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Determination of Bottlenecks Limiting Wild and Enhanced Juvenile Salmon and Steelhead Production in BC using PIT tags and Spatially Comprehensive Arrays

Mid-Term Progress Report  
DRAFT



BRITISH COLUMBIA  
CONSERVATION  
FOUNDATION

## Table of Contents

List of Abbreviations .....	i
Executive Summary .....	1
Project Rationale .....	1
Project Overview .....	2
Chapter 1: Bottlenecks to survival of wild and hatchery Chinook and coho salmon:.....	2
Chapter 2: Juvenile Chinook salmon winter ecology study: .....	3
Chapter 3: Understanding steelhead bottlenecks:.....	3
Chapter 4: Enhanced fishery monitoring:.....	3
Permits .....	3
Study Area .....	4
General Methodology .....	6
Fish Handling & Biodata Collection.....	6
PIT Tagging .....	7
Genetic Stock Identification and Parentage Based Tagging Sampling and Analysis .....	8
PIT Tag Detection Arrays.....	9
Survival Analyses.....	11
Chapter 1: Bottlenecks to Survival of Wild & Hatchery Chinook and Coho Salmon.....	13
Objectives.....	13
Methodology .....	13
Hatchery Tagging .....	13
In-River & Early Marine Tagging .....	14
Capture Methods .....	15
Beach Seining.....	15
Pole Seining .....	16
RST .....	17
Smolt trap .....	18
Microtrolling .....	19
Adult Tagging.....	20
Logistics.....	21

Regional Database Exploration .....	21
Data Management .....	21
Data Analysis.....	22
Background.....	22
Data preparation .....	22
Model framework.....	23
Model fitting and evaluation .....	24
Future directions .....	24
Interim Results .....	24
Fish Capture and PIT-Tagging.....	24
Hatchery Tagging .....	24
In River and Estuarine Tagging .....	25
Microtrolling .....	29
Adult Tagging.....	35
Escapement Detections .....	36
Associated Studies & Anticipated Reporting.....	37
Lessons Learned & Next Steps .....	39
Low Proportion of Natural Origin Chinook .....	39
Coho Marine Capture.....	39
Chinook In-river Capture.....	40
Chapter 3: Juvenile Chinook Salmon Winter Ecology .....	41
Objectives.....	41
Methods .....	41
Microtrolling .....	41
Lab processing.....	43
Prey.....	43
Chinook Salmon 2020-2021:.....	43
Chinook Salmon 2021-2022, 2022-2023: .....	43
Scales:.....	43
Analyses .....	44
Habitat Use:.....	44
Diet Composition and Quality: .....	44

Assessing Evidence of Nutritional Stress: .....	44
Assessment of critical size, critical period hypothesis:.....	46
Biomarker assessment of the role of pathogens and nutritional stress in overwinter mortality: .....	47
Interim Results .....	47
Habitat Use: .....	47
Diet composition and prey quality:.....	49
Assessing Evidence of Nutritional Stress: .....	51
Bioenergetic Modelling, somatic indices: .....	54
Assessment of critical size, critical period hypothesis: .....	56
Biomarker assessment of the role of pathogens in overwinter mortality:.....	56
Associated Studies & Anticipated Reporting.....	57
Lessons Learned & Next Steps .....	57
Spatial Distribution of Effort .....	57
Chapter 4: Understanding Steelhead Bottlenecks.....	59
Objectives.....	59
Methods .....	59
Study Areas .....	59
PIT Tagging .....	59
Hatchery Tagging .....	59
In-river & Early Marine Tagging .....	59
MiniPAT Tags.....	61
Adult Capture & PIT Tagging .....	61
Adult Capture and Mini-Pat Satellite Tagging .....	61
Reconditioning .....	64
Interim Results .....	65
Fish Capture and PIT-Tagging.....	65
Hatchery and Early Marine Tagging.....	65
Steelhead Kelt Satellite Tagging.....	67
2021.....	67
2022.....	67
2023.....	68
Kelt Reconditioning.....	70

Lessons Learned & Next Steps .....	72
Englishman River Steelhead.....	72
Steelhead Smolt Capture .....	72
Reconditioning and PSAT Tagging.....	72
Chapter 5: Enhanced Fishery Monitoring .....	73
Objectives.....	73
Methods .....	73
Interim Results .....	74
Infrastructure Development .....	74
Area 17 - Brechin Marina, Nanaimo .....	74
Area 14 – French Creek, Parksville .....	74
Area 13/14 – Pacific Playgrounds, Black Creek.....	76
PIT Detection Data to Date .....	76
Adipose Clip Head Submission Rate.....	77
Refining Temporal Distribution of Creel Sampling.....	79
Lessons Learned & Next Steps .....	81
REFERENCES.....	82
Appendix A: .....	87
PIT Infrastructure Installation List .....	87

## Table of Figures

Figure 1. Map of the Salish Sea depicting all rivers that are part of the <i>Bottlenecks Project</i> (2023). ....	5
Figure 2. The 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). ....	6
Figure 3. PIT tags are inserted into the body cavity, anterior to the pelvic girdle, of each fish using a sterile, one-time-use hypodermic needle (Rodgers et al. 2022) (Pellet et al. 2017). ....	8
Figure 4. Installation of the Nanaimo River mainstem PIT array, July 2021 (photo by Danny Swainson). ....	10
Figure 5. Quinsam River hatchery fishway PIT antennas (2021) (photo by Jamieson Atkinson). ....	10
Figure 6. Summary of in-river and early marine tagging methods and locations in 2021, 2022, and 2023. ....	15
Figure 7. Beach Seine used for capture of juvenile Chinook and coho in both estuary and riverine settings (photos by Danny Swainson) ....	16
Figure 8. Pole seine used for capture of juvenile Chinook and coho (photo by Kevin Pellett). ....	17
Figure 9. RST style smolt trap installed in the mainstem of the Cowichan River, just downstream of Allenby Road Bridge. Note screened fence panels installed on either side of the RST (May 5, 2021) (photo by Jeramy Damborg). ....	18
Figure 10. Photo of the RST with the 'yolk' that was built and installed under the drum of the Allenby Road RST in an attempt to increase trap efficiency (photo by Jeramy Damborg). ....	18
Figure 11. A typical smolt trap set up for capturing out-migrating juvenile Chinook and coho salmon, as well as rainbow/steelhead and cutthroat trout. Image shows smolt trap and tagging setup at Center Creek, in the Englishman River watershed in 2021 (photo by Danny Swainson). ....	19
Figure 12. Microtrolling sets conducted to date by BCCF (red), UVic (green), and volunteer (blue) crews in the winters of 2020-21, 2021-22, and 2022-23. Polygons and numbers indicate PFMA. ....	31
Figure 13. Stock composition by month and PFMA grouping (Figure 12) of FO winter Chinook salmon sampled in winter 2020-21 and 2022-23. ....	32
Figure 14. Stock composition by month and PFMA grouping (Figure 12) of SO winter Chinook salmon sampled in winter 2020-21. ....	33
Figure 15. Stock composition by month and PFMA grouping (Figure 12) of FO winter coho salmon sampled in winter 2020-21. ....	34
Figure 16. Biological sampling effort (left panel) and systematic habitat sampling effort (right panel, location indicated by inset in left pane) conducted by UVic crews in the initial two years of the <i>Bottlenecks Project</i> . Red ellipses indicate regional groupings referred to in the current document. ....	42
Figure 17. Effects plot for preliminary generalized additive mixed model (GAMM) of the effect of a. year, b. site, and c. transect (bottom depth); and non-linear effects of d. depth, e. day of year, and site-specific deviation from	

the global effect of day of year at f. Comox and g. Salmon Point on the probability of catching a first ocean winter Chinook salmon on a given hook. As the site-specific deviation from the global effect of day of year at South Denman/Hornby was not significantly different from a horizontal line it was penalized out of the model. ....	48
Figure 18. Individual mean diet proportions for first ocean winter Chinook Salmon from October to April for 3 regions of the Canadian Salish Sea. Sample size for diets examined is above the bars. ....	49
Figure 19. Non-metric multidimensional scaling (NMDS) ordination of Bray-Curtis dissimilarities between individual mean diet proportion data for prey classifications of juvenile Chinook salmon at our sampling regions, where the Northern Strait of Georgia region was broken down into the two main sites (Comox, Salmon Point). Each point represents a sample which is the average diet composition from a single sampling day, the size of the points indicates the number of fish stomach samples examined from that field day, and point transparency denotes sampling date. Ellipses are 95% confidence intervals around group designations (sampling region and year combinations). ....	50
Figure 20. Energy density (J/g wet weight) values of diet items for both years (pooled due to small sample sizes), where colour denotes broad prey category. Boxplots show the range in energy density values for each taxonomic group, where the center line represents the median, solid dot represents the mean, box limits display the interquartile range, whiskers represent 1.5X the interquartile range, open circles are outliers, and numbers to the right of each boxplot indicate sample size. ....	51
Figure 21. Locally weighted scatterplot smooth (loess; span = 1) by date of (A) the mean energy content (J) of prey in individual fish diets by their relative weight proportion (g), (B) the fullness (g prey in the diet relative to fish mass(g)), and (C) the energy content (J) of individual fish diets relative to fish mass (g). This includes only fish captured in the Northern Strait of Georgia but pools both years. ....	52
Figure 22. Locally weighted scatterplot smooth (loess; span = 1) by date of the mean energy content (J) of fish diets by the proportion of prey in the diets (g) where the red points and line include all fish diets, and the blue points and line indicate diets which contained Pacific herring. This includes only fish captured in the Northern Strait of Georgia but pools both years. ....	52
Figure 23. Nose Fork length for FO Chinook salmon by date in the Northern Strait of Georgia in Winter 2020-21 and 2021-22. Non-linear GAM smooths. ....	53
Figure 24. Condition (residuals of a regression of log weight on log fork length) for FO Chinook Salmon by date in Winter 2020-21 and 2021-22. Non-linear GAM smooths. ....	53
Figure 25. Locally weighted scatterplot smooth (loess; span = 1) of energy density (J/g wet weight) values for retained first ocean winter Chinook salmon from 2020-2021 (solid line) and 2021-2022 (dashed line) by date. Colour denotes stock group (“Unknown” stock group indicates a failure of genetic assignment) and shaded regions represent 95% confidence intervals for loess smooths. ....	54
Figure 26. Bioenergetic model outputs of average ( $\pm$ SD) monthly specific growth rate (top), specific consumption rate (middle), and feeding rate (proportion of Cmax; bottom) of juvenile Chinook Salmon in 2020-21. ....	55
Figure 27. Residuals of gastrointestinal somatic indices (a), and hepatosomatic indices (b) of juvenile Chinook Salmon captured in the Strait of Georgia in Winter 2021-22. Non-linear GAM smooths. ....	56

Figure 28. Steelhead and rainbow trout capture methods. A) Center Creek (Englishman River watershed) smolt trap; B) is of beach seining in the Nanaimo Estuary; and C) image of the wolf trap on the Quinsam River in 2021 (photos by Danny Swainson (A, B) and A-Tlegay Fisheries Society (C)).....	60
Figure 29. Adult steelhead just prior to release, after PIT tagging and bio-sampling, Cowichan River (February 13, 2018) (photo by Jeremy Damborg).....	61
Figure 30. Images depicting MiniPAT Satelite tag (a), tag backpack with acoustic tag (b,c) and hyprdermic needles (d) used for tagging (photo by Danny Swainson). .....	63
Figure 31. Images showing tagging procedure and post tagging result. 2022 (photos by Danny Swainson).....	64
Figure 32. Robertson Creek Hatchery steelhead release locations for 2021 and 2022. .....	66
Figure 33. Release locations for miniPAT tagged steelhead Kelt for study years 2021 and 2022. ....	68
Figure 34. 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).....	74
Figure 35. Images of the landing site at French Creek Marina's north table before (A) and after (B) infrastructure upgrades conducted in 2021 (photo by Kevin Pellett). .....	75
Figure 36. Images of the landing site at French Creek Marina's south table before (A and B) and after (C and D) infrastructure upgrades conducted in 2021 (photos by Kevin Pellett).....	75
Figure 37. Cleaning table shelter under construction at Pacific Playgrounds in Black Creek, Spring 2023 (photo by Kevin Pellett).....	76
Figure 38. Summary of PIT tags recoveries from opportunistic mobile scanning around southern BC cleaning tables through spring 2022. .....	77
Figure 39. Monthly landings and head submissions by species and adipose clip status at Brechin Marina, from July 26, 2021 to March 20, 2022. .....	78
Figure 40. Monthly landings and head submissions by species and adipose clip status at French Creek Marina north table from August 11 to October 31, 2021.....	78
Figure 41. Monthly landings and head submissions by species and adipose clip status at French Creek Marina south table from August 30 to October 31, 2021.....	78
Figure 42. Daily Chinook and coho landings at Brechin Marina, stratified by weekends and weekdays; July 6 to October 15, 2021.....	79
Figure 43. Chinook landings by hour at the Brechin Marina between July 26 and October 15, 2021. ....	80
Figure 44. Map of creel Area 17-E, outlined in red in relation to adjacent sub areas, as well as the Brechin Marina indicated by a blue arrow. ....	80
Figure 45. Preliminary comparison of boat trips in creel area 17-E estimated from the creel program to daily landed catch at Brechin Marina between July 28 and August 30, 2021.....	81

## Table of Tables

Table 1. Required permits for the Bottlenecks Project. ....	3
Table 2. Summary of hatchery tagging as of 2023. ....	14
Table 3. Summary of hatchery-based PIT tagging of Chinook, coho, and steelhead between 2020 and 2023. ....	25
Table 4. Summary of PIT tagged Chinook (ck), coho (co), chum (cm), steelhead (stl), rainbow trout (rbt), cutthroat trout (ct), and brown trout (bt), from in-river and estuary captures for 2021.....	26
Table 5. Summary of PIT tagged Chinook (ck), coho (co), chum (cm), steelhead (stl), rainbow trout (rbt), cutthroat trout (ct), brown trout (bt), and sockeye (so) from in-river and estuary captures for 2022. ....	26
Table 6. Genetic stock composition of Chinook and coho salmon PIT tagged at the Nanaimo and Puntledge Rivers in spring 2021 and 2022. ....	27
Table 7. The proportion of fish identified by GSI (likely natural origin) and PBT (likely hatchery origin) for Chinook and coho salmon PIT tagged at the Nanaimo and Puntledge Rivers in spring 2021 and 2022. All adipose clipped and PBT fish must be hatchery origin while some hatchery fish are unclipped or cannot be identified by PBT due to poor DNA quality or incomplete genotyping of broodstock. ....	29
Table 8. Number of FO winter Chinook salmon from major stock groups tagged by microtrolling in the winters of 2020-21 to 2022-23. ....	34
Table 9. Number of FO winter Chinook salmon from individual stocks tagged by microtrolling in the winter of 2020-21 and 2021. The proportion of fish identified by GSI (likely natural origin) and PBT (likely hatchery origin) is indicated).....	35
Table 10. Number of SO winter Chinook salmon from major stock groups tagged by microtrolling in the winter of 2020-21 and 2021-22. ....	35
Table 11. Summary of Chinook adult spawn migration detections in 2021. ....	36
Table 12. Summary of Chinook adult spawn migration detections in 2022. ....	36
Table 13. Summary of coho adult spawn migration detections in 2021. ....	37
Table 14. Summary of coho adult spawn migration detections in 2022. ....	37
Table 15. Summary of technical and primary report products associated with Chapter 1 studies. ....	37
Table 16. Summary of technical and primary report products associated with Chapter 3 Chinook salmon winter ecology studies. ....	57
Table 17. Summary of Robertson Creek Hatchery PIT tagging of steelhead, including release locations between 2020 and 2023. ....	65
Table 18. Summary of PIT tagged steelhead from in-river and estuary captures between 2021 and 2022. ....	67
Table 19. Summary of Cowichan River steelhead kelts captured for PSAT tracking study in 2021. ....	69

Table 20. Summary of Cowichan River steelhead kelts captured for PSAT tracking study in 2022. ....	69
Table 21. Summary of Cowichan River steelhead kelts captured for PSAT tracking study in 2023. ....	70
Table 22. Summary of steelhead kelts held for reconditioning in 2021. ....	70
Table 23. Summary of steelhead kelt reconditioning. 2021.....	71
Table 24. Summary of PIT antenna installations and constructed materials for all systems included in the Bottlenecks Program. .....	88

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## List of Abbreviations

Abbreviation	Definition
BC	British Columbia
BCCF	British Columbia Conservation Foundation
BCSRIF	British Columbia Salmon Restoration and Innovation Fund
Bt	Brown trout
CH	Community hatchery
circ	Circular tank
CJS	Cormack-Jolly-Seber open population survival models
Ck	Chinook
Cm	Chum
Co	Coho
COSEWIC	Committee on the Status of Endangered Wildlife in Canada
CPUE	Catch per unit effort
Ct	Cutthroat trout
CWT	Coded wire tag
DART	Columbia Basin Research Data in Real Time
DFO	Department of Fisheries and Oceans
DFO-SEP	Department of Fisheries and Oceans Salmon Enhancement Program
ECVI	East Coast Vancouver Island
FLNRORD	Ministry of Forests, Lands, Natural Resource Operations, and Rural Development
FO	First ocean
FOR	Ministry of Forests
GSI	Genetic stock identification
MGL	Molecular Genetics Lab
MoECCS	Ministry of Environment and Climate Change Strategy
MoT	Ministry of Transportation
NOAA	National Oceanic and Atmospheric Administration
PFMA	Pacific Fishery Management Area
PBT	Parental based tagging
PIT	Passive integrated transponder
PSAT	Mini-Pat satellite tags
PSF	Pacific Salmon Foundation
RDN	Regional District of Nanaimo
RST	Rotary Screw Trap
rw	Runway tank
SHRP	Salmon Head Recovery Program
SNP	Single nucleotide polymorphisms
SO	Second ocean
SRKW	Southern resident killer whale
SSMSP	Salish Sea Marine Survival Project
St	Steelhead
StAD	Stock Assessment Division
TMS	Tricaine methanesulfonate
UNBC	University of Northern British Columbia

UVic  
WSAC

University of Victoria  
Wild Salmon Advisory Committee

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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”*, 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 project is comprised of 5 activities: activities 1, 2 and 4 utilize PIT and satellite telemetry to characterize survival bottlenecks for Chinook, coho and steelhead, respectively, while also providing an independent assessment of hatchery practices. Activity 3 is a focused investigation of the first marine winter as a survival bottleneck for juvenile Chinook salmon. Activity 5 is developing novel methods to refine the assumptions of recreational creel monitoring programs through video monitoring and passive PIT tag detection at fish cleaning stations located at highly utilized public boat ramps.

This DRAFT document provides an overview of the Bottlenecks Project’s progress entering the final year of the original program funding. Four chapters summarize the methods and preliminary results of the five project activities. The level of detail reported varies across activities and activity sub-components given variable timelines of data availability. Results of core program objectives involving PIT tag-based stage-specific survival estimates will require PIT tag detection data that will not be available until fish tagged by the program return from the ocean (the first set of complete returning Chinook data will be Fall 2024). This document also lists the anticipated products of the many individual studies arising from the Bottlenecks Project.

## Project Rationale

Recent declines in the abundance and productivity of Chinook (*Oncorhynchus tshawytscha*) salmon, coho salmon (*O. kisutch*), 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 & Shardlow 1991); similarly, marine recreational fishery effort, formerly representing 90% of effort in BC, decreased by 90% between the 1980s and 2000s (Strongitharm 2006). 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 salmon are also the primary prey of the endangered 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 salmon. Beginning in 2019, the critical conservation status of Chinook salmon in Southern BC led to unprecedented restrictions on commercial, recreational, and First Nations food, social, and ceremonial fisheries (Department of Fisheries and Oceans (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). The Province of British Columbia frequently invests in freshwater habitat enhancement projects, but this approach has limited ability to offset low marine survival. Predation, competition, climate change, and fishing mortality are the dominant hypotheses to account for poor steelhead returns, but the relative contributions of each are neither well estimated nor understood (Kennedy *et al.* 2022; Wade *et al.* 2013). Understanding the factors limiting Chinook, coho, and steelhead productivity is a key cultural, economic, and ecological priority for BC.

As wild salmon and steelhead abundance continue to decline or remain at historic lows, there is growing recognition that traditional hatchery mitigation is not meeting conservation and recovery objectives for wild stocks (Naish *et al.* 2008). In 2019, the Province 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.

A project implemented under the Pacific Salmon Foundation's (PSF) Salish Sea Marine Survival Project (SSMSP) by the British Columbia Conservation Foundation (BCCF), used passive integrated transponder (PIT) tags 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). 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 handle or kill fish to determine its origin.

PIT tags provide information on fish at the individual level. Furthermore, PIT tags are two orders of magnitude less expensive than other types of electronic tags (e.g. radio and acoustic tags), allowing economical marking of thousands of individuals. The landmark Cowichan PIT tag study highlighted the importance of the link between freshwater flows and in-river mortality, and indicated there is likely high

mortality after the first marine summer, and the much lower survival of hatchery-produced salmon over wild fish (Pearsall *et al.* 2021). These 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).

## Project 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 Project’).

Initiated in 2020, the project proposed expanding the Cowichan study and implementing PIT arrays in several priority Strait of Georgia/Fraser River/West Coast of Vancouver Island systems. The purpose of the project was to provide information on survival bottlenecks for Chinook, coho, and steelhead in both freshwater and early marine environments. Additionally, this program collaborated with and enhanced several PIT tag projects that were already underway and/or being considered by DFO and other project partners. In 2023, the project is in the final year of the initial BCSRIF proposal; however, a second proposal was submitted to BCSRIF in November 2022 to expand the project and continue core activities until March 2026.

The *Bottlenecks Project* was subdivided into five primary activities, each comprising several projects. Detailed descriptions and up-to-date results for each activity are presented within the subsequent chapters. Overviews of each chapter are provided below:

### Chapter 1: Bottlenecks to survival of wild and hatchery Chinook and coho salmon:

We amalgamate Activities 1 and 2 as they share methods and approaches to address similar objectives for Chinook (Activity 1) and coho salmon (Activity 2).

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 bottlenecks to survival, to identify the fundamental causes of mortality, and develop directed actions to improve survival of these iconic species.

Implementing PIT tag architecture in East Coast Vancouver Island (ECVI) hatchery systems will also provide an innovative means to monitor and evaluate hatchery rearing and release strategy experiments, hatchery/wild interactions, and research at ECVI salmon enhancement facilities. Program performance and identification of optimal release strategies and locations can be assessed through rigorous monitoring and evaluation in collaboration with DFO's Stock Assessment Program (StAd), Salmon Enhancement Program (SEP), and Molecular Genetics Lab (MGL). Performance improvements would allow for release of fewer hatchery fish to achieve harvest goals and maximize the survival of wild stocks by limiting adverse ecological and genetic interactions. These activities occur in collaboration with local First Nations, SEP, StAD, and multiple community groups.

**Chapter 2: Juvenile Chinook salmon winter ecology study:**

The first winter in the marine environment is hypothesized to be a critical period for juvenile Chinook salmon (Beamish and Mahnken 2001), and the SSMSM Cowichan PIT tag study confirmed that high mortality occurs after the first marine summer. However, very little empirical research has investigated Chinook salmon 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 salmon survival. This component of our program will involve a detailed winter ecology study of Chinook in the Strait of Georgia by the University of Victoria (UVic), BCCF, DFO, and recreational anglers to assess habitat use, diet, growth, and the potential role of pathogens and physiological stress on overwinter mortality.

**Chapter 3: Understanding steelhead bottlenecks:**

PIT tag programs for steelhead in the Stamp/Somass, Cowichan, and Englishman Rivers will be conducted in collaboration with partners at the Ministry of Forests (FOR). Through capturing and tagging all life stages of steelhead, studies will determine production, freshwater and marine survival, outmigration timing, adult return timing, and adult abundance (through mark-recapture programs) for several wild and hatchery populations, which will provide the necessary information to inform watershed management actions. Additional investigations will include kelt reconditioning (in-hatchery treatments) as a potential approach to facilitate population persistence and allow an investigation into mechanisms of adult mortality. Further, research with FOR will look to compare impacts of hatchery rearing and release strategies at Robertson Creek Hatchery on steelhead marine survival, and to study depensation and local predation of steelhead adults by pinnipeds in the Englishman River.

**Chapter 4: Enhanced fishery monitoring:**

An innovative and novel fishery monitoring program, utilizing motion-activated PIT tag antenna systems at landing sites, will be used to electronically track recreational fishery catches. Paired installation of PIT tag antennas with cameras on cleaning tables at major landing sites allow for detection of tagged fish adding valuable data to the study. Other arrays may be installed at known seal haul-outs to allow for inclusion of estimates of predation by harbour seals (*Phoca Vitulina*).

The installation of PIT tag arrays and development of PIT tag programs provides the opportunity for several other future studies and activities, including but not restricted to: alternative stock assessment programming; assessment of the relationships between freshwater ecological indicators (flows, temperature, acidity, availability of terrestrial prey, etc.) and survival; assessment of the relationships between fish health and freshwater and marine survival; studies of the relationships between contaminant loads in juvenile and adult salmon and survival; and studies to reduce predation.

## Permits

All required permits from DFO and MOF for fish collection were acquired (Table 1). All renewal applications have been submitted for the 2023-24 sampling year.

Table 1. Required permits for the Bottlenecks Project.

Year	Agency	Permit #	Purpose	Approved/Pending
2020-21	DFO	XR 356 2019	Capture and tag salmon	Approved
	DFO	XHAB 94 2020	Capture and tag salmon	Approved

	MOF	NA20-605217	Capture and tag steelhead	Approved
	DFO	XR 31 2021	Capture and tag salmon	Approved
2021-22	MOF	NA21-620245	Capture and tag steelhead/trout	Approved
	MOF	NA21-623320	Install PIT antennas	Approved
	Mosaic	4593	Access agreement	Approved
	DFO	XR 31 2022	Capture and tag salmon	Approved
	FOR	NA22-708063	Capture and tag steelhead/trout	Approved
	MoECCS	105333	Install PIT array in Goldstream	Approved
2022-23	RDN	R3881	Install smolt trap in park	Approved
	MoT	2022-02534	Install PIT antennas	Approved
	Mosaic	6204	Access agreement	Approved
	MOF	1005555	Install PIT antennas	Approved
	KFN	2022-16	Cultural Heritage Investigation	Approved
	DFO	XR 28 2023	Capture and tag salmon	Approved
	FOR	TBD	Capture and tag steelhead/trout	Pending
	Mosaic	7705	Access agreement	Approved
2023-24	RDN	R4454	Install smolt trap in park	Approved
	MoT	2023-01722	RST Installation	Pending
	MoECCS	105333	Maintain PIT array in Goldstream	Approved
	MOF	1005687	Install smolt traps in Englishman R.	Approved
	MOF	100405998	Install PIT antennas	Pending

## 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 area spans from Campbell River on Vancouver Island to the Olympic Peninsula. 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 2011). 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 the Nanaimo River spring and summer-run Chinook.

Our study area is concentrated in the Strait of Georgia, the northeastern portion of the Salish Sea and includes 14 rivers across 13 watersheds (Figure 2). Additionally, two west coast watersheds, the Stamp/Somass Rivers and the Toquaht River (Figure 1).

