Science for salmon conservation and management across multiple scales: A summary of research and preliminary findings from the Pacific Salmon Strategy Initiative

Cory R. Lagasse, Joe Enns, Nicholas Brown, Isobel Pearsall, Ann-Marie Huang, Diana Dobson (editors)

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Beginning in 2021, the Pacific Salmon Strategy Initiative (PSSI) was a five-year, $647 million investment by the Government of Canada to restore and sustain Pacific salmon and their habitats. This report summarizes scientific research and preliminary findings from 47 PSSI-funded projects led by Fisheries and Oceans Canada's Pacific Region Science branch, complemented by 72 external agreements for phase two of the BC Salmon Restoration and Innovation Fund (BCSRIF). Research spanned a range of disciplines and addressed major themes relevant to salmon conservation and management, including freshwater and marine ecosystems, climate change vulnerability, life-cycle approaches to assessment, hatchery modernization, fisheries monitoring, stock assessment, and data stewardship. Across these themes, PSSI expanded scientific capacity, advanced new analytic and monitoring tools, and improved our understanding of individual and cumulative pressures affecting salmon abundance and their survival across life stages. The initiative also supported more standardized assessment processes, improved data systems, and scientific partnerships. Together these advances will continue to inform salmon conservation, rebuilding, and sustainable fisheries management beyond the life of the initiative.

RÉSUMÉ

Lagasse, C.R., Enns, J., Brown, N., Pearsall, I, Huang, A.-M., Dobson, D. (eds.). 2026. Science for salmon conservation and management across multiple scales: A summary of research and preliminary findings from the Pacific Salmon Strategy Initiative. Can. Tech. Rep. Fish. Aquat. Sci. 3768: vii + 414 p. https://doi.org/10.60825/9rf0-z464

Commencer en 2021, l'Initiative de la Stratégie relative au saumon du Pacifique (ISSP) était un investissement de 647 millions de dollars sur cinq ans du gouvernement du Canada visant à restaurer et à maintenir le saumon du Pacifique et ses habitats. Ce rapport résume les recherches scientifiques et les conclusions préliminaires de 47 projets financés par l'ISSP et dirigés par la direction des sciences de la région du Pacifique de Pêches et Océans Canada, complétés par 72 ententes externes pour la deuxième phase du Fonds de restauration et d'innovation pour le saumon de la Colombie-Britannique (BCSRIF). Les recherches ont porté sur un éventail de disciplines et ont abordé des thèmes majeurs pertinents pour la conservation et la gestion du saumon, notamment les écosystèmes d'eau douce et marins, la vulnérabilité au changement climatique, les approches d'évaluation basées sur le cycle de vie, la modernisation des écloseries, la surveillance des pêches, l'évaluation des stocks et la gérance des données. À travers ces thèmes, l'ISSP a accru la capacité scientifique, fait progresser de nouveaux outils d'analyse et de surveillance, et amélioré notre compréhension des pressions individuelles et cumulatives affectant l'abondance du saumon et sa survie aux différentes étapes de sa vie. L'initiative a également soutenu des processus d'évaluation plus normalisés, l'amélioration des systèmes de données et des partenariats scientifiques. Ensemble, ces progrès continueront d'éclairer la conservation du saumon, le rétablissement des stocks et la gestion durable des pêches au-delà de la durée de l'initiative.

EXECUTIVE SUMMARY

Beginning in 2021, the Pacific Salmon Strategy Initiative (PSSI) was a five-year, $647 million investment by the Government of Canada to restore and sustain Pacific salmon populations and their habitats. This report summarizes scientific research and preliminary findings from PSSI-funded projects led by Fisheries and Oceans Canada's (DFO) Pacific Region Science branch. This research was complemented by a major expansion of the BC Salmon Restoration and Innovation Fund (BCSRIF), which supported 72 new collaborative agreements with First Nations, academic institutions, non-governmental organizations, and industry.

DFO-led research under PSSI was organized primarily through two initiatives: Improved Understanding of Salmon Ecosystems and Science to Support Hatchery Modernization. The overarching aim of Improved Understanding of Salmon Ecosystems was to enable effective conservation management for wild salmon and their ecosystems by developing a comprehensive understanding of habitat, ecosystem, and climate change impacts on salmon productivity, while Science to Support Hatchery Modernization aimed to provide scientific advice and information to inform hatchery planning and operations, including the expansion of hatchery programs under PSSI. These initiatives supported multi-disciplinary work across freshwater, estuarine, and marine environments, while also targeting research on genetics, fish health, fisheries monitoring, and data stewardship. This report summarizes scientific advances and preliminary findings across eleven thematic areas (Figure 1), with more detailed information provided within 47 project reports that highlight findings from individual projects. Key findings and outcomes will be refined in the near future as researchers complete and publish analyses.

Freshwater Ecosystems

PSSI-funded freshwater research advanced our understanding of the habitat conditions that influence spawning, incubation, juvenile rearing, and migration. Studies examined the influence of streamflow, temperature, dissolved oxygen, sediment dynamics, and habitat connectivity on freshwater productivity and habitat condition. New geospatial and mechanistic modelling approaches improved the ability to assess cumulative effects from land use and climate change, identify vulnerable watersheds and conservation units, and support habitat planning and recovery actions.

This work also highlighted several emerging threats. In urban and agricultural systems, monitoring showed that temperatures and oxygen can regularly attain levels considered stressful for salmon. Contaminant studies identified areas exposed to 6PPD-quinone, a tire-derived chemical now recognized as a source of mortality for coho salmon in some watersheds. Research on invasive species and predators showed that non-native fishes such as smallmouth bass can impose substantial mortality on juvenile salmon from at-risk populations. Together, these studies reinforce the need to evaluate freshwater habitats through a cumulative effects lens rather than focusing on single stressors in isolation.

Marine Ecosystems

Research addressed both bottom-up processes—including food availability, coastal productivity, and environmental drivers of prey quantity and quality—and top-down processes—including predation, competition, and disease. This work spanned from estuaries of the Fraser river to the Strait of Georgia to the West Coast of Vancouver Island and into the open North Pacific. Additional research investigated compounding anthropogenic stressors including habitat degradation in nearshore juvenile Chinook rearing areas, toxic contaminants, and biotoxins, as well as behavioral and life history variation within and among salmon species that shapes their vulnerability to these pressures. Climate change is exerting pervasive effects on these processes, further complicating the interactions affecting prey availability, water quality, and salmon susceptibility to disease and contaminants.

Collectively, these studies are revealing new aspects of ecosystem structure and highlighting emerging threats to salmon survival. Examples include shifts in pteropod nutritional quality under ocean acidification, evidence of high sockeye salmon mortality associated with salmon sharks and other predators, and observations that some early marine habitats are increasingly experiencing thermal and hypoxic conditions near or beyond salmon tolerances. Looking across BC’s coastal regions, studies reveal considerable variation in water quality, productivity, and prey availability during the critical early marine rearing period. The degree of variation suggests that place-based management strategies tailored to local conditions will increasingly be needed.

Climate Change Vulnerability

Climate change emerged as a cross-cutting theme throughout the report and is increasingly central to understanding salmon status and future risk. New research is applying downscaled climate modelling, genomics, life-cycle models, and vulnerability assessments to examine how climate-related changes may affect different species, regions, and conservation units. Downscaled hydrologic and stream-temperature models show that by 2100 Pacific salmon in BC will on average face freshwater temperatures about 3°C warmer than the previous century. Vulnerability assessments then linked these changing conditions to salmon responses: life-cycle models for sockeye quantified how productivity in different populations responds to freshwater and marine covariates, revealing especially high sensitivity in southern systems and during early marine stages, while genomic offset analyses identified populations spawning in the lower Fraser and Thompson River regions as requiring the most genetic change to adapt to future climates. Within the Fraser Basin, quantitative exposure and vulnerability assessments showed that vulnerability varies markedly among species and conservation units, with many sockeye and Chinook CUs, especially summer migrants and those already in poor condition, projected to face the highest risks. This research provides an improved foundation for climate-informed planning, but also highlights uncertainty about life-cycle effects, non-stationary relationships, and adaptation potential.

Life Cycle Approaches for Assessment

PSSI enabled advances in life cycle assessments, tracking salmon from eggs to mature adults in order to identify mortality bottlenecks and limiting factors. The Follow the Fish program was developed to identify and assess anthropogenic, biological, and environmental factors limiting the productivity of West Coast Vancouver Island natural-origin Chinook salmon, while the Bottlenecks to Survival Project aimed to identify survival bottlenecks and their causes for Chinook, coho, and steelhead in the Strait of Georgia. Synthesis of results from these programs is ongoing and will ultimately serve a range of management applications from informing recovery and rebuilding programs, to identifying measures to improve salmon productivity across freshwater and marine ecosystems, to guiding optimal hatchery release timing and enhancement strategies.

Throughout this work, researchers have deployed an array of advanced monitoring technologies. These include eDNA analysis to characterize marine ecosystems; autonomous echosounders to identify prey hotspots and juvenile salmon abundances; scat analysis, biochemical diet tracers, and acoustic and satellite tagging to assess predator diets and spatial overlap with salmon; advanced molecular tools such as Fit-Chips to evaluate an array of environmental and physiological stressors on juvenile salmon; and passive integrated transponder (PIT) tags combined with detection array networks to identify stage-specific survival rates and pinpoint mortality bottlenecks.

One notable outcome was the establishment of the first Laser Ablation-Inductively Coupled Plasma-Mass Spectrometry facility at DFO's Institute of Ocean Sciences, providing the Department with in-house analytical capability for otolith microchemistry and salmon life history research. In addition, a life-cycle simulation model (SalmonMSE) was developed to support decision making and to evaluate trade-offs among harvest regulation, hatchery enhancement, and habitat restoration.

Hatchery Modernization: Genetics and Fish Health

Research under the Science to Support Hatchery Modernization initiative focused primarily on genetics and fish health. Genetics research investigated the fundamental differences between hatchery and natural-origin salmon, and the mechanisms driving those differences. Using advanced techniques including whole-genome sequencing, methylation sequencing, and parentage-based tagging (PBT), researchers found that hatchery fish exhibit distinct epigenetic signatures relative to natural-origin fish that vary by population, rearing strategy, and life stage, and that can in some cases be inherited by offspring. A complementary study on relative reproductive success highlighted the methodological challenges of estimating hatchery-wild fitness differences, and identified grand-parentage-based tagging as a tractable pathway forward. On the operational side, whole-genome sequencing of chum salmon across southern BC yielded an improved genetics panel with greater stock identification accuracy, while a new rapid genotyping assay to distinguish among conservation units based on run-timing genotypes was tested for field deployment.

Fish health projects focused on improving how hatcheries assess, prevent, and manage disease and stress, while clarifying the environmental drivers of health outcomes for both hatchery and wild salmon. Long-term analyses of broodstock screening and disease records showed that for key pathogens such as BKD and IHNV, environmental factors often play a larger role than direct parent-to-offspring transmission. PSSI investments modernized diagnostic capacity by developing and validating qPCR assays for multiple endemic pathogens, testing new approaches such as pre-fertilization egg disinfection, and building non-lethal screening protocols. Novel tools, including salmon Fit-Chips and environmental RNA sampling, demonstrated the ability to track pathogen exposure, physiological stress, and smoltification status in near real time. Other work on stress physiology, hatchery nutrition, thiamine deficiency, and vateritic otolith formation clarified when proposed biomarkers or diet changes are (and are not) useful, and showed that relatively simple adjustments to rearing practices can reduce some health-related abnormalities.

Fisheries Monitoring and Harvest Techniques

Work focused on fisheries monitoring and harvest techniques advanced tools and approaches for more selective and precautionary fisheries management. In recreational fisheries, an expanded creel survey led by the Central Coast Indigenous Resource Alliance improved spatial coverage and genetic sampling of salmon catches, while a DFO-led mark-selective fishery (MSF) reference fishery collected fishery-independent data on hatchery mark rates, stock composition, and sizes of Chinook encountered. A five-year study by UBC's Pacific Salmon Ecology and Conservation Laboratory evaluated post-release mortality in recreational fisheries, finding that outcomes vary with fish condition, species, size, and water temperature, and yielded evidence-based best practices to reduce injury and stress from catch-and-release angling. In commercial fisheries, an enhanced bycatch monitoring program in the groundfish trawl fishery tracked a large increase in Chinook bycatch and directly informed the development of a new bycatch management plan. Other work on commercial gillnet vessels piloted electronic monitoring as a cost-effective alternative to at-sea observers and explored selective salmon trap technologies for First Nations terminal fisheries.

Standardizing Salmon Stock Assessments

PSSI coincided with a transition in Pacific salmon stock assessment and legislative requirements following implementation of the Fish Stocks Provisions of the Fisheries Act and standardized national science advice templates. Additional capacity enabled input into the design and more widespread application of a standardized national template for assessment of salmon stock management units (SMUs) that includes hatchery, harvest, and habitat considerations unique to Pacific salmon. During the latter years of PSSI, stock assessments for eleven Pacific salmon SMUs underwent review through a Canadian Science Advisory Secretariat (CSAS) Salmon Sprint Week and individual peer review processes. This work advanced a regular and structured assessment model for Pacific salmon stocks, although sustaining this progress will require continued analytical capacity and population monitoring.

Improving Salmon Data Stewardship

Progress was also made in improving data stewardship and the infrastructure underpinning Pacific salmon research. Key outcomes included the modernization of some legacy databases, the development of centralized platforms to link field sampling with analytical results, and the establishment of data standards to ensure information is findable, accessible, interoperable, and reusable (FAIR) across programs and jurisdictions. While these advancements represent an important step toward more integrated data systems, ongoing investment is required to fully modernize remaining legacy systems and migrate historical datasets into managed databases.

Recommendations

The research summarized in this report represents a substantial expansion of the science available to support Pacific salmon management and conservation. Overall recommendations emphasize the continued advancement of life-cycle assessment approaches that account for interacting stressors across freshwater, estuarine, and marine ecosystems. As climate change creates a shifting baseline, it is increasingly important to understand its current and future effects and consider them in the design of monitoring programs, assessments, and decision-making. Furthermore, the report highlights the needs to adopt a cumulative effects perspective to address overlapping pressures rather than assessing and managing stressors in isolation. Across many populations and areas, there remains considerable potential for research and assessments to identify critical limiting factors and support development of mitigation measures.

A significant outcome of the PSSI was the development of numerous tools, monitoring methods, and assessment frameworks; the critical next step is to move toward applying these innovations to inform assessments, management decisions, and operational activities. This includes integrating modern genomic and fish-health diagnostics into hatchery practices and building upon the solid foundation established for data management and standardized stock assessments. Throughout these efforts, the importance of collaboration remains a recurring theme that was emphasized across research efforts. Ultimately, long-term success will depend on fostering cross-jurisdictional partnerships with other governments and Indigenous groups to co-develop research and implement evidence-based recovery strategies that support resilient Pacific salmon populations.

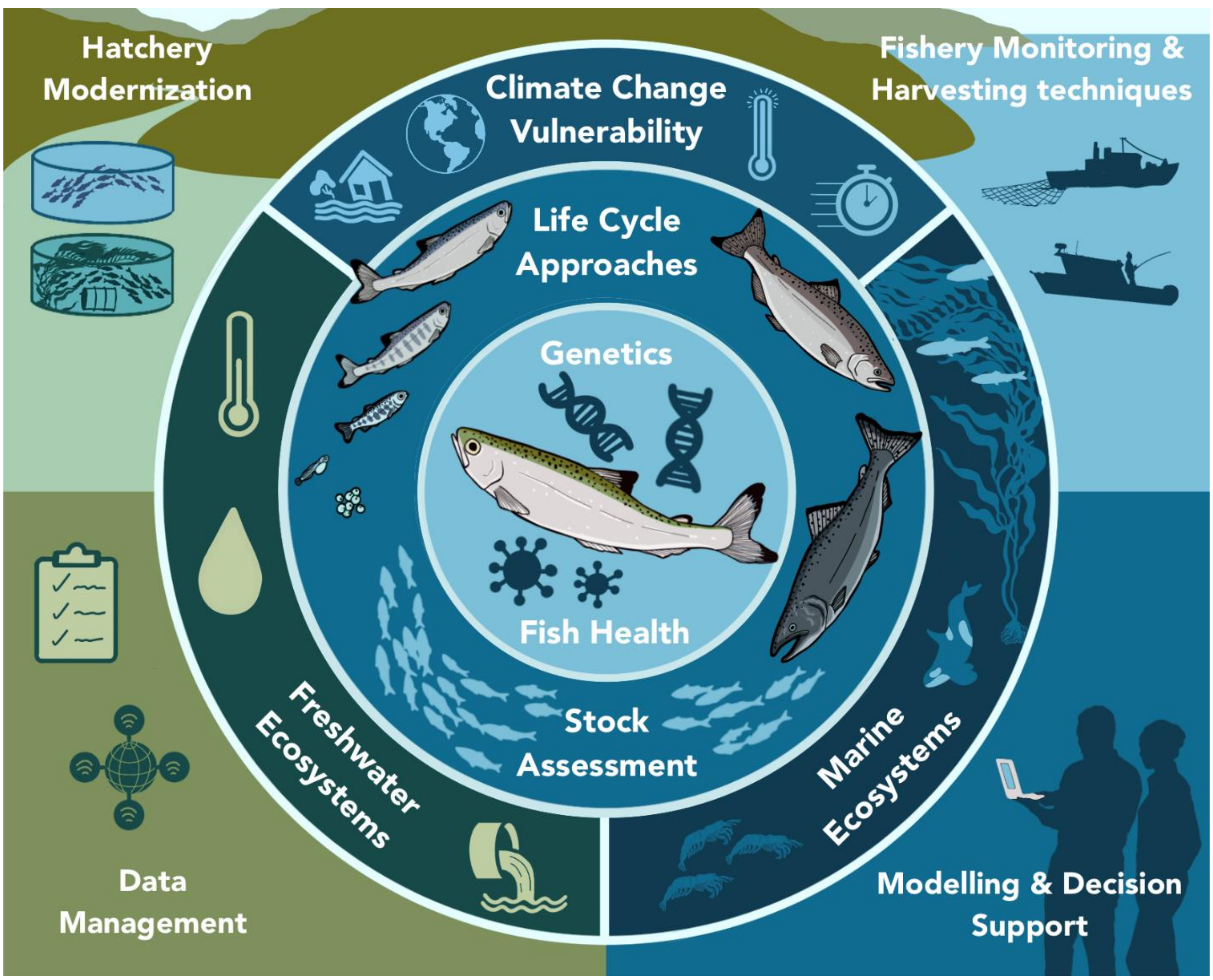


Figure 1. Thematic research areas included in this report to summarize research and monitoring funded by PSSI.

INTRODUCTION

Pacific Salmon Strategy Initiative Overview

The Pacific Salmon Strategy Initiative (PSSI) was a generational investment of $647 million in habitat restoration, hatchery enhancement, fisheries management, scientific research, and other activities related to Pacific salmon. PSSI was initiated in 2021 in response to long-standing concerns about declines in salmon populations, increasing pressures from climate change, and the need for more integrated approaches to management and recovery. Over its five year span, the multi-faceted initiative sought to restore vulnerable populations of Pacific salmon and their habitats, support sustainable fishing opportunities while reducing impacts on at-risk stocks, and build capacity among partners to achieve better outcomes for Pacific salmon.

PSSI brought significant new capacity and resources to Fisheries and Oceans Canada (DFO), the lead federal agency for the initiative, enabling expanded scientific research, enhanced stewardship and restoration activities, additional capacity for enhancement and monitoring, and new collaborative approaches with Indigenous and non-Indigenous partners. The initiative was initially designed and managed across four pillars intended to provide a framework for aligning and coordinating actions across habitat, hatcheries, fisheries, and governance. The four pillars (Conservation and Stewardship, Salmon Enhancement, Harvest Transformation, and Integration and Collaboration) each involved multiple sectors within DFO and were composed of several “initiatives”, which were distinct elements for funding and reporting (Table 1).

The conservation and stewardship pillar focused on new activities and investments supporting the long-term persistence and rebuilding of Pacific salmon populations. Key components included a doubling of the British Columbia Salmon Restoration and Innovation Fund (BCSRIF), investing in research to improve our understanding of salmon and their ecosystems, advancing integrated planning for salmon ecosystems to mitigate pressures on freshwater habitats, developing integrated rebuilding plans for vulnerable salmon populations, improving supports for salmon stewardship activities through engagement, and capacity-building with First Nations and community partners.

The salmon enhancement pillar aimed to modernize hatchery programs to more effectively support the conservation, recovery, and sustainable use of Pacific salmon. A key objective under this pillar was to invest in new hatchery infrastructure and capacity, including retrofitting existing facilities and building new facilities in the Upper Fraser area. The pillar also aimed to strengthen collaboration and enhancement partnerships, including with First Nations and other stakeholders, while investing in hatchery science related to genetics, fish health, and operational monitoring. In addition, this pillar supported development of a modernized enhancement policy intended to guide decision-making in a way that better supports the overall enhancement vision, including the targeted use of conservation-based hatchery production to help recover, stabilize, and restore vulnerable salmon stocks.

The harvest transformation pillar was intended to change how Pacific salmon fisheries were managed in response to long-term stock declines and ongoing conservation concerns. Its key objectives included adopting more precautionary and selective fishing approaches, including exploring mark-selective fisheries, and developing new tools to better monitor harvest impacts across sectors. The pillar also included commitments to update the Salmon Allocation Policy and to update licensing, regulatory, and management frameworks, including measures such as licence buyback programs and long-term commercial fishery closures in times and areas transited by stocks of concern. In addition, it aimed to improve the timeliness and accuracy of fishery monitoring and catch reporting programs to inform decision-making.

Finally, the integration and collaboration pillar focused on strengthening collective capacity to address Pacific salmon declines by improving how DFO worked both internally and with external partners. Key objectives were to provide capacity support to various internal and external groups involved in salmon conservation and management, to improve collaboration among federal, provincial, territorial, Indigenous, and other governments, to develop new infrastructure and tools for sharing data, and to prioritize salmon stocks for recovery through coordinated, cross-jurisdictional planning and decision-making processes.

Table 1. The 24 major components of the PSSI (known as initiatives) and their associated pillar. Initiatives that were led by or included DFO Science branch are shown in bold text.

Pillar	#	Initiative Name
Conservation and Stewardship	**1**	**Improved Understanding Of Salmon Ecosystems**
	2	**High Seas Monitoring And Enforcement**
	3	Integrated Salmon Ecosystem Planning
	4	**Salmon Stewardship And Restoration**
	5	**BC Salmon Restoration And Innovation Fund Phase Two**
Salmon Enhancement	6	New Upper Fraser DFO Hatcheries
	7	Retrofitting DFO Hatcheries
	8	New And Retrofitted Community-Based Hatcheries
	9	**Modernized Hatchery Management (Harvest)**
	10	**Expansion Of Mass Marking**
Harvest Transformation	11	Pacific Salmon Allocation Policy Review Process
	12	Transition To Selective Harvesting Methods For FSC
	13	New And Innovative Harvest Opportunities (First Nations)
	14	Modernized Management Approach For First Nations Fisheries
	15	Long Term Conservation Closures On Non-Selective Fishing, And Mitigation Measures
	16	Modernized Licensing And Management Approach (Commercial)
	17	**New Recreational Harvest Opportunities (Mark Selective Fisheries)**
	18	**Modernized Licensing And Management Approaches (Recreational)**
Integration and Collaboration	19	PSSI Implementation Secretariat
	20	Integrated Salmon Workplanning
	21	**Strategic Data Policy And Analytics Team**
	22	Inter-Jurisdictional Salmon Collaboration
	23	BC First Nations Salmon Stewardship Governance
	24	International Salmon Collaboration

Scientific Research Supported By PSSI

The PSSI pillars were underpinned by a dual-track investment in scientific research, combining internal DFO expertise with external grants and partnerships. This new scientific capacity supported a diverse range of projects intended to inform rebuilding plans, identify factors driving population declines, better understand the impacts of climate change, and pilot new approaches for monitoring, enhancement, fisheries harvest, and restoration. By supporting research within DFO and externally, the initiative aimed to leverage and build on existing capacity within the federal government and across academic institutions, Indigenous organizations, non-governmental organizations, and industry.

While the first phase of BCSRIF was already underway with 97 agreements, PSSI significantly expanded this reach by funding a second phase. This resulted in 72 new collaborative agreements (Appendix A), with many focused on scientific research in areas such as climate change modelling, habitat restoration effectiveness, and monitoring innovation. These investments enabled First Nations, academic researchers, industry, and community organizations to work alongside DFO scientists, strengthening the evidence base for management decisions while incorporating Indigenous knowledge, local observations, and novel technologies into the broader PSSI research portfolio.

Within DFO Science, PSSI resources were primarily concentrated into two initiatives: Improved Understanding of Salmon Ecosystems and Science to Support Hatchery Modernization. Targeted funding also bolstered research in support of the Habitat Restoration Centre of Expertise, improving the management and accessibility of salmon-related data, increasing the capacity of the molecular genetics lab, and expanding monitoring of recreational fisheries. This work was implemented across the Pacific Region's four Science divisions (Stock Assessment, Ecosystem Science, Ocean Science, and Aquatic Diagnostics) enabling multi-disciplinary approaches to research and monitoring.

The largest PSSI initiative led by DFO Science was Improved Understanding of Salmon Ecosystems. The overarching aim of this initiative was to enable effective conservation management for wild salmon and their ecosystems by developing a comprehensive understanding of habitat, ecosystem, and climate change impacts on salmon productivity. Research planning and prioritization began in 2022 with a DFO workshop that identified knowledge gaps and research themes (Lagasse 2024). Subsequently, research proposals underwent a peer-review process and steering committee evaluation. Beginning in 2023, dozens of multi-year projects were funded, including the establishment of new research programs and the expansion or continuation of existing long-term programs.

The second major DFO Science initiative, Science to Support Hatchery Modernization, was a part of the Salmon Enhancement pillar. This initiative was designed to provide scientific advice and information to inform hatchery planning and operations, including the expansion of hatchery programs under PSSI. Research plans were co-developed by a steering committee representing the Salmonid Enhancement Program (SEP) and DFO Science.

In this report, we summarize the outcomes and findings of research projects funded through the PSSI, with a focus on work led by DFO Science in the Pacific Region. We synthesize results across several research themes aligned with the major PSSI initiatives (Figure 1), providing an overview of findings from a diverse set of multi-disciplinary projects. For the Improved Understanding of Salmon Ecosystems initiative, we review research within five thematic areas:

salmon population monitoring, life-cycle assessment approaches, freshwater ecosystems, marine ecosystems, and climate change vulnerability. For the Science to Support Hatchery Modernization initiative, we outline research focused on genetics and fish health. In addition, we describe broader research and scientific priorities supported by PSSI, including work related to fisheries monitoring and new harvest techniques, stock assessment advice, data stewardship and new tools and models to support decision making. We provide project summaries for 47 DFO-led research projects, offering a snapshot of the current state of Pacific salmon science under PSSI. Although some results are preliminary and the synthesis is not comprehensive of all research conducted under PSSI, this review highlights the insights, knowledge gaps, and future priorities identified during the five years of the initiative.

UNDERSTANDING SALMON ECOSYSTEMS

Deteriorating freshwater and marine ecosystem conditions, arising from climate change and human pressures, are a leading threat to salmon populations. Broadening the focus of research and assessment from salmon to salmon ecosystems is therefore crucial for future conservation and management. Recognizing this need, DFO has committed to pursue an Ecosystem Approach to Fisheries Management (EAFM), which includes bolstering foundational scientific knowledge:

"Incorporating ecosystem information into fisheries management decision making has long been a goal of the department. Continuing research in ecosystem and fisheries science, and with considerations gathered from Indigenous groups and stakeholders, we aim to fully utilize existing ecosystem information, as well as collect new information, to improve the advice informing fisheries management decisions. This will result in a more holistic fisheries management approach."

Improved Understanding of Salmon Ecosystems was thus a forefront initiative under PSSI that supported major research efforts from DFO Science. This work was also complemented by many projects led by other organizations and supported by BCSRIF. In this section, we attempt to thematically summarize and synthesize this substantial body of work.

FRESHWATER ECOSYSTEMS

Freshwater ecosystems that support Pacific salmon are experiencing incremental and accumulating pressures due to human activity and exacerbated by climate change (Ulaski 2025). Research supported by PSSI within freshwater ecosystems monitored and modelled habitat conditions to better understand the combined impacts of cumulative stressors and climate change (Figure 2), as well as specific emerging stressors, such as toxic tire-derived contaminants and invasive smallmouth bass. Research included physiological and hydrological modelling to provide fine-scale observations and predictions, as well as high-resolution geospatial models that provide comprehensive information on individual and cumulative stressors to freshwater habitats at broad spatial scales. Data collected and project results support decisions on habitat management such as regulatory authorizations, watershed planning, water governance, and species recovery efforts.

Stream temperature and hydrology

Streamflow and temperature are critical determinants of freshwater habitat quantity and quality for Pacific salmon. As climate change intensifies, shifts in precipitation patterns and reduced winter snowpack are predicted to increase summer droughts (Ruzzante and Gleeson 2025, Moore et al. 2025), while increased winter flows can scour streambeds leading to reduced egg-to-fry survival (Shanley and Albert 2014). To support our ability anticipate and manage these changes to freshwater ecosystems, PSSI-funded research expanded upon stream monitoring, conducted in-situ experiments, and developed improved hydrologic models.

Table 2. DFO and BCSRIF projects associated with the freshwater ecosystems theme.

ID	Project Title
DFO Science	
2398	WCVI sediment transport and redd scour assessment
2410	Improved decision making for salmon by understanding the threats of freshwater Aquatic Invasive Species both now and in the future
2414	South Coast freshwater ecological indicator pilot
2424	Mechanistic modelling to link hydrology to juvenile salmon habitat quality and productivity
2425	Geospatial indicators and metrics for threats to fish habitat in the Fraser River Basin with Thompson-Nicola as a case study
2442	Habitat use and predation on juvenile Chinook salmon in the Canadian Okanagan River and Lake system
2443	Quantitative assessment of the impact of smallmouth bass suppression efforts in Cultus Lake and SMB emigration from Cultus Lake
2493	Improved understanding of cumulative impacts on salmon survival across freshwater life-stages; tools and approaches for mechanistic assessments
2504	Identifying and characterizing tire-related chemical (6PPD-quinone) toxic hotspots in salmon habitat
BCSRIF	
BCSRIF_2020_217	Developing a cumulative effects modelling framework for the recovery of aquatic salmonid populations
BCSRIF_2022_334	First Nations led salmon habitat and population monitoring, research and cumulative effects assessment in the Lower Fraser River and Boundary Bay
BCSRIF_2022_361	Identifying and mitigating hot spots of salmon exposure to toxic road runoff
BCSRIF_2022_368	Thompson-Shuswap Salmon Habitat Assessment, Monitoring & Restoration Program (2023-26)
BCSRIF_2022_389	Mitigating Inputs of Tire Wear Toxins to Protect Salmonid Habitat on Vancouver Island
BCSRIF_2022_426	Investigation of water acidification and habitat on imprinting and homing in Pacific salmon
BCSRIF_2022_435	Colquitz River Salmonid Restoration and Monitoring Project
BCSRIF_2022_449	Analysis of forestry effects on Pacific salmon in Musgamagw Dzawada'enuxw territory and across coastal BC

Naman et al. (2424) developed and applied models to estimate instream flow needs for juvenile salmonids in relation to warming climates using habitat simulations for 17 coho-rearing tributaries across the North Thompson watershed. This modelling can support real-time flow and temperature monitoring or be linked to flow and temperature projections under different scenarios. Initial model outputs have been shared with Secwépemc Fisheries Commission to support drought monitoring in several priority systems. The Secwépemc Fisheries Commission (on behalf of the Thompson-Shuswap Salmon Collaborative) also expanded monitoring in the Thompson-Shuswap sub-region (BCSRIF 2022 368), establishing hydrometric networks in drought-sensitive streams, and identifying and mapping cold-water refugia.

In the Lower Fraser River and Boundary Bay, the Salish Sea Indigenous Guardians Association (Kwantlen and Semiahmoo First Nations; BCSRIF 2022 334) began a program to monitor salmon populations and habitat, measuring temperature, flow, dissolved oxygen, and juvenile abundance in overlooked streams. Findings showed that summer temperatures regularly exceeded 20°C and that seasonal stream drying occurs in coho-bearing reaches of the Tatalu (Little Campbell) River. This work provides baseline data and demonstrates an Indigenous perspective on cumulative effects.

Increased winter run-off can jeopardize salmon redds by displacing eggs or smothering them with fine sediment (Montgomery et al. 1996). On the West Coast of Vancouver Island (WCVI), a freshwater risk assessment for Chinook salmon identified redd scour as a knowledge gap and potential limiting factor. McHugh, in collaboration with the Tla-o-qui-aht First Nation and Redd Fish Restoration, (2398) installed hydrometric stations along with accelerometer scour monitors (ASMs) at surveyed spawning locations in hiłsyaqƛis (Tranquil Creek). A 2D hydraulic model will estimate the spatial extent of bed disturbance in key Chinook and chum spawning areas. Pending analysis will link the 2D hydraulic model to bed disturbance observations, integrate egg-to-fry survival data from rotary screw traps, and compare results with companion projects in the Sarita and San Juan rivers.

Water quality and temperature was also measured across a collection of WCVI streams as part of an ecological indicator pilot project (2414, McHugh). As part of the project periodic water quality observations were collected in 13 watersheds providing improved coverage throughout WCVI streams and addressing a knowledge gap surrounding water quality as a potential limiting factor for juvenile WCVI Chinook.

