BOTTLENECKS TO SURVIVAL
SYNTHESIS REPORT

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EXECUTIVE SUMMARY

Declines in the abundance of Chinook and coho salmon and steelhead in the Salish Sea have resulted in ecological, economic, and cultural impacts throughout the Pacific Northwest. Established approaches cannot pinpoint periods of elevated mortality (survival "bottlenecks") that may be responsible for these declines. Identifying survival bottlenecks and their causes is necessary to evaluate the relative costs and benefits of strategies aimed at improving survival at specific life stages, including decisions around hatchery rearing and release strategies.

Through funding from the BC Salmon Restoration and Innovation Fund (BCSRIF), the Pacific Salmon Foundation (PSF) and British Columbia Conservation Foundation (BCCF) have developed an innovative program utilizing Passive Integrated Transponder (PIT) tags and a comprehensive system of arrays around Vancouver Island to provide insights into stage-specific survival of Chinook and coho salmon and steelhead. The project, "*The Determination of Bottlenecks Limiting Wild and Enhanced Juvenile Salmon and Steelhead Production in BC using PIT tags and Spatially Comprehensive Arrays*" (hereafter the *Bottlenecks Program*), has established a network of partners to develop and implement PIT tag application and detection programs across 13 systems along the East Coast of Vancouver Island and two systems on the west coast (Stamp and Toquaht rivers).

The purpose of the *Bottlenecks Program* was to provide information on survival bottlenecks for Chinook, coho, and steelhead in freshwater and early marine environments. No other study has approached the "black box" of salmon survival in this way, therefore, this program was, and is, an exploratory effort to develop novel methods for understanding and improving salmon survival. We set out to 1) create a monitoring and evaluation framework built on PIT infrastructure to determine survival bottlenecks in freshwater and marine environments for hatchery and wild Chinook, coho, and steelhead, 2) conduct research, monitoring and evaluation that could maximize the performance of hatchery and wild stocks, and 3) implement the infrastructure to allow for adaptive management.

To date, our program has led 46 antenna installations across 13 watersheds, creating the foundation for extensive data collection on salmon movements and survival. This infrastructure development led to a number of meaningful collaborations with a broad range of First Nations, government, and community partners which have contributed to the success of the program thus far. Together, we have put out more than 250,000 PIT tags in salmon and trout species across 15 rivers on Vancouver Island in the first four years of the program. *Bottlenecks Program* data have been compiled into a comprehensive data information system using a Postgres database designed to ensure referential integrity and a high level of data quality. Additional years of return data are required before we can report on stage-specific survival, however, the infrastructure is in place and the monitoring and evaluation framework for survival analyses is nearing completion as we begin to work with preliminary return data.

With the PIT tagging infrastructure in place, a broad range of research projects have been initiated. Investigations by the *Bottlenecks Program* include: tagging-related mortalities; overwinter survival of coho in earthen channels at hatcheries; release location strategies for enhanced steelhead trout; freshwater survival; predation by herons and pinnipeds; marine distributions of Chinook, coho, and steelhead; the winter ecology of juvenile Chinook salmon (including an extensive analysis of overwinter diet and condition); mechanisms of marine mortality; the feasibility of kelt reconditioning; and enhanced fisheries monitoring. In addition, our program has fostered collaboration with governments, academic researchers, and local groups, who, with the support of the *Bottlenecks Program*, are leading novel studies into the influence of vaterite on coho survival, the effects of habitat restoration on population rebuilding, and freshwater outmigration timing and survival given changes in river conditions. While these studies have been designed to answer questions outside of the *Bottlenecks Program*, PIT tag detections will be used to supplement our survival analyses and their findings will guide the nature of our program moving forward. A high-level overview of our objectives for each of the *Bottlenecks Program* and collaborator studies and the outcomes of our research to date are presented in this synthesis report.

Innovations and novel techniques developed during the program include our customized method for capturing juvenile salmon at sea using "micro-trolling" gear. Not only has this method allowed us to sample salmon from understudied or unrepresented habitats, it also has allowed us to investigate the winter ecology of juvenile salmon in detail for the first time. We've conducted over 12,800 microtrolling sets, of which approximately 4,100 collected additional samples for overwinter diet, bioenergetic, scale, and pathogen analyses. Using microtrolling, we have tagged over 8,300 Chinook and 1,500 coho in the marine environment with little by-catch. In addition, the deployment of mini pop-up archival transmitting tags (miniPATs) on steelhead kelts generated new insights into the marine migrations and mortality mechanisms of adult steelhead, and is the largest study of this kind.

Through four years of program development and implementation, many lessons have been learned related to large-scale salmon tagging, rearing and release strategies, and predation studies, among others. One significant issue was the lack of coho captured during microtrolling in the marine environment during mid-late winter and the low proportion of target stocks of coho caught at all times in marine waters. This prevented us from estimating stage-specific survival of coho. As a result, the *Bottlenecks Program* engaged with Fisheries and Oceans Canada (DFO) and other project partners to assist in the development of a number of supplementary studies to help inform fisheries managers about optimal coho rearing practices. Additionally, the continued PIT tagging of hatchery and wild coho in Bottlenecks systems provides freshwater survival estimates on some systems, as well as escapement and smolt to adult survival and estimates.

Moving forward, we intend to continue the core program activities, informed by the lessons learned during the program's initial phase and will explore a number of additional topics, including: size at ocean entry of Chinook using otoliths; migration patterns of Chinook; rearing and release strategies with Quinsam River coho; freshwater outmigration survival of summer-run Puntledge Chinook; and interactions of Chinook and coho with pinnipeds through lower river and estuarine monitoring programs.

In conclusion, the *Bottlenecks Program* has made significant progress towards elucidating the survival bottlenecks of Chinook, coho, and steelhead salmon through innovative technologies, methodologies and collaborative efforts. While some of the program activities have been adjusted due to the realities of the species and ecosystems being studied, the infrastructure development alone has catalyzed numerous scientific investigations into freshwater and marine distributions and survival. Continued support and expansion of the program are essential for building on the initial findings and informing management practices that support the long-term sustainability of these iconic species.

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PROGRAM BACKGROUND

Recent declines in the abundance and productivity of Chinook (*Oncorhynchus tshawytscha*), coho (*O. kisutch*) salmon, and steelhead trout (*O. mykiss*) in the Salish Sea have resulted in ecological, economic, and cultural impacts in British Columbia (BC). Reduced abundance of these species resulted in the closure of targeted commercial troll fisheries in the Strait of Georgia in the 1990s (Ryall and Shardlow 1991); similarly, marine recreational fishery effort, formerly representing 90% of effort in BC, decreased by 90% between the 1980s and 2000s. This decline represents a large loss of potential economic benefit given that marine recreational fisheries in BC generate over $700M in annual revenue (Government of Canada 2023). Chinook are also the primary prey of Southern Resident Killer Whales (SRKW; *Orcinus orca*), which have been listed as an endangered species in both the United States and Canada (COSEWIC 2008; NOAA 2022). It is believed that the poor health of SRKW is related to dwindling populations of Chinook. Beginning in 2019, the critical conservation status of Chinook in Southern BC led to unprecedented restrictions on commercial, recreational, and First Nations food, social, and ceremonial fisheries (DFO 2020; Government of Canada 2018).

There is a growing consensus that the first year in the marine environment plays a key role in regulating Pacific salmon productivity (Beamish and Mahnken 2001). Given the complexity of their anadromous life cycles, we need to consider cumulative effects across the life cycle to inform focused and effective management. A life-cycle modelling approach allows us to identify the specific life stages where bottlenecks to survival are occurring – a topic of great debate. While many suggest that marine conditions are the ultimate determinant of survival, others point to freshwater conditions, or composite effects. Conventional smolt to adult return estimates conflate freshwater survival to ocean entry, estuarine residence, the first marine summer, the first winter at sea, the adult marine residency, and the adult freshwater migration to spawn, preventing insights into the spatiotemporal context of potential critical mortality periods. By examining survival rates at and between stages, we can assess the efficacy and impact of managerial practices within and across life stages.

Other studies have looked at the mechanisms of mortality across life stages, or identified bottlenecks within stages, but few have taken this broader approach of estimating stage-specific survival along with the mechanisms operating at these stages. We know that there are carry-over effects on salmon survival from one stage or environment to the next (Healey 2011, Chasco et al. 2021). By examining the survival rate to adult return at multiple life stages through active capture and PIT tagging, the *Bottlenecks Program* is exploring a novel approach to opening the "black box" of salmon survival. Additionally, the program's large geographic study area allows for comparisons of regional environmental conditions which may be driving survival. We hope to identify specific survival bottlenecks in freshwater and marine environments and assess their impact within and across life stages, at a large regional level.

Here in the Strait of Georgia, this life-cycle approach was first applied in the landmark Cowichan study during the Salish Sea Marine Survival Program (SSMSP). The study used PIT tags[1] to mark cohorts of juvenile Cowichan River Chinook as a novel approach to studying both freshwater and marine survival. In-river PIT tag arrays were installed to detect tags as the fish passed over on their outward or return migrations (PSF 2018). Results showed an important link between freshwater flows and in-river mortality, and indicated there is likely high mortality after the first marine summer and much lower survival of hatchery-produced salmon over wild fish (Pearsall et al. 2021). The findings prompted decisions by the DFO Salmon Enhancement Program (SEP) to change their hatchery release locations for Cowichan Chinook, resulting in higher survival of hatchery fish and providing the impetus to address minimum ecological flows. However, hatchery Chinook on the Cowichan still exhibit a third to half of the survival of their wild counterparts, and data collated to date suggest that the difference may be established over the first winter (Pearsall et al. 2021).

As abundances of several wild salmon and steelhead populations remain at historic lows, there is growing recognition that traditional hatchery mitigation is not meeting conservation and recovery objectives for wild stocks. In 2019, the provincial government released the *BC Wild Salmon Advisory Council Recommendations for a Made-in-BC Wild Salmon Strategy*, which identified investment in and support for salmon enhancement activities that are strategic, science-based (Strategy 1.5), and key to wild stock recovery (WSAC 2019). For salmon enhancement programs to effectively contribute to harvest and conservation, the performance (i.e., survival and fitness) of hatchery fish must be high relative to wild fish. The influence of hatchery release practices on freshwater residence time and survival to estuarine entry is not well-understood. PIT tags can be used in rearing and release trials to better understand the factors that contribute to successful hatchery production and can also improve survival estimates relative to conventional CWT methods.

[1] PIT tags are tiny electronic tags that are cost-effective, easily applied, and have a 12-digit unique code. The tag can be automatically detected and decoded as the fish crosses an antenna, eliminating the need to kill a fish to determine its origin. They provide information on individual fish and are an economical way of marking thousands of individuals relative to other electronic tagging methods.

PROGRAM OVERVIEW

Together, the PSF and BCCF acquired funding from the BC Salmon Restoration and Innovation Fund (BCSRIF) to undertake the project, "*Determination of Bottlenecks Limiting Wild and Enhanced Juvenile Salmon and Steelhead Production in BC using PIT tags and Spatially Comprehensive Arrays"* (henceforward '*Bottlenecks Program*'). Inspired by the Cowichan study, the project proposed an ambitious expansion of PIT tag infrastructure and methodologies in several priority Strait of Georgia systems. The purpose of the *Bottlenecks Program* was to provide information on survival bottlenecks for Chinook, coho, and steelhead in both freshwater and early marine environments. Understanding the timing of key mortality events and critical periods will allow managers to focus on the periods in the life history that serve as survival bottlenecks, identify the fundamental causes of mortality, and develop directed actions to improve the survival of these iconic species. No other study has approached the "black box" of salmon survival in this way, therefore, this program was, and is, an exploratory effort to develop novel methods for understanding and improving salmon survival.

Our vision was for the PIT infrastructure and extensive exploration of survival bottlenecks to serve as a foundation for future PIT tagging programs, creating a lasting physical and methodological legacy for salmon research initiatives. To achieve this, we set out to 1) create a monitoring and evaluation framework built on PIT infrastructure to determine survival bottlenecks in freshwater and marine environments for hatchery and wild Chinook, coho and steelhead, 2) conduct research, monitoring, and evaluation that could maximize the performance of hatchery and wild stocks, and 3) implement the infrastructure to allow for adaptive management.

While the primary objective of the program is to identify survival bottlenecks, the data being generated can also facilitate research into the nature of PIT tagging studies (i.e., tagging effects), life history and rearing strategies, hatchery effectiveness, predation, spatiotemporal marine distributions of various life stages and stocks, and more. In addition, the data have the potential to improve fisheries monitoring and escapement estimates. The research provides valuable insights into the complex interactions between environmental factors, human activities, and salmon populations, essential for developing targeted conservation strategies. Therefore, through extensive collaborations with our program partners, we have pursued the study of these additional topics where possible to inform both the future of the *Bottlenecks Program* and ongoing salmon management and conservation efforts being led by our partners.

The initial proposal was funded for four years, from 2020-2024; however, a second project was approved by BCSRIF to expand the *Bottlenecks Program* and continue core activities until March 2026. Given that Chinook, coho and steelhead life spans range from 2-5 years, our findings from the initial four years are preliminary, a 'first look'. By extending the lifespan of the *Bottlenecks Program* we will have two more years of juvenile outmigration tagging from which to investigate survival bottlenecks and mechanisms of mortality. Much of the work we began in the initial funding regime will continue into the second phase and is, therefore, incomplete at this time. However, as we conclude the initial four years, this report captures the progress to date and lessons learned to guide future activities.

The *Bottlenecks Program* was subdivided into five primary activities, each comprising several projects of their own. These activities were:

1. Identification of survival bottlenecks for hatchery-reared Chinook and sympatric wild stocks using a PIT-based mark/tag program
2. Identification of survival bottlenecks for hatchery-reared Coho and sympatric wild stocks using a PIT-based mark/tag program
3. Implementation of unique winter studies of ECVI Chinook trophic ecology, growth, and physiology over a critical mortality period
4. Implementation of a steelhead bottlenecks to survival program and an optimization of steelhead hatchery production
5. Enhanced fishery monitoring

These projects were designed to collect data across the salmon life cycle from freshwater to adult return. Given the considerable overlap in our approach across activities, we will present our progress, findings, lessons learned and recommendations to date through a life cycle lens rather than by activity.

Herein, we present preliminary data from the first two study years (2020-2021 and 2021-2022) on returns and survival from different tagging periods to initiate an exploration into where and when survival bottlenecks could occur. However, more years of return data will be required before any specific conclusions can be drawn on survival bottlenecks. We then summarize our hatchery and freshwater tagging activities, exploring tagging-related mortality and hatchery rearing and release impacts on survival. Moving downstream, we explore outmigration timing, freshwater survival, and predation by Great Blue Herons. We present our findings from tagging in the marine environment through the first winter at sea, providing an in-depth exploration of the overwinter ecology of juvenile Chinook, specifically. We then investigate marine distributions of coho and steelhead, predation by pinnipeds, and the utilization of PIT technology to enhance fisheries monitoring. Several technical reports have been produced as a result of this work and can be found at [https://www.survivalbottlenecks.ca/reports-and-products/] and will be referenced throughout this synthesis document. While this synthesis provides a high-level overview of all work completed through the *Bottlenecks Program*, the technical reports will provide greater details on data and methods.

METHODS

Detailed descriptions of our program's methods are provided in Appendix A. Methods specific to a given sub-component of the program can be found in the respective technical reports. A high-level overview is provided herein.

Study Area

The Salish Sea is an inland sea encompassing Puget Sound, the Strait of Juan de Fuca, and the Strait of Georgia (Figure 1). The Salish Sea is home to 37 species of mammals, 172 species of birds, 253 fish species, and more than 3,000 species of invertebrates (Gaydos and Pearson 2011; Brown and Gaydos 2009). Multiple threatened and endangered species as listed under the *Canadian Species at Risk Act* and the *United States Endangered Species Act,* call the Salish Sea home; these species include the SRKW and ecologically significant units of Pacific salmon, such as Nanaimo River spring- and summer-run Chinook.

Our study area is concentrated in the Strait of Georgia, the northern portion of the Salish Sea, and includes 14 rivers across 13 watersheds (Figure 1). Our primary rivers of interest for the study of Chinook salmon are the Cowichan, Nanaimo, and Puntledge rivers. In these systems, concerted efforts have been made to put out high numbers of tags at a number of salmon life stages. Our secondary rivers of interest for Chinook are the Big Qualicum, Little Qualicum, and Quinsam rivers. Tagging in these systems has focused on hatchery and marine tagging stages only and is being used to inform marine survival estimates. For coho, the primary rivers of interest are the Cowichan, Nanaimo, Englishman, Puntledge, and Quinsam rivers. Similar to Chinook, our intention was to put out high numbers of PIT tags at each stage for these populations. Secondary rivers of interest include Big Qualicum, Black Creek, Mill Stream, Millstone, and Goldstream rivers where our program has partnered with others to investigate freshwater survival, impacts of restoration efforts, and hatchery rearing effects on coho salmon. And finally for steelhead, our rivers of interest are the Stamp, Cowichan, Englishman, and Quinsam rivers, each with its own specific question and study design. On the Stamp River, we investigated differential release strategies with a cohort of steelhead released near the mouth of Alberni Inlet to bypass freshwater, as well as early marine limiting factors. In the Cowichan River, we experimented with kelt reconditioning and the use of archival satellite tags to track marine movements of steelhead kelts. In the Englishman and Quinsam rivers, our intention was to gain a better understanding of freshwater and marine survival. However, the Englishman Steelhead population collapsed in 2020, with < 50 adult spawners, therefore the Englishman River was dropped from our steelhead studies.

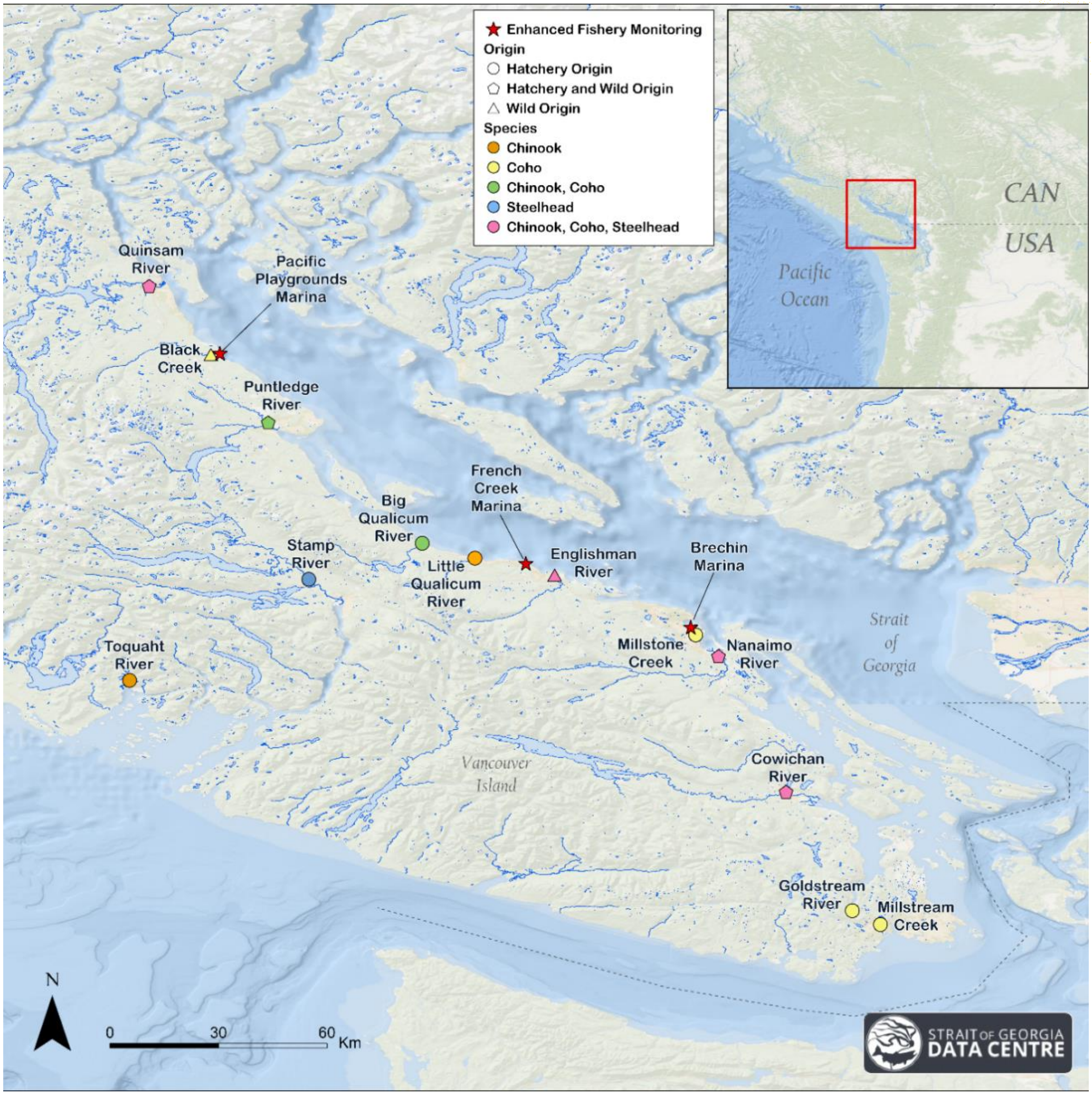

Figure 1. Map of the study region (Northern Salish Sea / Strait of Georgia) showing river systems outfitted with PIT infrastructure, target species for tagging (colour-coded circles), and recreational landing sites for enhanced fishery monitoring programs (red stars).

General Methodology

In order to estimate stage-specific survival, the *Bottlenecks Program* sought to tag fish at the following stages: within hatcheries (for hatchery production), downriver outmigrations, estuary residency, and first or second marine winter. Subsequently, adults returning have also been tagged through a collaboration with DFO's Avid Anglers as of 2022. The *Bottlenecks Program* began in the fall of 2020 with the PIT tagging of Chinook and coho salmon in the marine environment via *microtrolling*, a novel fishing technique that uses small recreational vessels and micro-sized lures to capture first- and second-winter salmon (Duguid and Juanes 2017). This method allowed for discrete sampling of near-shore environments, largely underrepresented when using more traditional methods (i.e., seining, trawling, and trolling). Complete tagging across all stages began in 2021 and is currently scheduled to continue until the winter of 2025/2026.

Microtrolling has been conducted by three discrete groups within the program: BCCF or program staff, UVic, and volunteer anglers (Figure 2). Microtrolling efforts have been generally spread across three regions: the Discovery Islands (Figure 3), the northern Strait of Georgia (Figure 4), and southern Gulf Islands (Figure 5) with variable effort of the three groups across each region. Much of the microtrolling and tagging efforts in the Discovery Islands have been led by volunteers, in the northern Strait of Georgia by UVic, and in the southern Gulf Islands by BCCF crews.

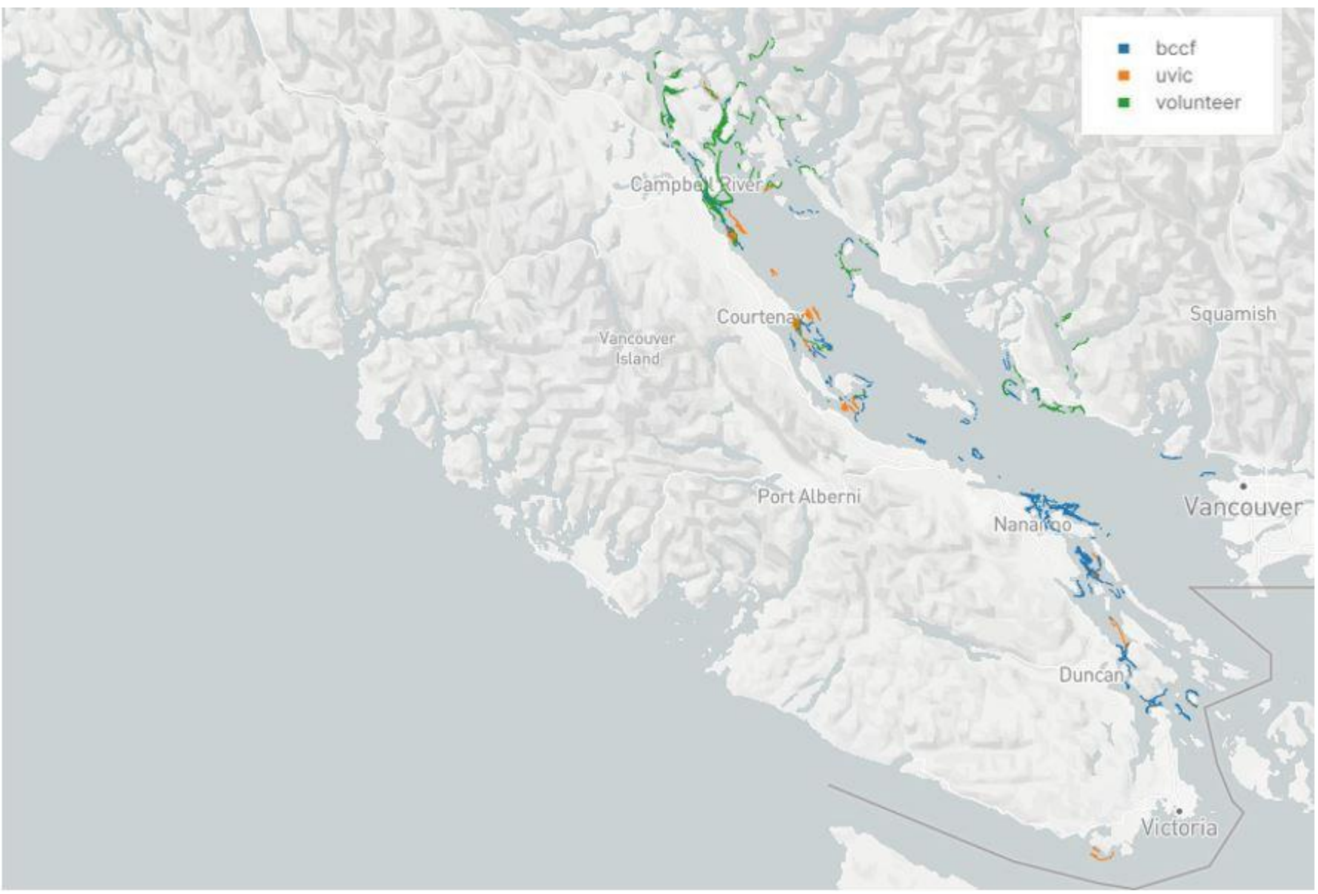

Figure 2. Map of the Salish Sea depicting sampling locations for each microtroll sampling day. Map developed using the Bottlenecks Data System.

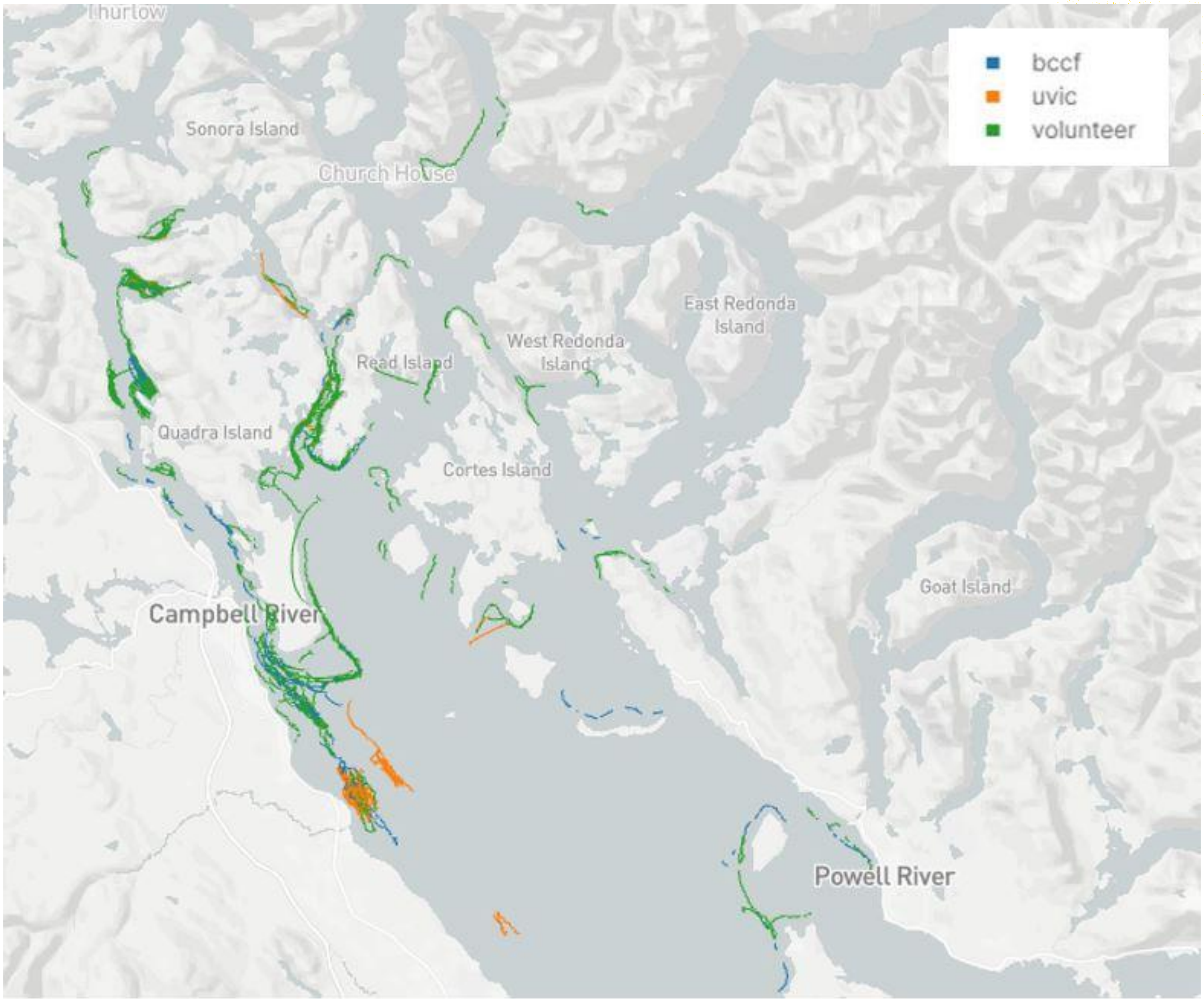

Figure 3. Map of the Discovery Islands area depicting sampling locations for each microtroll sampling day. Map developed using the Bottlenecks Data System.

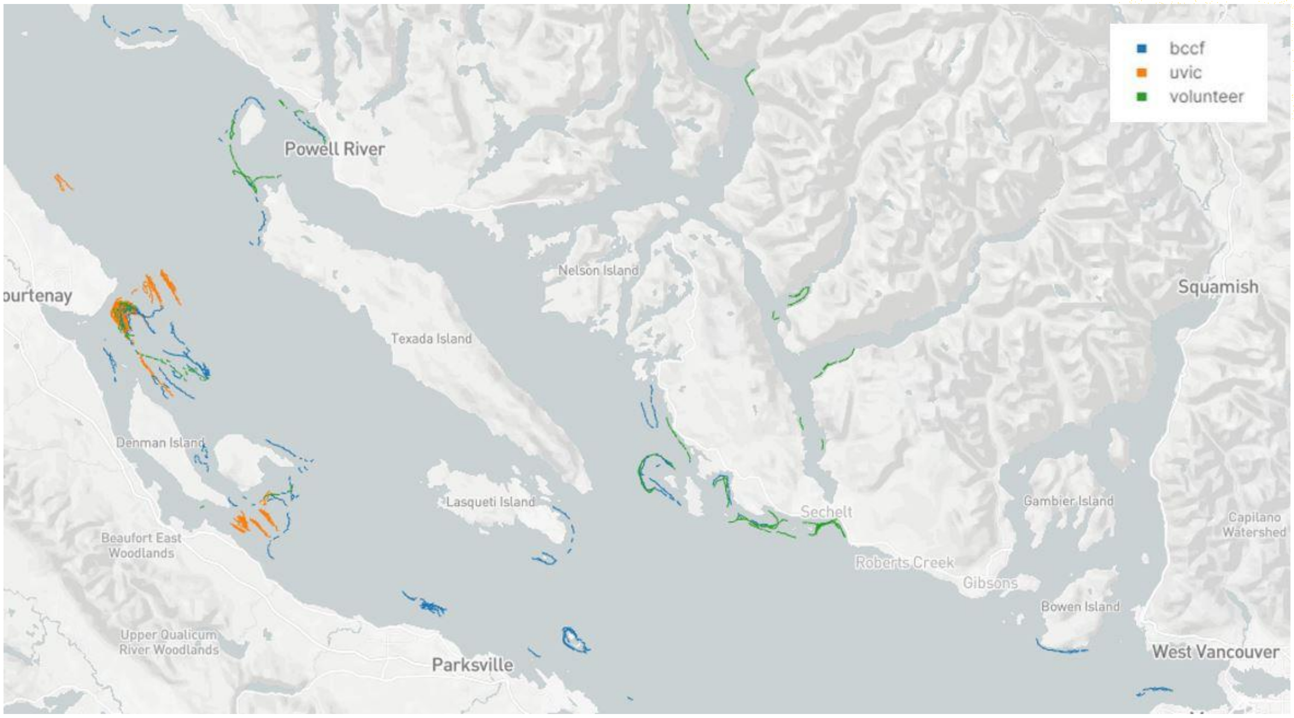

Figure 4. Map of the Northern Gulf Islands and Sunshine Coast area depicting sampling locations for each microtroll sampling day. Map developed using the Bottlenecks Data System.