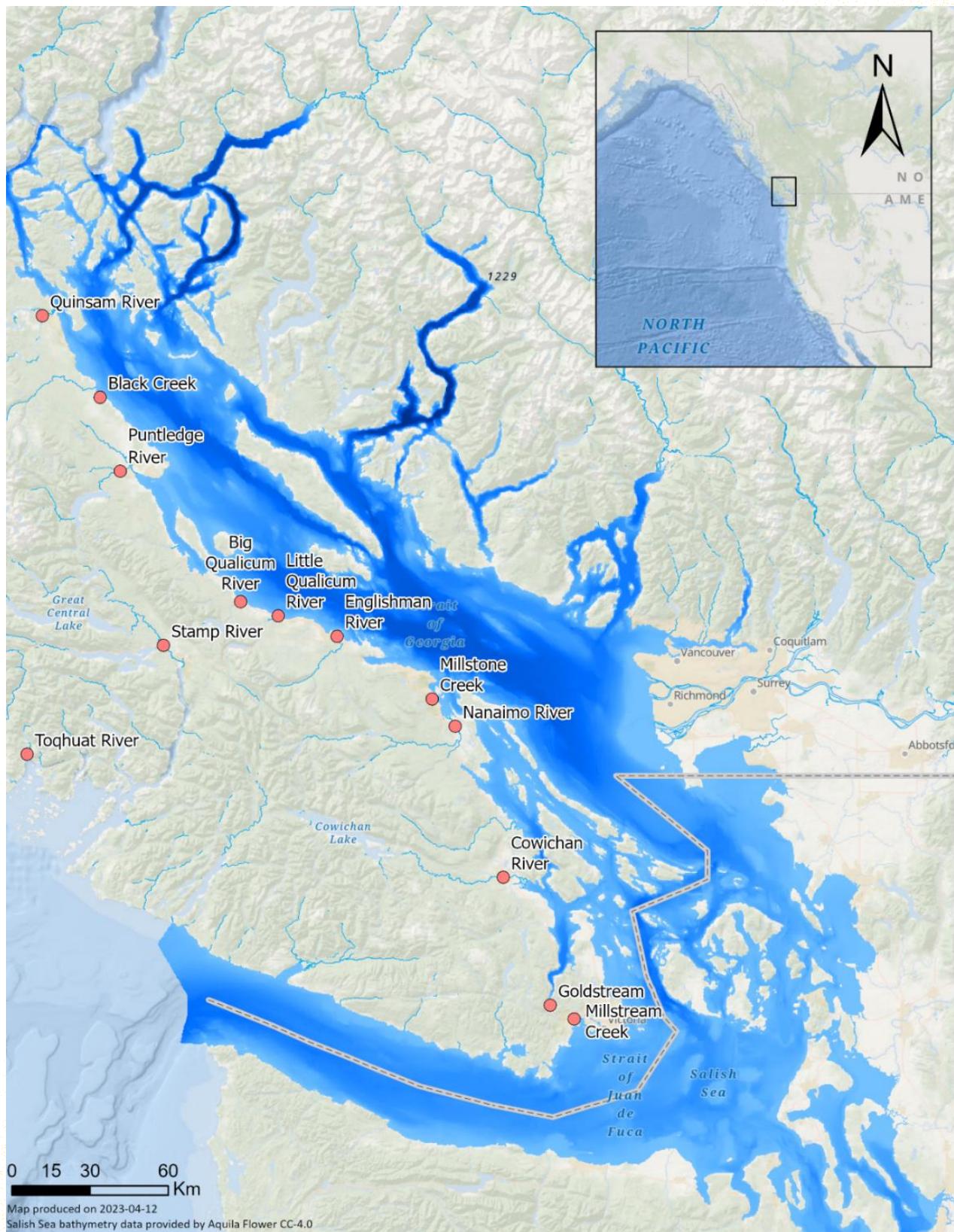


Figure 1. Map of the Salish Sea depicting all rivers that are part of the Bottlenecks Project (2023).

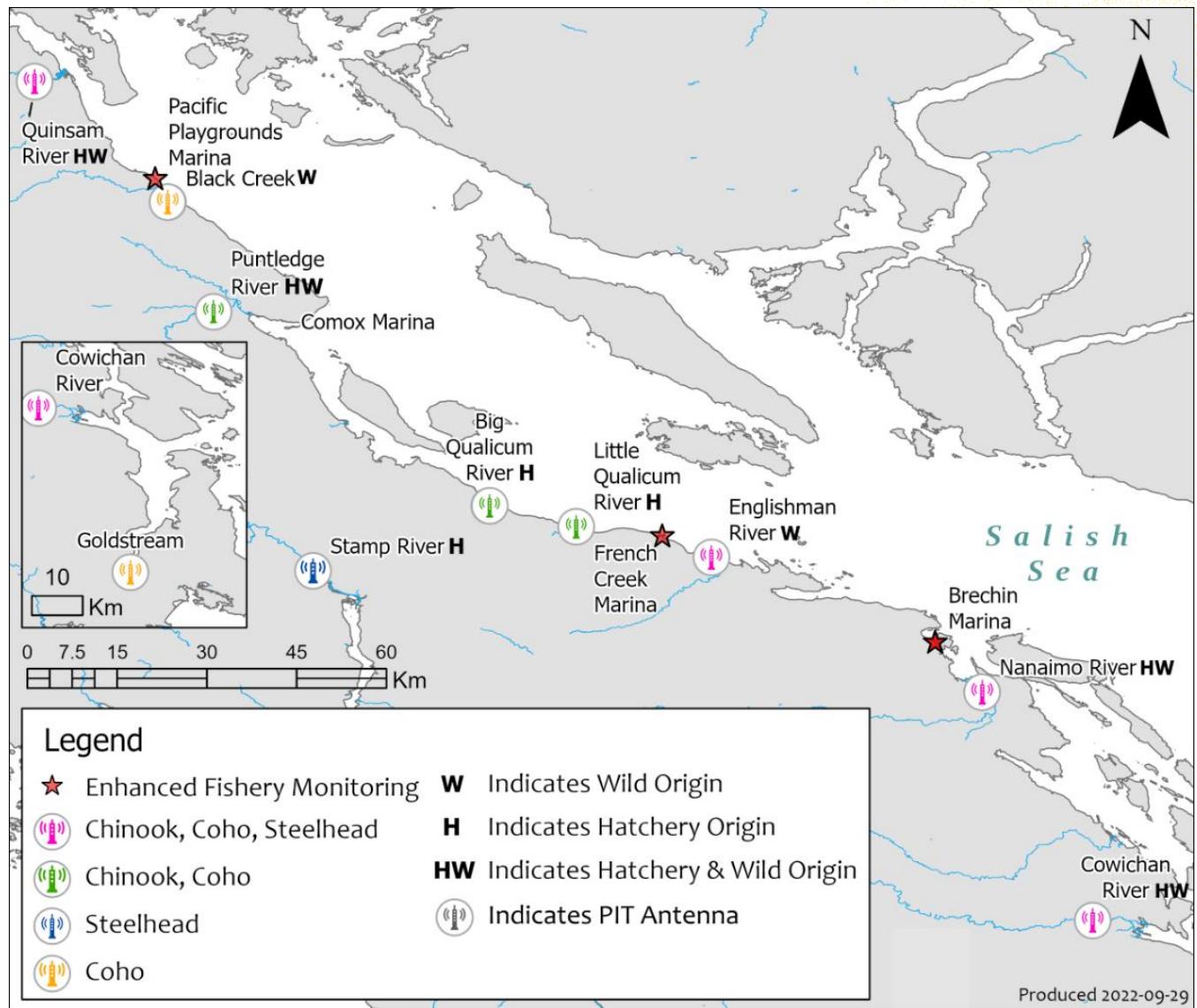


Figure 2. The map of the study region (Northern Salish Sea / Strait of Georgia) showing river systems outfitted with PIT infrastructure, target species for tagging (colour-coded circles), and recreational landing sites for enhanced fishery monitoring programs (red stars).

## General Methodology

This section describes capture, PIT tagging, genetic stock identification, tag detection, and other methodologies applied across activities of the Bottlenecks Project. Activity-specific methods or variations from the general methodologies described here are detailed within each chapter.

### Fish Handling & Biodata Collection

All fish caught were/are initially kept in fresh or saltwater, depending on capture location and time of year, with aeration. Once crews are ready to collect biodata, the fish are transferred into a fresh or saltwater bath prepared with 50 mg/L of Tricaine methanesulfonate (TMS), buffering with sodium bicarbonate ( $\text{NaHCO}_3$ ) to prevent acidification, following the Canadian Council on Animal Care's standardized methodology prepared by Ackerman, Morgan & Iwama (2005). However, sodium

bicarbonate was not added to saltwater anesthetic baths, as acidification is not a concern. 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 is adequately anesthetized (i.e., slowed breathing, subdued response to touch, movements slowed), after approximately four minutes in the anesthetic bath, they are handled carefully and quickly to reduce the time they are exposed to TMS and the air. Fish are held firmly, but gently (not squeezed), and returned to water between procedures/measurements to reduce stress.

Biodata collected varies with the activity, but could include species identification, fork length, clip status, and weight. In addition to the biodata collected, all activities incorporate PIT tagging of all salmonids of appropriate size (see the *PIT Tagging* section for methods overview). Further, a genetic tissue sample is 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 are kept in a freshwater bath to fully recover before returning to the freshwater, estuarine, and/or marine environment (Ackerman *et al.* 2005).

#### PIT Tagging

All Chinook, coho, and steelhead were/are tagged with 12 mm FDX-B PIT tags (Biomark, Boise, ID). PIT tags are administered in salmonids with a fork length equal to or greater than 69 mm, in hatchery environments and 65 mm for all other environments, as the 12 mm PIT tags should equate to ~17.5% of a salmonid's fork length to minimize risk of mortality from tagging (Vollset *et al.* 2020). Once anesthetized, PIT tags are injected into the body cavity, anterior to each fish's pelvic girdle (Figure 3) with a sterilized, one-time-use, preloaded needle.

Holding the fish in their non-dominant hand with the belly facing upwards, the crew member places the tip of the needle at a 45-degree angle (tag side of needle down) along the midline, just above the pelvic girdle and gently insert the needle a few millimeters (just enough to pierce the skin). The tag is inserted by pulling the PIT tag gun's 'trigger'; the tag is inserted forward, towards the head, as the needle is gently drawn back toward the tagger. Once injected, the tag sits within the peritoneal cavity.

In all instances, except hatchery tagging, an HPR-Lite hand scanner (Biomark, Boise, ID) is used to scan the tag before injecting or immediately after doing so. The last four numbers of the PIT ID are recorded.

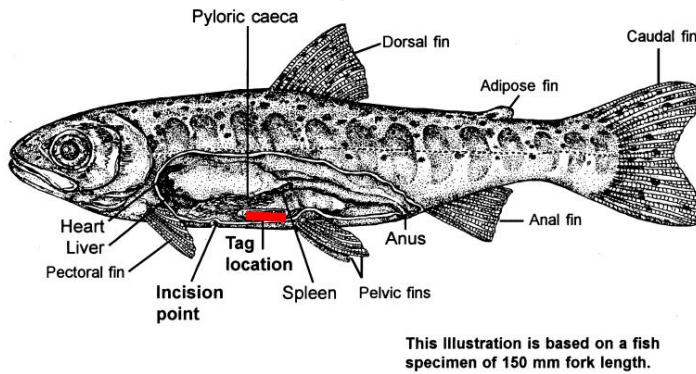


Figure 3. PIT tags are inserted into the body cavity, anterior to the pelvic girdle, of each fish using a sterile, one-time-use hypodermic needle (Rodgers et al. 2022) (Pellet et al. 2017).

#### *Genetic Stock Identification and Parentage Based Tagging Sampling and Analysis*

While some hatchery stocks and species (e.g., Cowichan River Chinook, Quinsam Coho) have 100% external marking (adipose clip), the majority of hatchery production is unmarked (refer to DFO SEP internal hatchery compendia for details). 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.

The majority of genetic tissue samples consisted of fin clips on customized numbered sheet of Whatman paper while a smaller number were scales on gummed scale cards. Fin clip DNA samples were taken from the lower caudal fin with a target clip width of 2 mm, scissors or forceps were wiped after each sample to avoid contamination. The sample was then placed on the Whatman paper in the center of each grid cell, flat to allow for proper adhesion to the paper. Extreme care was taken to ensure Whatman sheets remained dry. For scale sampling 5-10 scales were removed from the preferred area (above or below the lateral line just posterior to and under the dorsal fin) using forceps and transferred to a single square of a gummed scale book. Care was taken to ensure scales were spread out and placed on the card in the same orientation as on the fish (outside up) to facilitate pressing on acetate sheets for growth analysis (see Chapter 2). Forceps were wiped clean between fish and extreme care was taken to ensure scalebooks remained dry.

Tissue samples were transferred to MGL at Pacific Biological Station, prepared, and genotyped as described in Beacham *et al.* (2022) and references therein. Each sample was first run against species-specific baselines of genotyped hatchery parents using COLONY software. Fish that could be assigned to two hatchery parents were considered to be 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 based on single nucleotide polymorphisms (SNP) allele frequencies in species-specific population baselines using a Bayesian genetic stock identification model in the software RUBIAS. This 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 without the application of a threshold. 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. In the present document, assignment of stock of origin by PBT vs GSI can be considered an interim proxy for hatchery vs wild origin. However, in subsequent analyses, we intend to account for both ungenotyped broodstock and DNA sample quality in assessing the robustness of this relationship. 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.

To date, GSI and PBT results are available for estuarine tagging and microtrolling conducted in winter 2020-21 and 2021-22. 2022-23 microtroll DNA samples will be submitted to MGL in June 2023.

#### *PIT Tag Detection Arrays*

The installation of multiple PIT tag 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 Project* were custom-built in a variety of ways (Appendix A, Table 24).

Permanent pass-over array's consisting of two to 12 prefabricated, individually controlled antennas were installed in the mainstem of rivers. Each antenna coil was housed in welded 4" HDPE pipe, measuring 0.8 m x 6.1 m (Figure 4) 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.

Fishway antennas were designed in a pass-through orientation and were custom-made by Biomark or BCCF staff (Figure 5; Appendix A, Table 24).



Figure 4. Installation of the Nanaimo River mainstem PIT array, July 2021 (photo by Danny Swainson).



Figure 5. Quinsam River hatchery fishway PIT antennas (2021) (photo by Jamieson Atkinson).

### Survival Analyses

This PIT tag-based investigation of Salish Sea Chinook and coho salmon and steelhead survival will require a number of independent and complementary survival analytical approaches. The overarching goal is to understand details of how mortality during the first two years of life impacts adult abundance. Current survival analyses for Salish Sea Chinook and coho salmon rely on coded wire tags (CWT). In simple terms, data on catch and escapement of CWT'ed fish, and assumptions regarding natural adult mortality, are used to estimate how many tagged fish recruit to the fishery; this estimate is then divided by tags released to derive a survival estimate from release to recruitment. As consensus is growing that early marine survival plays a key role in regulating productivity of Chinook and coho salmon populations (Beamish and Mahnken 2001), these survival to recruitment estimates have been used extensively as response variables in analyses aimed at understanding trends in marine survival (Ruff *et al.* 2017; Zimmerman *et al.* 2015,) and investigating potential causes of change (Sharma *et al.* 2013). Exclusive dependence on these estimates is problematic. Survival to recruitment estimates combine freshwater migration from release to ocean entry, estuarine entry and residence, the first marine summer, and the first winter at sea, preventing insights into the spatiotemporal context of potential critical mortality periods (Beamish and Mahnken 2001). Where CWT-based survival metrics are used to evaluate experimental hatchery release strategies, it is not possible to tease apart the stages at which fish subject to one strategy perform better than another. Survival models are rarely available for hatchery and wild fish from the same system, obscuring how hatchery rearing influences survival and necessitating an assumption that hatchery fish are adequate proxies for sympatric wild fish for the purpose of management. Finally, violation of the assumption of stationary natural adult mortality will propagate through CWT-based survival models, biasing survival to recruitment estimates.

Survival estimates based on PIT tagging and detecting fish at multiple time points during their freshwater and marine lives can provide insights into stage specific mortality that can be used to test the assumptions of existing CWT-based survival models; drill down into where and when important mortality is occurring; and inform strategies to improve survival of both hatchery and wild salmon and steelhead. The complexity of a project spanning three species, multiple stocks and systems, and hatchery and natural origin fish will prevent a single unified analysis framework being applied to all the data. Additionally, given the exploratory nature of the work, the number of tags that can be applied to each life history stage, for each stock and origin (hatchery/wild) group, remains somewhat uncertain.

Where possible, we intend to develop stock-specific or multi-stock Cormack-Jolly-Seber (CJS) open population survival models, which will estimate stage-specific abundance and survival through marking and recapture events. We have developed a hierarchical Bayesian CJS model which we are currently evaluating using simulated data sets (see Chapter 1). This model will be applied to coho and Chinook salmon mark, recovery, and detection data from hatcheries, in-river and estuarine tagging, marine tagging, and passive detections at fishways and in-river antennas to derive stage-specific survival estimates. A key outcome of this survival modelling exercise will be the production of a generalized life history stage survival curve that can be integrated with, and compared to, existing survival estimates derived from CWT data. This survival curve can then be used to test the effects of changes to abundance or survival at different life history stages, in turn informing managers and stakeholders about the potential benefits of alternate management actions. An urgent need currently exists for such a tool (Wilf Luedke, DFO South Coast Stock Assessment Area Chief, pers. comm. 2021). Another key outcome from stage-specific survival modelling will be comparing relative stage-specific survival (i.e., the “shape” of the survival curve) between years and stocks that exhibit relatively better and worse survival to recruitment as indicated by standard CWT-based survival models. Such comparisons will provide insight

into whether elevated mortality at specific stages during the first years of life disproportionately influence stock productivity.

Sample sizes and data complexity will prevent all research questions from being addressed within an integrated survival modelling framework. To investigate factors influencing individual survival (for example pathogen presence or physiological stress as indicated by fit chip results; see Activity 3: Chinook Salmon Winter Ecology), we may employ simpler logistic regression models, with survival to return from a sampling event treated as a binomial variable. Investigating freshwater survival in different systems will also require system-specific analyses that account for limited encounters with individual stocks in the marine environment. We are working with Toquaht Nation, Thornton Creek Salmon Enhancement Society, and the University of Northern BC (UNBC) to develop CJS state-space models, fitted using Bayesian inference, that use empirical detection probability data collected at different flow levels as priors to inform modelled detection probability (Balfour 2023). These models may be applied to investigate the effects of size, migration distance, and migration date on freshwater survival in multiple systems.

# Chapter 1: Bottlenecks to Survival of Wild & Hatchery Chinook and Coho Salmon

This project component aims to elucidate key survival bottlenecks in freshwater and early marine environments for Chinook and coho to inform evidence-based strategies that may help improve their survival. Additionally, routine scans of known pinniped haul-outs and heron rookeries for expelled PIT tags will be conducted to better understand predation.

## Objectives

1. To measure stage-specific mortality of Strait of Georgia hatchery and wild Chinook salmon;
2. To measure stage specific mortality of Strait of Georgia hatchery and wild coho salmon;
3. To investigate survival at later stages in the life cycle (i.e., to sub adult) and to compare CWT survival to age two estimates;
4. To determine rearing hotspots of coho by sampling in the winter;
5. To examine the differences in survival among hatchery and wild conspecifics; and,
6. To pilot alternative methods for recreational fishery exploitation rate estimates.

## Methodology

### Hatchery Tagging

Chinook (Ck), coho (Co), and steelhead (St) were PIT tagged at 11 hatchery facilities (SEP and community hatcheries (CH)) during the first two years of the *Bottlenecks Project* (Figure 2, Table 2). Fish were removed from their primary populations the day of or the day before tagging. Fish were starved for 24 hours prior to 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.

In 2021, Chinook tagging at the Puntledge hatchery saw significant tagging-related mortality. During this tagging event the crews did not have flow-through tagging tables or flow-through recovery baths; tagging and recovery were done with static tubs and tanks. These factors are likely attributed to the high tagging-related mortality rates that occurred. Preventative measures were put in place after an onsite meeting was held with the DFO SEP vet Ian Keith during the next tagging event at the Big Qualicum River on May 4, 2021. Preventative measures included a review of tagging size and an adjustment to 69 mm fork length (Vollset et al. 2020), flow-through tagging tables, and a higher degree of monitoring when new taggers are onsite.

Table 2. Summary of hatchery tagging as of 2023.

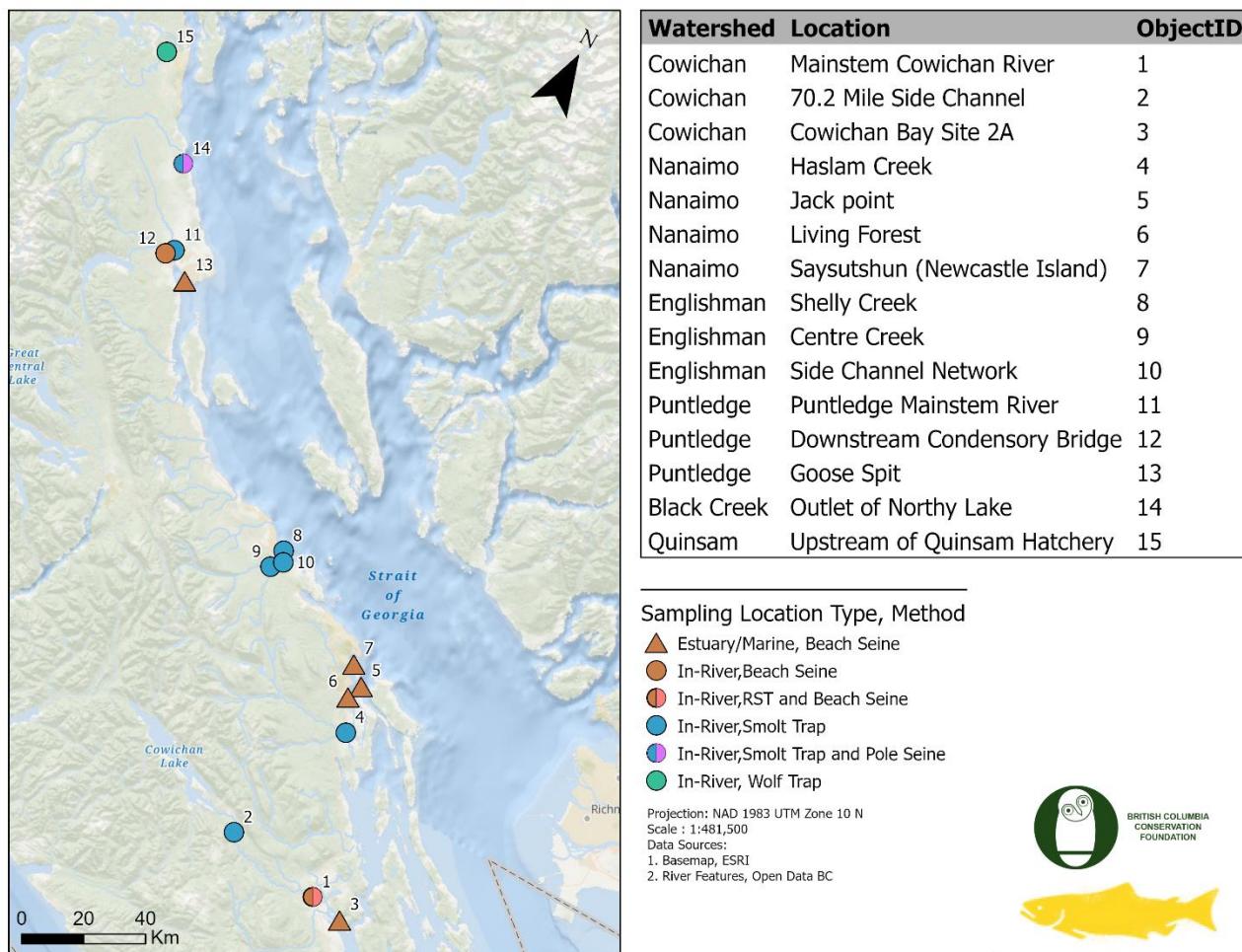
Watershed	Hatchery	SEP/CH	Species	Holding Tank (circ,rw ,other)	Years
Cowichan	Cowichan River	CH	Ck	rw	21_22_23
Nanaimo	Nanaimo River	CH	Ck/Co	circ	21_22_23
Little Qualicum	Little Qualicum	SEP	Ck	rw	21_22_23
Big Qualicum	Big Qualicum	SEP	Ck/Co	rw	21_22_23*
Puntledge	Puntledge River	SEP	Ck/Co	circ	21_22_23
Quinsam	Quinsam River	SEP	Ck/Co	circ	21_22_23
Toquaht	Thornton Creek	CH	Ck	rw	21
Goldstream	Goldstream River	CH	Co	circ	22_23
Millstream	Goldstream River	CH	Co	circ	22_23
Millstone	Nanaimo River	CH	Co	circ	22_23
Stamp/Somass	Robertson Creek	SEP	St	circ	21_22_23

\* Depicts where coho were not tagged in 2023

#### In-River & Early Marine Tagging

Chinook and coho salmon 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 (RST), beach seine, smolt trap, pole seine, and/or wolf trap) depending on the system and location (Figure 6). This activity was completed for the 2021, and 2022 study years and is in-

progress in spring 2023.



\*The 70.2 smolt trap was installed in 2021, but was not re-installed in 2022 as the RST was then being utilized.

\*Haslam Creek was installed for approximately two weeks in 2021, but had to be removed due to high flows. It was discontinued in future years

\*Beach seining was attempted in the Puntledge River in 2021 and 2022; due to limited catches, was discontinued.

\*The Bottlenecks Project also collaborates with an A-tlegay Fisheries Society- and DFO-led project that applies PIT tags to coho salmon smolts captured at the downstream fence and trap at Miracle Beach Provincial Park. Several thousand smolts are tagged at this site each year but these numbers are not reported in the present document.

Figure 6. Summary of in-river and early marine tagging methods and locations in 2021, 2022, and 2023.

### Capture Methods

#### *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 pursed the net in from the shore (Figure 7). 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 salmonid prior to release (see *Error! Reference source not found.* and *PIT Tagging* sections for full review of methods).



Figure 7. Beach Seine used for capture of juvenile Chinook and coho in both estuary and riverine settings (photos by Danny Swainson)

#### *Pole Seining*

Wild juvenile Chinook and coho were captured primarily 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 (Figure 7). The design incorporated a square basket where fish would collect as the lead line broke the surface at the end of each set (Figure 8). 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.

Live wells were located at the portable wet lab set up every morning prior to the first seine set. Portable 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 large plastic 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 salmonid prior to release (see *Error! Reference source not found.* and *PIT Tagging* sections for full review of methods).



Figure 8. Pole seine used for capture of juvenile Chinook and coho (photo by Kevin Pellett).

#### RST

A 1.8 m RST was assembled and deployed on the Cowichan River, at the DFO counting fence site (Figure 9), located approximately 100 m downstream of the Allenby Road bridge. The RST ran from April 28 to May 28, 2021, and from May 2, 2022, to June 24, 2022. The RST was placed in the thalweg, near the left bank. Multiple wood frame meshed panels ( $3 \times 1$  m) were installed similarly to a smolt fence to concentrate downstream migrating fish into the RST, to help increase catch rates. In addition, a ‘yolk’ was fabricated to conform to the large end of the RST cone to help prevent fish from swimming under the drum and avoiding capture (Figure 10). In addition, the adult fish fence panels, made from aluminum bracing and 6 m lengths of PVC pipe, used while enumerating adults during spawning migration, were installed in an attempt to catch a higher portion of the fish migrating downstream.



Figure 9. RST style smolt trap installed in the mainstem of the Cowichan River, just downstream of Allenby Road Bridge. Note screened fence panels installed on either side of the RST (May 5, 2021) (photo by Jeramy Damborg).



Figure 10. Photo of the RST with the 'yolk' that was built and installed under the drum of the Allenby Road RST in an attempt to increase trap efficiency (photo by Jeramy Damborg).

Live wells were located at the portable wet lab set up every morning prior to retrieving captured fish from the trap. Portable 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 salmonid prior to release (see [Figure 11](#) and [PIT Tagging](#) sections for full review of methods).

#### *Smolt trap*

Fence-style smolt traps were utilized to capture out-migrating juvenile Chinook and coho salmon, as well as rainbow, steelhead, and cutthroat Trout in the Englishman watershed (Shelly Creek, Center Creek, and the side channel network). Smolt traps were attempted in other systems in year 1, but were

discontinued due to incompatible flows and implementation of new sampling techniques (i.e., RST in Cowichan River and Nanaimo River mainstems).

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. 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 11. A typical smolt trap set up for capturing out-migrating juvenile Chinook and coho salmon, as well as rainbow/steelhead and cutthroat trout. Image shows smolt trap and tagging setup at Center Creek, in the Englishman River watershed in 2021 (photo by Danny Swainson).

Live wells were located at the portable wet lab set up every morning prior to retrieving captured fish from the trap. Portable wet labs consisted of U.V. protected tents (3.3 m x 3.3 m; when required), two foldable plastic tables (1 m x 3 m), two or three large plastic 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 salmonid prior to release (see [Figure 11](#) and [PIT Tagging](#) sections for full review of methods).

#### *Microtrolling*

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. This activity was completed for winters 2020-21, 2021-22, and 2022-23.

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 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. 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.

#### **Adult Tagging**

While not included in the original *Bottlenecks Project*, an opportunity emerged to conduct opportunistic tagging of adult Chinook and coho salmon in conjunction with the Avid Angler Program administered by DFO. The Avid Anglers are a group of recreational anglers and fishing guides that are permitted by DFO to collect biological samples from all fish, whether released or retained. Sample collection includes species, fork length, clip status, and a fin clip for stock identification (see *Genetic Stock Identification and Parentage Based Tagging Sampling and Analysis*); anglers also administered PIT tags (see *PIT Tagging*).

As this stock identification is funded through DFO, the cost of this addition to the *Bottlenecks Project* was limited to the number of PIT tags available. Seven Avid Anglers were provided with HPR-Lite hand scanner, PIT tags, and training in tag application. Tagging occurred from May through September. Genetic stock identification results for fish tagged by Avid Anglers were obtained for the *Bottlenecks Project* from DFO's CREST database. As gear (e.g., hook size) for this activity was not standardized, Avid Anglers were instructed to tag all fish and record the type of gear used and any bleeding, eyes hooked, or otherwise injured fish. This component of the project is ongoing and continuing in summer 2023.

#### Logistics

In the summer of 2020, the BCCF and PSF project managers were hired, a preliminary database conceptual design was completed, and an electronic microtroll data collection application was developed. Outreach to other organizations began in the summer of 2020, including discussions regarding collaborations within watersheds with First Nations, local streamkeeper organizations, and the Federal and Provincial governments.

