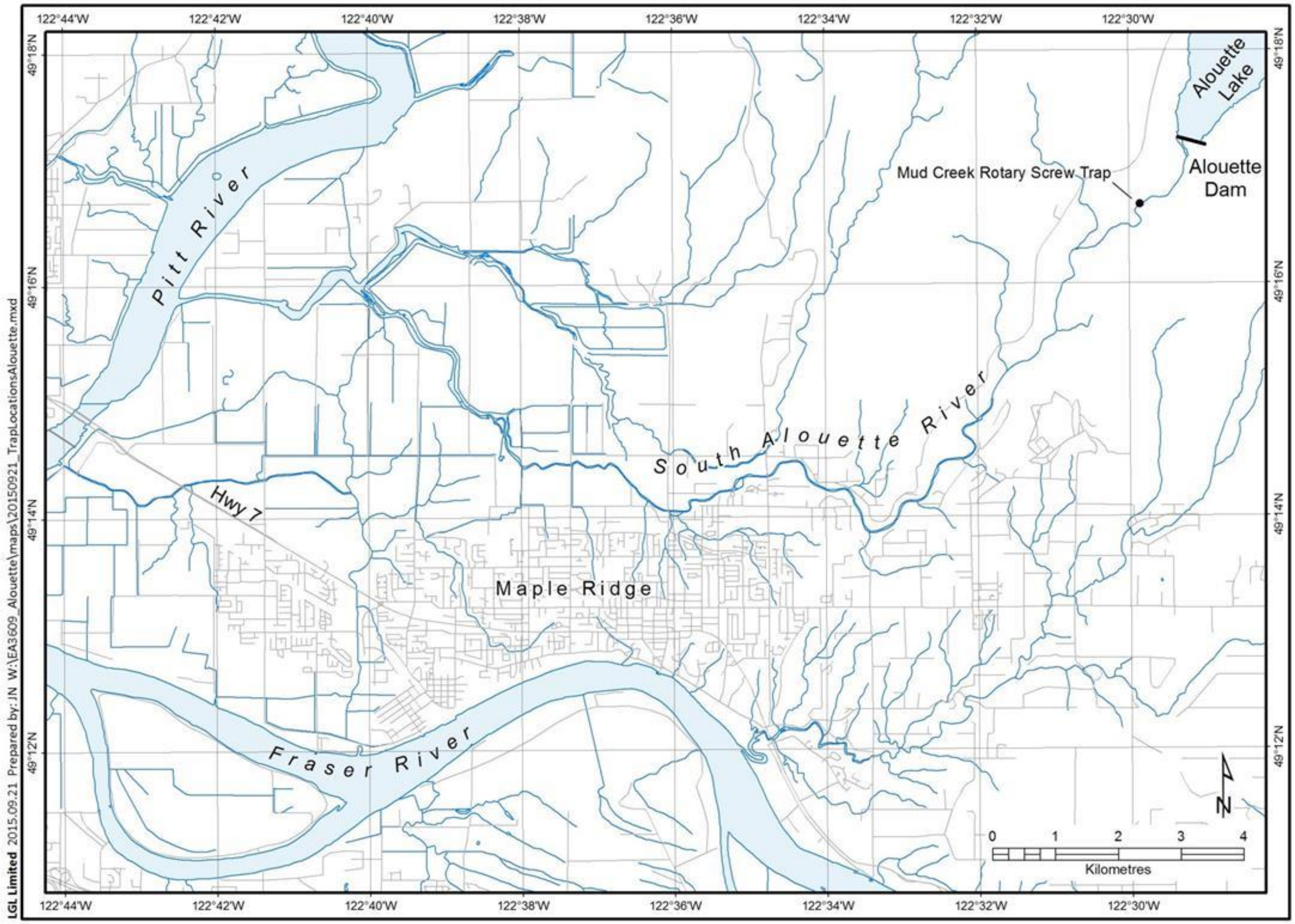

Figure 1-2 Map of the South Alouette River and location of the Mud Creek rotary screw trap in 2017.

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 O. nerka 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. In total, 4,600 O. nerka were captured at the RST, yielding a total estimate of 14,201 fish (95% CI: 13,624–14,778) from 18 April to 24 May. An additional 1,233 migrants were estimated based on trap efficiency (37.2%) outside of the marking period, resulting in a total estimate of 15,434 O. nerka (Mathews and Bocking 2011). In 2011, 9,841 O. nerka were captured at the Mud Creek RST and a mark-recapture estimate of 35,542 fish (95% CI: 34,034−37,051) was generated (Mathews et al. 2012). The 2012 study recorded the lowest catches (83 O. nerka) since trapping began at the Mud Creek site; resulting in the second lowest mark-recapture estimate of 728 fish (95% CI: 348–1,108; Mathews et al. 2013). In 2013, an estimated 6,179 O. nerka (95% CI: 5,350−7,008) migrated from the Alouette Reservoir (Mathews et al. 2014) and in 2014 the fourth largest migration was estimated at 13,413 smolts (95% CI: 12,423−14,403) (Mathews et al. 2015). The 2015 smolt migration was the lowest on record since the mark-recapture study began in 2005 as only 677 smolts (95% CI: 394−959) were estimated (Mathews et al. 2016).

In the summer of 2017, three adult Sockeye salmon returned to the Allco Hatchery fence (G. Borick-Cunningham, 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) (Borick-Cunningham and Smith 2017).

Ten 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.

The revised Alouette Water License issued in April 2009 confirmed that the surface release and associated *O. nerka* 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 eight weeks each year. Annual monitoring would continue in order 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 nine years of full-season monitoring, 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 and 2009 migrations, and two weeks later than in 2008, 2010, 2012, 2013, 2014, and 2015. The peak of the 2009 migration occurred in the latter half of May, while the peaks in 2007, 2008, 2010, 2013, and 2014 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 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. Subsequent years of monitoring are, therefore, beneficial to help to improve our understanding of the timing of the run.

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 seven days could induce additional migrants to move out of the reservoir. The first year of flush was attempted in 2009 and was scheduled for seven days at the tail end of the migration. However, once flows reached a maximum of 6.5 m^3/s, the integrity of the RST and safety of the crew and fish captured became a concern, so the flush was terminated after only three days. As a result, it was proposed that a flush occur again in 2010 with an alternative gear type (IPTs) that could be operated safely during high flows. However, as discussed earlier, the IPTs were not effective at capturing *O. nerka* smolts, so operational modifications were made to the RST so that it could operate safely and effectively during the seven-day flush period. No increases in *O. nerka* 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 ~4.5 m^3/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.

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 m^3/s from the Alouette Dam (obtained through the spillway gate) was adequate to promote the downstream migration of *O. nerka* smolts out of the Alouette Reservoir. In each year of study, *O. nerka* catches at the Mud Creek RST showed a distinct start, peak, and end, which is a characteristic pattern for out-migrating Kokanee/Sockeye smolts. Second, this monitoring program revealed that a post-surface release flush of 6–9 m^3/s, lasting seven days following the tail end of the out-migration period, did not encourage more smolts to leave the system. Flush events (2009, 2010, and 2011) and pulse flows (2014) did not yield an increase in *O. nerka* catches at the Mud Creek RST. And third, this monitoring program showed that a surface-release period from mid-April to early June will ensure the out-migration of all *O. nerka* 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) 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 Fish and Wildlife Compensation Program (FWCP) funding was completed in 2015 and the annual monitoring continued. However, in 2016 FWCP funds were not awarded and hence no smolt migration monitoring occurred. The 2017 smolt monitoring proposal was then included as a component of the 'Alouette Watershed Sockeye Fish Passage Feasibility – Year 1' application, which included numerous projects recommended by the ARSRP Committee, and was successfully awarded funds by FWCP to continue the annual monitoring of the 2017 *O. nerka* smolt migration.