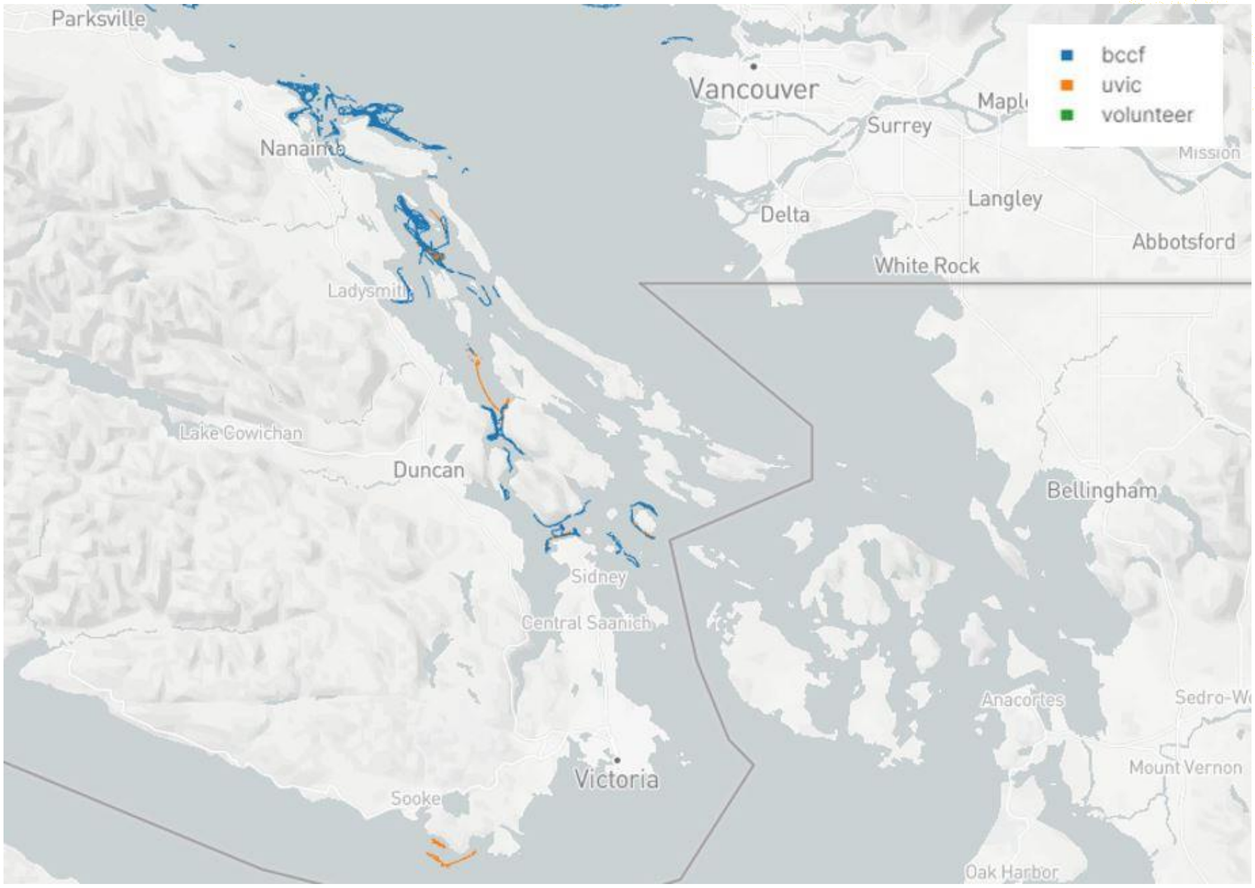

Figure 5. Map of the Southern Gulf Islands and Strait of Juan de Fuca areas depicting sampling locations for each microtroll sampling day. Map developed using the Bottlenecks Data System.

Survival Analyses

PIT tag-based investigation of Salish Sea Chinook, coho, and steelhead survival requires a number of independent and complementary survival analytical approaches. LK Environmental was contracted to lead the survival analyses.

SAR estimates

Stage-specific survival to adult return (SAR) estimates have been calculated for each tagging cohort. SAR is calculated as the percentage of tagged fish detected returning as adults on in-river PIT antennas. Adult return detections were calculated to account for imperfect detection efficiencies using the confirmed adult detections at each river system's mainstem PIT receiver and the receiver's calculated detection efficiency. Because Chinook PIT tagging only began in 2020, we currently do not have full return data for any Chinook study cohort (e.g., 5-year-old returns are expected later this year in the fall of 2024 for the 2020 cohort). Accurate SAR are therefore not currently possible for Chinook, so we instead provide survival to return for each available age-class for Chinook tagged in 2020 and 2021.

Because the *adjusted adult detections* of each study cohort have a given error distribution due to a level of uncertainty surrounding the detection efficiency of the adult return PIT receivers, 95% confidence intervals for SAR estimates were calculated using the delta method (Stuart and Ord 2009). This allows us to account for the error distribution surrounding the adult return PIT receiver detection efficiencies, which ultimately affects our SAR estimate.

Bayesian modelling

We developed a hierarchical Bayesian Cormack-Jolly-Seber (CJS) model (Cormack 1964; Jolly 1965; Seber 1965) capable of estimating detection probability at each site, survival probability between each site, and probability of survival from tagging release to each detection occasion. CJS models are often applied to study the directed migrations of species (such as Pacific salmon) through use of telemetry data. However, issues can arise when telemetry data present low recapture or detection rates, low survival rates, or low sample sizes, which can result in imprecise model parameters and survival estimates. Multi-state mark-recapture models can be applied to such datasets with low detection and survival probabilities, allowing data to be 'borrowed' from other sites while also allowing for different survival, movement, and detection probabilities at each 'state'. Multi-state mark-recapture models can be fitted with either Frequentist or Bayesian approaches. Bayesian approaches can provide greater analytical power and precision for sparse telemetry data as prior knowledge about parameter distribution can be incorporated, and parameters are considered random variables as opposed to fixed and unknown.

Currently, the survival model has been developed, tested, and refined using a simulated dataset. Developing models using simulated datasets is advantageous as it allows us to test model parameters based on the known survival and detection probabilities used to create the simulated dataset, thus allowing us to refine and validate our model. Stages with low detection efficiency (for example the estuary beach seine and microtroll which have very low recaptures) are not capable of producing accurate survival estimates between stages. Accurate survival estimates to adult return can be produced due to high detection efficiencies of the final adult PIT receivers.

GLMM

The second modelling approach being assessed is a generalized linear regression mixed model (GLMM) using a binomial link for survival. This model is typically utilized to assess different variables (i.e., river discharge, temperatures, water quality predation) that influence survival rates. While this model does not assess the differences in survival between stages, it allows for accurate survival-to-adult return (SAR) rates to be calculated for each stage and does not require recapture rates to inform the model's confidence; these are calculated from the detection efficiencies at the terminal PIT arrays, located in the *Bottlenecks Program* primary and secondary river systems. However, while the GLMM does not account for survival between stages, assuming that the study is following the same fish throughout its stages of tagging is reasonable, supported by known recapture rates of tagged fish throughout the study at each stage.

At this stage, both models require further development and, at minimum, the fourth and fifth years of returns for the first complete study year 2021-2022 before finalizing the models and obtaining stage-specific survival estimates for Chinook.

Bottlenecks Database System

Using modern software engineering practices and open-source software, we have developed a robust information system for managing the research data collected by the project.

Through the Strait of Georgia Data Centre's partnership with UBC's Institute of Oceans & Fisheries, the Bottlenecks team was able to secure cloud infrastructure to host a Postgres database to house their operations and research data. A remote Linux server is used to host the relational database management system, as well as the software used by the researchers to access and manage the data.

The database schema is designed to ensure referential integrity, and the system enforces data quality through the use of automated data processing and constraints. State-of-the-art web-based analytics software is used to allow researchers to perform ad hoc queries of the database, as well as build data visualizations and interactive dashboards to be used for internal and external reporting. The ongoing development of the system aims to integrate additional external data sources, such as environmental and climate data, to broaden the research scope.

For a more detailed description of our data management system, see "Bottlenecks to Survival: Database Report".

OUTCOMES

Herein we provide a brief overview of the outcomes to date from the first four years of the *Bottlenecks Program*. Unless otherwise stated, these findings are preliminary and will be updated with each subsequent year of data for the remainder of the program (through March of 2026). While the overarching objective of the program is to investigate where and when the bottlenecks to salmon survival are occurring, we only have two years of return data (2022 and 2023) and cannot yet draw any final conclusions. A more comprehensive analysis of the data will be available by 2026. In the meantime, significant strides have been made in creating an extensive PIT infrastructure across Vancouver Island, exploring rearing and release strategies, investigating freshwater survival mechanisms, tracking marine distributions, understanding the winter ecology of juvenile Chinook, and improving fisheries monitoring methods. In addition, our infrastructure and learnings from the program to date have aided other researchers and collaborators in pursuing their own salmon studies. Therefore, here we present a first look at our stage-specific survival estimates for Chinook and coho, followed by a comprehensive overview of the incredible work that has come out of the *Bottlenecks Program* and its partners so far.

Stage-Specific Survival

Chinook

A total of 142,534 PIT tags were deployed in juvenile Chinook across nine watersheds during the first four years of study. A summary of all PIT tag deployments by watershed, species, year and stage is located in *Appendix B: Bottlenecks Program Data*. It should be noted that these tables include all age classes captured at each stage, while the analysis below only utilizes first-winter Chinook.

Preliminary stage-specific "survival" estimates have been calculated for the primary and secondary stocks of the *Bottlenecks Program* for the first two study years 2020-2021 and 2021-2022, where possible (Tables 1 and 2). These are not true survival estimates as not all age classes have returned to these systems. Rather, these are the percent of tagged fish that were detected returning at each age. The numbers of tags out and tags detected returning were not large enough to derive survival estimates for all stages for all stocks.

The percentage of all fish returned to date detected on a PIT receiver in a non-natal river system ('strays') was also calculated (Tables 1 and 2).

Table 1. Chinook contributions to adult returns for each age class for the primary populations of the *Bottlenecks Program* including the total number of Chinook tagged during each stage (hatchery, river, estuary, and microtroll) for the first two study years, the total number of tagged fish detected returning on PIT receivers to date (expanded to account for detection efficiencies (DE) of each PIT antenna), and % strays. We note that the total number of detected returns is not complete for any of the cohorts shown in this table as additional returns are expected in subsequent years.

STOCK	YEAR	STAGE	# TAGGED	TOTAL RETURNS TO DATE (DE CORRECTED)	% 1-YO RETURNS (95% CIS)	% 2-YO RETURNS (95% CIS)	% 3-YO RETURNS (95% CIS)	% 4-YO RETURNS (95% CIS)	% STRAYS
Cowichan	2020	microtroll	487	23	0.21	1.97 (1.74–2.19)	1.60 (1.46–1.74)	0.91 (0.84–0.98)	0.00
	2021	hatchery	6744	72	0.36 (0.32–0.40)	0.49 (0.45–0.53)	0.21 (0.20–0.23)	NA	2.78
	2021	river	4978	99	0.43 (0.38–0.48)	1.09 (1.00–1.19)	0.47 (0.43–0.50)	NA	0.00
	2021	estuary	2911	45	0	1.07 (0.98–1.16)	0.49 (0.46–0.53)	NA	2.20
	2021	microtroll	468	24	0	3.30 (3.03–3.57)	1.90 (1.75–2.04)	NA	4.11
Nanaimo fall	2020	microtroll	93	2					
	2021	hatchery	5000	85	0.02 (0.00–0.53)	0.94 (0.72–1.16)	0.74 (0.54–0.94)	NA	3.53
	2021	river	163	2					
	2021	estuary	715	9	0	0	1.26 (0.57–1.94)	NA	0.00
	2021	microtroll	33	1					
Nanaimo summer	2020	microtroll	13	0					
	2021	hatchery	5000	13	0	0.08 (0.01–0.15)	0.18 (0.08–0.28)	NA	7.69
	2021	river	69	1					
	2021	estuary	297	2					
	2021	microtroll	23	1					
Puntledge fall	2020	microtroll	227	6	0	0.44	0.88	1.50 (1.22–1.79)	0.00
	2021	hatchery	5000	24	0	0.10 (0.00–0.27)	0.39 (0.31–0.46)	NA	0.00
	2021	estuary	963	17	0	1.56 (0.00–4.15)	0.24 (0.19–0.28)	NA	0.00
	2021	microtroll	598	15	0	0.84 (0.00–2.23)	1.71 (1.39–2.03)	NA	0.00
Puntledge summer	2020	microtroll	19	1					
	2021	microtroll	6	0					

Table 2. Chinook contributions to adult return estimates for each age class for the secondary populations of the *Bottlenecks Program* including the total number of Chinook tagged during each stage (hatchery, river, estuary, and microtroll) for the first two study years, the total number of tagged fish detected returning on PIT receivers to date (expanded to account for detection efficiencies (DE) of each PIT antenna), and % strays. We note that the total number of detected returns is not complete for any of the cohorts shown in this table as additional returns are expected in subsequent years.

STOCK	YEAR	STAGE	# TAGGED	TOTAL RETURNS TO DATE (DE CORRECTED)	% 1-YO RETURNS (95% CIS)	% 2-YO RETURNS (95% CIS)	% 3-YO RETURNS (95% CIS)	% 4-YO RETURNS (95% CIS)	% STRAYS
Big Qualicum	2020	microtroll	204	6	0	1.71 (1.01–2.41)	0	1.47	0.00
Big Qualicum	2021	hatchery	5000	33	0.11 (0.06–0.15)	0.12 (0.04–0.20)	0.44 (0.29–0.59)	NA	0.00
Big Qualicum	2021	estuary	15	0					
Big Qualicum	2021	microtroll	509	4	0	0	0.68 (0.12–1.23)	NA	25.00
Little Qualicum	2020	microtroll	137	1					
Little Qualicum	2021	hatchery	5000	41	0.04	0.32 (0.04–0.60)	0.46 (0.39–0.53)	NA	7.31
Little Qualicum	2021	estuary	24	1					
Little Qualicum	2021	microtroll	421	10	0	1.68 (0.35–3.00)	0.76 (0.68–0.84)	NA	19.50
Quinsam	2020	microtroll	23	0					
Quinsam	2021	hatchery	5000	3	0	0	0.06 (0.003–0.12)	NA	0.00
Quinsam	2021	microtroll	281	0					

With these preliminary data in hand, we can now begin to refine our initial analytical approaches based on the data actually attainable through the program. For the Bayesian CJS models, recaptures of tagged individuals between stages are important in deriving accurate survival estimates. However, we have found that detecting (i.e., recapturing) fish in the marine environment is challenging. While recaptures have occurred throughout the program (n = 401), most of those occurred during beach seining, where recaptures were of fish tagged only a few days or weeks apart (n = 340). To date, only 39 Chinook have been recaptured while microtrolling. Ultimately, the field program was not designed to effectively recapture large numbers of PIT tagged individuals, therefore alternative modelling approaches are being explored that may be better suited to the types of data being generated by the program.

While the overall design of the CJS model is not a perfect fit for our data, its utilization for deriving detection probabilities and inferring mortality between stages is highly useful, even with larger confidence intervals that accompany the low recapture rates. Further, developing a hierarchical CJS model with Bayesian inference may increase the statistical power necessary to derive differences in survival. While our sample sizes indicate the ability to derive accurate survival estimates for most stages for each primary watershed and, to a lesser extent, secondary watersheds, our sample sizes are not large enough to separate out the different origin types and cohorts present. As such, deriving survival estimates for hatchery and wild cohorts and estimates for the endangered summer-run stocks in the Nanaimo and Puntledge rivers is unlikely without the utilization of hierarchical modelling or alternative analytical approaches.

It is important to note, however, that the numbers of tags deployed has generally increased over the first four years of the program through capture methodology refinements and adapting to lessons learned in the field. As such, the preliminary stage-specific survival estimates provided include years with the some of the fewest tags deployed (Appendix B). This is a good sign and indicates that we are likely to be successful in estimating stage-specific survival for the majority of stages in the primary watersheds for all other study years.

Coho

The consistent capture and tagging of meaningful numbers of first ocean winter coho in the marine environment proved to be difficult through the winter months. In the program's first three years, only 1,435 first-year winter coho were captured during microtrolling. The majority of these captures occurred from September to November. Throughout the later winter and early spring months, very few coho have been encountered.

In addition, genetic stock composition analysis from the program's first year suggested a low proportion of fish (~ 20%) were from *Bottlenecks Program* systems. Further, only 25% of these fish were identified by parentage-based tagging (PBT). Given the high rates of straying in coho and many small enhanced and unenhanced systems throughout the Strait of Georgia, genetic stock identification (GSI) stock assignments could not confidently predict the system to which a coho would be expected to return. We have determined that high coho salmon CPUE can be achieved in offshore areas of PFMA 14 and 17 in October; focusing efforts at these identified locations and times could dramatically increase the number of fish tagged.

Preliminary stage-specific survival estimates have been calculated for the first three study years (2020-2022), where possible (Table 3). The numbers of tags out and tags detected returning were not large enough to derive survival estimates for all stages for all stocks. The percentage of all fish returned to date detected on a PIT receiver in a non-natal river system ('strays') was also calculated (Table 3).

Table 3. Survival estimates (with 95% confidence intervals) for six populations of coho tagged during the first three years of the program (2020-2022), including the total number tagged during each period (hatchery, river, estuary, and microtroll), the total number of fish detected returning to date (expanded to account for detection efficiencies), the proportion of strays and the proportion of 4-year olds (4-YO) returning. We note that the total number of detected returns may not be complete for cohorts tagged in 2022, as potential four-year-olds may return to rivers in the fall of 2024.

STOCK	YEAR	PERIOD	# TAGGED	TOTAL DETECTED RETURNS TO DATE (DE CORRECTED	SAR (%) (95% CIS)	% STRAYS	% 4-YO
Big Qualicum	2020	microtroll	34	1			
Big Qualicum	2021	hatchery	4995	78	1.54 (0.29-2.78)	10.13	1.31
Big Qualicum	2021	microtroll	1	0			
Big Qualicum	2022	hatchery	2949	87	2.96 (1.65-4.28)	5.00	?
Cowichan	2020	microtroll	5	0			
Cowichan	2021	estuary	2	0			
Cowichan	2021	river	5009	332	6.61 (5.97-7.25)	0.00	0.42
Cowichan	2022	river	2501	120	4.81 (3.93-5.69)	0.00	?

Englishman	2021	river	3646	77	2.12 (1.57-2.67)	16.85	0.00
Englishman	2022	river	2900	141	4.88 (3.05-6.70)	7.07	?
Nanaimo	2020	microtroll	1	0			
Nanaimo	2021	hatchery	3862	142	3.69 (2.08-5.29)	2.92	0.00
Nanaimo	2021	river	5	0			
Nanaimo	2021	estuary	3	0			
Nanaimo	2022	hatchery	1102	7	0.68 (0.00-2.05)	0.00	?
Nanaimo	2022	river	7	0			
Nanaimo	2022	estuary	98	3			
Puntledge	2020	microtroll	41	2			
Puntledge	2021	hatchery	4913	469	9.34 (3.19-15.49)	0.30	2.15
Puntledge	2021	river	1	0			
Puntledge	2021	estuary	202	50	24.75 (8.58-40.92)	0.00	0.00
Puntledge	2021	microtroll	2	0			
Puntledge	2022	hatchery	4477	410	9.16 (2.95-15.38)	1.12	?
Puntledge	2022	estuary	1078	101	9.37 (7.98-10.77)	0.00	?
Quinsam	2020	microtroll	10	1			
Quinsam	2021	hatchery	4941	136	2.75 (1.98-3.53)	0.00	0.00
Quinsam	2021	microtroll	2	0			
Quinsam	2022	hatchery	4923	77	1.56 (1.05-2.08)	0.00	?

Given the low proportion of target stocks and the difficulty in deploying sufficient tag numbers across stages, tagging of coho to derive stage-specific survival will not be continued within the *Bottlenecks Program*. Tagging of coho will continue for some stocks/stages to provide overall survival estimates and support stock assessment where appropriate. Further conversations with stock assessment and First Nations partners are required to finalize coho tagging plans moving forward.

Freshwater Enhancement and Survival

Led by the *Bottlenecks Program*, a number of studies have been undertaken within enhancement facilities or with enhanced fish to explore tagging related mortality, overwinter mortality of coho in earthen channels, release strategies to improve the survival of enhanced steelhead, and predation by Great Blue Herons. These studies based in freshwater are critical pieces of the larger Bottlenecks Program and are described below. Greater detail can be found in the individual technical reports.

In addition, our program has fostered collaboration with governments, academic researchers, and local groups, who, with the support of the *Bottlenecks Program*, are leading novel studies into the influence of vaterite on coho survival, the effects of habitat restoration on population rebuilding, and freshwater outmigration timing and survival given changes in river conditions. While these studies have been designed to answer questions outside of the *Bottlenecks Program*, PIT tag detections will be used to supplement our survival analyses and their findings will guide the nature of our program moving forward.

Overall, outmigration survival is believed to play a significant role in determining overall cohort success, but few studies have successfully attributed variation in survival estimates to freshwater or marine phases. By partitioning survival into freshwater and marine stages, we hope to better identify where and when bottlenecks to survival are occurring.

Tagging-Related Mortality

When designing a tagging program, it is important to consider the type of tag required, size of the tag, tag retention, and the impact of tagging on fish behaviour and survival. PIT tags have grown in popularity for fish monitoring since their introduction in the mid-1980s (Gibbons and Andrews 2004). They do not require batteries and are small, long-lasting, and affordable relative to other tagging methods. However, the PIT tagging process and the tags themselves can impact the fish’s health and performance, thus affecting the study's validity. The tagging event could cause physical injury or stress to the fish, resulting in mortality, or the presence of the tag in the body cavity could create a burden that is too large and impact physiology and swimming performance. A systematic review of PIT tagging studies found that the best practice for tagging juvenile salmon was to tag individuals no smaller than 69 mm when using 12 mm tags to minimize the negative effects of tagging (Vollset et al. 2020). At this tag to body size ratio, mortality is expected to be approximately 0-5%.

To follow best practices and check the assumption that our PIT tagging methods did not exceed the expected 5% mortality rate, we used hatchery Chinook and coho tagging events at Goldstream (coho only), Nanaimo, Puntledge and Quinsam rivers during the first three years of the *Bottlenecks Program* to explore tagging related mortalities and rejections. Fish handling and tagging methods were as described in the methodology in Appendix A. Tagging-related mortality can be high over a short period immediately after tagging but drops off significantly over time (Vollset et al. 2020). Therefore, our fish were held for a minimum of two weeks post-tagging to monitor tagging-related mortalities and tag rejections.

A total of 59,900 Chinook and 62,500 coho of hatchery origin were PIT-tagged across the four hatchery facilities on the east coast of Vancouver Island between August 2020 and May 2023 (Table 4). Over the first three years of the study, there were 2,505 non-viable tags, which resulted in an **overall tagging survival rate of 98.0%**. The 2,505 non-viable tags comprise four categories, and their associated percentages per year are shown in Table 4.

During the first three years of the *Bottlenecks Program*, overall **tagging-related mortality for Chinook and coho smolts was estimated to be 1.74 and 0.62%**. These results align with the 0 – 5% tagging-related mortality determined by Vollset et al. (2020).

Table 4. Summary of non-viable tags from all species and years of hatchery tagging during the *Bottlenecks Program*.

TAG STATUS	OUTMIGRATION YEAR					
	2021		2022		2023	
	N	%	N	%	N	%
mortality	517	1.48	240	0.56	652	1.73
reject	290	0.83	557	1.31	46	0.12
squib	0	0.00	21	0.05	0	0.00
unknown	106	0.30	0	0.00	0	0.00
euthanized	0	0.00	0	0.00	76	0.17

Temporal trends showed that the first two days post-tagging were critical, with **50% of both mortalities and rejections occurring by day 3**, and **90% by day 7.** This highlights the importance of early post-tagging handling and protocol improvements to reduce adverse impacts.

We noted an **overall decrease in tagging-related mortality and rejections over the three years**, with a few exceptions **driven by new inexperienced, or a single, specific tagger.** In Year 1, facilities without tagging rooms or flow-through tagging tables experienced higher mortality rates in Chinook due to static anesthetic baths and multiple handling events post-tagging. As such, a review of handling and tagging methodologies was completed, and recommendations from the DFO-SEP veterinarian in May of 2021 included using flow-through tagging tables to reduce post-tag handling and adhering to a 17.5% tag weight to body weight limit.

Individual taggers significantly impacted mortality rates, with higher mortality rates associated with new taggers, underscoring the need for consistent training and monitoring. For instance, in 2023, one tagger had extraordinarily high mortality rates at the Nanaimo hatchery (Table 4 and Figure 6). This suggests that further training and standardized procedures are required to mitigate such high mortality rates.

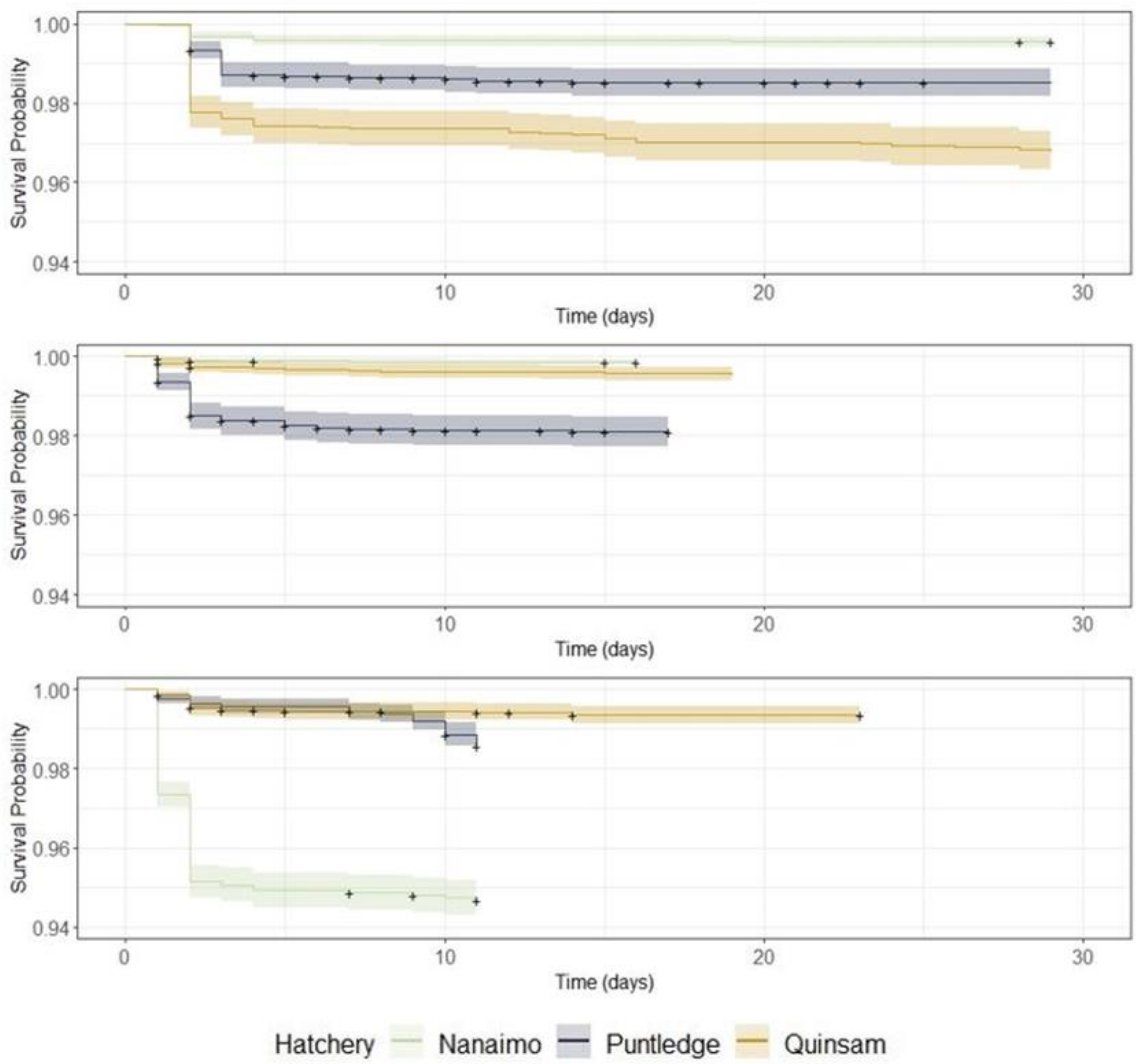

Figure 6. Kaplan-Meier survival curves for Chinook smolts tagged in 2021 (top), 2022 (middle), and 2023 (bottom) across three hatcheries: Nanaimo, Puntledge, and Quinsam.

More information on this study is provided in the report "Tagging-Related Mortalities and Rejections for Hatchery-Reared Chinook and Coho Salmon."

Earthen Channel Overwinter Survival of Coho

Recent research found that differences in hatchery and wild salmon survival rates can partly be attributed to underestimating prerelease mortality of hatchery fish (Irvine 2020). To investigate this, we adapted our PIT methodology to monitor the survival of coho reared in earthen channels – specialized, outdoor, pond-like habitats excavated from the earth, designed for juvenile salmon rearing. After emergence from eggs in the winter, coho are often reared in circular tubs, concrete raceways or Burrow's ponds, marked (with CWTs and adipose fin clips) in the spring/fall, and transferred to earthen channels where they rear for approximately a year until release the following spring. Given the extended period between tagging and release, a proportion of those fish are expected not to survive, affecting final release estimates. Some hatcheries apply a blanket mortality rate (e.g., 1-5% mortality depending on the hatchery and species) to account for these losses, while others do not apply any correction. Overestimating the numbers of hatchery fish being released can result in underestimating survival rates (number of adult returns divided by number of juveniles released).

Our primary objective was to estimate survival of juvenile coho salmon during earthen channel residency at four hatchery facilities on the east coast of Vancouver Island: Big Qualicum River, Nanaimo River, Quinsam River and Puntledge River Hatcheries. Fish were PIT tagged and held in earthen channels at each facility for varying lengths of time prior to release as smolts. PIT receivers were installed at the outlet of each earthen channel to detect the outmigrating tagged coho salmon upon release. We also examined survival to adult return and return ages from each release group.

Survival rates in the earthen channels were highly variable among hatcheries and years. For instance, juvenile coho survival in the Big Qualicum ponds varied from 99.90% in 2021 to 60.35% in 2022, whereas at Quinsam River Hatchery, survival was over 99% in both years (Figure 7). However, because the period of time over which survival was measured also varied between years, a daily mortality rate was calculated. Daily mortalities were exceptionally high at Nanaimo River Hatchery where a family of otters were found predating upon the salmon in the earthen channels (overall survival as low as 22.14% in 2022). Therefore, **applying a blanket pre-release mortality rate, or not applying one at all, will lead to inaccuracies in hatchery survival estimates**. Thus, the **survival estimates conventionally reported by the hatcheries (i.e., ponding to adult return) were either lower or the same as survival estimates based on the earthen channel releases** (i.e., where pre-release mortality is accounted for Figures 8 and 9).