#### Regional Database Exploration

Extensive fact-finding has been conducted regarding data standardization for PIT tag database development and developing a framework to share PIT tag data among other Salish Sea PIT tagging programs. On 13 April 2022, the *Bottlenecks Project* management team hosted an online fact-finding meeting with managers of PIT tagging programs in the Columbia and Klamath River basins and other Canadian PIT tag researchers. A second workshop was held on 23 June 2022, and focused on: developing a catalogue of projects applying and detecting PIT tags in the Salish Sea and southern BC; developing an interim plan for identifying the source of orphan detections (until a comprehensive data sharing framework can be developed); establishing what data types would be desirable to share among projects eventually and include in a central PIT tag database; discussing the feasibility and steps involved in moving towards a data exchange standard; and developing a plan for regular virtual meetings of a Salish Sea PIT tag data management working group. The workshop featured presentations from the Columbia River PTAGIS database management, Columbia Basin Research Data in Real Time (DART), and the Pacific States Fishery Management Commission, who host both the PTAGIS and the binational CWT databases. Meeting summary and notes are provided as an attachment to this document (*Salish Sea/Southern British Columbia PIT Tag Data Management Framework Meeting*).

In February of 2023, Bottlenecks Project personnel applied lessons from these workshops to support DFO STAD staff in submitting a Pacific Salmon Strategy Initiative application for developing a regional PIT tag data management framework. Development of a public orphan tag (refers to tags detected by a project but not applied by that project) database for the Salish Sea is planned for summer 2023. Introducing this database will provide a further opportunity to build communication and collaboration among Salish Sea PIT tag programs, and an additional workshop will be hosted by the Bottlenecks Project in 2023 (Further meeting details can be found in “BCSRIF Bottlenecks to Survival 2022 Management Meeting\_notes”).

#### Data Management

Capture, biological, tagging and detection data for Chinook and coho salmon are collected and managed using a combination of software platforms including ArcGIS, EForms mobile, FME (Safe Software), and the R statistical computing environment.

Details on the EForms mobile data collection app for microtrolling are included in the microtrolling SOP provided as an attachment to this report (Rodgers et al. 2022). Details on the PIT tagging data

collections app, designed by Campbell Geospatial, for tagging outside of the hatchery environments is still under construction, an SOP will be developed for this application in 2023. The Pacific Salmon Foundation's Strait of Georgia Data Centre supports the Bottlenecks Project by developing automated data management workflows in FME for data compilation, quality assurance, and control. This is particularly important for large volumes of PIT detection data (>1.6 million detections to date). Reports describing FME workflows for microtrolling and PIT tag detection data management are attached to the present document.

### Data Analysis

#### *Background*

Cormack-Jolly-Seber (CJS) models (Cormack, 1964; Jolly, 1965; Seber, 1965) are often applied to study the directed migrations of species (such as Pacific salmon) through use of telemetry data (Buchanan and Skalski, 2007; Brown *et al.*, 2013). However, issues can arise when telemetry data presents low recapture or detection rates, low survival rates, or low sample sizes, which can result in imprecise model parameters and survival estimates (Pollock *et al.* 1990; O'Brien, Robert & Tiandry 2005; Morris *et al.* 2006). 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' (Calvert *et al.*, 2009). 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 (Harwood & Stokes, 2003; Gelman *et al.*, 2004; Calvert *et al.*, 2009; Kéry and Schaub, 2011). Further, Calvert *et al.* (2009) found that hierarchical Bayesian multi-state mark-recapture models produced more precise and accurate parameter estimates when compared with non-hierarchical models for sparse datasets.

We developed a hierarchical Bayesian CJS model capable of estimating survival and detection probabilities over multiple states for our 'bottlenecks Project' dataset. All data preparation and modelling were performed using R statistical software (R Core Team, 2022).

#### *Data preparation*

For most river systems in this project, fish tagging efforts occur on three occasions across different life stages of Pacific salmon target species: (1) fry tagging occurring in the hatchery environment, (2) smolt tagging occurring in the estuarine environment, and (3) sub-adult tagging occurring during microtrolling. At each of these events, fish are captured, tagged, and released, and there is also opportunity for recapture of previously tagged individuals. In addition, PIT receivers have been installed in the riverine environment, allowing detection of tagged individuals downstream of the hatchery environment, and upon spawning migration return. Our dataset therefore comprises of five 'states', with tagged individuals released at three separate stages. This data was formatted as binary data, where '1' represented either a tag release or detection at a following site and '0' represented no detection at a site (meaning either the individual passed undetected, permanently emigrated, or died). Capture histories of each individual could therefore be represented by a five-digit, binary code representing presence or absence (1 or 0, respectively) of a fish across our five stages. For example, a fish tagged in the hatchery environment, detected as it passed the downstream PIT receiver, not recaptured during estuarine netting or microtrolling efforts, but detected at the final PIT receiver upon spawning migration return would be represented by a capture history of '11001'.

### Model framework

We developed a Bayesian CJS model capable of estimating detection probability at each site ( $\rho$ ), survival probability between each site ( $\theta$ ), and probability of survival from tagging release to each detection occasion ( $\psi$ ). This model estimates detection and survival probabilities separately for each site.

If a fish  $f$  successfully reaches site  $s$  it is denoted by  $x_{f,s} = 1$ ; if fish  $f$  does not successfully reach site  $s$  it is denoted by  $x_{f,s} = 0$ . Survival to each site by a fish is therefore given as binary data. If fish  $f$  successfully reaches site  $s$ , the successful detection of that fish at that site is denoted by  $y_{f,s} = 1$ ; if the fish is not successfully detected it is denoted by  $y_{f,s} = 0$ . We make the assumption that there are no false positive detections.

Following this, the detection probability  $\rho$  of fish  $f$  at site  $s$  is given by:

$$\rho_{f,s} = \text{Prob}(x_{f,s} = 1 \mid y_{f,s} = 1) \quad (1)$$

where probability density values were calculated for the Beta Distribution bounded between [0,1]. For a fish to be successfully detected at site  $s$  ( $y_{f,s} = 1$ ), the fish must also have survived to that site ( $x_{f,s} = 1$ ).

Survival probability  $\theta$  of fish  $f$  between two sites is given by:

$$\theta_{f,s} = \text{Prob}(x_{f,s-1} = 1 \mid x_{f,s} = 1) \quad (2)$$

Initial detection probability  $\rho$  and survival probability  $\theta$  for the first tagging site of each fish was set as 1, as the fish was known alive and ‘detected’ during tagging. Our model was also constrained in that detection probability at site 5 (final adult return PIT receiver) was set at 0.9, thus assuming 90% detection efficiency at this site. This value is therefore user defined and needs to be specified prior to running the model.

We further constructed a hierarchical model to estimate the presence of a fish at a given site  $y_{f,s}$  in terms of detection probability  $\rho_{f,s}$ ; here, presence of a fish at a site is assumed to be a random process with Bernoulli distribution (Forbes et al., 2011) and probability a function of the detection probability at that site ( $\rho_s$ ) and probability that the fish reaches that site ( $x_{f,s}$ ):

$$y_{f,s} = \text{Bernoulli}(\rho_s x_{f,s}) \quad (3)$$

Survival of a fish to a given site  $x_{f,s}$  is also assumed to be a random process with Bernoulli distribution and probability a function of site survival probability  $\theta$ . This function also contains an observation component ( $x_{f,s-1}$ ) because the fish must’ve been alive in ‘s-1’ to have non-zero survival probability at ‘s’:

$$x_{f,s} = \text{Bernoulli}(\theta_s x_{f,s-1}) \quad (4)$$

Finally, probability of survival from tagging release to each detection occasion ( $\psi_{f,s}$ ), or ‘cumulative survival’, is given as a function of probability of cumulative survival of a fish to the previous location ( $\psi_{f,s-1}$ ) and probability of detection of a fish at the given location  $\theta_{f,s}$ . Cumulative survival,  $\psi$ , for a fish at its initial tagging site was set at 1. Cumulative survival,  $\psi$ , of all following sites is given by:

$$\psi_{f,s} = \psi_{f, s-1} \theta_{f,s} \quad (5)$$

#### *Model fitting and evaluation*

Our Bayesian CJS model was fitted using a Markov Chain Monte Carlo (MCMC) approach through R package “rjags” (Plummer, 2022) which provides an interface from R statistical software to the JAGS library (Plummer, 2003) for data analysis. The model was estimated using four MCMC chains, each with 2,500 iterations, 2,500 burn-in with thinning by selecting the 5<sup>th</sup> iteration. We constrained our model by specifically inputting the known detection efficiency of the final PIT receiver installed to detect tagged adults returning to the river during spawning migrations. PIT receiver detection efficiencies are calculated separately and this value can therefore be specified as a prior in our model. Three parameters were calculated in this model: (i) detection probability at each site, (ii) survival probability between each site, and (iii) probability of surviving from release to a detection occasion (i.e., cumulative survival). We tested our model for successful convergence using Gelman and Rubin’s convergence diagnostic (Gelman and Rubin, 1992). This was performed using the *gelman.diag()* function of R package “coda” (Plumer et al., 2022). We considered the model to have successfully converged if no parameters had Gelman-Rubin statistics greater than 1.05. Diagnostic plots were also produced to visualize convergence and model parameters using R package “postpack” (Staton, 2022) which allowed us to examine plots of autocorrelation, trace, and posterior density for each parameter. Through this package we also calculated 95% confidence intervals and coefficient of variation (CV) values for all model parameters estimated at each site. Finally, effective sample size (ESS) was calculated to assess the information content of the MCMC chain in our model (Kass et al., 1998; Martino et al., 2017). ESS was calculated using the *effectiveSize()* function of R package “coda”.

#### *Future directions*

Currently, the model has been produced, developed, and tested on a simulated dataset. Developing models using simulated datasets can be preferred 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. Such simulations also allow us to test sample sizes (tag numbers) deployed at various locations in this project under a variety of survival and detection efficiency scenarios to assess the expected precision and confidence of model parameters subsequently produced in the survival model.

As we now begin to collect final spawning migration return data from the first cohort of tagged fish released in 2021, we can move towards running our survival model with real data collected as part of this project. We also plan to further develop the model to incorporate covariates allowing us to compare survival between different origins (hatchery vs wild), sex (male vs female) and age at maturity (i.e., age at which the fish returns during spawning migrations).

## **Interim Results**

#### Fish Capture and PIT-Tagging

##### *Hatchery Tagging*

In total, 70,747 Chinook, 76,900 coho, and 15,000 steelhead were tagged in hatchery settings across 11 watersheds on Vancouver Island between September 2020 and April 2023 (Table 3; Figure 2).

Table 3. Summary of hatchery-based PIT tagging of Chinook, coho, and steelhead between 2020 and 2023.

Hatchery	Species	Cohort	Tagging Date	Tags Deployed
Cowichan	Ck	Fall	2021-05-05	6,747
	Ck	Fall	2021-05-04	5,000
	Big Qualicum	Co	Smolt	2021-04-14
		Co	Smolt	2021-12-01
		Ck	Fall	2022-05-17
Little Qualicum	Ck	Fall	2021-05-11	5,000
	Ck	Fall	2022-05-31	5,000
Nanaimo	Ck	Fall	2021-04-22	5,000
	Ck	Summer	2021-04-23	5,000
	Co	Smolt	2021-03-17	5,000
		Ck	Fall	2022-05-10
		Ck	Summer	2022-05-10
	Co	Smolt	2022-01-25	5,000
	Co	Smolt	2023-03-07	5,000
Millstone	Co	Smolt	2022-01-25	1,000
	Co	Smolt	2022-10-05	1,000
Puntledge	Ck	Fall	2021-04-12	5,000
	Co	Smolt	2021-04-12	5,000
	Ck	Fall	2022-05-24	5,000
	Co	Smolt	2021-12-02	5,000
Quinsam	Ck	Fall	2021-04-01	5,000
	Co	Smolt	2020-09-21	5,000
	Ck	Fall	2022-04-14	5,000
	Co	Smolt	2021-11-08	5,000
	Co	Smolt	2022-11-30	4,000
	Co	Smolt	2022-12-20	4,000
Thornton Creek	Ck	Fall	2021-04-01	5,000
Robertson Creek	St	Smolt	2021-01-20	5,000
	St	Smolt	2022-01-18	5,000
	St	Smolt	2023-01-18	5,000
Millstream	Co	Smolt	2022-02-23	2,000
	Co	Smolt	2023-01-26	2,000
Goldstream	Co	Smolt	2022-03-02	7,500
	Co	Smolt	2023-03-14	5,200
	Co	Smolt	2023-03-28	5,200

#### In River and Estuarine Tagging

In total, 21,218, 17,929, and 1,382 Chinook, coho and steelhead, respectively, were tagged in-river or estuarine environments in spring 2021 and 2022 during the outmigration window (Table 4 and Table 5). Prior to the beginning of the *Bottlenecks Project*, tagging of fish in the natural environment also occurred at Black Creek (since 2018) and Cowichan River (since 2014). While these data are not reported here, recoveries of these tags may be included in program analyses. At the time of preparation of this report, tagging in rivers and estuaries was ongoing for the 2023 outmigration season.

Table 4. Summary of PIT tagged Chinook (ck), coho (co), chum (cm), steelhead (stl), rainbow trout (rbt), cutthroat trout (ct), and brown trout (bt), from in-river and estuary captures for 2021.

Species	Watershed							Total
	Black Creek	Cowichan	Englishman	Nanaimo	Puntledge	Quinsam		
Ck	0	8645	0	1343	832	0		10820
Co	838	5579	3647	11	325	0		10400
Stl	0	411	18	35	3	487		954
Rbt	0	57	121	54	18	0		250
Ct	3	14	70	24	15	0		126
Bt	0	150	0	0	0	0		150
Cm	0	6	0	1	1	0		8
Unknown (Ck, Co)	3	3	1	0	1	4		12

Table 5. Summary of PIT tagged Chinook (ck), coho (co), chum (cm), steelhead (stl), rainbow trout (rbt), cutthroat trout (ct), brown trout (bt), and sockeye (so) from in-river and estuary captures for 2022.

Species	Watershed							Total
	Black Creek	Cowichan	Englishman	Koksilah	Nanaimo	Puntledge	Quinsam	
Ck	0	5972	1	281	2107	2037	0	10398
Co	924	2410	2906	91	107	1091	0	7529
Stl	0	85	3	0	0	2	338	428
Rbt	0	8	101	31	4	4	0	148
Ct	0	13	79	0	0	84	0	176
Bt	0	2	0	0	0	0	0	2
Cm	0	0	0	0	0	0	0	0
Unknown (Ck, Co)	0	1	1	0	0	0	0	2
So	0	2	0	0	0	0	0	2

In the initial two years of river and estuarine tagging as part of the *Bottlenecks Project*, genetic samples were collected only at the Puntledge and Nanaimo rivers. These two systems have summer Chinook salmon populations (referred to in the present document as “Nanaimo and Puntledge Summer”) for which juveniles can only be distinguished from the dominant fall run populations using genetics. In 2021, stock composition analysis indicated that approximately one-third of the Nanaimo Chinook salmon tagged in-river and estuary were summer runs while only 13% were summer runs in 2022 (Table 6). At Puntledge, the summer run proportion was 18% in 2021 and 2% in 2022. Small proportions of fish captured both in-river and by beach seining at both sites were assigned to stocks outside of the river of origin. For in-river fish this almost certainly reflects uncertainty in GSI-based stock assignments. Some samples at each site were either unusable due to poor DNA quality or were identified as being from the wrong species. Sample quality was improved in 2022 relative to 2021 with fewer species misidentifications. Where Chinook were misidentified as coho or coho as Chinook, it will be possible to re-run these samples in the GSI/PBT analysis.

Very few coho salmon were tagged in the river or estuary at the Nanaimo River, while 324 and 1091 coho were tagged at the Puntledge River in 2021 and 2022, respectively. Genetic tissue samples for

coho salmon tagged in 2022 were not analyzed due to the high proportion of Puntledge River origin fish (92%) tagged in 2021. Due to incomplete adipose marking of hatchery coho salmon at Puntledge River hatchery it may be necessary to run these samples to attempt to determine hatchery origin through PBT assignments (see below).

Table 6. Genetic stock composition of Chinook and coho salmon PIT tagged at the Nanaimo and Puntledge Rivers in spring 2021 and 2022.

Year	River	Stock	Chinook			Coho				
			River	Marine	Total	River	Marine	Total		
<b>2021</b>										
<b>Nanaimo</b>										
Cowichan	7	34	41	0	0	0	0	0		
East VI Fall (Nanaimo)	124	536	660	0	0	0	0	0		
Lower Fraser	0	5	5	0	0	0	0	0		
Nanaimo and Puntledge Summer	84	298	382	0	0	0	0	0		
Qualicum Puntledge Fall	0	36	36	0	0	0	0	0		
Southwest VI	0	5	5	0	0	0	0	0		
East Coast VI Coho (mostly target)	0	0	0	1	2	3	0	0		
Other Fraser Coho	0	0	0	0	1	1	0	0		
Wrong species or poor DNA	21	174	195	0	1	1	0	0		
No Sample	4	15	19	2	2	4	0	0		
<b>Puntledge</b>										
Cowichan	0	0	0	0	0	0	0	0		
East VI Fall (Nanaimo)	0	8	8	0	0	0	0	0		
Lower Fraser	0	0	0	0	0	0	0	0		
Nanaimo and Puntledge Summer	112	14	126	0	0	0	0	0		
Qualicum Puntledge Fall	363	218	581	0	0	0	0	0		
Southwest VI	0	0	0	0	0	0	0	0		
East Coast VI Coho (mostly target)	0	0	0	17	174	191	0	0		
Other Fraser Coho	0	0	0	0	1	1	0	0		
Wrong species or poor DNA	7	79	86	0	127	127	0	0		
No Sample	5	26	31	0	6	6	0	0		
<b>2022</b>										
<b>Nanaimo</b>										
Cowichan	0	1	1	0	0	0	0	0		
East VI Fall (Nanaimo)	320	1275	1595	0	0	0	0	0		
Lower Fraser	0	9	9	0	0	0	0	0		
Nanaimo and Puntledge Summer	1	231	232	0	0	0	0	0		
Qualicum Puntledge Fall	0	81	81	0	0	0	0	0		
Southwest VI	0	0	0	0	0	0	0	0		
East Coast VI Coho (mostly target)	0	0	0	0	0	0	0	0		

Other Fraser Coho	0	0	0	0	0	0
Wrong species or poor DNA	1	10	11	0	1	1
No Sample	0	150	150	6	100	106
<b>Puntledge</b>						
Cowichan	0	0	0	0	0	0
East VI Fall (Nanaimo)	0	1	1	0	0	0
Lower Fraser	0	0	0	0	0	0
Nanaimo and Puntledge Summer	0	42	42	0	0	0
Qualicum Puntledge Fall	0	1733	1733	0	0	0
Southwest VI	0	0	0	0	0	0
East Coast VI Coho (mostly target)	0	0	0	0	0	0
Other Fraser Coho	0	0	0	0	0	0
Wrong species or poor DNA	0	8	8	0	12	12
No Sample	0	252	252	86	988	1074

In 2021, the majority of fall and summer Chinook salmon captured in-river and by beach seining at the Nanaimo River were identified by GSI rather than PBT, suggesting natural origin (Table 7) while both fall and summer run Puntledge Chinook were dominated by fish assigned by PBT, indicating hatchery origin (PBT assigns fish to hatchery broodstock parents). In 2022, fall Chinook tagged at both systems were dominated by fish identified by PBT while Nanaimo summer run Chinook were identified primarily by GSI and only a very small number of summer run Chinook (42) were tagged at Puntledge. The PBT proportion for fall Chinook salmon at both sites across years was considerably lower than for the same stocks captured by microtrolling. It is possible that poor DNA sample quality or incomplete genotyping of broodstock contributed to the proportion of fish assigned by GSI rather than PBT. For example, of 47 adipose clipped fish encountered during in-river and beach seine sampling at Puntledge in 2021, only 40 were identified by PBT (85%) despite > 99% genotyping of 2020 broodstock at the Puntledge River Hatchery.

**Table 7.** The proportion of fish identified by GSI (likely natural origin) and PBT (likely hatchery origin) for Chinook and coho salmon PIT tagged at the Nanaimo and Puntledge Rivers in spring 2021 and 2022. All adipose clipped and PBT fish must be hatchery origin while some hatchery fish are unclipped or cannot be identified by PBT due to poor DNA quality or incomplete genotyping of broodstock.

Year	River	Stock	GSI			PBT				
			Clip	UnClip	% Clip	Clip	UnClip	% Clip		
<b>2021</b>										
<b>Nanaimo</b>										
	Cowichan	0	41	0%	0	0				
	East VI Fall (Nanaimo)	0	391	0%	0	269	0%			
	Nanaimo and Puntledge Summer	0	270	0%	0	112	0%			
	Qualicum_Puntledge Fall	0	15	0%	0	21	0%			
	<i>East Coast VI Coho (mostly target)</i>	0	3	0%	0	0				
<b>Puntledge</b>										
	East VI Fall (Nanaimo)	0	8	0%	0	0				
	Nanaimo and Puntledge Summer	4	15	21%	24	83	22%			
	Qualicum_Puntledge Fall	3	206	1%	16	356	4%			
	<i>East Coast VI Coho (mostly target)</i>	3	134	2%	9	45	17%			
<b>2022</b>										
<b>Nanaimo</b>										
	Cowichan	0	1	0%	0	0				
	East VI Fall (Nanaimo)	0	444	0%	0	1151	0%			
	Nanaimo and Puntledge Summer	0	191	0%	0	41	0%			
	Qualicum_Puntledge Fall	0	15	0%	2	64	3%			
<b>Puntledge</b>										
	East VI Fall (Nanaimo)	0	1	0%	0	0				
	Nanaimo and Puntledge Summer	1	22	4%	9	10	47%			
	Qualicum_Puntledge Fall	1	304	0%	15	1413	1%			

### *Microtrolling*

Across three microtrolling sampling seasons (fall to spring 2020-21, 2021-22, and 2022-23), nine volunteer anglers were trained and participated in winter microtrolling efforts, completing 138 days. Additionally, BCCF staff completed a total of 217 microtrolling days and UVic crews a total of 159 days (Figure 12). Across these 514 days of total effort, crews logged more than 12,000 sets with a total of 7,529 first ocean year (FO) Chinook, 584 second ocean year (SO) Chinook, and 1,435 coho captured; fork length thresholds for separating FO from SO Chinook salmon were 360 mm prior to May and 400 mm in May. Of these, 7,210 FO Chinook, 556 SO Chinook, and 813 coho were tagged with PIT tags and released. Additionally, 31 Chinook and three coho salmon captured by microtrolling were recaptures; six of the Chinook recaptures were caught microtrolling, 15 were tagged in rivers or estuaries and eight were tagged at hatcheries. Two recaptured coho had been tagged in the wild during outmigration while one was a hatchery tagged fish. Two recaptured Chinook tags could not be linked to the *Bottlenecks Project*.

Chinook salmon CPUE varied greatly by period and area (discussed more in Chapter 3). High catches were generally encountered in all areas in October, with CPUE dropping precipitously in November. In some areas (e.g. Northern Stuart Channel and near Cape Lazo in the Northern Strait of Georgia), CPUE remained modest and consistent from December through February. In the second season of microtrolling, areas of consistently high CPUE (30 to 50 fish per day) were encountered in mid-winter and early spring in the Discovery Islands, but this high CPUE was not repeated in 2022-23. Microtrolling CPUE in the eastern Strait of Georgia (PFMAs 15, 16, and 29) was almost universally very poor. Catch of SO Chinook salmon was concentrated in the Northeast Strait of Georgia. Overall, FO Chinook CPUE in the northern Strait of Georgia was much lower in 2022-23 than in previous winters, while catches in the southern Gulf Islands were similar to, or higher than, previous years. Patterns identified during the initial seasons of microtrolling should facilitate tagging of considerably greater numbers of Chinook in subsequent years of the project.

In the first microtrolling season (2020-21), tagging began in August, with considerable effort prior to October. In 2021-22, tagging began in October and in 2022-23, tagging began in September. Given the steeply declining CPUE after October, trade-offs may exist between tagging an adequate number of fish and tagging them over the optimal periods for survival models (before and after winter). Targets for marine captured coho via microtrolling were challenging to achieve. While large catches were encountered in a few locations in October of all years, CPUE declined significantly after October with encounter rates near zero for the remainder of the winter.

As of spring 2023, Chinook salmon genetic stock composition data have been analyzed for the first two seasons of microtrolling. Overall, 84% of FO Chinook salmon (Figure 13) and 69% of SO Chinook Salmon (Figure 14) were assigned to stocks originated from systems containing *Bottlenecks Project* PIT tag detection infrastructure. Genetic stock composition results from the first season of microtrolling (2020-21) found that only 23% of coho salmon (Figure 15) sampled by microtrolling originated from ECVI systems, with an estimated 90% of these fish originating from systems containing PIT tag detection infrastructure. As a result, a decision was made to discontinue tagging coho salmon by microtrolling after winter 2021-22 and genetic tissue samples collected in this second year of microtrolling were not processed.

One important consideration for PIT tag-based survival estimates for fish tagged by microtrolling is variability in marine migration strategies of SOG Chinook salmon (partial migration). While many Chinook migrate out of the SOG after the first ocean summer (migrants), others remain for part or all of their marine lives (residents). Migrants and residents likely experience very different food resources, predation pressure, and exploitation rates in the SOG when compared to the continental shelf, resulting in different survival rates. Emigration from the SOG may be size- or growth-selective, and winter PIT tagging/sampling may be biased towards residents. We developed an acoustic tagging study to assess these effects to complement the *Bottlenecks Project*. Chinook were tagged in October 2022 and January 2023 and will be tracked within and out of the SOG to determine migration strategy and outmigration timing. Residents and migrants will be compared to assess if migration strategies differ in initial body size, early marine growth, and/or condition. This project was conducted as part of Activity 3 sampling in 2022-23 (see Chapter 3). A progress report on this project is included as an attachment to this document ("Acoustic Tagging Field Report 2023").

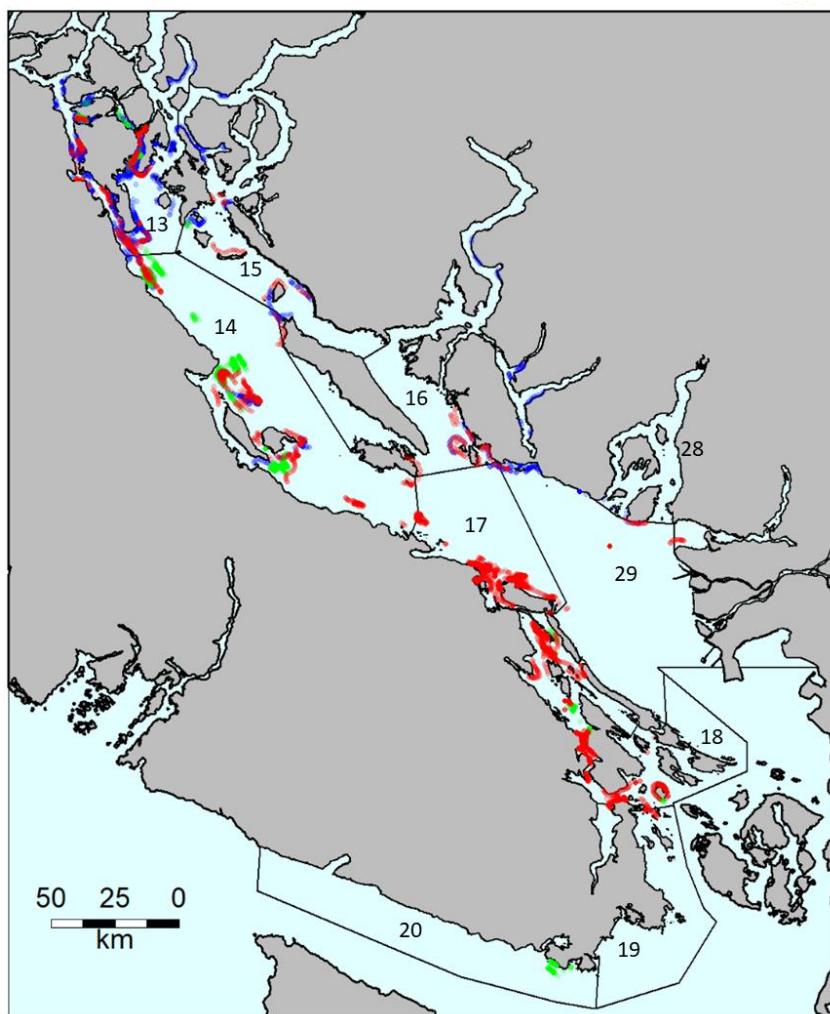


Figure 12. Microtrolling sets conducted to date by BCCF (red), UVic (green), and volunteer (blue) crews in the winters of 2020-21, 2021-22, and 2022-23. Polygons and numbers indicate PFMAs.