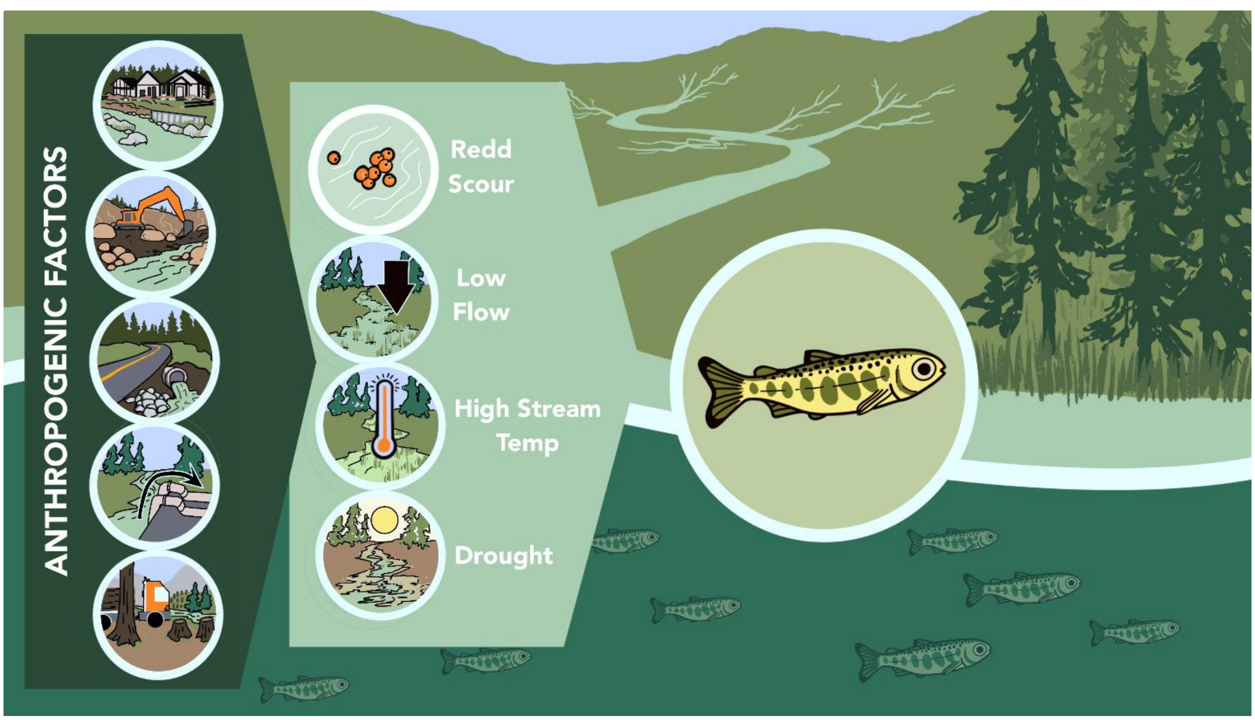


Figure 2. Stressors and characteristics of freshwater ecosystems investigated by PSSI-funded research projects.

Cumulative effects

Research into cumulative effects and stressor-responses provides a framework for understanding the complex interactions that influence the freshwater survival and productivity of Pacific salmon. Salmon populations face simultaneous and incremental habitat threats that interact in ways that may not be taken into account during conventional impact assessments or watershed planning (Ulaski et al 2025; Dakin Kuiper et al. 2026). Research related to this theme addressed these challenges using multiple approaches including geospatial modelling, population stressor-response models, and mechanistic studies.

At the landscape scale, Iacarella et al. (2425) developed geospatial estimates of individual and cumulative threats for salmon and Species At Risk habitat for streams within the Fraser River Basin. This research identified which conservation units (CUs) face the greatest cumulative stress from eight different threats that were individually modelled: aquatic invasive species, riparian disturbance, in-stream habitat destruction, flow alteration, latitudinal fragmentation, sedimentation, pollutant loading, and nutrient loading (Weller et al. 2024; Iacarella 2025). For climate change threats, model projections were used to estimate threats of flood-risk, low and high stream flow, and high summer stream temperature from 2040–2060. This work showed that the highest cumulative threat scores are around the lower Fraser River and within the interior plateau of the Fraser River Basin for threats from both human activity and climate change. Riparian disturbance, nutrients, and sedimentation were the largest contributors to human activity threats, while high stream temperatures were the most prevalent among climate change threats.

To support salmon rebuilding, researchers from the BC Ministry of Environment and Climate Change Strategy, Alberta Environment and Parks, and Simon Fraser University (BCSRIF 2020 217) developed the Cumulative Effects Model for Prioritizing Recovery Actions (CEMPRA) platform, a modelling framework with a user-friendly application that integrates stressor-response functions with spatially-explicit stressor magnitudes to estimate habitat carrying capacity and simulate the outcomes of competing recovery actions (Bayly et al. 2024; Rosenfeld et al. 2022). CEMPRA has been applied to salmon populations such as Interior Fraser coho and Nicola Chinook, as well as species-at-risk including Nooksack dace and Salish suckers. By providing evidence-based stressor response relationships, the application allows managers to evaluate the expected population-level outcomes of competing management actions without requiring decades of before-after studies or in-situ assessments.

At the mechanistic level, Patterson et al. (2493) developed and validated bioindicators related to multiple stressors (e.g. thermal stress, hypoxia, starvation, indicators of cardiac stress) for use in field and laboratory studies. This consists of methods to evaluate physiological and behavioural responses to environmental stressors such as: insulin-like growth factor as a marker of somatic growth, troponin as an indicator of cardiac stress under hypoxia, and triglycerides for nutritional status. Life-stage specific relationships were examined using samples from three large-scale field programs (Lakes, E-Watch, North Thompson Salmon Ecosystem Program). This mechanistic approach allows for increased understanding of the relationship between juvenile fish conditions and freshwater habitat factors, which can inform assessments of habitat quality and carrying capacity.

6PPD-quinone

Tire-wear toxins such as 6PPD-quinone (6PPD-Q) enter streams in repeated pulses during rain events and expose coho and other salmonids to potentially lethal concentrations (Scholz et al. 2011). While this non-point source pollution has previously been studied in Puget Sound, Washington State, few measurements had been collected in BC. Through PSSI, Loseto et al. (2504), the University of British Columbia's (UBC) Department of Civil Engineering (BCSRIF 2022 361), and the British Columbia Conservation Foundation (BCSRIF 2022 389) measured 6PPD-Q concentrations and temporal dynamics in salmon-bearing streams across southwestern BC and Vancouver Island, identifying hotspots associated with road runoff, and evaluating green infrastructure solutions to protect aquatic habitat.

Initial results show that 78% of monitored sites in Metro Vancouver, Squamish, and Vancouver Island exceeded lethal 6PPD-Q concentration (LC50) thresholds for coho during wet weather events. Concentrations were positively associated with residential and commercial land cover, turbidity, and the number of dry days preceding rainfall. At baseflow, concentrations did not exceed water quality guidelines, but any sustained rainfall caused streams to surpass published toxicity thresholds. A predictive hotspot map for salmon-bearing streams in the Lower Mainland, Squamish, and Vancouver Island is in final development and will direct green infrastructure investment to the highest-priority locations. Project findings are also informing the reassessment of 6PPD-Q as a toxic substance under the Canadian Environmental Protection Act.

Aquatic invasive species

Aquatic invasive species (AIS) pose a serious threat to biological diversity and associated salmon habitat across the Pacific Region (Dextrase and Mandrak 2006; Sanderson et al. 2009). Therriault and colleagues (2410) adapted and expanded a Non-Indigenous Species Screening Tool (NISST, Wilcox et al. 2025) to fill gaps and address common limitations in previous tools for screening potentially invasive species. NISST uses a three-module scoring system that explicitly incorporates uncertainty and accounts for changes in invasion risk under climate change projections. The NISST resulted in a ranked list of AIS by freshwater ecoregion that shows the taxonomic identity of the invader (fish, invertebrate, or plant), its invasion status (present versus not yet detected), the effect of climate change, and uncertainty. Southern ecoregions were found to have more established invaders, including brown bullhead, goldfish, common carp, and rosy red minnow, as well as invasive plants and invertebrates. The ranked AIS lists by ecoregion may inform AIS monitoring programs within DFO, the Province of BC, and Yukon, and can support future amendments to the AIS Regulation under the Fisheries Act.

Recovery Potential Assessments for endangered salmon populations, specifically Okanagan Chinook and Cultus Lake sockeye, have identified invasive predators as either an unknown threat risk, or a high risk with "unknown ecological effects" (DFO 2020; Mahoney 2019). Smallmouth bass (*Micropterus dolomieui*) are common in both systems and represent a knowledge gap with regards to predation on juvenile salmonids (DFO 2020).

Research in the Okanagan Basin (2442, Weir and Pontbriand) investigated habitat use and survival of endangered juvenile Chinook salmon through acoustic tagging, in partnership with Thompson Rivers University and the Okanagan Nation Alliance (ONA). Sub-yearling Chinook raised at the ONA’s kł cp̓əlk̓ stim̓ hatchery were tagged and released in two groups in the Okanagan River then tracked as they migrated downstream. Results showed sharp declines in detection rates and low survival with significant mortality concentrated at Vaseux Lake, Osoyoos Lake, and vertical drop structures within the Okanagan River. Smallmouth bass were the dominant species caught in targeted angling efforts in the Okanagan River, Vaseux Lake, and Osoyoos Lake. While DNA barcoding of bass stomach contents only detected Chinook in one sample, a sample acoustic tag was recovered from stomach contents, which shows a direct observation of predation. Proposed management actions include reconnecting side channels, re-naturalizing riparian zones, adding pools and woody debris, managing macrophyte growth, adjusting dam operations for cold-water protection, and targeted smallmouth bass removal at vertical drop structure sites.

In Cultus Lake, Doutaz et al. (2443) assessed the impact of smallmouth bass suppression efforts to protect endangered sockeye, as well as, the endemic Cultus pygmy sculpin (*Cottus aleuticus*). Electrofishing and angling operations removed smallmouth bass over three years, with electrofishing accounting for 95% of removals. Mark-recapture data from PIT tags suggest the population was approximately 16,000 individuals in 2024, though this estimate is likely biased low because a substantial portion of the population may occupy depths beyond electrofishing capture. Approximately 10% of stomach samples contained juvenile salmonids (fry and smolts), and 2% contained sculpins. Meanwhile, pumpkinseed bycatch rose from 2 individuals in 2023 to 2,553 in 2025, a drastic increase that signals a rapidly expanding secondary invasion. The findings across projects suggest that invasive species monitoring and suppression should be sustained and adaptive in order to be effective.

MARINE ECOSYSTEMS

Pacific salmon productivity and survival depend on complex interactions between bottom-up and top-down forces that vary across regions and life stages. PSSI research addressed both bottom-up and top-down processes across a broad spatial range from BC estuaries and the Strait of Georgia to the West Coast of Vancouver Island and the North Pacific (Figure 3). Bottom-up studies examined coastal productivity, environmental drivers of the salmon food web, and prey availability, quantity, and quality. Top-down studies investigated competitors and predators. Additional research explored compounding stressors including nearshore habitat degradation, toxic contaminants, diseases, and harmful algae blooms. Because life history variation among salmon populations affects their exposure and resilience to these stressors, deciphering life history diversity, particularly during the early marine phase, was also a research priority.

Bottom-up studies: relationships between coastal productivity and environmental factors on salmon and the salmon food web

Juvenile salmon spend a short but critical period of their lives rearing in nearshore coastal habitats after emigrating from their natal watersheds. This early marine life stage has long been understood as a period of elevated mortality, whose variations strongly determine subsequent adult cohort size (Parker 1962). Various physical and biological factors in coastal salmon habitats are gradually being linked to juvenile mortality through dedicated research, and numerous PSSI-funded studies contributed to these efforts.

Table 3. DFO and BCSRIF projects associated with the marine ecosystems theme.

ID	Project Title
DFO Science	
2404	Improving baseline knowledge of environmental conditions in Vancouver Islands fjords through observations and modelling, with a focus on hypoxia dynamics, climate change, and the potential implications for Pacific salmon
2406	Changing coastal productivity: using sediment cores, water properties and archived plankton data to identify changes at the bottom of the food web in BC's coastal waters
2409	Convergent tracks: a tagging study to quantify salmon predation by sea lions
2412	Investigation of the impacts of singular and coinciding acute climate stressors on the nutritional quality of the pteropod *Limacina helicina*, a juvenile Pacific salmon dietary species
2413	Barkley Sound and Clayoquot Sound krill monitoring
2416	Monitoring and predicting the exposure of Pacific salmon to harmful algal biotoxins
2422	Development and application of laser ablation-inductively coupled plasma-mass spectrometry (LA-ICP-MS) to determine estuary entry size of juvenile salmonids and track habitat usage
2427	Salish Sea plankton and oceanography
2433	Integrated Salish Sea acoustic monitoring of salmon and salmon prey
2447	Innovative ecosystem based approaches to identify cumulative stressors: Salmon Fit-Chips and eDNA
2513	Characterizing and monitoring priority contaminants of concern in WCVI juvenile salmon
BCSRIF	
BCSRIF_2022_341	ʔaayaaqa (Herring) Herring Spawn Dynamics
BCSRIF_2022_358	Determining the mechanisms of impacts of a changing climate on zooplankton in the Salish Sea using models and observations
BCSRIF_2022_379	Strait of Georgia Herring: Restoring the Salmon Food Web
BCSRIF_2022_397	Mapping, monitoring and restoring important forage fish habitats in Coastal British Columbia to support salmon conservation efforts.
BCSRIF_2022_404	Oolichan From Estuary to Offshore: Assessment of Early Marine Populations and Limiting Factors of Central Coast Oolichan (Eulachon: *Thaleichthys pacificus*) in Douglas Channel and Gardner Canal
BCSRIF_2022_425	Empirically resolving interspecific competition experienced by North Pacific salmon in the open ocean
BCSRIF_2022_430	Resilient Estuaries in the Salish Sea: Phase Two (Baseline Assessments and Ground-truthing)
BCSRIF_2022_436	Establishing baselines, risks, and mechanisms of thiamine deficiency in British Columbia Chinook salmon
BCSRIF_2022_444	Enhancing Estuary Resilience: A Collaborative Approach to the Monitoring and Restoration of Estuaries with Coastal First Nations

A few PSSI studies applied oceanographic modelling to characterize coastal environmental factors across time and space and to forecast conditions under future climate change. Bianucci and colleagues developed a model to analyze ocean conditions in the fjord areas of Clayoquot Sound, BC, representing temperature and oxygen levels that salmon may encounter during nearshore migration and rearing (2404; Foreman et al. 2024). Analyses of model results and observations indicate that although environmental conditions are generally heterogeneous among Clayoquot Sound inlets, suboptimal dissolved oxygen concentrations and supraoptimal surface water temperatures for salmon are common among all inlets during certain seasons (Rosen et al. 2022; Geng et al., in prep). Modelled future climate scenarios suggest that the magnitude and duration of these physical stressors is likely to increase (Geng et al., in prep). At a broader scale, researchers from UBC's Allen Lab harnessed the "SalishSeaCast" biophysical model to investigate how climate change is reshaping prey availability for juvenile salmon and resident adults in the Salish Sea (BCSRIF_2022_358, Allen et al.). Their work has unpacked the key drivers of zooplankton grazing, mapped seasonal and regional variability, and assessed how shifting winds, marine heatwaves, and ocean acidification affect food availability throughout the system.

A consistent finding across the modeling work is that zooplankton biomass is highest near zones of strong tidal mixing, areas where phytoplankton are advected in from more productive neighboring waters and provide enhanced grazing opportunities. These insights offer a window into bottom-up food web dynamics at spatial and temporal scales that traditional field sampling cannot achieve, helping to clarify what drives lower trophic level production across the Salish Sea.

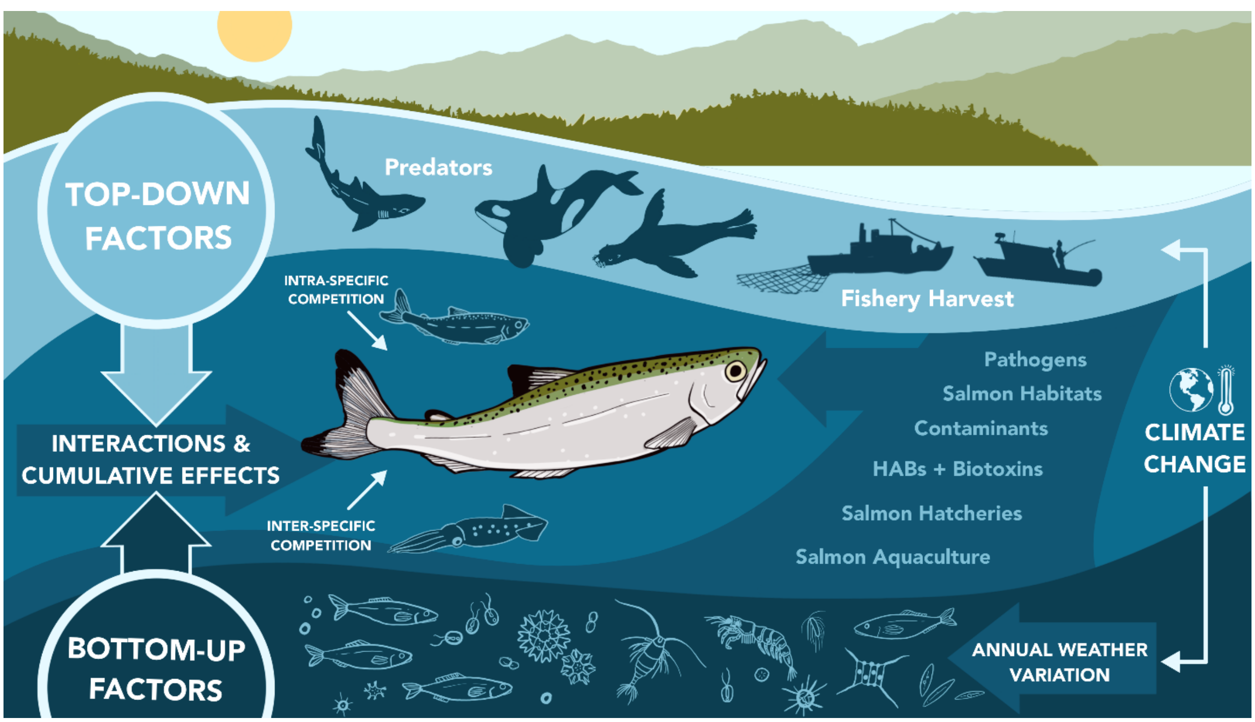


Figure 3. Bottom-up, top-down and other factors investigated by projects within the Marine Ecosystems theme.

Building on this foundation, ongoing research is investigating how the changing climate may influence salmon by exploring connections between climate stressors and plankton biomass, as well as examining how phytoplankton and zooplankton communities respond to warming temperatures and elevated CO_2. For example, Johannessen and team at the Institute of Ocean Sciences (IOS) used sediment core records from a number of BC coastal fjords to test for recent climate-driven changes in phytoplankton productivity (2406). While fisheries models for the Salish Sea attributed salmon declines to 30% reduced primary productivity since the 1970s, sediment core geochemistry showed total productivity remained constant over the past century (Johannessen et al. 2021); however, it is possible that a change in the type of productivity could have affected salmon by changing the nutritional value of available food. Results to date indicate a change toward a less nutritious food web in some inlets but not others, which would suggest that some inlets provide a more consistently productive salmon food web. Ongoing work aims to determine environmental drivers of phytoplankton productivity and predicted climate change effects.

Sastri and colleagues at IOS conducted a series of studies that also focused on linking plankton productivity to ocean climate variables (2413). They examined availability and quality of zooplankton prey, particularly euphausiids (krill), for juvenile Chinook along the West Coast of Vancouver Island (WCVI). Their work revealed that prey availability differs on a local scale among sounds (e.g. lower in Barkley than Clayoquot), and that developmental timing of the key euphausiid prey, *Thysanoessa spinifera*, varies among years in accordance with ocean climate forces, creating potential phenological mismatches with salmon outmigration. In the Strait of Georgia, Sastri's team characterized prey availability and developed novel 'rapid ecosystem' assessment methods to measure productivity and estimate energy available to zooplankton consumers (2433), metrics that can be directly applied to juvenile salmon survival models (Perry et al. 2021) and biophysical models (Peña et al. 2016; Olson et al. 2020).

Another project took a closer look at whether climate stressors are degrading the nutritional quality of pteropods, specifically *Limacina helicina*, a pelagic sea-snail commonly preyed on by juvenile Pacific salmon (2412, Pearce et al.). The concern is that changes in pteropod nutritional value could ripple up the food web, affecting salmon growth, condition, and ultimately survival. The study focused on the Strait of Georgia, where both mean seasonal temperatures and pCO_2 levels are climbing, and acute disturbances such as marine heatwaves and low-pH upwelling events are becoming more frequent. Findings reveal that ocean acidification can alter the fatty acid composition of pteropods, with potential consequences for nutritional quality and the efficiency of energy transfer through the food web.

Thiamine deficiency complex—a condition stemming from insufficient levels of vitamin B1—is an emerging concern for BC salmon that has been linked to climate change effects on the marine food web (Mantua et al. 2025; Lerner et al. 2026). Thiamine deficiency complex offers a striking example of how shifts in the marine ecosystem can directly affect Chinook salmon. Thiamine is an essential nutrient that all organisms rely on to convert food into energy, and when salmon eggs contain low thiamine levels, the consequences can be severe: fry mortality can exceed 90%, and deficiencies can produce harmful effects across multiple life stages (Balk et al. 2016). Because salmon obtain thiamine through their marine diet, thiamine levels in individual fish fluctuate in response to changing ocean conditions and prey composition. A BCSRIF-funded project led by UBC's Hunt Lab has begun filling critical knowledge gaps by establishing baseline thiamine levels in BC Chinook salmon populations (BCSRIF_2022_436, Hunt et al.). The findings have shown that across populations, a sometimes large and highly variable proportion of female Chinook exhibit egg thiamine concentrations low enough to be considered deficient. The authors note that there are effective treatment strategies that can be applied to mitigate effects on fry mortality, some of which are already being implemented at hatcheries and were investigated as part of a study under the Fish Health theme (2418; Eliason et al.).

Bottom-up studies: forage fish as critical salmon prey

As juvenile salmon grow and begin to migrate offshore, forage fish constitute an increasingly dominant portion of their diets. Changes and fluctuations in the abundance, distribution, and composition of this critical prey base therefore carry important consequences for salmon survival. Considerable efforts under PSSI and BCSRIF were dedicated to investigating these linkages.

Pacific herring are a dominant forage fish and crucial prey for many salmon populations in the Salish Sea. The Salish Sea Marine Survival Project provided substantial evidence linking herring availability to salmon growth and survival (Pearsall et al. 2021). Comparing recent and historical diet data suggests juvenile herring are currently less available to juvenile salmon compared to earlier periods of higher salmon survival (pre-1990s). Understanding factors controlling juvenile salmon access to herring is key to understanding salmon productivity and developing recovery strategies for both herring and salmon.

The Pacific Salmon Foundation, with academic and First Nations partners, used BCSRIF funding to address critical knowledge gaps related to herring availability to salmon, spawn habitat quality, and health and structure of Strait of Georgia herring populations (BCSRIF_2022_379, PSF). Preliminary results suggest differences in herring availability across the Strait of Georgia and new estimates through otolith stable isotope analysis indicate that about 30% of the Strait of Georgia spawning stock may be made up of non-migratory herring. These non-migratory herring are likely important to salmon rearing within the Strait, which may be competing directly with the Strait of Georgia commercial herring fishery for this important food resource. These findings are a significant departure from the current management assumption of an entirely migratory herring population, and suggest a need to consider this life-history diversity when setting conservation priorities for both herring and salmon.

Another BCSRIF herring program, led by the Nuu-chah-nulth Tribal Council, aims to develop a Nuu-chah-nulth approach to ecosystem-based fisheries management by integrating life-history-driven differences in population responses to environmental changes and fishing into models of WCVI Pacific Herring spawning populations (BCSRIF_2022_341, NTC). This work addresses the topics of resilience and biodiversity, and is the first project to address these topics with an aim to developing Indigenous management models and frameworks that could be implemented in real-world fisheries.

Ecofish Research, in partnership with the Haisla Nation, received BCSRIF funding to address knowledge gaps in eulachon (oolichan) productivity and limiting factors in estuarine and marine environments (BCSRIF_2022_404, Ecofish). Eulachon are culturally vital to the Haisla Nation, serve as key forage fish for Pacific salmon, and have been assessed as threatened by COSEWIC in the nearby Nass and Skeena River. The program aims to provide data to inform conservation and recovery efforts for the Kitimat River population.

Top-down studies: predation and competition

Pacific salmon occupy middle trophic levels throughout their marine life phases, and can therefore be influenced by competitors at similar trophic levels and predators at higher trophic levels. PSSI and BCSRIF supported deployment of advanced monitoring technologies, including satellite tags, autonomous moored echosounders, and environmental DNA (eDNA) analysis to characterize marine ecosystems, identify predation hotspots, and track temporal changes in the food web.

For example, Gauthier's team at IOS deployed autonomous echosounder moorings across the Strait of Georgia and WCVI to examine juvenile salmon habitat use, prey availability, and predation and competition pressures (2427 and 2432). Moorings in Barkley Sound detected juvenile salmon year-round, primarily in the upper 15–20 meters, with peak abundance in late summer to early fall, coinciding with euphausiid presence. The studies identified persistent euphausiid hotspots along the BC coast and documented year-round presence of competitors (Pacific herring) and fish predators (Walleye pollock or Pacific hake) that migrate vertically, mixing with juvenile salmon in surface waters at night. In the Strait of Georgia, large-scale acoustic surveys revealed increasing Pacific hake biomass throughout the Strait, likely intensifying predation pressure on juvenile salmon—a sharp contrast to WCVI where hake biomass has declined dramatically in recent years. Nearshore moorings detected year-round juvenile salmon presence at relatively low abundance in habitats dominated by Pacific herring, suggesting that juveniles face competition for prey in these inside waters.

Other PSSI and BCSRIF research addressed critical knowledge gaps in predation and competition affecting Pacific salmon. While most studies have focused on cetacean and Harbour seal predation on salmonids (Chasco et al. 2017a & b; Walters et al. 2020; Nelson et al. 2024), the dramatic increase in Steller sea lion abundance beginning in the 1990s and coinciding with Fraser River sockeye declines prompted investigation. Freshwater and Tucker's DFO teams jointly investigated Stellar sea lion predation using scat analysis and biochemical diet tracers, and employed acoustic and satellite tagging to assess spatial overlap between sockeye and sea lions (2409). High sockeye mortality was documented, but salmon sharks, rather than sea lions, were inferred to cause the most mortality. Results suggest sockeye are vulnerable to a broader predator suite than previously thought, with predation risk varying across space and time.

Understanding competition has become critical due to an emerging consensus that limited prey resources can impose a carrying capacity for salmon in the North Pacific (Connors et al. 2024). Many Pacific salmon mature in the Gulf of Alaska with dietary overlap that insinuates interspecific competition, especially among chum, pink, and sockeye (Graham et al. 2021). While competition severity across the North Pacific is debated (Northern Hemisphere Pink

Salmon Expert Group 2023), it has been suggested that there is minimal competition in the western Pacific due to high prey abundance (Naydenko and Somov 2022), while the extent of competition in the less productive northeastern Pacific was a critical knowledge gap. A BCSRIF-funded study from UBC's Hunt Lab used International Year of the Salmon samples to shed new light on winter resource competition among meso-predators in the North Pacific (BCSRIF_2022_425, Hunt et al.). They found substantial dietary overlap between Pacific salmon and several squid and myctophid species—a significant concern given that the combined biomass of non-salmonid competitors may exceed that of salmon. As the first study to analyze pelagic food webs in the North Pacific high seas during winter, the authors make a compelling case for how improved knowledge of salmon overwintering locations could enhance production estimates.

Exacerbating factors: habitat, disease, biotoxins, and contaminants

Additional factors compound bottom-up and top-down pressures on Pacific salmon: habitat degradation limits primary productivity while toxins and disease influence salmon health and resilience. Research under PSSI and BCSRIF focused on knowledge gaps related to these factors.

Harmful algal biotoxins cause illness and mortality in marine animals including juvenile fish (Lefebvre et al. 2005). Since 2020, BC coastal monitoring has revealed significant correlations between climate variables (e.g., water temperature) and biotoxin concentrations in Pacific salmon habitats (Ross et al. 2025). Harmful algae were identified as an emerging threat to critical status WCVI Chinook salmon during a Marine Risk Assessment process (Irvine et al. 2024), yet biotoxin exposure levels in rearing habitats like Barkley and Clayoquot sounds remained unknown. Ross and colleagues at IOS used liquid chromatography and mass spectrometry to demonstrate that juvenile WCVI Chinook in Barkley Sound during late summer are exposed to biotoxins at levels sufficient to accumulate in tissues and that these levels vary between Robertson and Sarita stocks (2416). The team is developing predictive tools linking biotoxin levels to environmental conditions, enabling DFO to forecast exposure and consider mitigation strategies, such as attuning hatchery release timing to mitigate biotoxin exposure (Ross et al. 2025).

Anthropogenic contaminants in rivers and estuaries impair juvenile Chinook salmon growth and survival (Lundin et al. 2023; Meador et al. 2014). The Loseto lab at IOS examined contaminants in WCVI Chinook from Barkley Sound, finding heavy metals, polycyclic aromatic hydrocarbons (PAHs), and polychlorinated biphenyls (PCBs) as the top three classes with highest tissue concentrations (2513). However, contaminant levels were generally much lower than those reported from more urbanized coastlines, such as Puget Sound and Oregon (O'Neil et al. 2020; Anzalone et al. 2022; Lundin et al. 2021), consistent with the remoteness of WCVI populations from major urban and industrial centers. WCVI juvenile Chinook showed contaminant concentrations 3–100 times lower than Fraser River juveniles.

Several BCSRIF-funded studies have focused on estuary monitoring, restoration, and mapping of critical forage fish habitats. Comox Valley Project Watershed created a predictive model identifying Pacific sand lance and surf smelt pelagic hotspots and spawning beaches (BCSRIF_2022_397, Comox Valley Project Watershed). Once validated, the model will support marine spatial planning by highlighting forage fish aggregations critical for juvenile salmon, seabirds, and marine mammals, while spawning beach mapping informs conservation priorities. SeaChange Marine Conservation Society assessed critical salmonid habitats in resilient estuaries, with the aim of identifying and restoring estuaries that will provide crucial ecological hotspots as oceans are altered as a result of climate change (BCSRIF_2022_430, SeaChange Marine Conservation Society). Nature Trust of BC applied the marsh resilience to sea-level rise (MARS; Raposa et al. 2016) tool to evaluate estuary resilience to climate impacts coastwide (BCSRIF_2022_444, Nature Trust BC). This collaborative program united 16 First Nation communities, non-governmental organizations, academics, and government to collect monitoring data, establishing partnerships ensuring adaptive management of restoration sites for ecosystem function goals. These studies provide vital information on current and predicted future health and status of BC estuaries, can guide prioritization of conservation and protection actions, and inform ecosystem-based fisheries planning.

Bass, Miller, and Deeg employed advanced molecular tools to assess cumulative environmental and physiological effects on juvenile Chinook during their ocean-entry year along the WCVI (2447, Saunders et al.). The team evaluated stress and infectious agents at the individual level using salmon Fit-Chips from minimally-invasive gill biopsies, while concurrent eDNA sampling assessed ecosystem-level community composition from pathogens to predators. This dataset constitutes one of the largest and most comprehensive surveys of stress and infectious agents in Chinook salmon in their first marine year. Multiple factors—thermal stress, hypoxia, and infectious agents—were associated with Chinook survival impacts. Thermal stress and hypoxia impacts will likely intensify with climate change, and net pen aquaculture was associated with elevated pathogen levels. eDNA revealed Chinook association with aquaculture sites, potentially due to attraction to high biomass or feeding opportunities, which could increase pathogen exposure for juvenile Chinook in WCVI inlets. These findings inform policy and planning for aquaculture and hatchery operations, particularly regarding animal welfare and biosecurity, and can guide recreational fishery management to minimize catch-and-release mortality during critical periods.

Early marine life history variation

The degree to which any of the environmental factors discussed above can affect salmon depends on spatiotemporal overlap as well as salmon resilience. It is therefore necessary to derive a detailed understanding of salmon early life histories so that we can anticipate their exposure and responses to such stressors.

Research from the Salish Sea Marine Survival Project revealed remarkable diversity in Chinook salmon rearing strategies within the Salish Sea, including variation in outmigration size and timing, estuary residence duration, habitat use patterns, and survival rates across life history types. However, understanding the prevalence and relative success of these different life history strategies along the West Coast of Vancouver Island remained a critical knowledge gap.

To that end, Liao's team at IOS established the first Laser Ablation-Inductively Coupled Plasma-Mass Spectrometry (LA-ICP-MS) facility within DFO for otolith microchemistry analysis (2422). By analyzing the concentration and location of different elements within rings deposited in salmon otoliths over their lifespan, this analytic method can determine the transition timing among freshwater, estuarine, and marine habitats, thereby revealing the prevalence of different life history strategies across WCVI Chinook populations. These included variation in outmigration life stage (fry versus parr), estuary residence duration (extended rearing versus rapid transit), and subsequent habitat use (continuous marine residence versus temporary returns to estuaries). Natural-origin Chinook migrating later as larger parr exhibited higher survival rates than those leaving earlier as smaller fry, and also survived better than similarly-sized hatchery fish released in the same areas. However, the largest and oldest returning spawners were disproportionately fish that had migrated early at small sizes. Hatchery releases of large, late-migrating juveniles appear to favor the return of younger, smaller adults, potentially reducing population productivity through lower fecundity, fewer eggs per female, smaller egg sizes, and intensified competition for spawning sites. These findings underscore the life history diversity of WCVI Chinook and highlight critical trade-offs that must be considered when intervening in populations with complex life histories.