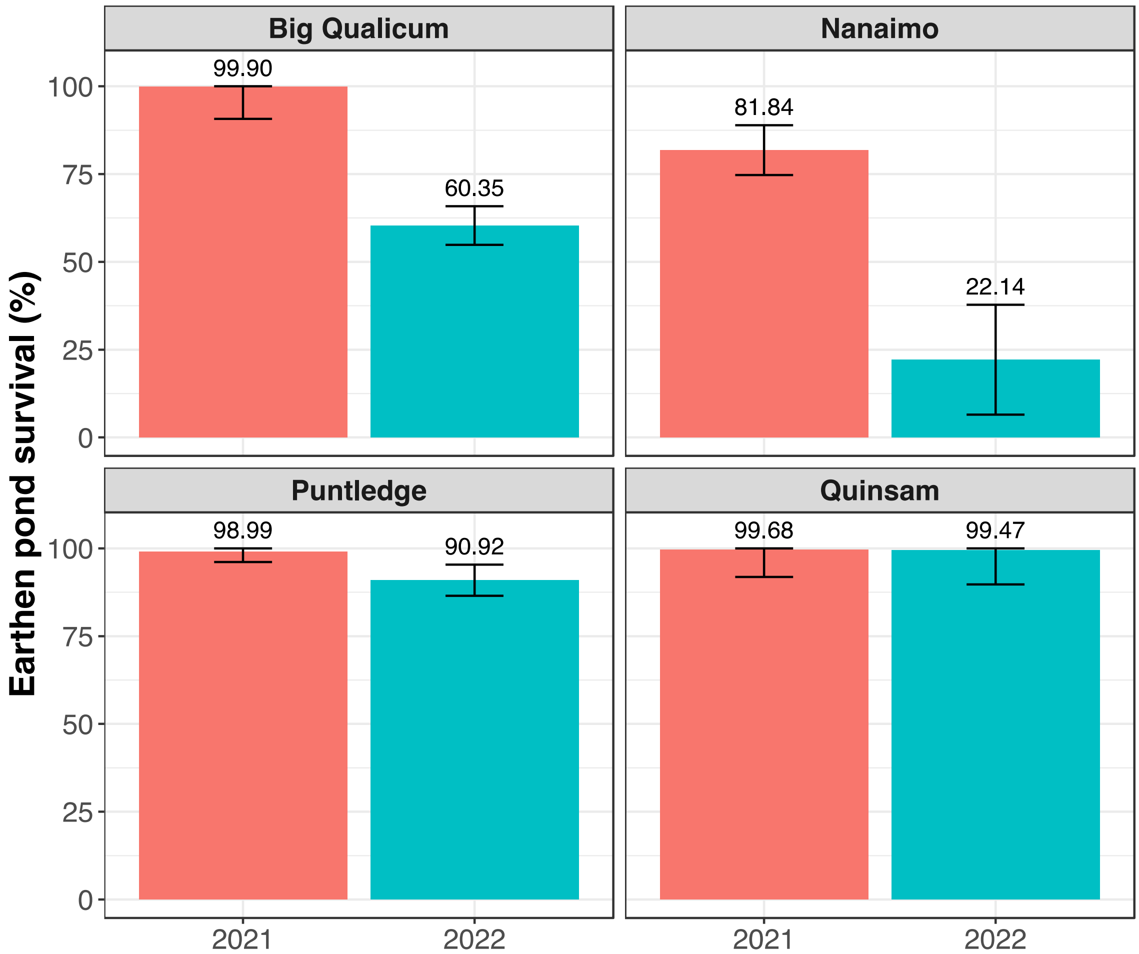

Figure 7. Survival of PIT tagged coho that were held in earthen channels/ponds at four hatcheries (Big Qualicum, Nanaimo, Puntledge, Quinsam). Error bars represent the 95% confidence intervals.

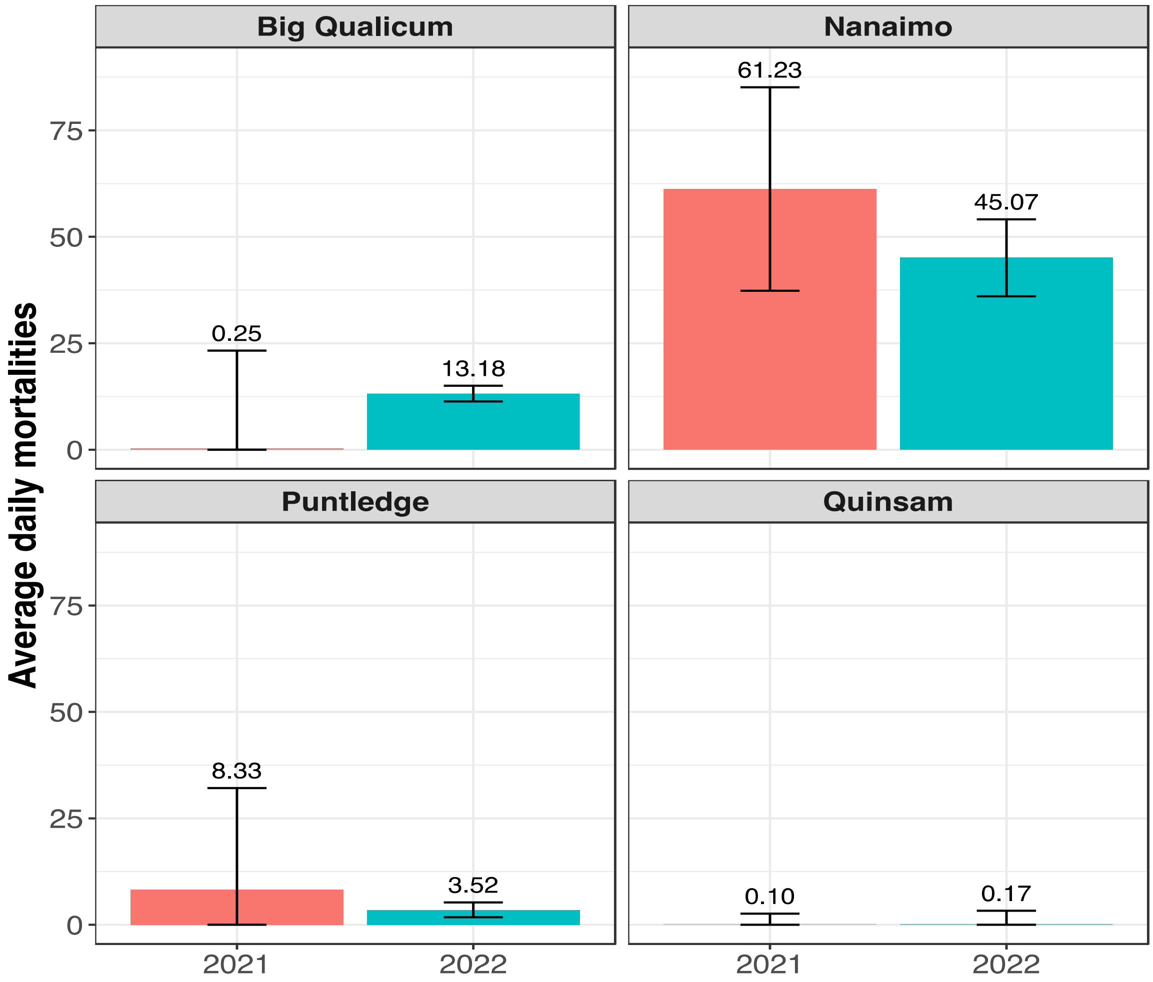

Figure 8. Estimated number of daily coho mortalities for each earthen channel in both 2021 and 2022. Average daily mortalities were calculated by dividing the total number of estimated mortalities for each earthen channel by the total residency time (in days) for each channel. Error bars represent the 95% confidence intervals.

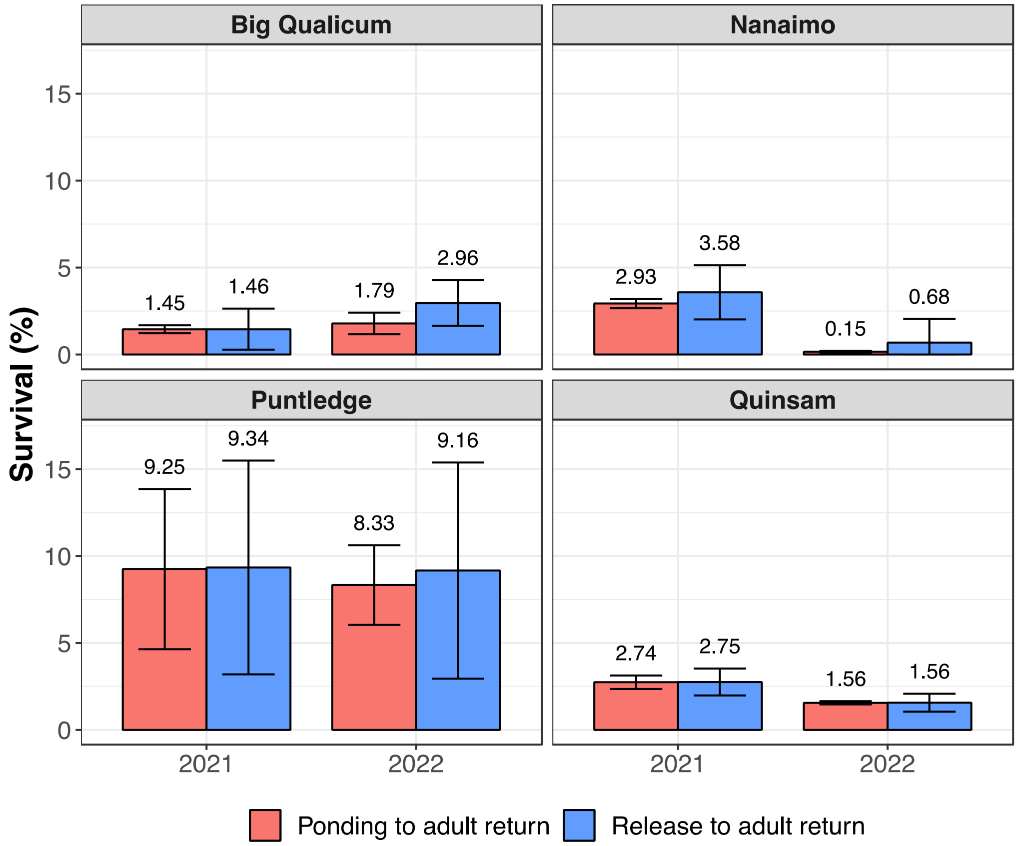

Figure 9. Estimates of coho survival from earthen channel entry to adult return (red) and earthen channel release to adult return (blue) for each cohort. The mean survival estimate is shown directly above each bar. Error bars represent the 95% confidence intervals.

This study also provided some unintended insights. **Straying rates were generally low (<5%),** except for Big Qualicum coho, who were found straying into the Little Qualicum and Englishman Rivers at rates of 5-10%. **A dozen early-run 4-year-old coho returned to the Puntledge River Hatchery**. Such a life-history strategy within this system has not been previously documented and warrants further investigation. The return timing is more consistent with Chinook than coho, but the misidentification of species within the hatchery is unlikely. Additional years of return data will help clarify the nature of the 4-year-old coho returns.

Finally, PIT-tagged cutthroat trout were detected at the Quinsam earthen pond antennas during the release, suggesting that cutthroat likely predate juvenile coho in-river and could be a source of post-release mortality.

For more information on the earthen channel survival study, see the report "Overwinter Survival of Hatchery Coho Salmon in Earthen Channels".

Robertson Creek Enhanced Steelhead Differential Release Trials

Steelhead populations have declined substantially in the Pacific Northeast, and low survival has led to persistently low returns in British Columbia. Steelhead enhancement may also threaten wild populations if done improperly, with negative impacts including adverse interactions between hatchery and wild fish and high levels of residualism (i.e., nonmigratory life-history) impacting wild genetics in hatchery steelhead. Despite the potential negative effects, low survival rates and habitat degradation may necessitate the use of hatcheries to support sports fisheries, population re-establishment, or conservation programs. Identifying the potential impacts of predation, environmental conditions, competition, and freshwater residualism are critical to increasing the post-release survival of hatchery-reared steelhead while also decreasing their impacts on wild steelhead.

The objectives of this study were to:

1. Examine the effects of differential release locations on the survival of hatchery steelhead on the west coast of Vancouver Island.
2. Determine the bypass rate of returning adult steelhead at the Stamp Falls Fishway to inform expansions of camera data collected by Fisheries and Oceans Canada (DFO).

A total of 14,866 Robertson Creek steelhead were PIT tagged and released over three years; 6,897 were released into the ocean, 6,443 into the Stamp River (Figure 10). Due to a data error, the release group (ocean or river) was not recorded for 1,526 tagged steelhead in the 2021 outmigration year. PIT arrays were installed into the Stamp River Fishway and upstream at the Robertson Creek Hatchery to detect returning fish.

Steelhead detected within the first ten months post-release were considered residualized, and data from the 2022 and 2023 release years showed a **minimum residualization rate of 1.3-1.5%**.

Preliminary adult return data indicated 37 steelhead returning to the Stamp Falls Fishway Array as of April 2024 with various run timings (Figure 13). Survival to age two and age three for the 2021 river release were 0.20 and 1.01% respectively, with 0.53% survival to age two for the 2022 river release. The unknown release group fish had a survival rate of 0.07 and 0.26% for return ages 2 and 3, respectively. There were no returns from the 2021 ocean release group, while the 2022 ocean release group had a survival rate to age 2 of 0.04% (n = 1). These **low survival rates of ocean-release fish suggest that this release method was not successful, however additional years of return data are still outstanding**.

The Stamp Falls Fishway demonstrated a 92.3% pass-through rate, which indicates **that the fishway is the primary migration corridor for adult steelhead migrating into the upper Stamp River**.

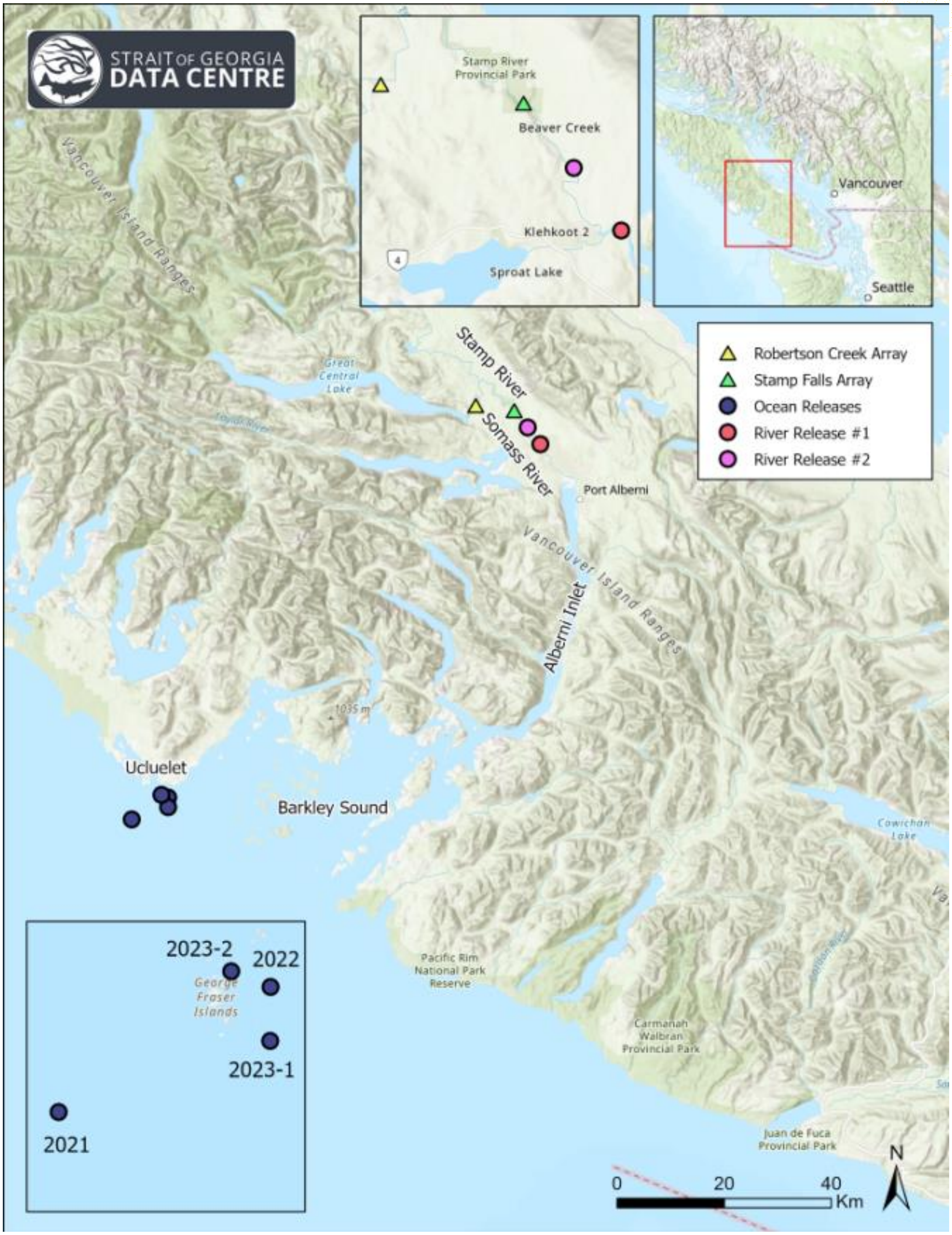

Figure 10. Map depicting release locations for the steelhead differential release study on the west coast of Vancouver Island.

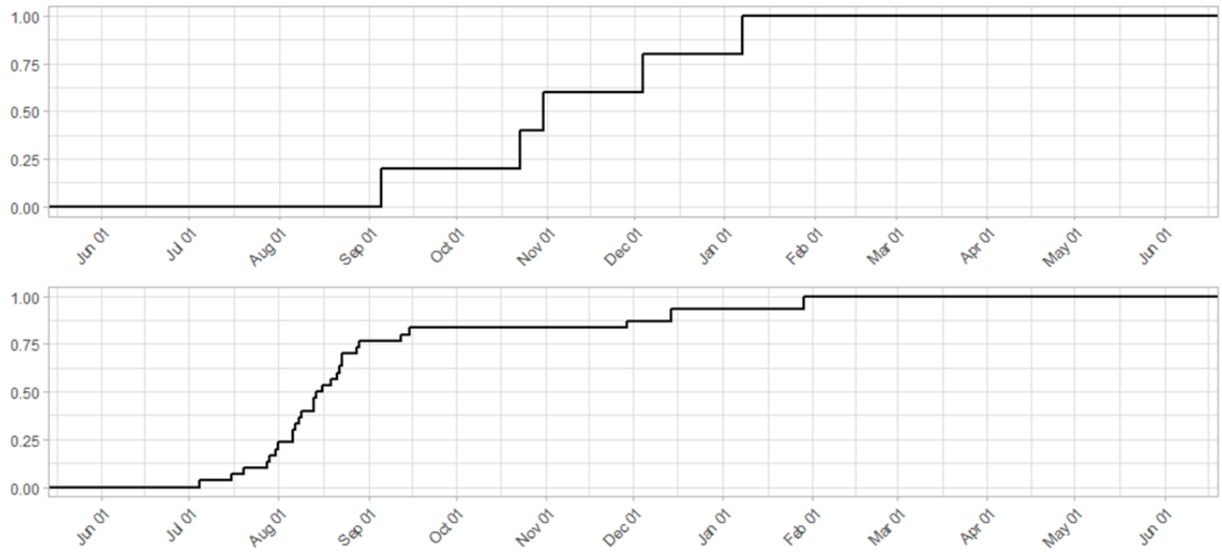

Figure 11. Adult return timing for the 2022-2023 (top) and 2023-2024 (bottom) returns. These return curves represent fish from the 2021, and 2022 release groups. Both summer and winter run steelhead cohorts are represented, from the 2021 release group, due to mixing of stock before tagging. The 2022 release group was comprised of the winter-run cohort only.

Overall, while these preliminary findings highlight areas of concern, ongoing monitoring and additional data collection will be critical for making final assessments and informing future management practices. Recommendations include installing a full-stream mainstem PIT array, deriving accurate outmigration timing, supporting annual PIT tagging with provincial funding, allocating funds to monitoring programs, and developing adult escapement estimates using mark-recapture methods.

Great Blue Heron Predation on Juvenile Salmonids

A significant discovery made during the SSMSP was the predation of juvenile Chinook by the Pacific Great Blue Heron (*Ardea herodias fannini*), a predator not previously recognized for its impact on salmon populations. This finding emerged from the novel idea of scanning beneath heron rookeries for defecated PIT tags. Given the high numbers of PIT tags being put out by the *Bottlenecks Program*, we are expanding upon the previous work completed through SSMSP to include a broader area and more years of data. Our objectives are to:

1. Determine the predation rates of Great Blue Herons on PIT tagged fish.
2. Assess the impact of fish origin (wild vs. hatchery) on predation rates.
3. Assess the impact of predation for different salmon species.
4. Evaluate the effect of fish release dates on predation rates.
5. Investigate the influence of fish size on predation rates.
6. Analyze the effects of environmental variables (river discharge, water temperature, air temperature) on predation rates.

Poisson Consulting Ltd. was contracted to develop the analytical model. Bayesian methods were employed for parameter estimation, ensuring robust and reliable results. The analysis incorporated variables such as fish origin (wild vs. hatchery), release dates, fish size, and environmental factors (e.g., river discharge). The model considers the probability that a PIT tag remains detectable at a rookery (i.e., is not damaged or washed away), and detection probability.

So far, the only rookeries with sufficient scanning data are the Cowichan River and Beacon Hill (Victoria) rookeries (Table 6). Six other rookeries have been scanned over the course of the program, however more scans are required before meaningful analyses can be conducted at these sites.

The annual survival rate of a PIT tag at a rookery was 90-95%, assuming that survival probabilities decline exponentially with the number of years between visits. The predation model showed that the effects of cohort origin, tagging period, and distance between the river system mouth and the heron rookery affect predation rates. These preliminary analyses show that **environmental variables, particularly river discharge, played an important role in shaping predation dynamics with higher predation rates at lower flows.**

Moving forward, we intend to scan rookeries with > 50 tags (Cowichan, Beacon Hill, Deep Bay) twice per year: once approximately one month after hatchery releases from nearby systems, and again six months later. For those rookeries with < 50 tags, we will scan them once per year, approximately two months after the nearby hatchery releases have been completed. With two more years of data, we hope to be able to describe predation rates of Great Blue Herons on a number of river systems on the east coast of Vancouver Island and the factors influencing predation.

Table 5. The numbers of PIT tags from various tagging systems detected at the five heron rookeries scanned where tags were present.

TAGGING SYSTEM	HERON ROOKERY	# PIT TAGS
Big Qualicum	Pipers Lagoon	1
Robertson Creek	Cowichan	1
Millstone	Pipers Lagoon	1
Nanaimo	Pipers Lagoon	4
Nanaimo	Cowichan	1
Koksilah	Cowichan	9
Cowichan	Deep Bay	1
Cowichan	Chemainus	2
Cowichan	Cowichan	886
Cowichan	Beacon Hill	3
Goldstream	Cowichan	2
Goldstream	Beacon Hill	163
Millstream	Beacon Hill	5

Collaborator Outcomes

Vateritic Otoliths in Hatchery-Reared Coho Salmon

Differences have been observed between the sagittal otoliths of hatchery-reared and wild-origin Pacific salmon. Sagittal otoliths are essential sensory structures that enable all teleost fish to hear and maintain balance and are normally composed of aragonite, a polymorph of calcium carbonate. However, otoliths with inclusions of vaterite, an abnormal polymorph, also occur (Figure 12). Although these 'vateritic otoliths' have been shown to occur in less than 10% of wild-origin Pacific salmon, they are extremely common in hatchery facilities, affecting 60-80% of hatchery-reared Pacific salmon. Vaterite formation is irreversible once begun and results in otoliths which are larger, lighter, more brittle, and less regularly shaped than their aragonite counterparts. Because of these differences, vaterite deposition likely reduces otolith function and causes severe hearing loss in salmon; potentially leading to modified behaviour and associated impacts on individual survival and population recovery.

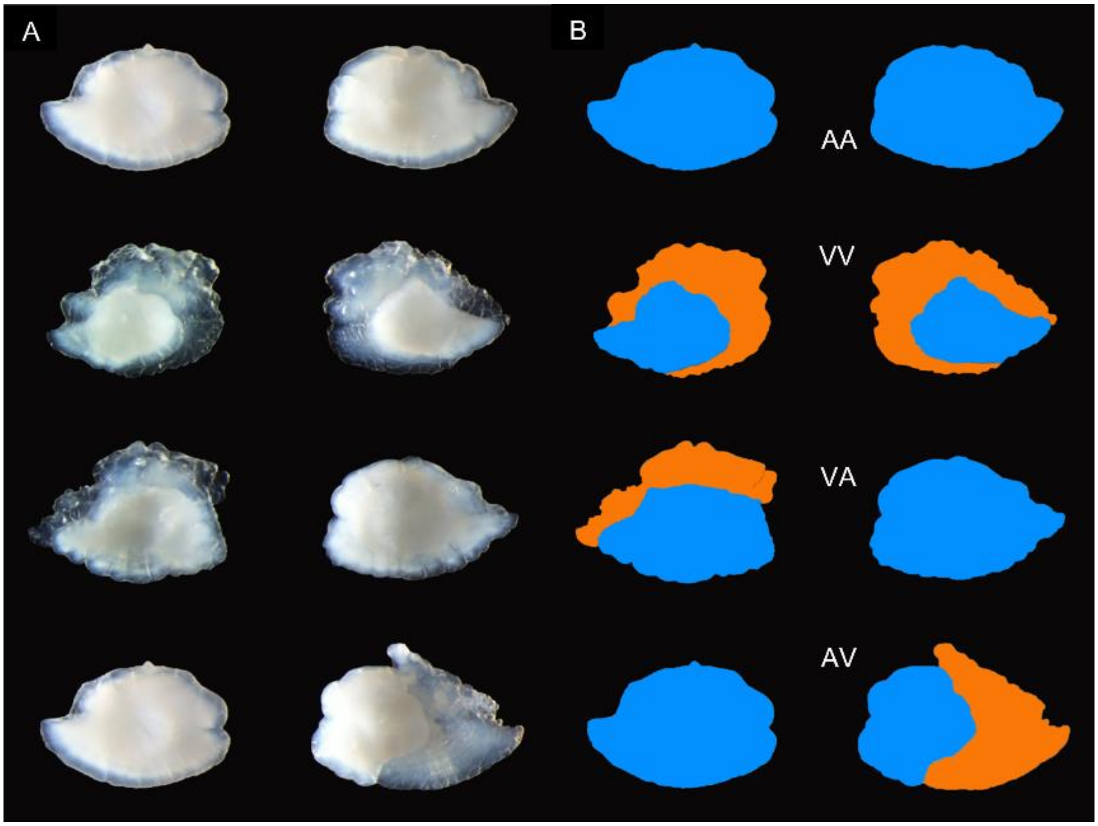

Figure 12. A) Photographs of pairs of otoliths from four different coho Salmon smolts from Goldstream Hatchery. B) Illustration of aragonite (blue) and vaterite (orange) within the otolith pairs to determine vaterite composition. The first pair of otoliths are aragonite-aragonite (left otolith=0% vaterite; right otolith= 0% vaterite); the second pair are vaterite-vaterite (left otolith=49% vaterite; right otolith= 47% vaterite); the third pair are vaterite-aragonite (left otolith=37% vaterite; right otolith= 0% vaterite); the fourth pair are aragonite-vaterite (left otolith=0% vaterite; right otolith= 53% vaterite).

Despite the prevalence of vaterite formation in hatchery and aquaculture environments, few studies have investigated vaterite formation. Much remains uncertain regarding the impacts of vaterite formation and why and when it occurs, but it is thought to be related to elevated environmental stress or differences between wild- and hatchery-rearing environments.

Leigh Gaffney, a PhD student in the Juanes Lab at UVic, is leading an experiment at the Goldstream River Hatchery to investigate the formation of vateritic otoliths. The *Bottlenecks Program* has supported this research by providing the PIT tags, as well as training, personnel, and installation and maintenance of the PIT array in the lower river. Specifically, her objectives are to:

1. Determine which hatchery-rearing practices cause formation of vateritic otoliths in coho.
2. Investigate whether vateritic otoliths influence coho survival.

To address the first objective, coho fry were reared from first ponding to release as smolts at the Goldstream River Hatchery under three rearing trial experiments: tank-water flow direction, environmental enrichment, and biodensity. For the tank-water flow direction trials, fish were reared in circular tanks with clockwise-only, counterclockwise-only, or alternating water flow directions. Environmental enrichment trials included coho reared in hatchery-standard, barren tanks, or enriched tanks with tunnels and plastic plants. Biodensity trials included tanks reared in standard densities (5,000 fish per 4,000 L tank) and low densities (1,000 fish per 4,000 L tank). It was found that **alternating water flow, enriched tanks, and standard biodensities produced fewer vateritic otolith pairs** overall, in comparison to the controls (Figure 13).

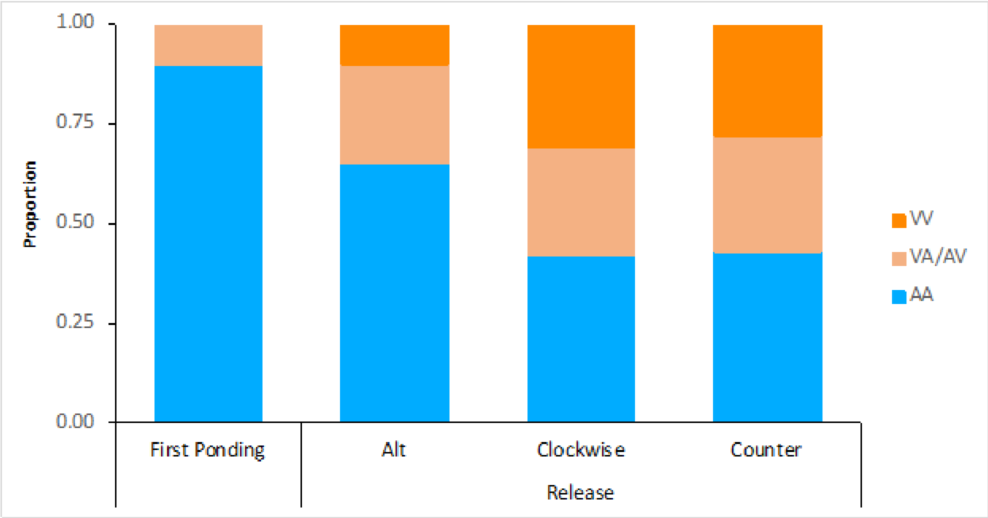

Figure 13. Results from two years of tank-water flow-direction trials at Goldstream hatchery. At first ponding, the majority of otolith pairs are composed of aragonite-aragonite (AA) pairs, however a year later at release, the number of vaterite-vaterite (VV) pairs increases in the clockwise-only and counter-clockwise only tanks. The alternating flow direction tanks have lower amounts of VV pairs in comparison to the clockwise-only and counterclockwise-only tanks.

To estimate survival impacts, the *Bottlenecks Program* provided PIT tags to tag 7,500 coho from the water flow direction trials in 2022, and 10,000 coho from each of the environmental enrichment and biodensity trials in 2022 and 2023 (Table 5).

In 2023, **more adult coho which were reared in the alternating tank water flow direction tanks returned** than those reared in either the clockwise- or counterclockwise-only water flow direction tanks. Further, **smolt survival was higher in both the enriched tanks and standard biodensities** compared to barren and low-density tanks. These results suggest that slight changes to hatchery-rearing practices may have substantial impacts on fish survival. Trials were conducted for a third year (2024), and adult coho will be returning through fall 2026. Thus, greater insights into the impacts of vaterite on coho survival are forthcoming.

Table 6. Summary of tag deployed per treatment group for study years 2022 and 2023 and detection numbers of adult returns (top) and outmigrating smolts (bottom).

REARING TRIAL MANIPULATION (TAGGED 2022)	NUMBER RELEASED	ADULT RETURNS (2023)
Clockwise only	2,500	75
Counter-clockwise only	2,500	66
Alternating	2,500	82
REARING TRAIL MANIPULATION (TAGGED 2023)	**NUMBER RELEASED**	**SMOLT OUTMIGRATION DETECTIONS (2023)**
Barren	2,600	1,052
Enriched	2,600	1,102
Standard density	3,500	1,260
Low density	1,621	505

Pinpointing the causes of vateritic otolith deformity and determining whether vateritic otoliths impact the survival of coho could enable government and community enhancement entities to improve the generally poor success rates of Pacific salmon hatchery restoration efforts, and aid in conservation efforts and salmonid stock recovery.

Given that this study comprises Leigh Gaffney's PhD research, no technical report has been written on findings to date. The final outcomes of this research will be publicly available in her PhD dissertation in 2025. Freshwater outmigration and marine survival data from the PIT tag detections of the Goldstream River coho will be incorporated into our broader analysis of coho survival.

Millstone River Restoration for Coho

The Millstone River, flowing through the heart of Nanaimo, historically supported a significant coho run. In recent years, efforts have been made to restore and enhance the habitat to support salmon populations, particularly coho.

Since 2007, a key initiative has been the construction of an 800-meter bypass channel around impassable falls in Bowen Park. This channel has facilitated the migration of coho to their spawning grounds in the upper watershed. The City of Nanaimo and various organizations have contributed to this project, leading to substantial ecosystem, educational, and community benefits.

Kevin Pellett and Karalea Filipovic of DFO's south coast Stock Assessment are leading this restoration assessment with assistance from the *Bottlenecks Program*. The *Bottlenecks Program* provided in-kind technical and equipment services and 1,000 PIT tags per year. This collaborative effort aims to:

1. Estimate smolt survival of transplanted coho releases into Brannen Lake.
2. Investigate the feasibility of smolt production monitoring through video-based enumeration in the bypass channel.
3. Estimate adult returns and survival.

In Spring 2022 and 2023, 1,000 Nanaimo River coho smolts were tagged and released into Brannen Lake to overwinter and migrate downstream the following spring (Figure 14).

A total of 367 PIT tagged coho smolts passed through the lower river arrays in 2022 and 195 passed through in 2023. Therefore, smolt survival from Brannen Lake was estimated to be 36.7% in 2022 and 19.5% in 2023. Simultaneous antenna installation in future years will help improve detection efficiency and expand the total number of smolts detected.

The first two years of assessing smolt survival from Brannen Lake proved successful. Smolts were tagged and released without any major issues and antennas were installed in time to capture outmigration. Data on returns of these individuals will be recorded in the coming years. PIT tag detections from the Millstone River will be incorporated into the broader *Bottlenecks Program* coho survival analysis.