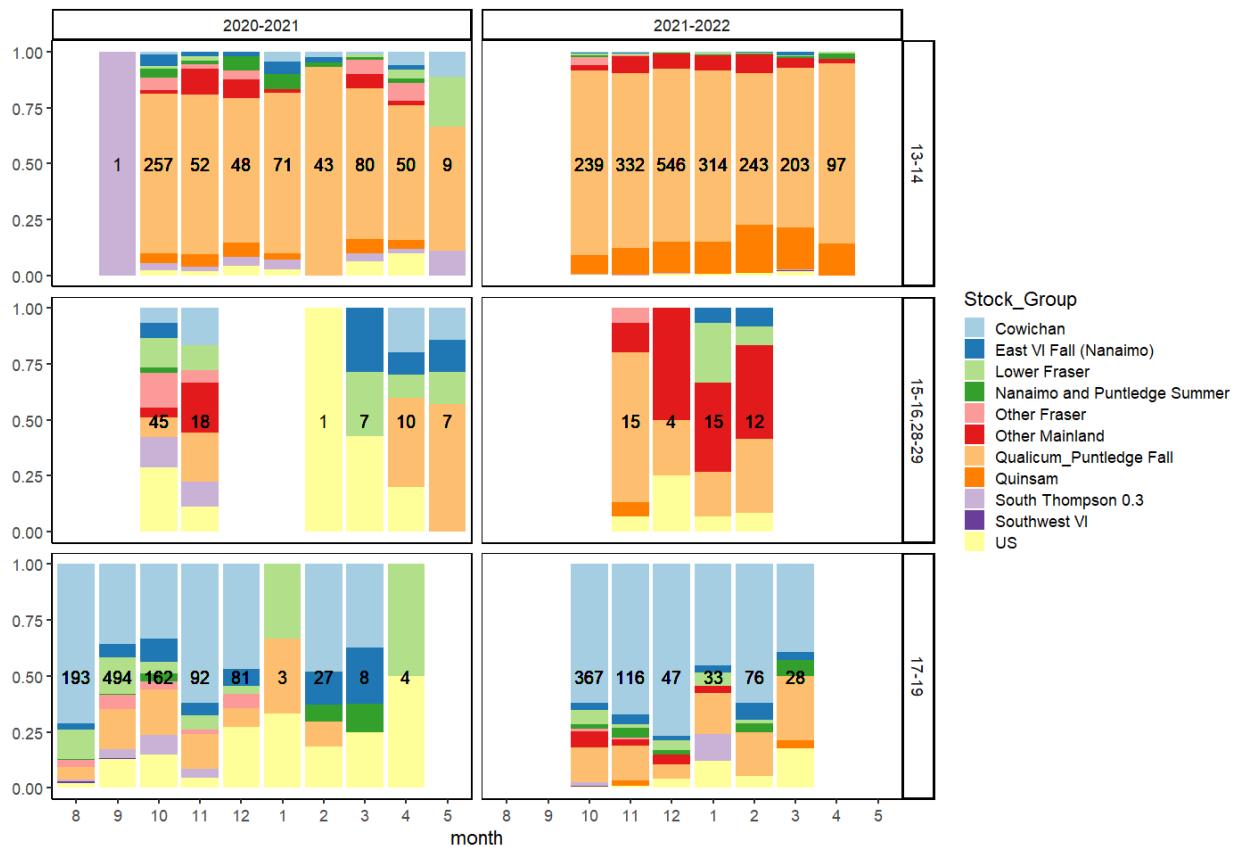


Figure 13. Stock composition by month and PFMA grouping (Figure 12) of FO winter Chinook salmon sampled in winter 2020-21 and 2022-23.

To date microtrolling has been most successful at tagging Puntledge and Qualicum River fall Chinook salmon, followed by Cowichan River Chinook (Table 8). Tag numbers for other stock groups were modest, although 276 Quinsam Chinook were tagged in the second season. Given regional patterns of CPUE in the third season of microtrolling, and regional stock composition observed in the first two seasons, we anticipate that more Cowichan Chinook salmon and fewer Puntledge Qualicum and Quinsam Chinook salmon were tagged in 2022-23 than in previous years. A concentrated effort around the Nanaimo area in fall of 2022 aimed to increase the number of tags applied to Nanaimo River Chinook salmon which were poorly represented in the first two seasons of microtrolling. Genetic stock composition results (summer 2023) will reveal whether this effort was successful.

Stock-specific ID and PBT vs GSI assignments indicate that FO Cowichan Chinook were primarily of natural origin while those from other target stocks were primarily hatchery origin (Table 9). Unfortunately, dramatically curtailed adipose clipping in spring 2020 due to the COVID-19 pandemic limits some inference about the hatchery or natural origin of Chinook salmon captured by microtrolling in the first winter of the program. While Cowichan River Chinook salmon have typically been close to 100% clipped in recent years, only about one-third of releases were tagged and clipped in spring 2020. Concerningly, 71 out of 251 adipose clipped FO Chinook salmon assigned by genetics to *Bottlenecks Project* systems were identified by GSI rather than PBT, despite a very high rate of genotyping of Chinook salmon brood at these hatcheries in fall 2019 and 2020. This result emphasizes the importance of further refinement of GSI vs PBT assignments as a proxy for hatchery vs wild origin.

We estimate that 45 to 60 SO Chinook salmon from the Cowichan River and Puntledge-Qualicum fall stock groups were tagged in each microtrolling season (Table 10). Approximately 10 to 20 SO Chinook from each of the Nanaimo fall and ECVI summer (Nanaimo and Puntledge) stocks were tagged in each year.

An interactive map of stock composition of salmon captured by microtrolling is available at <https://psfsogdc.maps.arcgis.com/apps/dashboards/dfd60eff62714806b731d3bfe7e98066>

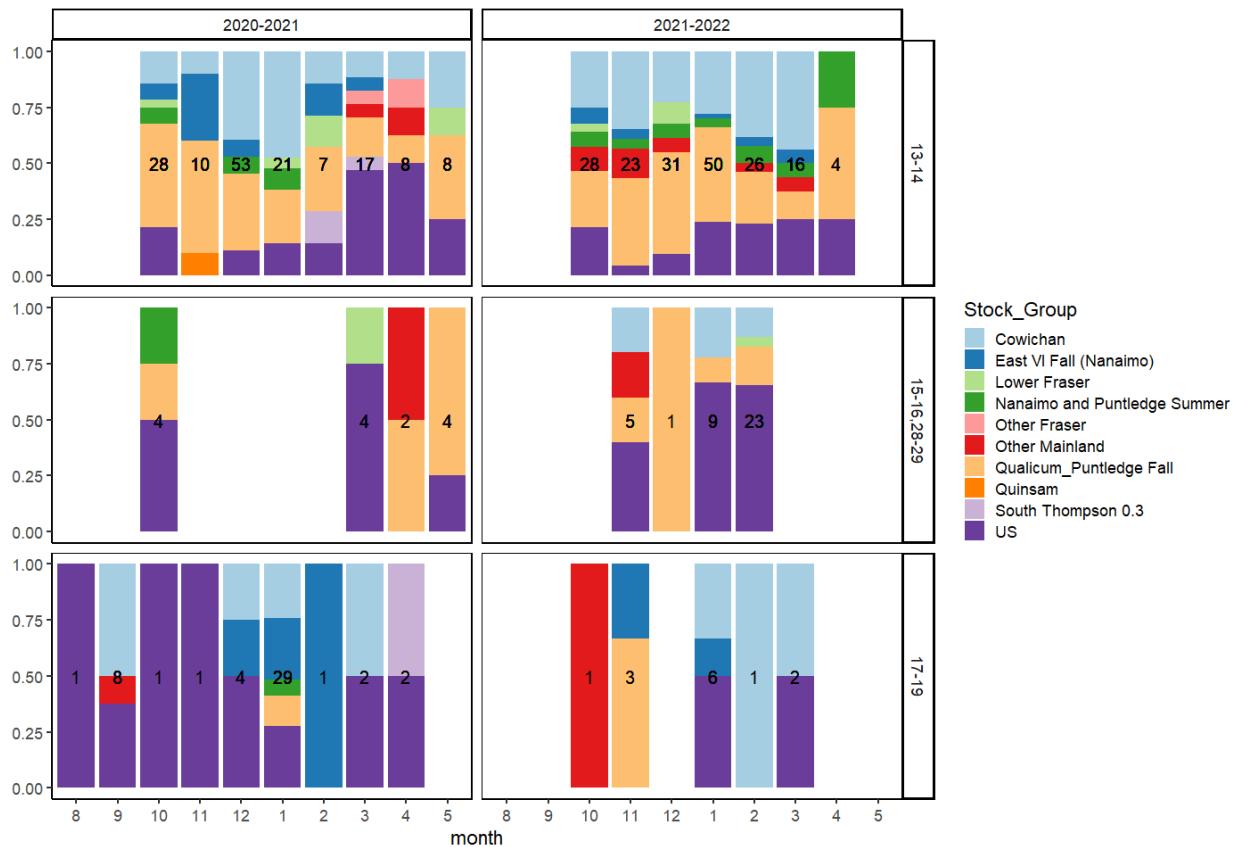


Figure 14. Stock composition by month and PFMA grouping (Figure 12) of SO winter Chinook salmon sampled in winter 2020-21.

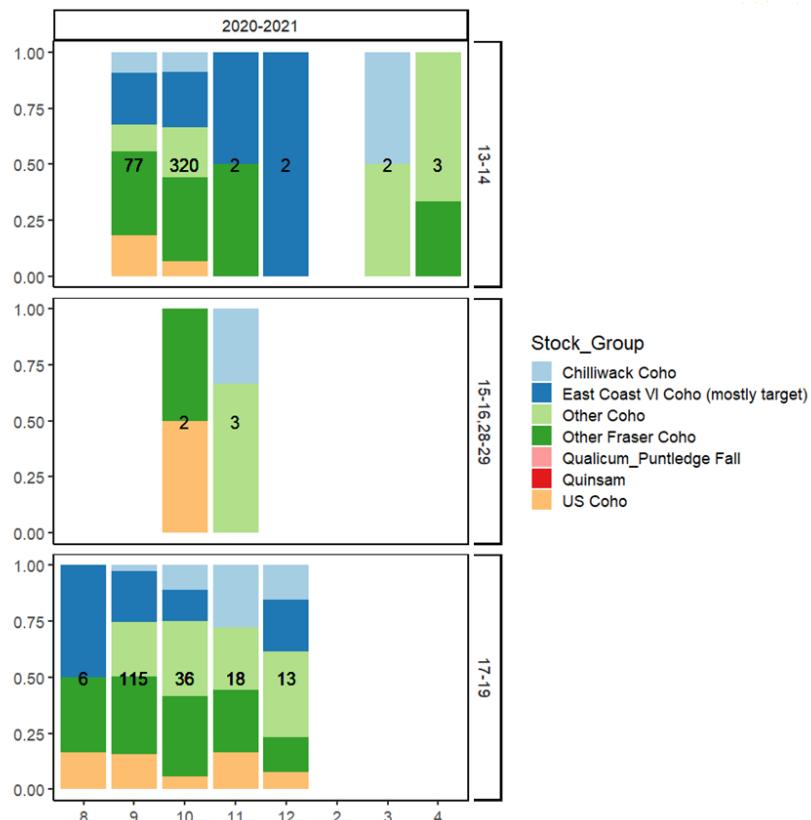


Figure 15. Stock composition by month and PFMA grouping (Figure 12) of FO winter coho salmon sampled in winter 2020-21.

Table 8. Number of FO winter Chinook salmon from major stock groups tagged by microtrolling in the winters of 2020-21 to 2022-23.

Stock Group	2020-2021	2021-2022	2022-2023
Cowichan	487	398	NA
East VI Fall (Nanaimo)	93	31	NA
Lower Fraser	143	57	NA
Nanaimo and Puntledge Summer	32	25	NA
Other Fraser	82	21	NA
Other Mainland	26	161	NA
Qualicum_Puntledge Fall	570	1557	NA
Quinsam	23	276	NA
South Thompson 0.3	65	15	NA
Southwest VI	3	5	NA
US	168	92	NA
Unknown	157	329	2394
Target Total	1205	2287	NA
Total	1849	2967	2394

Table 9. Number of FO winter Chinook salmon from individual stocks tagged by microtrolling in the winter of 2020-21 and 2021. The proportion of fish identified by GSI (likely natural origin) and PBT (likely hatchery origin) is indicated.

Stock Aggregate	STOCK	2020-21		2021-22	
		GSI	PBT	GSI	PBT
<b>Cowichan</b>	COWICHAN_RIVER	362	117	374	19
<b>East VI Fall (Nanaimo)</b>	NANAIMO_RIVER_fall	7	86	12	19
<b>Nanaimo and Puntledge Summer</b>	NANAIMO_RIVER_summer	7	6	10	9
	PUNTLEDGE_RIVER	1	18	1	5
<b>Qualicum_Puntledge Fall</b>	LITTLE_QUALICUM_RIVER	22	116	59	341
	PUNTLEDGE_RIVER_fall	26	201	43	537
	QUALICUM_RIVER	28	176	98	476
<b>Quinsam</b>	QUINSAM_RIVER	2	21	30	244
<b>Target Stock Totals</b>		455	741	627	1650

Table 10. Number of SO winter Chinook salmon from major stock groups tagged by microtrolling in the winter of 2020-21 and 2021-22.

Stock Group	2020-2021	2021-2022	2022-2023
Cowichan	53	59	NA
East VI Fall (Nanaimo)	19	8	NA
Lower Fraser	4	5	NA
Nanaimo and Puntledge Summer	9	11	NA
Other Fraser	2	NA	NA
Other Mainland	4	12	NA
Qualicum_Puntledge Fall	58	66	NA
Quinsam	1	NA	NA
South Thompson 0.3	3	NA	NA
US	51	67	NA
Unknown	1	13	110
<b>Target Total</b>	140	144	NA
<b>Total</b>	205	241	110

#### Adult Tagging

During the 2021 and 2022 study years, a total of 493 and 1,099 Chinook and nine and 52 coho salmon were captured and PIT tagged by Avid Anglers, respectively. For Chinook and coho tagged by Avid Anglers in 2021, 147 were assigned by genetics to systems which have PIT tag antennas, 85 either did not have a genetic sample or have not yet been analyzed, and 209 were identified by genetics as destined for other systems. Most samples from 2022 have yet to be analyzed.

### Escapement Detections

A total of 111 and 303 Chinook salmon and 200 and 789 coho salmon were detected on in-river arrays during adult spawn migrations in 2021 and 2022, respectively (Table 11 – Table 14). As hatchery and wild river and estuary tagging did not commence until spring of 2021, returns/detections in 2021 were primarily expected to be coho jacks (age 2) and Chinook mini-jacks (age 1) in all systems except Black Creek and Cowichan River due to previous tagging efforts. The 2022 return year was the first complete return year for coho tagged in the *Bottlenecks Project* (Table 14) and the first year for Chinook jack returns for the *Bottlenecks to Survival Project* (Table 12).

Table 11. Summary of Chinook adult spawn migration detections in 2021.

Stage at Tagging	Chinook Escapement 2021					
	Big Qualicum	Cowichan	Little Qualicum	Nanaimo	Puntledge	Quinsam
Hatchery	6	24	2	1	0	2
In-river	N/A	21	N/A	0	0	N/A
Estuary	N/A	0	N/A	2	0	N/A
Microtrolling	3	9	0	0	1	0
Adult Marine Tagging	12	12	1	5	6	1

Table 12. Summary of Chinook adult spawn migration detections in 2022.

Stage at Tagging	Chinook Escapement 2022					
	Big Qualicum	Cowichan	Little Qualicum	Nanaimo	Puntledge	Quinsam
Hatchery	9	39	12	53	3	0
In-river	0	95	N/A	0	0	0
Estuary	N/A	N/A	N/A	3	0	N/A
Microtrolling	4	20	3	1	6	0
Adult Marine Tagging	20	22	4	8	3	1

Table 13. Summary of coho adult spawn migration detections in 2021.

Stage at Tagging	Coho Escapement 2021						
	Big Qualicum	Cowichan	Goldstream	Nanaimo	Puntledge	Quinsam	Englishman
Hatchery	20	N/A	N/A	20	108	29	N/A
In-river	N/A	8	N/A	0	N/A	N/A	14
Estuary	N/A	N/A	N/A	0	0	N/A	N/A
Microtrolling	0	0	N/A	0	1	0	0
Adult							
Marine Tagging	0	0	N/A	0	0	0	0

Table 14. Summary of coho adult spawn migration detections in 2022.

Stage at Tagging	Coho Escapement 2022						
	Big Qualicum	Cowichan	Goldstream	Nanaimo	Puntledge	Quinsam	Englishman
Hatchery	64	N/A	4	116	237	94	N/A
In-river	N/A	203	0	0	N/A	N/A	56
Estuary	N/A	N/A	N/A	0	17	N/A	N/A
Microtrolling	0	0	0	0	1	1	0
Adult							
Marine Tagging	0	0	0	0	0	0	0

## Associated Studies & Anticipated Reporting

Table 15. Summary of technical and primary report products associated with Chapter 1 studies.

Report and Papers			
Study	Overview	Study Initiation Year	Status of Reporting
<b>Thornton Creek</b>	Tom Balfour Master's thesis and publication: Freshwater survival of Toquaht River hatchery Chinook	2021	Completed
<b>Shelly Creek</b>	Shelly Creek Cutthroat Trout Movements: Partnered study with the Mid Vancouver Island Habitat Enhancement Society.	2021	Completed
<b>Steelhead MiniPat Study</b>	Technical and primary publication for the steelhead MiniPat kelt behaviour study. (Cowichan,	2021	In Progress

	Englishman, Nahrwitti, Keogh).		
<b>Tagging Related Mortality and Rejection</b>	A comprehensive analysis of tagging related mortality and tag rejection rates for all hatchery tagged Chinook and coho. Technical report and primary article.	2020	In Progress
<b>Earthen Pond Overwintering Study</b>	Primary publication and technical report on the overwintering earthen pond studies (Nanaimo, Puntledge, Big Qualicum, and Quinsam).	2020	In-Progress
<b>Stage Specific Survival of ECVI Chinook</b>	Primary publication and technical report.	2020	Not started
<b>Synthesis report on Comparisons of Wild and Hatchery Coho</b>	Comparisons of survival rates, sizes at outmigration, return timings environmental influences of wild (Englishman River and Black Creek) and hatchery coho (Puntledge, Nanaimo, Big Qualicum, Quinsam). Synthesis report on the differential survival rates of hatchery and wild Chinook stocks on the East and West Coast of Vancouver Island, where applicable (Cowichan, Nanaimo, and Toquaht).	2021	Not started
<b>Synthesis report on Chinook Freshwater Studies</b>	Utilizing all coastal cutthroat trout captures and movements to compare (not been done before) the Nanaimo, Englishman, Puntledge, Black Creek, and Quinsam systems.	2021	Not started
<b>Synthesis Report on Coastal Cutthroat Trout</b>	Primary publication on the values and systems used to develop the volunteer angler microtrolling program.	2021	Not started
<b>Volunteer Angler Microtrolling Program</b>	Primary publication on the distribution through time of Chinook stocks in the Salish	2020	Not started
<b>Marine Stock Distribution</b>		2020	Not started

	Sea. This would require Avid Angler DNA and microtrolling DNA.			
<b>Hatchery and Wild Straying Report</b>	Primary publication and technical report on straying rates of hatchery and wild fish (Chinook, coho, and steelhead).	2020	Not started	
<b>Millstone and Millstream Hatchery Coho Report</b>	Similar studies trying to help kick-start wild populations of coho while monitoring their survival to return and from implanting to outmigration. Comparison between the two stocks, outmigration survival and outmigration timing and influence of water temperature and photoperiod could be done in partnership with Peninsula Streams Society and DFO StAd.	2022	Not started	
<b>Englishman Wild Coho Report</b>	Freshwater survival study for coho. Assess out-migration survival and timing between three sites (two primary sites) and influences of water temp, flow, size, and between systems. Continue in 2023.	2021	Not started	

## Lessons Learned & Next Steps

### Low Proportion of Natural Origin Chinook

The proportion of natural origin fish (as indicated by GSI vs PBT) seems to be very low for all target Chinook salmon stocks with the exception of Cowichan River fall and potentially Nanaimo River summer and fall Chinook salmon. It may not be possible to assess hatchery vs wild survival for the majority of *Bottlenecks Project* stocks.

### Coho Marine Capture

The capture and tagging of FO winter coho in the marine environment proved to be difficult. In the program's first three years, 1,435 FO 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.

Genetic stock composition analysis was only run for coho in the program's first year and suggested a low proportion of fish were (~20%) from *Bottlenecks Project* systems. Further, only 25% of these fish were

identified by PBT. Given the high rates of straying in coho and many small enhanced and unenhanced systems throughout the Strait of Georgia, 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 in October; focusing efforts at these identified locations and times could dramatically increase the number of fish tagged. However, given the low proportion of target stocks, the continuation of the coho marine tagging portion of the *Bottlenecks Project* is not planned.

#### *Chinook In-river Capture*

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.

## Chapter 3: Juvenile Chinook Salmon Winter Ecology

The goal of this component is to understand if, and how, the first winter at sea regulates survival of both hatchery and wild fish.

### Objectives

1. Investigate overwinter survival and ecology of enhanced and wild Chinook in the Strait of Georgia;
2. Characterize the habitat preference (depth, water column depth, and temperature) of juvenile Chinook (wild and enhanced) salmon occupying the Strait of Georgia from October to March;
3. Provide the first diet composition and quality data for juvenile Chinook salmon occupying the Strait of Georgia in winter;
4. Assess whether there is evidence for overwinter nutritional stress that would be consistent with the physiological mediated winter mortality predicted by the critical size – critical period hypothesis;
5. Further to #3, use bioenergetics models parameterized with empirical data collected as part of this project (salmon size and energy density, prey composition and energy density, and *in situ* temperature) to assess the plausibility of overwinter starvation and the sensitivity of overwinter nutritional state to juvenile salmon size, prey availability, and water column temperature;
6. Directly test the relative strength of the predictions of two interpretations of the critical size – critical period hypothesis: specifically, that fish with inadequate early marine growth and/or fish with inadequate size prior to winter, experience nutritional stress during winter, which is consistent with starvation; and,
7. Assess the potential role of infectious agents and their interactions with nutritional stress in causing overwinter mortality.

### Methods

#### Microtrolling

Fish sampling was conducted on an on-call basis, from fall through early spring (2020-21, 2021-22, and 2022-23), dependent on weather conditions. Salmon were sampled by microtrolling from a 6 m vessel using the modified recreational fishing gear described in Chapter 1 (Duguid and Juanes 2017; Rodgers et al. 2022). Each downrigger fished a maximum of six lines, typically 15.2 m apart, and depths were staggered on opposite sides to spread gear at 7.6 m intervals. Terminal gear consisted of five in purple hot spot micro-flashers and #01 “Dick Nite” spoons modified for #12 barbed fly-tying hooks with a 5 mm point-to-shank gap.

In winter 2020-21 and 2021-22, fishing activity was conducted systematically (see *Habitat Use*), 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 (hereafter “habitat days”;

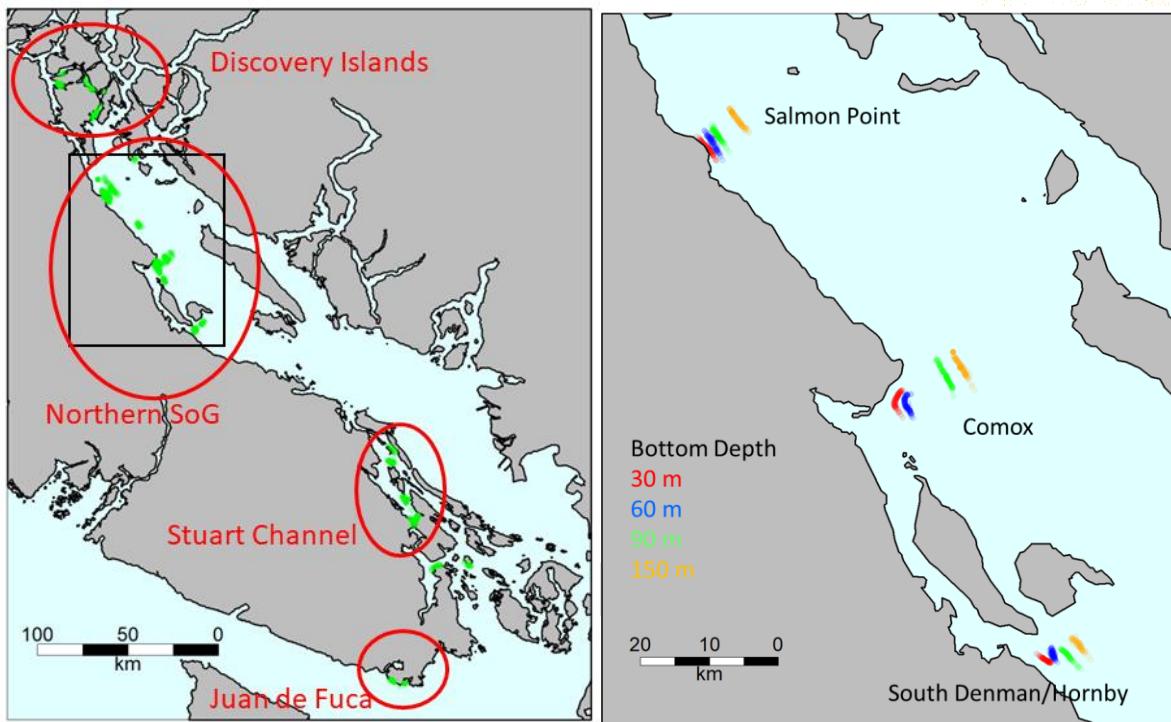


Figure 16). On a monthly basis, temperature of the water column to 90 m was recorded by a Castaway CTD (SonTex, San Diego California) cast at each of these sites. On all other occasions, fishing activity occurred haphazardly with vessel location, number of hooks, and gear depth adjusted for the purpose of maximizing catch (hereafter “biosampling days”). 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 FO 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 (see Chapter 1 for details).

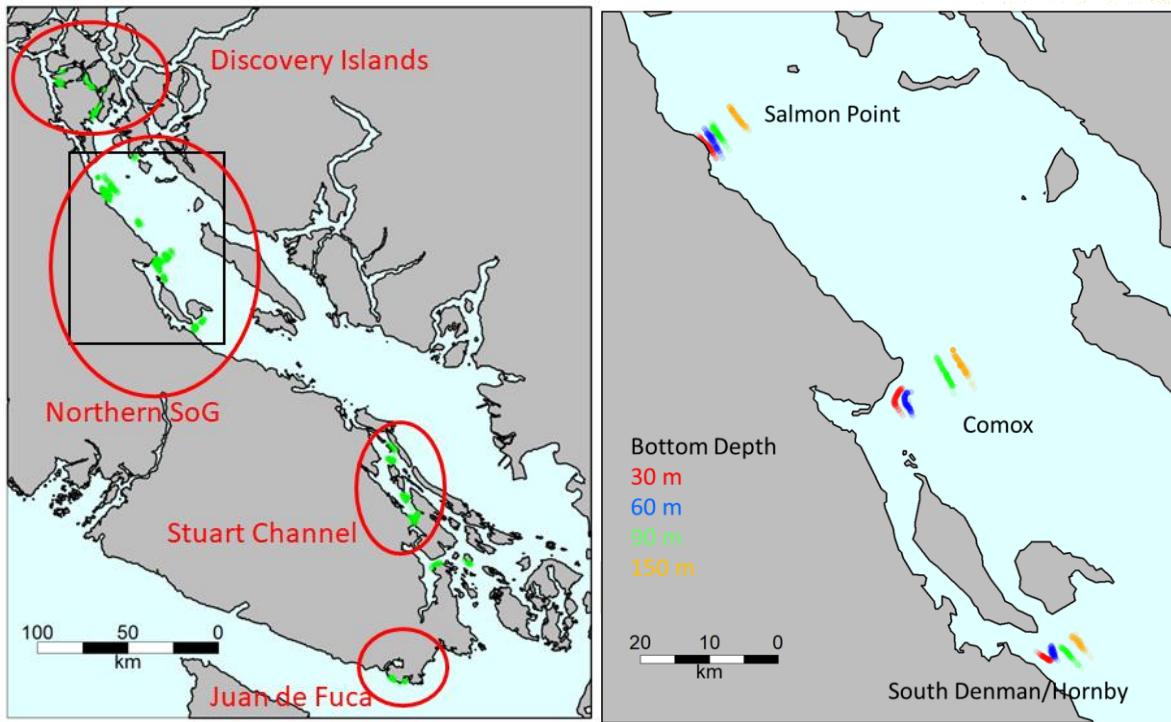


Figure 16. Biological sampling effort (left panel) and systematic habitat sampling effort (right panel, location indicated by inset in left pane) conducted by UVic crews in the initial two years of the *Bottlenecks Project*. Red ellipses indicate regional groupings referred to in the current document.

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 FO 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 Activities 1 and 2.

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.