1.1 Project Objectives

Specific objectives for the 2017 study year were to:

1) Operate a rotary screw trap (1.8 m diameter) continuously from 15 April to approximately early June (or when the migration ceases) at a site located 1.5 km downstream from the Alouette Dam;
2) Inspect all *O. nerka* captured for a mark, and apply marks to all unmarked *O. nerka* captured up to a specified daily target;
3) Transport all marked fish to the plunge pool located immediately downstream of the Alouette Dam and release (on a daily basis); and
4) Collect biosamples from a subset of individual *O. nerka* captured, including length, weight, scales (for ageing), and a tissue sample (fin clip for genetic analysis).

2. Methods

2.1 Study Area

The Alouette Reservoir is in east Maple Ridge in southwest British Columbia (Figure 1-1). The Alouette River watershed is a relatively small system (144 km^2) 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 Kokanee (*O. nerka*), rainbow trout (*O. mykiss*), bull trout (*Salvelinus confluentus*), cutthroat trout (*O. clarki clarki*), lake trout (*Salvelinus namaycush*), stickleback (*Gasterosteus* sp.), sculpin (*Cottus* sp.), northern pikeminnow (*Ptycheilus oregonensis*), peamouth chub (*Mylocheilus caurinus*), bridgelip sucker (*Catostomus columbianus*), largescale sucker (*Catostomus macrocheilus*), and redside shiner (*Richardsonius balteatus*; Wilson et al. 2003).

2.2 BC Hydro Operations

As per the Water Act Order for the Alouette Reservoir, BC Hydro provided a spring surface release of a minimum 3 m^3/s for the period of 13 April to 14 June. With the exception of an extremely brief, one-minute opening of the low-level outlet, the spillway release and low-level outlet closure were consistent throughout the duration of the RST operation.

2.3 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 1-2, Photo 1). The Mud Creek RST was checked twice daily. 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. Each evening, crews checked the RST for debris and ensured that all fish in the holding box were healthy. All fish captured after the morning check were processed the following morning.

Up to a daily maximum of 150 randomly chosen *O. nerka* 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 released into the plunge pool below the dam during the evening on the day they were marked which allowed adequate time for recovery.

Sampling protocol dictated that the first 40 randomly chosen *O. nerka* 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 to be collected from the first 10 randomly chosen *O. nerka* 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 to be collected from the first 40 randomly chosen *O. nerka* each day, from all target samples. Genetic samples were sent to the Pacific Biological Station to process for stock identification at a later date. See Section 'Data Collection Issues and Corresponding Assumptions' for a discussion of unintended deviations from the sampling protocol.

Photo Plate 2-1 Mud Creek rotary screw trap, 8 May 2017.

2.4 Statistical Analyses

2.4.1 Abundance Estimate

A pooled Petersen estimator with Chapman modification was used to estimate the number of *O. nerka* migrating from the reservoir:

$$N = \frac{(M+1)(C+1)}{R+1} - 1 \text{, where} \quad (1)$$

C = total number of fish caught in second sample (including recaptures),

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 for the abundance estimate (*N*) were calculated as follows:

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

$$\text{Standard error} = \sqrt{VarianceofN} \quad (3)$$

$$N \pm 1.96 * \text{Standard Error} \quad (4)$$

2.4.2 Fish Lengths, Weights, and Condition Factors

The lengths, weights, and condition factors of randomly chosen one-year-old *O. nerka* smolts (i.e., fish considered to have over-wintered for one year in the Alouette Reservoir) were compared by year of monitoring using ANOVA. Length-at-age data from 2005 to 2010 (Mathews and Bocking 2011) indicated that one-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 HSD post-hoc multiple comparison was used to assess pairwise differences.

3. Results

3.1 BC Hydro Operations

The Alouette Dam spillway gate was opened on 13 April 2017 at 1121 hours and remained open until 14 June at 1452 hours. During the *O. nerka* smolt migration period from 15 April to 1 June, average daily releases from the spillway gate ranged from 2.14 m^3/s (minimum measured from the first full day of spilling from the crest gate) to 4.76 m^3/s (Figure 3-1 ; Appendix A). Other than a very brief, one-minute opening on 9 May, the low-level outlet gate was closed from 13 April (1110 hours) to 14 June (1415 hours). Spillway flows were similar to those maintained during the full monitoring years (2007 and later) and neither flushing nor pulse flows occurred in 2017. As was the case in most past years, the majority of Alouette flows were diverted to the Stave Reservoir via the adit gate during this spring period (ranging from 15.23 m^3/s – 49.83 m^3/s).

3.2 Fishing Effort and Physical Conditions

The Mud Creek RST was operated continuously from 12 April (1345 hours) to 1 June (1015 hours). Although spillway flows continued as planned until 14 June, monitoring ceased on 1 June when daily catches had decreased substantially and the run had presumably ended.

Water temperature, RST rotational speed, and general weather conditions were recorded daily each morning from 12 April to 1 June at the Mud Creek site (Appendix . 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 (~10 km downstream of the Mud Creek RST site), and ranged from 3.46–9.13 m^3/s (mean = 4.97 m^3/s) between 12 April and 1 June (Figure 3-2). Alouette River discharge did vary throughout the smolt migration; the largest peak occurred on 24 April before dropping down close to the minimum discharge of the migration, another peak then occurred on 5 May followed by more minor fluctuations. Spillway flows remained relatively consistent and did not have a corresponding peak on 24 April when the discharge peaked, however the peak spillway flow did occur following the smaller discharge peak in early May (Figure 3-2 ; Appendix A).

Primary water level data from WSC Station No. 08MH005 is also included in Appendix as the staff gauge used to measure water level at the Mud Creek site was mistakenly moved throughout the sampling period.

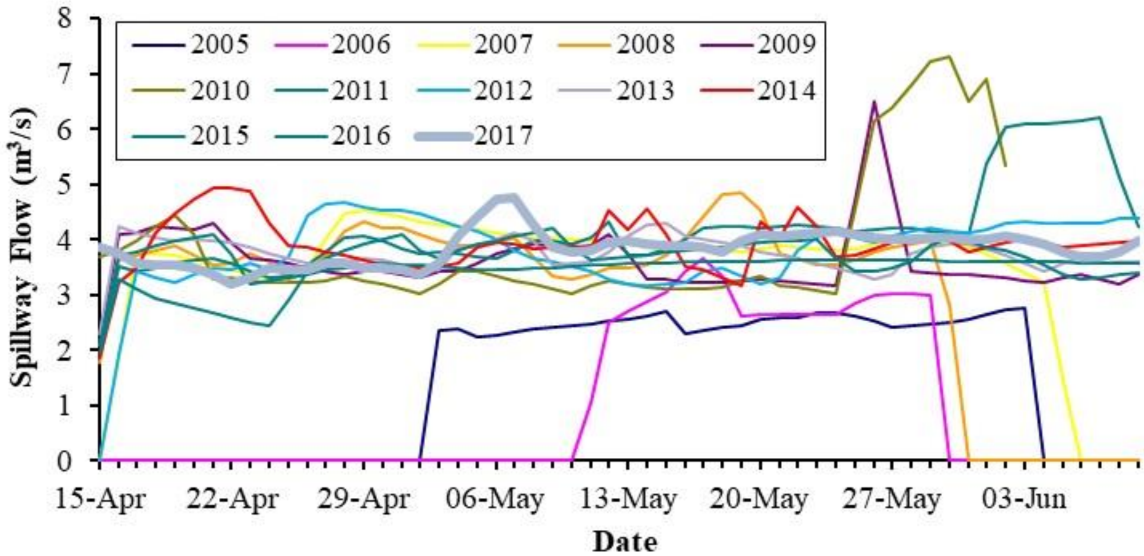

Figure 3-1 Comparison of flows at the Alouette Dam spillway gate during the O. nerka migration period, 2005–2017.