Figure 14. Map of the Millstone River. Red Arrows indicate where tagged coho were released (Brannen Lake) and the mainstem of the river. The red star indicates the Pryde Vista PIT antenna location, while the red cross indicates the Bowen Park antenna location.

Mill Stream Restoration for Coho

The Mill Stream Watershed provides an important habitat for coho. Since 1993, coho have been reared at the Goldstream hatchery and approximately 5,000 coho are released into Mill Stream each year. Fishways in the lower watershed facilitate coho migration through the system and are equipped with cameras for enumeration. Peninsula Streams Society (PSS) led the construction of a new fish ladder in 2020-2021, providing access to 7 km of additional habitat in Mill Stream. Moreover, in August 2023, PSS in collaboration with local organizations, restored a 50 m section of the watershed.

With increasing restoration work being done in the watershed as well as the recent fish ladder construction, the primary research questions were:

1. Are coho able to access and utilize the restored habitats in the upper reaches?
2. What is the migration timing of introduced coho within this system?
3. What are the survival rates of the transplanted hatchery coho, and when is the best time of year for release to maximize returns and minimize straying?

Coho PIT tagging began in 2022 in collaboration with the *Bottlenecks Program* and Goldstream Hatchery, where 2,000 coho fry were tagged and released. A temporary PIT antenna array was installed to detect coho downstream migration. Of the **2,000 coho tagged and released in 2022, 729 coho were detected** on the downstream array (Figure 15).

A permanent array was installed in Mill Stream in 2023; however, due to production and shipping delays, installation occurred after most of the coho had migrated downstream. Only 105 coho were detected on the array. Adult coho returns in 2023 were poor, likely due to extended fall droughts and low flow conditions, which affected some coho populations across southern Vancouver Island. **In 2023, 90 adult coho were observed returning on the camera**, however no PIT tagged coho were detected on the PIT array.

Moving forward, PIT tagged coho will continue to be released into Mill Stream, comparing different release locations in the upper watershed as well as alternate release timings to maximize outmigration survival. An additional array will be installed at the top of Ladder 6 to inform whether or not coho are utilizing the newly constructed fish ladder. The *Bottlenecks Program* will continue to provide PIT tags and logistical support.

PIT tag detection of Mill Stream coho will be incorporated into the broader *Bottlenecks Program* coho survival analysis.

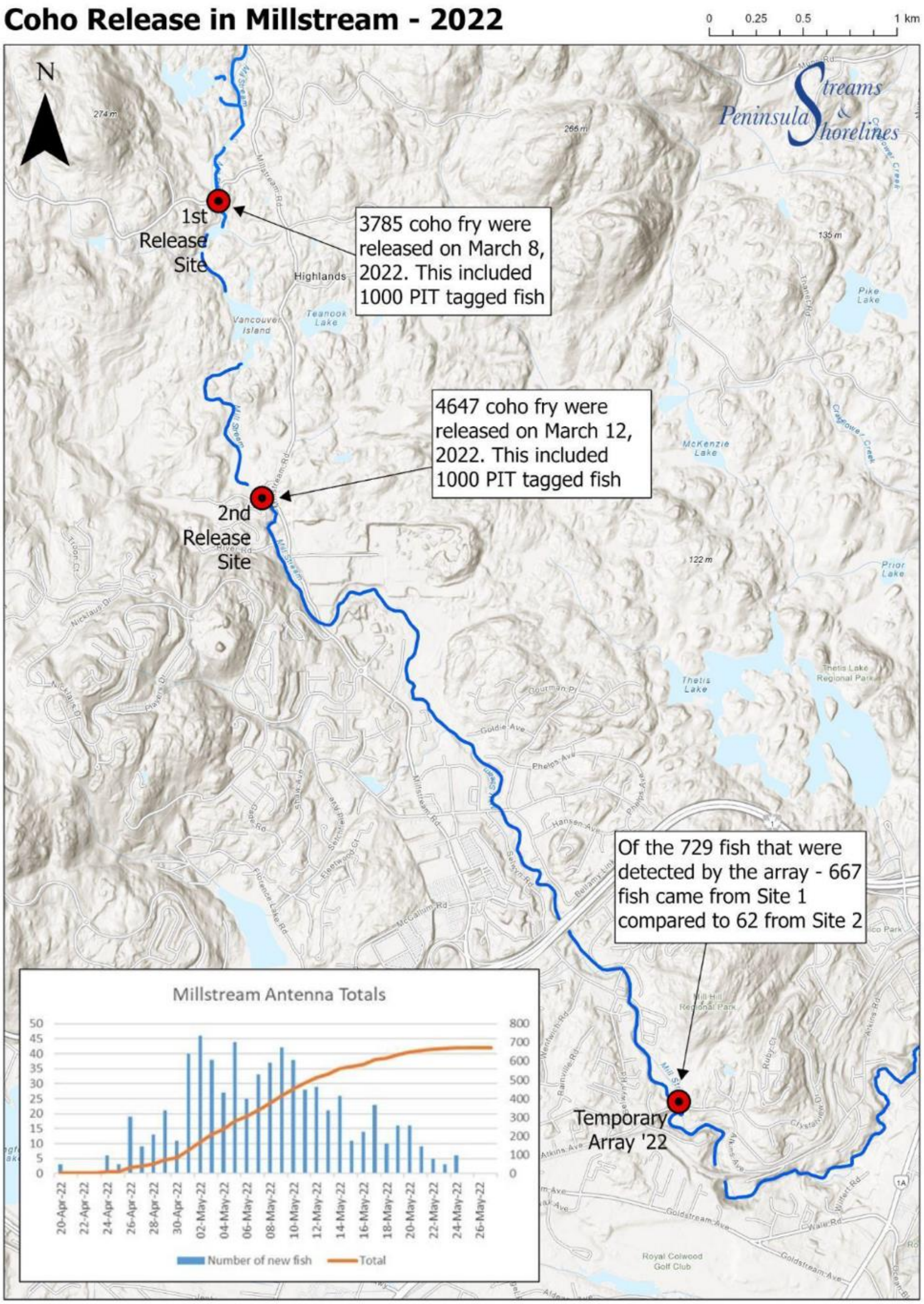

Figure 15. Map of the Mill Stream release locations and 2022 PIT antenna array. PIT tag detections from 2022, where 2,000 coho fry were tagged and released from two separate locations in the upper reaches.

Freshwater Residence and Survival of Hatchery-reared Juvenile Chinook Salmon

This study employed PIT tags to evaluate the relationships between the size of individuals at release, release location, and release timing on the duration of freshwater residence and survival of hatchery-produced Chinook in the Toquaht River watershed, located on the west coast of Vancouver Island, British Columbia. This research was led by Tom Balfour for his MSc at the University of Northern BC. The *Bottlenecks Program* provided PIT tags, as well as the PIT infrastructure for the study. A total of 4,848 PIT-tagged Chinook smolts were released on three dates, and during each release, fish were split evenly between three different locations within the watershed.

The PIT tag detection data were analyzed using an integrated model of freshwater residence and capture-recapture using Bayesian inference. An integrated model for the duration of freshwater residence after release was developed with a state-space version of the Cormack-Jolly-Seber model to quantify how body size at release, release location, and date of release influence freshwater residence duration and survival. River stage was highly responsive to rain events, and when the river height was too high, juvenile salmon migrating in the upper water column were too far above the array to be detected. Therefore, this model utilizes precipitation data to infer river height, which allows for an informed detection efficiency when detections are low (Figure 16 and 17).

Overall, the study provided further evidence that **hatchery release strategies can significantly influence freshwater residence and survival**, and these practices should be well-understood and flexible in the face of changing environmental conditions.

The **integrated freshwater residence and capture-recapture model using Bayesian inference developed for this project will be further utilized across several *Bottleneck Program* systems**. Leveraging this powerful model will **allow for more confidence in outmigration detection efficiencies** at lower river antennas and improve analysis of outmigration survival in years with high spring flows and low detections.

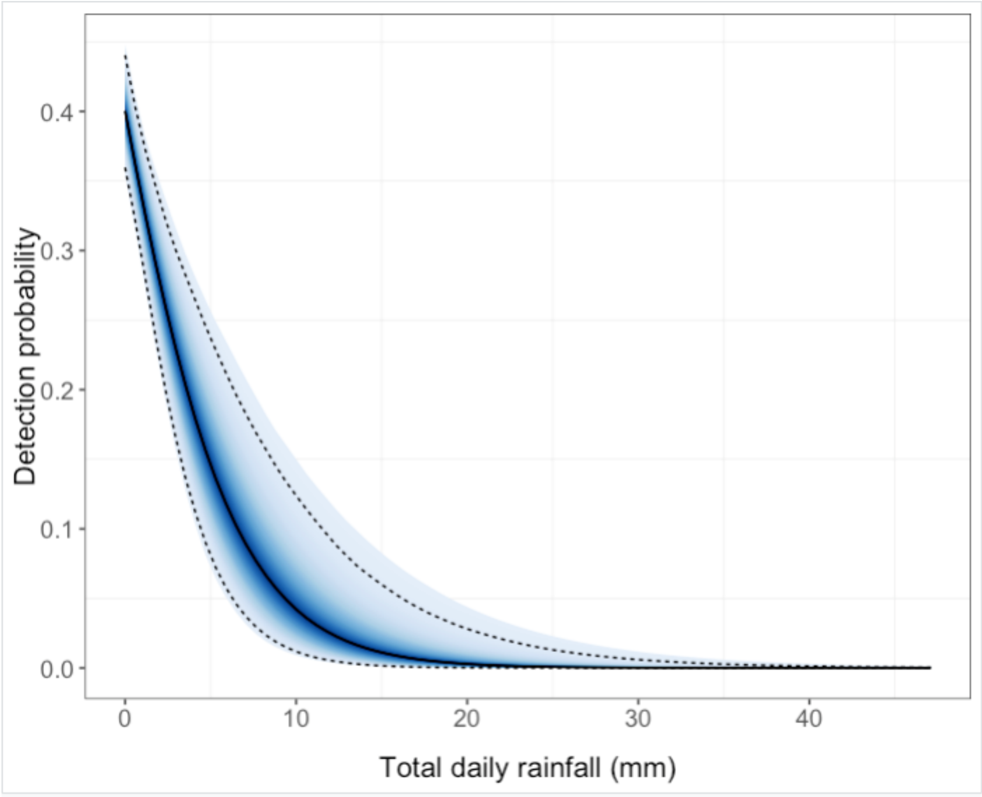

Figure 16. Detection probability as a function of two-day lagged rainfall during the study period. The solid line represents the median of the posterior distribution of detection probability at a given amount of rainfall, whereas the dashed lines represent the highest posterior density 95% credible interval. The shading denotes the density of the full posterior distribution of detection probability, with higher probability densities denoted by darker shades. Detection probability declined sharply, with total rainfall being virtually zero at about total daily rainfall amounts of 20 mm.

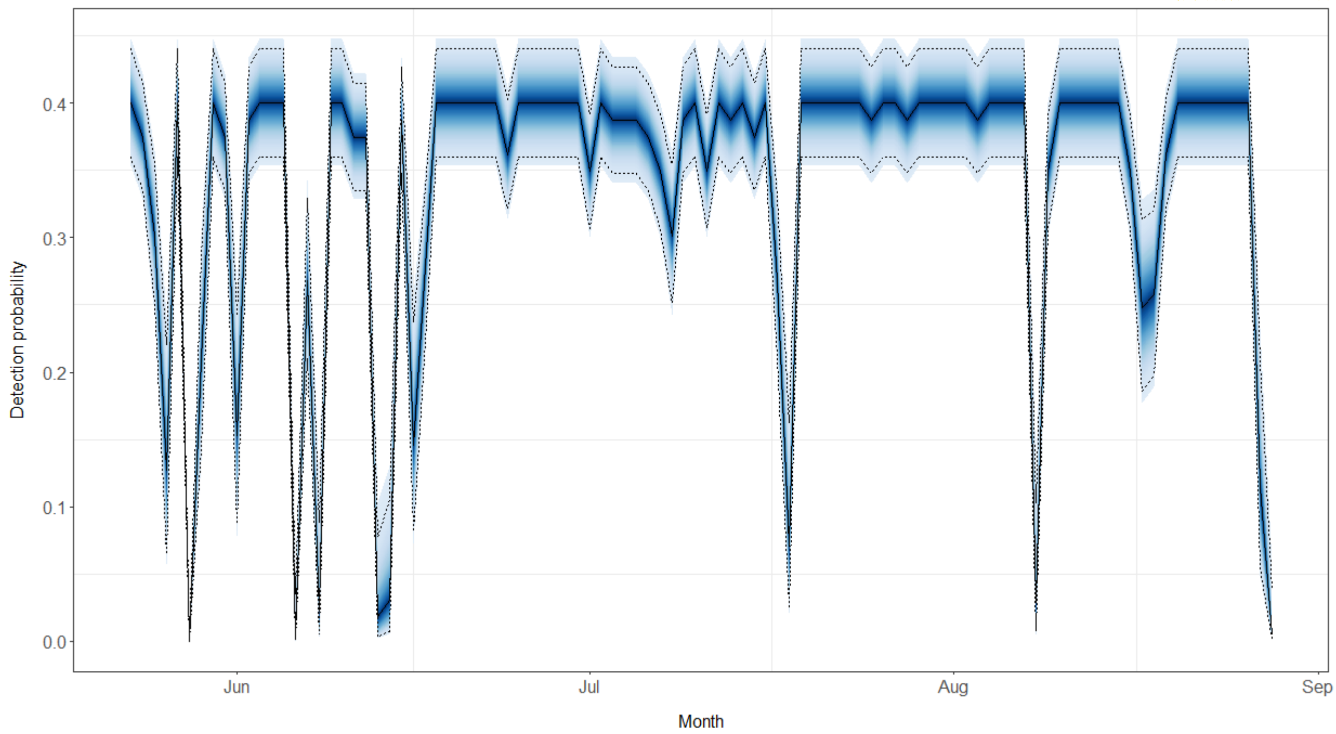

Figure 17. Predicted detection probability throughout study period based on two-day lagged rainfall. The solid line represents the median of the posterior distribution of detection probability at a given amount of rainfall two days prior to a date, whereas the dashed lines represent the highest posterior density 95% credible interval. The shading denotes the density of the full posterior distribution of detection probability, with higher probability densities denoted by darker shades. High rainfall events were frequent during the first month of monitoring, resulting in several events of low detection probability.

Marine Survival and Distribution

To investigate the survival of Chinook and coho during the first winter at sea, we captured and PIT-tagged salmon from August to May throughout the Strait of Georgia by microtrolling. With these data, we have developed interactive maps that allow users to visualize information collected by the *Bottlenecks Program* during winter microtrolling. Users can filter maps by species, study year, age class, and view stock breakdowns throughout the region. These data are useful in understanding juvenile salmon overwinter distribution and could be used to support fisheries management decisions.

Below is a description of the various investigations into survival and distribution in the marine environment lead by the *Bottlenecks Program*.

Winter Juvenile Chinook Distribution

Juvenile Chinook were captured in 4,422 of 12,798 microtrolling sets conducted during the initial three years of the *Bottlenecks Program*. Fish were assigned to age classes (first ocean year, second ocean year, or third or greater ocean year) based on the month and their fork length, with assignments validated using lengths of fish for which age was known from genetic assignment to parental hatchery brood year (parental based tagging or PBT). Stock of origin was determined for 7,204 first ocean year, 631 second ocean year, and 28 third or greater ocean year Chinook. **First ocean year Chinook captured by the Bottlenecks Program were 78% of target stocks.** Stock composition of first ocean winter Chinook differed by region of the Strait of Georgia with Cowichan Chinook largely limited to the Southern Gulf Islands and Puntledge-Qualicum fall Chinook dominating the northern Strait of Georgia and Discovery Islands. Quinsam Chinook were encountered primarily in the Discovery Islands. The central Strait of Georgia had a more mixed stock composition. When data are aggregated across years, regional patterns of stock composition remained relatively constant through the winter (Figure 18).

Spatial distribution for the second ocean winter Chinook was quite different from that of the first ocean winter Chinook (Figure 19). Of the target stocks, only Cowichan and Puntledge Qualicum fall Chinook were frequently encountered during the second ocean winter. Both stocks were distributed throughout the Strait of Georgia with few second ocean winter Chinook encountered in the Southern Gulf Islands. Fish of US origin (primarily Puget Sound stocks) were encountered throughout the Strait of Georgia during their second ocean winter.

As part of his PhD thesis work, supported through the *Bottlenecks Program* (see next section), Wesley Greentree will be working with genetic stock composition data collected through all years of the *Bottlenecks Program* to model spatial and temporal shifts in Chinook stock composition in the Strait of Georgia. This analysis will also integrate DFO Creel survey data, data collected through the volunteer Avid Angler program, and Chinook bycatch data from groundfish trawl fishery dockside monitoring to generate the most comprehensive picture to date of how different Chinook stocks utilize the Strait of Georgia through their lives.

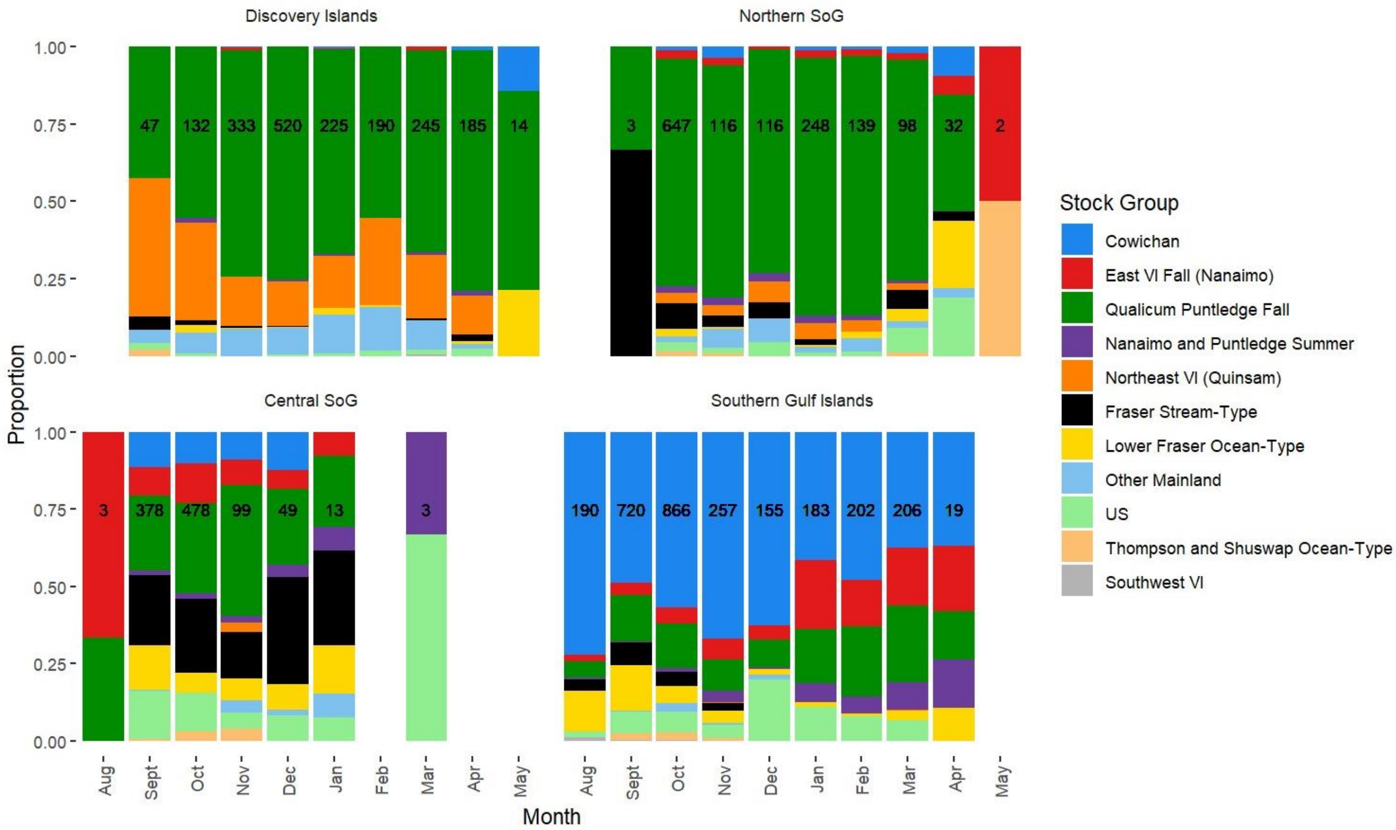

Figure 18. Monthly stock composition of first ocean winter Chinook by region of the Strait of Georgia for the initial three years of the Bottlenecks Project.

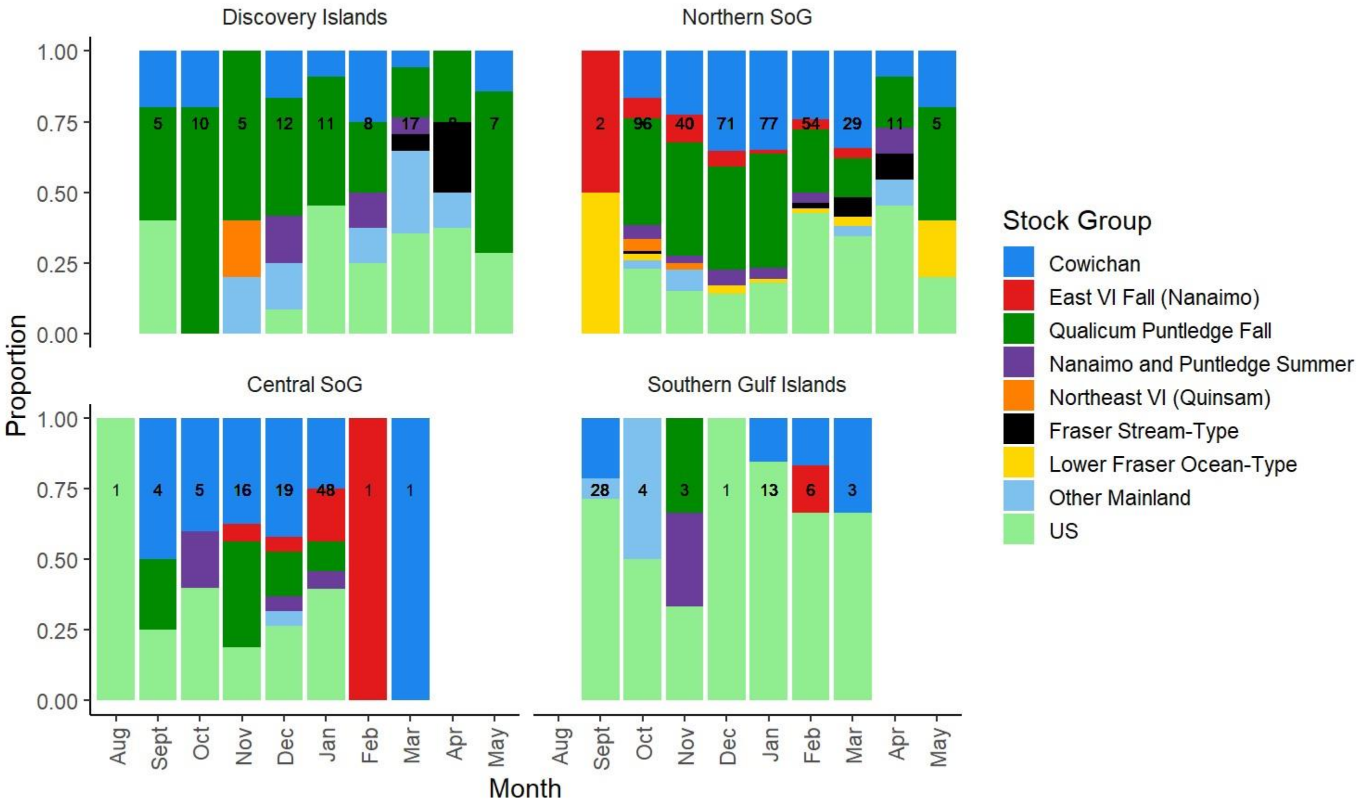

Figure 19. Monthly stock composition of second ocean winter Chinook by region of the Strait of Georgia for the initial three years of the Bottlenecks Project.

Marine Migrations and Overwinter Mortality of Juvenile Chinook Salmon in the Strait of Georgia

Chinook exhibit diverse life history strategies across freshwater rearing, ocean entry timing, marine migrations, and maturation timing. The marine migrations of Chinook are poorly resolved in terms of space, time, and individual variation. In Chinook populations from rivers draining into the Strait of Georgia, ocean-type juveniles spend their first summer at sea feeding and growing in the Strait. At an unresolved time after the first ocean summer, some juveniles emigrate to the continental shelf off the west coast of Vancouver Island and the Washington outer coast. Other individuals remain resident in the Strait of Georgia for most or all of their marine life. Since migrants and residents likely encounter distinct feeding opportunities, predation risks, and fisheries exploitation, it is important to determine if individual physiological condition influences migration behaviour.

The *Bottlenecks Program* may be tagging juvenile salmon across a period (or multiple periods) of outmigration from the strait. Thus, the proportion of different migration life-history types may change through the tagging period, with implications for estimation of overwinter survival. Resolving outmigration timing and relationships with individual traits is necessary to validate assumptions of marine survival estimates and test key hypotheses about overwinter mortality as state-dependent outmigration may influence interpretation of results.

For his PhD research, and in partnership with the *Bottlenecks Program*, Wesley Greentree at UVic is conducting an acoustic tagging study to address knowledge gaps about juvenile Chinook migratory behaviour in the Strait of Georgia. Acoustic telemetry uses small transmitter tags (2-5 g) that emit ultrasonic pings to track fish as they move through coastal oceans. The primary objectives of this study are to:

1. Determine when migrants leave the Salish Sea – does outmigration occur in one large pulse or do smaller numbers of migrants leave throughout the first ocean winter in a continuous diffusion process. Do some individuals outmigrate after the first ocean winter?
2. Identify if migratory strategies vary with individual traits (e.g., body condition, fork length, early marine growth) during the early marine period. For example, is outmigration size- or growth-selective?

To address these objectives, we captured fish using microtrolling and tagged 95 first ocean-winter Chinook in October 2022 and 55 Chinook in January 2023. All tagging was conducted near Comox, in the Strait of Georgia, in part to target Qualicum-Puntledge fall Chinook which are a major target stock of the *Bottlenecks Program*. As such, this study is well-positioned to test assumptions of the broader study's survival model. Arrays of acoustic receivers operated by Ocean Tracking Network (OTN, Dalhousie University) monitor the exits of the Salish Sea, and additional receivers deployed throughout the Strait were utilized (Figure 20).

We found that **all tagged Chinook overwintered in the Strait of Georgia**, and typically remained close to Comox throughout the first ocean winter. In their second ocean spring and summer, salmon moved more widely throughout the northern Strait of Georgia. Between April and July 2023, 27 individuals emigrated through Queen Charlotte Strait. Across both October and January release groups, 19 tags were detected as resident at least through August 2023. Chinook migrants were non-significantly larger than those which remained resident (Figure 21). Preliminary results also suggest that **survival was higher in Chinook tagged in late winter** (January) than in early winter (October; Figure 22). A second year of tagging was conducted in winter 2023-24, and these results together will both bolster our knowledge of juvenile Chinook overwinter migration and survival and allow us to assess if migration differs among years.

More information on this study can be found in the interim report "Marine Migrations and Overwinter Mortality of Juvenile Chinook Salmon in the Strait of Georgia, 2022-2024".

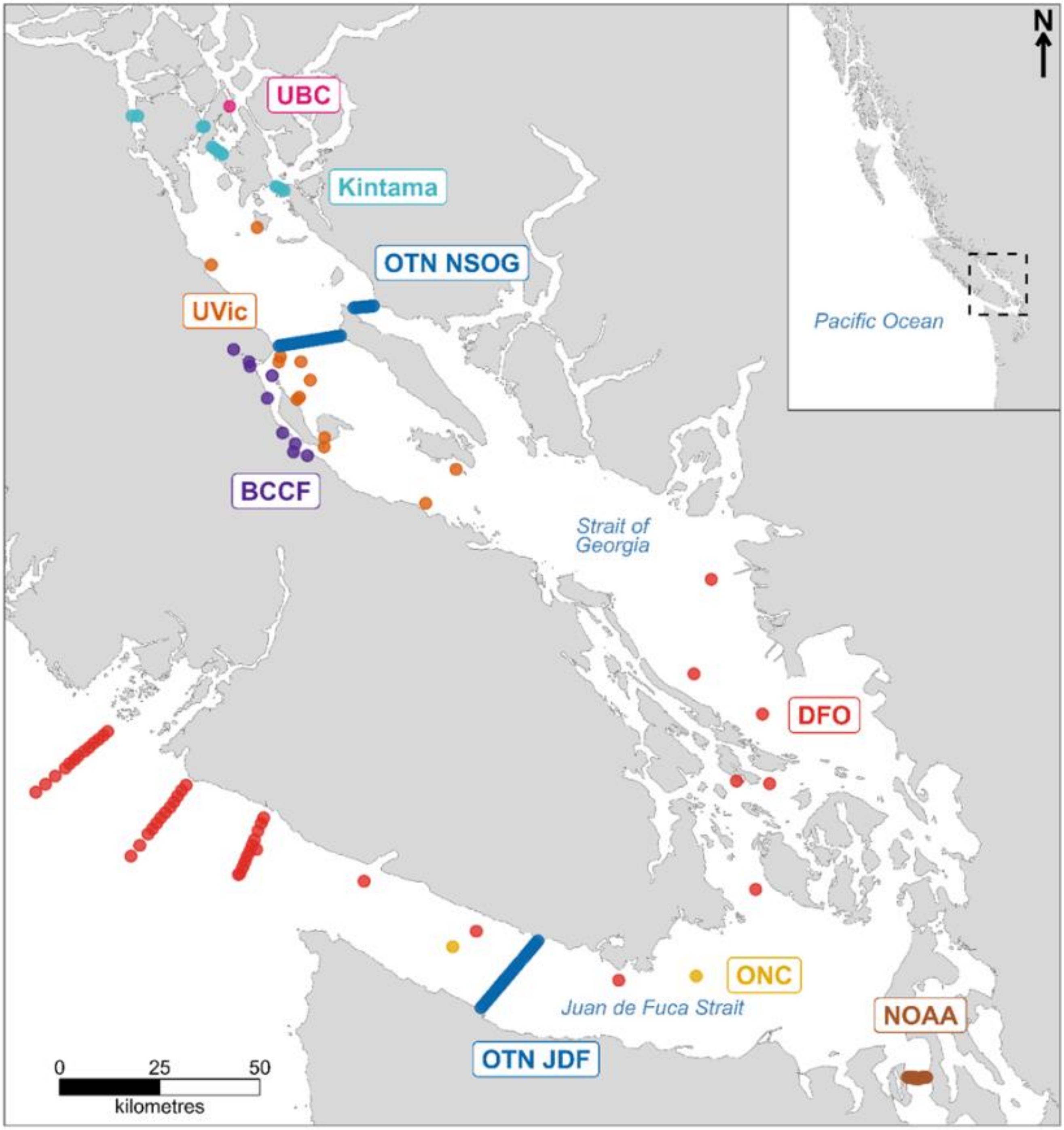

Figure 20. Acoustic receiver arrays in the Salish Sea.