#### Lab processing

#### *Prey*

Chinook salmon prey samples were sorted into taxonomic groups under a dissecting microscope, with taxonomic resolution varying by group based on ease of identification and frequency of occurrence. Diet items were blotted on a KimWipeTM to remove excess moisture and weighed to the nearest 0.0001 g. A subset of prey in near-perfect condition (typically live specimens) were weighed individually in pre-

ashed weigh boats. These samples were frozen at -20 °C then transferred to -80 °C for storage prior to determination of energy density (ED). The remaining prey items were bulk weighed in their respective taxonomic groupings.

Preserved prey samples were oven dried at 60 °C until a constant mass was reached and weighed to determine the dry weight (DW). These dried samples were placed in a muffle furnace at 550 °C for 3 h and weighed again for the ash weigh (AW). AW was subtracted from the DW and divided by the wet weight (WW) to determine the ash-free dry weight (AFDW) to WW ratio. This ratio was used to predict energy density using the methods of Weil et al. (2019).

#### *Chinook Salmon 2020-2021:*

Frozen Chinook salmon were thawed, and otoliths were removed and stored dry for possible subsequent use in microchemistry work to reconstruct marine migrations. A caudal fin clip and 5 mm<sup>3</sup> dorsal muscle biopsy were removed, dried at 60 °C, and stored in a desiccator for later stable isotope analysis. The stomachs were dissected out and examined for remaining contents following the field gastric lavage procedure; if present, diet items were identified and weighed. The whole body (including the empty stomach) was portioned and dried at 60 °C until a constant mass was reached. Dried fish were weighed, homogenized into a fine powder, and stored in a desiccator. Three aliquots of approximately 1 g of homogenized tissue per fish were ashed in a muffle furnace for 3 h at 550 °C in pre-ashed aluminum weigh boats, and weighed to 0.00001 g. A control homogenate was made from Chinook salmon fillet, and portions of this control accompanied each step of the laboratory process.

#### *Chinook Salmon 2021-2022, 2022-2023:*

Biopsies of muscle and liver tissues were taken from 2021-2022 fish for lipid analysis, and muscle biopsies will continue to be collected for 2022-23 fish for stable isotope analyses. All fish from the second and third sampling seasons were also dissected for somatic index analysis. Specifically, each fish was weighed (nearest 0.001 g) and measured (FL; 1 mm), and the viscera was dissected. Carcass (viscera removed) and viscera, comprised of the heart, liver, spleen, gall bladder, and gastrointestinal tract (with stomach contents removed) were weighed. The gastrointestinal tract with and without intestine contents and the liver were weighed separately. Subsequently, these fish were dried and processed as described above.

#### *Scales:*

Impressions of Chinook salmon scales were made at the DFO Pacific Biological Station by pressing scale cards onto acetate sheets using a DK20SP 16X20 Automatic Digital Swinger swing-away heat transfer press following methods described in Hudson and Crosby (2010). Processing of these scale impressions is in progress. Scale impressions are photographed at 8X magnification or other magnification adjusted due to scale size, using bright field illumination with an Olympus DP26 digital camera mounted on an Olympus S2X16 stereomicroscope. Scale impressions are only analyzed when a clearly defined origin indicates that the scale is not regenerated. CellSens software will be used to draw a line from the center of the origin to the scale margin in an anterior direction along the longest axis of each scale. The point tool will be used to place points sequentially beside this line at the center of the origin, margin of the origin, and at the outer margin of each circulus out to the edge of the scale. The line length measurements and cartesian coordinates of points for each scale will be exported as comma separated value (csv) files and custom code in the “R” statistical language will be to count the number of circuli and calculate the linear distance between sequential points. Where the sum of these linear distances (the

radius of the origin and spacing of each circulus) differs by more than 2% from the scale radius measured using cellSens software, the measurement process for the scale will be repeated.

### Analyses

#### *Habitat Use:*

As a preliminary investigation of how FO Chinook salmon CPUE in the Northern Strait of Georgia varied spatially and through the season we employed a binomial GAM. We hypothesized that Chinook Salmon CPUE would differ among years, sites, and transects (defined by bottom depth) and would vary globally and non-linearly by hook depth and day of year (DOY). We also hypothesized that site-specific non-linear relationships might exist between CPUE and DOY. Our binomial GAM included a parametric term for site and transect; global smooth terms for depth, and DOY; and site-specific smooth terms for DOY. Models were fit using maximum likelihood (ML) and default thin plate splines. To facilitate comparison of the effect of site, year and transect on CPUE relative to the mean across levels, rather than to a reference level of each factor, we employed deviation coding for all parametric effects. For DOY, where both a global smooth and site-specific smooth were included in the model, a first derivative penalty was applied to the site-specific smoother. We limited the maximum degrees of freedom (knots) of smoothers to 4. The clustering of hooks within an individual gear deployment (set) represented a potential violation of the assumption of independence in our modelling approach. The GAM function in ‘mgcv’ allows the inclusion of random effects modelled similarly to smoothers as penalized regression terms (bs = “re” in ‘gam’ model formula; Wood 2008). We used this approach to include set as a random effect in our model, thereby generating a generalized additive mixed model (GAMM). Due to the dataset’s relatively large size, this GAMM was fit using the function ‘bam’ rather than the function ‘gam’ in the package ‘mgcv’ in R. The function ‘bam’ is optimized for more computationally efficient fitting of generalized additive models to large datasets (Wood et al. 2015).

#### *Diet Composition and Quality:*

As a preliminary exploration of diet composition, we plotted bulk gravimetric composition of diets by mass aggregated by year and into three broad regions (Northern Strait of Georgia, Discovery Islands, and Stuart Channel). Data were represented as overall biomass proportions rather than means of individual diet proportions. Diet composition was also explored using Non-metric multidimensional scaling (NMDS) ordination of Bray-Curtis dissimilarities between daily individual mean diet proportion data in different sampling regions with the Northern Strait of Georgia region being broken down into the two main sites (Comox, Salmon Point). Confidence ellipses (95%) were used to explore differences in diet composition (location) and variability (dispersion) for site-by-study year data groupings. Taxonomic variation in diet energy density was represented graphically as box plots of energy density by prey category.

#### *Assessing Evidence of Nutritional Stress:*

As a preliminary investigation into the plausibility of winter as a period of nutritional stress, we assessed the energy content of diets and fullness of first-ocean-year Chinook salmon over the sampling period. We also compared the energy contents of diets in relation to fish weights, given different diet compositions. These analyses included pooled data for the initial two study years and were only conducted for Chinook salmon captured in the Northern Strait of Georgia. The energy density of retained fish from the first two years of the study were plotted by date, and further analyses will include fish from additional sampling years. In all cases, locally weighted smooths were fit to highlight patterns. We also examined condition of first ocean year Chinook salmon by examining seasonal trends in residuals from a regression of log weight on log fork length. Generalized additive model smooths were

fit independently to represent the relationship between these residuals and date. Analyses will be refined and conducted at a stock-specific level when genetic stock identification data are available for all years.

Bioenergetic modelling is a valuable tool to investigate ecological questions related to fish growth. Bioenergetic models are based on mass balance equations in which the input of energy is balanced by metabolic demands, waste losses, specific dynamic action (the energy required to handle and digest food), and growth or energy storage (Deslauriers et al. 2017). Models are being developed with the Wisconsin bioenergetic modeling framework using the Fish Bioenergetics 4.0 (FB4) Shiny application in RStudio. This application allows researchers to modify species- and habitat-specific parameters used as inputs in the models, e.g., using data collected in the field. The physiological parameters for our models are taken from literature values (Stewart and Ibarra 1991; Plumb and Moffitt 2015), but for all other variables we are using data collected in the field as inputs. These include fish size, diet composition, energy density of both Chinook salmon and their prey, and temperature at depth of capture. Field variables included in the models will change over time (likely monthly) as relevant.

These models can be run at the individual or cohort level, and we will develop various models for our broad stock grouping (ECVI), and may investigate differences in finer groupings, data permitting. We also intend to develop growth period specific models. We will determine breakpoints in growth rate using the “segmented” package in R. Various bioenergetic models will be developed to compare the consumption rates required to support these differing periods of growth. We will simulate the consumption rates of first-ocean-year juvenile Chinook Salmon and assess the likelihood that these fish are starving.

Following consultation with experts, we have decided not to develop cesium mass balance models to derive independent estimates of consumption rate as originally proposed for this activity. Cesium mass balance models have not been parameterized at a species-specific level, limiting confidence in resulting consumption rate estimates.

In the second year of the project (2021-2022) we conducted a preliminary investigation of total lipid and lipid composition for lethally sampled Chinook salmon from target stocks. Structural lipids, within the class of polar lipids, are present in cell membranes (Parrish 2013); however, these lipids are not readily used as a source of energy for fish, except as a last resort (Næsje et al. 2006). Storage lipids, typically in the form of triacylglycerols (TAGs), can be broken down and mobilized when dietary energy intake does not meet metabolic energetic demands (Sheridan 1988; Finstad et al. 2010). The energy density of fishes is closely linked to storage lipid content (Martin et al. 2017). While total lipid content can provide some insights into the energetics of fish and act as a reasonable proxy for TAG in fishes at high TAG levels, the relative composition of TAGs and polar lipids may yield greater insights into fish health, especially when TAG levels are low (Næsje et al. 2006). For example, in Atlantic salmon (*Salmo salar*), TAG content decreased throughout winter by 34-57% suggesting that energy-selective (rather than size-selective) mortality occurred in fish with the lowest TAG levels (Næsje et al. 2006). Additionally, Finstad et al. (2004) energetically modeled juvenile Atlantic salmon and similarly found that individuals with low storage energy dropped out of the population.

Lipid analyses were attempted (total and lipid composition) in two tissue types (liver, muscle). However, no TAGs were detected in any of the liver samples and reduced TAG was present in the muscle samples. While the total lipids reported in these samples was likely accurate, we decided not to run additional samples given the high cost and close link between total lipid and energy density. We suspect that the

lipid composition analysis failed due to one or more storage issues. First, whole fish were killed in the field and held on ice for several hours, and occasionally overnight, prior to freezing at -20 °C. During this time, it is plausible that the TAGs broke down to free fatty acids rapidly in the liver and more slowly in the muscle tissues, resulting in the discrepancy. Second, these frozen fish were then stored in a -20 °C freezer for several months prior to transfer into a -80 °C freezer. Further lipid degradation may have occurred while stored at this warmer temperature. Finally, analysis was conducted 9-12 months after euthanasia, close to the maximum recommended storage time limit.

From all retained Chinook we have collected caudal fin clips and dorsal muscle biopsies. We intend to use funds initially dedicated to lipid analysis for stable isotope analyses. Stable isotopes will be used to understand longer-term Chinook salmon diets and may also be used as proxies for lipid content (Post et al. 2006, Hoffman et al. 2015). Estimates of trophic position derived from  $^{15}\text{N}:\text{N}^{14}$  ratios will be used to understand whether the transition to piscivory (specifically consumption of age-0/1 Pacific herring) for juvenile Chinook salmon is limited by size, with potential implications for growth and survival (Duguid et al. 2021).

*Assessment of critical size, critical period hypothesis:*

Different versions of the critical size-critical period hypothesis have slightly different predictions regarding mortality during the winter critical marine period. In the original formulation of the hypothesis (Beamish and Mahnken 2001) it is fish that fail to achieve adequate size prior to winter which experience physiologically mediated mortality. More recent descriptions of the hypothesis state that fish which do not experience rapid enough early marine growth will not switch from growth to lipid storage soon enough (during the summer) and therefore may be more subject to overwinter mortality (Beamish et al. 2008, Beamish and Neville 2016). While the absolute size of such doomed fish at the end of summer might be the same as that of likely survivors, they would have lower energy reserves (primarily lipid). Scale samples from microtroll-caught Chinook salmon will be used to assess growth rate during the period immediately after ocean entry. Spacing of the circuli (ridges) on fish scales is positively related to somatic growth rate (Doyle et al. 1987; Fisher and Pearcy 1990). We will measure the width of all scale circuli following Duguid et al. (2018), and will use the mean spacing of the first ten circuli after the saltwater entry check as an index of growth rate over approximately the first two months in the ocean (see Gamble et al. 2018 for data on the circulus deposition rate of juvenile Salish Sea Chinook salmon). We will develop generalized linear models with condition factor (Fulton's K) as response variables for all fish, and with energy density as a response variable for lethally sampled fish. Predictor variables for candidate models will include fish length, early marine growth, and the interaction of these variables with date. We will use these models to test the predictions of the critical size-critical period hypothesis; specifically, that energy density (and possibly, but not necessarily condition factor) will decline more over the winter for smaller fish or fish which experienced poor early marine growth.

*Biomarker assessment of the role of pathogens and nutritional stress in overwinter mortality:*

Juvenile Chinook salmon captured by microtrolling were subject to non-lethal gill biopsies (Martinelli-Liedtke et al. 2011) which were preserved in RNA later and subsequently frozen at -20 °C before transfer to -80 °C for storage. We will select a subset of these samples (up to 600 samples over the course of the planned three years of sampling) for biomarker assessment based on genetic stock identification results and stratified sampling from the size and lipid content distribution of monthly samples. We will analyze samples from well represented stock groups to avoid potential confounding effects of rarely encountered stocks. Gill biopsies will be analyzed by the Molecular Genetics Laboratory at the Pacific Biological Station which has pioneered the use of gene expression biomarkers to detect viral disease

states (Miller et al. 2017) and physiological responses to environmental stress (Houde et al. 2019) that may precede and predict mortality in Pacific salmon. Infective agents known to occur and proliferate during winter will be combined with stressor and disease biomarker panel sets to produce a custom over winter ‘Fit Chip’ (Houde et al. 2019). Biomarker expression patterns and microbe loads from Fit Chip analyses will be combined to determine if specific microbes are associated with a disease state in juvenile Chinook salmon. Stratified sampling from across the size and lipid content distribution of juvenile Chinook salmon will also facilitate analysis of whether microbe loads and potentially associated disease states are correlated with small size, poor condition, and/or low energy reserves. As juvenile Chinook salmon are being sampled monthly from October to March it will also be possible to assess changes in the prevalence of microbes over time. A decrease in prevalence for infectious agents which also exhibit truncation of load (an absence of high load individuals from the population), would be consistent with disease mortality (Tucker et al. 2018), potentially corroborating disease state biomarker and histopathology results.

Concurrent with collecting gill biopsies as part of Activity 3, the Molecular Genetic Laboratory has engaged a postdoctoral fellow conducting juvenile Chinook salmon food limitation challenge trials at two temperatures. These fish will be subject to gill biopsies which will be used for an RNA-Seq study to identify gene expression markers of food limitation (and potentially nutritional stress). If successful, these markers will be incorporated into the Fit Chips used to run samples from Activity 3 to specifically test the hypothesis that fish are food limited in winter. The inclusion of these markers on the FIT chips run for Activity 3 represents an excellent opportunity to add value to this work. For this reason, analysis of these samples (currently archived at -80 °C) will be delayed until winter 2023-24.

## Interim Results

### Habitat Use:

Systematic microtrolling at three sites in the Northern Strait of Georgia suggested distinct patterns of overwinter habitat use by Chinook salmon in the first winter at sea. The effect of hook depth on CPUE was negative at depths shallower than 30 m and very few FO Chinook were caught shallower than 30 m (Figure 17). CPUE increased rapidly to a peak at 60 m and then declined to the deepest depth fished at 90 m. Chinook Salmon CPUE decreased with increasing transect bottom depth. The effect of transect on CPUE was most positive for the 30 m transect, positive for the 60 m transect, and similarly negative for the 90 m and 150 m transect. Despite the trend towards increasing CPUE with decreasing bottom depth, the strong peak in CPUE at a hook depth of 60 m resulted in the aggregate proportion of hooks with FO Chinook Salmon (for hooks spaced evenly from 7.6 m to the bottom) being higher for the 60 m bottom depth transect (6%) than for the 30 m bottom depth transect (4%). First Ocean winter Chinook salmon CPUE was marginally higher in 2021-2022 than in 2020-2021 and was elevated at Comox and depressed at Deep Bay. At all sites CPUE was high in October and then dropped off dramatically. Only Comox exhibited a significant deviation from this trend with relatively elevated CPUE in mid-winter.

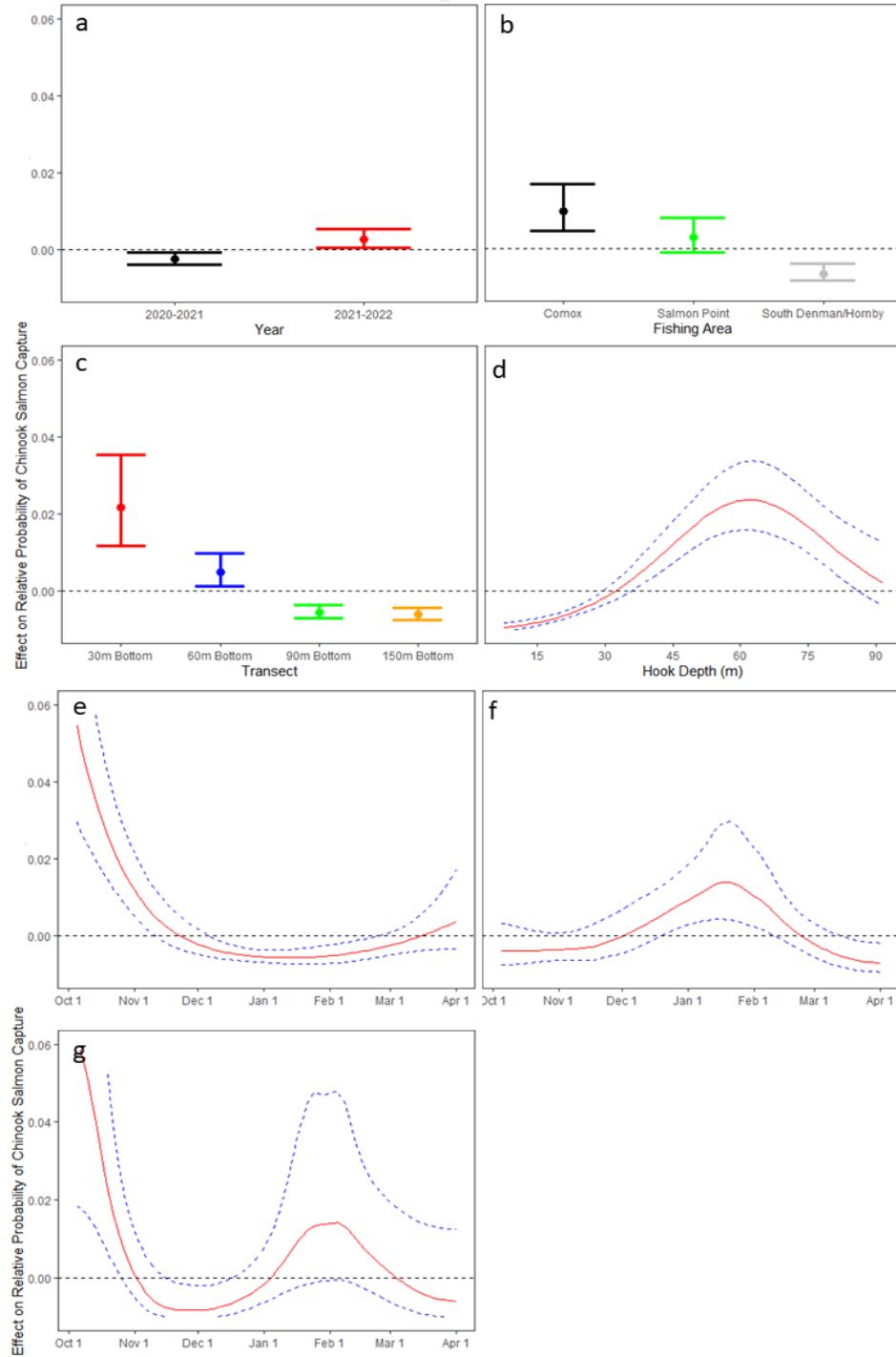


Figure 17. Effects plot for preliminary generalized additive mixed model (GAMM) of the effect of a. year, b. site, and c. transect (bottom depth); and non-linear effects of d. depth, e. day of year, and site-specific deviation from the global effect of day of year at f. Comox and g. Salmon Point on the probability of catching a first ocean winter Chinook salmon on a given hook. As the site-specific deviation from the global effect of day of year at South Denman/Hornby was not significantly different from a horizontal line it was penalized out of the model.

### Diet composition and prey quality:

Juvenile Chinook salmon diet analysis indicates that there are spatiotemporal differences in the prey consumed throughout winter (Figure 18, Figure 19). At the Northern Strait of Georgia (NSoG) sites, Comox and Salmon Point, diets are invertebrate dominated. Further, cephalopods are seemingly more important in Comox, whereas Euphausiids are more abundant in the diets from at Salmon Point, and polychaetes are meaningfully present at the Comox site in late winter. In both the Discovery Islands (DI) and Southern Gulf Islands (SGI) regions, fish make up a greater proportion of the diets. In all regions, we see near absence of decapod larvae which are very important in summer diets, and these fish are still feeding when Pacific Herring are absent.

The NMDS ordination (Figure 19) includes data from both years and compares diet composition by region and year; points closer in space are more similar. At the NSoG sites there is more diet overlap in the same year at different sites than within a site over multiple years. This suggests that the interannual difference in diets is greater than among site differences, as indicated by the separation of ellipses. In the second field year (2021-2022), there are also similarities in diet composition. The SGI diets overlap with both other regions, which is largely driven by Pacific herring and euphausiids, but the NSoG and DI are less similar to each other despite their closeness geographically.

Our preliminary prey ED analyses show variability both within and between prey categories (Figure 20). The broad range of ED values in some groups, such as *Paraeuchaeta*, may be explained by our use of both live and dead but near-perfect specimens, and this will be explored further.

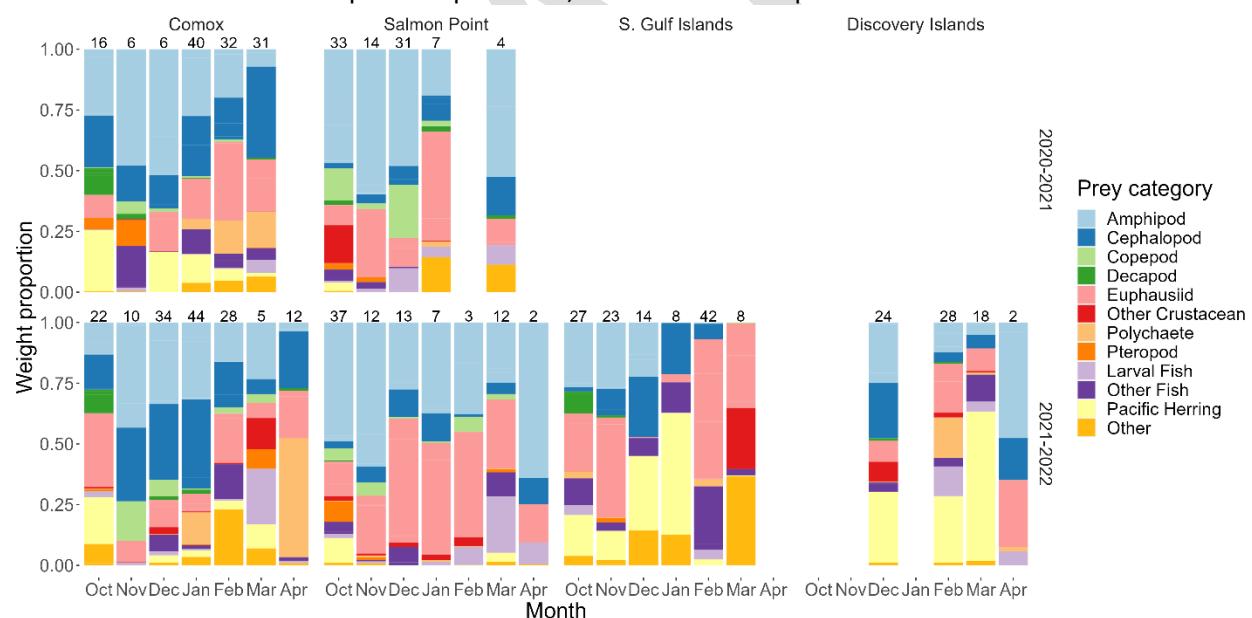


Figure 18. Individual mean diet proportions for first ocean winter Chinook Salmon from October to April for 3 regions of the Canadian Salish Sea. Sample size for diets examined is above the bars.

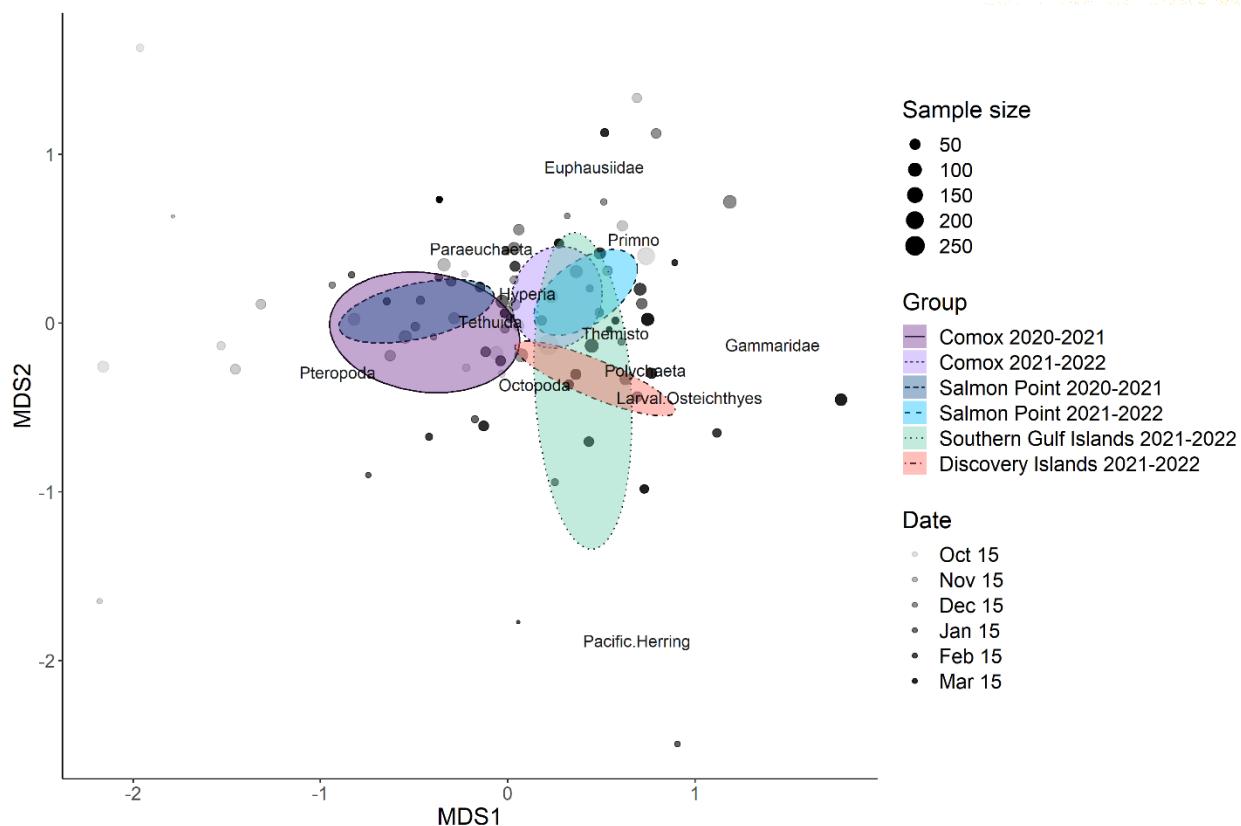


Figure 19. Non-metric multidimensional scaling (NMDS) ordination of Bray-Curtis dissimilarities between individual mean diet proportion data for prey classifications of juvenile Chinook salmon at our sampling regions, where the Northern Strait of Georgia region was broken down into the two main sites (Comox, Salmon Point). Each point represents a sample which is the average diet composition from a single sampling day, the size of the points indicates the number of fish stomach samples examined from that field day, and point transparency denotes sampling date. Ellipses are 95% confidence intervals around group designations (sampling region and year combinations).