Marine ecosystems summary

Taken together, these studies paint a consistent picture: habitat quality, productivity, and food web structures vary considerably across BC's coastal regions during the critical early marine rearing period, and these differences have real consequences for salmon growth and survival. The degree of variation between inlets and regions suggests that a one-size-fits-all management approach may fall short, and that place-based strategies tailored to local conditions will increasingly be needed. Also apparent is a clear signal of escalating climate-related risk to the marine ecosystem and the salmon food webs that depend on it. Researching these effects thus aids salmon management by strengthening stock assessment forecasts, informing hatchery release timing, and advancing the shift toward ecosystem-based fisheries management along the BC coast.

CLIMATE CHANGE VULNERABILITY

The significance of climate change for Pacific salmon is well-established and has been highlighted by many studies across their range in the North Pacific (Mantua et al. 2010; Grant 2019; Crozier et al. 2019; McClure et al. 2023). Climate change emerged as a key theme during the PSSI Science planning workshop (Lagasse 2024) and was a central element of the Improved Understanding of Salmon Ecosystems initiative. Discussion papers, ministerial mandate letters, funding initiatives, and national adaptation plans have recognized the need to make climate change considerations central to decision-making and planning (MacDonald and Grant 2023). This need follows from the understanding that climate change introduces additional risk and uncertainty into plans and decisions because expectations based on past climate relationships may not hold true.

Yet there is still much that is uncertain about how climate changes will unfold for Pacific salmon, such as which species and stocks will be most affected, when physiological thresholds or ecological tipping points will be reached, the relative influence of various environmental changes on productivity, and the degree to which populations will be able to evolve and adapt to changing conditions and increasing temperatures (Chittenden et al. 2009; Schoen et al. 2017;

Crozier and Siegel 2025). Research within this theme sought to better understand and resolve these uncertainties through a variety of approaches including downscaled climate modelling, whole genome sequencing, life-cycle modelling, and vulnerability risk assessments.

Table 4. DFO and BCSRIF projects associated with the climate change vulnerability theme.

ID	Project Title
DFO Science	
2405	Biological models to support prioritizing salmon stocks under future climates
2437	Adaptive genetic variation and climate change resilience in Canadian Pacific salmon
9001	Climate Vulnerability Indicators for Salmon (CVIS)
BCSRIF	
BCSRIF_2022_360	Basin-scale Events to Coastal Impacts (BECI)
BCSRIF_2022_362	Watershed Futures Initiative: Towards climate resilience of salmon watersheds
BCSRIF_2022_384	Development of High-resolution Climate Change Freshwater Hazard Data for BC
BCSRIF_2022_399	Evaluating climate change scenarios for the Quesnel Watershed to determine flood, fire and temperature risks posed to Upper Fraser salmon stocks.
BCSRIF_2022_401	Supporting and connecting community-based monitoring for climate-resilient salmon ecosystems

Downscaled climate modelling

Global climate modelling—the simulation of earth systems into the future under different greenhouse gas emission scenarios—is the basis for much of our understanding about future climate change as reported on by the intergovernmental panel on climate change (IPCC). However, these global models lack the necessary detail to tease out fine-scale environmental changes to aquatic habitats that will strongly influence the responses of Pacific salmon over the coming decades. Recent work is addressing these gaps through downscaling of global climate models to marine and freshwater environments of British Columbia.

Within freshwater habitats, the Pacific Climate Impacts Consortium (PCIC) has developed a gridded hydrologic model for gauged watersheds in British Columbia, with projections at a daily resolution spanning from 1950 to 2100. This model allows for detailed investigations into changes in stream temperatures and flow over time, and is accompanied by an online Salmon Climate Impacts Portal providing visualizations of changes in freshwater conditions over time. This model is being improved upon under phase two of BCSRIF to provide higher resolution projections at the stream level with expanded coverage of watersheds throughout British Columbia (BCSRIF_2022_384). Statistically downscaled models of August stream temperature have also recently been developed for streams throughout British Columbia, providing an alternative method for evaluating how temperatures will change during one of the hottest months of the year (Weller et al. 2024). Both models reveal gradients of temperature changes throughout British Columbia influenced not only by global climate patterns and latitude, but by topology, glacial influence, and stream order. However, the overall trend of warming stream temperatures is unequivocal, and by the year 2100 Pacific salmon in British Columbia are expected to experience temperatures that are on average around 3°C warmer than the previous century.

Within marine areas, regional oceanographic models developed by DFO's Ocean Science division project changes in salinity, temperature, and biogeochemistry for waters across the continental shelf of British Columbia (Holdsworth et al. 2021; Peña and Fine 2024). While these models have recently been applied to understand how climate change will affect habitat availability for groundfish (Thompson et al. 2023), applying them towards the assessment of climate change vulnerability for Pacific salmon is more challenging because of their anadromous life cycle and our limited information on their marine distributions. The Basin-Scale Events and Coastal Impacts initiative, a part of BCSRIF phase two, aimed to bring together research and advance modelling efforts across the Northeast Pacific, including the development of a knowledge network to connect and synthesize information about changing ocean conditions (BCSRIF_2022_360). Further developing and applying oceanographic models to understand how climate change will influence marine stressors and Pacific salmon survival is an important area for future research given the complex oceanographic dynamics along the BC continental shelf.

Vulnerability assessments

For the purposes of Pacific salmon management, projecting future environmental conditions is only helpful if we can predict how Pacific salmon will respond to those changes. Climate change vulnerability assessments apply a diverse range of methods to consider how the combined exposure and sensitivity of a species or population determines the risks they face from climate change (Foden et al. 2019). While such assessments have been applied to thousands of different species at regional and global scales, including to Pacific salmon in the continental US (Crozier et al. 2019), it is only in recent years that studies have modelled the implications of environmental changes for climate vulnerability across CUs of Pacific Salmon in Canada. Vulnerability assessments undertaken as part of PSSI used distinct but complementary methods for evaluating the complex mechanisms of climate change vulnerability and the various risks to Pacific salmon CUs. Collectively, these studies sharpen our outlook on what the future for Pacific salmon looks like across BC, revealing the challenges they will face and where mitigation actions would be most effective.

Finke and colleagues used a Bayesian inference approach with age-structured life cycle models to examine the influence of environmental variables on the productivity of 13 sockeye salmon populations spanning across BC from the Columbia to the Taku watersheds (2405). The application of these sophisticated models to data-rich populations of sockeye allows for a scientifically robust, quantitative evaluation of the influence of environmental covariates on historic productivity, which can then inform predictions of how productivity will change under future projections. The study looked at a comprehensive suite of environmental covariates including freshwater summer and winter rearing temperatures, discharge during return migrations, coastal sea surface temperatures, and offshore sea surface temperatures. Preliminary findings highlight the variation in sensitivity to future impacts across populations, with impacts most severe in southern regions where populations were particularly sensitive to changes in the early marine stage.

A separate line of inference regarding climate vulnerability comes from genomic techniques that can shed light on adaptation potential in particular. Healy and colleagues used low-coverage, whole-genome resequencing to assess patterns of genetic variation among populations of Pacific salmon from the southern US to Alaska (2437). The study identified thousands of genomic regions associated with environmental variation and adaptation among archived tissue samples. By analyzing patterns in this variation relative to climate model projections, they evaluate relative differences in genetic variation required to track climate changes, a trait known as genomic offset (Tigano et al. 2023). Preliminary findings suggest that changes in maximum temperature are consistently important in predicting genetic change requirements, meaning that genetic adaptation would require greater change within the Fraser and Thompson Rivers in particular. Further analysis and application of these genome-wide datasets is planned and related work is described under the Genetics theme within the Science to Support Hatchery Modernization initiative.

Two other projects looking at climate vulnerability were focused on the Fraser Basin, the largest and most diverse river basin for Pacific salmon in Canada. Peacock and colleagues developed a model to quantify life-stage specific exposure of Pacific salmon CUs to environmental conditions above optimal thresholds, including high temperature and low flow thresholds (BCSRIF_2022_401). Lagasse et al. developed a climate vulnerability indicators framework that incorporates various downscaled climate models, conservation status, cumulative habitat impacts, and genetic diversity to characterize key mechanisms of vulnerability. Together, these studies reveal significant differences among climate change risks across species and CUs. Pink, chum, and coho salmon within the Fraser basin are expected to have lower overall vulnerability and exposure to harmful temperatures compared to many CUs of sockeye and Chinook salmon. Sockeye and Chinook salmon, both represented by a high diversity of CUs and life history types in the Fraser Basin, showed variable levels of exposure and vulnerability with those that migrate during the summer and rear in the Thompson and lower Fraser particularly at risk. CUs already with a poor conservation status also tended to have lower genetic diversity and are projected to face even greater risk as climate change intensifies.

Vulnerability to climate change is influenced not only by intrinsic characteristics of CUs, but by the cumulative effects from multiple anthropogenic stressors that reduce resilience. Thus, managing for resilient salmon populations and watersheds requires consideration of the interaction between climate stressors and cumulative effects, which was the focus of the Watershed Futures Initiative led by Moore and colleagues (BCSRIF_2022_362). This program has led to many insights and advice related to salmon stewardship and managing cumulative effects, including identifying barriers and opportunities to cumulative effects management in BC (Ulaski et al. 2025), a conceptual framework of safe operating spaces for salmon watersheds under climate change (Moore et al. 2025), and identifying salmon watershed archetypes using cumulative pressures and climate changes (Dakin Kuiper et al. 2026).

LIFE CYCLE APPROACHES FOR SALMON ASSESSMENTS

Multiple interacting stressors affect salmon productivity and habitat capacity in ways that can be difficult to predict. While most restoration and mitigation for salmon habitat typically occurs in freshwater ecosystems, recent evidence highlights the importance of marine factors as drivers of salmon declines (e.g. Welch et al. 2020; Pearsall et al. 2021; Elliott et al. 2026). Life cycle approaches aim to improve on stock assessments by tracking salmon from egg to spawning adult, integrating environmental factors (temperature, flows, habitat quality), biological parameters (mortality, growth, maturation, fecundity), and stressor impacts (habitat loss, predation, competition, fishing, disease, climate change, water quality) to elucidate mortality drivers across all life stages. This holistic perspective identifies critical bottlenecks, recognizes how conditions at one stage can have 'carry-over' effects on subsequent performance, and determines which habitat factors most impede recovery and how much survival improvement is needed and at what scale.

Comprehensive population monitoring is required for salmon life cycle assessments. PSSI and BCSRIF funded development of novel and expanded population monitoring programs and two major life cycle initiatives, the Follow the Fish Program and the Bottlenecks to Survival Program. DFO's Risk Assessment Method for Salmon (RAMS) provides a life-cycle risk assessment tool for data-limited stocks of conservation concern (Irvine et al. 2024), supporting Rebuilding Plans under the Fish Stocks Provisions of the Fisheries Act by ranking limiting factors and identifying research gaps. The Follow the Fish program arose from the application of RAMS to WCVI Chinook, which highlighted the need for research focused on presumed high-risk factors during the early marine life stage. The Bottlenecks to Survival program was developed to assess life-stage-specific survival rates and limiting factors impacting Strait of Georgia Chinook, coho and steelhead. Identifying survival bottlenecks and their causes is necessary to evaluate strategies aimed at improving overall survival, including decisions around hatchery rearing and release strategies.

The development of these approaches represent a paradigm shift from single-stage (adult return) to ecosystem-based fisheries management, recognizing that salmon traverse multiple jurisdictions, habitats, and food webs while facing stage-specific stressors. Below we describe these monitoring efforts and life cycle initiatives and key findings to date.

EXPANDED SALMON POPULATION MONITORING

PSSI and BCSRIF projects developed numerous salmon monitoring programs, many employing novel methods to assess populations and understand factors affecting freshwater, estuarine, and marine survival. In nearly all cases, these programs were led by or developed in partnership with local First Nations.

Davidson (DFO) and Pacheedaht First Nation created an integrated San Juan Chinook life history monitoring program within the Follow the Fish initiative (2403). Methods include rotary screw trapping to enumerate and sample emigrating juveniles (collecting otoliths and stomach contents for size-specific survival and diet analysis); estuary beach seining to compare diet and residency between hatchery and natural-origin fish; Port San Juan purse seining through late spring to fall for mixed-stock data; and carcass sampling to assess adult age-at-return, PNI, and spawner stock composition. Results will guide improvements to natural-origin juvenile survival while ensuring hatchery fish complement rather than compete with wild populations.

Table 5. DFO and BCSRIF projects associated with the salmon population monitoring theme.

ID	Project Title
DFO Science	
2402	Quantifying Yukon Chinook migration mortality and its implications for fisheries management and rebuilding under the Fish Stock Provisions of the Fisheries Act
2403	San Juan River adult and juvenile assessment program
2426	Sakinaw sockeye juvenile research on measures to increase marine survival
2430	Feasibility of estimating Chilko River smolt abundance using upward- and side-Looking SONAR methods
BCSRIF	
BCSRIF_2022_329	Meziadin River Up-looking Hydroacoustic Sockeye Smolt Enumeration Project
BCSRIF_2022_345	Digital Imaging of Wild Coho Returns to the Lillooet River Conservation Unit
BCSRIF_2022_346	Genetic monitoring of Kokanee-sockeye salmon (*Oncorhynchus nerka*) hybrid fitness and long term outcomes associated with an experimental re-introduction program
BCSRIF_2022_351	Estimating aggregate Coho salmon escapement to the Lower Fraser Management Unit
BCSRIF_2022_451	Boundary Bay Chinook salmon restoration in the TA'TALU watershed

In the Yukon River basin, an international collaboration between DFO Science, Yukon First Nations, and the Alaska Department of Fish and Game investigated the critical decline of Yukon River Chinook salmon by quantifying mortality during their extensive freshwater spawning migration (2402, Connors et al). Historically, fisheries management assumed that all fish crossing the Alaska-Canada border reached their Canadian spawning grounds; however, recent "missing" fish have rendered this assumption increasingly tenuous. By deploying a network of 20 remote tracking stations within the Canadian portion of the Yukon River basin and utilizing aerial telemetry to track tagged adults, researchers found that approximately 85% of tagged fish reached their spawning grounds from the Yukon/Alaska border in 2024. These insights, supported by the development of a hierarchical Bayesian mark-recapture model, will allow managers to establish evidence-based precautionary buffers for border-passage goals and adjust in-season management to account for environmental stressors. Just as importantly, the project has established the scientific infrastructure and a collaborative framework that will support further monitoring and research for Yukon Chinook recovery.

Sakinaw sockeye, assessed as endangered by COSEWIC since 2003, face perpetually low marine survival and have failed to recover despite a captive brood program. The 2017 Recovery Potential Assessment identified marine survival as the greatest limiting factor, with seal predation on smolts and adults ranked as high-risk (Ramshaw et al. 2019). Pellett's DFO team, collaborating with shíshálh Nation, used PIT tagging to study marine survival and test whether releasing smolts past pinniped haul-outs would improve survival (2426). Preliminary results led to recommendations against operationalizing smolt transport for Sakinaw recovery.

Doutaz and colleagues from DFO (2430), partnering with Aquacoustics Inc. and Tŝilhqot'in National Government, assessed upward- and side-looking SONAR methods to estimate Chilko River sockeye smolt abundance. Chilko represents the only wild Fraser sockeye indicator stock, with the annual smolt assessment, ongoing since 1951, comprising the sole long-term time series for juvenile recruitment. In some years, unusually early freshets prohibit the use of traditional fish counting weirs and photographic methods. Results from three years of comparisons showed high correspondence between hydroacoustic and weir counts, suggesting there is the potential to use SONAR methods as a replacement or complement to fish counting weirs in the Chilko system.

Similarly, Gitanyow Fisheries Authority, partnering with Skeena Fisheries Commission through BCSRIF funding, employed upward-looking hydroacoustics to collect Meziadin Lake sockeye data including emigrating smolt abundance, size, age composition, and origin (BCSRIF_2022_329). This method supports understanding of productivity, identification of survival bottlenecks, and development of restoration priorities and management approaches.

Innovative solutions emerged to overcome challenges in operating monitoring programs at remote locations. Lil'wat Nation's digital imaging of wild coho returns to the remote Lillooet River Conservation Unit required Adaptive Resolution Imaging Sonar (ARIS) but lacked grid power access. The solution was a battery system using six golf cart batteries that powers the underwater sonar camera for coho enumeration, demonstrating a simple and effective approach for running ARIS at remote locations, such as the Lillooet River and tributaries.

Common methodologies across BCSRIF and PSSI monitoring programs that led to improved population monitoring included SONAR, hydroacoustics, PIT tagging, genetic methods (Genetic Stock Identification and Parental-Based Tagging), and eDNA. Numerous projects, in addition to those discussed above, availed of these methods. PIT tagging applications included Lower Fraser Fisheries Alliance Society's mark-recapture program for Chilliwack River Hatchery coho, and Pacific Salmon Foundation projects assessing stage-specific survival and bottlenecks along WCVI and in the Strait of Georgia. eDNA was employed by A Rocha Canada with Semiahmoo First Nation to study Boundary Bay Chinook in the Tatalu watershed, and by Deeg's DFO lab to characterize WCVI salmon ecosystems. GSI and PBT were used throughout the PSSI-funded Follow the Fish program (see below) to identify Pacific salmon stocks rearing in WCVI sounds, while UBC, collaborating with Okanagan First Nation, applied genetic, morphological, and microchemistry analyses to investigate behavior, fitness, and hybridization between anadromous sockeye and resident kokanee in Skaha Lake.

FOLLOW THE FISH PROGRAM

The Follow the Fish (FtF) Program was developed to identify the key biological and environmental factors across freshwater, estuarine, and nearshore marine environments that are limiting survival of WCVI natural-origin Chinook salmon. WCVI Chinook are a priority stock for rebuilding. Their status is poor—particularly in Clayoquot Sound—due to low natural spawner abundance, high hatchery introgression, and demographic shifts toward fewer, smaller females. The Risk Assessment Methodology for Salmon (RAMS; Irvine et al. 2024) identified and prioritized factors limiting WCVI Chinook recovery currently and under anticipated 2050 climate conditions. RAMS assesses biological risks from natural and anthropogenic stressors across freshwater, estuarine, and marine life stages using life history models to determine when, where, and how stressors influence population productivity and capacity.

Table 6. DFO and BCSRIF projects associated with the Follow the Fish theme.

ID	Project Title
DFO Science	
2397	Identifying good practices for considering Indigenous Knowledge in Rebuilding Plan targets and stock assessment reference poi
2403	San Juan River adult and juvenile assessment program
2404	Improving baseline knowledge of environmental conditions in Vancouver Islands fjords through observations and modelling, with a focus on hypoxia dynamics, climate change, and the potential implications for Pacific salmon
2407	Characterizing juvenile Chinook salmon distribution, diet and health on the West Coast of Vancouver Island
2413	Barkley Sound and Clayoquot Sound krill monitoring
2416	Monitoring and predicting the exposure of Pacific salmon to harmful algal biotoxins
2422	Development and application of laser ablation-inductively coupled plasma-mass spectrometry (LA-ICP-MS) to determine estuary entry size of juvenile salmonids and track habitat usage
2432	Barkley Sound acoustic monitoring of salmon and salmon prey
2447	Innovative ecosystem based approaches to identify cumulative stressors: Salmon Fit-Chips and eDNA
2513	Characterizing and monitoring priority contaminants of concern in WCVI juvenile salmon
BCSRIF	
BCSRIF_2019_040	Determination of Bottlenecks Limiting Wild and Enhanced Juvenile Salmon and Steelhead Production in BC using PIT tags and Spatially Comprehensive Arrays
BCSRIF_2022_332	Research in support of Sarita Chinook as an Ecological Indicator and WCVI Chinook Salmon Rebuilding
BCSRIF_2022_337	Chinook Salmon Assessments and WCVI Chinook Salmon Rebuilding in the Kaouk and Artlish Watersheds
BCSRIF_2022_442	Identifying factors that influence early marine survival of WCVI Chinook salmon
BCSRIF_2022_456	Informed Approaches to Determine Bottlenecks to Survival for Chinook and Coho Salmon and Steelhead

Freshwater RAMS processes were applied to 18 watersheds in San Juan, Barkley Sound, Clayoquot Sound, Nootka Sound, and Kyuquot. A subsequent Marine Risk Assessment examined factors affecting WCVI Chinook smolts, sub-adults, and adults in nearshore, coastal, and North Pacific waters (Irvine et al. 2024). RAMS results showed that declining natural-origin WCVI Chinook survival and productivity result from cumulative effects across the life cycle. Freshwater assessments indicated habitat degradation has likely reduced productivity in many systems through decreased egg-to-smolt survival, earlier fry emigration, and smaller smolts. A critical "carry-over effect" emerged as high risk: smaller, less robust fry and smolts face elevated vulnerability during estuary and early marine rearing. Marine assessments found that the highest mortality occurred during the early marine life stage, with almost all limiting factors rated high risk (Irvine et al. 2024). These risks span multiple ecosystem factors: large-scale ocean processes affecting nearshore ecosystems; local water quality (high temperature, low oxygen, summer harmful algal blooms); pathogens, parasites, and disease; prey quality, quantity, and timing during first spring through winter; predation; and competition with hatchery fish.

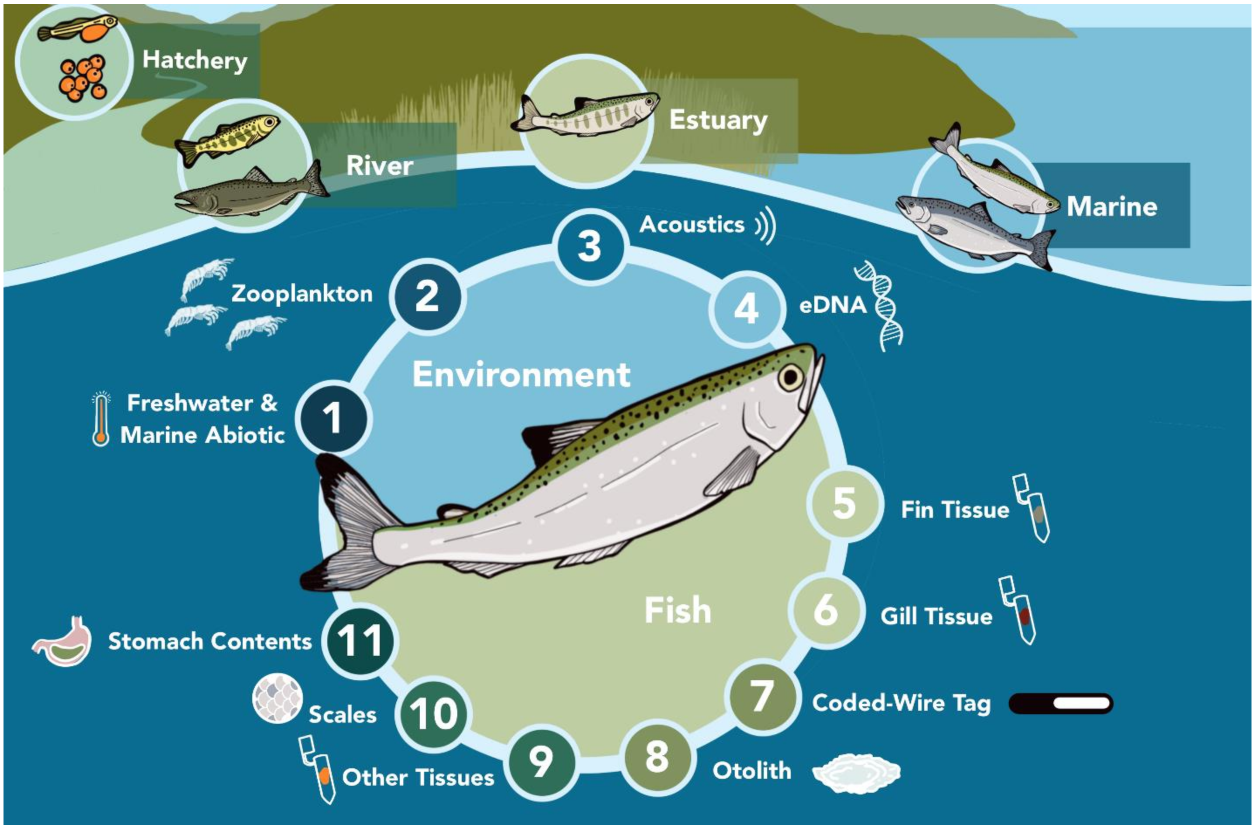


*Figure 4. Graphical abstract of the Follow the Fish research program that includes sampling of Chinook salmon and the environments they reside in along the WCVI. Numbered items are the different research components as follows: **1.** Abiotic variables (e.g. temperature, dissolved oxygen, alkalinity) measured in select freshwater river systems and marine waters. **2.** Zooplankton surveys to evaluate abundance and timing of key Chinook prey. **3.** Acoustic moorings to characterize distributional patterns of juvenile Chinook salmon and their prey. **4.** Environmental DNA (eDNA) to identify species compositions of salmon and their predators, prey, competitors, and pathogens. **5.** Chinook fin tissues to identify stock of origin using genetic stock identification methods. **6.** Non-lethal gill tissue samples to inform fish health status. **7.** Coded-wire tags to determine stock of origin. **8.** Otoliths (ear bones) to assess the size of Chinook smolts at ocean entry and size-specific trends in survival and estuary residence time. **9.** Other tissues (muscle, liver, kidney, spleen, brain, heart) to measure, characterize and monitor contaminants and biotoxins in Chinook. **10.** Scales to assess relative growth rates of Chinook stocks. **11.** Stomach contents to characterize prey availability and diet of Chinook.*

To address knowledge gaps related to these factors, the FtF program had three core objectives: 1) strengthen confidence in the assessment of key limiting factors and address critical knowledge gaps, 2) better characterize the highest-risk factors, their potential causal mechanisms, and options for mitigation, and 3) inform Chinook rebuilding efforts by identifying the mitigation actions most likely to succeed. Projects examined freshwater redd scour and habitat quality; developed ocean models for WCVI fjord conditions; assessed zooplankton, juvenile salmon, and forage species abundance and seasonal patterns through sampling and hydroacoustics; characterized environmental community composition via eDNA analysis; investigated juvenile Chinook distribution, growth, and diet across space and time; assessed health through stress and infectious agent profiling using salmon Fit-Chip technology in freshwater, estuary, and marine environments; and evaluated harmful algal biotoxins and contaminant prevalence and impacts. Much of this work is summarized in the Freshwater Ecosystems and Marine Ecosystems sections, above.

The FtF program attained a breadth of collaborations not previously seen in Pacific salmon science in Canada. Projects were designed to be complementary by addressing overarching questions from multiple perspectives. WCVI First Nations were key partners or leaders in most FtF projects, using their deep knowledge of local salmon distributions and behaviours to help design and implement monitoring projects targeting particular life stages. For example, an extensive survey of juvenile Chinook was accomplished through WCVI First Nations conducting standardized microtrolling surveys within their Ha'houthlee (2407, Bokvist et al.). Juvenile Chinook caught in these surveys were sampled extensively to inform on their genetics, diet, health, and growth; these samples were analyzed in several other PSSI projects that assessed stress, biotoxins, contaminants, and other stressors (e.g. 2513, 2447, 2416).

The Huu-ay-aht First Nation examined whether the Sarita Chinook population could serve as an ecological indicator for the West Vancouver Island, Ocean, Fall (South) and WCVI-South conservation units (BCSRIF_2022_332). The project provided reliable juvenile production estimates and enhanced understanding of natural-origin Chinook ecology including dietary behavior across freshwater, estuarine, and nearshore marine habitats, and spatial-temporal distribution from egg to marine entry.

In addition to indicator development, this work also positioned Sarita Chinook as an ideal case study for salmonMSE (2449, Holt et al.; described below in New Tools and Models to Support Decision Making). DFO and Huu-ay-aht applied this tool to Sarita River Chinook to assess how mark-selective fisheries and various hatchery scenarios affect the capacity to meet a range of conservation, harvest, and hatchery objectives. The results are revealing important potential trade-offs: achieving both high abundances for harvest and wildness objectives simultaneously may not be possible under poor freshwater survival, indicating habitat restoration may be necessary to attain management goals.

Ka:'yu:'k't'h'/Che:k:tles7et'h' First Nations conducted a three-year study in the Kaouk and Artlish Rivers addressing life history information gaps for two of three Chinook indicators for the West Vancouver Island, Ocean, Fall (North) conservation unit (BCSRIF_2022_337). The data are improving understanding of limiting factors in freshwater and marine environments within KCFN traditional territory, supporting WCVI Chinook rebuilding.

The Pacific Salmon Foundation addressed gaps related to early marine mortality using microtrolling and Fit-Chips, focusing on habitat utilization, ecological stressors, and salmon health across multiple WCVI sounds (BCSRIF_2022_442). The tools established are now producing ecological data to inform management decisions and improve our understanding of WCVI Chinook survival bottlenecks.

In summary, the Follow the Fish program will generate data and knowledge that will directly contribute to WCVI Chinook rebuilding plans, and will identify management measures to improve productivity across freshwater and marine ecosystems, supporting wild WCVI Chinook rebuilding through ecosystem-based approaches.

BOTTLENECKS TO SURVIVAL

The Pacific Salmon Foundation and British Columbia Conservation Foundation have led a major BCSRIF-funded initiative using PIT tags and a comprehensive array network around Vancouver Island to track stage-specific survival of Chinook and coho salmon and steelhead along BC's South Coast. Known as the "Bottlenecks Program," this effort has brought together a network of partners to deploy PIT tags and detection arrays across 13 east coast Vancouver Island watersheds and two on the west coast—the Stamp and Toquaht rivers. This program is the first of its kind to apply PIT tags to cohorts of juvenile salmon in the open ocean to determine stage-specific survivals and to compare outcomes for wild and hatchery-enhanced Chinook and coho across multiple systems, life history stages, and enhancement strategies—pinpointing the periods and places where mortality is highest.

The project has delivered new and improved escapement estimates for five east coast Vancouver Island populations, doubling the number of systems represented in DFO's 2025 Coho Marine Forecast Bulletin. It has also contributed baseline marine survival rates to inform the Nanaimo summer Chinook Recovery Potential Assessment. The Bottlenecks Program also collaborated with SEP and developed multiple studies to help inform enhancement processes and improve overall survival of hatchery Chinook and coho. A dedicated winter ecology study of Strait of Georgia Chinook shed new light on first-year habitat use and feeding behavior, offering fresh evidence of long-term salmonid residency in the Strait.

Complementing the PIT tagging work, the Bottlenecks program has integrated genetic analysis to enable non-lethal stock identification of captured fish, and assessment of physiological health and condition. Together, these tools allow researchers to examine how environmental and physiological stressors shape individual fish outcomes and identify the biological markers associated with mortality.

STANDARDIZING SALMON STOCK ASSESSMENTS

Pacific salmon management is uniquely complex due to their diverse life histories, the mixed-stock nature of fisheries, and the various considerations related to harvest, habitat, and hatcheries. These complexities necessitate transparent and defensible stock assessments that can support decision making across multiple management domains. The undertaking of PSSI coincided with the introduction of national fisheries science advice templates and the gradual prescription of major salmon stocks under the Fisheries Act, providing the opportunity to reshape the delivery and scope of salmon assessment work in the Pacific Region.

Canada amended the Fisheries Act in 2019 to include Fish Stocks Provisions (FSP) for major fish stocks. Once a stock is prescribed in regulations, DFO is obligated to manage it at levels necessary to promote sustainability and to develop and implement rebuilding plans for stocks that fall below their Limit Reference Point. The first batch of major fish stocks was prescribed in 2022 and included three Pacific salmon stocks: Interior Fraser Coho, Okanagan Chinook, and West Coast Vancouver Island Chinook. A second batch of major fish stocks has been working its way through the legislative process and includes an additional six Pacific salmon stocks: Fraser Pink, Yukon Chinook, Stikine Sockeye, Barkley Sound Sockeye, Fraser Sockeye-Early Stuart, and Okanagan Sockeye.

A standardized national template for communicating fisheries science advice was piloted in 2023–2024 and fully implemented in 2025. Its purpose is to provide timely, consistent, and streamlined stock assessments in support of the FSP. The templates emphasize decision-focused advice, clearly articulated uncertainty, and alignment with the DFO Precautionary Approach Framework. For salmon, additional dedicated sections for hatchery and habitat advice were incorporated to reflect the more diverse management considerations for Pacific salmon relative to most other fish species in Canada. More broadly, the templates were designed to support the transition to ecosystem-based fisheries management and advance open-data initiatives.

The nearly 400 conservation units identified under the Wild Salmon Policy are aggregated into 69 stock management units (SMUs) for Pacific salmon. While only a portion of these SMUs are expected to be prescribed as major stocks under the Fisheries Act, the long-term goal is to conduct stock assessments for all major stocks and to review them on a regular, ongoing basis. Achieving this would represent a substantial shift in the type, scope, and frequency of peer-reviewed science available to decision makers. Historically, peer-reviewed science for Pacific salmon was produced following requests for science advice, often focused on specific issues such as abundance forecasts, recovery potential assessments under the *Species at Risk Act*, or periodic methodological reviews. Routine peer review of management outcomes has not historically been expected. The introduction of standardized templates that integrate biological status, management performance, and rebuilding considerations into a single document has the potential to provide meaningful benefits for both managers and biologists.

Pacific Region contributed to the national template pilot by convening a CSAS Salmon Sprint Week in spring 2024 to assess multiple salmon stocks, followed by a second sprint week in spring 2025. Additional individual SMU reviews were conducted outside these events. Table 8 provides links to SMUs with publications that are either currently available or are in the approvals and translations queue. SMUs that have been reviewed but do not yet have publications in the approvals and translation queue as of 31 March 2026 include Fraser Chinook Spring 5_2, Fraser Chinook Summer 5_2, Fraser Sockeye - Early Stuart, and Stikine Sockeye.