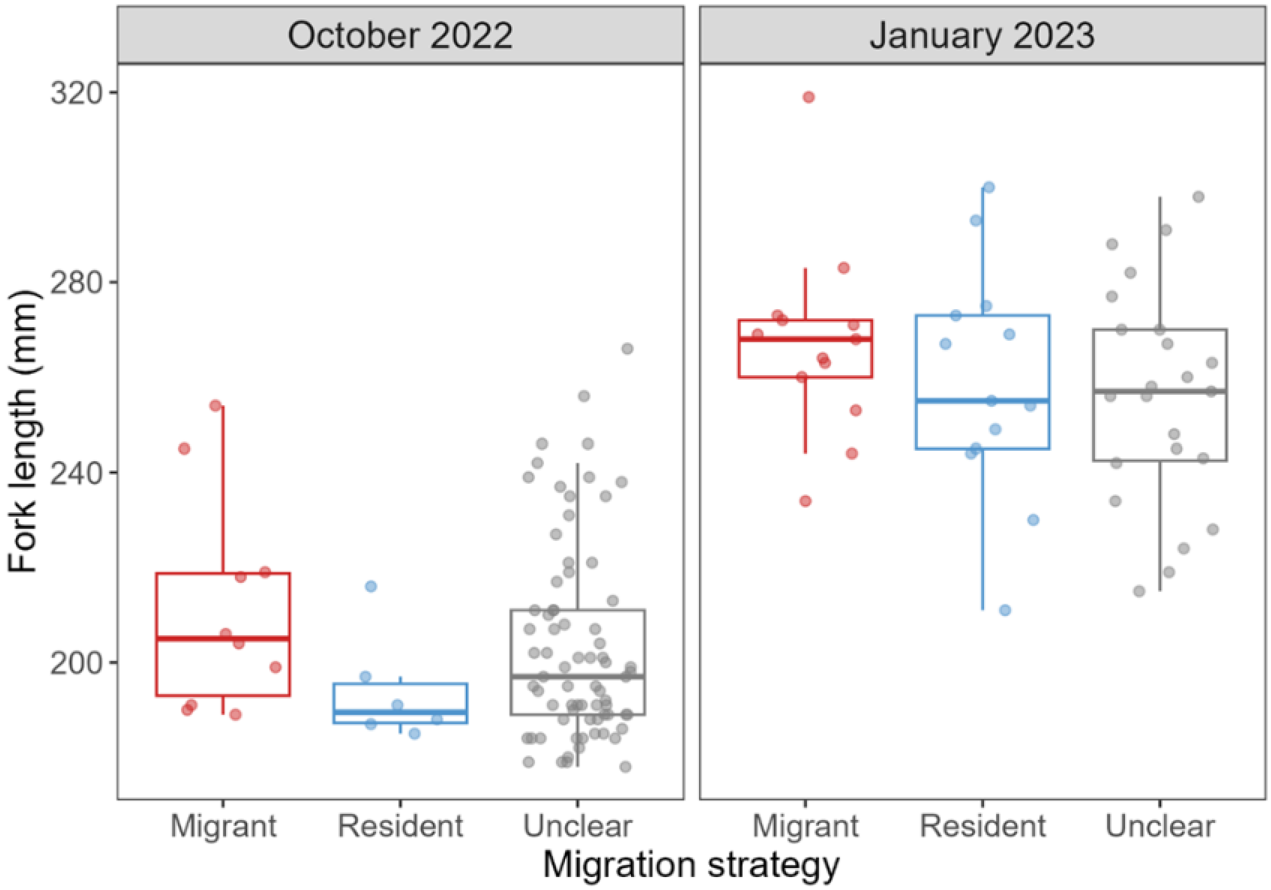

Figure 21. Fork length, by migration strategy, for Qualicum-Puntledge fall Chinook. The Unclear migration strategy represents fish that were not detected after July 26, 2023.

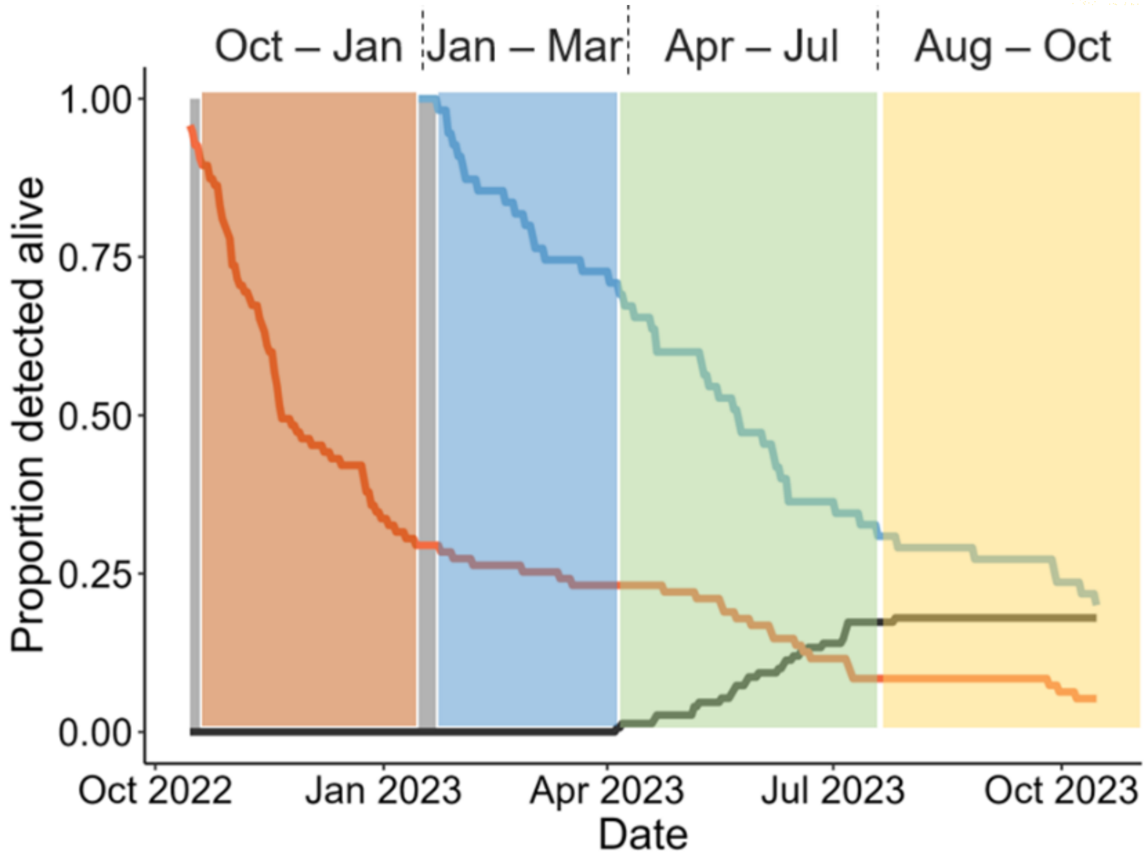

Figure 22. Kaplan-Meier survival curve for juvenile Chinook tagged in October 2022 and January 2023.

First Marine Winter Coho Distribution

The *Bottlenecks Program's* microtrolling method allows for discrete sampling of near-shore environments, largely underrepresented when using more traditional methods (i.e., seining, trawling, and trolling). In addition, we have been able to use PBT or GSI analysis on all sampled coho for stock identification. These technologies and methodologies are being used to provide new information on the marine distributions of coho in the Strait of Georgia. These data are now displayed in the Strait of Georgia Data Centre interactive coho marine hotspots map. This map provides detailed insights into the spatial and temporal distribution patterns of juvenile coho, crucial to both the understanding and development of conservation strategies and fisheries management.

Given the difficulties in capturing adequate numbers of coho of target stocks throughout the winter months for our stage-specific survival analyses, concerted efforts to tag coho in the marine environment were reduced or curtailed in subsequent years of the program. Therefore, our analysis of the marine distribution of first ocean winter coho is limited to the data collected in the first year of the program (August 2020 to May 2021; for further details see "*First Marine Winter Coho Salmon Distribution in the Strait of Georgia*").

Specifically, the objectives of the *Bottlenecks Program*'s coho studies were to:

1. Utilize microtrolling as an effective method for capturing and monitoring juvenile coho in the Strait of Georgia.
2. Collect comprehensive data on the spatial distribution patterns of coho during their first winter in the marine environment.
3. Create a detailed marine hotspot map visually representing the areas within the Strait of Georgia where juvenile coho were found during winter.
4. Develop a stage-specific survival model for coho.

Across the 2020 - 2021 microtrolling sampling seasons, 197 sampling days were conducted with more than 3,666 sets (Figure 23). A total of 707 coho were captured, all of which were processed for bio-data collection, and of these 676 coho were tagged.

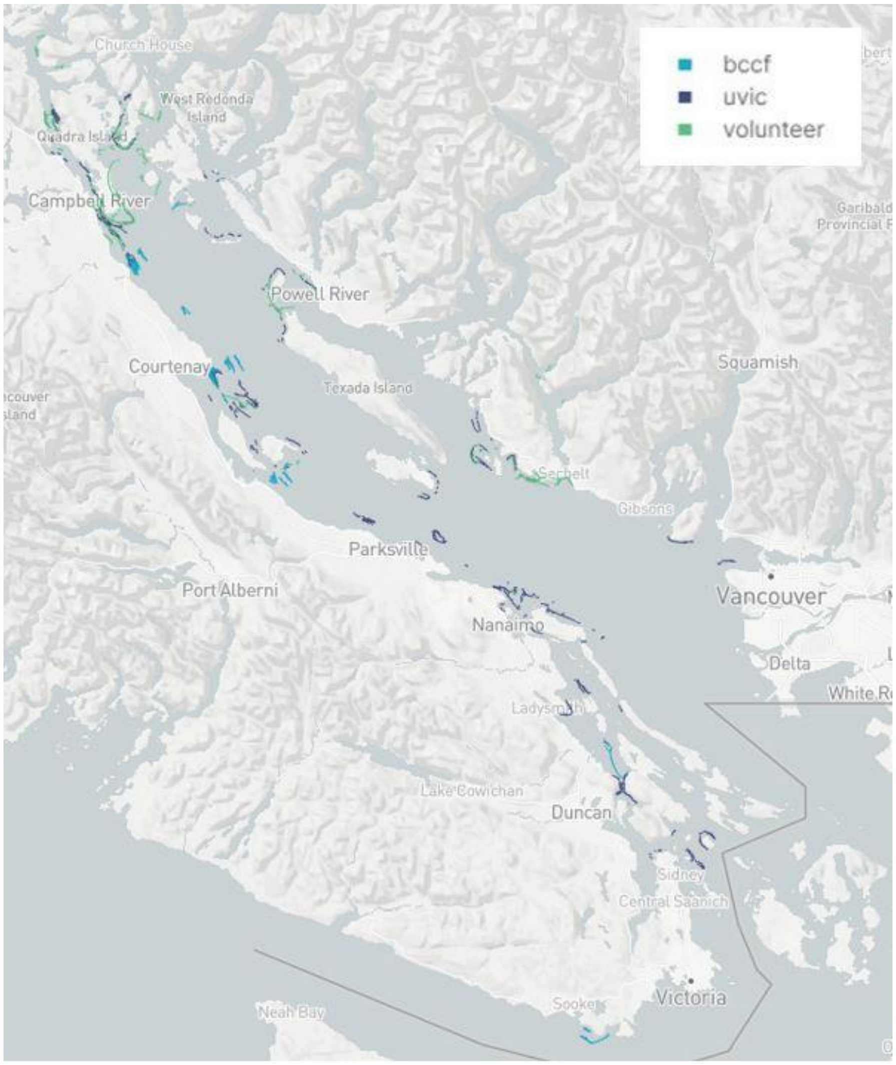

Figure 23. Map of the Salish Sea depicting sampling locations for each microtroll sampling day in the first year of the program. Map developed using the Bottlenecks Data System.

The analysis of fork length for coho during the 2020-2021 study year revealed patterns in growth and distribution. The lengths of coho ranged from 150 mm to 346 mm, with an average length of 279.7 mm.

In August, CPUE values were relatively low and variable, with a notable increase in September, particularly in PFMA 14 and PFMA 17 (Figure 24). **September and October saw the highest CPUE values, especially in PFMA 14, 16, 17, and 19 indicating peak coho presence**. In November, CPUE varied with some areas showing no catches. December showed a general decline in CPUE across sampled PFMAs which continued until the spring months of March and April where PFMA 13 showed a slight increase.

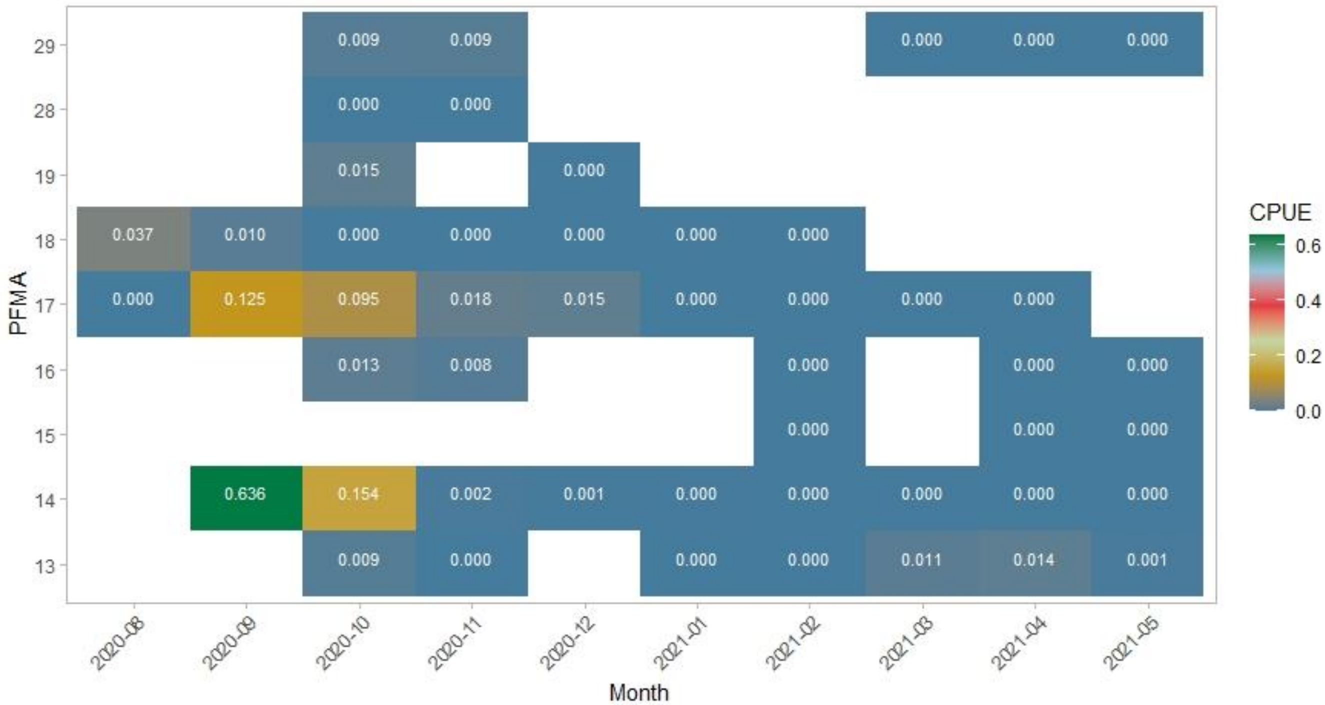

Figure 24. Catch-per-unit-effort of coho during the first study year 2020_2021 of the *Bottlenecks Program*. CPUE was calculated to the "hook" level.

A total of 58 unique stocks were identified within our catch. The most common stock was Puntledge River (n = 53), followed by Chilliwack River (n = 51) and Jones Creek (n = 42), both of which are non-target stocks.

The ECVI target stock group abundance was prominent during the late summer and early autumn months, peaking in September and October and drastically declining in November (**Figure 25**). The Fraser stock group displayed a consistent distribution across multiple months, with notable spikes in abundance in September and October, highlighting its widespread temporal presence. The Eastern Strait of Georgia stock group demonstrated a marked seasonal significance, particularly dominating the samples in March (in low numbers) and showing a strong presence in both September and

October. While less dominant, the US stock group appeared consistently throughout the study period, particularly in September and October, indicating a persistent presence.

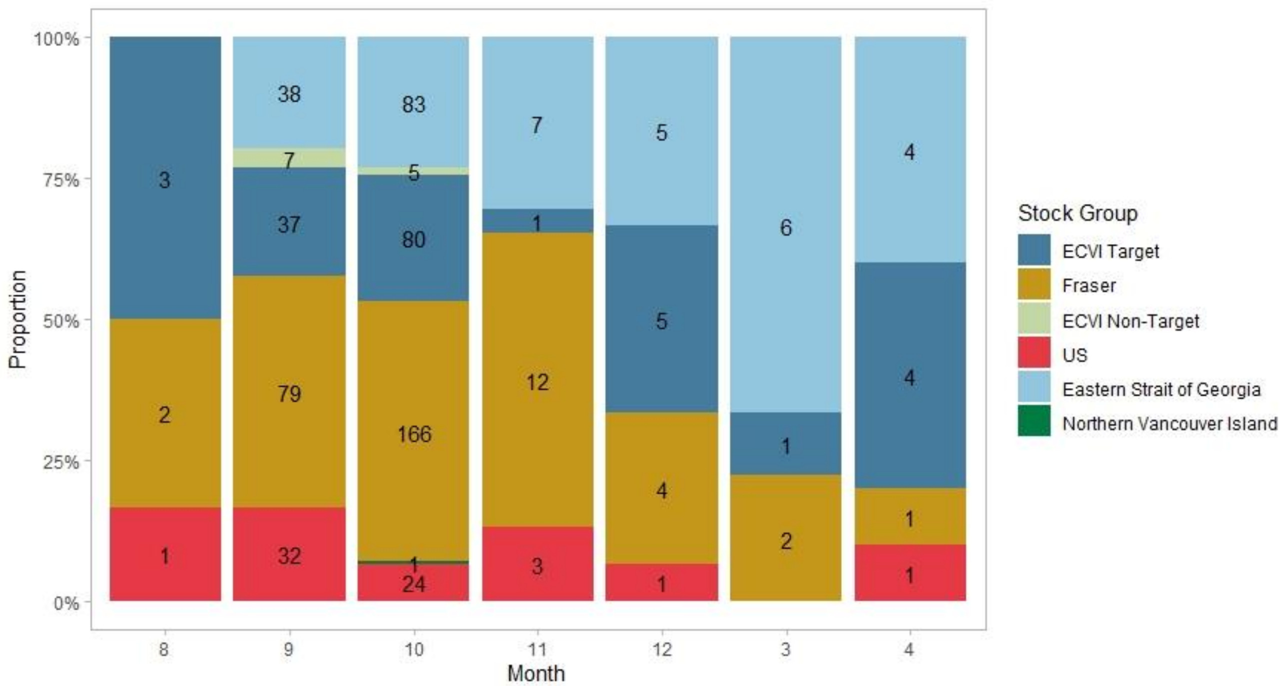

Figure 25. Temporal distributions of coho stock groups across during the 2020-2021 study year. The y-axis indicates the percent contribution (%) of each stock group, and the x-axis represents the months.

The results aligned with previous research, showing **high numbers of coho in September and October, declining through the winter.** Our data also showed coho abundance **increasing in the Discovery Islands region in March and April**. The data suggest that coho most likely leave for the Pacific Ocean in late fall or form large schools in deep, open waters of the Strait during the winter months, which is outside of our sampling areas. Microtrolling allowed us to study coho distributions in unexplored habitats, offering valuable new insights into their first marine year. The interactive map improves our understanding of coho marine behaviour, providing essential information for resource managers and community partners.

Winter Ecology of Chinook Salmon

Very little empirical research has investigated Chinook ecology during the first winter at sea. More biological data for overwintering fish, enhanced and wild, are needed to understand if and how the first winter at sea regulates Chinook survival. We conducted an intensive, three-year study of the winter ecology of juvenile Chinook in the Strait of Georgia (described in detail in the 'Winter Ecology Summary Report') to address the core objectives:

1. Identify the winter habitat preferences of juvenile Chinook in the Strait of Georgia.
2. Describe overwinter diet composition and quality and assess the plausibility that winter is a period of nutritional stress for juvenile Chinook.
3. Test the critical-size, critical-period hypothesis, i.e., if larger salmon or those with a history of more rapid growth are more likely to survive winter than smaller salmon or those with a history of slower growth.
4. Use molecular biomarker techniques on Chinook gill tissue to assess the role of infectious agents (parasites and pathogens) and physiological stressors (hypoxia, salinity and potentially starvation) in causing overwinter mortality.

First ocean winter Chinook were captured from late September through early April using microtrolling in three regions (Discovery Islands, Northern Strait of Georgia, Southern Gulf Islands) over three consecutive winters (2020-2023). Biosamples collected from all Chinook included fork length (mm), weight (g), adipose fin clip status, gill biopsies, stomach contents (via gastric lavage), scales, and an injury and overall visual health assessment. A subset (up to 50 per year) of juvenile Chinook were retained for body condition analyses, and all others were PIT tagged and released.

To identify trends in overwinter habitat use, we conducted systematic sampling surveys in the first two years (2020-2022). Using data from 34 systematic sampling days (capturing 219 first ocean winter Chinook) in the Northern Strait of Georgia, we found evidence that these fish were **more likely to be caught in shallower water (30 and 60 m) than further offshore (90 and 150 m) and that catch per unit effort (CPUE) peaked at a hook depth of about 60 m** (Figure 26). An understanding of where juvenile salmon reside during the winter can suggest possible sources of mortality, and variability in catch rates across regions and years could reflect changes in mortality, migration, or distribution.

To address outstanding questions regarding the quality and quantity of overwinter diets of juvenile Chinook we collected diet samples via gastric lavage from over 1,000 fish and identified and weighed over 4,500 prey items. Chinook **feed throughout the winter on prey including Pacific herring, euphausiids, amphipods, and squid** (Figure 27). Both body condition and diet energy content declined slightly over time. Temporal trends in Chinook energy density and relative gut mass suggested that available energy was allocated to storage through the fall and declines in mid-winter food availability may have initiated the utilization of stored energy in late winter. Ultimately, these results provide some evidence that juvenile Chinook experience food limitation in winter but do not suggest that starvation is occurring.

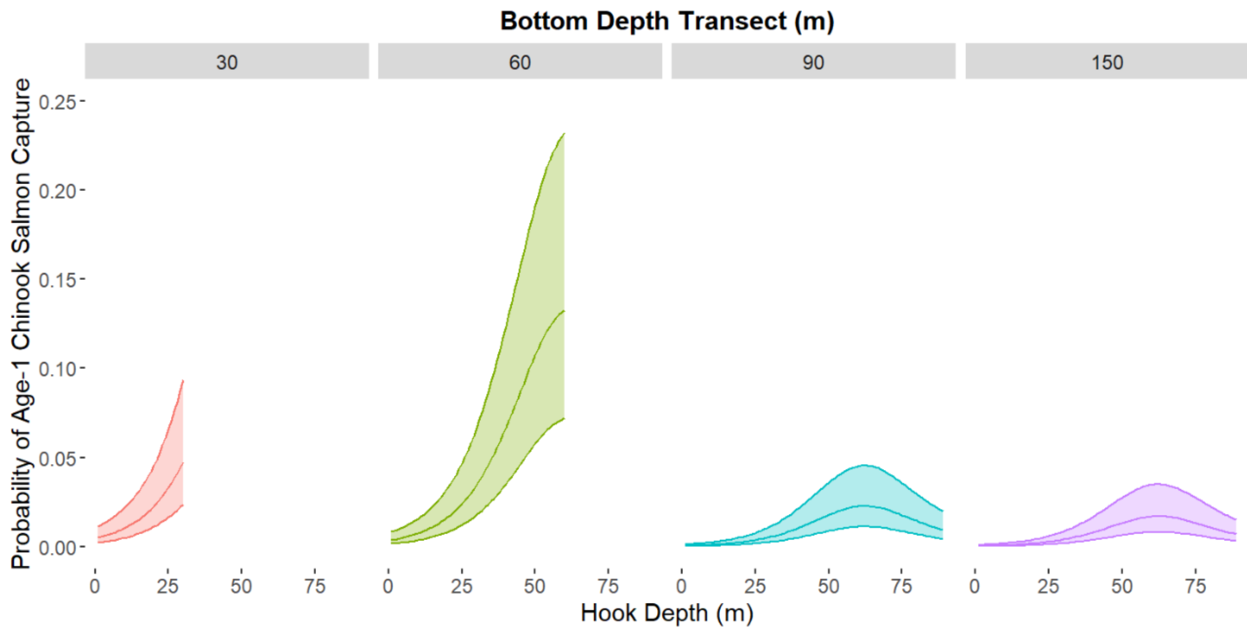

Figure 26. Model-predicted probability of catching a first ocean year Chinook on hooks deployed between the surface and 90 m on each of four bottom depth transects (30, 60, 90, and 150 m). Coloured ribbons indicate the standard error of the prediction.

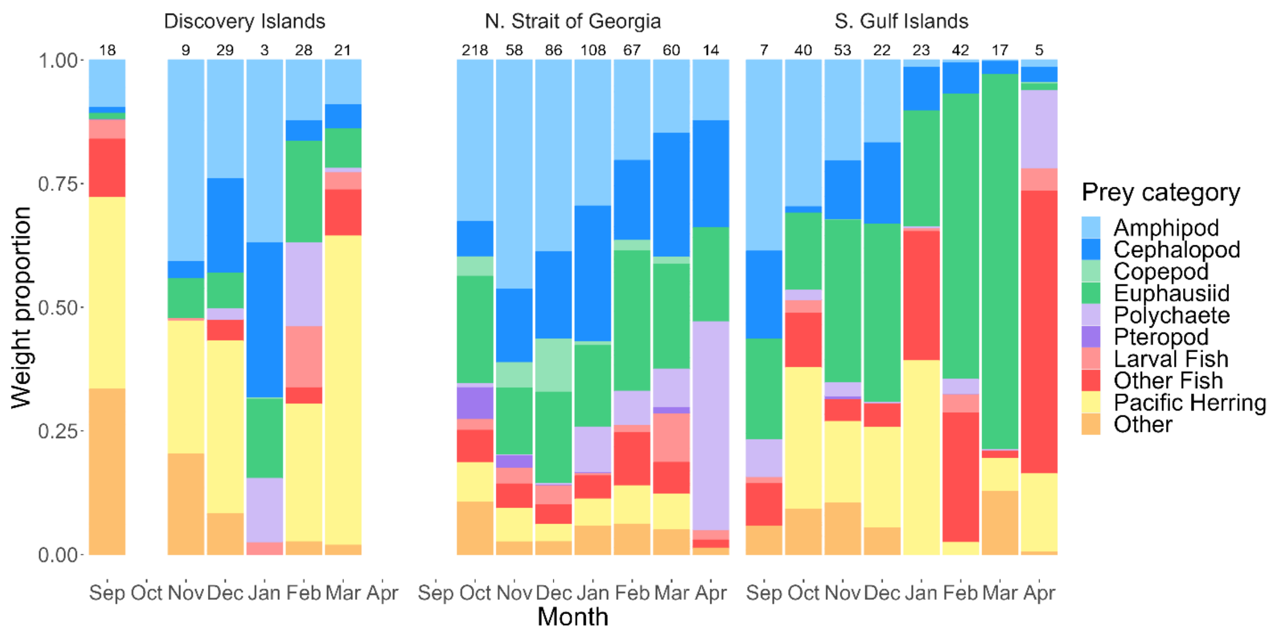

Figure 27. The relative contributions of prey groups to overwintering Chinook diets in the Strait of Georgia by region and month. Data from all three sampling years (2020-2023) are pooled. Colours denote the prey group, and the numbers above each bar represent the number of stomach samples examined.

Bioenergetic models were used to estimate overwinter feeding rates from October to March over two winters (2020-2022) in two regions (Northern Strait of Georgia and Southern Gulf Islands). Preliminary results suggest that **juvenile Chinook consumption rates are lowest in January and February across regions and years, possibly due to a reduction in food availability**, and that late winter growth and consumption was higher in the Southern Gulf Islands than Northern Strait of Georgia, possibly due to an availability of high-energy prey such as Pacific herring and euphausiids. Preliminary stable isotopes analyses were conducted on dorsal muscle and caudal fin tissue of 174 retained Chinook which showed that there was greater enrichment of nitrogen 15 (N_{15}; the heavier isotope) late in winter which is consistent with feeding on organisms higher in the food chain, and regional differences were detected.

We collected gill tissue from over 1,500 juvenile Chinook throughout the winter to assess the type and quantity of infectious agents and stressors in these fish over time. Lab capacity issues prevented these samples from being analyzed during the project, but processing and analysis are planned for 2024. In the interim, an investigation into juvenile Chinook food limitation in different temperature regimes was conducted (Figure 28). Preliminary results have **identified candidate gene expression markers of food limitation** in gill tissue which will be incorporated into custom Fit-Chips used to analyze archived samples, allowing us to assess how food limitation may interact with other stressors to mediate mortality. Samples for Fit-Chip analysis will be selected to include fish that did and did not survive to return to investigate relationships between pathogens, stress and survival.

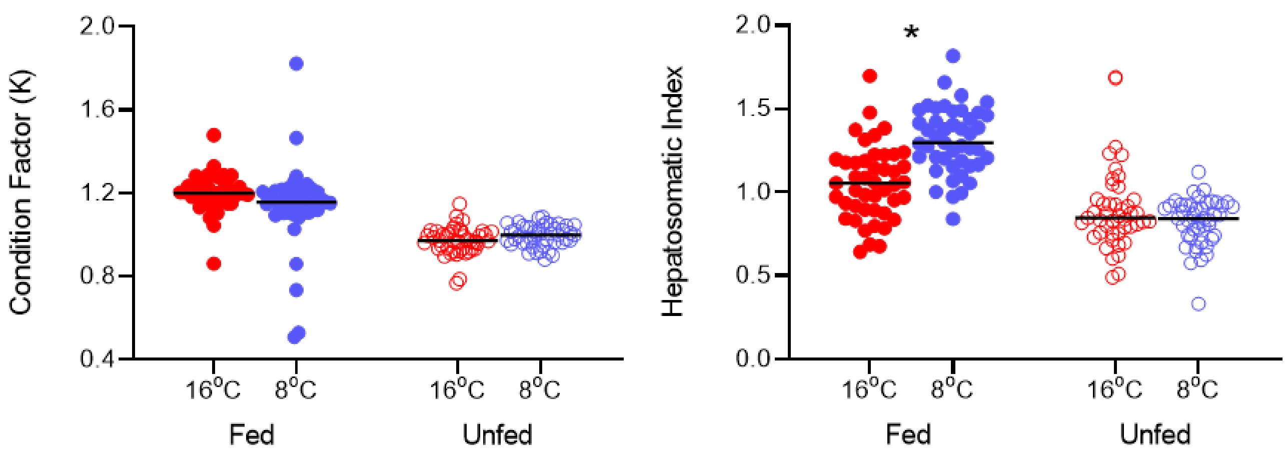

Figure 28. The condition factor (left) and hepatosomatic (liver) index (right) of juvenile Chinook which were fed (filled circles) or unfed (open circles) and exposed to either 16 °C (red) or 8 °C (blue) temperature treatments. The asterisk represents a significant difference between the responses of the temperature treatments.

Movement and Modes of Mortality of Steelhead Trout in the Northeast Pacific Ocean

To fill in some of the data gaps surrounding BC's steelhead populations, biologists from the Province of BC partnered with the *Bottlenecks Program* to investigate marine migrations and mechanisms of mortality. To do this, mini pop-up archival transmitting tags (miniPATs) were applied to steelhead kelts to collect previously unattainable data on adult steelhead movements and mortality. Specifically, the goals of the study were to:

1. Determine the viability of, and refine techniques for, tagging winter-run steelhead kelts with pop-up satellite archival tags (PSATs).
2. Identify the range and dispersal of steelhead kelts after leaving their spawning streams.
3. Identify mechanisms of mortality of adult steelhead at-sea.

Recent advancements in PSATs are allowing for additional information to be collected without physical tag recovery. MiniPAT tags are a sophisticated combination of archival and Argos satellite technology. PSAT tags are designed to track the large-scale movements and behaviour of fish and other animals that do not spend enough time at the surface to allow utilization of real-time Argos satellite tags. Sensor data (including temperature, depth, light level, and acceleration) are collected while deployed on steelhead at sea and archived in onboard memory. Upon release from its host animal, by either a pre-selected release date, a predation event (where the tag is detached as a result of consumption), or if the premature release and mortality detection mechanism deems the animal has died, the MiniPAT tag surfaces, and uploads a summary of the archived data to Argos satellites. If tags are collected after release, a full dataset (including some additional data not uploaded via satellite, such as acceleration) can be downloaded directly from the tag. These tags have recently been reduced in size and can now be deployed on smaller animals such as adult salmon-sized fishes. Given that PSAT tags are still too large to be deployed on juvenile salmon, and other anadromous salmon perish soon after spawning, steelhead kelts provide a unique opportunity to track behaviour and survival in the open ocean.

Between 2021 and 2023, 47 adult steelhead kelts were captured from the Cowichan, Englishman, Nahwitti and Keogh Rivers on Vancouver Island (Table 7). In 2021, kelts were held for a month in conditions intended to "recondition" the fish (i.e., improve health and chances of successfully kelting). However, this approach proved to be ineffective and was not continued in subsequent years (see full kelt reconditioning summary in the next section).

MiniPAT-348K satellite tags were applied using a 'backpack' method of attaching them to the dorsal area on either side of the dorsal fin (Figure 29).

Figure 29. Images depicting MiniPAT Satelite tagging process. Showing the flow through tagging troughs (top left), and then the tagging process starting with the hypodermic needles (top right), tying coated metal cables for the backpack (bottom left) and then attaching the MiniPat with wire crimps (bottom right).

Table 7. Summarized release location and sample sizes for all steelhead kelts with available time series for fish released from 2021 through 2023.

RELEASE YEAR	ISLAND REGION	RIVER	RELEASED	DATA RECOVERED
2021	Mid-Island	Cowichan	10	9
		Englishman	1	1
	North-Island	Keogh	3	3
		Nahwitti	3	2
2022	Mid-Island	Cowichan	8	7
	North-Island	Keogh	3	2
2023	Mid-Island	Cowichan	5	5
	North-Island	Keogh	8	6
		Nahwitti	6	6
Total			47	41

Tags were programmed to detach from their hosts after 90 days, however, all 41 tags from which data were recovered detached earlier than 90 days. Early detachment suggests mortality events that triggered the tag to transmit data, and we can use time series plots of the sensor data retrieved from the tags to infer a possible mortality mechanism. The full length of tag deployment ranged from a half day to 72.6 days and was 15.4 days on average. **About 50% of the tags were deployed for less than a week and 24% of the tags were deployed for more than three weeks.** The **migration distances varied immensely from 1-2,016 kms with an average travel distance of 295 km**. The track of the longest migration is shown in Figure 30.