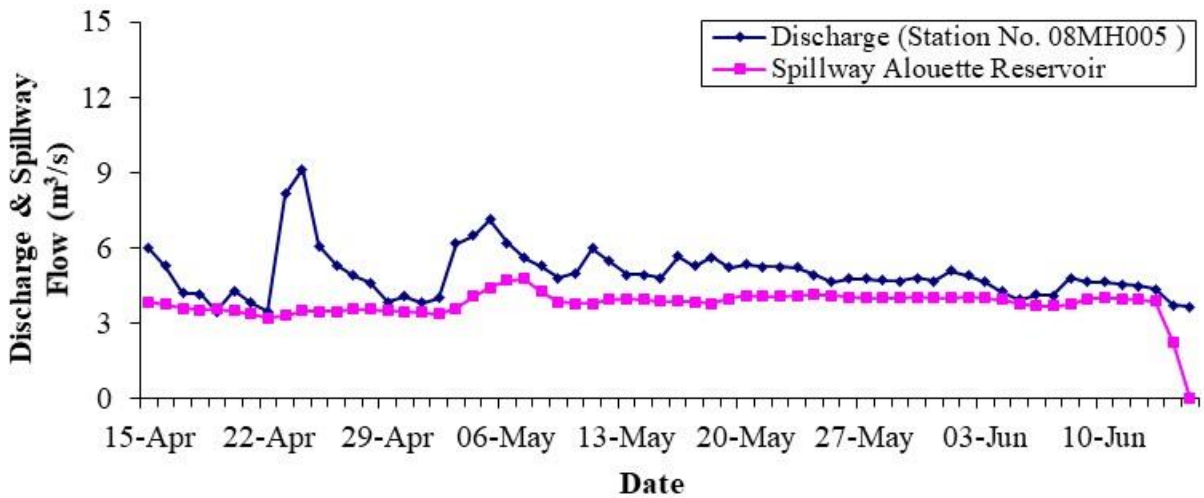

Figure 3-2 Daily discharge (m**3/s) at WSC Station No. 08MH005 and spillway flows from the Alouette Reservoir (15 April–15 June 2017). The WSC station is located on the mainstem South Alouette River at the 232nd Street bridge (discharge data from WSC website: https://wateroffice.ec.gc.ca/search/real_time_e.html).**

3.3 Fish Capture and Sampling

3.3.1 O. nerka

In 2017, 3,100 unmarked *O. nerka* were captured in the Mud Creek RST from 15 April to 1 June (

Table 3-1 ; Figure 3-3). The peak catch of 358 smolts occurred on 8 May. The first *O. nerka* was captured on 17 April, and the last *O. nerka* was captured on 1 June; a migration duration of 46 days.

A total of 1,239 *O. nerka* ('M') were marked (lower caudal clipped) and released below the dam from 13 April to 30 May 2017 (Table 3-2). In total, 3,320 smolts ('C') captured at the Mud Creek RST were examined for marks and considered available for recapture, and 220 ('R'; 6.6%) of those examined were lower caudal clipped recaptures. Capture efficiency at the Mud Creek RST was estimated to be 17.8% (220 recaptures out of 1,239 marked fish released). Using a pooled Petersen estimator, an estimated 18,633 ('N'; 95% CI: 16,486–20,780) smolts migrated from the Alouette Reservoir from 13 April to 30 May (**Error! Reference source not found.**).

A total of 857 unmarked *O. nerka* captured were measured for fork length, 847 of which were weighed, 282 were scale sampled, and fin clip tissue was collected from 168 of those smolts for genetic stock identification.

The lengths of *O. nerka* sampled ranged from 55–235 mm FL (mean = 87 mm FL; n = 857; Figure 3-4). The largest number of *O. nerka* were in the 81–85 mm FL (n = 242) size class, the second largest size class was 76–80 mm FL with only two less fish (n = 240). The weights of *O. nerka* sampled ranged from 1.8–112.0 g and averaged 6.4 g (n = 847). Figure 3-5 displays a length–weight relationship established for the 2017 *O. nerka* smolts migrating from the Alouette Reservoir.

Of those *O. nerka* measuring less than 100 mm FL (i.e., fish considered to have over-wintered for one year in the Alouette Reservoir), mean lengths varied significantly among years ($F_{11, 5885} = 474.5$, $P < 0.0001$; Table 3-3). Post-hoc pairwise comparisons revealed a complex pattern of differences among years (Figure 3-6 where years that are not connected by the same letter are significantly different). Mean lengths in 2017 were significantly higher than those in 2005-2009, 2011-2012, and 2014-2015, and significantly lower than in 2013.

No weight data was collected in 2008, and the weight data collected in 2005 was excluded due to sampling biases. The average weight of one-year-old *O. nerka* varied significantly among study years ($F_{9, 5174} = 591.8$, $P < 0.0001$; Table 3-4). Post-hoc pairwise comparisons revealed a complex pattern of differences among years (Figure 3-6). Mean weights in 2017 were significantly higher than those in 2006-2012, and 2014-2015, and did not differ significantly from those in 2013.

No condition factors were calculated from data collected in 2005 or 2008. The average condition factor varied significantly among study years ($F_{9, 5174} =140.9$, $P < 0.0001$). Results of the post-hoc pairwise comparisons between years are shown in Figure 3-6, where years that are not connected by the same letter are significantly different. Mean condition factor in 2017 was significantly higher than in 2009-2014 and did not differ significantly from those in 2006-2007 or 2015.

The average length of *O. nerka* smolts measuring less than 100 mm FL and the estimated abundance of *O. nerka* (all sizes) that migrated from the South Alouette Reservoir were also compared (Figure 3-7). There was no apparent relationship between smolt size and abundance.

Table 3-1 Daily catch of O. nerka in the Mud Creek rotary screw trap, 2017.

	Mud Creek	
Date	Unmarked	Clip Recaptures
13-Apr	0	0
14-Apr	0	0
15-Apr	0	0
16-Apr	0	0
17-Apr	1	0
18-Apr	1	0
19-Apr	0	0
20-Apr	0	0
21-Apr	0	0
22-Apr	0	0
23-Apr	0	0
24-Apr	0	0
25-Apr	0	0
26-Apr	1	0
27-Apr	2	0
28-Apr	1	0
29-Apr	20	0
30-Apr	3	0
01-May	8	0
02-May	14	1
03-May	5	1
04-May	3	1
05-May	0	1
06-May	8	2
07-May	35	1
08-May	358	3
09-May	242	2
10-May	237	4
11-May	295	4
12-May	306	9
13-May	255	13
14-May	149	19
15-May	0	0
16-May	4	1
17-May	80	0
18-May	20	4

Table 3-1 Continued.