Together, the implementation of the Fish Stocks provisions and the adoption of national science advice templates represent a substantial shift toward more structured, transparent, and comprehensive assessment processes for Pacific salmon. As additional SMUs undergo review and new assessments are published, the Pacific Region will be better positioned to meet legislative requirements, support ecosystem-based management, and provide decision makers with timely, defensible, and integrated advice. Continued collaboration among scientists, managers, and Indigenous and community partners will be essential to sustaining this transition and ensuring that resulting science products support the long-term conservation and rebuilding of salmon populations.

Table 7. Salmon stock management units (SMUs) with published documents or documents currently in approvals and/or translation process Fisheries Science Advisory Reports (FSAR) or Fisheries Science Response Reports (FSRR), rebuilding plans, and research documents. Rebuilding plans are only developed for stocks batched under regulation that are assessed as being below the limit reference point, currently consisting of Okanagan Chinook and WCVI Chinook. Published CSAS publications can be found at: https://www.isdm-gdsi.gc.ca/csas-sccs/applications/Publications/search-recherche-eng.asp

SMU	FSAR or FSRR	Research Documents & Rebuilding Plans
Okanagan Chinook	Okanagan Chinook Stock Assessment 2023	Rebuilding plan: Okanagan Chinook Salmon [*Oncorhynchus tshawytscha*] [ntytyix | sk'lwis]
Fraser Pink	Stock Assessment of Fraser River Pink Salmon in 2023	Research Document: Estimating Precautionary Approach Reference Points and Assessing Consequences of Harvest Control Rules for Fraser River Pink Salmon (*Oncorhynchus gorbuscha*)
Interior Fraser Coho	Interior Fraser Coho Stock Assessment for 2022	No Research Document. Rebuilding plan not required (stock assessed as above limit reference point)
WCVI Chinook	West Coast of Vancouver Island Natural-Origin Chinook Salmon Stock Assessment in 2024	Rebuilding plan : West Coast of Vancouver Island Chinook, *Oncorhynchus tshawystcha*, Suuhaa | SȾOḰI | sat'sam; Research document publication in process pending translation
Fraser Chinook Spring 4_2	In approvals	No Research Document. Stock is currently not prescribed under FSP.
Barkley Sockeye	Publication in process	Research document publication in process pending translation
Yukon Chinook	Stock Assessment of Yukon River Chinook Salmon in 2024	Research document publication in process pending translation

SCIENCE TO SUPPORT HATCHERY MODERNIZATION

DFO's Salmonid Enhancement Program (SEP) was created in 1977 to build, manage, and operate hatchery facilities for Pacific salmon to meet harvest, stock assessment, conservation, and stewardship objectives across British Columbia. Over the decades, SEP operations have grown in scale and complexity, transitioning from a primarily production-oriented program to one that now includes conservation-focused hatcheries and targeted rebuilding efforts. Independent assessments, particularly the Pacific Salmon Foundation's hatchery effectiveness review, have highlighted both the benefits of enhancement and key risks and uncertainties (Riddell et al. 2024). As SEP hatchery roles have diversified, so have the scientific needs and opportunities to support effective planning, monitoring, and operations. Contemporary hatcheries must integrate modern genetic tools, high-resolution pathogen diagnostics, standardized health monitoring, and environmental risk assessments in ways that were not envisioned when the program was established. PSSI investments were directed at deliberately addressing these needs by building new capacity and collaborative frameworks to target priority research questions.

To translate these objectives into action, a SEP-Science Steering Committee was established under PSSI with subject matter experts from both DFO Science and SEP (including Planning and Assessment, Hatchery Modernization, and Policy and Operations groups). The purpose of the group was to articulate joint needs, support collaborative projects, and set research priorities ranging from operational support for hatcheries to long-term strategic science advice. This co-development structure is a demonstrated way to ensure the relevancy of conservation science

(Buxton et al. 2021), in this case aiming to ensure that research questions were grounded in the practical realities of hatchery management while also being scientifically rigorous.

Under the SEP-Science Steering Committee, four cross-sectoral working groups were established to identify priority research needs in Genetics, Fish Health, Operational Assessment and Monitoring, and Ecosystem Science. Each working group brought together SEP and Science staff to identify knowledge gaps, evaluate potential projects against a standard set of criteria, and develop project plans for implementation. In the following sections we summarize research outcomes for the two largest research themes in terms of funding and capacity: Genetics and Fish Health.

GENETICS

Research under the Genetics theme addressed three central questions posed by SEP: 1) how do hatchery and natural-origin fish differ? 2) what are the mechanisms driving those differences? and 3) what are the implications for long-term population fitness? These questions sit at the heart of how enhancement programs are designed and evaluated, and they bear directly on the Proportionate Natural Influence (PNI) framework that Canada uses to manage hatchery genetic effects on wild populations (Withler et al. 2018). To address these questions, researchers used advanced genetic techniques including genome-wide sequencing, methylation sequencing, and parentage-based tagging that were made possible through monitoring and broodstock programs at SEP hatcheries. In addition to addressing the three central research questions above, some genetics projects were focused on more operational applications to improve the accuracy of Genetic Stock Identification (GSI) for chum salmon and develop rapid turn-around diagnostic tools to differentiate among Chinook salmon conservation units. PSSI investments also supported core GSI work over multiple years, providing stable funding that expanded genotyping capacity and produced information for escapement estimation, mixed-stock analysis, stray identification, marine distribution studies, and real-time in-season decision-making (2545, Rondeau et al.).

One of the most striking findings within this theme came from a pair of studies led by Healy and colleagues that looked at patterns of DNA methylation among hatchery and natural-origin Chinook and coho salmon (2435). DNA methylation is an epigenetic process in which chemical tags (methyl groups) are added to DNA and alter gene expression without changing the underlying DNA sequence. As part of these studies, DNA methylation was measured by sequencing thousands of sites across the genome from fin tissue samples. Across all populations studied, hatchery fish showed distinct epigenetic signatures relative to natural-origin fish, though the specific patterns varied by population, rearing strategy, and even among choice of fin sampling site (i.e. caudal versus adipose fins). Slower-growth, smaller-size hatchery releases produced juveniles with methylation profiles closer to natural smolts, highlighting the potential for hatchery practices to shape these effects. Importantly, controlled crosses demonstrated that some hatchery-associated methylation patterns can be inherited by offspring, pointing to possible long-term fitness implications for enhanced populations. While the population-specific nature of these patterns limits the development of universal biomarkers, the results suggest that understanding and adjusting hatchery practices to reduce harmful epigenetic shifts may help mitigate performance impacts in the future.

Table 8. DFO and BCSRIF projects associated with the genetics theme.

ID	Project Title
DFO Science	
2434	SHERLOCK assay for rapid genotyping applications
2435/2543	Epigenetic variation between hatchery- and natural-origin Canadian Chinook salmon / Intergeneration transfer and parental origins of DNA methylation variation in coho and Chinook salmon
2436	Chum whole genome sequencing for improved stock delineation
2451	Relative reproductive success of hatchery- versus natural-origin salmon in Canadian integrated populations
2452	Genetic associations with age of return in male Canadian Chinook salmon
2545	Genetics stock identification and parentage based tagging of Pacific salmon

Complementary work on relative reproductive success (RRS) in the Sarita River clarified the feasibility of measuring relative fitness in integrated hatchery populations (2451, Healy et al). RRS is a valuable metric to compare hatchery with wild fitness (Christie et al. 2014), however, it has not been estimated to date for any integrated populations enhanced by SEP. The pilot study found it was extremely difficult to achieve the sample sizes needed for reliable parentage-based RRS estimates, even in one of the most tractable and well-monitored enhanced river systems in BC with extensive broodstock genotyping, escapement sampling, and smolt monitoring. This led to a methodological recommendation that grand-parentage-based tagging methods should be developed using existing genotyping infrastructure to evaluate the fitness effects of enhancement within and across populations. Although our knowledge gaps on RRS remain, project findings provide a tractable pathway forward to address them.

Another study examined genomic factors linked to age at maturity in male Chinook salmon produced in multiple hatchery facilities throughout BC (2452, Healy et al). Leveraging reduced representation sequencing of Chinook salmon samples from the Atnarko River, Chilliwack River, Big Qualicum River, and Puntledge River Fall populations, the project examined the association between single-nucleotide polymorphisms (SNPs) and variation of age of return for males, with a particular emphasis on understanding factors associated with returning at younger ages (i.e. jacks) to inform SEP broodstock management. Results show that genetic associations with age of return in males were largely population-specific, with few genetic loci being independently associated with age of return. This variation amongst enhanced populations suggests there are complex interactions between genetics, hatcheries, and environmental effects influencing age of return that require further work to resolve. Studies focusing on genetic associations with age of return for natural-origin Chinook salmon are an important next step to distinguish between genetic effects and environmental effects of hatchery rearing.

Work to improve stock delineation for chum salmon (2436, Tigano et al) used whole-genome sequencing of populations across southern BC and Washington state to develop an improved panel for genetic stock identification. Analyses of genome-wide markers revealed finer-scale differentiation among Fraser River and Strait of Georgia populations than previously recognized and led to the creation of a more extensive SNP panel with higher assignment accuracy than the one currently in use. This work addresses a long-standing gap for chum salmon, whose stock structure has historically been less-well characterized compared to other Pacific salmon species, and can be operationalized to support the monitoring and management of mixed-stock fisheries.

A final line of work evaluated whether SHERLOCK, a rapid field-deployable genetic assay, could be used to support broodstock management at the Puntledge River Hatchery by providing in-season genotyping of run-timing markers that distinguish summer- and fall-run Chinook salmon (2434, Wellband et al). Under controlled laboratory conditions, the SHERLOCK assay showed excellent accuracy, matching conventional SNP genotypes for Puntledge Chinook 99% of the time. However, when tested in the field results were inconsistent and most assays failed, indicating that the method is not yet reliable for operational use. While the study confirms the tool's potential for fast, on-site genetic screening, further optimization and simplification are needed before it can meaningfully improve broodstock selection and support the conservation of the Puntledge summer-run population.

Across all genetics projects, some key findings emerge: the genome of hatchery and wild populations are essentially indistinguishable, but hatchery environments generate variable epigenetic effects that are heritable; genome-wide sequencing and SNP panel development are strengthening the foundation for stock identification and broodstock management; and long-term fitness evaluation will require updated genetic tagging frameworks. The research sheds light on SEP's original research questions, while highlighting additional complexities and nuances that can be addressed through further work.

FISH HEALTH

Fish health projects were organized around three research questions: 1) how can we better assess and track fish condition and stress? 2) how do we advance and modernize diagnostic and health management practices? and 3) how can new molecular and technological tools help detect issues early and inform decision-making? Research in this theme addresses these questions using a variety of established and innovative methods, from pathogen surveillance and disease modelling to stress monitoring using environmental DNA and RNA. A subset of projects also looked at nutritional and development issues associated with hatcheries and ways to mitigate them. This work is meaningful for SEP hatcheries because healthier fish have higher survival, improved disease resistance, and better reproductive success, making enhancement programs more effective and resource efficient. These advancements are particularly important in supporting SEP as it expands conservation-based hatcheries, where disease outbreaks and mortality events can have significant implications for population persistence.

Table 9. DFO and BCSRIF projects associated with the fish health theme.

ID	Project Title
DFO Science	
2400	Assessment of SEP Chinook and coho broodstock ELISA screening data by modelling for explanatory variables, and yearling DFAT prevalence data by modelling for predictive variables
2401	Epidemiological modeling of infectious hematopoietic necrosis virus in sockeye salmon
2408	Improvement, expansion and modernization of salmonid health diagnostic services for optimizing salmonid hatchery health management
2417	Optimization of feeds used in the hatchery production of Pacific salmon
2418	Prediction of reproductive success of Chinook salmon based on thiamine concentrations in returning adults
2421	Measurement of stress hormones in scales and its application for the identification of conditions causing chronic stress in Pacific salmon
2448	Developing a proactive, modernized, holistic approach to ensure optimal health and condition of hatchery production
2494	Modeling interactions of environmental, biological and infectious factors with respect to production of Pacific salmon (*Oncorhynchus* spp.) at the Quinsam River hatchery
BCSRIF	
BCSRIF_2020_311	The application of nanopore technology for the rapid detection and characterization of pathogenic organisms in enhancement hatcheries
BCSRIF_2022_326	Aeromonas salmonicida Genome Sequencing and qPCR Test Development

Disease prevalence and screening

Two projects were focused on understanding the factors influencing the prevalence of endemic pathogens and their associated diseases among hatchery facilities over time. A study by Long et al (2400) modelled long-term Chinook and coho broodstock screening data to identify variables associated with bacterial kidney disease (BKD) prevalence. Results show that environmental and population factors, particularly water temperature, watershed characteristics, and overall BKD prevalence, often overshadow direct parent-to-offspring transmission in wild and enhanced stocks. Similarly, Garver et al (2401) found that for the infectious hematopoietic necrosis virus (IHNV) parent to progeny transmission was unlikely among the four sockeye salmon populations analyzed. Instead, watershed or regional-specific factors are likely more important in influencing IHNV levels. Both of these pathogens can be significant sources of mortality for wild and hatchery salmon, and these results help us understand the factors driving their occurrence, which can ultimately lead to better predictions of when outbreaks may occur and how they can be proactively managed by hatcheries.

Another crucial means of proactively managing fish health is through pathogen screening and disease testing. A major project undertaken by Long et al (2408), was focused on modernizing the diagnostic tools available for SEP hatcheries by developing new disease assays and applying them to better understand pathogen distribution in juveniles and broodstock. The project successfully developed and validated qPCR assays for a suite of endemic pathogens, including *Flavobacterium psychrophilum* (cold water disease), BKD, and IHNV. A new technique for disease-prevention using pre-fertilization egg disinfection was also tested. The findings reveal important considerations for non-lethal broodstock screening, as pathogen detectability varies by tissue type, creating operational trade-offs for hatcheries.

New diagnostic tools

A landmark project under PSSI developed proactive tools for pathogen and stress monitoring using salmon Fit-Chips applied to both minimally invasive gill biopsies and non-invasive environmental RNA (eRNA) from hatchery water (2448, Deeg et al). In collaboration with multiple SEP hatcheries, the team showed that Fit-Chips effectively detect pathogen prevalence, track exposure from source waters, identify stressors such as temperature or hypoxia, document smoltification progress to inform release timing, and even reveal viral disease development, including discovering a novel Influenza-B–like virus. Key findings highlight the influence of water source on pathogen load, the potential for eRNA to provide early warning of infections, and the ability to identify underlying causes of mortality such as food deprivation. Future work priorities include improving automated sampling, refining lab processes, and integrating molecular data into hatchery operations to support salmon conservation management.

Meanwhile, Ahmed Siah and the BC Centre for Aquatic Health Sciences (BCSRIF_2020_311) evaluated nanopore sequencing as a rapid method to detect and characterize fish pathogens relevant to hatchery and wild salmon health, with the goal of complementing routine diagnostics (e.g., targeted qPCR) by providing broader genetic information on organisms present in samples. The project demonstrates the operational potential of nanopore as an applied tool for pathogen identification that can complement established assays.

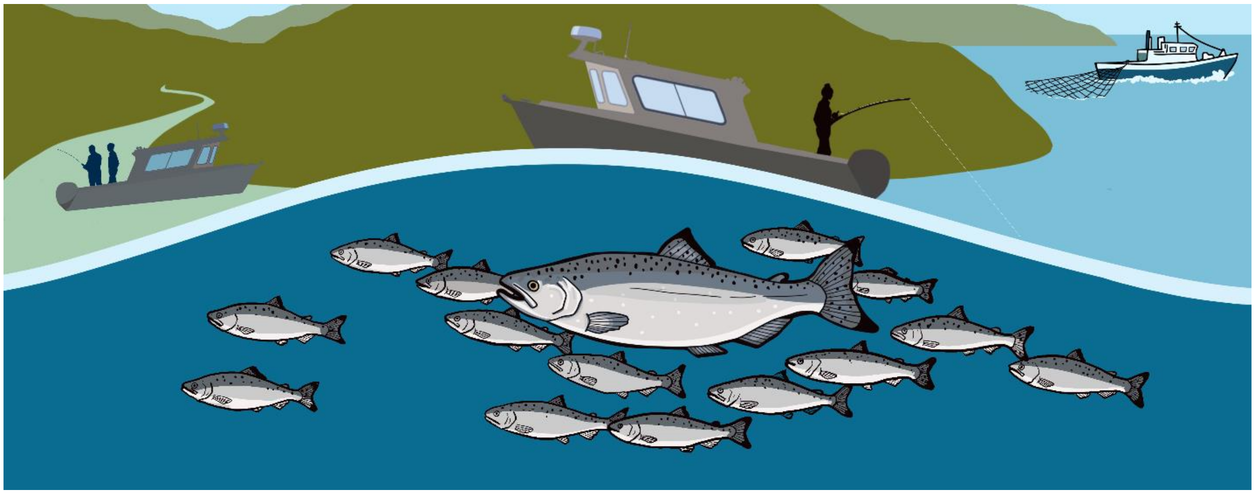
Stress physiology was the focus of work by Johnson et al (2421), which evaluated the use of cortisol measured from scales as a non-lethal biomarker for retroactive stress exposure in Chinook and Coho salmon. While scale cortisol content had been proposed as a reliable way to understand the stress history of fishes (Laberge et al. 2019), the project determined that levels of corticosteroids in fish scales are far more dynamic than previously thought. Scale cortisol is therefore not recommended as a reliable biomarker. Although the study did not result in the recommendation of a new diagnostic tool, it has improved our understanding of scale corticosteroid dynamics in Chinook and coho salmon.

Hatchery nutrition and rearing

Nutrition, growth, and survival were addressed through two studies by the DFO Nutrition lab at the Pacific Science Enterprise Centre in West Vancouver. The first study (2417, Eliason et al) tested whether a specialized, seawater transition diet at hatcheries could improve smoltification, growth, or early marine survival in Chinook salmon. They found that fish showed similar gill Na^+/K^+-ATPase activity and survival regardless of diet, therefore, the project ultimately recommended that transition diets not be adopted in DFO hatcheries at this time. The second project was focused on the emerging concern of thiamine deficiency complex (2418, Eliason et al), a nutritional issue that may be contributing to elevated fry and adult mortality (Mantua et al. 2025). This work established Canada's first in-house thiamine analysis capability for Pacific salmon and applied the new analytic technique to hatchery and wild salmon. Results revealed that while coho and Chinook eggs generally had adequate thiamine levels, pink salmon and especially sockeye salmon populations exhibited low concentrations consistent with thiamine deficiency. Within hatchery settings, preliminary testing of broodfish-thiamine-injections proved effective at improving thiamine levels, revealing a potential way to mitigate the issue.

A sometimes overlooked consequence of hatchery rearing is the formation of abnormal, vateritic otoliths, which may impair the sensory functions of the inner ears in coho salmon. As part of BCSRIF_2020_239, Gaffney et al. investigated the prevalence, causes, and consequences of vateritic otoliths in hatchery coho salmon, and tested practical ways to reduce their formation. Comparisons among hatcheries and stocks revealed significant variation in the prevalence of vateritic otoliths (Gaffney et al. 2025), while experimental trials indicated that relatively simple rearing modifications, such as altering water flow patterns and adding structural enrichment, can substantially reduce vaterite formation. These results reveal that hatchery practices, rather than inherent genetic differences, are the primary drivers of the problem and that operational changes could reduce its prevalence.

FISHERY MONITORING AND HARVEST TECHNIQUES



PSSI-supported work in fishery monitoring and harvest techniques advanced tools and approaches needed for more selective, precautionary salmon fisheries in British Columbia and Yukon. Research focused on developing, testing, and applying improved catch monitoring and reporting frameworks to address longstanding information gaps, particularly with respect to mixed-stock fisheries. Pilot projects were also conducted to evaluate selective and mark-selective fishing methods to better understand their effectiveness in reducing impacts on stocks of concern while maintaining harvest opportunities. Collectively, these projects lay the foundation for a refined approach to managing and regulating Pacific salmon fisheries. Below we summarize preliminary results and management implications from a selection of projects.

Table 10. DFO and BCSRIF projects associated with the fisheries monitoring and harvest techniques theme.

ID	Project Title
DFO Science	
9000	Enhanced Mark Selective Fishery (MSF) monitoring (including a Chinook Reference Fishery)
2394	Enhanced salmon bycatch monitoring and sampling in the Pacific region groundfish trawl fishery
BCSRIF	
BCSRIF_2019_045	Empowering Indigenous community fisheries with deep learning - computer vision for adaptive management of terminal salmon fisheries
BCSRIF_2019_058k	Enhancing Sustainability of capture & release marine recreational Pacific salmon fisheries using new tools/technology
BCSRIF_2020_292	First Nations-led catch monitoring to inform sustainable mixed-stock fisheries management on the Central Coast
BCSRIF_2022_347	Selective Fishing Using a Salmon Trap in the Campbell River Estuary
BCSRIF_2022_357	TFN Fish Trap – Capacity Building, Communications and Operations 2023-26
BCSRIF_2022_371	Skeena River Fish Trap Project
BCSRIF_2022_453	Establishing a Test Fishery for Chinook Salmon in key areas of the BC Coast
BCSRIF_2022_454	FRIM – Short term mortality holding and respirometry studies

Enhancements to recreational monitoring

British Columbia is a renowned destination for salmon angling. Active recreational fisheries span the entire coastline, bolstered by an extensive network of lodges and guiding operations. Likewise, recreational fishing is prevalent and popular in many of BC's salmon-bearing watersheds. It is a considerable challenge to monitor and assess the impacts to salmon of such widespread, diffuse fisheries, and critical information gaps exist. As a result, several new recreational fishery restrictions have been introduced in recent years to protect declining stocks. PSSI sub-initiative 18.2, part of the harvest transformation pillar, focused on developing or improving recreational fishery monitoring to better inform management actions.

In one such effort, the Central Coast Indigenous Resource Alliance has developed and implemented a creel survey with expanded coverage across a large swathe of the Central Coast (BCSRIF_2020_292, CCIRA). Researchers designed an improved survey and analytical framework that fills gaps in existing DFO programs and is more robust against data limitations. The survey also includes expansive genetic sampling that will better inform the stock composition of local salmon catches, particularly coho. This work is strengthening First Nation leadership in fishery monitoring and paves the way for a more active role moving forward.

Aside from spatiotemporal coverage, another key information gap in recreational fishery monitoring pertains to assessing impacts on released fish. With funding from PSSI, DFO South Coast Area Stock Assessment prosecuted a reference fishery to directly observe the size, mark status, and stock composition of Chinook salmon that are encountered and released at sea (9000, Rechisky et al.). Such information is needed to evaluate the potential effects of implementing mark-selective fisheries (i.e. retention only allowed for hatchery-origin salmon), which have been proposed for several areas in southern BC to expand recreational fishing opportunities. The reference fishery closely mirrored normal recreational fishing practices, using chartered sport-fishing vessels operated by experienced guides and standardized sampling protocols to capture, measure, and genetically sample all Chinook encountered, regardless of size or mark status. These data, collected from 2023–2025, provide an unbiased baseline of hatchery mark rates, legal-size rates, and stock composition of Chinook vulnerable to recreational fisheries in candidate mark-selective fishery areas. Results to date indicate that monitoring mark-selective fisheries using current creel survey protocols may underestimate release mortality impacts, since stocks of concern were more commonly encountered among unmarked fish (which would be released and therefore not be observed in the creel survey). If mark-selective fisheries are sanctioned, intermittent reference fisheries may be necessary to provide accurate data on released fish.

In January 2024, a PSSI workshop on innovations within recreational catch monitoring brought together internal and external participants with subject matter expertise. The workshop highlighted several projects focusing on catch estimation, verification, sampling, data management and digital innovation, including the reference fishery and the Central Coast Indigenous creel survey. Another PSSI project presented on was an "Overflight Digitizer," which is a digital software used to automate some aspects of aerial survey data collection. During flights, the software automatically tracks the flight location and data points for boat sightings directly on the map. Other projects that help improve monitoring capacity have utilized cameras and other new technology, leveraged citizen science, and improved efficiency of data systems. A key take-away theme from the workshop is the importance of integrating all recreational monitoring programs across BC to optimize accuracy and efficiency.

Research on release mortality and best practices for recreational fisheries

The Pacific Salmon Ecology and Conservation Laboratory at the University of British Columbia undertook a 5-year research program to study the mechanisms and impacts of injuries sustained by chinook and coho salmon when released by recreational anglers (BCSRIF_2019_058, Hinch et al.; BCSRIF_2022_454, SFI). The BC Sport Fishing Institute, Pacific Salmon Foundation, Canada's Ocean Tracking Network, DFO, and Kintama Marine Research were key collaborators on this work.

Results arising from acoustic telemetry tracking, extended holding studies, and physiological assays demonstrate that post-release mortality varies considerably among catch and release methods and that fish condition, species, size, and environmental conditions are also important factors. In broad terms, chinook salmon released in good physical condition generally exhibit low mortality, whereas individuals exhibiting injuries such as bleeding, scale or fin damage, or eye trauma experience substantially higher mortality. Coho salmon appear less resilient compared to chinook released under similar conditions. In addition, smaller fish suffer higher mortality than larger fish, and warm ocean temperatures during capture and release exacerbate losses. These findings indicate that release mortalities in marine recreational fisheries can be significant but that outcomes depend strongly on the circumstances under which fish are captured and released.

Based on these findings, the Pacific Salmon Ecology and Conservation Laboratory and Sport Fishing Institute of British Columbia are developing practical, evidence-based recommendations to minimize injury, physiological stress, and subsequent mortality when releasing salmon. Key recommendations emphasize reducing physical contact and air exposure, avoiding the use of landing nets and on-board handling, releasing fish at the waterline, and minimizing fight times (Hinch et al. 2024). Gear recommendations include eschewing in-line flashers as well as large or multiple hooks, especially treble hooks, all of which increase injury risk and severity. Recommendations for fishery management include minimizing fishing in areas dominated by immature fish or salmon predators, winding down fisheries when surface water temperatures are exceptionally warm, and stopping fishing trips once daily retention limits have been achieved. These best practices provide new options to reduce recreational fishing impacts while maintaining opportunity. Researchers are working with recreational fishers to develop resources to help integrate release mortality considerations into monitoring and public education programs (e.g. https://www.sportfishing.bc.ca/release-them-right).

Bycatch monitoring in the groundfish trawl fishery

An emergent conservation concern that surfaced during PSSI was the bycatch of Pacific salmon in the groundfish trawl fishery, particularly Chinook salmon which make up most salmon bycatch and where there are potential for interceptions of stocks of concern. PSSI funding enabled the development and multi-year implementation of an enhanced monitoring program to accurately estimate Pacific salmon bycatch by species, and determine stock composition and coded-wire tag catches of Chinook salmon (2394, Lagasse et al). Results revealed large year-to-year fluctuations in Chinook bycatch, with the initiation of the program coinciding with a spike in bycatch numbers to over 26000 Chinook salmon caught (Lagasse et al. 2025). The program directly informed the development of a new salmon bycatch management plan, including a fleet-wide Chinook cap of 9500 fish, which came into effect for the 2024–2025 trawl fishery and led to a two-thirds reduction in bycatch. By providing accurate monitoring information, the program has improved our understanding of the impacts of the fishery on Chinook salmon, and enabled the development of effective mitigation measures.

Selective harvest methods and monitoring to support adaptive management

Several research initiatives focused on improving the timeliness, accuracy, and operational relevance of fishery data to support measures aiming to reduce impacts on stocks of concern. A central theme across projects is the integration of emerging technologies with established fishing practices and community-based monitoring programs. All projects recognized the need for innovation in both fishing practices and monitoring to better support precautionary management.

DFO fishery management indicated that expanded fishery observer coverage is required on the North Coast. This motivated efforts to advance electronic monitoring for commercial vessels as an alternative or offset to the costly at-sea observer program. A pilot study was conducted by the United Fishermen & Allied Workers Union, Teem Fish Monitoring, and Ecotrust Canada during a Skeena River gillnet demonstration fishery. The electronic monitoring system accurately captured core information, including fishing effort, retained catch, released catch, and fish condition at release. Species identification, camera placement, and potential for crew members to block the view were important limitations, but these might be diminished through improved camera placement, lighting, and fisher cooperation. Future integration of automated image analysis and artificial intelligence could further improve data processing and cost efficiency, emphasizing the value of continuing to develop electronic monitoring systems for commercial salmon fisheries.

Complementary efforts explored selective harvest and monitoring tools in First Nation terminal fisheries. A pilot study led by the A-Tlegay Fisheries Society revitalized traditional salmon trap technologies in the Campbell–Quinsam estuary to enable selective harvest of hatchery salmon while safely releasing wild salmon and steelhead (BCSRIF_2022_347, A-tlegay Fisheries Society). To support improved First Nation terminal fishery management and monitoring, the Pacific Salmon Foundation developed deep-learning approaches to automate salmon counting and species identification from video and sonar data (BCSRIF_2019_045, PSF; Atlas et al. 2023), with the goal of linking these tools to escapement monitoring programs on the North and Central Coast. By enabling near-real-time data integration, this work supports more responsive management of terminal fisheries. Together, these projects illustrate how selective fishing methods, combined with modern monitoring technologies and Indigenous leadership, can yield more flexible and sustainable fisheries.

IMPROVING SALMON DATA STEWARDSHIP

Pacific salmon research and management is data intensive. From fisheries catch statistics, to genetic stock identification, to environmental monitoring, to escapement estimates, decision-making relies on many data sources, files, databases, and enterprise data systems. Research advances and effective collaboration among scientists also rely on robust data that is findable, accessible, inter-operable, and reusable (FAIR), particularly to produce ecosystem-level insights and advance ecosystem approaches to fisheries management. Recognizing the necessity of data stewardship to support analytic capability, PSSI included investments in enterprise-level data systems via creation of a PSSI Strategic Data Unit, as well new staff capacity within the Pacific Region Science branch. In this section, we focus on investments and outcomes supporting data stewardship in DFO's Pacific Region Science branch specifically.

The Fishery and Assessment Data Section (FADS) provides centralized support and capacity for data management within DFO Science, particularly for stock assessment and commercial fisheries catch reporting. PSSI bolstered capacity of FADS via the creation of a new Data Stewardship Unit, funding for IT support, and additional capacity for knowledge mobilization. Investments were aimed at leveraging contemporary technologies to develop enterprise-level solutions that make salmon data FAIR and aligned with the National Data Strategy.

The science data approach was developed around three complementary goals: 1) improving existing data management; 2) enhancing capacity to generate, manage, and analyze high-quality data, and 3) improving the creation and communication of high-value data products. Progress towards these goals was achieved through new data projects that were completed or are nearing completion, as listed in Table 11 and further detailed in Appendix B. We summarize progress and recommended next steps related to each goal below.

Improving Existing Data Management

This goal focused on modernizing core data systems and establishing stronger data governance and standardization practices. A key component of this work was the renewal and creation of databases in partnership with the Chief Digital Officer Sector (CDOS), DFO's Information Technology branch. For example, CDOS contributed to upgrading key regional databases such as the New Salmon Escapement Database System (NuSEDS). These assets represent significant, region-wide investments and form the foundation of operational data holdings. Many were at risk of becoming obsolete but now offer substantial added value through enhanced functionality, improved interoperability, clearer provenance, and expanded data-sharing capabilities. Some legacy systems such as NuSEDS and CREST were improved at a basic level but require additional funding and support to fully modernize the applications.

Table 11. Data tools and management applications developed by the Fisheries and Assessment Data Section as part of PSSI. Links are provided within the Title field where available, but some tools are only available internally to DFO staff. Additional details for applications are provided in Appendix B.

Title	Status	Access
FOS External Data Explorer	In Pilot	Publicly available
FOS Internal Data Explorer	Operational	Internal to DFO
Salmon Space	Operational	Publicly available
STREAM Platform	Operational	Internal to DFO
STAMP platform	In development	Internal to DFO
SILScanner	In development	Internal to DFO
DocFlow	In Pilot	Internal to DFO
Salmon Population Summary Repository	Operational	Internal to DFO
Qualark Data System	In Pilot	Internal to DFO
DFO Salmon Data Standards	Operational	Publicly available
Genetic Results Database	In Pilot	Internal to DFO
Salmon Outlook Enhancements	Operational	Publicly available
FADS Open Science Hub	Operational	Publicly available
Escapement Estimate Toolkit	Operational	Publicly available
metasalmon R Package	Operational	Publicly available
Salmon Data Package Specification	Operational	Publicly available
Salmon Data GPT	In Pilot	Publicly available
Salmon Data Wiki	Operational	Internal to DFO

An important component of this goal was the development of new systems for datasets that had historically been unmanaged or orphaned. By bringing these datasets into governed, structured systems, FADS aimed to address gaps in accountability and accessibility. This included creating an operational Genetics Results Database (GRD) capable of housing parentage-based tagging and genetic stock identification outputs and linking them to field data through other systems. Tools such as the Sample Tracking and Management Platform (STAMP) were developed to connect biological sampling workflows with downstream genetic or ageing results, helping streamline stock assessment processes. STAMP is currently being piloted and includes data integration between field datasets such the Fishery Operations System (FOS) and KREST, which house commercial and recreational catch data, respectively.

Standardization was advanced through several complementary projects that establish an interoperable framework for salmon data across the Pacific Region. A central piece was the development of the DFO Salmon Data Standards, including the DFO Salmon Ontology and associated controlled vocabularies, which provide a machine-readable, cross-program schema for describing stocks, surveys, samples, measurements, and analytical outputs. By aligning with international standards such as Darwin Core, the ontology enables consistent variable definitions, clearer provenance, and interoperability across databases and analytical tools. These standards form the backbone of the Salmon Data Package (SDP) specification, which provides a lightweight, spreadsheet-friendly way to encode metadata and variable semantics for biological and fisheries datasets. They are also used by Custom Salmon Data GPT, which converts messy spreadsheets into standardized data packages using AI-assisted workflows.