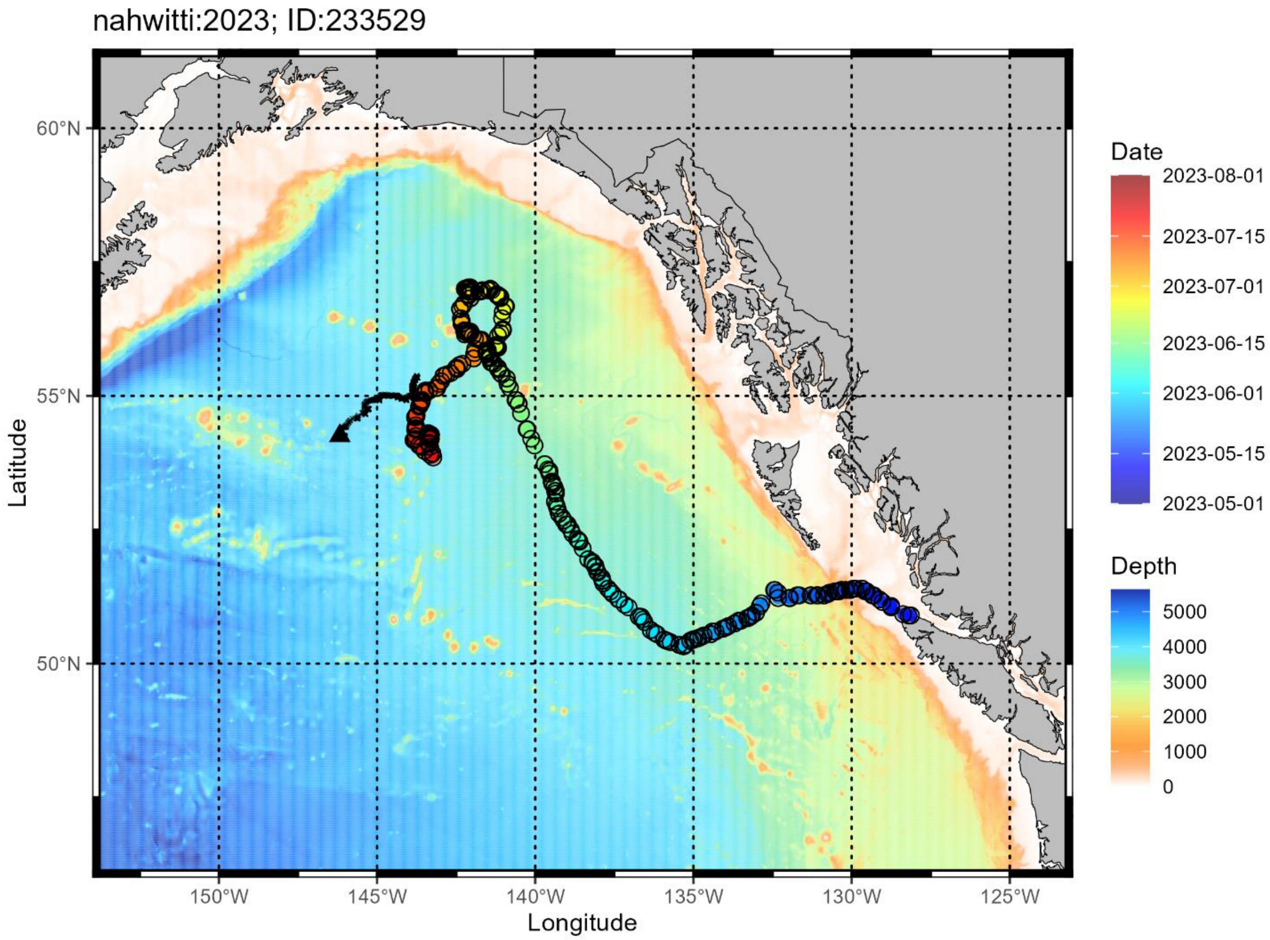

Figure 30. Migration track of a Nahwitti steelhead (ID 233529) tagged and released in 2023. Coloured circles show the dates of data transmissions from the miniPAT tag with blue being closer to the release date and red being closer to the final detection. The black triangle is where the satellite tag surfaced after a mortality event, with the black track showing the movement of that tag underwater before surfacing.

The fates of each steelhead were assessed based on the light, depth, acceleration, and temperature sensor data retrieved from the tags. Sudden changes in any of these values provided insight into what may have happened to that individual. For instance, steelhead spent much of their time in the top 5 meters of the water column. **A sudden increase in tag depth, increase in temperature, and decrease in light could represent predation by a marine mammal** (e.g., Figure 31). Alternatively, a sudden increase in tag depth, and decrease in light with no change in temperature could represent predation by an ectothermic pelagic fish (e.g., Figure 32). While most of the fates remain unknown, these large changes in sensor data **allowed us to classify the likely mechanism of mortality for 32% of the tagged steelhead** (

Table 8).

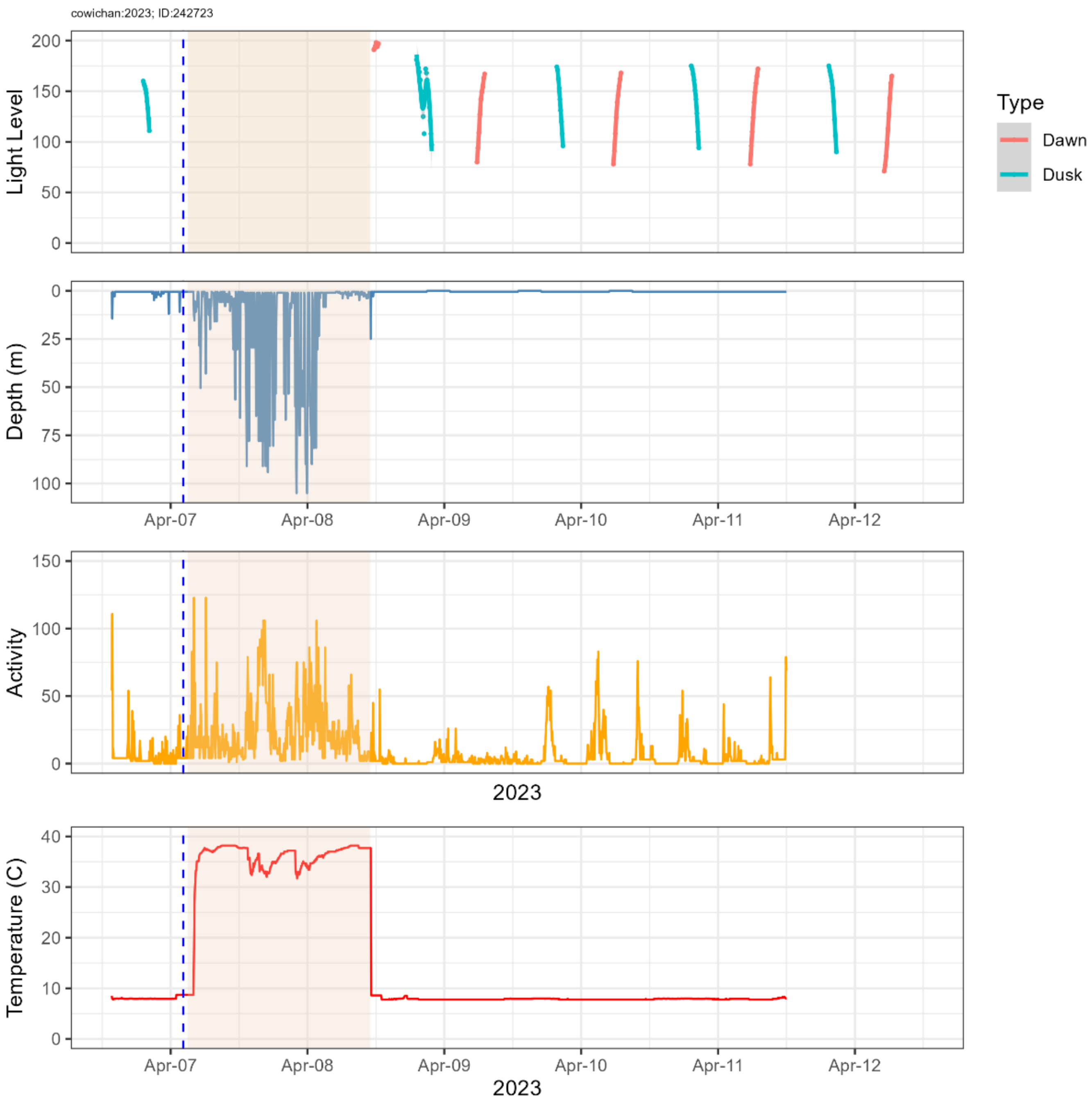

Figure 31. The light level, depth, activity (from accelerometer data) and temperature data retrieved from a Cowichan steelhead (ID: 242723) wherein rapid changes in sensor data suggest predation by a marine mammal.

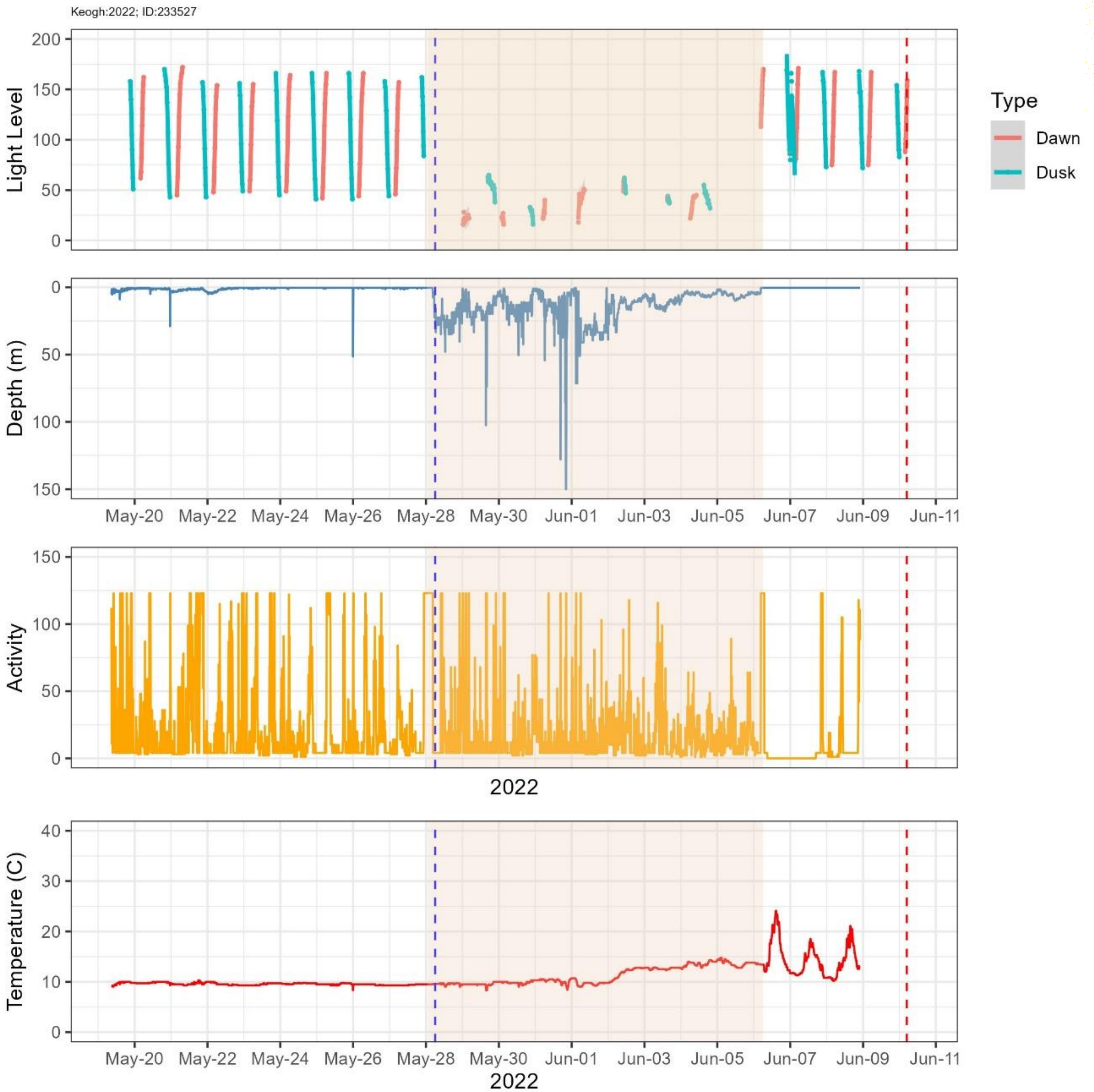

Figure 32. The light level, depth, activity (from accelerometer data) and temperature data retrieved from a Keogh steelhead (ID: 233527) wherein rapid changes in sensor data suggest predation by an ectotherm.

Table 8. Hypothesized cause of death in all steelhead with available time series for fish released from 2021 through 2023.

PREDATION TYPE	MID-ISLAND	NORTH ISLAND	TOTAL
Alive	0	1 (5%)	1 (2%)
Bottom fish	0	1 (5%)	1 (2%)
Marine mammal	1 (5%)	0	1 (2%)
Pelagic Ectotherm	4 (18%)	6 (32%)	10(24%)
Possible fish	0	1 (5%)	1 (2%)
Unknown	17 (77%)	10 (53%)	27 (66%)
Total	22 (100%)	19 (100%)	41 (100%)

Steelhead in British Columbia, particularly Vancouver Island, are currently in a low abundance regime. The information from this study provides insights into a largely unknown life-stage. Repeat spawning is a life-history trait that is uncommon in long-ranging Pacific salmonids that have several population-level advantages (such as fecundity and lifetime reproductive success). A better understanding of the marine centered life stage provides insights into the population dynamics and the potential efficacy of various management approaches to increasing population abundance. More information can be found in the report "Movement and Mortality of Steelhead Trout (*Oncorhynchus mykiss*) in the Northeast Pacific Ocean, elucidated from pop-up satellite archival tags (PSATs)".

Evaluating the Effectiveness of Cowichan River Steelhead Kelt Reconditioning

Kelt reconditioning is a novel technique hypothesized to increase overall spawning abundance by increasing the health and condition of the kelts between spawn events. Reconditioning involves capture of outmigrating steelhead kelts, and treating, holding, and feeding and medicating them to improve gonad regeneration and overall survival to repeat spawning.

The primary objective of this study was to utilize reconditioning methods on steelhead kelts from the Cowichan River to try to increase their condition for a complementary steelhead migration study, and secondarily to determine the feasibility of conducting a large-scale reconditioning program. The steelhead kelt migration study objectives were to understand the mechanisms of mortality, dispersal, and survival (see the report "Movement and Mortality of Steelhead Trout (*Oncorhynchus mykiss*) in the Northeast Pacific Ocean, elucidated from pop-up satellite archival tags (PSATs)"). Reconditioning was conducted at the Freshwater Fisheries Society's Trout Hatchery in Duncan, BC.

Of the 20 steelhead kelts captured via angling techniques in 2021, 13 survived the 30-day reconditioning treatment. Contrary to expectations, the **reconditioning did not improve the overall condition of steelhead kelts with the overall condition found to be significantly lower at release than upon arrival** (Figure 33). Further, no reconditioned kelts returned to spawn in subsequent years.

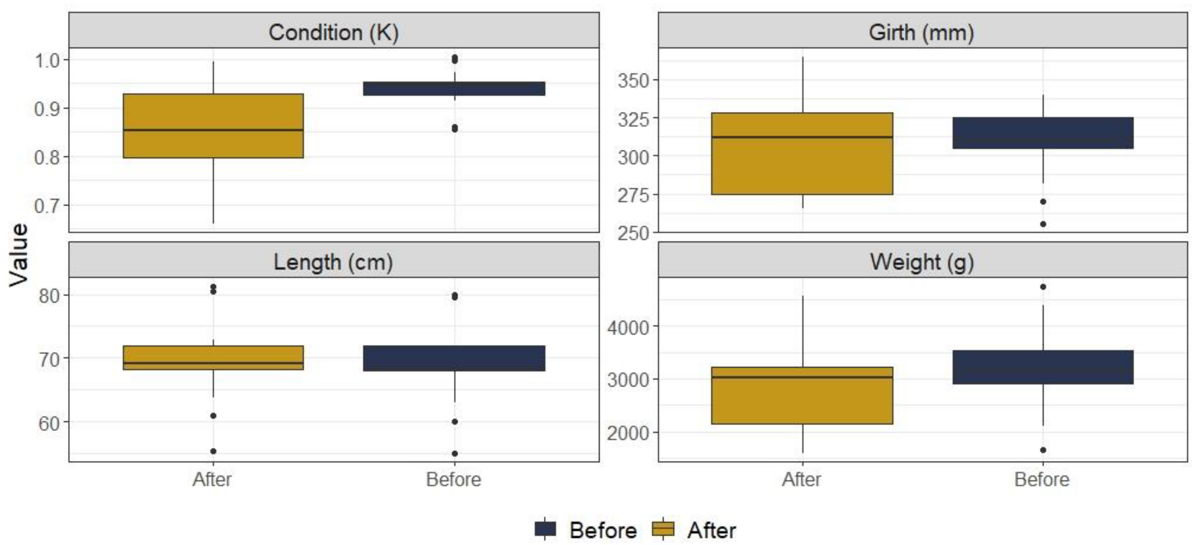

Figure 33. Condition factors for Cowichan River steelhead kelts before (Arrival) and after (Release) reconditioning in the hatchery environment.

The reconditioning process involved high financial costs and logistical challenges due to extensive handling and transportation. Compared to other successful programs focused on increasing steelhead survival and rates of iteroparity, the lack of necessary infrastructure in the Cowichan River limited this study's effectiveness. The **current method proved ineffective for increasing steelhead kelt condition** before an intensive tagging procedure. If another attempt were to be made at kelt reconditioning, a downstream capture facility, longer holding times, and a reassessment of the program's scale and approach would be required, however we believe the success of such a program is unlikely.

Seal Predation Pilot Studies

PIT tags are not battery-powered and remain dormant until they encounter an electromagnetic field generated by PIT antennas. This functionality enables the detection of both live fish crossing antennas and those that have been predated, providing valuable insights into the survival and ultimate fates of individual fish. Given prior research demonstrating the recovery of tags post-predation, this study aimed to enhance the understanding of the spatiotemporal effects of predation on juvenile salmonids.

Specifically, our objectives were to:

1. Detect tags residing on pinniped haul-outs using manual scanning.
2. Develop in-situ PIT tag monitoring sites on pinniped haul-outs.
3. Estimate predation rates on tagged salmon by Pacific harbour seals (*Phoca vitulina*).

This section highlights the *Bottlenecks Program's* investigative efforts, focusing on the recapture of PIT tags consumed and expelled at harbour seal haul-outs using both mobile scanning and installed antenna infrastructure.

<u>Mobile Scanning</u>

Scans were conducted at **13 known harbour seal haul-outs, with 10 sites yielding 29 unique tags, mostly from Chinook and coho**. The substrate type of the haul-out (i.e., sand vs. rock) influence both the residency time of the tag on the haul-out and the probability of detection while on the haul-out, with tags susceptible to removal from wave action over time. The oldest tag recovered was deployed in 2015, illustrating that **tags can reside on haul-outs for extended periods of time**.

In-situ Antenna on Miami Islet

The **Miami Islet antenna recorded 19,438 detections from 10 unique tags** (Table 9). Six tags were identified as *Bottlenecks Program* fish, and **three tags were linked to images of seals over the antenna** (Figure 34).

The pilot study demonstrated the potential of PIT tags to provide valuable insights into predator-prey interactions affecting salmonids. Mobile scanning and in-situ monitoring effectively confirmed predation events on tagged salmonids. However, determining the exact predator species remains challenging, as multiple marine animals could consume the tagged fish. We recommend increased scanning efforts, particularly at high-detection sites, and the development of real-time data access for in-situ antennas to improve detection efficiency and data accuracy.

Table 9. Summary of PIT tags detected at Miami Islet haul-out.

WATERSHED	SPECIES	COHORT	STOCK	OUTMIGRATION YEAR	TAG ID	RELEASED	FORK LENGTH (MM) AT TAGGING	ORIGIN	DATE/ TIME DETECTED	CONFIRMED WITH IMAGE
Nanaimo	ck	fall-run	Nanaimo	2022	989.001042002795	2022-05-10		hatchery	2022-08-17 16:14	Y
Nanaimo	ck	fall-run	Nanaimo	2022	989.001042002373	2022-05-10		hatchery	2022-08-24 13:48	
Nanaimo	ck	summer-run	Nanaimo	2021	989.001039398482	2021-04-23		hatchery	2022-09-22 12:50	Y
Cowichan	ck	fall-run	Cowichan	2022	989.001041919671	2022-06-07	71	wild	2022-09-24 6:33	
Nanaimo	ck	fall-run	Nanaimo	2022	989.001042002084	2022-05-10		hatchery	2022-10-02 0:02	
Nanaimo	ck	summer-run	Nanaimo	2022	989.001041993660	2022-05-10		hatchery	2022-10-10 21:09	Y

Figure 34. Miami Islet haul-out antenna with positive identification of a harbour seal associated with a tag detection.

Enhanced Fishery Monitoring

This activity aims to modernize recreational salmon fishery landing sites by installing and updating fish cleaning tables to support enhanced fishery monitoring (EFM). Given the hundreds of thousands of PIT tags being deployed in wild and hatchery-produced Chinook and coho through the *Bottlenecks Program*, PIT tag detections at cleaning tables can provide specific information about the individual fish and the recreational fishery. To do this, EFM tables include an integrated PIT tag antenna paired with an overhead motion-activated camera system. This system allows each fish cleaned on the table to be automatically scanned for a PIT tag, inspected for species and origin (hatchery/wild), and assessed for participation in the head recovery program. Data will be used to identify PIT tagged fish that survived the juvenile phase to contribute to a fishery (i.e., survivors) as well as to estimate the total number of tags removed by the fishery in each area. Video data will be evaluated for integration into the Creel survey, where increased sample size can reduce uncertainty in estimates of harvest, mark rates, and head submission rates.

PIT and video data collected at EFM sites on the East Coast of Vancouver Island will provide valuable information about stock-specific exploitation rates, and help supplement DFO’s head recovery, coded wire tag, and creel survey programs.

This study's objectives were to:

1. Upgrade and modernize cleaning tables at selected recreational landing sites with integrated PIT tag and video systems.
2. Identify individual PIT-tagged fish, which contributed to the fishery, and estimate the total contribution to the fishery by area.
3. Estimate total landings at each table by species, month, and origin.
4. Estimate head submission rates for adipose-clipped fish to the head recovery program.
5. Evaluate the use of landed catch to infill harvest estimates for days when the Creel survey is not actively sampling.

Throughout the first three years of the *Bottlenecks Program*, three locations (Brechin Hill, French Creek, and Pacific Playgrounds) and four EFM tables were established (Figure 1 and 35). Data retrieval and processing for 2023 are still underway and the data presented here are preliminary. Mobile scanning, wherein crews take an antenna housed in a PVC frame and 'jig' it across the seafloor beneath the cleaning tables, was also conducted at a number of cleaning tables throughout Vancouver Island and the Mainland Coast in the second two years of the program to increase PIT tag detections at fish cleaning tables beyond those retrofitted with permanent antennas.

Few PIT tags were detected in the first two years of the program; however, detections are expected to increase as the number of fish PIT-tagged by the *Bottlenecks Program* begin to return as adults. We have begun to see evidence of increased PIT detections in the preliminary 2023 data.

Video footage from the cleaning tables has revealed that head submission rates are low. Anglers are encouraged to remove, label, and submit heads from adipose-clipped (i.e., hatchery-origin) Chinook and coho at Salmon Head Recovery Program depots (located at several marinas and cleaning tables). Chinook head submission rates ranged from 11% to 25%, while coho submission rates ranged from 12% to 34%. **The majority of Chinook landed were unmarked** (presumed wild origin) with only 12-23% of the landings being hatchery-origin fish. The opposite was true for coho, wherein **the majority of coho landed were of hatchery-origin** (31% to 89%).

Chinook landings at Brechin Hill were also tallied by hour to understand the temporal distribution of landings and inform Creel surveys (Figure 36) No fish were landed before 7 AM and few before 10 AM, **with the largest number between 8 and 10 PM**. A relatively steady number of fish were landed between 10 AM and 8 PM.

With the expected return of the first cohort of age 4 Chinook tagged by the *Bottlenecks Program* in 2024, PIT detections on these cleaning tables should significantly increase in the coming years. This will help inform additional enhanced monitoring table expansions led by DFO in the coming years and will assist in accurately estimating recreational harvest rates.

Figure 35. Images of the landing site at Brechin Marina before (A) and after (B and C) infrastructure upgrades conducted in July 2021 (photos by Kevin Pellett).

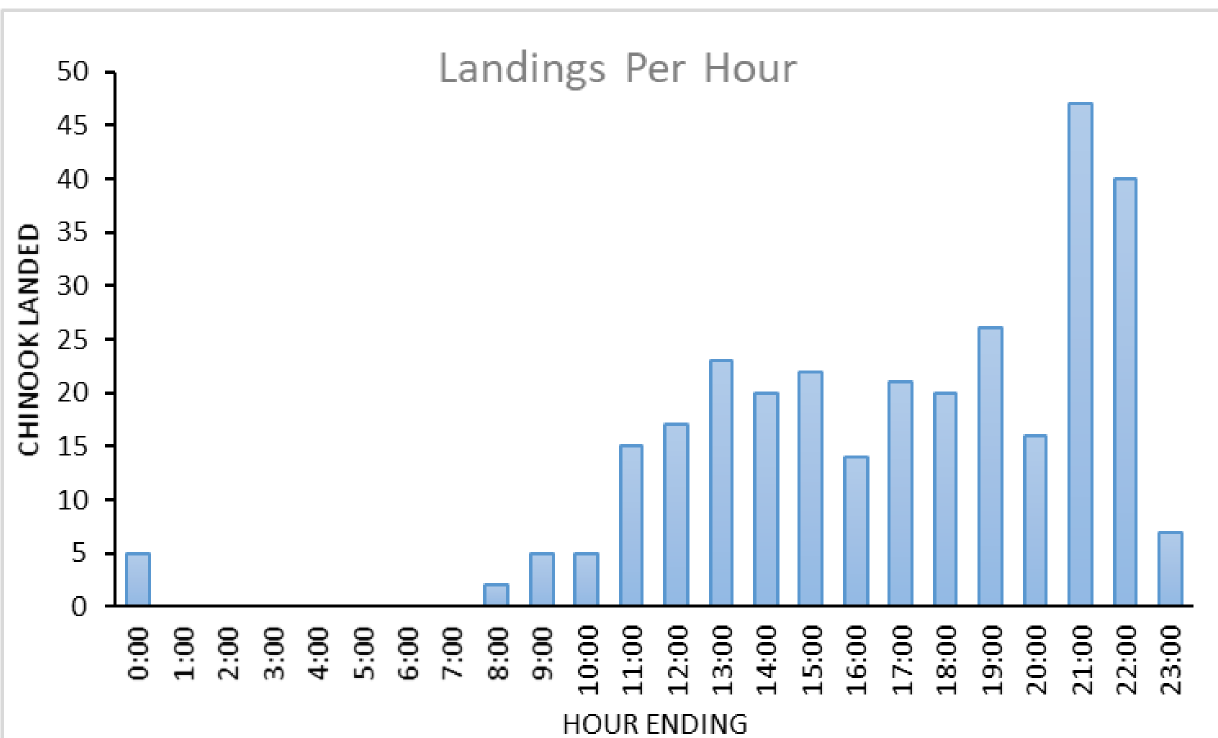

Figure 36. Chinook landings by hour at the Brechin Hill Marina between July 26 and October 15, 2021.

BOTTLENECKS PROGRAM APPLICATIONS

The *Bottlenecks Program* was designed to collaborate with several First Nations, NGOs, government scientists, stream-keepers, and non-profits to increase its ability to conduct meaningful studies. These partnerships, including those with DFO's Salmon Enhancement Program and Stock Assessment, and the Province of British Columbia, have been instrumental in the program's success. The *Bottlenecks Program* has successfully developed a number of synergistic relationships, enhancing its core objectives and meaningfully contributing to other ongoing projects.

Partnerships with First Nations were a pillar of the *Bottlenecks Program*. Data collected with First Nation's partners have been utilized by the Nations to help inform the management of their fisheries. For example, the Bottlenecks Program has partnered with Snuneymuxw First Nation to collect contemporary data and new information on the outmigration timing, survival (freshwater and SAR), life history strategies, and estuary utilization of the endangered Nanaimo summer-run Chinook stock (COSEWIC 2020). These data will soon be analyzed with Snuneymuxw First Nation and summarized to assist in a rebuilding plan for this stock, which is currently underway by DFO. Similar outputs can be developed to inform the endangered Puntledge summer-run Chinook rebuilding plan. To date, three years of freshwater survival estimates of hatchery-tagged summer-run Chinook have already been completed, with another year remaining (2025).

The collaborations developed with DFO have provided several outputs helping inform South Coast Stock Assessments' critical objectives. Notably, the *Bottlenecks Program's* data have provided new information on harvest rates by recreational fisheries, estimated marine survival rates for previously unassessed stocks, and helped derive escapement estimates. Specific examples are described below.

The *Bottlenecks Program's* EFM tables have provided meaningful information on recreational anglers' behaviours and catches. In the inaugural year, camera data from the EFM tables demonstrated that many fish are harvested at the cleaning tables after 8 PM, which is after Creel surveys are completed. Considering this, DFO has updated their Creel survey hours to include 8-10 PM.

In 2023, the Goldstream River's fish fence failed, reducing the ability to derive an accurate escapement estimate. To assist, the *Bottlenecks Program* provided DFO with our PIT tag return data. This allowed DFO stock assessment to release escapement estimates for the system. Further, DFO stock assessment utilized our coho data to develop their 2024 Coho Southeast Coast forecast report. The *Bottlenecks Program* provided data on an additional five systems in the forecast, including one wild coho system, bringing the number of systems monitored in Southern BC to eight.

A recent collaboration has been made with DFO's South Coast Johnstone Strait Stock Assessment group. Due to issues with predators consuming dead Chinook, fall escapement estimates in the Quinsam River have been inaccurate. The *Bottlenecks Program* was asked to assist DFO in altering their escapement methodology by PIT tagging adults entering the lower river/estuary and redetecting them on *Bottleneck Program* PIT antennas located at multiple points in the Quinsam River. This study will begin in the fall of 2024 and will likely provide improved escapement estimates for the system.

The *Bottlenecks Program* also collaborated with SEP and developed multiple studies to help inform enhancement processes and improve the overall survival of hatchery Chinook and coho. From 2021-2023, the *Bottlenecks Program* conducted an overwinter earthen channel mortality study at four facilities (Quinsam, Puntledge, Big Qualicum, and Nanaimo River Hatcheries). This project demonstrated that high mortality does occur and that it is mainly associated with predation. It also provided recommendations on how to improve overwinter survival estimates and how to derive them immediately post-release. Further, additional studies have been developed such as the "Quinsam eight" coho study, which assesses the differences in survival of the different cohorts and release groups (traditional, late, fed fry, wild) while also assessing the impacts of harvest rates (by tagging clipped and unclipped cohorts of the traditional and late release groups). In addition, a freshwater survival study on summer-run Puntledge River Chinook (using fall-runs as a conduit) is in the design phase and will be completed in spring 2025.

Local stream-keeper groups, NGOs and not-for-profits have collaborated with the *Bottlenecks Program* in various areas, bringing the benefits of the program's work to their communities. For instance, the Peninsula Streams Society (PSS) partnered with the *Bottlenecks Program* to PIT tag Goldstream River hatchery coho and release them in restored reaches of the Mill Stream River in Victoria. This collaborative effort, led by PSS, demonstrated how a small amount of equipment and resources supplied by the *Bottlenecks Program* allowed another group to expand their project meaningfully and fostered a sense of community and shared success.

The *Bottlenecks Program* has also provided significant contributions to numerous academic studies from several institutions. Studies conducted by the Hinch Lab at UBC used the expansion of PIT tag infrastructure completed by the *Bottlenecks Program* to provide additional information on survival rates. Further, UNBC MSc student Tom Balfour utilized the *Bottlenecks Program's* tagging, antenna development, installation expertise and equipment to complete his thesis on the freshwater survival of Toquaht River Chinook. A multi-year partnership was created with PhD student Leigh Gaffney at UVic to assess the influence of otolith vaterite presence on hatchery coho survival. The *Bottlenecks Program* provided the study with tags, tagging expertise, PIT array infrastructure, and power analyses.

LESSONS LEARNED

The *Bottlenecks Program* conducted novel research which has produced a vast body of work. Over four years of program development and implementation, many lessons have been learned with regards to large-scale salmon tagging, rearing and release strategies, and predation studies, among others. This section will outline these lessons and point to the individual projects which informed these learning outcomes.