	Mud Creek	
Date	Unmarked	Clip Recaptures
19-May	106	6
20-May	60	15
21-May	150	8
22-May	219	12
23-May	192	30
24-May	92	19
25-May	35	10
26-May	48	15
27-May	56	20
28-May	42	7
29-May	25	7
30-May	18	3
31-May	6	2
01-Jun	3	0
Total	**3,100**	**220**

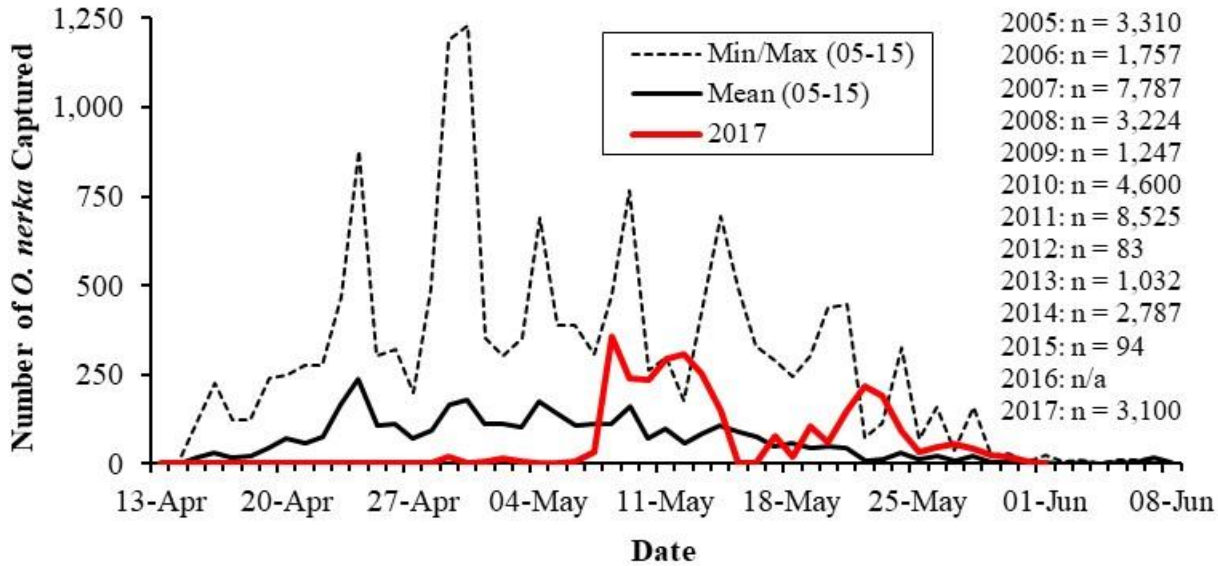

Figure 3-3 Daily catch of O. nerka at the Mud Creek rotary screw trap in 2017 in comparison to the maximum, mean, and minimum catches of the previous eleven years (spillway opened 3 May, 11 May, 16 April, 15 April, 15 April, 14 April, 15 April, 16 April, 15 April, 15 April, 15 April, and 13 April for 2005–2017, respectively.

Table 3-2 Total estimated O. nerka migration from the Alouette Reservoir, 2017.

No. *O. nerka* Clipped and Released Below Dam ('M')	1,239
No. *O. nerka* Examined for Clips ('C')	3,320
No. *O. nerka* Recaptures ('R')	220
Estimated *O. nerka* Passage (13 April–30 May 2017) ('N')	**18,633**
95% Confidence Interval	16,486-20,780
Trap Efficiency	17.8%

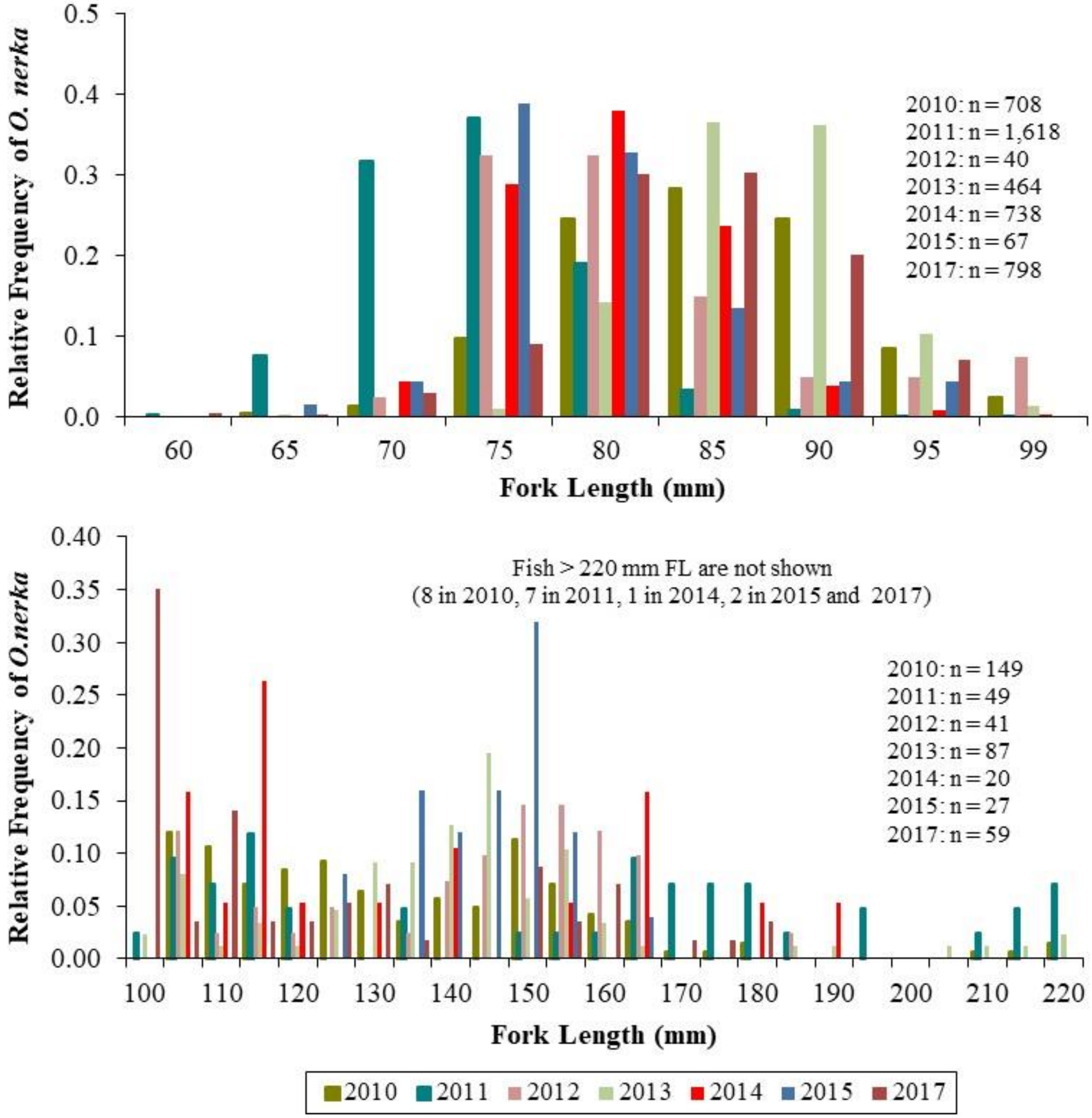

Figure 3-4 Length frequency distribution of O. nerka measuring less than 100 mm FL (top panel), and 100 mm FL or greater (bottom panel), captured in the Mud Creek rotary screw trap operated in the South Alouette River (random samples), 2010–2017.

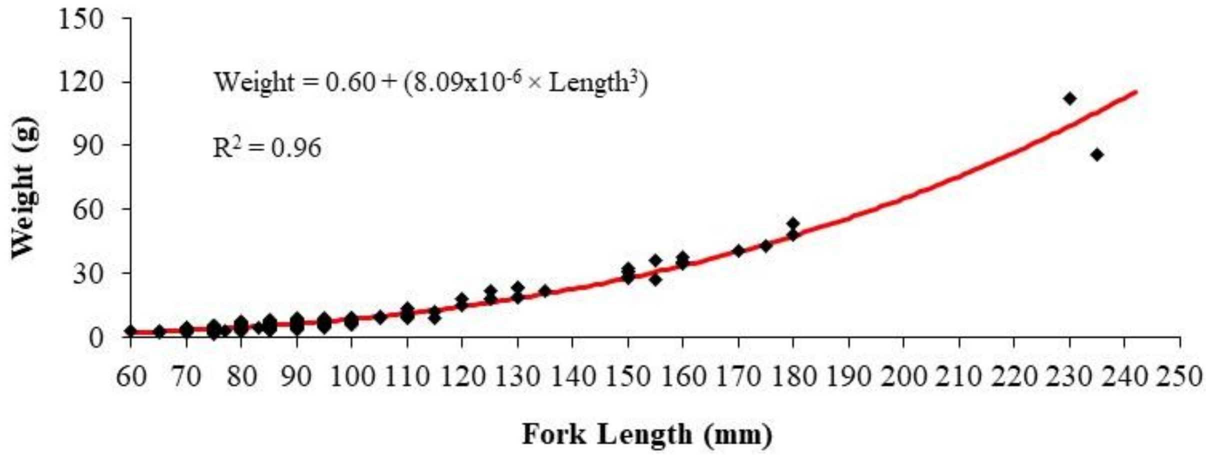

Figure 3-5 Length-weight relationship of O. nerka smolts migrating from the South Alouette Reservoir, 2017.