Standardization efforts also included the maintenance of an SMU–CU–DU crosswalk, which harmonizes spatial and stock unit definitions across programs; the development of updated escapement reporting and quality standards in collaboration with regional and international partners; and the creation of the Salmon Escapement Estimates Classification Toolkit, an R Shiny application that guides users through a reproducible and documented process for classifying escapement estimate types, addressing inconsistencies in NuSEDS.

Collectively, this work created a more stable and transparent foundation for salmon data management. However, several legacy systems require further modernization, and historical datasets, particularly older genetic results, juvenile salmon monitoring data, and archival escapement reports, remain orphaned and must be migrated into managed systems.

Enhancing Capacity to Generate, Manage, and Analyze High-Quality Data

The second major focus under PSSI involved improving how data are generated, digitized, and processed. This includes developing new tools and workflows for data-capture, such as digitized data-collection methods, and efforts to integrate diverse data sources into centralized repositories and management systems.

Advances in data capture were made through the use of Optical Character Recognition using the SILScanner, a cloud-based digitization system built specifically to convert Stream Inspection Logs, one of the most paper-dependent field programs, into machine-readable datasets. By supporting archival document digitization and extraction workflows, SILScanner is beginning to recover data locked in historical records. In parallel, DocFlow provides AI-assisted extraction of structured information from unstructured PDFs, helping operational programs transform large regulatory or monitoring document collections into searchable and analyzable formats.

To support scientists working with large and complex datasets, the FADS Linux-Managed Desktop provides a networked development environment where analysts can build shared databases, host analytical applications, and run reproducible workflows. These efforts increase the region's capacity to handle higher data volumes and conduct more advanced analytics.

Several new systems were created to support analysts working across multiple data sources. The Salmon Population Summary Repository (SPSR) centralizes escapement, recruitment, and exploitation time series into a structure, managed database that can be used for stock assessments and advisory processes, such as FSARs. SPSR is intended to replace scattered spreadsheets and local datasets with a single internal source of standardized indices and metadata, improving consistency, and reproducibility across assessments. Similarly, the STREAM platform modernizes how escapement data are entered, reviewed, and analyzed by providing a unified interface connected directly to regional databases. STREAM is intended to improve the timeliness of escapement information and support status reporting, and internal and external communication of salmon population trends.

This work is helping streamline data workflows and enable more integrated analyses across programs. However, further work is needed to fully onboard users to these tools, complete integration with legacy systems, and expand digitization efforts to additional datasets and regions.

Creation and Communication of High-Value Data Products

The third goal was to increase the accessibility and utility of scientific data through the development of new interfaces, knowledge products, and communication tools, both within DFO and for the public.

Public-facing access to salmon escapement data was improved through Salmon Space an interactive spatial application that displays Conservation Unit and Stock Management Unit information in a clear, map-based format. Drawing from regional databases, Salmon Space provides open access to escapement trends, stock status, and spatial metadata. Similarly, the external Fishery Operations System (FOS) Data Explorer will improve access to commercial salmon catch information through interactive Power BI dashboards that allow users to query, visualize, and export up-to-date fishery data. The FOS Data Explorer is not yet live while Salmon Space is now publicly available.

Work was also targeted towards internal communication and accessibility. The Salmon Data Wiki provides internal documentation on salmon datasets, systems, and workflows, supporting onboarding and improving consistency across programs. The Pacific Salmon Data Community of Practice fostered collaboration among analysts, biologists, and data stewards, enabling shared problem solving and alignment on data standards and reporting practices. In addition, enhancements to reporting tools, such as automated Power BI dashboards, R Shiny applications, and improved workflows for products like the Salmon Outlook, helped streamline the production of summary materials.

TOOLS AND MODELS TO SUPPORT DECISION MAKING

Table 12. DFO and BCSRIF projects associated with the tools and models to support decision making theme.

ID	Project Title
DFO Science	
2410	Improved decision making for salmon by understanding the threats of freshwater Aquatic Invasive Species both now and in the future
2439	Modernizing fish age estimation using Fourier transform-near infrared and neural network techniques
2449	A decision-support tool that considers harvest, hatchery, and habitat management levers to support implementation of the Fisheries Act for Pacific salmon
3682	Legislation Applicable to Pacific Salmon and Ecosystems (LAPSE)
BCSRIF	
BCSRIF_2022_415	Restoring freshwater connectivity for Pacific salmon
BCSRIF_2022_401	Supporting and connecting community-based monitoring for climate-resilient salmon ecosystems

Rapid advances in technology and technological literacy are reshaping how we monitor, assess, and manage Pacific salmon, creating new opportunities for research and data collection. Many projects funded by PSSI embraced innovation, applying it towards new analytic methods, open-source applications, and decision-making tools that help support sustainable management. This section highlights new tools and frameworks that are improving decision-making related to harvest, hatcheries, and habitat.

Decision-support tools

Several tools were designed to support objective-setting and prioritization of management strategies for Pacific salmon. One such tool was salmonMSE (2449, Holt et al), an open-source decision-support application that evaluates harvest, hatchery, and habitat objectives for Pacific salmon management. Built on management strategy evaluation (Walters and Martell 2004), salmonMSE simulates population outcomes across a range of conditions, and can explicitly model interactions between hatchery-origin and natural-origin fish, incorporate mark-selective fisheries, and represent multiple life-history strategies, while appropriately incorporating uncertainty. Applied to Sarita River Chinook in collaboration with Huu-ay-aht First Nation, the tool revealed trade-offs among conservation, harvest, and wildness objectives, and highlighted how habitat restoration may increase the likelihood of achieving all objectives.

The Non-Indigenous Species Screening Tool (NISST) was developed in collaboration with DFO to assess the risk posed by more than 500 potential aquatic invasive species across five freshwater regions in the BC and Yukon (2410, Therriault et al). The tool identifies fish, plants, and invertebrates that could negatively interact with salmon and produces region-specific priority lists, highlighting which invasive species are already present, which may arrive soon, and how climate change could worsen their impacts (Wilcox et al. 2025). Results can help guide monitoring programs, improve recovery and management plans, and support proactive actions to keep high-risk species out of salmon watersheds.

The Watershed Connectivity Restoration Planning framework, created by the Canadian Wildlife Federation, provides an open-source, geospatial decision-support tool that identifies and ranks fish passage barriers for salmon habitat restoration across British Columbia (Mazany-Wright et al. 2021). By combining spatial data on stream networks and habitat potential with information on human-made barriers, the tool produces connectivity maps and prioritized barrier lists that help prioritize field assessments and restoration actions. Under phase two of BCSRIF, the tool was further applied and improved by developing Indigenous-led watershed connectivity plans, improving habitat-suitability modelling, and identifying high-priority barriers caused by railway infrastructure (BCSRIF 2022 415).

The LAPSE project (3682, Enns et al) developed a systematic framework and open-source tool that relates Pacific salmon threats to federal and provincial legislation. The tool parses and categorizes 40 000 legislative clauses across 196 statutes, linking them to management domains and anthropogenic threats based on the International Union for Conservation of Nature threat classification system (Salafsky et al. 2008). Results reveal management domains where legislative protection may be lacking, classifies mandatory versus discretionary clauses, and showcase the inter-jurisdictional nature of salmon management, where many threats span federal and provincial responsibility. By making a large body of legislation easier to navigate, the tool seeks to aid practitioners in understanding the complex regulatory landscape governing salmon stewardship in BC.

Application of AI

Other projects leveraged Artificial Intelligence (AI) and other new technologies to improve analytic capabilities. The Alternative Age Estimation program is developing an AI-driven pipeline to expand fish aging capacity in DFO's Sclerochronology Lab (2439, Wischniowski et al). Using neural networks trained on more than 15 000 chum salmon scale images, the team achieved classification accuracy up to 94% for the most common age classes. Complementary approaches such as Fourier Transform near-infrared spectroscopy (Benson et al. 2023) produced reliable age predictions and strong taxonomic and stock discrimination for several rockfish species. Ultimately, the program aims to augment expert age readers and address chronic laboratory processing bottlenecks to increase the volume of high-quality age data essential for stock assessment.

A major collaborative initiative led by the Pacific Salmon Foundation is applying AI-based computer vision to automate salmon detection, tracking, and counting across video weirs, sonar systems, and drone surveys (BCSRIF 2022 401). These models are already being used at remote monitoring sites, providing timely estimates that reduce manual processing demands and can achieve better than 90% accuracy in video-based species counts (Atlas et al. 2023). The platform allows First Nations, DFO, and partners to rapidly validate detections, integrate results into in-season stock assessments, and expand monitoring coverage.

CONCLUSIONS AND RECOMMENDATIONS

The body of work summarized in this report expands and deepens our knowledge to guide the stewardship of Pacific salmon in British Columbia and the Yukon. Across freshwater, estuarine, and marine ecosystems, as well as hatchery science, fisheries monitoring, stock assessment, and data stewardship themes, PSSI-supported projects have generated new observations, analytical tools, and scientific understanding relevant to salmon conservation and management. Although some findings remain preliminary, several common themes emerged from the individual project recommendations and synthesis of work within each thematic area. The following recommendations are offered to guide the continued development and application of science to support decision making for Pacific salmon.

Continue to advance life-cycle assessment to inform ecosystem-based approaches to salmon management

It is now understood that salmon productivity is shaped by interacting processes across the full life cycle, rather than any single factor operating in isolation. Multiple projects identified important linkages among freshwater habitat condition, estuarine transition, early marine survival, food-web structure, predation, disease, hatchery effects, and harvest-related pressures. Continued use of life-cycle and ecosystem-based approaches for monitoring and assessment is needed to further understand and evaluate these linkages across habitats, stressors, and salmon life stages, with the ultimate goal of informing effective rebuilding planning for WCVI Chinook and other at-risk salmon stocks across BC and the Yukon.

Embed climate change considerations in future research, assessments, and decision making

Climate change is no longer a background consideration; it is now a shifting baseline to which salmon research and management must increasingly adapt. PSSI studies documented warming freshwater and marine habitats, altered streamflow regimes, hypoxic stress in marine systems, shifts in plankton and prey dynamics, and other climate change effects. These have important consequences for salmon productivity, distribution, and resilience. Climate vulnerability was also shown to vary among species, conservation units, and regions. These findings suggest that research, stock assessments, and management decisions would benefit from continued integration of climate-informed modelling, vulnerability assessments, and adaptive monitoring. There is also a need to consider and better understand salmon responses at different spatial and temporal scales, rather than relying on broad, regional averages.

Adopt and refine cumulative effects and multi-stressor perspectives

Project-level findings repeatedly showed that salmon are exposed to overlapping pressures, including habitat degradation, altered hydrology, warming temperatures, biotoxins, contaminants, invasive species, predation, pathogens, and changing marine food webs. Several studies emphasized that these stressors can interact in nonlinear ways, and that single-stressor approaches are unlikely to fully capture risk. Continued refinement of cumulative effects frameworks, stressor-response relationships, and spatial prioritization tools would improve our understanding of where, when, and for which populations multiple pressures are most likely to constrain survival and recovery, thereby enabling more precautionary and informed approaches to landscape planning and resource development.

Continue targeted research on early freshwater, estuarine, and marine life stages

Early freshwater, estuarine, and marine life stages are persistent areas of uncertainty. A number of studies identified these stages as likely bottlenecks for survival, particularly for Chinook, yet they remain the least consistently monitored phases of the salmon life cycle. New approaches developed or expanded under PSSI—including PIT-tag arrays, acoustic telemetry, otolith microchemistry, eDNA, Fit-Chip applications, and integrated field programs such as Follow the Fish and Bottlenecks to Survival—demonstrate the potential for targeted research to better understand these life stages. A logical next step is to continue targeted efforts to clarify which mortality bottlenecks are most influential, how they vary among regions and populations, and which uncertainties most limit decisive intervention.

Apply new methods and analytical tools towards operations, assessment, and decision-making, where appropriate

Projects supported by PSSI generated substantial methodological and analytical innovation that now provides opportunities for more integrated and timely science support. Projects developed or advanced a range of tools, including geospatial threat indicators, climate downscaling products, management strategy evaluation tools, genetic stock identification improvements, pathogen diagnostics, AI-assisted analytical applications, and new data standards and platforms. In many cases, the next challenge is less about proof of concept than about identifying use cases, validation, implementation, and sustained application. Future work would benefit from evaluating which tools are sufficiently mature for routine application, what training or infrastructure is needed for wider adoption, and how outputs can be consistently linked to decisions affecting assessment, recovery planning, hatchery operations, habitat preservation and restoration, and fisheries management processes.

Integrate modern genetics and fish health monitoring into hatchery practices and planning

The hatchery modernization research suggests that enhancement will benefit from continued integration of new methods for genetics, fish health, and operational monitoring. The studies summarized here show that hatchery and natural-origin salmon can differ in important ways, including epigenetic profiles, disease exposure, and developmental outcomes. At the same time, this work points to practical opportunities for improving diagnostic screening, release strategies, and evaluation of hatchery-wild interactions. Given that many findings are population- and context-specific, future work should continue to emphasize comparative evaluation across systems and careful development of objectives that consider trade-offs between conservation and production.

Recognize data stewardship as a core requirement of conducting salmon science

Data stewardship is not a peripheral issue; it is a core enabling function for conducting salmon science. PSSI investments produced new databases, standards, analytical workflows, and public- or internal-facing tools that improve the findability, accessibility, and usability of salmon information. These advances create important opportunities for creating linkages across programs, assists with reproducibility, and more efficient delivery of science information and advice. At the same time, these advances underscore the basic need for continuity in data governance, maintenance of reference datasets, and interoperability among legacy and emerging systems. Continued attention to data stewardship and management will be important if the full value of salmon science programs are to be realized over the longer term.

Expand stock assessment coverage through multi-year planning
An additional recommendation is to continue expanding Pacific salmon stock assessment coverage and rebuilding plans in response to the requirements of the Fish Stocks provisions and standardized national science advice processes. PSSI investments have strengthened the analytical foundation for this work through tools and data streams such as salmonMSE and the Salmon Population Summary Repository. If paired with a multi-year assessment schedule, these advances create a practical pathway toward routine, peer-reviewed assessments across major stock management units.

Sustain collaborative and cross-jurisdictional approaches to research and monitoring
Finally, a recurring characteristic across projects was the extent of collaboration among DFO, First Nations, the Province of BC, academic institutions, non-governmental organizations, and other partners. Many monitoring programs, research initiatives, and analytical advances were enabled through these partnerships, and in several cases partner-led work filled important spatial, temporal, or technical gaps. Future progress in salmon science will depend not only on research capacity within DFO, but also on maintaining collaborative frameworks that support shared monitoring, co-development of research priorities, data exchange, and the integration of Indigenous knowledge and local observations alongside other lines of evidence.

Taken together, the findings in this report point toward the need for continued work across scales; sustained monitoring for key habitats and life stages; refinement of tools that support cumulative effects, climate vulnerability, and life-cycle assessment; and systematic transition of promising methods into longer-term scientific and management applications. As many of the results summarized here are preliminary, an important near-term priority will be to complete cross-project evaluations to identify where evidence is already strong, where uncertainty remains high, and where additional work is most urgently required.

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This report draws upon the collective work of hundreds of biologists, researchers, technicians, students, Indigenous guardians, practitioners, managers, volunteers, and other passionate supporters of Pacific salmon. As this report showcases, collaboration is essential to meaningful research and effective stewardship of Pacific salmon. Across all projects there were over a hundred collaborators identified from within DFO and other organizations, including many First nations and non-profit organizations, academic institutions, and other government agencies. The partnerships and relationships built among these organizations was one of the most meaningful outcomes of all of this work whose legacy will extend well beyond the five-year lifespan of the PSSI.

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PROJECT REPORTS

Reports included in this section are organized by research themes and were contributed by DFO project leads using a standardized reporting template. DFO staff are identified as project leads although many projects were planned and implemented in partnership with external groups, identified within the reports as collaborators. Links to publications related to projects are provided at the beginning of each report where available, while publications in progress are also identified.

FRESHWATER ECOSYSTEMS

2398 – Redd Scour Monitoring

Collaborations: Tla-o-qui-aht First Nation, Redd Fish Restoration: Daphnee Tuzlak, J. Hutchinson

Region: West Coast Vancouver Island

Waterbodies: Tranquil Creek

Species: Chinook

Populations: South West Vancouver Island Chinook

Highlights

- In 2020, West Coast Vancouver Island (WCVI) Chinook were listed as “Threatened” by Canada’s Committee on the Status of Endangered Wildlife, leading to a freshwater risk assessment that identified redd scour as a priority data gap and potential limiting factor.
- The study combined continuous hydrometric monitoring, discharge measurements, accelerometer scour sensors, geomorphic surveys, and sediment sampling to quantify redd scour, sediment deposition, and spawning-bed dynamics across multiple flood seasons.

- Preliminary results suggest surplus sediment has been more of an issue than redd scour in hiłsyaqƛis (Tranquil Creek). Further analysis of results, including an additional year of data for 2025, is in progress.

Background

In 2020, West Coast Vancouver Island (WCVI) Chinook were listed as “Threatened” by Canada’s Committee on the Status of Endangered Wildlife, triggering a freshwater risk assessment (FWRA) conducted with DFO and 16 First Nations. The FWRA found the incubation life history phase to be extremely data deficient across WCVI watersheds with redd scour identified as a high-priority data gap across 22 indicator watersheds. In hiłsyaqƛis (Tranquil Creek), industrial logging beginning in the 1960s increased sediment supply, widened the channel, reduced pool habitat, and degraded key Chinook and chum spawning habitat in some reaches.

In 2022, Redd Fish Restoration Society in partnership with DFO launched a three-year redd scour study in hiłsyaqƛis in partnership with ƛaʔuukʷiʔath (Tla-o-qui-aht) First Nation, DFO, BGC Engineering, and the University of British Columbia. The study aims to quantify redd scour, sediment dynamics, and hydrological conditions at two known spawning sites, and to develop a monitoring protocol that can be replicated across WCVI.

Methods and Findings

The study used three integrated methods. DFO staff installed a hydrometric station on hiłsyaqƛis in September 2022 to record rainfall, air temperature, water temperature, and water depth at hourly intervals. Redd Fish staff measured discharge using an acoustic doppler current profiler (ADCP), a SonTek Flow Tracker2 velocimeter, and large-scale particle image velocimetry (LSPIV) from trail camera and drone videos. These measurements will produce a discharge rating curve to link observed water levels to flood magnitude.

Accelerometer scour monitors (ASMs) were deployed at two sites in Reach 2—Site 1 (5–8 ASMs) and Site 2 (8–10 ASMs)—prior to each flood season from 2022 to 2024. Each ASM is a chain of three accelerometers set at 0, 15, and 35 cm depth, designed to align with the surface, top, and mid-point of a Chinook egg pocket. A tilt change greater than 15 degrees signals scour at that depth. ASMs were retrieved each summer using a PIT tag reader, and post-flood bed elevations were resurveyed with RTK-GPS. Geomorphic surveys were conducted alongside ASM retrieval. In 2024, bulk sediment samples were also collected at each site.

Results from 2022–2023 showed minimal scour at both sites, but 18.5 to 30.5 cm of sediment deposition at Site 2. A shift in grain size (D50 from 59 mm to 46 mm) suggests fine sediments mobilized from upstream. In 2023–2024, scour was recorded at two Site 1 locations (maximum depth up to 44 cm) with consecutive infill; at Site 2, two ASMs were disturbed by chum salmon during peak spawning rather than by high flows. Deposition continued at both sites but at a smaller scale than in the prior year. Engineered log jams were installed at Site 2 in summer 2024 as a large-scale restoration intervention. The 2024–2025 ASM data will be retrieved in summer 2025 and will capture the first-year effects of this restoration on bed dynamics.

Insights

Across three flood seasons, very little redd scour was observed in hiłsyaqƛ̓is (Tranquil Creek). Where scour did occur, it rarely exceeded 15 cm and was followed by infill. By contrast, sediment deposition—up to 30 cm at Site 2 in 2022–2023—was substantial. These results indicate that sediment surplus, most likely driven by decades of industrial logging, is a greater threat to incubating salmon in this watershed than redd scour.

For salmon management, the findings shift the focus from peak flows and scour to sediment dynamics as a key limiting factor for incubation survival. Management actions that reduce upstream sediment delivery—such as road deactivation, slide remediation, and riparian restoration—may improve egg-to-fry survival more effectively than measures targeting scour alone. The study also confirms that ASMs can detect redd excavation by spawning salmon, providing an additional data stream for monitoring spawner-substrate interactions.

Key uncertainties remain: the discharge rating curve is not yet complete, the 2024–2025 ASM data have not been retrieved, and the 2D hydraulic model is still being calibrated. Starting in September 2025, a UBC master's student will quantify the sediment budget of hiłsyaqƛ̓is to better characterize the role of industrial forestry in sediment supply. The results from this study will also be synthesized with parallel redd scour studies on the Sarita and San Juan Rivers to provide a broader picture of incubation risk across WCVI.

Next Steps

Final reporting for the redd-scour assessment is currently underway. The next phase of work will focus developing a discharge curve, analyzing winter 2024–25 results, calibrating hydraulic models, linking to juvenile abundance, and considering parallel studies in the Sarita and San Juan watersheds. Redd Fish plans to partner with Dr. Marwan Hassan and a UBC master's student to quantify the sediment budget and determine how industrial forestry influences sediment supply.

2410 - Assessing AIS Threats to Freshwater Habitats

Wilcox, M.A., Johnson, D., Dyke, K., Gunsch, D., Lyons, D.A., DiBacco, C., and Therriault, T.W. 2025. Identifying higher risk invaders to the Columbia Glaciated Freshwater Ecoregion using a new screening tool: the Non-Indigenous Species Screening Tool (NISST). Management of Biological Invasions 16(1): 187-210. https://doi.org/10.3391/mbi.2025.16.1.12

Wilcox, M.A., Johnson, D.L., Dyke, K.D., Gunsch, D., Danielewicz, K., DiBacco, C., Lyons, D.A., and Therriault, T.W. 2026. Identifying higher risk invaders to British Columbia's five freshwater ecoregions and three Canadian marine ecoregions using a new screening-level risk assessment tool: NISST (Non-Indigenous Species Screening Tool), June 2024. DFO Can. Sci. Advis. Sec. Res. Doc. 2026/nnn. iv + xx p. (**in press**)

Contact: Thomas.Therriault@dfo-mpo.gc.ca

Collaborations: Province of British Columbia, Pacific Salmon Commission

Region: BC & Yukon

Highlights

- This project has prioritized the risk of 515 Aquatic Invasive Species across multiple taxa (primarily fish, invertebrates and plants) for five freshwater ecoregions in the Pacific Region.
- Several high-risk AIS were identified within each taxonomic group and ecoregion that could negatively impact salmon stocks throughout the Pacific Region.
- Managers and other decision makers need to explicitly consider the many threats posed by AIS in management and recovery plans for all salmon stocks in Pacific Region, recognizing these threats will not be uniform.

Background

Climate change and Aquatic Invasive Species (AIS) are leading threats to biodiversity globally. In British Columbia (BC), many salmon stocks have been assessed as at-risk by COSEWIC (Committee on the Status of Endangered Wildlife in Canada), but while climate change has been increasingly considered in salmon management and policy, the threat posed by AIS has largely been ignored. Further, stressors like increasing global temperatures are out of the control of regional management while AIS can be managed locally given resources and interest. By targeting those AIS most likely to have the biggest impact on salmon survival or productivity, we can improve salmon recovery by reducing the stress that these invasive species cause. AIS impacts on salmon are well documented in the US Pacific Northwest where, for example, invasive Walleye consume up to 2 million smolts a year in the Columbia River (Sanderson et al. 2009). The expansion of Northern Pike in Alaska has led to the decline of salmon productivity in some regions and all five salmon species have been classified as highly vulnerable to pike invasion in at least part of their Alaskan range (Jalbert et al. 2021). Habitat alteration can also impact salmon: Schwoerer et al. (2019) estimated the potential for $159 million annual damage to the Alaskan Sockeye salmon industry from one invasive plant species, Elodea. However, the extent and relative impact of freshwater AIS threats to salmon habitat and productivity have yet to be assessed in the Pacific Region (BC/Yukon). Here we will fill this gap by applying a novel screening level risk assessment tool to prioritize species (fish, invertebrates and plants) that have already invaded BC/Yukon, are nearby or in a known vector/pathway. By using freshwater ecoregions we are able to characterize the general risk of these species both now and in the future at a scale suitable to many management and policy venues.

Information generated via this project will have tremendous utility to those managers, First Nations, and stakeholders being impacted by AIS both now and in the future. As the freshwater assessments wrap up our intent is to reach out to various groups to convey the risk of the many species assessed here and to work with them on management or control plans based on their needs.

Methods and Findings

The Non-Indigenous Species Screening Tool (NISST, Wilcox et al. 2025), was developed in collaboration with this PSSI project to fill gaps and address common limitations in previous tools for screening potentially invasive species. It is organized into three separate modules examining steps in the invasion process combined with both ecological and socioeconomic impacts. This tool provides a semiquantitative valuation of risk which explicitly incorporates uncertainty into the score (using a novel Monte Carlo method) and recognizing the increasing importance of considering climate change when assessing invasion risk, this tool also incorporates a modifier for this. From the global species pool, we identified >3200 species (including fish, invertebrates and plants) that could become AIS in the Pacific Region and potentially impact salmon. From this master list, we identified 515 to be screened using NISST; with most having some history of invasiveness, being associated with a known invasion vector (e.g., organisms in trade, aquaculture, shipping, etc.), and/or having some climate match to the five freshwater ecoregions that have boundaries within the Pacific Region (British Columbia and Yukon) (Figure 1). This included 245 fish, 83 invertebrates, and 180 plants. This project will produce a ranked list of priority AIS by ecoregion, including arrows to indicate the change in risk under a future climate and a measure of uncertainty using error bars, for both species that have already invaded or have yet to invade. Further, it is possible to produce biplots showing the relative contribution of Invasion Potential vs. Ecological Impacts or Socioeconomic Impacts both now and in the future.

The resulting ranked list of AIS by freshwater ecoregion showing taxonomic identity of the invader (fish, invertebrate, or plant), its invasion status (present vs not yet detected), the effect of climate change and uncertainty. Additional project data will identify key vectors and pathways (i.e., recreational boating, natural dispersal, organisms in trade, etc.), and AIS-specific impacts to freshwater ecosystems and salmon stocks specifically. The identification of higher risk AIS is essential to refine other PSSI-related assessments of the multiple, often interacting threats to various Pacific salmon stocks and can be used in management plans, recovery assessments, or policy documents. For example, such information can be used to refine estimates of salmon mortality, recovery or productivity thus improving fisheries management advice for salmon. Further, the ranked list of AIS generated through these assessments will inform AIS monitoring and early detection programs both within DFO (AIS NCP), the Province of British Columbia (BC MOE) and the Yukon. Finally, higher risk species can be considered in future amendments to the AIS Regulation in the Fisheries Act and vectors and pathways common among higher risk AIS can be prioritized for policy and regulatory action.

To highlight key NISST outputs we include here working examples of the modular bi-plot outputs (Figure 2) and total risk scores (Figure 3) for some of the higher risk and lower risk fish species assessed for the Alaska and Canada Pacific Coastal ecoregion (FEOW 103 in Figure 1). Please note that there were 245 fish AIS to be assessed with NISST so the final products are likely to differ, and these figures are included to illustrate what can be expected at the end of this project. As expected, the range of scores obtained for species that are known to be introduced to this ecoregion and those not yet known were comparable across modules (Figure 2) and total risk scores (Figure 3) using two independent assessors. Further, the inclusion of climate change to the scores for each module typically increased the scores (Figures 2 and 3) although the magnitude varied by species.

Although work is ongoing to finalize the highest risk species for each of BC's five freshwater ecoregions and specific ranks are subject to change, there are notable differences between northern and southern ecoregions with southern ones (103 and 120) having more AIS present including well known invaders such as brown bullhead (*Ameiurus nebulosus*), goldfish (*Carassius auratus*), common carp (*Cyprinus carpio*), and rosy red minnow (*Pimephales promelas*). Further, there are higher risk AIS belonging to other taxa such as plants like Brazilian elodea (*Egeria densa*), purple loosestrife (*Lythrum salicaria*), curled pondweed (*Potamogeton crispus*), and invertebrates like Asian clam (*Corbicula fluminea*) and Chinese mystery snail (*Cipangopaludina chinensis*). When complete it will be possible to consider risk not only at the ecoregion level but across taxonomic groups and invasion status.

Among some of the highest-ranking fish species, common carp and goldfish are known to be environmental generalists, able to survive in a wide range of habitats. Goldfish (*Carassius auratus*) in particular are also widely available in the aquarium trade and thus their potential (illegal) release is an ongoing concern (Chan et al. 2019). Their ability to consume plant and animals, including eggs, makes them a potential threat to most aquatic organisms at some life stage, and their feeding activities can cause increased turbidity and disruption of aquatic plants, modifying the habitat (i.e., ecosystem engineers) resulting in both ecological and socioeconomic impacts (e.g., Deacon et al. 1964; Moyle 1976; Richardson et al. 1995; Miller and Beckman, 1996; Egertson and Downing, 2004; Weber and Brown, 2009, Jackson et al., 2010). They also carry an extensive number of diseases and parasites with the potential to impact native fish (e.g. Gilad et al., 2004; Poelen et al., 2014).

Another group of higher risk species include some catfish species. For example, channel catfish (*Ictalurus punctatus*) can spread rapidly due to a high reproductive rate and wide environmental tolerances (Jones et al., 1978). In the Columbia River they consume large numbers of juvenile salmon (Vigg et al. 1991; Sanderson et al. 2009) and predate on fish such as perch, shad, sunfish, razorback suckers, chubs, and endangered frogs (e.g. Robinette and Knight, 1981; Lentsch et al., 1996; Marsh and Douglas, 1997). Similarly, brown bullhead (*Ameiurus nebulosus*) negatively impact native fish via predation of eggs and competition with species such as endemic sticklebacks (*Gasterosteus* spp.) on Vancouver Island (Dextrase and Mandrak 2006), brassy minnows (*Hybognathus hankinsoni*) in the Fraser River (Nowosad and Taylor, 2013), and cisco, herring and lake trout in other parts of Canada (Scott and Crossman, 1973). In addition, they serve as vectors for finfish diseases such as viral haemorrhagic septicaemia (Faisal et al., 2012).

Perhaps not surprisingly most of the lowest risk species had poor climate match to Pacific Region ecosystems, were not known to be invasive elsewhere or possess traits known to facilitate invasion and lacked documented ecological and socioeconomic impacts. Although several are expected to benefit from a future climate, in most cases they are still not expected to become problematic. Almost half of these species were aquarium fish (116/245) representing both temperate organisms like weatherfish or tropical ones like danios and many (133/245) are known to be in trade in Canada.

Insights

It has been recognized for some time that AIS are a significant ecosystem stressor, especially in freshwater ecosystems (Sala et al. 2000), but also that ecosystem impacts can be highly context-dependent. This project is the first to comprehensively prioritize AIS for five freshwater ecoregions in Pacific Region both now and under future climate scenarios to improve management and policy decisions by explicitly considering higher risk AIS at multiple levels of decision making. NISST does not specify thresholds for high, medium, or low risk species but rather allows flexibility for management to set these to ensure they are fit-for-purpose. For example, different thresholds might be set for different ecoregions depending on external factors such as salmon conservation units.

Salmon management should more explicitly consider the risks of AIS (and likely other stressors) in the development of truly integrated management plans and Species-at-Risk recovery documents. By recognizing the threat posed by AIS managers can prioritize locations where preventing introductions or spread are a priority and can develop early detection programs for the highest risk species. In locations where AIS might already exist preventing spread or mitigating impacts, especially those on at-risk species, could help preserve ecosystem structure and function, including many salmon stocks. Finally, our project identified that several AIS would benefit from climate change and impacts are expected to increase. Accounting for these types of interactions and cumulative effects could improve management and policy outcomes.

Downscaling the ecoregion risk assessments may be necessary for specific waterbodies in BC to improve salmon or ecosystem management decisions and outcomes. The goal of screening level assessments like NISST is that they provide a relatively rapid characterization of risk for relatively similar areas (here ecoregions), but they are not intended to provide a detailed assessment for any specific waterbody/location within the assessment area. Here detailed risk assessments could be undertaken or screening assessments in conjunction with additional information/data could be used.

Finally, it should be recognized that there was considerable data/information gathered for both the species being assessed and the assessment area in this process (see databases in development above). This information can be used in many decision-making processes beyond the screening assessments themselves. For example, this information can be used by managers when developing early detection networks, rapid response, control or management plans for specific AIS, or recovery plans for at-risk species or areas being impacted by AIS. Further, this information can serve as a starting point for additional assessments beyond the Pacific Region as critical information will remain the same and can be used for assessment elsewhere in Canada or beyond.

Next Steps

AIS are not confined to freshwater ecosystems, given salmon life cycles they are likely to encounter additional high-risk AIS in estuarine and marine ecosystems. Work is currently underway to identifying these higher risk AIS (fish, inverts, plants, and algae) as well.

This project has identified higher risk AIS using a new screening tool such that results are standardized and can be used to inform potential regulatory amendments to the Aquatic Invasive Species Regulations in the Fisheries Act. A large number of higher risk AIS are not yet known from Pacific Region so listing could facilitate proactive measures to keep these species out or have early detection/surveillance and rapid response plans in place should they arrive.

Identifying and responding to AIS is a shared responsibility so communication products are needed to raise awareness among First Nations, stakeholders, and the public about the risks AIS pose to BC ecosystems, including salmon. This should include where to report suspicious species so the proper management actions can be undertaken (and responses are for AIS and not similar looking native species).