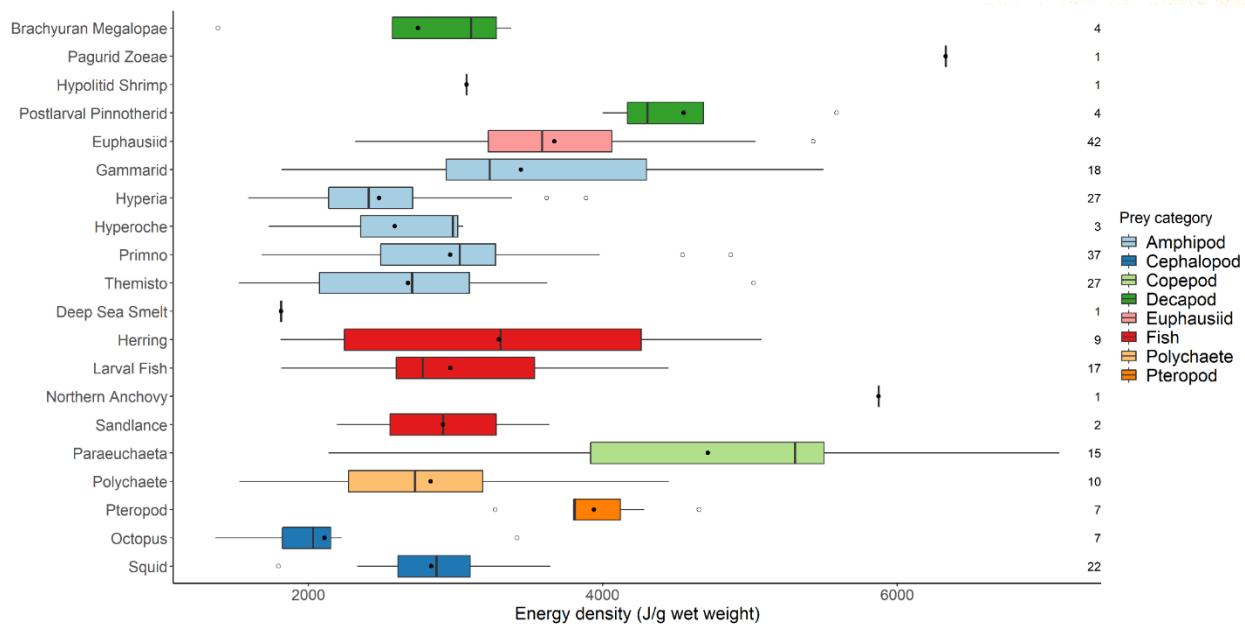


Figure 20. Energy density (J/g wet weight) values of diet items for both years (pooled due to small sample sizes), where colour denotes broad prey category. Boxplots show the range in energy density values for each taxonomic group, where the center line represents the median, solid dot represents the mean, box limits display the interquartile range, whiskers represent 1.5X the interquartile range, open circles are outliers, and numbers to the right of each boxplot indicate sample size.

#### Assessing Evidence of Nutritional Stress:

The energy content by weight proportion of first-ocean year Chinook Salmon diet items exhibits a seasonal trend. Energy content was high but declining from October through December followed by a sharp decline in January to plateau for the remainder of winter (Figure 21). Chinook Salmon stomach fullness and diet energy content relative to fish mass exhibit similar trends. These metrics increased to November until a decline from December through January to a stable low, with a possible increase at the beginning of April.

The mean energy content of individual Chinook salmon diets relative to fish mass was lower when considering all diets as compared to fish which had Pacific Herring as a component of their diet (Figure 22). However, the temporal effect (as explained above) was similar between groups.

Fork length of FO Chinook Salmon increased through the fall (apparent growth given an assumption of no size selective emigration or mortality), but this increase slowed or plateaued from late December on, before increasing again in March (Figure 23). Residuals of a regression of log weight on log length were also significantly positive prior to December and significantly negative after January (Figure 24) suggesting that fish were utilizing endogenous reserves for energy.

First-ocean year Chinook Salmon whole-body ED exhibited a clear temporal trend that is consistent in both years with a steady increase from October to January and a steep decline from January through April. These results emphasize the importance of our longitudinal sampling, particularly as these values will be used in bioenergetic models (Figure 25).

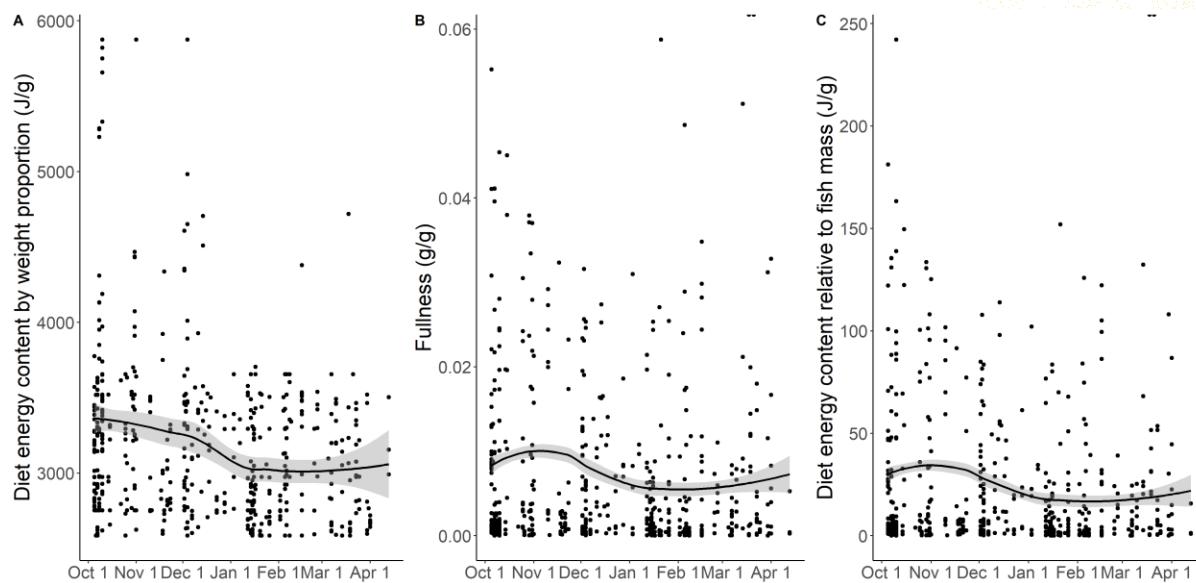


Figure 21. Locally weighted scatterplot smooth (loess; span = 1) by date of (A) the mean energy content (J) of prey in individual fish diets by their relative weight proportion (g), (B) the fullness (g prey in the diet relative to fish mass(g)), and (C) the energy content (J) of individual fish diets relative to fish mass (g). This includes only fish captured in the Northern Strait of Georgia but pools both years.

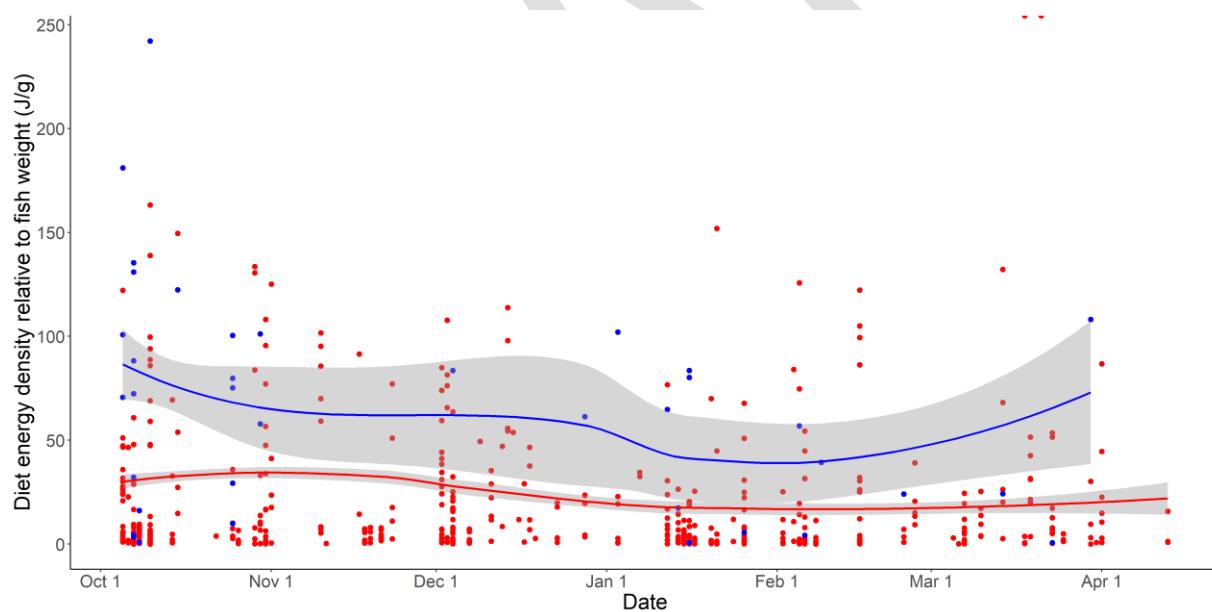


Figure 22. Locally weighted scatterplot smooth (loess; span = 1) by date of the mean energy content (J) of fish diets by the proportion of prey in the diets (g) where the red points and line include all fish diets, and the blue points and line indicate diets which contained Pacific herring. This includes only fish captured in the Northern Strait of Georgia but pools both years.

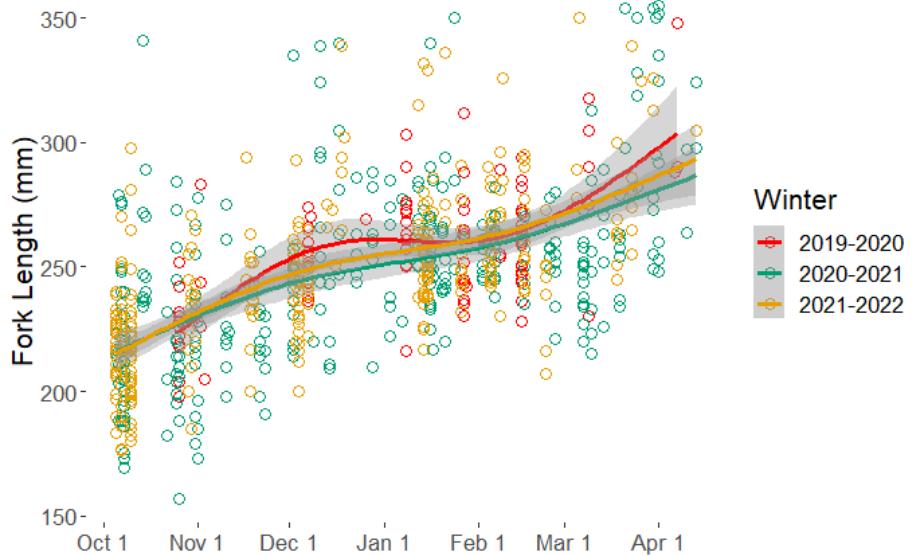


Figure 23. Nose Fork length for FO Chinook salmon by date in the Northern Strait of Georgia in Winter 2020-21 and 2021-22. Non-linear GAM smooths.

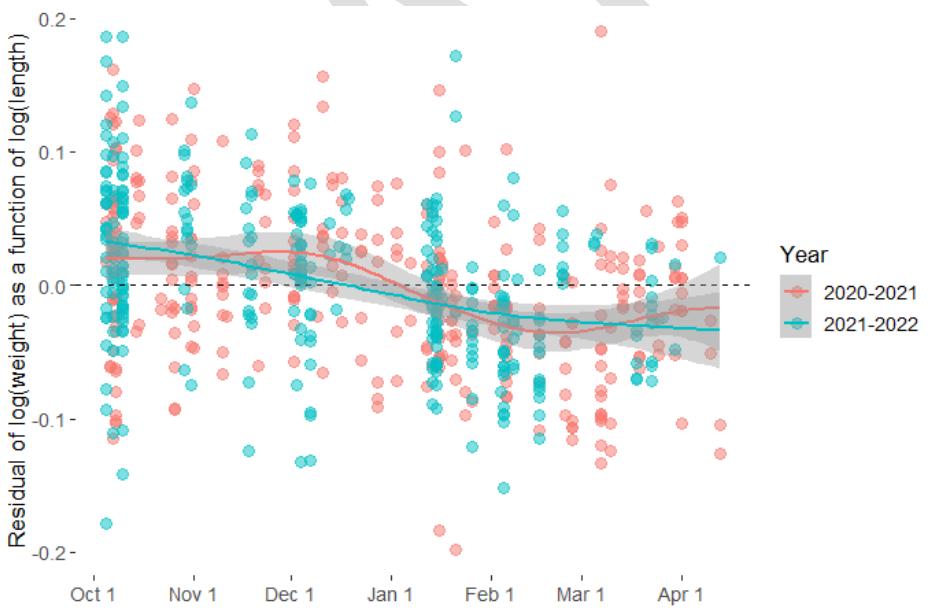


Figure 24. Condition (residuals of a regression of log weight on log fork length) for FO Chinook Salmon by date in Winter 2020-21 and 2021-22. Non-linear GAM smooths.

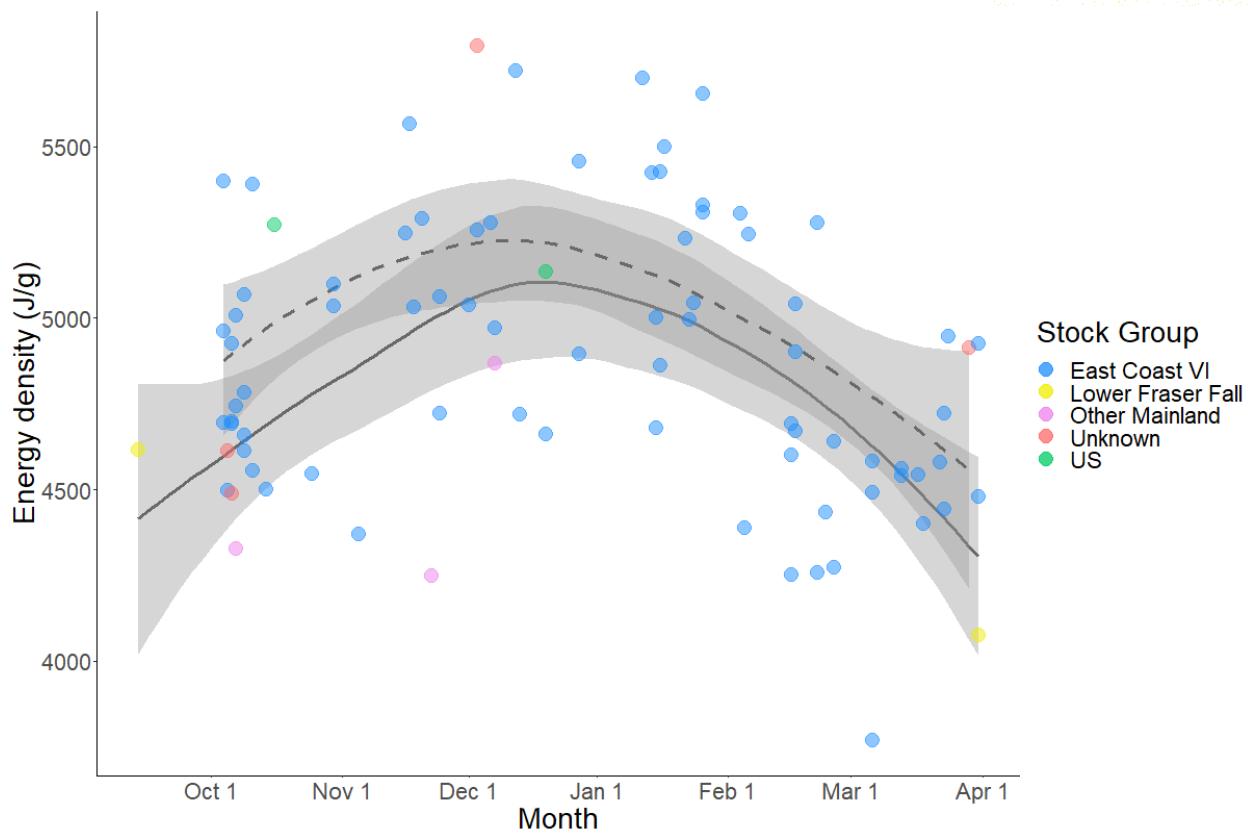


Figure 25. Locally weighted scatterplot smooth (loess; span = 1) of energy density (J/g wet weight) values for retained first ocean winter Chinook salmon from 2020-2021 (solid line) and 2021-2022 (dashed line) by date. Colour denotes stock group (“Unknown” stock group indicates a failure of genetic assignment) and shaded regions represent 95% confidence intervals for loess smooths.

#### Bioenergetic Modelling, somatic indices:

Preliminary bioenergetic models have been used to estimate specific growth rate, specific consumption rate, and specific feeding rate for juvenile Chinook salmon (Figure 26). This model was developed for the 217 fish identified as from the Qualicum-Puntledge fall (QP-fall) run stock group from October 2020 – March 2021 (total: 192 days). Using the Chinook salmon weight data, we built a generalized additive model (GAM) by day of year and used the predicted start and end weights as the initial and final weight input into the bioenergetics model (Fish Bioenergetics 4.0). To determine diet proportion, we first summed the weights of the diet items from QP-fall fish by taxon and day of year (DOY), and summed the total weights of all prey by DOY, to then determine the proportion of prey type by DOY through the sampling period. For predator energy density, we built a GAM from the QP-fall energy density data and used predicted daily energy density values through the whole sampling period (i.e., one energy density value for each day of the 192-day period). Prey energy densities were determined for each taxon (broad groups), and the same values were used throughout the entire period since sample sizes were too small to determine any temporal changes in prey ED. We used the mode of QP-fall capture depths for each month and determined the temperature at the nearest depths for all day where we had CTD data. If

there was more than one temperature value for a similar depth reading, we averaged the temperatures. Using these temperature data values, we built a GAM and used the predicted daily values as the temperature inputs. With these data, we ran the model (initial weight: 124 g, final weight: 308 g).

The model indicates that these fish are growing throughout early winter until January when there is a dramatic reduction in specific growth and consumption rates, which may indicate nutritional stress. Following this, in March, these rates increase substantially. These models assume that no size-specific mortality or emigration is occurring; however, the declines in specific growth and consumption in Jan and Feb could potentially be explained by size-selective processes. The potential influence of size-selective processes is being further explored by scale analysis and an acoustic tagging study.

Various juvenile Chinook Salmon somatic indices are being explored, including the gastrointestinal index (GISI) and hepatosomatic index (HSI; Figure 27) The preliminary GAM outputs show a declining GISI by DOY, with a minimum in late-December, followed by an increase through March. In contrast, no trend is evident from the HIS model over time. The decline in overwinter GISI may indicate a physiological response to food limitation.

The bioenergetic modelling approaches we are developing are sensitive to potential size-, growth-, or condition-selective emigration. As discussed in Activities 1 and 2 (microtrolling section) and outlined in an attached progress report, these questions are being addressed through a complementary acoustic tagging study.

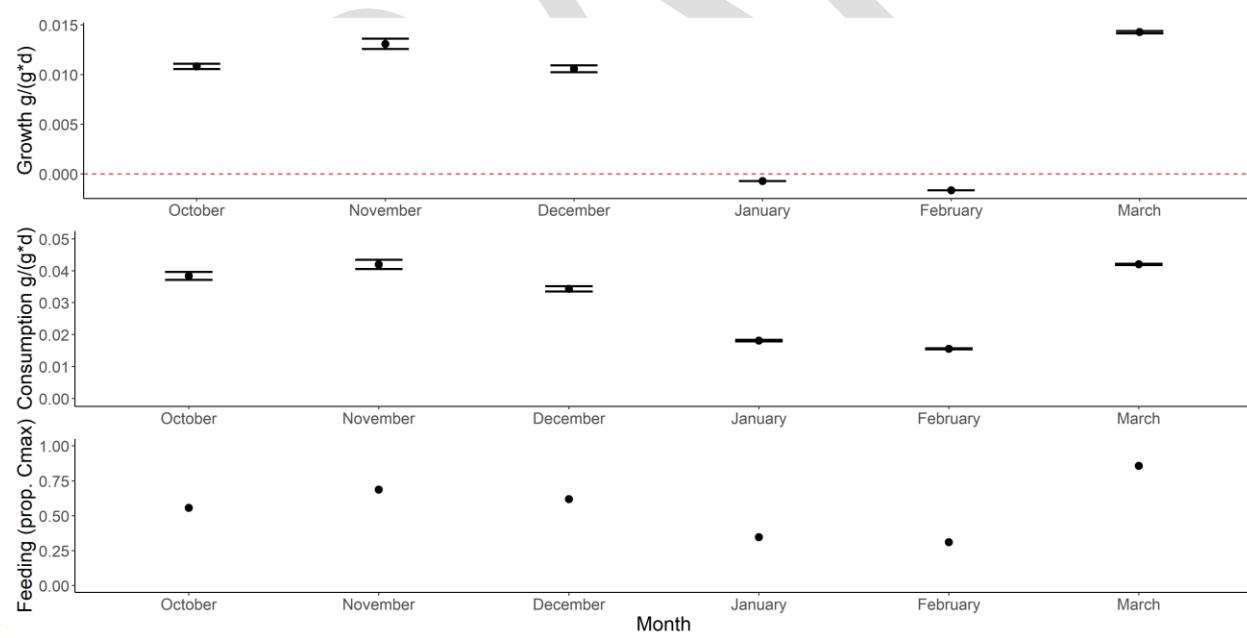


Figure 26. Bioenergetic model outputs of average ( $\pm$ SD) monthly specific growth rate (top), specific consumption rate (middle), and feeding rate (proportion of Cmax; bottom) of juvenile Chinook Salmon in 2020-21.

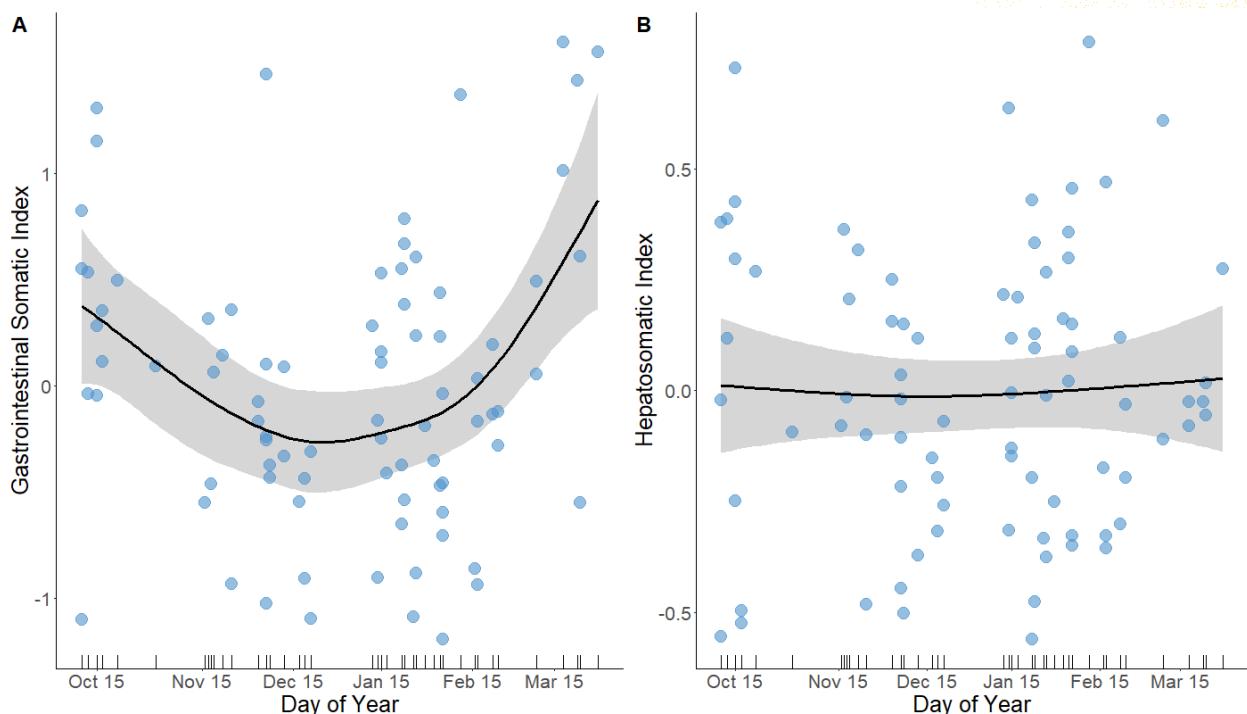


Figure 27. Residuals of gastrointestinal somatic indices (a), and hepatosomatic indices (b) of juvenile Chinook Salmon captured in the Strait of Georgia in Winter 2021-22. Non-linear GAM smooths.

Assessment of critical size, critical period hypothesis:

All scale books for all scales sampled as part of Activity 3 have been pressed onto acetate sheets. Digitization and measurement of these data are in progress.

Biomarker assessment of the role of pathogens in overwinter mortality:

Gill biopsies are currently in storage (in -80C) from 1295 First Ocean winter (<360 mm NFL) and 212 second ocean winter Chinook Salmon.

Selection of final samples for Fit Chip analysis will be informed by genetic stock composition results for final year (samples with Molecular Genetic Lab in spring 2023).

We plan to run samples on a modified Fit Chip including putative markers for nutritional stress developed through food limitation challenge trials with an RNA-seq study being carried out by an MGL postdoctoral fellow (Will Bugg) in summer 2023.

## Associated Studies & Anticipated Reporting

Table 16. Summary of technical and primary report products associated with Chapter 3 Chinook salmon winter ecology studies.

Report and Papers			
Study	Overview	Study Initiation Year	Status of Reporting
<b>Chinook Winter Ecology</b>	Katie Innes MSc thesis including literature review on winter ecology and bioenergetics of Chinook Salmon	2020	In Progress
<b>Winter Diet Study</b>	Primary publication on Strait of Georgia overwinter diets of Chinook Salmon	2020	In Progress
<b>Overwinter Bioenergetics</b>	Primary publication on bioenergetics of Chinook Salmon in first marine winter	2020	In Progress
<b>Scale Based Growth in Relation to Survival</b>	Primary publication relating Chinook Salmon early marine growth rate from scales and absolute size in autumn to late winter condition and energetic status (and potentially survival).	2022	In Progress
<b>Microtrolling Habitat Model</b>	Primary publication analyzing systematic Chinook Salmon habitat use surveys in the NSoG	2020	In Progress
<b>Winter Pathogen Presence and Load and Immune Status</b>	Primary publication analyzing overwinter changes in Chinook Salmon pathogen presence and load and immune and physiological status.	2022	Not Started

## Lessons Learned & Next Steps

### Spatial Distribution of Effort

Further analyses remain to be completed (including stock-specific analyses) on the northern Strait of Georgia CPUE data. Nevertheless, a fairly clear picture of overwintering habitat use in this region is emerging. Collecting these systematic survey data required fishing at sites (South Denman/Hornby), depths, and bathymetric strata where catches were very low. Given the limited good weather days

during winter, the benefits of conducting a third year of this sampling were outweighed by potential lost opportunities for alternative sampling.

First ocean winter Chinook salmon in the Northwest Strait of Georgia are overwhelmingly dominated by Puntledge/Qualicum Fall stocks (Figure 13). As we seek to understand and compare the overwinter ecology of multiple stocks, a benefit to expanding our effort into other regions was identified. In winter, Stuart Channel catches of FO Chinook salmon are dominated by Cowichan River fish. Reconnaissance sampling by UVic crews and effort by BCCF and volunteer vessels also suggested that depth distribution, size, and diet of FO Chinook salmon varies between the Southern Gulf Islands, Northern Strait of Georgia, and Discovery Islands Region. To capture this variation a modified sampling design was employed for the final field season of the Chinook winter ecology component of the Bottlenecks Project (winter 2022-2023). Systematic habitat surveys were discontinued and sampling was refocused on monthly biological sampling in three broad regions (Discovery Islands, NSOG and Stuart Channel) with specific sampling sites informed by logistics and recent CPUE by volunteer and BCCF vessels. This third sampling season was completed in April 2023 and sample and data processing are ongoing.

As described in the microtrolling section Chapter 1 and the bioenergetics section of the present activity section, a need was identified to understand the implications of variability in marine migration strategies of SOG Chinook salmon (partial migration) on the Bottlenecks Project. Some resources (vessel and personnel time) from Activity 3 were reallocated to this important objective, and extensive resources were provided in kind by DFO and other partners. A progress report on this complementary project is provided as an attachment to this document.

## Chapter 4: Understanding Steelhead Bottlenecks

This component aims to examine production, freshwater and marine survival, outmigration timing, adult return timing, and adult abundance (through mark-recapture programs) for several wild and hatchery populations of steelhead.

### Objectives

1. Determine outmigration timing for smolts and an at-sea survival estimate for Cowichan steelhead (smolt to adult) through PIT tag detections;
2. Obtain, through a mark-recapture program, total adult abundance, kelting, and repeat spawn rate estimates for Cowichan winter-run steelhead;
3. Investigate kelt reconditioning as a potential approach to supplement steelhead stocks at low abundance and investigate sources of mortality;
4. Examine differential survival of rearing treatments (e.g., semi-natural rearing, standard raceway rearing) and release strategies (e.g., offshore release (past surfline) and standard river release) for hatchery steelhead at Robertson Creek Hatchery; and,
5. Determine level of depensation and local predation of steelhead adults by pinnipeds in the Englishman River.

### Methods

#### Study Areas

Activity 4 is occurring in 3 watersheds across Vancouver Island: Cowichan River, Quinsam River, and the Stamp/Somass rivers.

#### PIT Tagging

##### *Hatchery Tagging*

Steelhead were PIT tagged at the Robertson Creek Hatchery facility during the first three years of the *Bottlenecks Project* (Table 3). Fish were removed from their primary populations the day of or the day before tagging. Food was withheld from fish for 24 hours prior to tagging. Fish were removed from the holding tank and anesthetized with 50 mg/L TMS for 4 minutes before tagging. Tagged fish were immediately released into flow through holding tanks or directly into the holding tank, where tagged fish were monitored for a minimum of 14 days prior to release. For more information, please refer to the “Prevalent Methodology” section above.