Tagging:

A main priority of PIT tagging projects is limiting tagging-related mortality. Tag burden, with regards to fish size and capacity in the abdominal cavity must be considered, i.e., restrict feeding 24 hours prior to tagging and do not exceed a tag length of 17.5% body length. Tagger effects were significant, therefore new taggers must be closely monitored and should be limited to a finite number of tags (e.g., one tray of 100 tags). Tagger ID should be recorded to address any individual tagger effects prior to future tagging events.

Rearing:

To improve survival estimates and detection efficiencies in hatcheries using earthen channels for rearing, it is important to apply an adequate number of tags to each cohort (e.g., 500 PIT tags) and that PIT tagged fish are transferred into the channels at approximately the same time as the rest of the cohort. PIT antennas should be installed and active for the entire duration of earthen pond residency for escapee estimation. Tagged fish should be released gradually to improve PIT antenna detection efficiencies and reduce uncertainty around survival and prerelease mortality estimates. Finally, if predation is a recurring source of significant prerelease mortality, additional predator control measures need to be investigated and implemented.

Freshwater Survival:

In the inaugural year of the *Bottlenecks Project* (2020/2021), initial capture plans for in-river tagging of wild fish included in-river seining and smolt trapping in the three key systems for Chinook (Cowichan, Nanaimo, and Puntledge rivers). However, due to the size of these river's mainstems and the low temperatures of the Nanaimo and Puntledge rivers during the spring out-migration, attempts to capture wild Chinook were met with low CPUE. Additionally, of the fish that were captured, the majority were too small to tag (< 70 mm fork length). Due to this, alterations in capture methodologies were made and beach seining in the estuary and near-shore marine environment became the primary method of capture.

Additional PIT antennas (temporary and long-term) should be installed to improve detection efficiency, freshwater survival estimates, and to measure outmigration timing. Release of fish at various locations and times of the year could be useful to identify spatial or temporal release strategies that maximize survival and minimize straying.

To improve the estimations of freshwater survival and timing of PIT tagged juvenile Chinook, it is essential to consider the size, location, and timing of their release, as well as river height during the outmigration period. By utilizing Tom Balfour's integrated model of freshwater and capture-recapture using Bayesian inference (see section "Freshwater Residence and Survival of Hatchery-reared Juvenile Chinook Salmon"), a clearer understanding of survival and timing can be achieved.

Marine Survival and Distribution:

Contrary to what was formerly believed, the proportion of natural origin fish (as indicated by GSI vs PBT) was very low for all target Chinook salmon stocks with the exception of Cowichan River fall and potentially Nanaimo River summer and fall Chinook salmon. Thus, it may not be possible to assess hatchery versus wild survival for the majority of *Bottlenecks Project* stocks. However, further discussions are required with the Molecular Genetics Laboratory on the applications of GSI vs PBT to determine hatchery versus wild origin.

The distribution of juvenile Chinook during the winter months in the marine environment needs further study to identify critical habitats and survival bottlenecks. Using microtrolling and other innovative methods can help gather necessary data for effective management strategies. Understanding distribution patterns can inform conservation efforts and improve the survival rates of juvenile Chinook.

At-sea acoustic tagging of first ocean year Chinook was practical and reduced handling and holding time when compared to shore-based tagging. Using longer lived tags and reduced ping rates relative to other marine studies of Pacific salmon is effective given the less-directed migrations and prolonged localized residency of juvenile Chinook. Continued monitoring using acoustic telemetry to inform annual variations may provide information on these implications for cohort survival. Application of smaller tags to juvenile Chinook earlier in the fall (September) will be of value to determine if a wave of outmigration occurs prior to October (when tagging occurred as part of this project).

The capture of target coho stocks in the marine environment throughout the winter months is not feasible. Therefore, the estimation of stage-specific survival of coho will not be possible. However, the data gained from microtrolling for coho throughout the early fall and mid-winter in the Strait of Georgia could help increase spatiotemporal information on their distribution.

Research on the winter ecology of juvenile Chinook in the Strait of Georgia has highlighted several important findings for future study design and methodology. Systematic microtrolling and acoustic depth sensor tags are recommended to understand habitat use across multiple regions. Future studies investigating winter biology of juvenile Chinook should consider that fish may be concentrated close to bottom, limiting catchability by midwater sampling gear. Diet, condition, and growth selective mortality of juvenile Chinook should be tracked for multiple stocks and brood years and related to PIT tag and CWT-based survival estimates to elucidate the role of winter mortality in regulating trends and interannual fluctuations in abundance.

Predation:

Regular scans at heron rookeries (i.e., two times per year) with high tag detection rates can improve data accuracy. Tag scanners that collect GPS coordinates and detailed fish length data for hatchery fish cohorts can refine predation models and enhance detection probabilities.

Mobile scanning at high-density pinniped haul-outs, combined with in-situ monitoring stations, can help improve our understanding of predation on salmon by pinnipeds. Addressing uncertainties related to detection probability, predator identification, and scanning logistics will be required to refine methodologies. These efforts can provide a clearer picture of predation impacts.

Steelhead:

To better understand steelhead residualization and the effects of differential release timing, various improvements could be made. The installation of a full-stream mainstem PIT array would improve estimates of smolt-to-adult survival, residualization rates of hatchery fish, and outmigration timing. Steelhead should also be released lower in the river near tidewater to reduce residualization rates, and different marine release locations should be explored. Overall, more work is required to identify where survival bottlenecks are occurring and to understand the magnitude of impacts hatchery cohorts may have on wild steelhead.

Kelt reconditioning is not an effective strategy for increasing the condition and thus survival of steelhead kelts. The short reconditioning holding period, the low numbers of captured kelts, the decrease in condition over the holding period, along with the high cost of capture, prevented the *Bottlenecks Program* from continuing further assessments of this methodology.

Advanced tracking technologies, such as acoustic tags and satellite transmitters, have been invaluable in gathering real-time data, emphasizing the importance of technological advancements in research. The relatively large size of the satellite tag likely influences behaviour and survival rates. The lack of a clear predation signal in nearly 75% of the tags released suggests that the use of PSATs has limited ability to fully explain mechanisms of mortality. The lack of clear signal could indicate seal predation as seals are known not to consume salmon (belly-biters) entirely and have a larger ability to handle prey than fishes. Further analysis of accelerometry data may provide information on predation events through changes in movement patterns that may further our understanding of these unknown mortalities. However, predation of nearly a quarter of the tagged kelts by ectothermic pelagic fish suggests that predators other than pinnipeds also significantly impact steelhead survival.

Enhanced Fisheries Monitoring:

The conceptualization and implementation of EFM cleaning tables was highly successful. Data collected using these technologies to inform and improve Creel surveys can provide more accurate estimates of fish populations and catch rates. Expanding EFM locations to additional sites based on mobile scanning data may enhance monitoring efforts and support sustainable fishery management.

CONCLUSIONS AND NEXT STEPS

The *Bottlenecks Program* set out to achieve the audacious goal of developing a large multi-stock, stage-specific survival study on the East Coast of Vancouver Island. During the first four years of the program, over 250,000 Chinook, coho, and steelhead across 13 river systems were tagged at various stages of their freshwater and early marine life phases. Tagging-related mortality was low and measures have been implemented to maintain the good health of the tagged salmon. Through partnerships with SEP, hatchery rearing and release strategies were explored to improve hatchery effectiveness. For steelhead, successful conditioning in an enhancement facility to increase their likelihood of successful iteroparity was not possible. In the ocean, a novel sampling method called microtrolling was used to sample through the winter months (August to May) in the Strait of Georgia, a season where few other studies have conducted similar sampling. The first detailed descriptions of the winter ecology of juvenile Chinook, including their diet and habitat utilization, were provided. Preliminary maps of the marine migrations and distributions of Chinook, coho, and steelhead were developed. The fates of salmon were tracked far and wide by scanning heron rookeries, seal haul-outs, and fish cleaning tables for deposited PIT tags. Through all of this, a number of synergistic partnerships were formed with First Nations, government, academia, and community members, which we hope to carry forward.

Looking ahead to the next two years, the program plans to continue core activities at primary and secondary watersheds until March 2026. The program will continue to build on the collaboration with DFO Stock Assessment and SEP by expanding coho SAR estimates on ECVI, assessing limiting factors of the endangered Nanaimo and Puntledge river summer-run Chinook, developing a new method for escapement estimation in the Quinsam River with Johnstone Strait Stock Assessment, and assessing different rearing and release strategies for Quinsam River coho.

Research led by Tom Balfour (UNBC) found that river conditions can greatly influence the detectability of PIT tagged salmon in the river and thus our estimations of freshwater survival. Given our core objectives of exploring stage-specific survival, accurate estimations of freshwater survival will be critical. Therefore, we will be working with a postdoctoral fellow at UNBC to utilize the model developed for Toquaht Chinook freshwater survival and expand it to other systems and species in the *Bottlenecks Program*. This model will be integrated into the larger stage-specific survival model.

In addition, there are a few key assumptions of our program that we intend to investigate, including size-selectivity and marine migration strategies of Chinook. To reduce tagging-related mortalities, PIT tags are only applied to individuals 70 mm or larger in fork length. Thus, we are not sampling the population of smaller outmigrating salmon. To explore the possible size-selective bias introduced by our tagging requirements, otoliths from both juveniles and adults will be used to determine the contributions of smaller fish to adult returns. Specifically, the *Bottlenecks Program* will collect juvenile Chinook from the Nanaimo and Cowichan rivers to develop system-specific fork length to otolith radius baselines. Final analysis of life history contributions to adult returns will be completed for 2026.

As for marine migrations, salmon are tagged in the Strait of Georgia from September through April, potentially spanning a period (or multiple periods) of outmigration. This raises the prospect that the proportion of different migration life-history types (i.e. resident and migrant Chinook) may change through the tagging period, with implications for estimation of overwinter survival. Resolving outmigration timing and relationships with individual traits is necessary to validate assumptions of marine survival estimates and test key hypotheses about overwinter mortality. Therefore, we are working with Wes Greentree for his PhD research to conduct an acoustic tagging study to address this assumption.

Through collaborations with our First Nations partners, a recurring topic of interest has been the interactions between pinnipeds and salmon. Given the spatial-temporal time series of salmon outmigrations and return migrations produced by the *Bottlenecks Program*, our program seemed well positioned to support the concurrent monitoring of pinniped populations at similar scales to explore these interactions. Therefore, we have partnered with four First Nations communities to develop a long-term pinniped monitoring program, involving shore-based surveys, wildlife cameras, sonar, and drone imagery. In addition to these surveys, there will be an increase in mobile PIT scans of targeted pinniped haul-outs in the Southern Gulf, Northern Gulf, and Discovery Islands. Further, in-situ haul-out monitoring sites will also be deployed this summer at two locations (Miami Islets and Vigilante Islets) at the Southern and Northern ends of the study area.

An orphan PIT tag database is currently under development. The *Bottlenecks Program* has the most extensive PIT infrastructure in the Salish Sea, and therefore has been highly effective at detecting tags from *other* programs. This database will compile all PIT tags detected on Bottlenecks infrastructure that are not part of the Bottlenecks Program and will be publicly accessible for all researchers to look for their tags. Additionally, other researchers will be able to upload their orphan tags, which will help us in finding any of our program tags that may have ventured further afield. Thus, all PIT tagging groups within the Salish Sea will be able to search for and find their tags when detected on another group's infrastructure. This initiative is also part of a growing PIT tag working group which brings together individuals and organizations leading PIT tag research on salmonids across BC, Washington, and Oregon.

REFERENCES

Beamish, R.J., and Mahnken, C. 2001. A critical size and period hypothesis to explain natural regulation of salmon abundance and the linkage to climate and climate change. Prog. Oceanogr. 49(1-4): 423-437. doi:10.1016/S0079-6611(01)00034-9.

Brown, N., and Gaydos, J. 2009. Species of concern within the Salish Sea marine ecosystem: changes from 2002 to 2008. Puget Sound Georg. Basin Ecosyst. Conf. 1(1): 1-10.

COSEWIC. 2008. COSEWIC assessment and update status report on the Killer Whale Orcinus orca, Southern Resident population, Northern Resident population, West Coast Transient population, Offshore population and Northwest Atlantic / Eastern Arctic population, in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. viii + 65 pp. (www.sararegistry.gc.ca/status/status_e.cfm).

COSEWIC. 2020. COSEWIC Assessment and Status Report on the Chinook Salmon (Oncorhynchus tshawytscha) Designatable Units in Southern British Columbia (Part Two – Designatable Units with High Levels of Artificial Releases in the Last 12 Years), in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. xxxv + 203 p.

Cormack, R. 1964. Estimates of survival from the sighting of marked animals. Biometrika 51(3/4): 429-438.

Department of Fisheries and Oceans (DFO). 2020. Government of Canada takes action to address threats to struggling Fraser River chinook. Available from https://www.newswire.ca/news-releases/government-of-canada-takes-action-to-address-threats-to-struggling-fraser-river-chinook-817254737.html.

Duguid, W.D.P., and Juanes, F. 2017. Microtrolling: An economical method to nonlethally sample and tag juvenile Pacific salmon at sea. Trans. Am. Fish. Soc. 146: 359-369. doi: 10.1080/00028487.2016.1256835.

Gaydos, J.K., and Pearson, S.F. 2011. Birds and mammals that depend on the Salish Sea: A compilation. Northwest. Nat. 92(2): 79-94. doi: 10.1898/10-04.1.

Government of Canada. 2023. Pacific tidal recreational fishing 2000 to 2021. Available from https://www.pac.dfo-mpo.gc.ca/consultation/fisheries-peches/pol/docs/rec-tidal-maree-2021-eng.html.

Government of Canada. 2018. Chinook salmon (*Oncorhynchus tshawytscha*): COSEWIC assessment and status report 2018: Document information. Available from https://www.canada.ca/en/environment-climate-change/services/species-risk-public-registry/cosewic-assessments-status-reports/chinook-salmon-2018/document-info-summaries.html.

Jolly, G.M. 1965. Explicit estimates from capture-recapture data with both death and immigration-stochastic model. Biometrika 52(1/2): 225-247.

Pearsall, I., Schmidt, M., Kemp, I., and Riddell, B. 2021. Synthesis of findings of the Salish Sea marine survival project, version 1.0. Available from https://marinesurvival.wpengine.com/wp-content/uploads/2021PSF-SynthesisPaper-Screen.pdf.

Ryall, P.J., and Shardlow, T.F. 1991. Review of 1989 south coast salmon troll fisheries. Prepared by Fisheries and Oceans Canada. Available from https://publications.gc.ca/collections/collection_2014/mpo-dfo/Fs97-4-2102-eng.pdf.

Seber, G.A. 1965. A note on the multiple-recapture census. Biometrika 52(1/2): 249-259.

Stuart, A., and Ord, J.K. 2009. Kendall's advanced theory of statistics, Volume 2B: Bayesian inference, 2nd edition. Wiley.

Vollset, K.W., Lennox, R.J., Thorstad, E.B., Auer, S., Bär, K., Larsen, M.H., Mahlum, S., Näslund, J., Stryhn, H., and Dohoo, I. 2020. Systematic review and meta-analysis of PIT tagging effects on mortality and growth of juvenile salmonids. Rev. Fish Biol. Fish. 30: 553-568. doi: 10.1007/s11160-020-09611-1.

Wild Salmon Advisory Committee (WSAC). 2019. B.C. Wild Salmon Advisory Council recommendations for a made-in-B.C. wild salmon strategy. Available from https://engage.gov.bc.ca/app/uploads/sites/121/2022/11/Wild-Salmon-Advisory-Council-Report.pdf.

APPENDIX A - METHODS

Study Area

Our study area is concentrated in the Strait of Georgia, the northern portion of the Salish Sea, and includes 14 rivers across 13 watersheds (Figure A1). Including two west coast watersheds, the Stamp River and the Toquaht River (Figure A1).

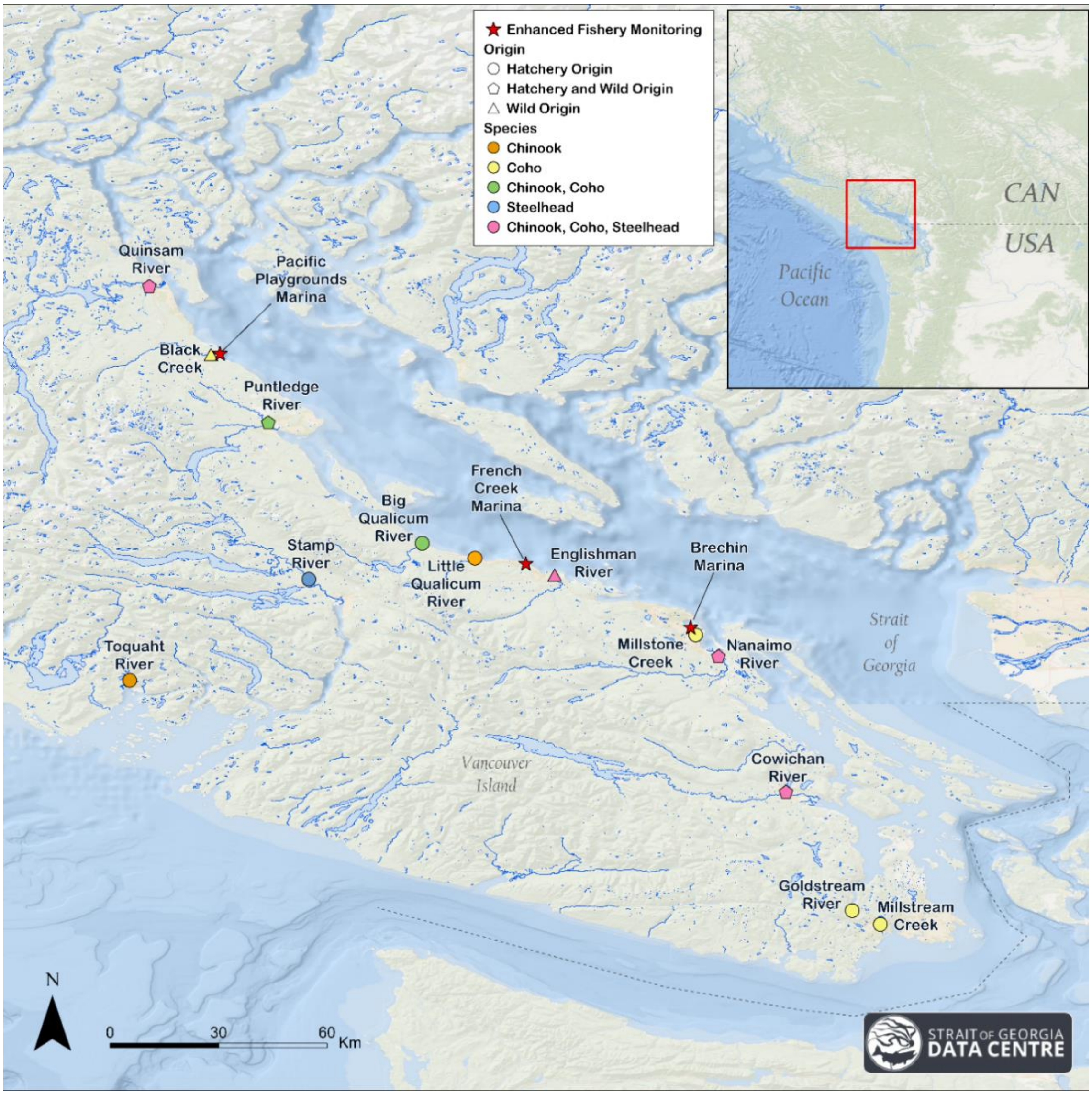

Figure A1. Map of the study region (Northern Salish Sea / Strait of Georgia) showing river systems outfitted with PIT infrastructure, target species for tagging (colour-coded circles), and recreational landing sites for enhanced fishery monitoring programs (red stars).

General Methodology

This section describes fish capture, passive integrated transponder (PIT) tagging, genetic stock identification, tag detection, and other methodologies applied across activities of the *Bottlenecks Program*. More details can be found in our Standard Operating Procedures.

Fish Capture

Chinook and coho salmon and steelhead trout were tagged in the lower rivers and/or estuaries in the Cowichan, Nanaimo, Englishman, Puntledge, Black Creek, and Quinsam watersheds. Fish were captured by various methods (i.e., rotary screw trap, beach seine, smolt trap, pole seine, and/or wolf trap) depending on the system and location.

Beach Seining

A 45.72 m x 2.42 m beach seine with 12.7 mm stretched mesh and a 9.5 mm stretched mesh bunt was utilized in all systems for both in-river and estuary seining activities. Nets were deployed from a 5.5 m aluminum boat (runabout style) or a 5.5 m hard floor Zodiac while a team of two to four people pursued the net from the shore (Figure A2). Once hauled in, crews would sort the bycatch (e.g., jellyfish, herring, squid, perch, stickleback) from the main net and use a small net to scoop juvenile salmonids into 20 l sorting buckets and then into 76 L live wells, with aerators.

Live wells were located at the portable wet lab set up every morning prior to the first seine set. Mobile wet labs consisted of U.V. protected tents (3.3 m x 3.3 m), two foldable plastic tables (1 m x 3 m), two or three plastic large rectangular shallow wash basins (45 cm x 32.7 cm x 12 cm) used for anesthetic baths. A crew of three to four would then collect biodata including species, clip status, fork length, take a DNA sample and PIT tag each juvenile salmon prior to release.

The same or similar portable labs were setup prior to any active fish capture day or any movement of fish during daily/weekly checks of passive capture methods presented below.

Figure A2. Beach Seine used for capture of juvenile Chinook and coho in both estuary and riverine settings (photos by Danny Swainson)

Pole Seining

Juvenile salmon were captured using a large pole seine fished in slow to moderate velocities (<1.0 m/s) and depths to 1.5 m. The pole seine (1.6 m x 6 m) consisted of a one-half-inch stretch knotless mesh with a three-quarter-inch lead line and plastic corks along the top edges. The design incorporated a square basket where fish would collect as the lead line broke the surface at the end of each set (Figure A3). Wing extensions (1.5 m each) were attached to each end to increase capture rates during mainstem seining; three-quarter inch metal conduit held the ends of the net open and provided a handle during operation.

Crews of two would work primarily in a downstream direction moving faster than the pace of the river to ensure the basket would inflate, providing an area for fish to collect. Occasionally, a third crew member would follow behind and hold back the basket in faster sites to prevent the net from collapsing on itself. The set would be completed by either drawing the lead line out of the water and rotating the net vertically or sweeping in a "J" pattern towards the beach and dragging the lead line out of the water. Fish were pursed in the basket and left in the water before being transferred to buckets and sorted on the beach.

Figure A3. Pole seine used for capture of juvenile salmon (photo by Kevin Pellet).

Rotary Screw Traps

Rotary Screw Traps (RST) are a method of passive capture, designed and manufactured on Vancouver Island (Key Mill Construction; Figure A). RSTs are specially designed passive traps with a circular cone. The trap faces in the upstream direction, and the circular cone rotates driven by the downstream current of the river. RSTs are positively buoyant due to their two large pontoons, which allow for the usage of cables from high vantage points (i.e. large trees, specially designed aluminum A-frames, and bulkheads, among others) to hold the trap in a specific location in a river, even during moderate to high river flows. Most of the RSTs designed for the *Bottlenecks Program* and affiliated programs have an additional 'yolk/gobbler' on the anterior end. This yolk is mounted to the front of the RST's pontoons, closing in the gaps below the cone when it's "fishing,". This forces fish migrating downstream to be reflected in an upward direction into the cone, increasing trap capture efficiency. The rotation of the aluminum cone passively captures juvenile salmon migrating downstream, then actively transports them into a large live-well at the posterior end of the trap (Figure A4). In addition, the juvenile fish fence panels, made from aluminum bracing were constructed of 38 x 89 mm frames and screened with 6.4 mm Vexar® screening. Panels were supported by 38 mm x 89 mm x 2.4 m lumber braces staked into the river substrate with 15 mm rebar. Panels were connected by overlapping the screening approximately 20 cm on the ends of each panel and securing the screening with 15 cm cable ties. Burlap sandbags and onsite river cobbles were used to fill gaps beneath the panels and to provide additional support where required. Panels came in a variety of sizes ranging from 1.2 m x 1.8 m to 1.5 m x 3.0.

Figure A4. RST-style smolt traps. The upper left image shows the “yolk”, the top left image shows an RST trap not in ‘fishing’ mode. The bottom two images show the different operating methods for RSTs installed in the Cowichan and Nanaimo rivers.

Smolt trap

Fence-style smolt traps were utilized to capture out-migrating juvenile salmon, as well as rainbow, steelhead, and cutthroat Trout in the Englishman watershed (Shelly Creek, Center Creek, and the side channel network). In the first year of the Bottlenecks study smolt traps were deployed in Haslam Creek (Nanaimo watershed) and in a side channel of the Puntledge River. However, these sites were not suitable for this capture method and were discontinued in future years.

Fences were constructed from a series of 0.9 m x 3.0 m panels, which were arranged to funnel migrating smolts into a 15 cm diameter flexible fish-safe pipe leading to a 1.0 m x 1.0 m x 1.8 m trap box on the downstream end (Figure A5). Panels were constructed of 38 x 89 mm lumber frames and screened with 6.4 mm Vexar® screening. Panels were supported by 38 mm x 89 mm x 2.4 m lumber braces staked into the river substrate with 15 mm rebar. Panels were connected by overlapping the screening approximately 20 cm on the ends of each panel and securing the screening with 15 cm cable ties. Burlap sandbags were used to fill gaps beneath the panels and to provide additional support where required.

Figure A5. Fence funnelling smolts downstream into a smolt trap.

<u>Microtrolling</u>

First ocean winter Chinook and coho salmon were targeted in marine waters from August to May. This sampling also provided the opportunity to capture and tag Chinook salmon in their second ocean winter (the winter prior to most entering the recreational fishery). Microtrolling (the application of scaled down recreational fishing gear following Duguid and Juanes (2017)) was used to capture juvenile Chinook and coho salmon in order to PIT tag and collect biological data from each individual. Microtrolling was conducted by BCCF staff, UVic, volunteers from PSF's volunteer angler program, and First Nations.

Each microtrolling boat is equipped with two downriggers (minimum of 300 ft of braid or cable), with which a crew of two can deploy six clips on each downrigger simultaneously. A 'clip' is defined as one fishing line for the downrigger; the fishing line is mounted as a 6 ft line (any clear 50 to 60 lb monofilament) with a trolling clip (any, Scotty 3" to 5" preferred), snubber (Luhr-Jensen Dipsy Diver Rubber Snubber, 12" heavy), and flasher (Hot Spot 'Micro' Plaid Mylar), connected by snap swivels (any), to a 3 ft leader (Maxima Ultragreen 15 lb monofilament) with spoon (Dick Nite #1 Nickel or Gibbs Mini G) and hook (Mustad #10 Signature C67S egg/caddis fly hook, August and September; Gamakatsu #10 siwash open eye, October to March) (Rodgers et al. 2022).

The bottom clip is to be attached approximately five feet above the cannonball (12 lb to 18 lb) on the downrigger braid/cable, with the next 5 clips attached at a specified interval depth. The interval depth will vary based on the depth of the fishing area and desired fishing depths; it can vary throughout the day (Rodgers et al. 2022). The clips are "fished" for five minutes and then retrieved, checked, and re-set if three or fewer fish are caught. If more than three fish are caught, the fish are to be processed before the gear is re-deployed to ensure processing is not rushed (Rodgers et al. 2022).

Georeferenced effort and biological data are recorded using a tablet and a custom eForms mobile app. The time and GPS location are collected at the start of each set (as soon as the first clip enters the water), and collected again at the end of the set (when the last clip is out of the water).

On landing, fish are assessed for any injuries, either pre-existing or due to hooking or handling. Additionally, biodata including species, adipose fin clip status, fork length, and weight, if the weather is not too rough, are collected. The fork length of each salmon caught is measured to the nearest millimeter. Weights are measured using a 500 g scale (Pesola® 10500 Light-Line Metric Spring Scale), or a 2,500 g scale (Pesola® 42500 Light-Line Metric Spring Scale), for larger fish. Additionally, each fish is scanned with an HPR-Lite hand scanner (Biomark®, Boise, ID) and those that are not previously PIT tagged have a PIT tag applied (see *PIT Tagging* for methods). Further, fin clips are taken to assess the river and stock of origin (see *Genetic Stock Identification and Parentage Based Tagging Sampling and Analysis* for methods). If a fish has a pre-existing injury, photos are taken of the injury. Any pre-existing injury does not preclude tagging; however, injuries due to handling, such as significant bleeding, lack of equilibrium prior to TMS bath, blood under cornea due to eye hook, etc. do preclude tagging. These injured fish are documented in the eForms Mobile app, euthanized, and retained (Rodgers et al. 2022). The time at which fish were kept in the TMS bath does not exceed five minutes and all fish are returned to the recovery tank before release.

The livewell (either a cooler or 6-chamber perforated livewell) where fish were anesthetized, is aerated and treated with 50 mg/L TMS and VidaLife (Figure A6). The recovery well (either another cooler or a separate livewell) is fresh, aerated saltwater bath, treated with VidaLife.

A detailed standard operating procedure document describing microtrolling methods and use of the Eforms Mobile data collection app (Rodgers et al. 2022) is provided as an attachment to this document.

Figure A6. Processing Chinook salmon captured during microtrolling in the Strait of Georgia. Fish captured on different hook depths are held in separate chambers of the livewell.

Winter Ecology

From September to May, in-depth winter ecology biosampling and tagging was conducted systematically, 1 day per month at three sites in the Northern Strait of Georgia; up to eight sets (5 minutes each) were fished along predetermined transect lines at 30 m, 60 m, 90 m, and 150 m water depth) (Figure A7). On a monthly basis, temperature of the water column to 90 m was recorded by a Castaway CTD (SonTex, San Diego California) cast at each of these sites. On all other occasions, fishing activity occurred haphazardly with vessel location, number of hooks, and gear depth adjusted for the purpose of maximizing catch. In winter 2020-21, all biosampling days occurred at the same sites as the habitat days. In 2021-22 and 2022-23, additional biosampling days were added at sites in Stuart Channel and the Discovery Islands in order to increase the diversity of stocks encountered. Some sampling also occurred in the Strait of Juan de Fuca as a reconnaissance to investigate temporal shifts in the stock composition of first-year Chinook salmon moving through this region. Regardless of activity type, GPS was logged at the onset of gear deployment, a five-minute timer was started when the gear reached depth, and GPS location was logged again once all gear was retrieved.

All captured salmon were immediately landed into a 94.6 L dark-blue interior insulated cooler, partially filled with seawater and aerated. Salmon were anesthetized for sampling (8 L of 40 mg/L TMS) and identified to species. Chinook salmon were examined for external signs or symptoms of parasite and pathogen presence. Adipose fin-clip status was assessed, and fork length was measured to the nearest millimetre for all salmon. All first-year winter Chinook salmon stomach contents were sampled by gastric lavage (except in Juan de Fuca), bagged with seawater, and stored on ice for up to 72 hours until processing. Fish were scanned for PIT tag presence, and untagged and uninjured individuals were PIT tagged as part of the main *Bottlenecks Program*.

Gill biopsies were collected from all Chinook salmon and preserved in RNAlater for 'Fit Chip' analysis. Scales were collected for GSI and growth analysis. Weight was determined using a Pesola® Lightline spring scale (max 500 g for small individuals and 2500 g for individuals over 500 g). Time under anesthesia did not exceed five minutes, and fish were returned to the cooler for recovery prior to release. A subset of Chinook salmon was euthanized (by overdose of TMS), weighed again onshore, and frozen at -20 °C until transferred into a -80 °C freezer for longer-term storage and subsequent lab processing. Fish injured during capture were used for this lethal sampling component where possible. An illustration of the biosamples collected for the winter ecology work is provided in Figure A6.