Tables and Figures

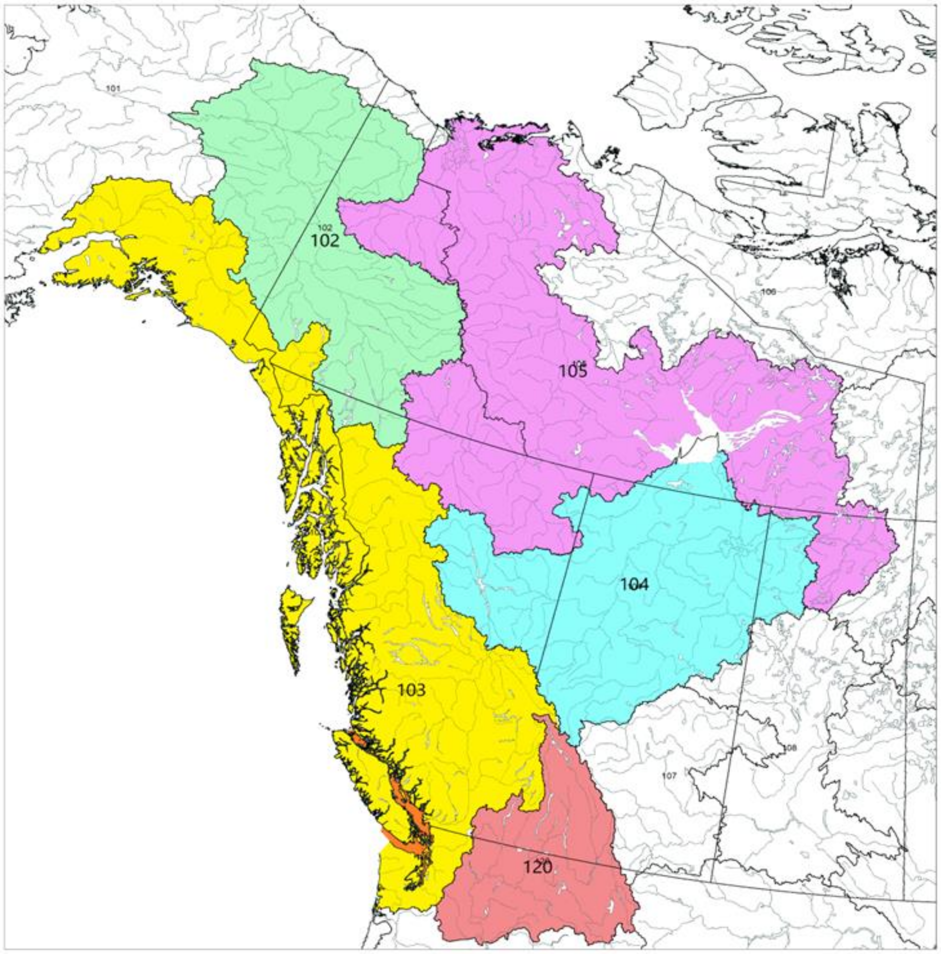

Figure 1. Map of the five freshwater ecoregions of the world (FEOW) that overlap with the Pacific Region. These ecoregions include the Upper Yukon FEOW (102), the Alaska and Canada Pacific Coast FEOW (103), the Upper Mackenzie FEOW (104), the Lower Mackenzie FEOW (105) and the Columbia Glaciated FEOW (120).

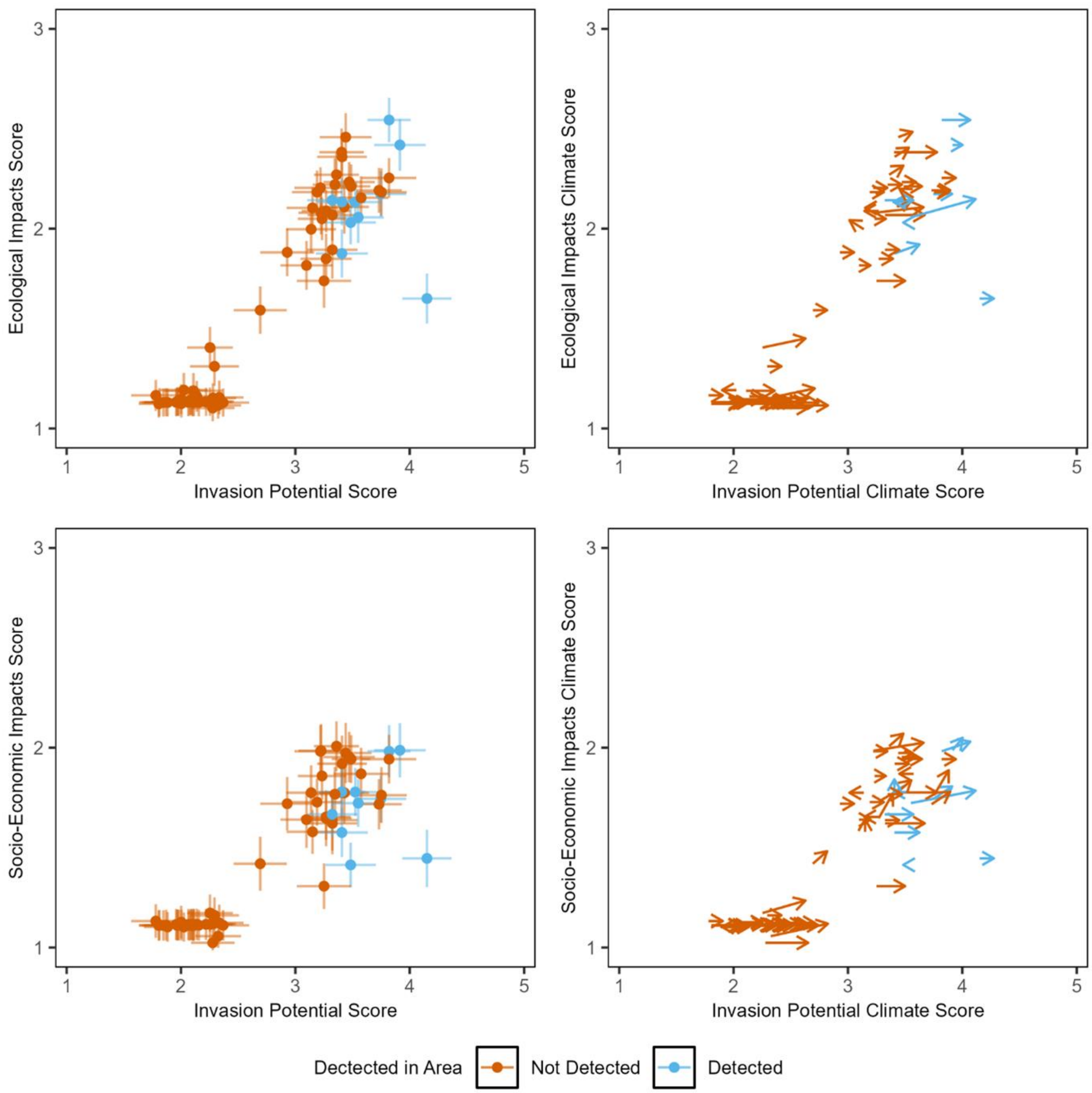

Figure 2. Biplots showing impact (ecological in the top panel and socioeconomic in the bottom panel) plotted against invasion potential for each example fish species screened using NISST for the Alaska and Canada Pacific Coast FEOW (103). Error bars represent the propagated error based on standard deviations from the Monte Carlo simulations. Vector plots showing the change in scores when using the climate modifier questions, where the base of the arrow depicts the unmodified score, and the tip of the arrow depicts the climate modified score (Right). The length of the line depicts magnitude, and the direction indicates the relative contributions of impacts and invasion potential to the modified scores. This plot is only showing a selection of higher risk and lower risk species - the same as those included in Figure 3. Note the final product will produce a continuum of scores.

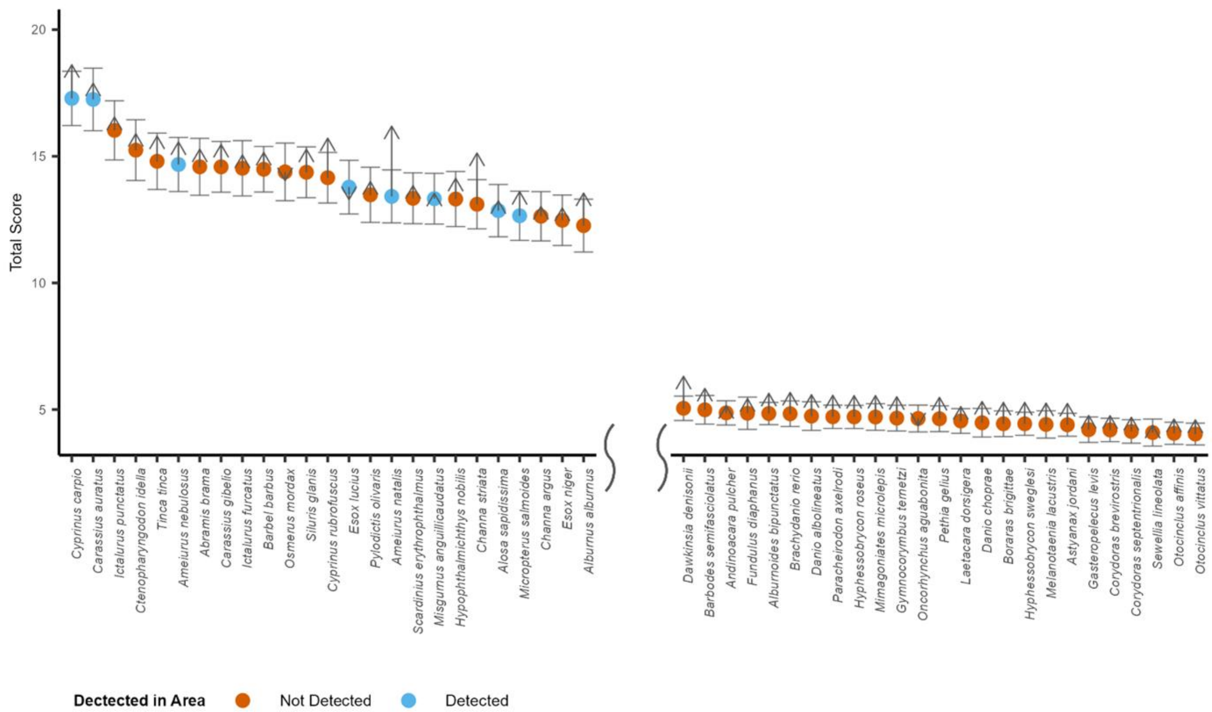

Figure 3. Ranked NISST scores for example fish species for the Alaska and Canada Pacific Coast FEOW (103). A selection of higher risk and lower risk species are shown (the final product will produce a continuum for the full extent of species assessed). Error bars represent propagated error based on standard deviations from the Monte Carlo simulation. Arrows depict the climate modified scores.

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2414 – WCVI Freshwater Indicators

WCVI Ecological Monitoring - Water Quality | Fisheries Map Gallery

VI Hydromets

Region: West Coast Vancouver Island

Waterbodies: Sarita, Sugsaw, Nahmint, Clemens, Bedwell, Ursus, Tranquil, Conuma, Leiner, Kaouk, Marble, Colonial, Cayeghle, Nimpkish

Species: Chinook

Populations: WCVI Chinook

Highlights

Water quality experienced by Chinook during freshwater life stages was identified as a gap in the RAMS process, undertaken to understand why wild WCVI Chinook returns are down even in seemingly pristine watersheds. The eco-indicator project was designed to start filling in those gaps. Periodic and opportunistic water quality data was collected in roughly 550 sampling events in 13 watersheds. Preliminary findings have not identified any major water quality issues.

Background

The core of this program involves collecting baseline environmental data from river systems on the west coast of Vancouver Island to address specific uncertainties identified in the RAMS process. The primary objective is to assess the health of these river systems in relation to salmon habitat quality and suitability. To ensure broad regional representation, monitoring was established in one or two major river systems within every major inlet to provide a comprehensive overview of the health of salmon-bearing watersheds along the west coast.

Methods and Findings

The project maintained a robust network of environmental monitoring stations to track water temperature, air temperature, water level, and precipitation via rain gauges. Field crews collected periodic water quality and discharge measurements to characterize the physical and chemical environment. Additionally, the project utilized drone technology to conduct detailed aerial photo surveys, providing high-resolution documentation of reach-scale habitat features.

Insights

- Thermal Regimes: Water temperatures in the monitored systems were generally maintained within suitable ranges for returning adults during the fall migration and spawning periods.
- Chemical Stability: Observed pH levels remained within the preferred range for salmonid health and development.

Tables and Figures

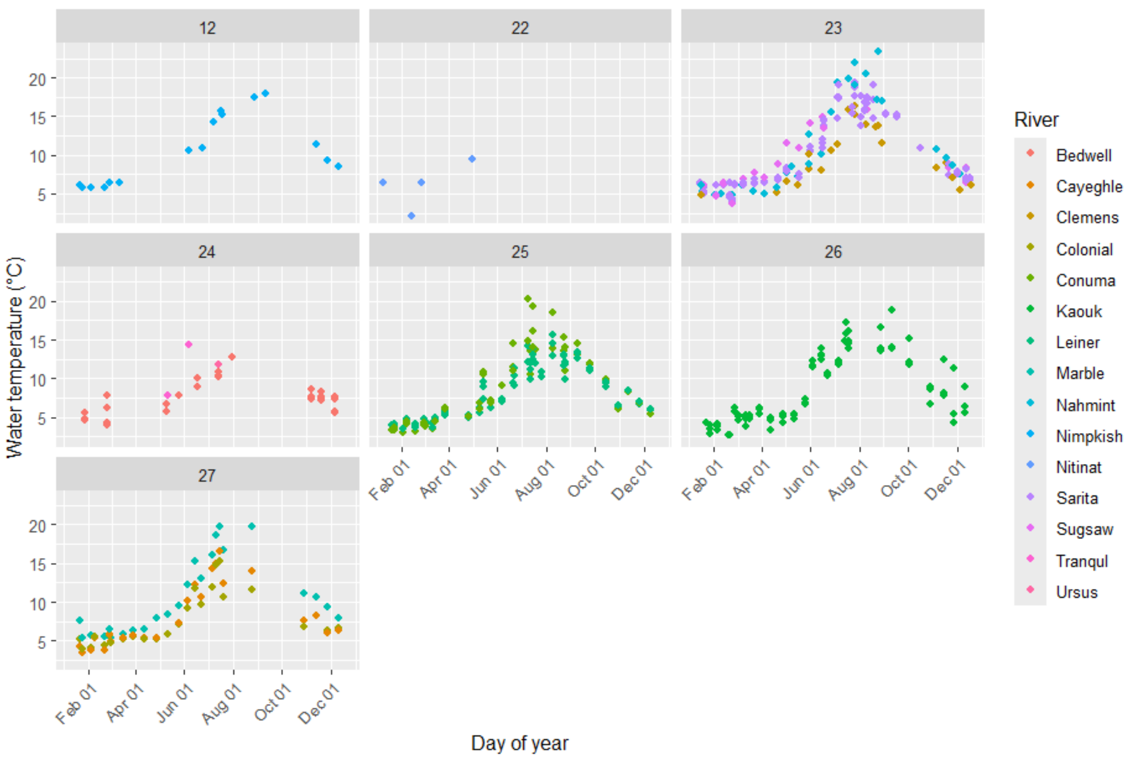
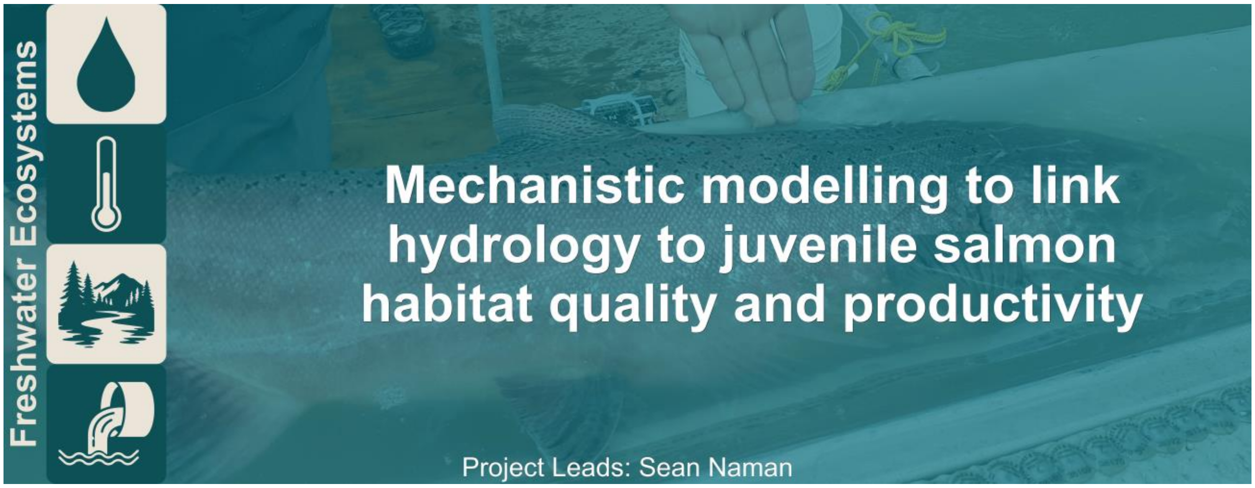


Figure 1. Water temperatures across 13 indicator streams aggregated across measurement years (2019-2025). Panels represent Pacific Fisheries Management Areas adjacent to stream locations.

2424 - Modelling Hydrology and Juvenile Salmon Productivity



Naman SM (**In revision**) Temperature dependent habitat suitability curves for instream flow modelling. North American Journal of Fisheries Management

Naman SM, Hnytka SM, Gronsdahl S, McParland D. (**In progress**) Simulating channel hydraulics using the Geomorphic Instream Flow Tool (GIFT): guidance for model use and interpretation. DFO Technical Report

Hnytka SM, Naman SM, Gronsdahl S, Kuchma S, Sterling J, Martens AM. (**In progress**). Flow-habitat relationships for coho rearing streams across the North Thompson watershed. DFO Technical Report

Naman SM, Hnytka SM, Gronsdahl S, Martens AM, Iacarella J, Weller D, Braun DC. (**In progress**). Modelling potential low flow habitat bottlenecks for coho salmon across a large watershed: influences of hydrology, geomorphology, and climate warming. Peer review publication [delayed]

Collaborations: DFO - Doug Braun, Josephine Iacarella; Secwépemc Fisheries Commission

Region: Fraser

Waterbodies: North Thompson

Species: Coho

Highlights

- This project developed and applied methods to estimate instream flow needs for juvenile salmonids in a warming climate. Habitat simulation models incorporating temperature were developed in 17 coho rearing tributaries across the North Thompson watershed.
- Relationships between flow and rearing habitat availability varied across streams, suggesting that conventional low flow thresholds may not be widely applicable. Temperature effects on flow-habitat relationships were also variable, but in some cases suggested higher flows are required if temperatures are warmer.

- Model outputs will inform real-time hydrometric monitoring and planning in the North Thompson, but the methods are broadly applicable to other salmon systems where both flow and temperature are of interest.

Background

Low flows during summer months can be an important bottleneck for stream-rearing rearing salmon. Determining how much water fish need is therefore a critical management question, especially given rising human water use and climate warming. Elevated water temperature is another threat facing stream-rearing salmon that is often linked to low flows. However, conventional modelling tools for determining instream flow needs have generally not explicitly considered temperature. This is a gap for management as it is unclear if current instream flow assessments will apply in a warmer future.

This project developed an analytical framework to integrate water temperature into habitat simulation models, a widely used method for determining instream flow needs. We used a bioenergetics framework that relates channel hydraulics (e.g., depth and velocity) and temperature to the daily energy balance of juvenile salmonids. We then applied the approach to 17 coho-rearing streams across the North Thompson watershed, interior BC (Naman et al. 2020). This work was collaborative with Secwépemc Fisheries Commission and Simpcw First Nation and will inform instream flow management through the lens of climate change.

Methods and Findings

A habitat simulation model framework was used to link streamflow to channel hydraulics, then channel hydraulics to fish using bioenergetics. The end result is a matrix of relative habitat availability across combinations of flow and water temperature. This can be used as a tool to support real-time flow and temperature monitoring or be linked to flow and temperature projections under contrasting climate change scenarios. Initial model outputs have been shared with Secwépemc Fisheries Commission to support drought monitoring in several priority systems.

Flow-habitat relationships were variable across the different streams, suggesting that generic thresholds of flow (e.g., 20% of mean annual discharge) may not always apply. The combined effect of flow and temperature was also variable, reflecting the complex nonlinear pathways that temperature influences fish.

While the specific model outputs generated to date are applicable to the North Thompson, the general approach is broadly applicable to other systems where the combined impacts of flow and temperature change are of interest.

Insights

Flow and temperature are both critical habitat dimensions for salmon in freshwater, but there is still significant uncertainty in their combined effects on fish. This study provides a framework to integrate temperature into instream flow models, which support a number of management decisions, including regulatory authorizations, watershed planning, and water governance. It is also relevant for cumulative effects, where flow and temperature are common pathways where various activities impact salmon and their ecosystems.

As with any modelling tool, there are simplifications and assumptions that should temper inferences. The approach developed here is intentionally simple and conforms to conventional habitat simulation modelling constraints. This simplicity is a benefit in that it maintains tractability, but a limitation in that the method is subject to many of the longstanding critiques of habitat simulation modelling approaches (see Railsback 2016).

Next Steps

Undertaking this work highlighted several important empirical knowledge gaps that should be the focus of future studies. First, there is surprisingly scarce empirical data on how salmonids shift their behaviour and habitat use at high temperatures in the wild. Predictions from our models at high temperatures should therefore be tempered. Second, there is considerable variation in how flow and temperature covary. For instance, low flows are often associated with warming water temperature, but this may not be the case in systems with groundwater influence. Work to better predict these complex dynamics would benefit the application of this modelling tool.

The analytical framework developed from this project is accessible and should be readily available to interested practitioners. Habitat simulation modelling is widely used and the advances from this project can be readily integrated (see Naman et al. 2020). Model outputs can provide a more dynamic perspective on flow needs for fish in a warming climate.

Tables and Figures

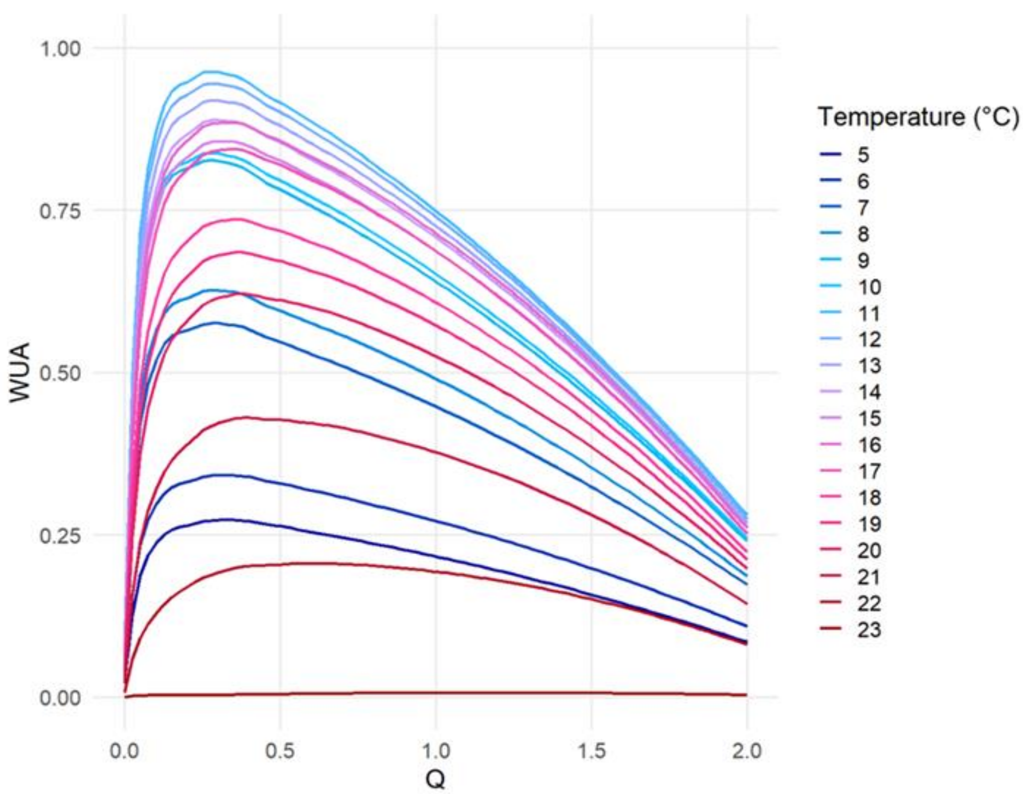


Figure 1. Example model output plotting weighted usable area (WUA), the relative area of suitable rearing habitat, against flow (Q) across different temperatures.

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2425 - Geospatial Threat Indicators in the Fraser River Basin

Iacarella, J.C., Paterson, K., Potapova, A., & Weller, J.D. 2025. Geospatial indicators and metrics for threats to fish habitat in the Fraser River Basin with Thompson-Nicola as a case study. DFO Can. Sci. Advis. Sec. Res. Doc. 2025/013. xiii + 126 p.

Region: Fraser

Waterbodies: Fraser River

Species: All *Oncorhynchus* spp.

Highlights

- Human activities, landscape disturbances, and climate change are presenting numerous individual and cumulative threats to fish and their freshwater habitat across British Columbia (BC). Modern tools and approaches for tracking and assessing these threats are needed to support responsive and integrated regulatory, planning, partnership, and monitoring activities to help safeguard fish and fish habitat.

- We developed geospatial estimates of individual and cumulative threats to salmon and Species At Risk habitat in the Fraser River Basin from human activities, landscape disturbance, and climate change (e.g. pollutant loading, sedimentation, flow alteration, high stream temperatures). We modelled and mapped 13 threats for the full stream network and identified where and for which species threats were higher. We further applied the threat scores and indicators of important habitat for salmon in the Thompson-Nicola to help inform restoration planning for salmon ecosystems.

- This project is the first to provide spatially extensive estimates of freshwater threats to salmon and inform how restoration and management actions can potentially improve population outcomes. The estimated threats are now used in salmon population life-cycle modelling to evaluate the impact on salmon across their freshwater life cycle.

Background

Understanding where and how fish and fish habitat are impacted by human activities and climate change is critical information for targeting effective conservation and management actions to help preserve populations. Geospatial cumulative effects assessments offer a powerful approach for evaluating simultaneous threats across large spatial scales, improving upon traditional field-based assessments (Halpern et al. 2008a; Halpern and Fujita 2013). However, many existing assessments rely on simple proxies of human activity (e.g., road density) rather than mechanistic metrics that directly link stressors to ecological responses relevant to fish and fish habitat (e.g., sediment loading or flow alteration) to provide more meaningful applications (e.g., stressor-response curves; Rosenfeld et al. 2022). To address this gap, this project advanced existing geospatial tools, indicators, and threat metrics for the Pacific Region (DFO 2022) by incorporating a mechanistic approach to better quantify anthropogenic and climate change impacts and inform management actions for salmon and Species at Risk (SAR) in the Fraser River Basin (FRB).

The Thompson-Shuswap and Nicola River watersheds were identified as pilot areas to deliver Integrated Planning for Salmon Ecosystems (IPSE) under the Pacific Salmon Strategy Initiative (PSSI). Within the scope of this project, we conducted a case-study on the Thompson-Nicola Ecological Drainage Unit (EDU) by developing examples of how individual and cumulative threat scores can be applied to help inform restoration prioritization and management actions. The Thompson-Nicola spatial analysis was used to inform IPSE collaborative planning processes in the Thompson-Nicola watersheds.

Methods and Findings

We developed a geospatial tool to summarize anthropogenic and climate change related cumulative threats to freshwater species and habitats using open-source input data and software that can be reproduced for different time periods and freshwater species and their habitats. All threats were estimated for each stream reach within the BC Freshwater Atlas (FWA). We derived nine individual human-activity and landscape disturbance threats: aquatic invasive species, riparian disturbance, in-stream habitat destruction, flow alteration, latitudinal fragmentation, sedimentation, pollutant loading, and nutrient loading. The input data was processed and combined to produce an individual threat score that characterizes the mechanism of disturbance to freshwater species for each score. For climate change threats, we compiled model outputs of projected stream flow and temperature to estimate threats of flood-risk, low and high stream flow, and high summer stream temperature from 2040-2060 under Representative Concentration Pathway (RCP) 4.5 and 8.5 scenarios. The individual threat scores were standardized across the study area, weighted equally, and added together to calculate a human activity and landscape disturbance cumulative threat score and a climate change based cumulative threat score (see Iacarella et al. 2025 for detailed methods). Finally, both cumulative threat scores were paired with salmon and SAR distributions (i.e., CU boundaries and delineated stream habitats, respectively) and evaluated to identify where threats were greatest and which species and CUs were exposed to the highest threat levels.

For the Thompson-Nicola EDU case study, we focused on human activity threats that may reasonably be mitigated, including riparian disturbance, water withdrawal, and longitudinal fragmentation from dams. We identified overlap between these threats and two approaches used to identify areas important to salmon: (1) CU delineations and (2) modelled environmentally favourable spawning habitats. The modelled environmentally favourability predictions were derived from large-scale environmental niche models to predict shifts in habitat favourability from current to future climate conditions (Iacarella and Weller 2023). We multiplicatively combined threat scores with environmental favourability for salmon spawning to create composite scores that reflect a gradient of potential management implications (see Fig. 20 in Iacarella et al. 2025). A high threat score combined with a high favourable habitat probability identifies an area that warrants localized investigation and potential restoration or mitigation actions. Conversely, a low threat score combined with a low favourable habitat probability identifies an area that is less likely to need management attention based on salmon values (i.e., predicted spawning habitat) and low level of anthropogenic impact.

Our results indicated the highest cumulative threat scores around the lower Fraser River and within the interior plateau of the FRB for both human activity and landscape disturbance based threats and climate change based threats (Figure 1). Watershed groups with the highest median cumulative threats were the Nicola River, Guichon Creek, and San Jose River. These heightened scores were predominately driven by riparian disturbance, nutrients, and sedimentation for the human activity based threats and high stream temperatures for the climate change based threats. Roads were the most frequent input that influenced human activity based threats across the FRB, and contributed consistently to in-stream habitat destruction, riparian disturbance, nutrients, and sedimentation. Other important inputs to these threats were forest fires, forest pest defoliation, rangeland, and forestry. We found that SAR with limited ranges (i.e., coastrange sculpin, green sturgeon, Nooksack dace, and Salish sucker) had higher median human activity cumulative threat scores relative to all streams in the FRB, corresponding to their at risk status (Figure 2). Median human activity threat scores tended to be more similar among salmon CUs and relative to all streams, though a few of the Threatened and Endangered sockeye salmon CUs had notably higher median threat scores (Figure 2).

Within the Thompson-Nicola EDU, median cumulative threat composite scores within watershed groups based on the multiplicative value of human activity cumulative threats and favourable spawning habitat under current and future conditions were highest for sockeye (Figure 3). The greatest shifts in median composite scores from current to future climate conditions (i.e., based on changes in predicted spawning favourability), were increases in Upper North Thompson River for Chinook (median score change = 0.14), Bonaparte River for pink (0.06), and Deadman River for sockeye (0.11), and a decrease in Thompson River for coho (-0.06). Overall, the Deadman and Adams River watershed groups were identified as having the highest cumulative composite scores under current and future climate conditions across salmon species in the EDU.

Insights

This project is the first to provide spatially extensive estimates of human activity and climate change threats that are directly linked to salmon, SAR, and their habitats at the stream reach scale. The approaches used to estimate each of the indicators provide an initial broad-scale standardized framework that can be applied to characterize threats throughout the Pacific Region. Within the FRB, we observed the highest threats in the Lower Fraser and interior plateau, and specifically, within the Nicola River, Guichon Creek, and San Jose River. Overall, roads were the greatest contributor to human activity-based threats, disturbing in-stream habitats, riparian areas, and contributing to sediment and nutrient loading. These results improve our understanding of the spatial distribution and relative magnitude of threats across the FRB, providing a foundation for predicting population-level impacts from cumulative effects and life-cycle modelling.

A major source of uncertainty is the spatial accuracy of the BC Freshwater Atlas. Known issues to the FWA include overestimates of headwater streams in interior regions, misaligned stream delineations and large river catchment areas. Each of the individual threat scores have their own uncertainties and limitations, as detailed in Table 2 of Iacarella et al. (2025). In general, the input data are subject to limitations arising from potentially misclassified land cover or land use, features included in datasets but not present on the landscape, and unmapped activities or features, which introduce uncertainty into individual threat scores and the cumulative score. An additional source of uncertainty is the unresolved habitat use and distribution of salmon and SAR within the FRB. The approach used to combine individual threats into a cumulative threat score (e.g., addition, multiplication, etc.) is another source of uncertainty that can be evaluated in future work by modelling population responses to individual and cumulative threats.

Next Steps

Although our threat estimates represent the mechanisms by which salmon and freshwater SAR are affected, the magnitude at which these threats influence salmon population dynamics remains unknown. To address this gap, we are continuing to refine existing threat estimates and developing new threats that are explicitly linked to stressor-response functions for cumulative effects and life-cycle modelling. For example, we have developed additional riparian disturbance metrics that better capture the impacts to riparian function (e.g., large-woody debris recruitment, disturbance to stream-shading, riparian filtering), which were not included in the original report. Moreover, we are developing a stage-structured population model for Interior Fraser Coho (IFC) to estimate how stressors (estimated threats) are influencing the population across their freshwater life stages. For this work, we are utilizing the Cumulative Effects Model for Prioritizing Recovery Actions (CEMPRA), which applies stressor-response functions to account for the impact of stressors on vital rates and the overall population overtime and under different climate change and mitigation scenarios (Bayly et al. 2024).