##### *In-river & Early Marine Tagging*

Steelhead were PIT tagged in the lower rivers and/or estuaries in the Cowichan, Nanaimo, Englishman, and Quinsam watersheds. Fish were captured by various methods depending on the system and location ([Figure 28](#)). This activity was completed for each of the three study years. For additional capture information, please refer to the “Prevalent Methodology” section above.



Figure 28. Steelhead and rainbow trout capture methods. A) Center Creek (Englishman River watershed) smolt trap; B) is of beach seining in the Nanaimo Estuary; and C) image of the wolf trap on the Quinsam River in 2021 (photos by Danny Swainson (A, B) and A-Tlegay Fisheries Society (C))

### MiniPAT Tags

MiniPat pop-up satellite archival tags are designed to provide a cost-effective way for conducting large-scale movement and behaviour studies for marine organisms. This project utilized MiniPAT-348K satellite tags (124 mm length, 38 mm diameter and weigh 60 g; [www.wildlifecomputers.com](http://www.wildlifecomputers.com)). MiniPAT tags are equipped with onboard memory, allowing data to be collected during deployment and stored until the tag is released from the host animal, and then summary data is uploaded to the Argos satellites. Multiple types of data are collected with these tags, such as temperature, depth, light level acceleration and geolocation, which can be calculated via light curves developed from the host animals horizontal habitat utilization and movements.

Tags are equipment with a recovery pinger which allows for tracking via a mobile Goniometer (GONIO RXG134). Retrieval of released tags allow for higher data quality as MiniPAT tags have an onboard archive which records depth, temperature, acceleration and light-level observations; this allows higher data quality if the tag is recovered post-study.

### Adult Capture & PIT Tagging

Returning adult steelhead were captured using standard drift fishing techniques with artificial or natural baits. Fish were held in a soft mesh knotless landing net during tagging/sampling (Figure 29). Prior to tagging, fish were inspected for injuries and scanned with an HPR-Lite hand scanner, looking for PIT tags in potential recaptures. For each steelhead caught, the fork length, sex, condition, time, location, and PIT tag number were recorded. All fish that were PIT tagged followed the PIT Tagging methods previously outlined, however, they were not anesthetized using TMS. All fish were released immediately after tagging.



Figure 29. Adult steelhead just prior to release, after PIT tagging and bio-sampling, Cowichan River (February 13, 2018) (photo by Jeramy Damborg).

### Adult Capture and Mini-Pat Satellite Tagging

Between March 18 and April 13 2021 and 2022, a total of 18 and 13 adult steelhead kelts were captured on the Cowichan River. Angling (float, weight and lure) via drift fishing techniques were used to capture fish from a dory style drift boat. To transport fish, the drift boat was outfitted with a 110 L cooler that was filled with fresh river water, and a small portable air-pump and air stone (Marine Metal Aeratr Bubble Box 1.5v). Fish captured were gently netted, placed into the cooler, and transported to the nearest road access location. Partial water changes would occur every 15 – 30 minutes, to ensure livewell temperatures remained consistent. From here the fish were again netted and transferred into a

truck equipped with a ~600 L aluminum fish transport tank, filled with fresh river water and equipped with airstone and pure oxygen tanks.

Fish were transferred from the river to the Vancouver Island Trout Hatchery (VITH) site on Boys Road, in Duncan, BC. Depending on location of capture, truck transport time was typically 20-25 minutes. Once at the hatchery, a VITH staff member would receive the fish and anesthetize them using Eugenol (Clove oil mixed with 95% ethanol), at concentrations between 40 and 60 mg/l PIT-tag them (refer to General Methodology section for more information on tagging methods). Fork length and circumference (taken just anterior to the dorsal fin), sex, weight and a photo of each fish were taken before placing into a 4 m diameter x 1.5 m deep fiberglass circular tank for holding. Preference was given to post-spawn females, and fish in good physical condition. Fish with open wounds, excess fungus and most of the males, were immediately released back into the stream at their location of capture.

Water quality was monitored daily for temperature and dissolved oxygen. The fish were also fed a mixture of krill and commercial trout food to try and improve the condition factor and overall health of the fish before tagging. Mortalities were immediately removed, scanned for their PIT tag, and disposed of.

The equipment used for the tagging of steelhead kelts was conducted in a similar method to Courtney et al. (2016). Mini-Pat tags were attached to two 50 mm long rigid backed plates using a nylon braid “tag backpack”, which has been refined for salmonids of similar size (Courtney et al. 2016; Courtney et al. 2019; Strom et al. 2017) ([Figure 30](#)) Tag backpacks were secured through the dorsal musculature below the dorsal fin through the pterygiophores, using two biocompatible plastic-coated stainless wires ([Figure 31](#)) The braid attaching the PSAT to the harness was encapsulated in a plastic coating to lift the PSAT up from the back of the fish. A biocompatible silicon pad was glued on the inside of the plates to reduce abrasion on the skin and an acoustic tag (V13 69 kHz) was epoxied to one side of the back-pack to track the fish if it happened to survive past the time the PSAT tag popped off ([Figure 31](#)).

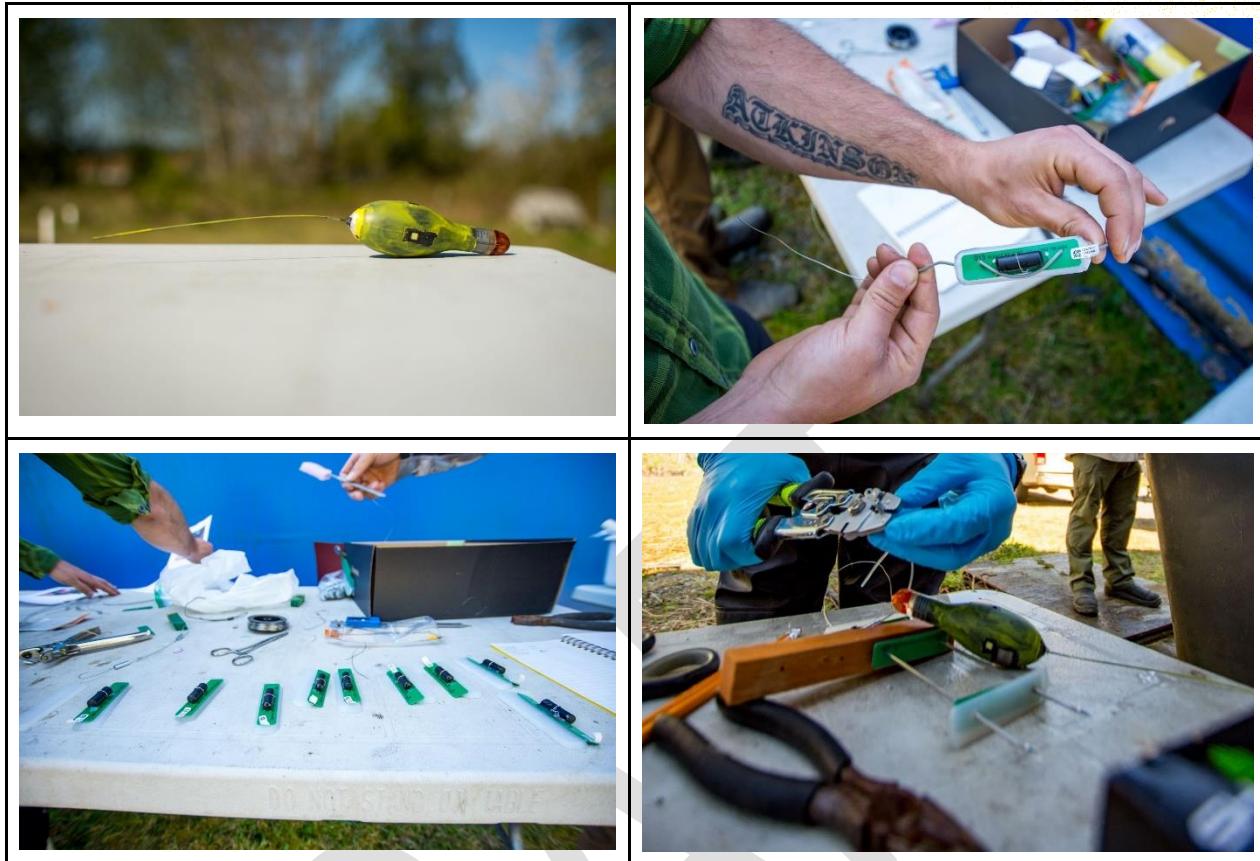


Figure 30. Images depicting MiniPAT Satelite tag (a), tag backpack with acoustic tag (b,c) and hyprdermic needles (d) used for tagging (photo by Danny Swainson).

Captured steelhead kelts were anesthetized using clove oil (Hilltech Canada, Canada) at a concentration of 40 mg/l. During the procedure, fish were provided freshwater flow over their gills (Figure 31). To attach the backpacks to the fish, two 100 mm hypodermic needles were used to thread 26 ga rubber coated stainless steel tie wire through the dorsal musculature below the dorsal fin through the perygiophores (Figure 31) The wire, with ends stripped of the rubber coating, was secured with a 'haywire twist', held two small (10 mm x 50 mm, 1 plastic and 1 silicone) plates on either side of the fishes back. A short (~10 cm) length of 80 lb. monofilament was crimped to each side of the backpack creating a loop that the PSAT tag was fastened to (Figure 31). After tagging fish were held in a live well with oxygen for at least 1 hour before being transported by vessel and released near Saltspring Island, BC.



Figure 31. Images showing tagging procedure and post tagging result. 2022 (photos by Danny Swainson).

#### Reconditioning

In 2021, steelhead adult kelts were captured throughout the spring and to determine whether holding and reconditioning would benefit the program, captured fish were held for up to 1 month prior to tagging in the Freshwater Fisheries Society hatchery in Duncan, BC. Fish were treated for bacteria, monitored, and fed daily.

## Interim Results

### Fish Capture and PIT-Tagging

#### *Hatchery and Early Marine Tagging*

A total of 15,000 hatchery steelhead have been tagged at the Robertson Creek Hatchery since 2021 (Table 17, Figure 28).

Table 17. Summary of Robertson Creek Hatchery PIT tagging of steelhead, including release locations between 2020 and 2023.

Cohort	Tagging Dates	Tags Deployed	Release Date	Habitat Type	Release Location
Sm	2021-01-20	2,500	2021-05-14	Freshwater	49.283857, -124.867128
Sm	2021-01-20	2,500	2021-05-15	Marine	48.945078, -125.410656
Sm	2022-01-18	2,500	2022-05-11	Freshwater	49.283857, -124.867128
Sm	2022-01-18	2,500	2022-05-12	Marine	48.945078, -125.410656
Sm	2023-01-18	2,500	2023-05-15	Freshwater	49.283857, -124.867128
Sm	2023-01-18	2,500	2023-05-16	Marine	48.945078, -125.410656

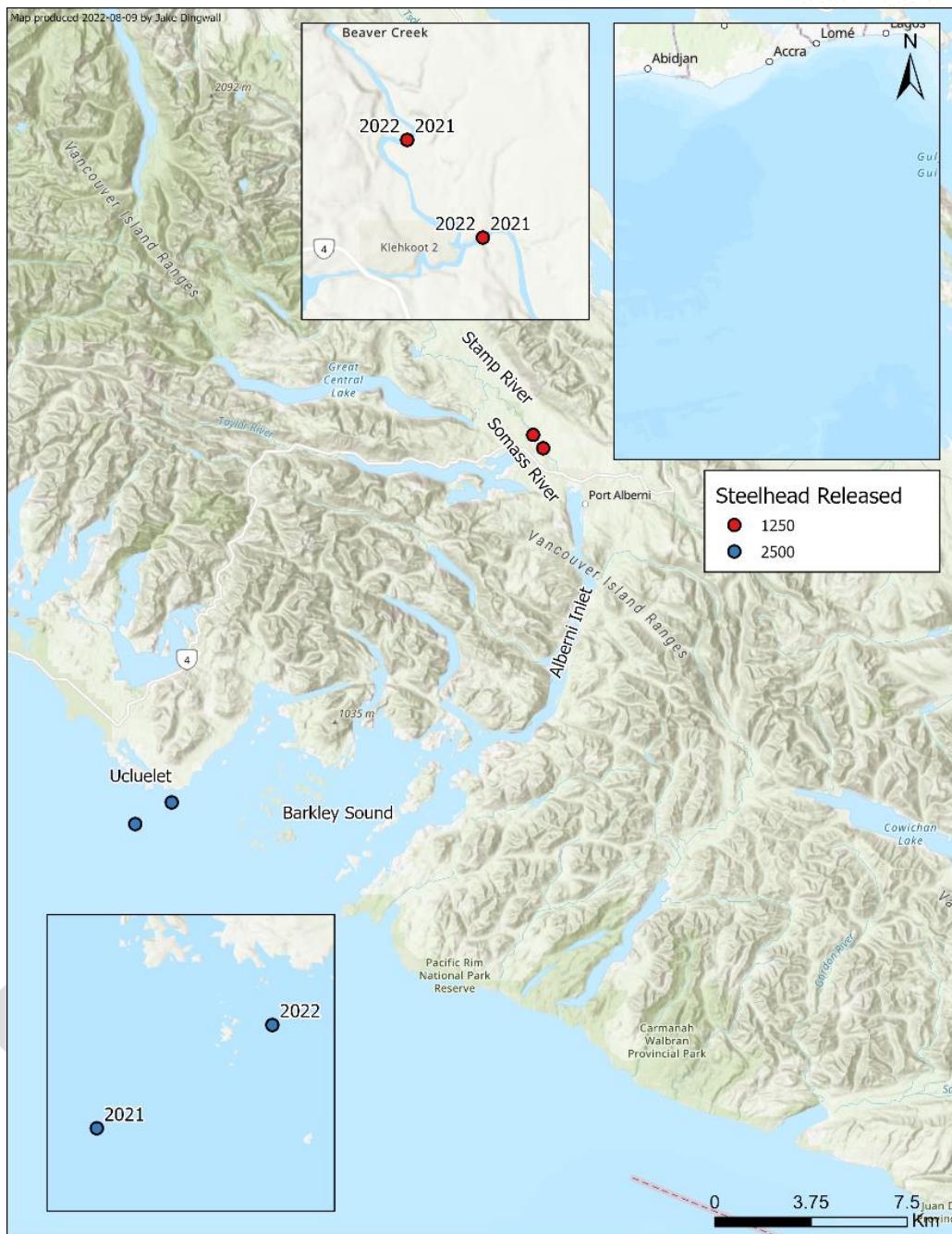


Figure 32. Robertson Creek Hatchery steelhead release locations for 2021 and 2022.

Additionally, during the outmigration window, 1,703 steelhead were tagged in-river or estuarine environments across four systems between 2021 and 2022 (Table 18). The primary systems of study are the Cowichan and Quinsam rivers which had the highest tag totals for each year (Table 18). Adult steelhead returns are expected to begin this winter/spring with most adults returning next winter/spring.

Table 18. Summary of PIT tagged steelhead from in-river and estuary captures between 2021 and 2022.

Species	Watersheds				Total
	Nanaimo	Englishman	Cowichan	Quinsam	
RBT	58	222	47	0	327
ST	34	21	496	825	1,376
Total	92	243	543	825	1,703

#### Steelhead Kelt Satellite Tagging

Summary of all PSAT tagged the three years of study on Cowichan River steelhead kelts are presented in Table 19 to Table 21.

#### 2021

On April 20, 2021, the ten healthiest female steelhead (judged by condition factor, silvery appearance, lack of scars or wounds etc.) were selected for tagging with Mini-Pat (Wildlife Computers) PSAT. A ‘backpack’ type method was used, similar to what was described by Courtenay et al. (2016), to fasten the PSAT to the fish (Figure 31). At the VITH Boys Road facility where the fish were being held, the fish were again anesthetized using the same methods described above and bio-sampled for length, weight, girth, and overall condition. In 2021, in addition to the ten PSAT tagged fish, five fish were tagged using the same ‘backpack method’; however, only an acoustic tag was fastened to one of the side plates, and no PSAT was attached.

Immediately post tagging, the fish were transferred with a knotless sport fishing net, into a 600 L fish transport tank, equipped with oxygen/air stone. The tank was in a 20 ft sport fishing vessel waiting on its trailer at the Boys Rd VITH site. After the tenth fish was PSAT tagged, the boat was towed to the nearest boat launch, located at Cowichan Bay, BC, approximately 10-minute drive. The boat was launched and then immediately motored out into Satellite Passage, where the fish were gently released, again with the use of a knotless sport fishing landing net, into the ocean. The release location of the PSAT fish was approximately 7.5 km ESE of the mouth of the Cowichan River (48.760 Lat, -123.545 Lon). The five ‘acoustic only’ fish were also transported immediately after tagging with the use of a 600 L transport tank and truck, these fish were released directly into the lower Cowichan River, approximately 4.0 km upstream of tidewater (48.7733 Lat, -123.6821 Lon) (Figure 29).

#### 2022

On April 15, 2022 eight healthiest-looking female steelhead (judged by condition factor, silvery appearance, lack of scars or wounds etc.) were selected steelhead were tagged with PSAT tags, using identical methods to 2021.

Immediately post tagging, the fish were transferred with a knotless sport fishing net, into a 600 L fish transport tank, equipped with Oxygen/air stone. The tank was in a 20 ft sport fishing vessel waiting on its trailer at the Boys Rd VITH site. After the 10<sup>th</sup> fish was PSAT tagged, the boat was towed to the nearest boat launch, located at Cowichan Bay, BC, approximately 10-minute drive. The boat was launched and immediately transited to Moresby Pass where the fish were gently released, again with the use of a knotless sport fishing landing net, into the ocean. Based on the results of year 1 the fish were transported farther into the Southern Gulf Islands, to Moresby Pass, approximately 32 km from the mouth of the Cowichan River (48.697 Lat, -123.347 Lon) (Figure 33). No acoustic tags were deployed in 2022. One fish was not tagged due to its small size and sustained an eye hook during capture.

2023

On April 6, 2023 five female steelhead were tagged with PSAT tags, using identical methods to 2021 and 2022.

Fish were transferred with a knotless sport fishing net, into a 600 L fish transport tank, equipped with Oxygen/air stone, immediately after tagging. After the fifth fish was tagged, they were moved to the Cowichan Bay boat launch and then transferred into another 600 L transport tank on a vessel. The tank was in a 20 ft sport fishing vessel waiting at the Cowichan Bay public boat launch dock. Immediately after transfer the vessel transported the fish where the fish were gently released, again with the use of a knotless sport fishing landing net, into the ocean. Similar to year two, and instructed by year one releases, fish were transported further into the Southern Gulf Islands, East of Swartz Bay, approximately 20 km from the mouth of the Cowichan River (48.697 Lat, -123.347 Lon) (Figure 33). No acoustic tags were put out in 2023. One fish was not tagged due to its small size, and it had sustained an eye hook during capture.

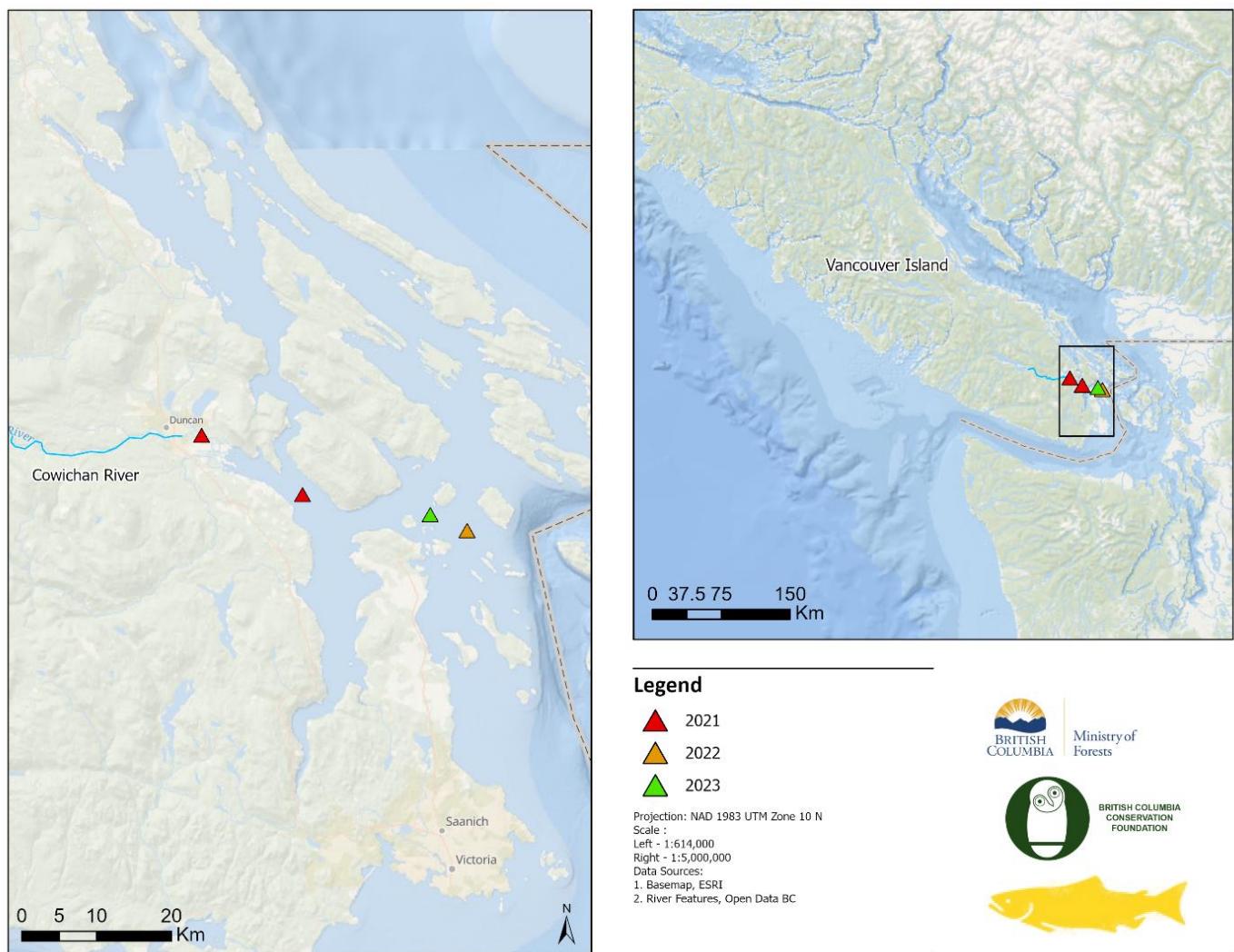


Figure 33. Release locations for miniPAT tagged steelhead Kelt for study years 2021 and 2022.

Table 19. Summary of Cowichan River steelhead kelts captured for PSAT tracking study in 2021.

Year	Tag ID	Fork Length (mm)	Release Location	Release Date	Pop-Off date	Days Survived
2021	1_cow_20210420_7180_3020_F	718	Satellite Channel	April 20	April 25	5
2021	2_cow_20210420_728_3280_F	728	Satellite Channel	April 20	April 26	6
2021	3_cow_20210420_692_320_F	692	Satellite Channel	April 20	April 25	5
2021	4_cow_20210420_719_3020_F	719	Satellite Channel	April 20	June 17	58
2021	5_cow_20210420_554_1580_F	554	Satellite Channel	April 20	May 15	25
2021	6_cow_20210420_687_3220_F	687	Satellite Channel	April 20	April 28	8
2021	7_cow_20210420_682_2960_F	682	Satellite Channel	April 20	April 24	4
2021	8_cow_20210420_720_3220_F	720	Satellite Channel	April 20	April 28	8

Table 20. Summary of Cowichan River steelhead kelts captured for PSAT tracking study in 2022.

Year	Tag ID	Fork Length (mm)	Release Location	Release Date	Pop-Off date	Days Survived
2022	cow_1_041422	565	Mooresby Pass	April 14	May 2	18
2022	cow_2_041422	725	Mooresby Pass	April 14	June 27	74
2022	cow_3_041422	625	Mooresby Pass	April 14	April 21	7
2022	cow_4_041422	597	Mooresby Pass	April 14	Non-report	Non-report
2022	cow_5_041422	545	Mooresby Pass	April 14	April 23	9
2022	cow_6_041422	620	Mooresby Pass	April 14	April 19	4
2022	cow_7_041422	618	Mooresby Pass	April 14	June 16	63
2022	cow_8_041422	620	Mooresby Pass	April 14	June 8	55

Table 21. Summary of Cowichan River steelhead kelts captured for PSAT tracking study in 2023.

Year	Tag ID	Fork Length (mm)	Release Location	Release Date	Pop-Off date	Days Survived
2023	Cowichan_1_2023	755mm	Shute Passage	April 6	April 12	6
2023	Cowichan_2_2023	735mm	Shute Passage	April 6	April 14	8
2023	Cowichan_3_2023	775mm	Shute Passage	April 6	April 11	5
2023	Cowichan_4_2023	765mm	Shute Passage	April 6	TBD	TBD
2023	Cowichan_5_2023	805mm	Shute Passage	April 6	TBD	TBD

Kelt Reconditioning

In 2021, 19 steelhead kelts were captured by recreational angling methods and held at the VITH hatchery for an average of 29.7 days. The objective of prolonged holding was to increase fitness before MiniPAT tagging and release, to increase tagging related survival. A total of six mortalities occurred during the 2021 study resulting in an overall mortality due to holding of 31.5% (Table 22). Further, fish which survived to tagging had a mean negative growth rate for weight (g) of -0.21 (Table 23). Due to this, it was decided to discontinue the study's reconditioning portion and release steelhead kelts soon after capture.

Table 22. Summary of steelhead kelts held for reconditioning in 2021.

Date	PIT Tag ID	Sex	Length at Capture (m)	Weight at Capture (g)	Circumference at Capture (mm)	Photo #	Date of Mortality
18-Mar-21	989.001006677480	F	720	3.54	335	1931	N/A
18-Mar-21	989.001006677523	F	800	4.4	340	1933	N/A
18-Mar-21	989.001006677519	F	600	2.1	282	1934	N/A
19-Mar-21	989.001006677521	F	550	1.66	255	1935	N/A
20-Mar-21	989.001006677476	M	795	4.76	370	1936	N/A
20-Mar-21	989.001006677471	F	701	3.28	315	1937	N/A
20-Mar-21	989.001006677508	M	555	1.58	255	1938	26-Mar-21

20-Mar-21	989.001006677509	F	680	3.16	325	1939	N/A
20-Mar-21	989.001006677502	F	680	2.96	305	1940	N/A
20-Mar-21	989.001006677531	F	760	4.1	335	1941	23-Mar-21
21-Mar-21	989.001006677510	F	715	3.34	340	1942	N/A
21-Mar-21	989.001006677503	F	710	3.64	340	1943	25-Mar-21
21-Mar-21	989.001006677568	F	685	2.98	310	1944	N/A
21-Mar-21	989.001006677499	F	680	2.92	310	1945	N/A
22-Mar-21	989.001006677538	M	630	2.48	335	1946	23-Mar-21
22-Mar-21	989.001006677554	F	700	2.84	300	1947/1948	18-Apr-21
29-Mar-21	989.001006677561	F	720	3.56	321	1949	N/A
31-Mar-21	989.001006677482	F	630	2.14	270	1950	N/A
01-Apr-21	989.001006677541	F	755	4.24	345	1951	03-Apr-21

Table 23. Summary of steelhead kelt reconditioning. 2021.

Sex	Length at Capture	Length at Release	Weight at Capture	Weight at Release	Capture Date
F	685	687	2.98	2.14	2021-03-21
M	795	813	4.76	4.58	2021-03-20
F	630	638	2.14	1.98	2021-03-31
F	715	718	3.34	3.02	2021-03-21
F	720	728	3.54	3.08	2021-03-18
F	680	692	2.96	3.2	2021-03-20
F	701	719	3.28	3	2021-03-20
F	550	554	1.66	1.58	2021-03-19
F	680	687	3.16	3.22	2021-03-20
F	680	682	2.92	2.96	2021-03-21
F	720	720	3.56	3.22	2021-03-29
F	800	805	4.4	3.98	2021-03-18
F	600	610	2.1	2.1	2021-03-18

## Lessons Learned & Next Steps

### Englishman River Steelhead

The original objectives pertaining to Englishman steelhead will not be able to be achieved. Unfortunately, this stock has drastically declined over the last ten years and has had raw adult counts of > 50 fish per year since 2019, and the reduced population has prevented the ability to meet objective 5.

### Steelhead Smolt Capture

Capturing and tagging steelhead smolts in the riverine environment has proved challenging. Limitations due to flow regimes and trap design have been limiting factors; while adequate numbers of steelhead smolts have been captured in the Cowichan and Quinsam Rivers in 2021, captures in the Nanaimo and Englishman rivers and 2022 captures in the Cowichan River have been few. Alterations in capture methodologies need to be reviewed. However, specifically for the Englishman River, adult steelhead returns have seen a drastic decline in the last four years, with snorkel survey observations dropping from 60 to 100 per year to ~ 20 in 2021, 2022, and 2023. These low returns limit the available smolts for future tagging efforts and add a limiting factor to our tagging program.