Table 3-3 Mean length of O. nerka less than 100 mm FL (random samples only), 2005−2017.

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	0.85	40
2013	85.6	0.25	464
2014	78.1	0.20	738
2015	77.8	0.64	67
2017	83.7	0.19	798

Figure 3-6 Comparison of mean fork length (top), weight (middle), and condition factors (bottom) across sampling years for O. nerka (<100 mm FL) captured at the Mud Creek RST, 2005-2017. Letters indicate results of the post-hoc pairwise comparisons between years, where years that are not connected by the same letter are significantly different.

Table 3-4 Mean weights of O. nerka less than 100 mm FL (random samples only), 2006−2007 and 2009–2015 and 2017.

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

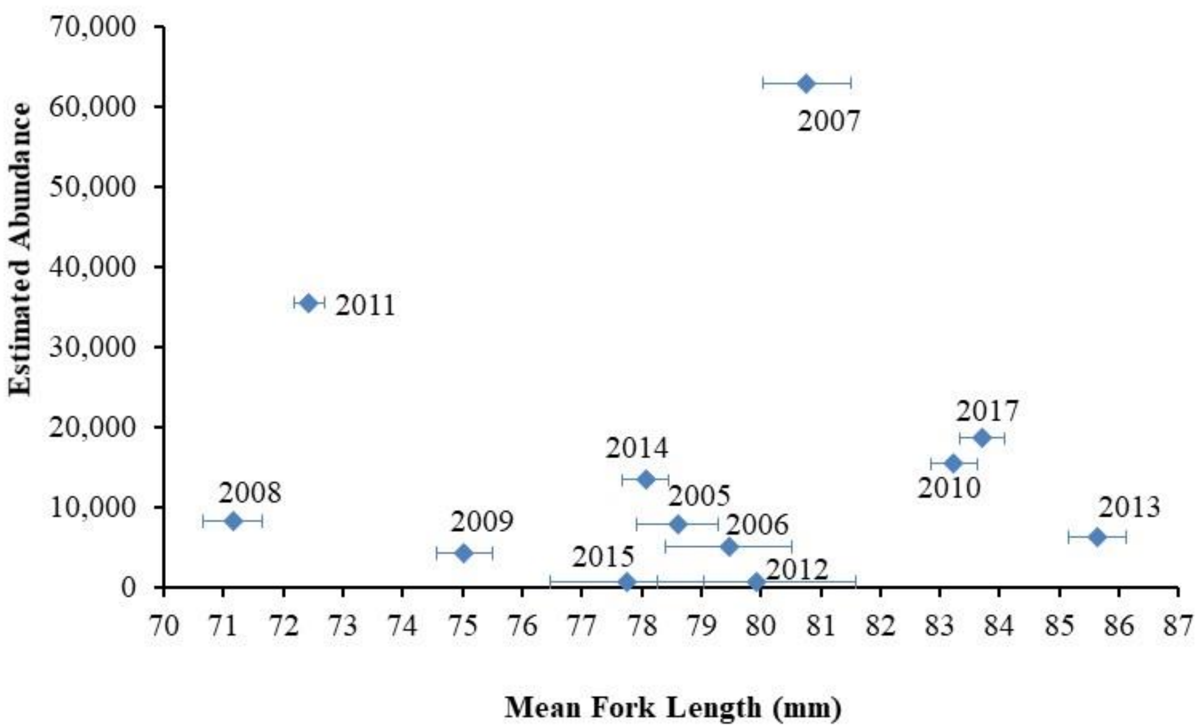

Figure 3-7 Comparison of the average length of O. nerka smolts measuring less than 100 mm FL and the estimated abundance of O. nerka (all sizes) that migrated from the South Alouette Reservoir, 2005–2017. Labels beside the data points indicate the study year.

3.3.2 Other Species

See Appendix for all non-target species catch data.

4. Discussion

4.1 BC Hydro Operations

Average daily spillway gate flows to the South Alouette River during the smolt migration were maintained at a similar range as past full monitoring years (2007 onward); 2017 flows ranged from 2.14–4.76 m^3/s (Figure 3-2) and neither a post-surface release flush or flushing flows occurred. The opening of the spillway gate occurred on 13 April, slightly earlier in 2017 than in most past years. Flows to the Stave Reservoir via the adit gate were comparable to most past years (except 2015), ranging from 15.23 m^3/s – 49.83 m^3/s.

4.2 Trapping Effort

For the seventh consecutive sampling season, the Mud Creek RST was operated consistently throughout the *O. nerka* migration period. Crews were able to effectively and safely operate the RST over a range of water conditions with no major down time.

4.3 Abundance Estimate

The South Alouette River *O. nerka* smolt migration at Mud Creek was estimated to be 18,633 (95% CI: 16,486–20,780) fish for the period of 13 April to 30 May 2017. This was the third highest estimate in all twelve years of study, the highest migration estimated since 2011 and 28 times greater than the last migration estimated in 2015 (Table 4-1).

Although 2017 had the third highest abundance estimate of all study years, the total catch of *O. nerka* (3,100 smolts) only ranked as the sixth highest. The 2017 Mud Creek RST capture efficiency of 17.8% was lower than the 2005–2015 median of 28.0%, but within the range of observed catch efficiencies since 2005 (11.3–42.0%; Table 4-1; Figure 3-3). There were no operational issues at the Mud Creek RST in 2017 to significantly influence the catch efficiency.

Table 4-1 Total catch at the Mud Creek rotary screw trap and the corresponding population estimate of O. nerka migrating from the Alouette Reservoir, 2005−2017.

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	62,923	48,436	77,410	12.0
2008	3,224	8,257	-	-	40.0
2009	1,247	4,287	3,833	4,741	33.5
2010	4,600	15,434	-	-	37.0
2011	8,525	35,542	34,034	37,051	28.0
2012	83	728	348	1,108	11.3
2013	1,032	6,179	5,350	7,008	19.0
2014	2,787	13,413	12,423	14,403	24.1
2015	94	677	394	959	14.9
2017	3,100	18,633	16,486	20,780	17.8

Based on coho salmon trap efficiency *(Baxter and Bocking 2006).*

Based on *O. nerka* trap efficiency *(Humble et al. 2006).*

Pooled Petersen estimate (19 April to 1 June) *(Mathews and Bocking 2007)* .