Additional next steps for this work include expanding the cumulative threats model to other watersheds in the Pacific Region. To date, the model has also been applied to the Upper Bulkley Watershed to aid in salmon habitat restoration planning. Validation is an important step of most modelling exercises, though is often not a standard component of cumulative effect assessments (Halpern and Fujita 2013). Validating these threats through field verification and in situ data would be beneficial for threats that involve applied relationships and estimations, such as the flow accumulated loadings (i.e., nutrients, pollution, sedimentation). Future work could re-run the model at regular intervals to evaluate change in threats over time. Finally, additional analyses could quantify uncertainty in modelled threats and evaluate underlying assumptions through sensitivity tests.

Tables and Figures

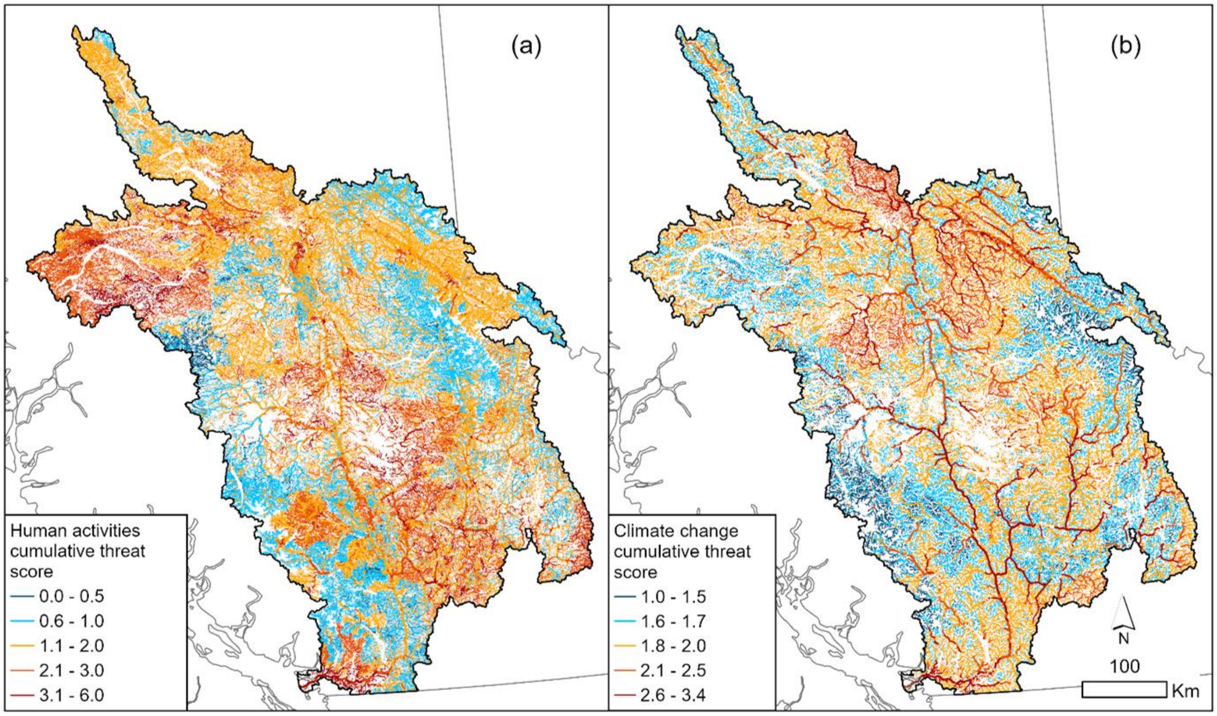

Figure 1. (a) Human activity and landscape disturbance based additive cumulative threat score, and (b) Climate change additive cumulative threat score for 2040-2060 under RCP 4.5. Blue indicates low threat levels and red indicates high threat levels.

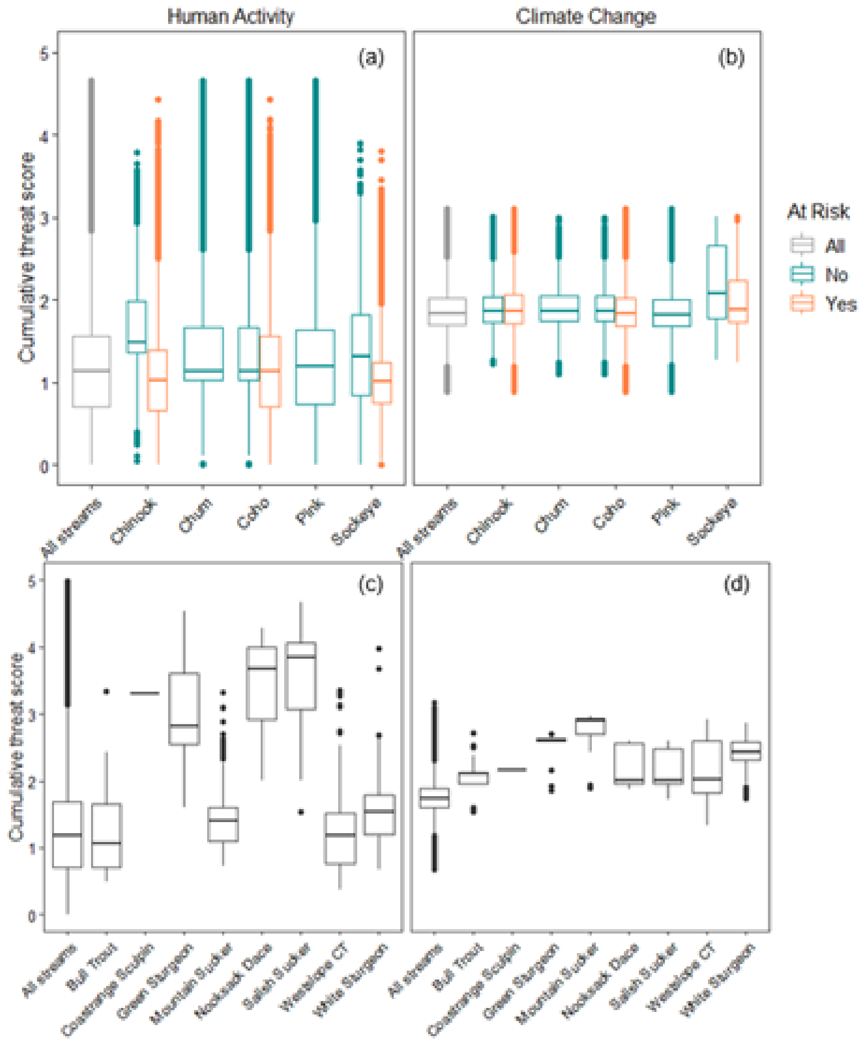

Figure 2. Tukey's box-whiskers plots of the cumulative threat scores from human activity and landscape disturbance based threats and climate change based threats for all streams in the FRB, (a & b) accessible streams within salmon CUs, and (c & d) delineated stream habitats of fish SAR. Salmon CUs identified as Special Concern, Threatened, or Endangered by COSEWIC were distinguished from those not at risk.

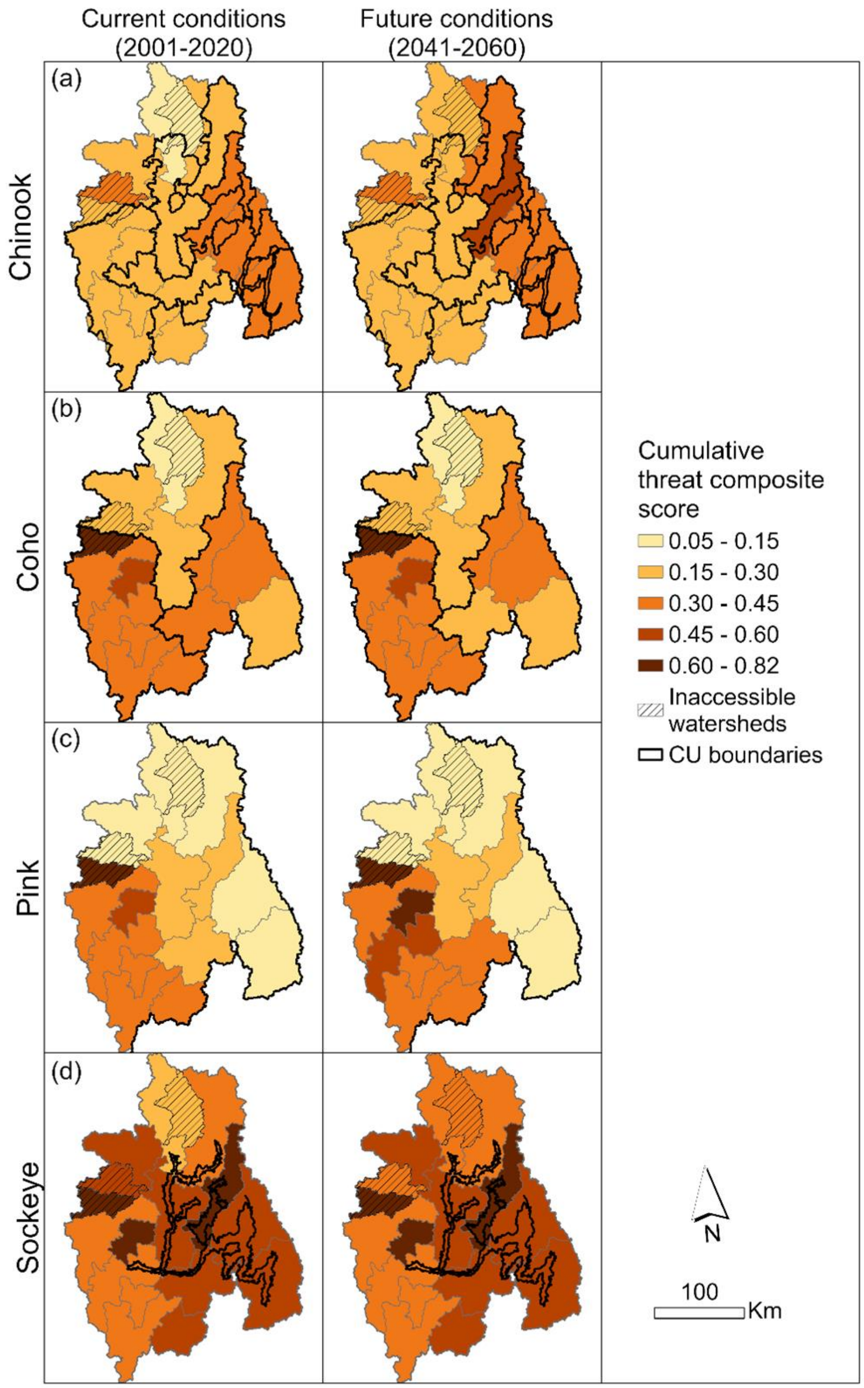

Figure 3. Median cumulative threat composite scores for watershed groups in the Thompson-Nicola EDU based on the multiplicative value of human activity and landscape disturbance based cumulative threats and modeled environmental favourability for spawning (row a) Chinook, (b) coho, (c) pink, and (d) sockeye salmon. Modeled environmental favourability probabilities used in the composite score were based on projected (column a) current and (b) future conditions for all stream reaches (≥ 4th order) including inaccessible streams from dams and natural barriers. Watershed groups that are largely inaccessible are identified by hatched lines, and salmon CU boundaries in black outlines. Colour scale indicates increasing need for localized investigation and potential restoration.

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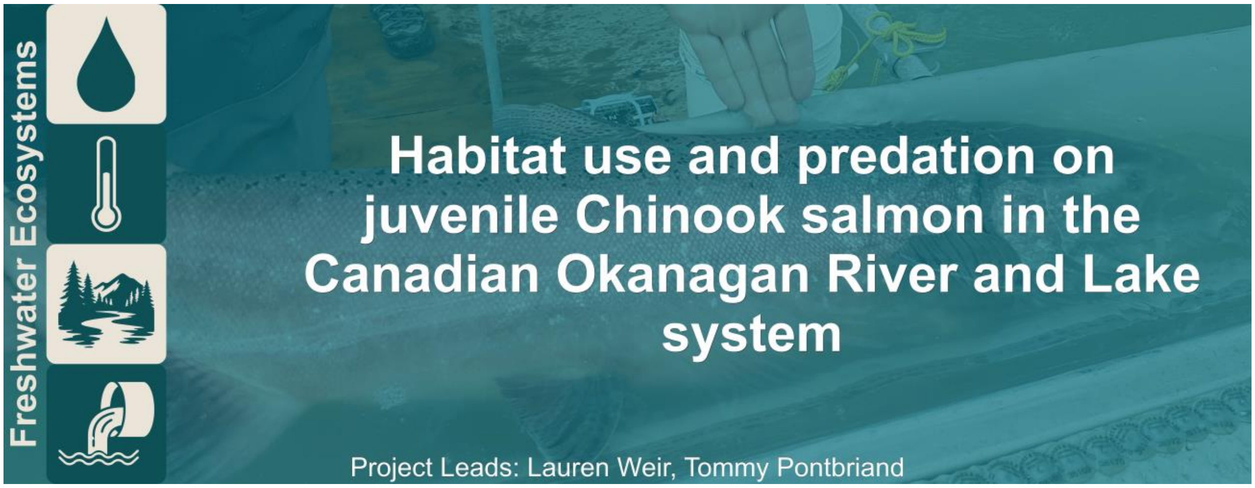
2442 - Habitat Use and Predation on Okanagan Juvenile Chinook



Selena Carl, MSc Thesis, Thompson Rivers University – Just Keep Swimming- Tracking Endangered Juvenile Okanagan Chinook Salmon (Oncorhynchus tshawytscha) Throughout the Okanagan River System (in progress)

Torrie Bell, MSc Thesis, Thomson Rivers University – Investigating Predation on Juvenile Sk'lwist (Chinook Salmon Oncorhynchus tshawytscha) in the Okanagan Basin: Diet Composition and Habitat-Specific Impacts of Smallmouth Bass (Micropterus dolomieu) (in progress)

Collaborations: Thompson Rivers University (TRU): Dr Brian Heise, Selena Carl (MSc student), Torrie Bell (MSc student); Okanagan Nation Alliance (ONA): Elinor McGrath

Region: Okanagan

Waterbodies: Okanagan River and Lake system

Species: Chinook

Populations: Okanagan Chinook

Highlights

The objective of this project was to understand factors influencing the survival of juvenile Chinook Salmon in the Okanagan River and Lake system. We found that survival is low during the downstream migration of sub-yearling Chinook in the spring and early summer. Disturbed rearing habitat, high water temperatures, and predation pressure from smallmouth bass were identified as the main threats to Okanagan Chinook juvenile survival. This new knowledge will help us target recovery efforts for this endangered population.

Background

The Canadian Okanagan Chinook population is currently the only Columbia River basin Chinook population in Canada. Chinook escapements to the Okanagan River have been extremely low (less than 100 spawners annually) and many habitat challenges are preventing the recovery of the population. Okanagan Chinook were assessed as Endangered by COSEWIC in 2017, and the population is under review for listing under the Species at Risk Act.

Some knowledge gaps that originated from those assessments were uncertainty around juvenile survival and factors influencing it.

To answer this knowledge gap, we partnered with Thompson Rivers University to support two graduate students to study factors influencing the survival of juvenile Chinook Salmon in the Okanagan River and Lake system. The project was also developed and implemented in collaboration with the Okanagan Nation Alliance's fisheries biologist Elinor McGrath.

Methods and Findings

Habitat use and survival

Subyearling Chinook (n=547) raised in the kł cp̓əlk̓ stim̓ hatchery were implanted with ATS SS400 injectable acoustic transmitters. They were released in two groups, with group A (n=273) released in the Okanagan River below Vertical Drop Structure (VDS) 17 and above Vaseux Lake, and group B (n=274) released downstream of Vaseux lake below McIntyre Dam. A network of 15 ATS SR3001 autonomous receivers was deployed from Okanagan Falls to Osoyoos Lake between 21 May and 8 August, 2024). Receivers were clustered into 7 detection sites, placed to form acoustic “gates” at lake inlets and outlets, narrows and channel constrictions, and potential rearing/migration corridors. An ATS SR3017 mobile receiver with hydrophone was used to survey shallow side channels, deeper offshore areas beyond stationary coverage, and upstream and downstream of VDS structures. The proportion of fish detected decreased sharply for both release groups as fish migrated downstream, which translated to low survival in both release groups. Tag burden was not deemed a source of direct mortality, but could have increased susceptibility to predation.

Smallmouth bass diet and predation

Targeted angling was conducted in the Okanagan River, Vaseux Lake, Osoyoos Lake from May 3 to August 7, 2024. The dominant species captured were smallmouth bass, which comprised 76% of the total catch (n=196), followed by Northern Pikeminnow (16%, n=41) and Yellow Perch (4%, n=11). There was a spatial shift in the distribution of smallmouth bass caught during the study. In May, less than half (45%) of smallmouth bass were caught at Vertical Drop Structures (VDS), but the proportion of smallmouth bass captured at VDS structures increased to 100% and 80% in June and July, respectively. Bass were observed utilizing rocky substrate and rip rap below the VDS structures to ambush prey. Diet content visual analysis was performed on a subsample of 73 of the total 196 smallmouth bass. A total of 162 fish stomach samples were sent for DNA barcode sequencing. Chinook salmon was only detected once in the DNA samples, but direct evidence of bass predation on juvenile Chinook was obtained by recovery of an acoustic tag used in the juvenile migration and habitat use study. DNA metabarcoding identified a diverse assemblage of 146 unique prey taxa. Aquatic insects (Diptera, Ephemeroptera, Trichoptera), invasive fish (smallmouth bass, yellow perch, common carp), and native fish (prickly sculpin, mountain whitefish, sockeye/kokanee, Chinook) were the most common prey items in smallmouth bass stomach contents.

Insights

The research conducted through this project added greatly to the limited knowledge of juvenile Chinook survival in the Okanagan River and Lake system.

The acoustic telemetry study revealed that juvenile Chinook survival is low during their spring outmigration in the Okanagan River. It identified critical freshwater mortality hotspots in Vaseux Lake, in the Okanagan River, and in the northern portion of Osoyoos Lake. This mortality was associated with warm water temperatures and habitat constraints and provides evidence for supporting habitat restoration strategies to increase juvenile survival. Proposed actions include:

- reconnecting side channels;
- re-naturalizing riparian zones;
- adding deep pools, woody debris, and cover;
- managing macrophyte growth;
- adjusting dam operations for cold water inflow protection; and
- adapting hatchery release strategy (timing and location) to maximize juvenile survival. The predation study revealed that predation pressure by native and invasive fish species, especially by smallmouth bass, is likely high and contributes to the low survival of juvenile Chinook in the Okanagan River and Lake system. It also identified predation hotspots at Vertical Drop Structure (VDS) sites on the Okanagan River. Proposed actions to mitigate the impacts of smallmouth bass predation include:
- reducing predation hotspots at VDS sites with restoration efforts to remove or modify existing structures;
- targeted smallmouth bass removal in the Okanagan River and Lake system with electrofishing or angling programs; and
- protect and enhancing rearing habitat for juvenile Chinook by supporting the habitat restoration strategies listed above.

Next Steps

The findings from this project should be considered in the rebuilding and conservation plan of this endangered conservation unit, as it identified specific and tangible actions that have the potential to increase juvenile Chinook survival, productivity, and abundance of the CU.

Remaining knowledge gaps and recommendations for future studies include:

- using predator-detecting acoustic tags to determine juvenile mortality from predation and finer-scale movement data to elucidate habitat use throughout the migration corridor;
- estimating the smallmouth bass population size in the Okanagan River and Lake system to quantify the predation pressure on juvenile Chinook; and

- understanding the role of predation from other native and invasive piscivorous fish and avian predators on juvenile Chinook survival.

Tables and Figures

Table 1. Total length (TL) and weight of the 196 smallmouth bass (Micropterus dolomieu) captured in the juvenile Chinook predation study. Bass were captured by angling in the Okanagan River and Lake system and were sacrificed upon capture for stomach content analysis.

Location	Month	n	TL (mm.±.SD)	Weight (g.±.SD)
Okanagan River	May	88	290.5 ± 65.9	440.0 ± 381.7
Okanagan River	June	15	291.4 ± 68.7	424.1 ± 382.9
Okanagan River	July	35	243.7 ± 55.1	245.2 ± 264.6
Osoyoos Lake	May	1	232.0 ± NA	175.0 ± NA
Osoyoos Lake	June	8	316.8 ± 87.3	550.0 ± 636.1
Vaseux Lake	May	19	268.9 ± 59.1	324.1 ± 228.5
Vaseux Lake	June	18	314.6 ± 67.8	509.8 ± 310.6
Vaseux Lake	July	12	274.5 ± 55.8	328.7 ± 165.2
Total		196	282.2 ± 66.8	395.6 ± 354.1

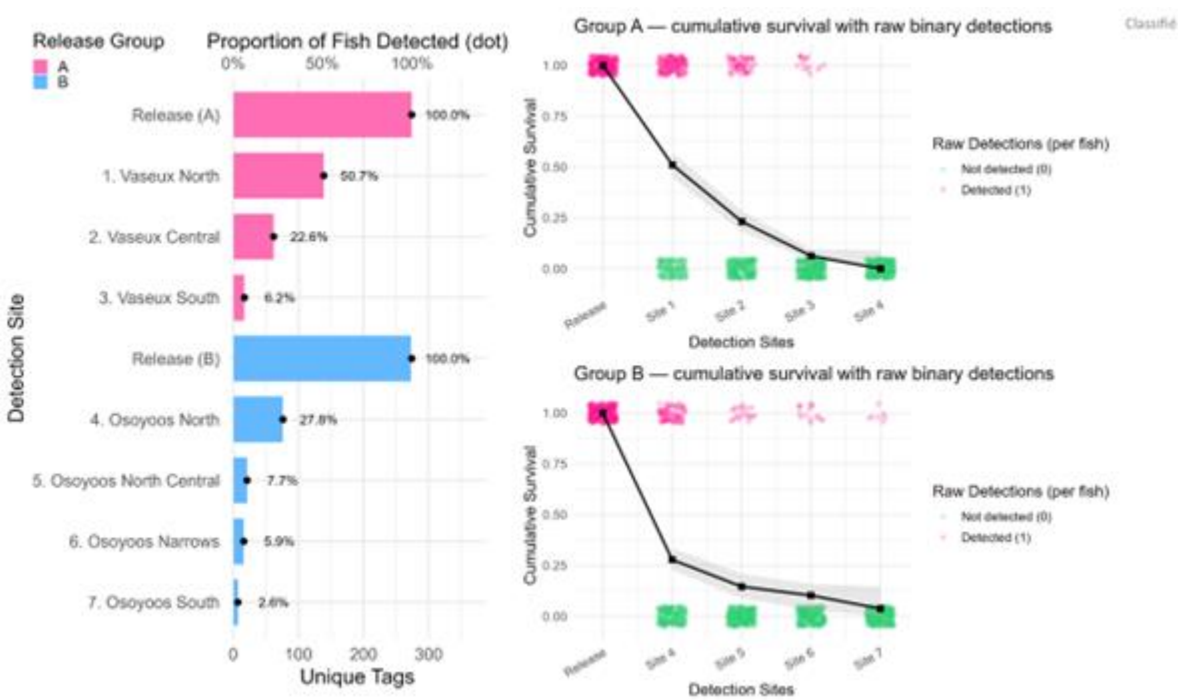


Figure 1. Proportion of acoustic tagged juvenile Chinook detected at downstream detections sites and resulting survival curves for release Group A (n= 273 upstream of Vaseux Lake) and B (n=274 downstream of McIntyre Dam). In both release groups, there is a sharp decline in the proportion of fish detected and survival is low during the downstream migration.

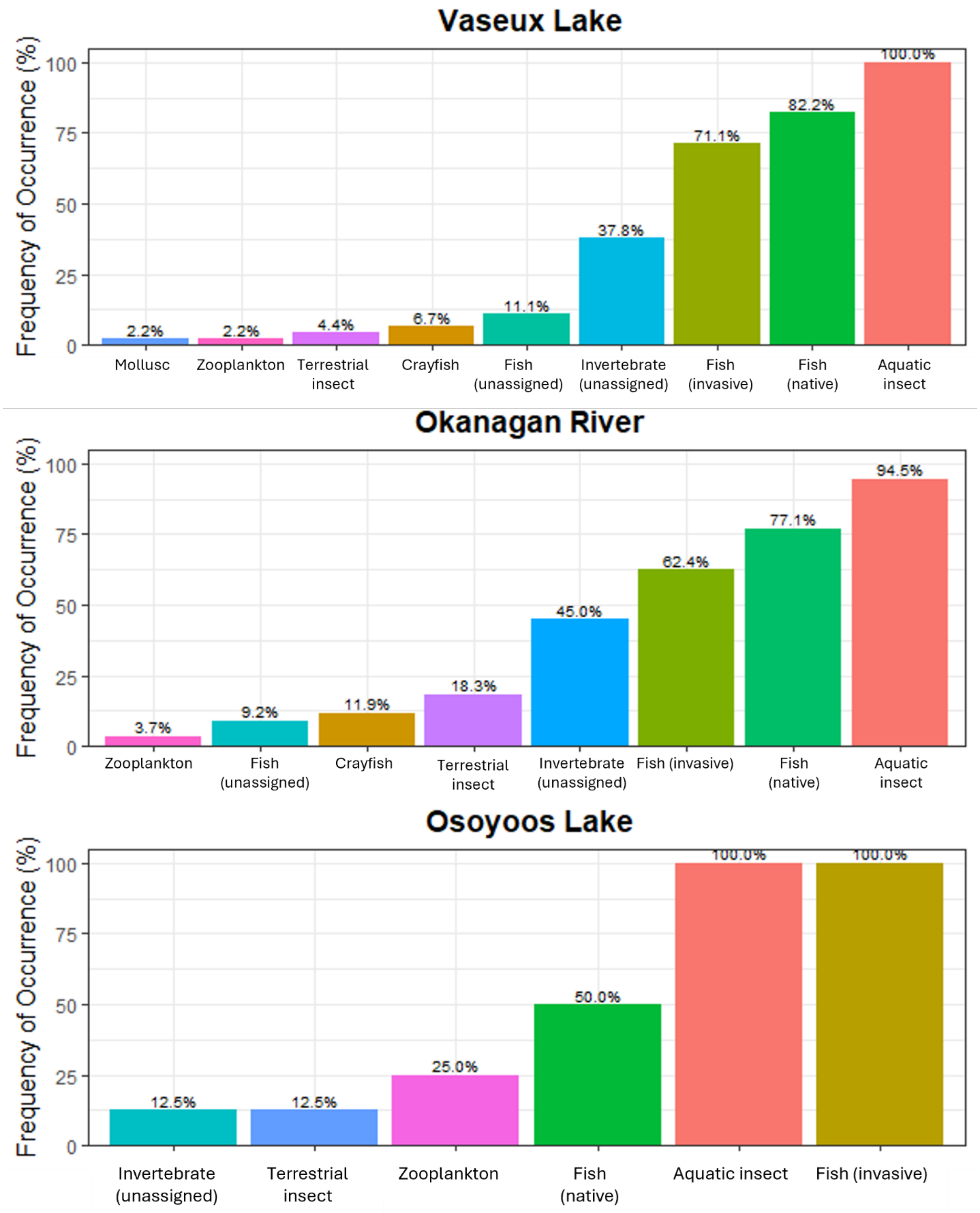
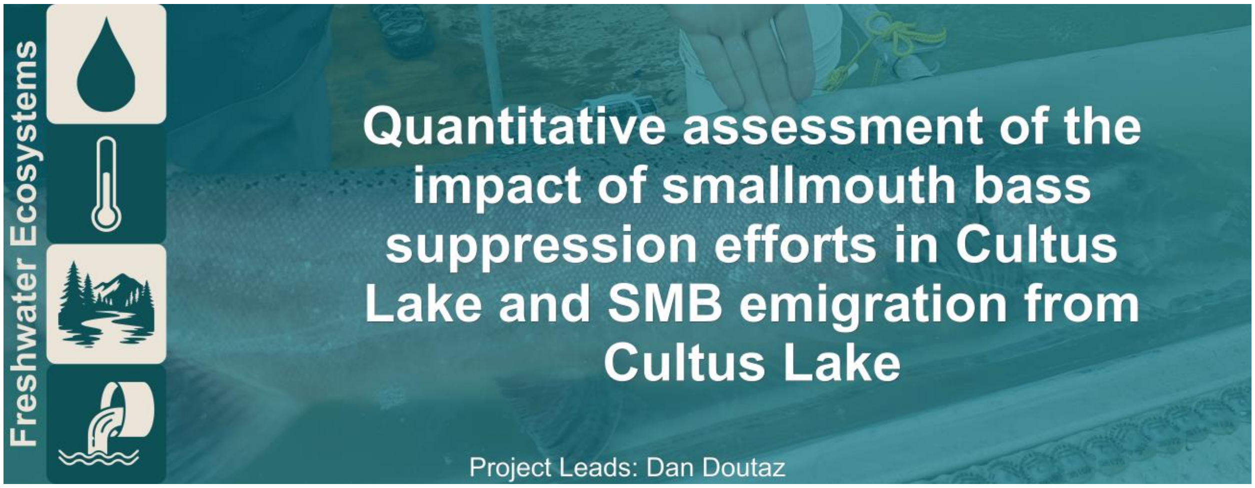


Figure 2. DNA metabarcoding stomach content analysis of n=162 smallmouth bass (Micropterus dolomieu) captured at various locations in the Okanagan River and Lake system. Aquatic insects (Diptera, Ephemeroptera, Trichoptera), invasive fish (smallmouth bass, yellow perch, common carp), and native fish (prickly sculpin, mountain whitefish, sockeye/kokanee, Chinook) were the most common prey items identified.

2443 - Assessing Smallmouth Bass Control Impacts in Cultus Lake



Collaborations: Province of British Columbia; Simon Fraser University

Region: Fraser

Waterbodies: Cultus Lake

Species: Sockeye

Populations: Cultus Lake sockeye

Highlights

- Smallmouth bass (SMB) were recently introduced into Cultus Lake and pose a significant risk to native species in the system, including endangered Cultus Late run sockeye salmon and pygmy sculpin. The main goal of this project was to investigate the population dynamics of SMB in Cultus Lake, explore suppression methods that can be employed in future years to manage SMB to reduce impacts on native species in the lake, and minimize expansion of the population downstream into other areas of the lower Fraser River.

- Key findings of this project indicate that the SMB population in Cultus Lake is expanding despite suppression efforts, and downstream movement through Sweltzer Creek towards the Vedder River has been detected at the DFO-operated juvenile enumeration fence. Biological samples have confirmed predation of SMB on juvenile salmonids and sculpin, confirming the potential risk on endangered sockeye salmon and pygmy sculpin, among other native species in the lake. Electrofishing has been shown to be extremely effective for suppression during the spring when SMB occupy near-shore habitat to build nests and spawn, however depths in which SMB occupy for most of the year (>20 feet) precludes their capture by electrofishing. In addition to SMB, the presence of pumpkinseed, another non-native invasive species, was detected in Cultus Lake as part of this work. Since 2023, catch rates of pumpkinseed while electrofishing have increased by ~1,200% indicating the population is rapidly expanding and poses a significant secondary risk to native species in the lake.

- This project has highlighted the risk SMB (and also pumpkinseed) pose both for native species within Cultus Lake, and in other areas of the Lower Fraser River if these populations continue to expand. Suppression efforts need to continue through time to both limit trophic effects within the lake, and downstream movement into the Fraser River through Sweltzer Creek.

Background

Smallmouth bass (Micropterus dolomieu), a piscivorous fish species native to eastern North America, have been introduced into Cultus Lake, British Columbia. Cultus Lake is home to endangered sockeye salmon (*Oncorhynchus nerka*) as well as endemic Cultus pygmy sculpin (*Cottus aleuticus*). Smallmouth bass introduced in other salmon-bearing habitat have been observed to exert substantial mortality on salmon fry and smolts, suggesting a similar impact may be possible in Cultus Lake. Observations of sockeye salmon, and Cultus pygmy sculpin in the diet of captured smallmouth bass, demonstrates predation upon two native species at risk. While smallmouth bass represent a threat to the Cultus Lake native fish community and species at risk specifically, they are also highly valued by some anglers. Importantly, as a source population, they also represent a real and present threat to other ecosystems in the Lower Mainland. Smallmouth bass are often found in streams and rivers; in fact, they have already been found downstream of Cultus Lake. Additionally, there is the threat of anglers moving smallmouth bass to other waterbodies in the Lower Mainland to create new bass fisheries, which themselves would create risk to receiving environments. While there are largemouth bass (*M. salmoides*) populations in various waterbodies throughout the Lower Mainland, this is the first verified smallmouth bass population, and has drawn a lot of attention from the angling community. Early work on this population has identified a divergence of public opinions: some value native species (especially sockeye salmon) and want to see bass suppressed; other values angling opportunities for smallmouth bass and will strongly oppose any measures to affect this valued fishery resource.

There are two issues that this project addresses: (1) understanding which suppression options will result in the lowest opposition from anglers and community members, thereby identifying the risk of unintended consequences (e.g., additional transfers to other lakes); and (2) determining the suppression strategy (combination of different suppression options) which will best inform estimates of effectiveness for each suppression option so as to maximize effective suppression moving forward to reduce impacts on sockeye salmon recruitment.

This project was conducted in collaboration with the Province of British Columbia (Ministry of Water, Land and Resource Stewardship), and Simon Fraser University.