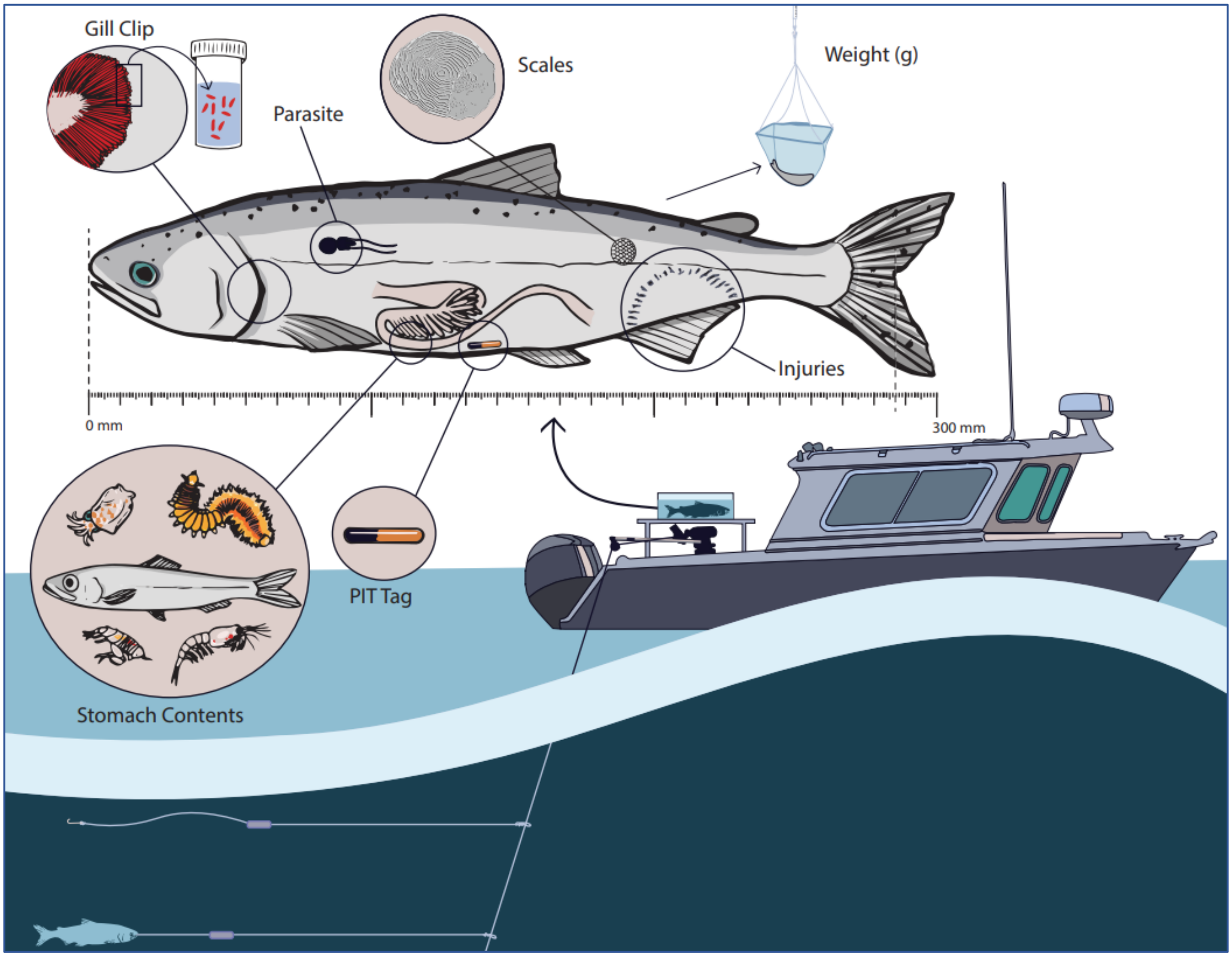

Figure A7. Schematic of Chinook capture and sampling by microtrolling for the Winter Ecology project.

Fish Handling and Biodata Collection

All captured fish were initially kept in aerated fresh or saltwater, depending on capture location and time of year. Once crews were ready to collect biodata, the fish were transferred into a buffered anesthetic bath following the Canadian Council on Animal Care's standardized methodology (Ackerman, Morgan & Iwama 2005). All anesthetic baths included Vidalife (Syndel Canada, Nanaimo, BC), a water conditioner that preserves the fish's natural mucous layer, preventing abrasions (Syndel 2019). Once a fish was adequately anesthetized (i.e., slowed breathing, subdued response to touch, movements slowed), they were handled carefully and quickly to reduce exposure to TMS and air.

Biodata collected varied with the activity, but included species identification, fork length, adipose fin clip status, and weight. A genetic tissue sample was also collected during specific project activities to identify an individual fish's stock of origin (see *Stock Identification* for methods overview).

Following measurements, tagging, and sample collection, the fish were kept in a recovery bath before returning to the freshwater, estuarine, and/or marine environment.

PIT Tagging

All Chinook, coho, and steelhead were tagged with 12 mm FDX-B PIT tags (Biomark, Boise, ID). PIT tags were administered in salmonids with a fork length equal to or greater than 70 mm in hatchery environments and 65 mm for all other environments (i.e., ~17.5% of a salmonid's fork length to minimize risk of mortality from tagging as per Vollset et al. 2020). Once anesthetized, PIT tags were injected into the body cavity anterior to the pelvic girdle (Figure A8) with a sterilized, single-use, preloaded needle. In all instances except hatchery tagging, an HPR-Lite hand scanner (Biomark, Boise, ID) was used to scan and record the inserted tag.

At hatcheries, fish were removed from their primary populations the day of or the day before tagging. Fish were starved for 24 hours before tagging. Fish were removed from the holding tank(s) and anesthetized with 50 mg/L TMS for 4 minutes before tagging (Keith, DFO SEP, pers. comm. 2021). Tagged fish were immediately released into flow-through tagging tables directly into the holding tank (either circular (circ) or runway (rw) tanks) or were transported from flow-through tables into static recovery tubs and then quickly released back into their holding tank. Tagged fish were monitored for PIT tag rejection and tag-related mortality for a minimum of 14 days in their holding tubes or tanks prior to release.

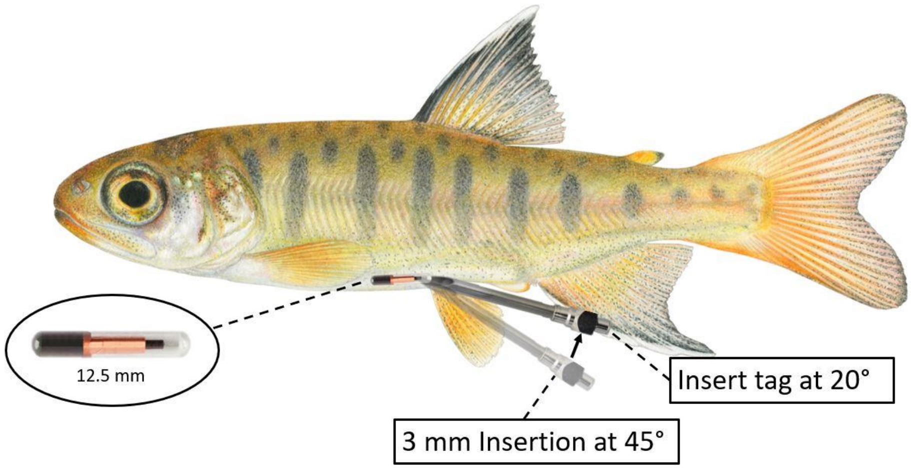

Figure A8. Illustration of the location and size of PIT tags inserted into the body cavity anterior to the pelvic girdle of each fish, using a sterile needle (Rodgers et al. 2022).

Genetic Stock Identification and Parentage Based Tagging Sampling and Analysis

While some hatchery stocks (e.g., Cowichan River Chinook, Quinsam River Coho) have 100% external marking (adipose clip), most hatchery production is unmarked. Genetic stock identification (GSI) and parental based tagging (PBT) were therefore employed to identify the origin (hatchery vs wild) and stock of most fish tagged and captured in the wild.

Most genetic tissue samples were taken as fin clips, although scale samples were also used. Fin clip DNA samples were taken from the caudal fin with a target clip width of 2 mm and stored on Whatman sheets. Scales (n = 5-10) were removed from the preferred area (above or below the lateral line just posterior to and under the dorsal fin) and stored in gummed scale books.

Tissue samples were transferred to the Molecular Genetics Laboratory (MGL) at the Pacific Biological Station and genotyped as described in Beacham et al. (2022) and references therein. First, each sample was run against species-specific baselines of genotyped hatchery parents using COLONY software. Fish that could be assigned to two hatchery parents were successful PBT assignments and were identifiable to population, hatchery, and brood year. Fish that could not be assigned to hatchery parents by COLONY were assigned to stocks using GSI, which uses single nucleotide polymorphisms (SNP) allele frequencies in species-specific population baselines in a Bayesian genetic stock identification modelling framework using the software RUBIAS. The GSI procedure assigned probabilities of each fish belonging to one or more stocks. For the preliminary analyses presented in this document, fish were assumed to belong to the stock with the highest probability.

We assume that successful assignment of stock of origin by PBT indicates hatchery origin and assignment using GSI indicates wild origin. However, in subsequent analyses, we will account for both ungenotyped broodstock and DNA sample quality in assessing the robustness of this relationship. Hatchery-origin fish may have been assigned to stock by GSI rather than PBT because either their parents were not successfully genotyped or the number of loci genotyped was insufficient for successful COLONY assignment, but sufficient for RUBIAS assignment. A high proportion of hatchery broodstock are currently being genotyped at SEP facilities. We are working with MGL to consider the number of successfully genotyped loci as a metric of confidence in using GSI as a proxy for natural origin.

As RUBIAS analysis applies a Bayesian approach to assign stock probabilities, final assignments are sensitive to the stock composition of the mixtures, which are run together through the model. It is, therefore, beneficial to stratify samples into spatiotemporal groupings that are expected to have similar stock composition. Analytical mixtures have been largely ad hoc based on the logistics of sample submission to MGL. While this approach provides preliminary results that deliver a good overall picture of stock composition to facilitate project refinement, all samples will be re-run in carefully considered spatiotemporal and age/size strata prior to stock assignment for final survival analysis.

PIT Tag Detection Arrays

The installation of multiple PIT antennas is required to detect PIT tagged fish during their juvenile freshwater outmigration and/or when they return to spawn. PIT antennas (single) and arrays (multiple antennas) come in a variety of sizes, constructed specifically to suit the requirements of each site. PIT antennas and arrays installed as part of the *Bottlenecks Program* were custom-built in a variety of ways.

1. Permanent pass-over arrays consisting of 2-12 prefabricated, individually controlled antennas were installed in the river mainstems. Each antenna coil was housed in welded 4" HDPE pipe, measuring 0.8 m x 6.1 m (Figure A) and was secured to the substrate using "duck bill" anchors at the end of a one-quarter inch stainless steel threaded rod, eight per antenna. Systems with two transects were installed typically at least 40 – 90 m apart, each consisting of four to six antennas, end on end. All antennas were wired into a master controller on the streambank and connected to a battery bank maintained by 120 V AC power.
2. Fishway antennas were designed in a pass-through orientation and were custom-made by Biomark or BCCF staff (Figure A10).

Figure A9. Installation of the Nanaimo River mainstem PIT array, July 2021 (photo by Danny Swainson).

Figure A10. Quinsam River hatchery fishway PIT antennas,2021 (photo by Jamieson Atkinson).

APPENDIX B - DATA

Bottlenecks Program Data

The Bottlenecks Program has recently finished its first four years of funding provided by the BC Salmon Restoration and Innovation Fund. The program has PIT-tagged and sampled over 250,000 salmon, primarily Chinook and coho, as well as steelhead, rainbow trout, and cutthroat trout and other salmon species. This data appendix includes all tagged fish from all study years (2020 – 2023) and detections of outmigrating juveniles (Tables B1-7). It also includes detections of returning adults from tags deployed only during the first two study years (2020-2021 and 2021-2022). Subsequent returns are incomplete.

Primary Systems Tags Deployed

Table B1. The Number of PIT tags applied to Chinook in the primary watershed of the Bottlenecks Program across the various habitats for the program's first four years.

WATERSHED	SPECIES	YEAR	TAG PERIOD	TAGS DEPLOYED	OUTMIGRATION DETECTIONS	ADULT RETURN DETECTIONS
Cowichan	ck	2021	estuary	2911	0	44
Cowichan	ck	2022	estuary	1	0	0
Cowichan	ck	2021	hatchery	6744	0	69
Cowichan	ck	2022	hatchery	5000	2	45
Cowichan	ck	2023	hatchery	5000	841	1
Cowichan	ck	2020	microtroll	489	0	29
Cowichan	ck	2021	microtroll	465	0	26
Cowichan	ck	2022	microtroll	607	0	22
Cowichan	ck	2023	microtroll	164	0	5
Cowichan	ck	2021	river	4978	1	102
Cowichan	ck	2022	river	6252	705	75
Cowichan	ck	2023	river	5612	1739	0
Nanaimo fall	ck	2021	estuary	715	0	9
Nanaimo fall	ck	2022	estuary	1459	0	5
Nanaimo fall	ck	2023	estuary	1547	1	0
Nanaimo fall	ck	2021	hatchery	5000	0	85
Nanaimo fall	ck	2022	hatchery	5000	239	34
Nanaimo fall	ck	2023	hatchery	5000	1748	0
Nanaimo fall	ck	2020	microtroll	87	0	3
Nanaimo fall	ck	2021	microtroll	51	0	5
Nanaimo fall	ck	2022	microtroll	143	0	3
Nanaimo fall	ck	2023	microtroll	94	0	1

Nanaimo fall	ck	2021	river	163	0	3
Nanaimo fall	ck	2022	river	383	0	0
Nanaimo fall	ck	2023	river	6	3	0
Nanaimo summer	ck	2021	estuary	297	0	2
Nanaimo summer	ck	2022	estuary	147	0	0
Nanaimo summer	ck	2021	hatchery	5000	0	14
Nanaimo summer	ck	2022	hatchery	5000	225	4
Nanaimo summer	ck	2023	hatchery	5000	1479	1
Nanaimo summer	ck	2020	microtroll	10	0	1
Nanaimo summer	ck	2021	microtroll	24	0	0
Nanaimo summer	ck	2022	microtroll	30	0	1
Nanaimo summer	ck	2023	microtroll	36	0	0
Nanaimo summer	ck	2021	river	69	0	0
Nanaimo summer	ck	2022	river	33	0	0
Puntledge fall	ck	2021	estuary	963	0	8
Puntledge fall	ck	2022	estuary	2048	0	0
Puntledge fall	ck	2023	estuary	3477	0	0
Puntledge fall	ck	2021	hatchery	5000	0	20
Puntledge fall	ck	2022	hatchery	5000	0	4
Puntledge fall	ck	2023	hatchery	4900	748	4
Puntledge fall	ck	2020	microtroll	168	0	3
Puntledge fall	ck	2021	microtroll	472	0	14
Puntledge fall	ck	2022	microtroll	331	0	8
Puntledge fall	ck	2023	microtroll	36	0	1
Puntledge summer	ck	2020	microtroll	17	0	1
Puntledge summer	ck	2021	microtroll	13	0	0
Puntledge summer	ck	2022	microtroll	10	0	0
Puntledge summer	ck	2023	microtroll	1	0	0

Table B2. The number of PIT tags applied to Coho in primary watersheds of the Bottlenecks Program across the various habitats for the program's first four years.

WATERSHED	SPECIES	YEAR	TAG PERIOD	TAGS DEPLOYED	OUTMIGRATION DETECTIONS	ADULT RETURN DETECTIONS
Cowichan	co	2021	estuary	2	0	0
Cowichan	co	2020	microtroll	5	0	0
Cowichan	co	2021	river	5009	0	331
Cowichan	co	2022	river	2501	69	118
Cowichan	co	2023	river	2112	467	2
Nanaimo	co	2021	estuary	3	0	0
Nanaimo	co	2022	estuary	98	0	3
Nanaimo	co	2023	estuary	11	0	0
Nanaimo	co	2021	hatchery	5000	1945	137
Nanaimo	co	2022	hatchery	5000	993	6
Nanaimo	co	2023	hatchery	5000	109	8
Nanaimo	co	2020	microtroll	1	0	0
Nanaimo	co	2021	river	5	0	0
Nanaimo	co	2022	river	8	0	0
Nanaimo	co	2023	river	366	2	0
Puntledge	co	2021	estuary	202	0	11
Puntledge	co	2022	estuary	1078	1	63
Puntledge	co	2023	estuary	588	0	0
Puntledge	co	2021	hatchery	5000	4537	334
Puntledge	co	2022	hatchery	5000	3312	269
Puntledge	co	2023	hatchery	2500	6	92
Puntledge	co	2020	microtroll	41	0	2
Puntledge	co	2021	microtroll	2	0	0
Puntledge	co	2021	river	1	0	0

Secondary Systems Tags Deployed

Table B3. The Number of PIT tags applied to Chinook in the secondary watershed of the Bottlenecks Program across the various habitats for the program's first four years.

WATERSHED	SPECIES	YEAR	TAG PERIOD	TAGS DEPLOYED	OUTMIGRATION DETECTIONS	ADULT RETURN DETECTIONS
Big Qualicum	ck	2020	microtroll	166	0	3
Big Qualicum	ck	2021	estuary	15	0	0
Big Qualicum	ck	2021	hatchery	5000	0	46
Big Qualicum	ck	2021	microtroll	410	0	11
Big Qualicum	ck	2022	estuary	57	0	0
Big Qualicum	ck	2022	hatchery	4000	2	3
Big Qualicum	ck	2022	microtroll	576	0	3
Big Qualicum	ck	2023	hatchery	5000	1	2
Big Qualicum	ck	2023	microtroll	102	0	0
Englishman	ck	2022	river	1	0	0
Englishman	unk	2021	river	1	0	0
Englishman	unk	2022	river	1	0	0
Englishman	unk	2023	river	34	0	0
Little Qualicum	ck	2020	microtroll	98	0	1
Little Qualicum	ck	2021	estuary	24	0	1
Little Qualicum	ck	2021	hatchery	5000	1	36
Little Qualicum	ck	2021	microtroll	286	0	4
Little Qualicum	ck	2022	estuary	6	0	0
Little Qualicum	ck	2022	hatchery	5000	4928	2
Little Qualicum	ck	2022	microtroll	373	0	6
Little Qualicum	ck	2023	hatchery	5000	4351	12
Little Qualicum	ck	2023	microtroll	73	0	1
Little Qualicum	unk	2020	microtroll	2	0	0
Quinsam	ck	2020	microtroll	17	0	0
Quinsam	ck	2021	hatchery	5000	0	5
Quinsam	ck	2021	microtroll	145	0	0
Quinsam	ck	2022	hatchery	5000	0	4
Quinsam	ck	2022	microtroll	213	0	0
Quinsam	ck	2023	hatchery	5000	1024	3
Quinsam	ck	2023	microtroll	19	0	0

Table B4. The Number of PIT tags applied to Coho in the primary watershed of the Bottlenecks Program across the various habitats for the program's first four years.

WATERSHED	SPECIES	YEAR	TAG PERIOD	TAGS DEPLOYED	OUTMIGRATION DETECTIONS	ADULT RETURN DETECTIONS
Big Qualicum	co	2020	microtroll	34	0	1
Big Qualicum	co	2021	hatchery	5000	3018	81
Big Qualicum	co	2021	microtroll	1	0	0
Big Qualicum	co	2022	hatchery	5000	2661	80
Englishman	co	2021	river	3646	0	65
Englishman	co	2022	river	2900	534	107
Englishman	co	2023	river	2624	1197	47
Goldstream	co	2020	microtroll	23	0	0
Goldstream	co	2022	hatchery	7500	0	224
Goldstream	co	2023	hatchery	10400	3917	28
Quinsam	co	2020	microtroll	10	0	1
Quinsam	co	2021	hatchery	5000	2252	112
Quinsam	co	2021	microtroll	2	0	0
Quinsam	co	2022	hatch_tag	5000	2922	71
Quinsam	co	2023	hatch_tag	8000	3417	182

Table B5. The number of PIT tags applied to steelhead in all watersheds of the Bottlenecks Program across the various habitats for the program's first four years.

WATERSHED	SPECIES	YEAR	TAG PERIOD	TAGS DEPLOYED	OUTMIGRATION DETECTIONS	ADULT RETURN DETECTIONS
Cowichan	stl	2021	estuary	2	0	1
Cowichan	stl	2021	river	407	0	11
Cowichan	stl	2022	river	85	6	4
Cowichan	stl	2023	river	66	37	3
Englishman	stl	2021	river	18	0	0
Englishman	stl	2022	river	3	1	0
Englishman	stl	2023	river	29	15	1
Nanaimo	stl	2021	river	34	0	9
Nanaimo	stl	2023	river	4	0	0
Puntledge	stl	2021	estuary	3	0	1
Puntledge	stl	2022	estuary	2	0	0
Quinsam	stl	2021	river	485	0	2
Quinsam	stl	2022	river	338	0	2
Quinsam	stl	2023	river	131	46	2
Robertson Creek	stl	2021	hatchery	5000	0	24
Robertson Creek	stl	2022	hatchery	5000	0	46
Robertson Creek	stl	2023	hatchery	5000	20	19

Table B6. Number of PIT tags applied to brown trout, cutthroat trout, and rainbow trout in each system across river and estuarine habitats across the last three years of the program.

WATERSHED	SPECIES	YEAR	TAG PERIOD	TAGS DEPLOYED	OUTMIGRATION DETECTIONS	ADULT RETURN DETECTIONS
Cowichan	bt	2021	river	75	1	0
Cowichan	bt	2022	river	2	0	0
Cowichan	ct	2021	estuary	3	0	0
Cowichan	ct	2021	river	11	0	2
Cowichan	ct	2022	river	13	5	5
Cowichan	ct	2023	river	11	10	5
Cowichan	rbt	2021	river	39	1	3
Cowichan	rbt	2022	river	39	1	7
Cowichan	rbt	2023	river	27	19	8
Englishman	ct	2021	river	70	0	2
Englishman	ct	2022	river	79	19	14
Englishman	ct	2023	river	114	61	21
Englishman	rbt	2021	river	121	0	13
Englishman	rbt	2022	river	101	16	24
Englishman	rbt	2023	river	60	25	8
Nanaimo	ct	2021	river	24	0	5
Nanaimo	ct	2023	estuary	1	0	0
Nanaimo	ct	2023	river	6	4	3
Nanaimo	rbt	2021	river	54	0	7
Nanaimo	rbt	2022	river	4	1	2
Nanaimo	rbt	2023	river	30	25	5
Puntledge	ct	2021	estuary	15	0	0
Puntledge	ct	2022	estuary	83	1	8
Puntledge	ct	2023	estuary	46	4	9
Puntledge	rbt	2021	estuary	18	0	0
Puntledge	rbt	2022	estuary	4	0	0

Table B7. Number of PIT tags applied to non-target salmon in each system across river and estuarine habitats across the last three years of the program.

WATERSHED	SPECIES	YEAR	TAG PERIOD	TAGS DEPLOYED	OUTMIGRATION DETECTIONS	ADULT RETURN DETECTIONS
Cowichan	cm	2021	river	6	0	0
Cowichan	so	2022	river	2	1	0
Cowichan	so	2023	river	1	0	0
Cowichan	unk	2020	microtroll	5	0	0
Cowichan	unk	2021	river	3	0	0
Cowichan	unk	2022	river	1	0	0
Englishman	unk	2021	river	1	0	0
Englishman	unk	2022	river	1	0	0
Englishman	unk	2023	river	34	0	0
Little Qualicum	unk	2020	microtroll	2	0	0
Nanaimo	cm	2021	estuary	1	0	0
Puntledge	cm	2021	estuary	1	0	0
Puntledge	cm	2023	estuary	2	0	0
Puntledge	unk	2021	estuary	1	0	0

APPENDIX C - RECOMMENDATIONS

The *Bottlenecks Program* has recently finished its first four years of funding provided by the BC Salmon Restoration and Innovation Fund. Over the past four years, we've gained valuable insights and developed recommendations to assist others in designing and implementing salmon research projects. The recommendations provided below are a key product of the *Bottlenecks Program*, where our primary goal was to develop PIT tag-based methodologies for collecting new information on salmon survival and movements along the East Coast of Vancouver Island.

Should you have any questions regarding our PIT infrastructure or methods that we have not captured here, please contact us at jatkinson@bccf.com or sjames@psf.ca.

Salmon Enhancement Projects

Through collaboration with several governments and local groups, multiple projects were developed within enhancement facilities or with enhanced fish to answer critical questions such as tagging related mortality, overwinter mortality of coho in earthen channels, and freshwater outmigration timing and survival of transplanted stocks. The following are recommendations for others looking to conduct similar research.

Tagging Related Mortality:

Throughout the first three years of the *Bottlenecks Program*, lessons have been learned to help increase survival after PIT tagging and decrease tag rejections while safely training new staff and reducing the potential impacts of high-mortality events. The recommendations for PIT tagging at hatchery facilities using FDX-B 12 mm tags are as follows:

1. Restrict food from the cohort of fish to be tagged for 24 hours before tagging.
2. Tag length should not exceed 17.5% of the fish length (~70 mm fork length when using FDX-B 12 mm tags) (Vollsett et al. 2020).
3. Utilize flow through tagging tables to reduce physical handling of fish post-tagging.
4. When training, limit new taggers to 1-tray (100 tags) during their first tagging event, and monitor new taggers closely.
5. Train new taggers on larger fish (e.g. coho smolts).
6. Tagger ID should be recorded so that tagger-related effects can be addressed prior to future tagging events.

Overwinter survival of Coho in Earthen Channels:

Our recommendations for hatcheries utilizing earthen channels for rearing any of their salmon production are as follows:

1. Apply 500 12 mm HDX PIT tags to each earthen pond cohort each year to get an accurate estimate of prerelease mortality.

    - A low number of HDX tags will allow for higher detection efficiencies at outmigration and will not impact FDX-B tag detections.
2. Apply PIT tags at the beginning of earthen channel residency for more accurate estimates of mortality.
3. Install PIT antennas for the entire duration of earthen channel residency for better estimation of escapees.
4. Release coho from earthen channels gradually to improve detection efficiencies and reduce uncertainty around survival and prerelease mortality estimates.
5. Where predation is a recurring source of significant prerelease mortality, additional predator control measures must be investigated and implemented.

Differential Release Trials of Enhanced Steelhead:

1. Install a full-stream mainstem PIT array to understand residualization of hatchery fish and winter-run Smolt to Adult Survival.
    a. Derive accurate outmigration timing.
    b. Derive accurate residualization rates.
    c. Derive lower river harvest rates.
2. Release steelhead lower in the river near tidewater to reduce residualization rates.
3. Conduct further work to identify the survival bottleneck and alter marine release location (e.g., release in the estuary removing freshwater mortality mechanisms but allowing for estuarine rearing and saltwater transition).

Steelhead Kelt Reconditioning:

From our experience, kelt reconditioning is not a feasible enhancement strategy. The effort and cost in capturing and reconditioning sufficient numbers of kelts given the low rates of iteroparity proved to be high for very little gain. Should others choose to attempt a similar study, the following recommendations may improve the chances of success:

1. Increase the number of kelts reconditioned.
2. Install downstream passive capture facilities (e.g. traps) during kelt outmigration (March-May) to increase efficiency of capture and reduce cost (as opposed to angling).
3. Increase reconditioning duration. A 4-9 month reconditioning timeline should be the target, as other studies suggest that longer holding times may be more successful (Hatch et al. 2013).
4. Use a control group to compare reconditioning survival to non-reconditioned fish.

Freshwater Outmigration Survival Projects

Transplanted Coho Projects:

The Bottlenecks Program collaborated with the Department of Fisheries and Oceans and Peninsula Streams Society to assist coho transplant programs in the Millstone and Mill Stream rivers. These urban rivers have undergone stream restoration projects, improving fish passage into the upper river and habitat enhancements. Understanding how successful these transplant programs are (i.e. freshwater survival, outmigration timing, smolt to adult survival) and if the restoration/fish migration projects are successful is essential in directing further restoration activities and informing and refining coho transplanting programs.

Deriving Freshwater Outmigration and Smolt to Adult Survival Estimates:

1. Tag hatchery smolts in the hatchery (follow tagging-related survival recommendations for tagging and post-tag monitoring)
2. Install Permanent/Temporary PIT array to detect outmigration timing and survival.
    a. Install in the lower rivers near tidal influence (within ~2 km)
    b. Use the same antenna/reader board for fall returns and marine survival estimates.
1. Install a camera system with the lower river PIT array
    a. Allows for mark recapture estimates
2. Install additional antennas at upstream locations as required.
    a. Refine detection efficiency and mark recapture estimates.
    b. Provide information on return migration timing and duration
        i. Provides information on migration barriers

In addition, the *Bottlenecks Program* collaborated with the University of Northern British Columbia to conduct a freshwater outmigration study on Chinook (Balfour 2024). The study developed an integrated model of freshwater residence and capture-recapture using Bayesian inference and utilized precipitation and river height to calculate detection efficiencies throughout the outmigration window. Due to juvenile salmon migrating in the upper portion of the water column, informing detection efficiencies, outmigration timing and survival estimates using environmental parameters will provide a more accurate understanding of freshwater survival.

1. Utilize model on previous PIT tag datasets.
    a. Collect hydrometry and precipitation for the study system.
2. Utilize state-spaced Bayesian model for new studies.
    a. Install staff gauge and level logger at PIT array site.

Predation Monitoring

Predator Monitoring:

Based on the findings from the *Bottlenecks Program*, several recommendations have been made to help derive accurate predation estimates over time at heron rookeries and on pinniped haulouts. These recommendations are for the refinement of the detection of PIT tags present at these predator sites and for the development of long-term monitoring plans to better understand the environmental impacts and spatiotemporal distribution of tags.

Great Blue Heron Predation on Juvenile Salmonids:

1. Conduct regular scans at heron rookeries (twice annually, once one month after the juvenile outmigration and again six months after the juvenile outmigration), to improve estimates of tag residency and detectability at the rookery.
    a. Rookeries with more than 50 tags should be scanned at least twice a year.
    b. Rookeries with fewer than 50 tags should be scanned at least once every two years.
2. Enhance detection data by using tag scanners that collect GPS coordinates to reduce uncertainty in detection probabilities.
3. Collect detailed fish length data for hatchery fish cohorts to refine predation models.

Pinniped Predation Monitoring:

1. Conduct mobile scanning at high-density pinniped haulouts.
    a. Select key haulouts based on location from tag deployments (< 20 km from tagging location).
    b. Increase the frequency of mobile scanning to enhance detection probabilities and derive temporal changes.
    c. Enhance detection data by using tag scanners that collect GPS coordinates to reduce uncertainty in detection probabilities.
    d. Address uncertainties related to detection probability, predator identification, and scanning logistics to refine methodologies.
        i. Install wildlife cameras to conduct predator surveys.
        ii. Conduct tag depletion studies to understand tag longevity rates at a given location.
2. *In-situ*-monitoring stations
    a. Select key haulouts based on location from tag deployments (< 20 km from haul-out).
    b. Develop real-time data access:
        i. Implement real-time data collection at *in-situ* monitoring sites to enable immediate issue remediation.
        ii. Reduce the frequency of site visits by utilizing real-time monitoring to address equipment failures or tag detection problems quickly.

Marine Projects

First Winter Marine Chinook and Coho Activities:

The Bottlenecks Program demonstrated the effectiveness of utilizing microtrolling in the marine environment to capture the first winter Chinook and coho in the Strait of Georgia. Recommendations were developed from the program's first four years to assist other researchers in conducting similar first marine winter sampling. Only the top recommendations are provided here for more details please refer to the “Microtrolling Standard Operating Procedure” (Rodgers et al. 2023).

First Marine Winter Chinook Distribution:

1. Microtrolling should be employed where economical and non-lethal sampling of juvenile Chinook is required for tagging and marine distribution studies.
2. Conduct five-minute set times.
3. Stop fishing if more than three fish per side are captured to allow time for fish processing.
4. Fish around ~2.6 km/hr boat speed through the water.
5. Utilize partitioned live wells to ensure accurate data is captured (i.e. depth of capture).

First Marine Winter Coho Distribution:

1. Combine DFO's historic summer and fall trawl survey data with winter microtroll data to develop a comprehensive spatiotemporal analysis.

Winter Ecology:

1. In at least some regions of the Strait of Georgia, first ocean winter Chinook are captured at a far higher rate deep (peak at 60 m) and close to bottom rather than in open water, this should be taken into account for:
    a. Interpretation of results of past winter studies utilizing trawl or other open water gear.
    b. Design of future winter studies of juvenile Chinook ecology.
2. As depth distribution may have important implications for mechanisms of overwinter mortality, systematic microtrolling, and acoustic depth sensor tags should be employed to understand habitat use in multiple regions of the Strait of Georgia (being implemented through continued BCSRIF Bottlenecks funding).
3. Preliminary overwinter diet, condition, and bioenergetic modeling results are not consistent with widespread overwinter starvation; however, preliminary analyses suggest growth selective mortality for Qualicum-Puntledge Chinook in one out of three study years:
    a. Diet, condition, and growth selective mortality of juvenile Chinook should be tracked for multiple stocks and brood years and related to PIT tag and CWT-based survival estimates to elucidate the role of winter mortality in regulating trends and interannual fluctuations in abundance (being implemented through continued BCSRIF Bottlenecks funding).
4. Acoustic tagging of juvenile Chinook suggested fish present in the Strait of Georgia in October did not migrate to the continental shelf prior to April of the following year. Additional acoustic tagging prior to October (using smaller tags to account for fish size) should be implemented to investigate whether a wave of outmigration occurs prior to October (being implemented through continued BCSRIF Bottlenecks funding).

Enhanced Fishery Monitoring

1. Utilize EFM data to help inform and improve creel surveys.
    a. For instance, expanding surveys later into the evening in specific months/areas.

2. Expand EFM locations to additional locations. Potential locations (based on mobile scanning data) include:
    a. Port Renfrew – Pacific Gateway
    b. Metchosin – Cheanuh Marina
    c. Sooke – Peddar Bay Marina
    d. Powell River – Powell River South Dock
    e. Campbell River – Discovery Marina

PACIFIC SALMON FOUNDATION

BRITISH COLUMBIA CONSERVATION FOUNDATION

Fisheries and Oceans Canada / Pêches et Océans Canada

BRITISH COLUMBIA

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