Trap efficiency estimate of 545 (15 April to 20 April & 9 May to 26 May) + Pooled Petersen estimate of 7,712 (95% CI 6,682 to 8,742; 21 April to 8 May) (*Mathews and Bocking 2009).*

Pooled Petersen estimate (21 April to 1 June) *(Mathews and Bocking 2010).*

Trap efficiency estimate of 1,232 (15 to 17 April) + Pooled Petersen estimate of 14,201 (95% CI 13,624 to 14,778; 18 April to 24 May) + Total catch of 1 (25 May to 1 June) *(Mathews and Bocking 2011).*

Pooled Petersen estimate (15 April to 8 June) *(Mathews et al. 2012).*

Pooled Petersen estimate (17 April to 1 June) *(Mathews et al. 2013).*

Pooled Petersen estimate (16 April to 31 May) *(Mathews et al. 2014).*

Pooled Petersen estimate (15 April to 25 May) *(Mathews et al. 2015).*

Pooled Petersen estimate (15 April to 23 May) *(Mathews et al. 2016).*

Pooled Petersen estimate (13 April to 30 May) *(Mathews et al. 2018 In Press).*

4.4 Run Timing

The 46-day duration of the 2017 Alouette Reservoir *O. nerka* migration (17 April–1 June) was the second longest duration of all full seasons monitored (equal to the 2007 duration), only the 51-day duration in 2011 was longer (2007–2015, range: 37–51 days; Figure 3-3). The start and peak dates for the 2005 and 2006 migrations were not comparable to those from 2007 to 2017 because the spillway was opened much later in those years (3 May 2005 and 11 May 2006), and presumably after the onset of the *O. nerka* migrations.

The first *O. nerka* capture in 2017 was on 17 April, four days after the opening of the spillway, indicating the spillway opening was timed well with the onset of the migration. This timing was similar to the start dates observed from 2007 to 2014 during full season monitoring (15–19 April). The peak catch of migrants occurred on 8 May, one day after the peak spillway flow of 4.76 m^3/s, indicating the higher spillway flows may have encouraged the main pulse of smolts to migrate (Figure 4-1). A smaller, secondary pulse occurred around 22 May; secondary pulses also occurred in 2007, 2008, and 2010.

With the exception of 2012 and 2015, catches during the enumerated period increased substantially in past years. This was again the case during the 2017 migration; peak catch occurred on 8 May when 358 smolts were captured. This timing was within the range of most earlier years (2007–2014, range: 23 April–18 May). The 2017 midpoint in catches occurred on 13 May, the same date as the midpoint catch timing of both 2011 and 2012.

The end date of the 2017 migration, 1 June, was one of the latest migrations of all years sampled, equal to the 2007 end date and one week earlier than the 2011 migration, the longest of all monitored years. Based on the twelve years of monitoring, the target spill period from mid-April to mid-June (as effected from 2007 to 2017) appears to cover the bulk of the smolt migration window in most of the years monitored to-date.

Although the RST operated smoothly throughout the full migration and showed no obvious signs of having been tampered with, no fish were captured on 15 May and very few were captured on 16 May. This was very unusual as both *O. nerka* and non-target species catches were significantly greater just prior and subsequent to these dates.

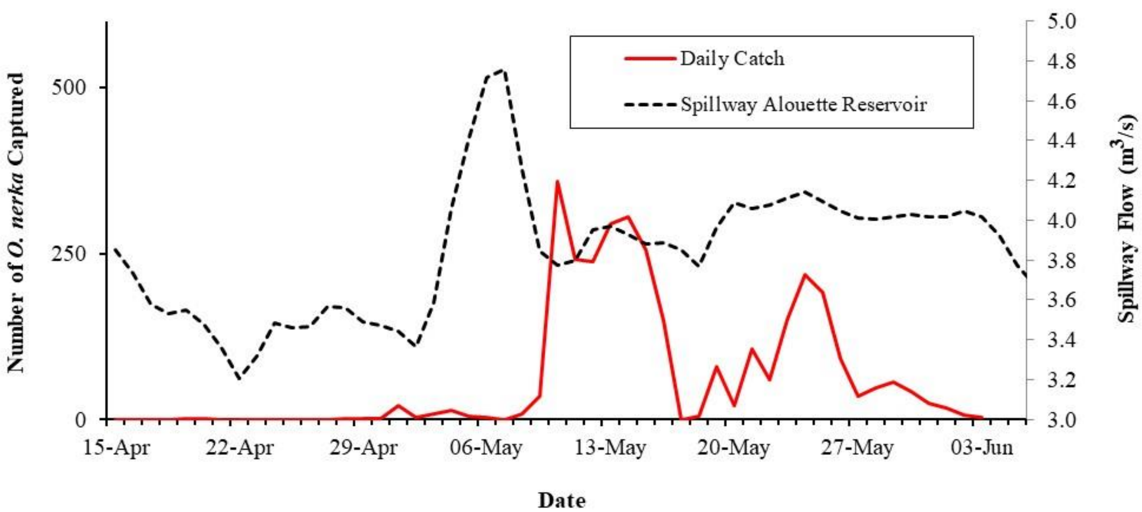

Figure 4-1 Comparison of daily catch of O. nerka captured at the Mud Creek rotary screw trap and spillway flows from the Alouette Reservoir, 2017.

4.5 Biosamples

Mean fork length of *O. nerka* (<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 3-3). The mean fork length observed in 2017 (83.7 mm FL; n = 798) was the second largest observed in twelve study years. In 2017, the greatest number of fish were in the 81-85 and 76-80 mm FL size classes, indicating larger fish than those sampled in 2015 (the largest number of fish in 2015 were in the 71–75 mm FL size class, followed by the 76−80 mm FL size class) (Figure 3-4). Size classes comprising the largest number of *O. nerka* have varied over the years: 66–70 (2008), 71–75 (2009, 2011, 2012, 2015), 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). Figure 3-4 displays length data for the last seven sampled years only (2010 to 2015); length data for all previous years from 2005 to 2013 can be found in Mathews et al. (2014). The smallest *O. nerka* sampled in 2017 measured 55 mm FL, while the largest fish measured 235 mm FL. The mean weight of *O. nerka* (<100 mm FL) sampled in 2017 (5.4 g; n = 789) was the second heaviest in all ten years of weight data, only 0.1g less than the mean weight determined in 2013, the largest mean weight calculated (Table 3-3).

Condition factor was compared across all years with length and weight data (with the exception of 2005 and 2008). The mean condition factor of the 2017 *O. nerka* smolts was 0.92 (n = 789), greater than all previous years (range from 0.80–0.90) and statistically similar to the condition factors in 2006, 2007 and 2015. (Figure 3-6).

In 2010, 2011, 2013, 2014, 2015, and 2017, the majority of *O. nerka* randomly sampled at the Mud Creek RST were one-year-old fish (70–99% of samples); of which the 2017 proportion was 99%. Two-year-old fish were the predominant age class in 2012 (71% of samples; (Table 4-2). Across all years other than 2017, every one-year-old fish measured less than 100 mm FL (range: 57−96 mm FL), however in 2017 the maximum length was 115 mm FL. Two-year-old fish were present annually from 2010 to 2015 (0.3–70.6% of random samples) and ranged in length from 80−184 mm FL. Three-year-old fish were randomly sampled in 2011, 2013, 2014, and 2015 (0.0–9.5% of random samples), but not in 2012 or 2017; and ranged in length from 100–247 mm FL. Of the target fish sampled in 2017, 83% were two-year-old fish and the longest target fish sampled for age was 230 mm FL, the lone three-year-old fish sampled for age in 2017.

No genetic analysis has been done thus far on the 2017 *O. nerka* samples. Results of past genetic analysis of the Alouette Reservoir Sockeye salmon population, including *O. nerka* smolt samples collected at Mud Creek during past study years, can be found in Godbout et al. (2011, 2013, 2014).

Table 4-2 Age composition and length-at-age results for O. nerka sampled at the Mud Creek rotary screw trap, 2010-2015, 2017.