### Reconditioning and PSAT Tagging

The primary objective for the PSAT program was to recondition steelhead kelts at the Freshwater Fisheries Society of BC's trout hatchery, over the course of 30 days and release them in the marine environment to monitor their movements and migration pathways. Reconditioning negatively affected the overall health of captured steelhead kelts ([Table 23](#)) and thus was discontinued in 2022 and 2023.

## Chapter 5: Enhanced Fishery Monitoring

This activity aims to modernize recreational salmon fishery landing sites by installing and updating fish cleaning tables. Each new table includes 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, 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.

### Objectives

1. Modernized cleaning tables at selected recreational landing sites that have integrated PIT tag and video systems;
2. Identification of individual PIT tagged fish, which contributed to the fishery, as well as an estimate of the total contribution to the fishery by area;
3. Estimates of total landings at each table by species, month, and origin;
4. Estimates of head submission rates for adipose clipped fish to the head recovery program; and,
5. Evaluate the use of landed catch to infill harvest estimates for days when the creel survey is not actively sampling.

### Methods

Sites were selected following on-site visits at main recreational landing sites (boat ramps and marinas) within the study area (PFMAs 13 to 17). Key information collected during visits included site layout, power and water sources, and existing infrastructure. Consultations with property owners, including cities, First Nations, private owners, were planned either during the initial site visit or as a follow up pending initial results.

For sites that were short-listed, a materials list and sketch of proposed upgrades to each fish cleaning station was created including electronics. As required, contractors were hired to perform specific trades (i.e., concrete, electrical, plumbing, framing/carpentry, etc.). PIT antennas were custom fabricated to meet varying table sizes and existing infrastructure was retrofitted, where possible. Incorporation of head depot freezers was part of the design at main sites and required coordination with Salmon Head Recovery Program (SHRP) staff.

Testing and operation occurred during the fishing season in most cases. Chinook fishing regulations for the 2021/22 season included an extensive non-retention period from April 1 to July 14, opening on July 15. Regular site visits were conducted to check equipment and download data. The majority of video data review was conducted by trained creel staff through the winter/spring, as time allowed.

## Interim Results

### Infrastructure Development

#### *Area 17 - Brechin Marina, Nanaimo*

Existing infrastructure at Brechin Marina in Nanaimo received structural and functional upgrades in spring 2021, including replacement of rotten structural beams and framing in a mechanical room to house a computer and electronics. The table top had a pre-existing PIT antenna, which was inspected and re-mounted, while a dual camera setup was installed overhead. The PIT antenna was operational on July 15, while cameras began recording on July 26. A pre-existing SHRP head depot freezer was also integrated into the site with a more convenient location, just an arms-length from the cleaning table.



Figure 34. 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).

#### *Area 14 – French Creek, Parksville*

Two tables at French Creek Marina were modified in 2021, including the north table that serves boats moored at the dock, as well as the south table that captures daily launches at the ramp. Upgrades to the north table included a completely new structure with metal roof and posts and a small electronics compartment in the rafters, integrated PIT antenna, and overhead cameras. The table and outlet pipe were re-used, and the existing plumbing/electrical was upgraded.



Figure 35. Images of the landing site at French Creek Marina's north table before (A) and after (B) infrastructure upgrades conducted in 2021 (photo by Kevin Pellett).

The south table at the French Creek Marina required considerably more work given it was relocated from the Government ferry dock to the high side of the boat ramp. Infrastructure upgrades included services (electrical, plumbing), a concrete slab, framing, and metal roofing/cladding to create two small mechanical rooms. The first room now houses the head depot freezer and water/power shut-off while the second has the PIT antenna, computer, and hard drive. Similar to the north table, the site now includes an integrated PIT antenna and two overhead cameras.



Figure 36. Images of the landing site at French Creek Marina's south table before (A and B) and after (C and D) infrastructure upgrades conducted in 2021 (photos by Kevin Pellett).

#### *Area 13/14 – Pacific Playgrounds, Black Creek*

Several potential sites were considered for enhanced monitoring sites in the Northern Strait of Georgia. These included the boat launch at Comox Marina, Big Rock boat launch in Campbell River, and existing cleaning tables at Discovery Harbour Marina. Considerable consultation occurred for all these sites, but delays or independent schedules of organizations overseeing these sites precluded moving forward on the timeline of the Bottlenecks Project.

However, a successful working relationship was developed with Pacific Playgrounds Resort and Marina near Saratoga Beach in Black Creek. This site had two older cleaning tables. The resort planned to (and now has) decommission one of these cleaning tables. The other site was expanded to 1.5x the working surface situated within a new post and beam, metal-roofed structure (Figure 37). This structure was completed in March of 2023 with the installation of tabletops with integrated PIT tag antennas, cameras, and other electronic scheduled for the beginning of May 2023.



Figure 37. Cleaning table shelter under construction at Pacific Playgrounds in Black Creek, Spring 2023 (photo by Kevin Pellett).

#### *PIT Detection Data to Date*

In total, three integrated PIT antennas were embedded in table tops for the 2021 fishing season. The Brechin Marina (Nanaimo) antenna was active for the July 15, 2021, opening for Chinook retention. The French Creek Marina antennas were activated later in the season, following the completion of the south

table on August 5, 2021 and north table on August 19, 2021. Additionally, mobile scanning under several other tables for discarded tags was opportunistically conducted through spring 2022.

A total of two PIT tags were detected on the cleaning table antennas during the 2021 season; the first occurred at Brechin Marina on July 22 and the second at the French Creek Marina south table on August 16. Avid Anglers deployed both tags in recreationally caught/released adult Chinook (>60 cm) during the 2021 season. The total number of tags deployed by this group by summer 2021 was 430, although not all were eligible for harvest (size) or local ECVI stocks expected to be harvested terminally. The majority of *Bottlenecks Projects* PIT tagged juveniles will be harvested in subsequent years, as Chinook enter the fishery predominantly two years after release (age 3). Hatchery marked coho, released in spring 2021, will enter the Strait of Georgia fishery on June 1, 2022, while older age classes of Chinook will be primarily targeted after July 15.

Mobile scanning around cleaning tables produced eight additional detections bringing the total to 73. In addition, the tag first detected on the table at Brechin Marina on July 22 was re-detected downstream of the outlet pipe in the winter. A summary of tags detected to date by species and location can be found below (Figure 38).

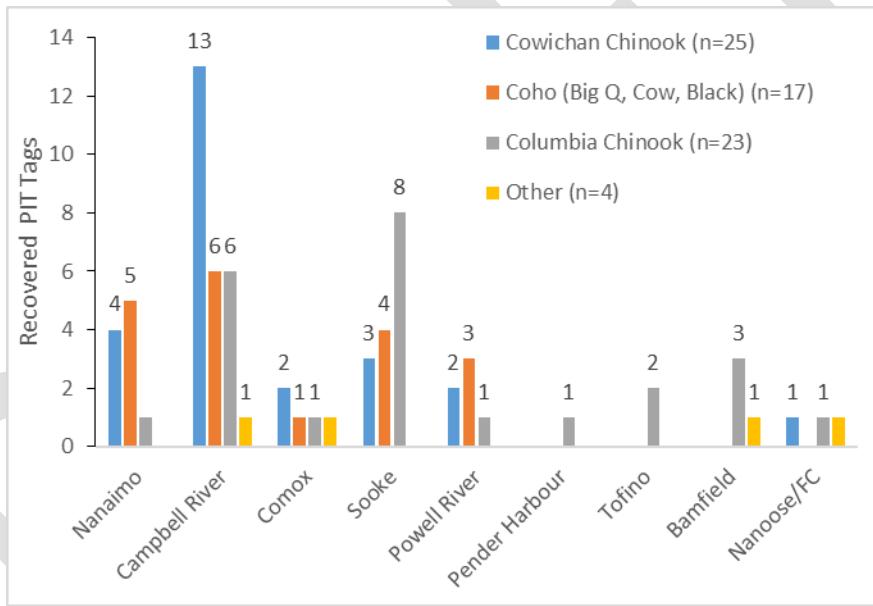


Figure 38. Summary of PIT tags recoveries from opportunistic mobile scanning around southern BC cleaning tables through spring 2022.

#### *Adipose Clip Head Submission Rate*

Adipose clip status and head submission rates for clipped fish were tracked at each of the three cleaning tables instrumented with overhead cameras. The monitoring period extended longer for Brechin Marina (July 26, 2021, to March 20, 2022) compared to the north (August 11 to October 31, 2021) or south (August 30 to October 31, 2021) tables at French Creek Marina due to differences in construction schedules. Data review for the November 1 to March 31 period at French Creek Marina has yet to be completed at the time of this report. Data collection at these locations is expected to span the entirety of the 2022/23 season.

Overall, head submission rates for Chinook were similar at Brechin Marina (22/88 or 25.0%) and French Creek Marina (29/115 or 25.2%). Coho submission rates were higher at 34.3% at Brechin Marina (12/35)

and 38.2% at French Creek Marina (29/76). See the monthly totals by site and species below (Figure 39 to Figure 41).

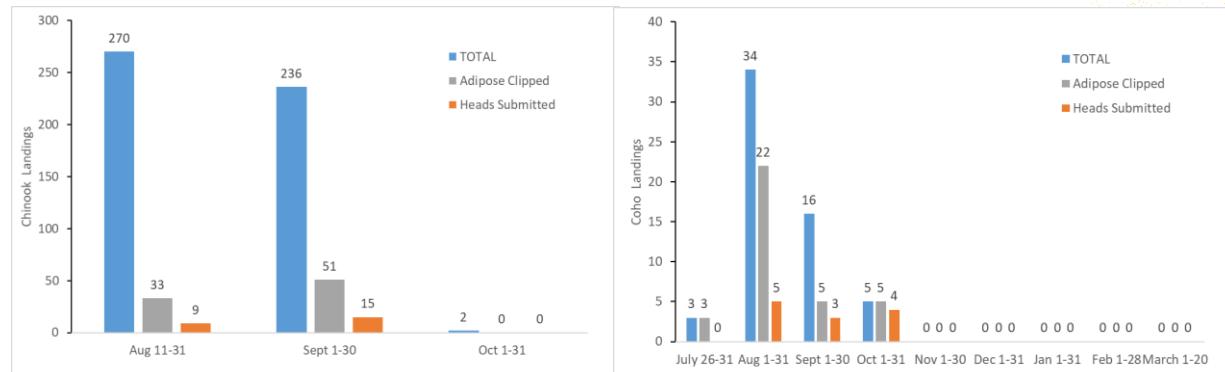


Figure 39. Monthly landings and head submissions by species and adipose clip status at Brechin Marina, from July 26, 2021 to March 20, 2022.

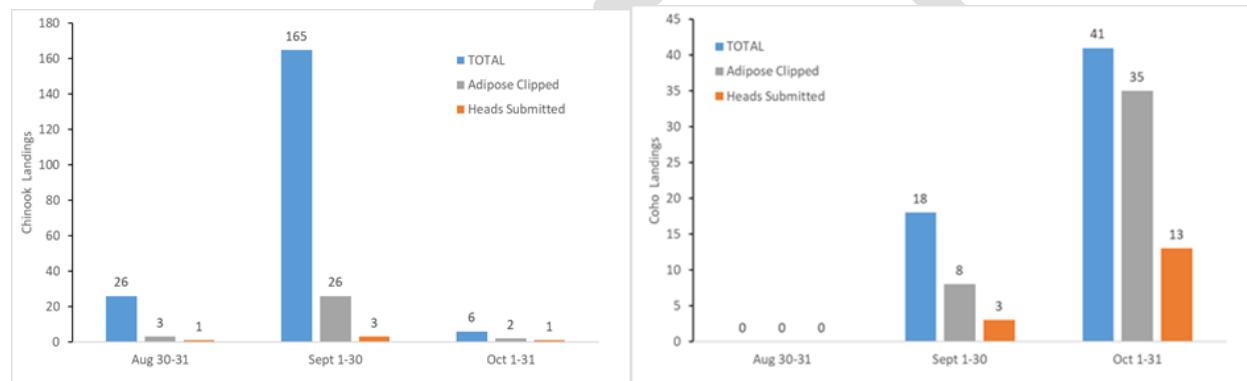


Figure 40. Monthly landings and head submissions by species and adipose clip status at French Creek Marina north table from August 11 to October 31, 2021.

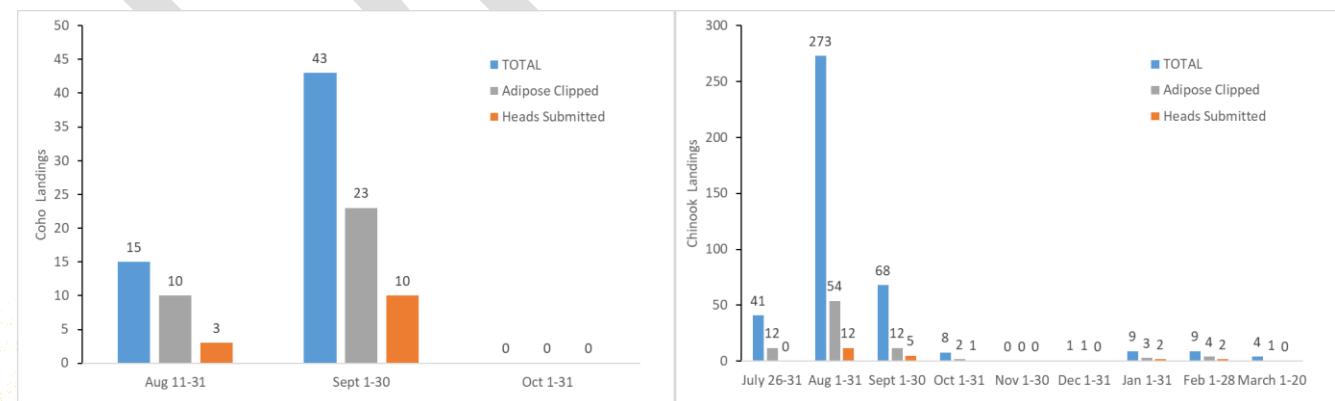


Figure 41. Monthly landings and head submissions by species and adipose clip status at French Creek Marina south table from August 30 to October 31, 2021.

### Refining Temporal Distribution of Creel Sampling

Continuous video monitoring of landings at Brechin Marina occurred between July 26, 2021, and March 31, 2022. The analysis focused on the peak months, as the creel program typically does not operate in Area 17 after September or before April; this data can be used to validate assumptions of low catch/effort in the winter. The creel program is designed using a stratified random sample approach with weekday and weekend strata. Through July and August, we found little evidence of variation in daily landings of either Chinook (9.0 vs 8.7 fish/d) or coho (1.0 vs 1.1 fish/d) between weekends or weekdays (Figure 42). The relationship was biased towards weekends in September, with more Chinook (2.8 vs 2.1/d) and coho (0.75 vs 0.45/d) landed per day on average but less than July and August overall.

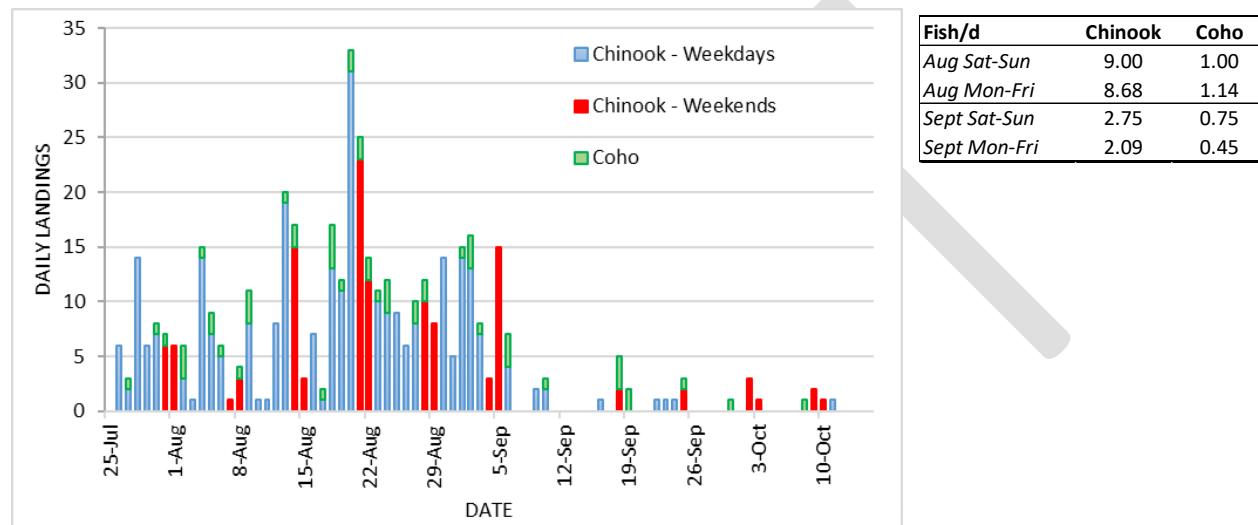


Figure 42. Daily Chinook and coho landings at Brechin Marina, stratified by weekends and weekdays; July 6 to October 15, 2021.

Chinook landings were also tallied by hour to gain a sense of the temporal distribution. Figure 43 suggests that 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. The timing of these landings suggests the “night bite” contributes disproportionality to daily catch and that creel shifts should extend to 10 PM within the randomized schedule.

A preliminary comparison was conducted between estimated boat trips in creel Area 17-E (Figure 44) and daily landings at Brechin Marina (Figure 45). The intent was to investigate if the relationship between catch and effort was strong enough to allow for infilling on days where overflights by DFO, where they survey the area for anglers, were not conducted. A normal schedule during this time includes one weekday and one-weekend flight every 7 days, leaving 5 days of infill. Periodic shifts in weather conditions or catch rates can dramatically affect individual days, but are assumed to average out over the survey. Preliminary results suggest the correlation is weak, although there is some evidence of saturation during periods of high effort (more effort does not equal more catch). This analysis also assumes that most boats fishing in creel Area 17-E are landing at Brechin Marina, which has not been validated.

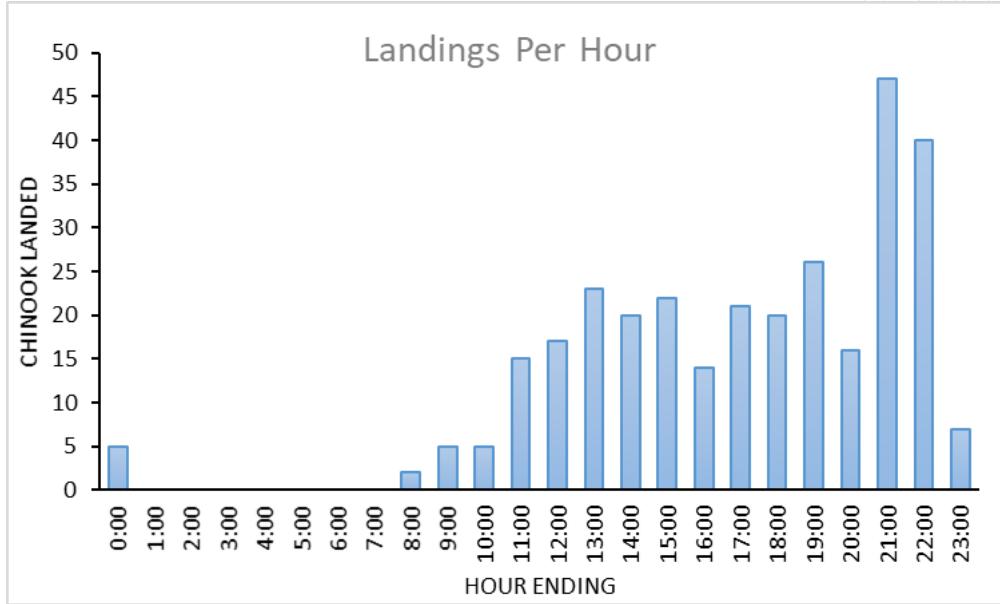


Figure 43. Chinook landings by hour at the Brechin Marina between July 26 and October 15, 2021.

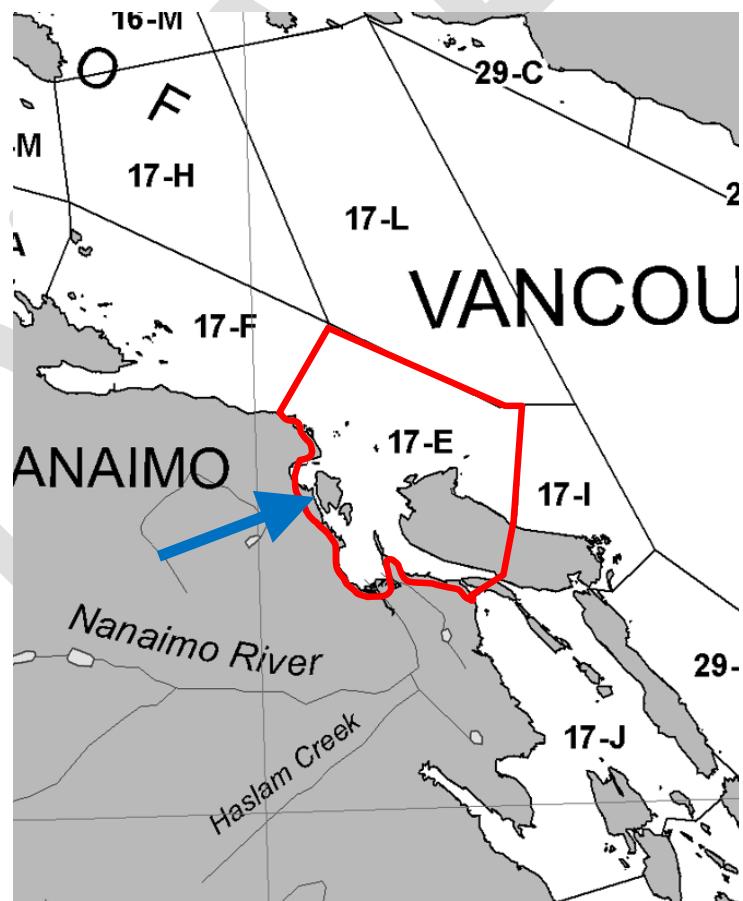


Figure 44. Map of creel Area 17-E, outlined in red in relation to adjacent sub areas, as well as the Brechin Marina indicated by a blue arrow.

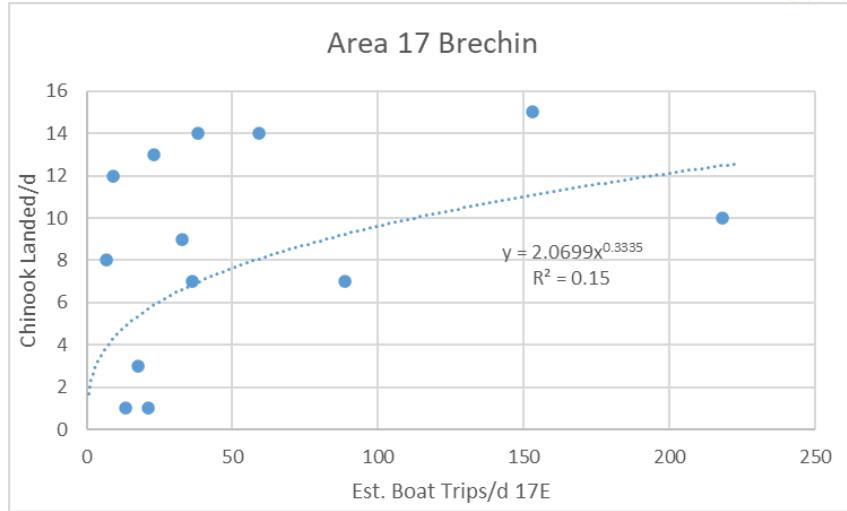


Figure 45. Preliminary comparison of boat trips in creel area 17-E estimated from the creel program to daily landed catch at Brechin Marina between July 28 and August 30, 2021.

## Lessons Learned & Next Steps

Developing the required relationships with marina operators, First Nation Governments, recreational anglers and the sport fishing institute were key pieces in order to design and implement an increased monitoring program such as this. Difficulties in certain target areas with building these relationships have restricted the project ability to expand beyond the current sites. However, with continued dialogue with local entities and governments, progress in ongoing and the future expansion of these enhanced monitoring sites is looking positive.

With the expected return of the first cohort of age 3 Chinook tagged by the *Bottlenecks Project*, PIT detections on these cleaning tables should significantly increase in the coming years. This will help the Bottlenecks Project team inform additional enhanced monitoring table expansions in the coming years, and will assist in developing a harvest rate that is new and novel.

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### **Personal Communications**

Keith, I. (2021). Personal communication during onsite review of tagging procedures. Ian Keith is the head vet at the Salmon Enhancement Program, Department of Fisheries and Oceans. May 2021.

McCulloch, M. (2022). Personal communication during a phone call interview. Mike McCulloch is the Region 1 Anadromous Fisheries Specialist for the Ministry of Forests. April 2022.

Luedke, W. (2020). Personal communication during initial meeting for the Bottlenecks to Marine Survival Proposal development. Wild Luedke was the section head for South Coast Stock Assessment. November 2019.

## Appendix A:

### PIT Infrastructure Installation List

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Table 24. Summary of PIT antenna installations and constructed materials for all systems included in the Bottlenecks Program.

Watershed	Location	Type (PO/FW/TMP)	Controller	Number of Antennas	Size of Antennas (m)	Material	Install Date	Removal Date
Black Creek	Fence	TMP	IS1001	2	0.2 x 0.2	0.03 ABS Solid Core, 12 AWG 600 volt	May-22	
	Mainstem Fence	PO	IS1001	1	6	HDPE (Biomark)	Jul-21	
	Fishway	FW	IS1001	2	2.2 x 1.5	HDPE (Biomark)	Jul-21	
Big Qualicum	Coho Earthen Pond	TMP	IS1001	2	5 x 0.2 & .5 x .5	12 AWG 600 volt Cable w 7 mm climbing rope, aluminum anchors; ABS 0.038 diameter with 12 AWG 5 cond 600 volt cable	May-21	May-21
	River Kilometer 7	PO	Master	12	6	HDPE (Biomark)	Sep-20	
	Skutz Falls	FW	IS1001	2		HDPE (Biomark)	Oct-17	
	South Arm	PO	IS1001	1	10	HDPE (Biomark) (DOP)	Jul-22	
	North Arm	PO	IS1001	1	10	Litz Chord	Jul-22	
Cowichan	Koksilah	PO	IS1001	1	10	HDPE (Biomark) (DOP)	TDB	
	Mainstem River km 0	PO	Master	10	10	HDPE (Biomark)	Aug-21	
	Mainstem River Km 0	PO	IS1001	2	10	HDPE (Biomark)	Aug-22	
	River Kilometer 2	PO	Master	2	10	HDPE (Biomark)	Aug-21	
	Hatchery Fishway	FW	IS1001	2	2.9 x 1.5	HDPE (Biomark)	Aug-21	
Englishman	Nanaimo River	PO	Master	12	6	HDPE (Biomark)	Jul-21	
	Coho Earthen Pond	TMP	IS1001	2	2 x 0.2	HDPE(Biomark) (antenna #1) and 12 AWG 600 volt Cable w 7 mm climbing rope, aluminum anchors (antenna #2)	May-21	May-21
Goldstream	River Kilometer 2.5 (48.450961, -123.481657)	TMP	IS1001	2	6	12 AWG 600 volt Cable w 7 mm climbing rope, aluminum anchors	Mar-22	
	Mainstem River km .5	PO	Master	2	10	HDPE (Biomark)	Aug-22	
	Fishway/Camera Box	FW	IS1001	1	0.3	0.03 ABS Solid Core, 12 AWG 600 volt	Jun-21	
	Hatchery Fishway	FW	MC	2	1.5 x 1.2	HDPE w 12 AWG 600 volt	TBD	
	Upper Fishway	FW	IS1001	2	1.5 x 1.2	0.07 ABS Solid Core, 12 AWG 600 volt	Jun-21	
Little Qualicum	Quinsam River Mainstem	PO	IS1001	1	10	HDPE (Biomark)	Aug-22	
	Hatchery Fishway	FW	IS1001	2	1.5 x 1.2	0.07 ABS Solid Core, 12 AWG 600 volt	Jun-21	
	Coho Earthen Pond	TMP	IS1001	2	4.8 x 0.9	HDPE (Biomark)	May-21	May-22
Stamp River	Stamp River Falls	FW	IS1001	2	3.3 x 1	0.07 ABS Solid Core, 12 AWG 600 volt	Aug-22	
	Robertson Creek Hatchery	FW	IS1001	2	.5 x .5	0.07 ABS Solid Core, 12 AWG 600 volt	Aug-22	
Toquaht	Thornton Creek	TMP	IS1001	2	15.2 x 0.6	12 AWG 600 volt Cable w 3 mm halibut rope, aluminum anchors	May-21	Jul-21

\* PO=Passover orientation

\* FW = Fishway antenna in a pass through orientation

\* TMP = a Temporary installation in either a pass over or under orientation