	Number of Fish (Percent)				Length at Age (mm FL)								
					Age 1			Age 2			Age 3		
Year	Age 1	Age 2	Age 3	n	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg
Random Samples													
2010	191 (99)	2 (1)	0 (0)	193	64	95	81	91	95	93	-	-	-
2011	286 (99)	1 (0)	1 (0)	288	57	93	73	105	105	105	228	228	228
2012	20 (29)	48 (71)	0 (0)	68	70	82	76	80	184	127	-	-	-
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	-	-	-
Target Samples													
2010	0 (0)	57 (98)	1 (2)	58	-	-	-	101	180	121	156	156	156
2011	0 (0)	5 (50)	5 (50)	10	-	-	-	112	191	152	180	251	217
2013	0 (0)	0 (0)	3 (100)	3	-	-	-	-	-	-	145	158	152
2017	3 (10)	25 (86)	1 (3)	29	110	135	123	100	175	131	230	230	230

4.6 Data Collection Issues and Corresponding Assumptions

Some data collection issues occurred in 2017, due in part to the challenges associated with hiring and training a new field crew. First, all larger, "target" smolts should have been adipose clipped to allow their stratification from randomly sampled smolts in the abundance estimate. However, some target fish were mistakenly given a lower caudal clip; hence these fish had the potential to bias the estimate towards larger-sized fish, albeit to a likely small extent. Second, on several occasions, the daily quota for marks applied (150 fish) was not met, despite the fact that greater than 150 unmarked fish were captured on these days. A smaller sample size of marked fish (M) may have reduced the precision of the abundance estimate. And third, fork lengths were rounded to the nearest 5 mm in 2017, which differs from past years when smolts were measured to the nearest 1 mm.

5. Recommendations

In October 2017, the Alouette River Management Society submitted the 'Alouette Watershed Sockeye Fish Passage Feasibility – Year 2' proposal to the Fish and Wildlife Compensation Program. As members of the ARSRP Committee, the Katzie First Nation and LGL Limited are proposing to continue monitoring the *O. nerka* smolt migration from the Alouette Reservoir in the spring of 2018 as a component of Task 4 of the Sockeye Fish Passage Feasibility proposal. The following recommendations are proposed for monitoring the *O. nerka* migration from the Alouette Reservoir in 2018:

1) Operate a rotary screw trap (1.8 m diameter) continuously from 15 April to approximately 31 May at a site located 1.5 km downstream from the Alouette Dam;

2) Maintain similar flows from the Alouette Dam spillway gate (3.0–4.5 m^3/s) throughout the out-migration period. If an early spill is required due to high reservoir levels (as was the case in 2015) it is requested that BC Hydro notify the ARSRP and all efforts should be made to operate the RST during and after the spill to enumerate any early migrants;

3) Inspect all *O. nerka* captured for a mark, and apply marks to all unmarked *O. nerka* captured up to a specified daily target;

4) Transport all marked fish to the plunge pool located immediately downstream of the Alouette Dam and release (on a daily basis);

5) Collect biosamples from a subset of individual *O. nerka* captured, including length, weight, scales (for ageing), and a tissue sample (fin clip for genetic analysis);

6) Record the number of all other fish captured; and

7) Provide increased oversight and training to the field crew to help prevent deviations from the sampling protocol.

6. Acknowledgements

The cooperation of many people was essential in meeting the objectives of this study. Special thanks to Gail Florence and Logan Chick from the Katzie First Nation for their assistance with daily operations and data collection. Thanks also to Denise Horvath and Debbie Miller from the Katzie Development Limited Partnership for their assistance in planning and project coordination. From FWCP we thank Julie Fournier and Trevor Oussoren for project management. From BC Hydro we thank Brent Wilson for project coordination, operations data, and logistics management; and Alexis Hall for project coordination and assistance, as well as technical review. 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 1 project. We thank Lyse Godbout and the Sclerochronology Laboratory of the Pacific Biological Station (Fisheries and Oceans Canada) for completing the age analysis. From LGL Limited, Bob Bocking assisted as a technical advisor and report editor, Shane Johnson and Chris Burns assisted with data collection and field operations, Dave Robichaud assisted with data analysis, and Dawn Keller formatted and edited the final report. 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 FWCP.

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8. Appendices

Appendix A. BC Hydro operations at the Alouette Reservoir, 12 April –15 June, 2017.

Date	Daily Average Alouette Reservoir Elevation (m)	Alouette Spillway Gate Position (mm)	Daily Average Alouette Reservoir Spill to Alouette River (cms)	Alouette Low Level Outlet Gate Position (open/closed)	Daily Average Alouette Reservoir Spill to Alouette River Via Low Level Outlet (cms)	Daily Average Alouette Reservoir Spill to Stave Reservoir Via Adit Gate (cms)
12-Apr	123.316	0	0.000	open	2.767	49.942
13-Apr	123.263	150 @ 11:21	2.136	closed (11:10)	1.278	49.834
14-Apr	123.188	150	3.933	closed	0.000	49.761
15-Apr	123.116	150	3.853	closed	0.000	49.666
16-Apr	122.989	150	3.735	closed	0.000	49.536
17-Apr	122.859	150	3.577	closed	0.000	49.362
18-Apr	122.895	150	3.530	closed	0.000	49.310
19-Apr	122.852	150	3.547	closed	0.000	49.329
20-Apr	122.787	150	3.480	closed	0.000	49.255
21-Apr	122.683	150	3.359	closed	0.000	49.147
22-Apr	122.601	150	3.206	closed	0.000	49.020
23-Apr	122.800	150	3.318	closed	0.000	49.113
24-Apr	122.838	150	3.487	closed	0.000	49.263
25-Apr	122.782	150	3.459	closed	0.000	49.233
26-Apr	122.715	160 @ 14:05	3.464	closed	0.000	49.157
27-Apr	122.735	160	3.566	closed	0.000	29.193
28-Apr	122.705	160	3.559	closed	0.000	28.906
29-Apr	122.671	160	3.489	closed	0.000	28.876
30-Apr	122.668	160	3.474	closed	0.000	28.870
01-May	122.634	160	3.441	closed	0.000	28.856
02-May	122.578	160	3.364	closed	0.000	28.823
03-May	122.668	180 @ 11:15	3.584	closed	0.000	28.820
04-May	122.868	180	4.057	closed	0.000	28.928
05-May	123.153	180	4.416	closed	0.000	29.098
06-May	123.273	180	4.715	closed	0.000	29.254

Appendix A. Continued.

Date	Daily Average Alouette Reservoir Elevation (m)	Alouette Spillway Gate Position (mm)	Daily Average Alouette Reservoir Spill to Alouette River (cms)	Alouette Low Level Outlet Gate Position (open/closed)	Daily Average Alouette Reservoir Spill to Alouette River Via Low Level Outlet (cms)	Daily Average Alouette Reservoir Spill to Stave Reservoir Via Adit Gate (cms)
07-May	123.251	180	4.756	closed	0.000	29.278
08-May	123.193	150 @ 10:40	4.254	closed	0.000	29.247
09-May	123.115	150	3.846	open (11:51) then closed (11:52)	0.000	29.199
10-May	123.064	150	3.774	closed	0.000	29.155
11-May	123.201	150	3.797	closed	0.000	29.169
12-May	123.282	150	3.950	closed	0.000	29.269
13-May	123.256	150	3.971	closed	0.000	29.284
14-May	123.194	150	3.926	closed	0.000	29.251
15-May	123.187	150	3.881	closed	0.000	21.272
16-May	123.184	150	3.888	closed	0.000	29.677
17-May	123.123	150	3.849	closed	0.000	29.653
18-May	123.041	150	3.766	closed	0.000	29.601
19-May	122.966	170 @ 9:50	3.967	closed	0.000	29.547
20-May	122.918	170	4.087	closed	0.000	29.502
21-May	122.921	170	4.060	closed	0.000	29.487
22-May	122.947	170	4.077	closed	0.000	29.497
23-May	122.974	170	4.114	closed	0.000	29.517
24-May	122.965	170	4.140	closed	0.000	29.531
25-May	122.933	170	4.096	closed	0.000	20.666
26-May	122.885	170	4.045	closed	0.000	29.479
27-May	122.874	170	4.010	closed	0.000	29.460
28-May	122.884	170	4.006	closed	0.000	29.458
29-May	122.890	170	4.020	closed	0.000	29.466
30-May	122.895	170	4.030	closed	0.000	29.471
31-May	122.864	170	4.017	closed	0.000	29.464

Appendix A. Continued.

Date	Daily Average Alouette Reservoir Elevation (m)	Alouette Spillway Gate Position (mm)	Daily Average Alouette Reservoir Spill to Alouette River (cms)	Alouette Low Level Outlet Gate Position (open/closed)	Daily Average Alouette Reservoir Spill to Alouette River Via Low Level Outlet (cms)	Daily Average Alouette Reservoir Spill to Stave Reservoir Via Adit Gate (cms)
01-Jun	122.904	170	4.017	closed	0.000	29.464
02-Jun	122.910	170	4.048	closed	0.000	29.481
03-Jun	122.849	170	4.018	closed	0.000	29.465
04-Jun	122.769	170	3.925	closed	0.000	29.415
05-Jun	122.670	170	3.772	closed	0.000	29.349
06-Jun	122.663	170	3.675	closed	0.000	15.359
07-Jun	122.670	170	3.678	closed	0.000	15.225
08-Jun	122.796	170	3.765	closed	0.000	15.244
09-Jun	122.866	170	3.968	closed	0.000	15.290
10-Jun	122.859	170	3.992	closed	0.000	15.297
11-Jun	122.831	170	3.971	closed	0.000	15.291
12-Jun	122.804	170	3.934	closed	0.000	15.281
13-Jun	122.769	170	3.889	closed	0.000	15.270
14-Jun	122.729	0 @ 14:52	2.244	opened (14:15)	1.074	15.256
15-Jun	122.811	0	0.000	open	2.701	15.249

Appendix B. Physical data collected at the Mud Creek rotary screw trap site, 2017.

Date	Water Temp (°C)	Weather Conditions	RST Speed (RPM)	Water Depth (cm)[1]	Date	Water Temp (°C)	Weather Conditions	RST Speed (RPM)	Water Depth (cm)[1]
12-Apr	7	rain	6	86	08-May	10	partly sunny	7	84
13-Apr	7	overcast	9	90	09-May	10	partly sunny	8	82
14-Apr	7	light rain	7	89	10-May	9	cloudy	7	83
15-Apr	7	light rain	7	88	11-May	10	cloudy	7	86
16-Apr	7	overcast	7	85	12-May	10	rain/hail	8	84
17-Apr	7	overcast	4	82	13-May	11	cloudy	7	82
18-Apr	7	overcast	4	82	14-May	10	partly sunny	7	83
19-Apr	6.5	overcast	4	79	15-May	10	rain/hail	7	82
20-Apr	7	rain	4	82	16-May	10	cloudy	7	85
21-Apr	7	partly sunny	4	81	17-May	10	cloudy	8	84
22-Apr	7	cloudy	3	79	18-May	12	partly sunny	8	85
23-Apr	8	cloudy	4	91	19-May	12	cloudy	8	83
24-Apr	10	partly sunny	5	94	20-May	12	sunny	8	84
25-Apr	10	cloudy	3	86	21-May	12	sunny	8	84
26-Apr	10	cloudy	3	84	22-May	13	sunny	8	84
27-Apr	10	cloudy	7	82	23-May	15	sunny	8	83
28-Apr	9	cloudy	8	81	24-May	10	cloudy	8	83
29-Apr	9	cloudy	8	79	25-May	15	sunny	8	82
30-Apr	9	cloudy	6	80	26-May	13	sunny	8	82
01-May	9	rain	7	79	27-May	12	sunny	9	82
02-May	9	cloudy	8	79	28-May	15	sunny	9	82
03-May	11	cloudy	8	86	29-May	14	sunny	8	82
04-May	12	sunny	8	87	30-May	15	cloudy	8	82
05-May	11	rain	8	89	31-May	13	cloudy	8	82
06-May	10	partly sunny	8	86	01-Jun		cloudy, rain		83
07-May	10	partly sunny	8	84					

[1] Water depth data is from WSC Station No. 08MH005, located on the mainstem South Alouette River at the 232nd Street Bridge (https://wateroffice.ec.gc.ca/search/real_time_e.html)

Appendix C. Catch of non-target species at the Mud Creek rotary screw trap, 2017.

	Species Composition (%)		Total Catch (# fish)								
Date	Chum Fry	/Coho Fry (<70mm	Salmon Fry (est.)	Chinook Parr/Smolt (>70 mm)	Coho Parr/Smolt (>70 mm)	Steelhead (<90 mm)	Steelhead (>90 mm)	Dace Spp.	Sculpin Spp.	Stickle-back	Lamprey
13-Apr	99	1	30,100				1	10			1
14-Apr	99	1	11,750		1		1	8	1		1
15-Apr	99	1	20,300		8			10	4		
16-Apr	99	1	27,300		6			7		1	
17-Apr	99	1	21,450					24	8	1	1
18-Apr	99	1	24,600		1			6	1		
19-Apr	99	1	39,300					7	6	1	1
20-Apr	99	1	52,450		2			6	6		
21-Apr	99	1	46,850		1			10	3		
22-Apr	99	1	30,100					15	1	1	
23-Apr	99	1	64,450		1			14	8		5
24-Apr	99	1	30,740		7	1	2	9	6		7
25-Apr	99	1	18,710		5		2	8	4	1	
26-Apr	99	1	14,825		1		1	11	7		
27-Apr	99	1	16,050		5	1	3	6	2	1	2
28-Apr	99	1	8,560				1	2	2	5	1
29-Apr	99	1	14,825		1		1	11	7		
30-Apr	99	1	18,335		2		2	1	1	1	
01-May	99	1	12,040		3		1	5	1	1	
02-May	100	0	2,620		1		4	1			
03-May	100	0	4,050		2			2	11	2	
04-May	100	0	3,650		5		3	9	4	2	
05-May	100	0	200		5		6	12	1		
06-May	100	0	70		7		2	5	1	2	

Appendix C. Continued.

	Species Composition (%)		Total Catch (# fish)								
Date	Chum Fry	/Coho Fry (<70mm	Salmon Fry (est.)	Chinook Parr/Smolt (>70 mm)	Coho Parr/Smolt (>70 mm)	Steelhead (<90 mm)	Steelhead (>90 mm)	Dace Spp.	Sculpin Spp.	Stickle-back	Lamprey
07-May	100	0	40		11			1		2	
08-May	100	0	66		12		5	2	3		
09-May	100	0	10						1	2	
10-May	100	0	100		4				1		
11-May	98	2	100		3				1	5	
12-May	100	0	100		3			1			
13-May	98	2	200		14			4	3	2	1
14-May	98	2	150		7			3	1	4	
15-May											
16-May											
17-May	99	1	20		3			1	2	2	
18-May	99	1	500		2			2	1	1	
19-May	0	100	520						2	9	
20-May	1	99	115		5		1	1		5	
21-May	0	100	19						1		
22-May	50	50	100		13			3			
23-May	0	100	100		4			5	2	3	
24-May	0	100	100						1		
25-May					1			4	1		
26-May	0	100	21		1		2	2	2	1	
27-May	0	100	50		4			2	5	6	1
28-May							1	2	3	1	
29-May					1			6		6	
30-May								3	3	2	
31-May					1			1		6	
01-Jun	0	100	64		2			1	4	8	1
Totals	--	--	515,700	0	155	2	39	243	122	84	22

Note: 14 unidentified fish were also captured throughout the sampling season

End Report