Methods and Findings

Electrofishing and angling was conducted in the spring to target SMB as they move to near-shore habitat to build nests and spawn. The perimeter of Cultus Lake was divided into quadrants (Figure 1) and swept with a boat electrofishing unit to target spawning SMB. In 2023, ten consecutive days of electrofishing were conducted (June 1-10, 2023), and all SMB captured (by electrofishing and angling) were implanted with a PIT tag and released to get an initial baseline of the population in 2024. A subset of SMB (n=25) were also implanted with acoustic transmitters to track movements within the lake, and downstream movement from the lake (acoustic receivers also deployed in 2023 in various locations). In 2024, two consecutive days (east side of lake day one; west side of lake day two) of electrofishing and angling were conducted for six consecutive weeks (May 9 - June 7, 2024), and all SMB were euthanized to get a PIT tag recovery sample and to see how the population responded to the cull the following year. In 2025, operations were conducted in two day intervals, for seven consecutive weeks (May 1 - June 13, 2025). For the first two weeks of the project all SMB were euthanized to reduce the spawning potential of the population, and for subsequent weeks 25% of all SMB were implanted with PIT tags and released. A subset of 44 SMB were also implanted with acoustic transmitters to track movements within, and from Cultus Lake. A total of 3,654 biological samples (length, weight (Figure 2); subset of stomach contents (Figure 3), scales, otoliths) were collected from SMB between 2023-2025. Of these samples, 268 stomach samples, 2,069 scale samples, and 20 otoliths samples were collected. Age analysis and acoustic tracking results are pending, and will be included in the final report (written by SFU).

Between 2023 and 2025, a total of 6,650 SMB were captured by a combination of electrofishing and angling (942 in 2023, 1,616 in 2024, 4,092 in 2025; 95% by electrofishing, 5% by angling). A total of 1,469 PIT tags were deployed (897 in 2023, 572 in 2025), and 69 acoustic tags were surgically implanted in SMB (25 in 2023, 44 in 2025). Of the PIT tags deployed in 2023, 47 were recaptured in 2024 (4.8% recovery) and 12 were recaptured in 2025 (1.2% recovery), giving a rough population estimate of approximately 16,000 SMB in 2024. However, observations from staff at the Cultus Lake Laboratory, the Province of BC, and anglers have indicated a significant portion of the population occupy habitat at depths that preclude SMB from capture by electrofishing, thus, this estimate is likely biased low. The PIT tags deployed in 2025 have yet to be captured in 2026, therefore a current population estimate is unavailable at this time. It should be noted that in 2023, a total of two pumpkinseed were captured during the electrofishing program. In 2024 the number increased to 60, and in 2025 increased to 2,553. Further to this, the capture of pumpkinseed was incidental as there is some overlap in habitat with SMB, and if efforts were targeted for pumpkinseed (i.e. heavily vegetated near-shore habitat), those numbers would be higher. The rapid increase in pumpkinseed bycatch over the course of this work is alarming and should be investigated in future years.

The subset of stomach samples taken, approximately 10% of samples contained juvenile salmonids (fry or smolt stage), and 2% contained sculpins. It is noted that many stomach samples were at an advanced stage of digestion therefore these estimates are biased low. Acoustic tracking of SMB is ongoing and will be discussed in the final report. However, between 2024 and 2025 a total of 17 SMB were captured at the DFO-operated smolt enumeration fence (run March - June annually), indicating some downstream movement of SMB in Sweltzer Creek to the Vedder River (tributary to the Fraser River). At this time there are no confirmed reports of SMB in the Vedder or Fraser rivers, however, as the population in Cultus Lake expands, downstream colonization is likely.

The following results, in addition to acoustic tracking data, an evaluation of suppression methods (paired with feedback from the public and social survey results), and up-to-date SMB population estimates will be presented in the final report written by SFU, DFO and the Province of BC in 2027.

Insights

This work has highlighted the Cultus Lake ecosystem is in peril with the introduction and expansion of not only SMB, but also pumpkinseed, threatening two endangered species (sockeye salmon and pygmy sculpin) and a variety of other native pacific salmonid populations (Chinook, coho, chum, pink, trout sp.). Cultus Lake is a unique ecosystem that is also one of the most popular recreational lakes in the lower Fraser watershed and concurrently faces other threats (e.g. eutrophication/water quality issues, invasive plant encroachment) that likely cumulatively impact native species within the lake, particularly those of conservation concern with severely depressed abundance. Further to this, the presence of SMB and pumpkinseed in Cultus Lake threatens the entire lower Fraser watershed as downstream movement from this source population has already been detected at the DFO juvenile enumeration fence for two consecutive years (2024 and 2025).

Given the conservation concerns for sockeye salmon and pygmy sculpin (both Red status under SARA), management decisions and mitigation planning should place a great emphasis on long-term suppression of SMB and pumpkinseed to reduce the immediate predation impacts on native species, in addition to other cumulative threats such as habitat degradation from invasive plants and water quality issues that will inevitably lead to trophic effects within Cultus Lake.

Next Steps

Sources of uncertainty and recommendations raised from this work include:

- The total population size of SMB in Cultus Lake is currently unknown, given a portion of the population occupies habitat that precludes capture by electrofishing. Future work should explore alternative methods of capture (e.g. increased angler effort, spearfishing, trapping) to target this portion of the population.
- The degree of SMB predation on endangered sockeye salmon and pygmy sculpin is unclear as many samples were at an advanced stage of digestion and were not analyzed for DNA. Future work should include a more thorough analysis of SMB gut contents to inform conservation measures for these species.
- The rapid increase in pumpkinseed bycatch (1 in 2023, to 2,553 in 2025) over the course of this work is alarming, and further work is needed to determine critical habitat within Cultus Lake, the source population (natural reproduction vs. continued introductions), and a suppression plan created to limit further expansion. This work has shown electrofishing to be an effective tool for SMB management, in addition to other invasive species that occupy near-shore habitat year-round or during their spawning period (e.g. bass, northern pike, pumpkinseed, crappie, perch, etc.). Electrofishing could be expanded into other areas of the lower Fraser River (e.g. sloughs, side channels, etc. to target other persistent populations of invasive species such as largemouth bass, sunfish

sp., bullhead sp., perch, among others) and other areas of the watershed that house invasive species (e.g. Nicola Lake yellow perch, Pitt Lake largemouth bass).

Tables and Figures

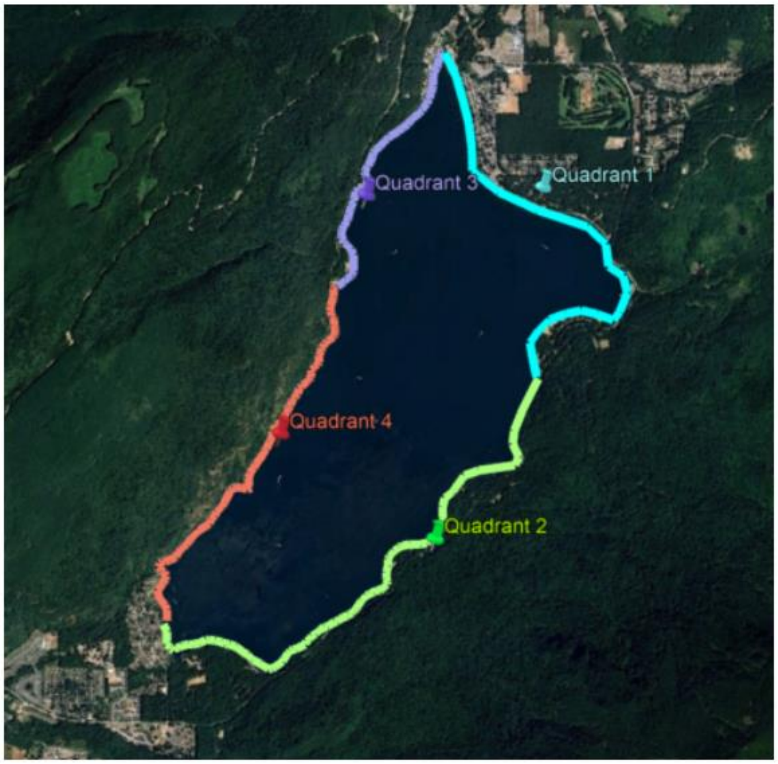


Figure 1. Map of Cultus Lake electrofishing quadrants.

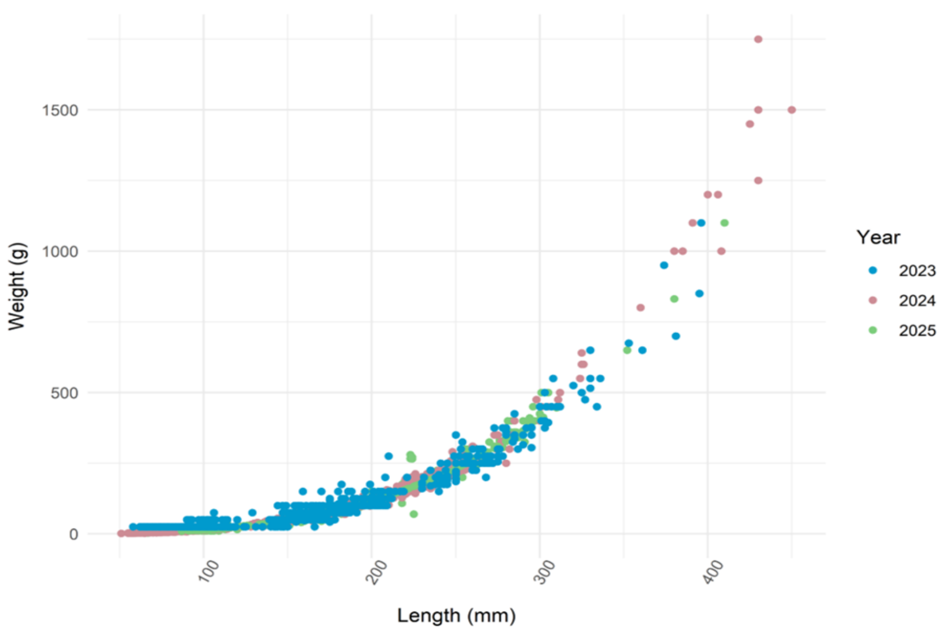


Figure 2. Lengths and Weights of all bass sampled between 2023-2025 (n=3,654).

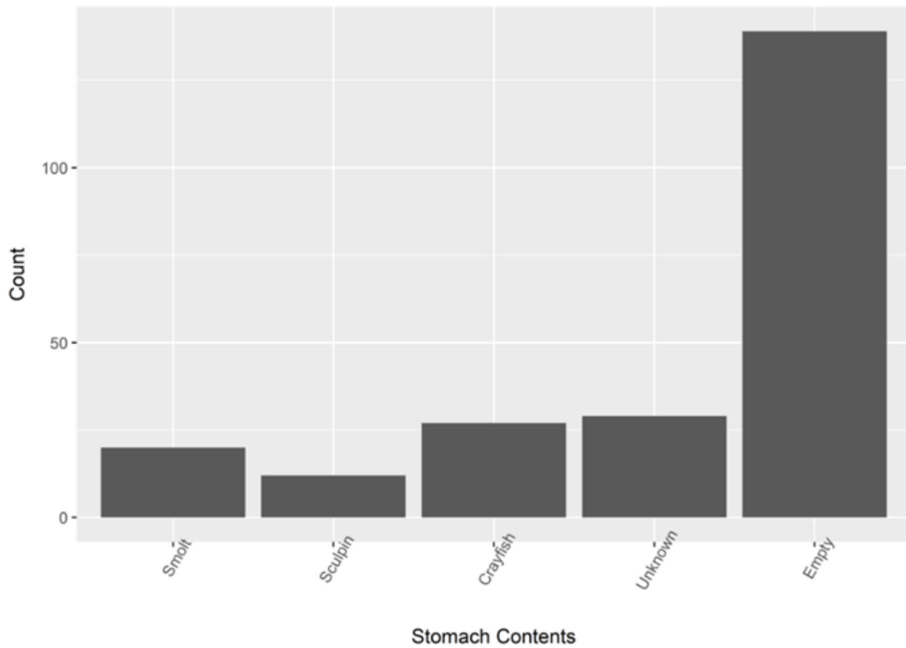


Figure 3. Smallmouth bass gut contents from a subsample of biological samples taken between 2023-2025.

2493 – Freshwater cumulative impacts mechanistic assessments

Gemmell, C. 2023. Interconnected effects of water temperature and habitat on relative abundance of juvenile salmonids during the summer months in coastal urban streams. Simon Fraser University. MRM.

Iacarella, JC, R Chea, DA Patterson, JD Weller. 2024. Projecting exceedance of juvenile salmonid thermal maxima in streams under climate change: A crosswalk from lab experiments to riparian restoration. Freshwater Biology, 00, 1–14

Kraskura, K DA Patterson, EJ Eliason. 2024 A review of adult salmon maximum swim performance. CJFAS 81 (9), 1174-1216

Iacarella, JC, R Chea, DA Patterson. 2025a. Potential limits to local adaptation of Coho Salmon populations from eggs to fry under naturally varying and warming temperature conditions. Trans. Amer. Fish. Soc.

Wright MJ, Hurson M, Robinson KA, Patterson DA, Venditti JG (2025) A typology of potential hydraulic barriers to adult salmon migration in a bedrock river. Can J Fish Aquat Sci 82: 1-19. https://doi.org/10.1139/cjfas-2024-0100.

Iacarella, JC, R Chea, DA Patterson. 2025b. Addressing issues of experimental design, ecological realism and local adaptation for applications of ectotherm upper thermal limits. doi:10.1242/jeb.250748

Fleming W, Braun DC, Moore JW, Patterson D, Loscerbo D, Martens AM, Cunningham DS, Wilson S, Naman SM. In Press. Associations between stream habitat and energetic condition in juvenile coho salmon (Oncorhynchus kisutch). Can J Fish Aquat Sci. (in press).

Collaborations: Josephine Iacarella, Kendra Robinson, Sean Naman, Daniel Selbie, Lucas Pon, Jeremy Venditti, Erika Eliason, Kim Birnie-Gauvin, Jon Moore

Highlights

- Developed and validated bioindicators related to multiple stressors (e.g. thermal stress, hypoxia, starvation, indicators of cardiac stress) for use in field and laboratory studies on Pacific salmon; for use in acute studies of environmental impacts (e.g. climate change projections, thermal thresholds, food deprivation) See: Iacarella et al. 2024; Bugg et al. 2025; Iacarella et al. 2025a,b, Fleming et al. 2026

- Developed novel biotelemetry and eco-hydraulic methods to evaluate physiological and behavioural responses to environmental stressors, for use in adult migration estimates of swim performance, mortality and effectiveness of different mitigation actions. See Kraskura et al. 2024; Wright et al. 2025; Robinson et al in review, Van Wert etal. In review, Birnie-Gauvin etal. In Review.
- Increased understanding of the relationship of juvenile fish condition across different freshwater habitats to different biophysical factors (e.g. Coho wetlands, Urban streams, Sockeye Lakes-); for use in setting escapement goals and valuations of habitat quality. See: Gemmell 2023; Watson In Review, Fleming et al. 2026). Developed science advice to managers related to quantifying the impact of multiple stressors on adult upstream migration success (Robinson et al. 2026; Patterson et al. 2026).

Background

Landscape level assessments of stressors on aquatic habitats, climate change projections, and population dynamics models can provide cautionary flags that identify potentially stressed or vulnerable watersheds and/or populations (e.g., RPA status assessment, Pacific Salmon Explorer). These approaches are useful for initial watershed or population prioritization. However, in most cases these approaches are limited in their ability to accurately describe the cumulative impact that multiple stressors can have on individuals and specific populations because they lack a mechanistic approach that can verify the complex interacting pathways of effects on fish. This complexity makes it difficult to understand how future landscape alterations and climate change will affect salmon in a given watershed; thus limiting our ability to provide specific advice to managers on how to predict which mitigation or recovery actions (e.g. habitat restoration, harvest reductions) will most effectively recover salmon populations. We proposed to link in situ ecophysiology information with other biophysical habitat monitoring data to develop mechanistic relationships that address management issues around habitat-population modeling, assessment of restoration function, and fish responses to climate change. The specific management questions were: Q1) What multi-factor stressors limit stage specific freshwater habitat distribution? Q2) What are the key drivers of stage-specific survival and growth for life-cycle modelling? Q3) What is the role of temperature in combination with other key factors in predicting climate change impacts on salmon growth and survival in a given habitat (e.g. lake, river, wetlands)? Q4) What are major habitat factors that affect salmon growth and survival to consider in planning and assessment of habitat mitigation, restoration, and offsetting effectiveness?

This project is distinct in that we are proposing a mechanistic approach to test the cumulative impact of multiple factors directly on individual fish response (i.e. growth, survival, stress) in their native habitats, leveraging multiple program expertise both within the freshwater section and beyond. Our experience is that science advice to major management decisions are best supported by a mechanistic understanding how environmental and physiological processes directly impact fish themselves. This is foundational work that can then be used to generate population responses were appropriate. However, we acknowledge that not all management questions to science require such an in-depth experimental approach, which is why we are proposing the guideline development to help managers and researchers prioritize how best to approach assessing cumulative impacts, as well as work with the other related projects.

Methods and Findings

Methods: We took a multifaceted approach to knowledge generation. The bioindicator development component combined a major literature review with the development and testing of new assays relevant to salmon in the lab. These were further validated using lab experiments and field surveys.

The work on cumulative impact projects included : 1) development of in situ stage specific mechanistic relationships among biophysical factors (dissolved oxygen (DO), temperature, flow, conspecific competition, distribution, physiological condition metrics, growth, and survival for juvenile salmonids - all measure in situ, 2) continue to develop and evaluate ecophysiology tools related to evaluating fish condition. Life-stage specific mechanistic relationships were examined using samples in-hand from three large scale field programs (Lakes, E-Watch, North Thompson Salmon Ecosystem Program) within the Freshwater Ecosystems Section. All three programs generate unique multi-year population data on multiple biophysical factors influencing juvenile salmon condition, growth, and survival such as, water quality, conspecific density, temperature, food availability, primary productivity, DO and water level in lakes, wetlands, and flows in rivers. Models examining the effects of multiple biophysical factors on condition were used to understand how interacting biophysical drivers (including stressors) shape fish condition. Concomitant lab work included the development of ecophysiology tools, such as growth hormones (IgF) for freshwater salmon growth, troponin for oxygen/cardiac stress, and triglycerides (TAG) for nutritional status, that can be used as potential indicators of habitat quality.

Products: The major products from the project include publications (see references below), new bioindicator assays for the physiology lab, and development of subject matter expertise (e.g. DFO Science employees and graduate students).

Advancements: Increased capacity for new lab assays for unique tissues (e.g red blood cell HSP70, cardiac/plasma troponin, muscle/plasma IgF) were developed for EWatch Physiology lab

Bioindicator Development - Major literature and lab review of the best methods to assay different biomarkers in adult and juvenile salmon (both lethal and non-lethal tissue assays). Validation of the biomarkers through lab experiments (Bugg et al. 2025; Iacarella et al. 2025a,b) and field validation (Fleming et al 2026; Watson In Review)

Advancements Communication- A major part of the project was to increase collaboration amongst the programs within the freshwater ecosystems section. Each of these programs brings their own connections to different DFO branches, First Nation groups, Academic institutions, NGO organizations and industry partners. In addition, we sought out new expertise both within DFO, such as the genomics lab to validate biomarkers, and academia for help with ecohydraulics (e.g. Wright et al. 2025; Robinson et al. In Review) and swim performance (Kraskura et al. 2024; Birnie-Gauvin et al. In Review, Van Wert et al. In Review). These relationships will extend past the life of the project.

Key results: Publications, development of subject matter expertise in assessing cumulative effects.

Insights

Knowledge: The project focused on knowledge generation of individual responses to environmental stressors. Scaling this work up to the population level will be the next major task, now that we have a better biological understanding of how fish interact with their environment. Urban, wetland and lake ecosystem work has helped improve our understanding of how ecosystems effect individual salmon condition.

Salmon Management: The adult migration work has helped to provide a much stronger biological rationale for making predictions of in-river mortality (Robinson et al. 2026). This information is then communicated to management is their decisions regarding harvest adjustments to accommodate the expected losses (Robinson et al. 2026; Patterson et al. 2026). Adult swim performance work can directly inform future mitigation activities related to passage success (Kraskura et al. 2024; Wright et al. 2025). The juvenile coho works supports advice regarding the importance of wetland habitats (Fleming et al. 2026). Juvenile sockeye work has direct implications on setting spawning escapement targets based on lake carrying capacity (Watson in review). Urban stream work has improved our understanding of the key drivers for thermal impacts (e.g riparian cover, substrate type) (Gemmell 2023). Juvenile thermal tolerance work that includes sub-lethal indicators of stress supports long term planning regarding identification of temperature sensitive streams (Iacarella et al.2024, 2025a,b,). .

Understanding: The overall project was focused on an improved mechanistic understanding of how interact with the multiple stressors they experience.

Next Steps

Knowledge Gaps/Future/Recommendations

Continue to focus on 2-3-factor lab experiments that use ecological relevant values for the stressors, such as temperature and dissolved oxygen, as well as ecologically relevant behavioural endpoints (preference, avoidance) and physiological responses (e.g. growth). Match this work with bioindicator development and then test these relationships in the field. The choice of species or habitat stressors can be informed by closer cooperation with managers based on the current needs (e.g. Major projects, SARA species).

Operationalization: Most of the activities within this overall project already had connections to salmon and habitat management groups. The next stage is to continue to share these results and the expertise with these respective managers (e.g. Robinson et al. 2026; Patterson et al. 2026). However, we recognize that a lot of this work could be value to those outside of our current network. We need to explore how best to share both within and outside of science.

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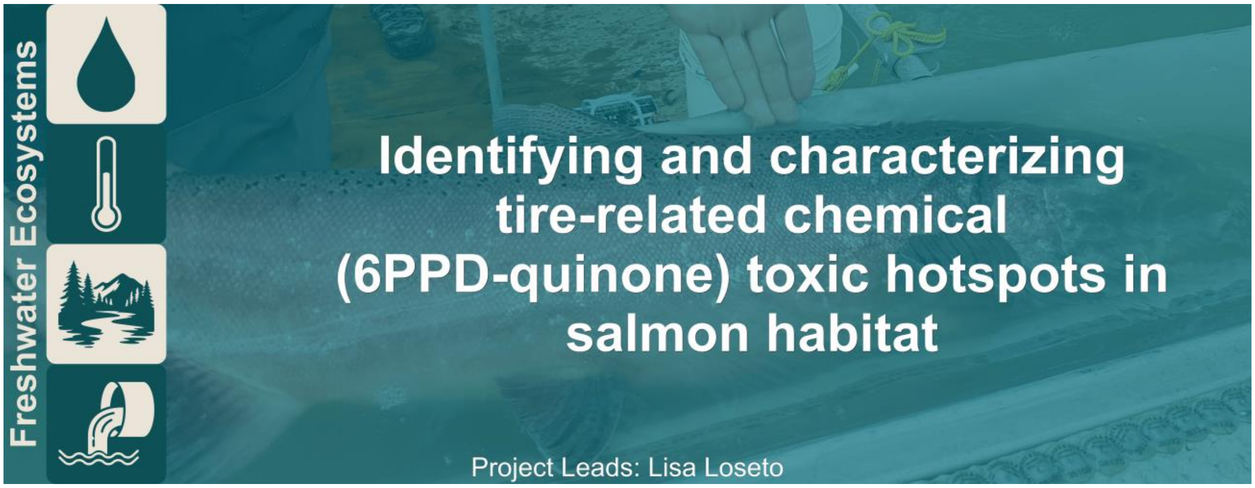
2504 - Identifying Toxic 6PPD-Quinone Hotspots in Salmon Habitat



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Rodgers, T.F.M., Drew, S., Brown, T.M., Hiki, K., Hiroshi, Y., King, M., Kolodziej, E.P., Krogh, E.T., McIntyre, J.K., Miller, K., Peng, H., Tomlin, H., Wang, Y., Scholes, R.C. 2025. Turning the corner on hazardous tire compounds: A management framework for tire additive pollution. Environmental Science & Technology Letters. doi.org/10.1021/acs.estlett.5c00453

Collaborations: Dr. T. Brown, SFU; Dr. Rachel Scholes, Dr. Tim Rodgers, UBC; Dr. Edward Kolodziej; Tsawwassen First Nation; Tsleil-Waututh Nation; Musqueam Nation; Cowichan Tribes; Redd fish Restoration; Vancouver Island University; BC conservation Foundation; World fisheries Trust; The Pacific Streamkeepers Federation; BC Ministry of Transportation; and Somenos Marsh Wildlife Society

Region: Southern BC

Species: All *Oncorhynchus* spp

Highlights

Our projects overall goals were to characterize 6PPD-quinone (6PPD-Q) concentrations before, during, and after wet weather events, develop a predictive hot spot map using the measured 6PPD-Q values in combination with land use, traffic density, and weather data, and assess the effectiveness of in-use raingardens at removing 6PPD-Q. This project builds on our earlier 6PPD-Q field program which characterized the presence 6PP-Q at 34 sites in salmon bearing creeks in the greater Vancouver area, Squamish and Vancouver Island before, during, and after rain events. The sample collection has been carried out with help from several ENGOs, First Nations, and University partners. Key findings include:

- 78% of the sites monitored during wet weather events have concentrations that exceed lethal threshold values for coho salmon;
- positive associations were observed between 6PPD-Q and residential cover and commercial cover, as well as environmental data including turbidity and the number of dry days prior to flow;
- water sample 6PPD-Q concentrations during rain events were strongly correlated with copper and zinc, all of which were found to exceed water quality guidelines in urban and semi-urban areas; and
- temporal monitoring indicated that during baseflow conditions, concentrations never exceeded water quality guidelines, but following any sustained rainfall streams failed water quality guidelines and usually surpassed published toxicity thresholds published for juvenile coho salmon and coastal cutthroat trout. Every monitoring period saw multi-hour periods (e.g. 4-19 hours) of 6PPD-Q which exceeded lethal thresholds for coho salmon. Collectively, this suggests a widespread toxicity hazard exists for coho salmon and related salmonid taxa in urban streams.

This project has delivered new data on 6PPD-Q levels in salmon bearing creeks in coastal British Columbia and is being used in the reassessment of 6PPDQ, the parent compound of 6PPD-Q, under the Canadian Environmental Protections Act (CEPA). This study is providing information to PSSI and fisheries managers as they aim to curb historic declines in Pacific salmon, particularly coho salmon which are highly sensitive to this chemical and enable their recovery.

Background

Pacific salmon are a foundational group of species in the Northeastern Pacific Ocean that rely on freshwater habitats along the west coasts of British Columbia (Canada) and the states of Alaska, Washington, Oregon and California (USA). Pacific salmon play a vital role in supporting wildlife, including pinnipeds, killer whales, bears, and seabirds, and serve as a valued source of food for coastal communities and Indigenous Nations.

Many salmon populations, however, have experienced significant declines in recent decades [1] due to climate change, habitat degradation, overexploitation, and diseases [2-4]. Habitat degradation in particular has resulted in the loss of reproductive potential in freshwater ecosystems, with forestry, agriculture, and urban developments, altering the nature of physical environments and resulting in the release of pollutants into waterways.

Urban stormwater runoff from roads, parking lots and other impervious surfaces is now recognized as a major nonpoint source of pollution to salmon-bearing streams. Wet weather events mobilize complex mixtures of contaminants, including tire wear particles, p-phenylenediamines (PPDs), polycyclic aromatic hydrocarbons (PAHs), metals, salts, and current-use pesticides that lead to pulses of pollutant releases into salmon habitats [5-7]. Urban

Runoff Mortality Syndrome (URMS) is known to cause mortality in adult coho salmon (*Oncorhynchus kisutch*) returning to urban and semi-urban waterways in Puget Sound, Washington State [8]. This syndrome has more recently been attributed to the tire-associated chemical N-(1,3-Dimethylbutyl)-N'-phenyl-p-phenylenediamine-quinone (6PPD-Q), which has been found to be the cause of toxic injury and death (40-90%) of adult coho salmon returning to urban and semi-urban waterways in Puget Sound.

At the start of the study, little data had been generated on 6PPD-Q concentrations in salmon bearing streams along the northwest coast of North America, no studies had carried out a temporal assessment of 6PPD-Q concentrations during wet weather events, and only one study had assessed the effectiveness of removal of 6PPD-Q in a raingarden. This study was aimed to help fill these gaps by achieving the following:

- providing new data on 6PPD-Q concentrations in salmon-bearing habitat;
- characterizing risk of exposure and lethality to coho salmon as well as other Pacific salmon species in the region; and
- incorporate our data into stormwater runoff modeling with our partners at UBC to be used in combination with weather, traffic data and flow measurements, or estimates, to identify high-priority areas for monitoring or green infrastructure initiatives Complete a hotspot map for salmon bearing streams in the Lower Mainland, Squamish, and Vancouver Island using our data combined, land use variables, statistical modeling, and GIS.

Methods and Findings

Field collections.A total of 2,118 stream water samples from salmon bearing streams, 27 road runoff samples, and 54 laboratory methods development and validation test water samples were collected and analyzed for 6PPD-Q.

Analytical Methods.6PPD-Q in unfiltered water samples was quantified using liquid chromatography-tandem mass spectrometry (LC-MS/MS) with an Agilent 1290 Infinity II UPLC system and a Sciex triple-quadrupole API5000 mass spectrometer equipped with a Turbo V Ion source. Water samples spiked with an internal standard (99% phenyl 13C6 6PPD-Q, ACP Chemical Inc.) were analyzed either directly after dilution or after solid-phase extraction.

Key Findings

- 78% of the sites monitored during wet weather events have concentrations that exceed LC50 values for coho salmon (Lethal Concentration at which 50% of a test population dies).
- Continual temporal monitoring revealed that 6PPD-Q concentrations exceeded the LC50 reported for juvenile coho salmon by up to 6-fold, with exceedances lasting from 4 to 19 hours during rain events.
- Salmon habitat in urban and semi urban areas across southern B.C. is subject to repeated pulses of 6PPD-Q, as well as other toxic chemicals (e.g., copper and zinc) over

the course of the wet season that expose coho salmon to toxic concentrations for considerable periods.

Insights

We have characterized 6PPD-Q contaminant concentrations and risks in nearly 100 salmon bearing creeks in southern British Columbia. Our results indicate a high risk of lethality for coho salmon and coastal cutthroat trout during wet weather events in streams located in semi-urban and urban areas. Management questions addressed by this project include those related to understanding and mitigating an identified stressor (i.e., 6PPD-Q) on at-risk salmon species and populations.

The findings from our project will directly inform regulatory risk assessments, as well as cumulative risk assessments led by resource managers, as well as other organizations, which will explicitly consider the combined fate and effects of a myriad of stressors for salmon (i.e. contaminants, climate change, habitat destruction, overharvesting, etc.). These findings will also enable a comprehensive understanding of the contribution that 6PPD-Q directly plays in the population level declines of coho salmon, as well as indirectly for other pacific salmonids, and key predators (e.g., at-risk Resident killer whales).

This cumulative information will be incorporated into developing recommendations for measures that will address contaminants affecting salmon and their habitat. In addition, it will inform coho salmon recovery plans for COSEWIC- and ESA-listed populations. Ultimately, decisions that regulate the release of 6PPD-Q and other priority contaminants of concern to salmon and other aquatic coastal wildlife can then be considered for source control, reduction or elimination measures.

Next Steps

- Completion of the predictive hot spot map for 6PPD-Q is underway and will be completed prior to March 31, 2026. This map will aid in identifying priority areas for monitoring this toxic chemical as well as identifying priority areas for the installation of environmental engineering initiatives.
- This information will be used to enable regional authorities (e.g. Metro Vancouver) and municipalities to make informed decisions around effective mitigation strategies on non-point source releases into high priority areas. This will have a positive effect as the findings will inform on road runoff discharges of contaminants into the habitat of hundreds, if not thousands of distinct salmonid populations, including coho, Chinook, sockeye, chum, pink, steelhead trout, and coastal cutthroat trout. Even more broadly, this information is likely to be relevant to potential road runoff exposure and associated impacts that other aquatic species may be experiencing both nationally and internationally in urban watersheds.
- At least five additional rain garden sites will be selected, aiming for a minimum of three rain event sample collection per site. In addition, soil microbial communities will be evaluated across the selected rain garden sites.

Tables and Figures

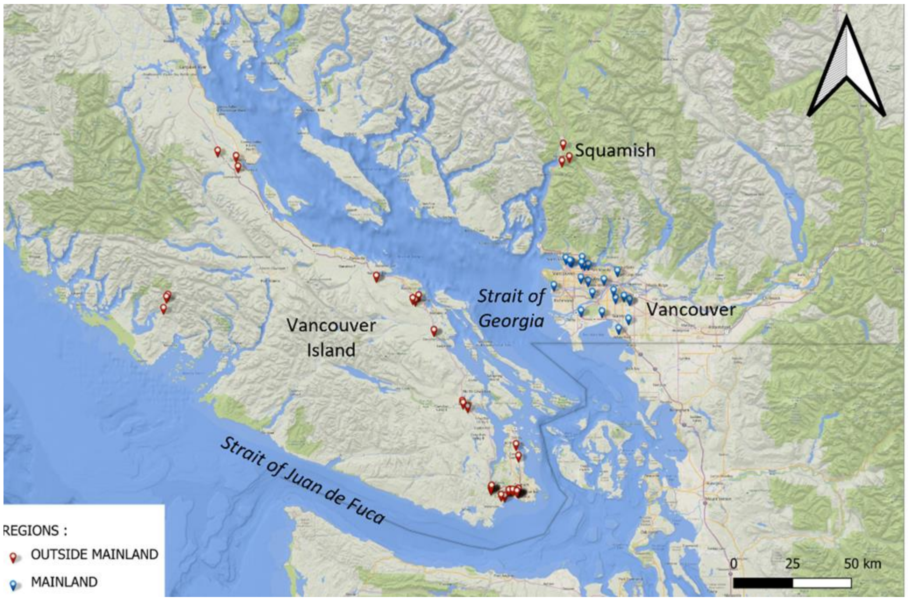

Figure 1. Map of 6PPD-Q monitoring sites (n=98) in salmon-bearing streams in southern British Columbia.

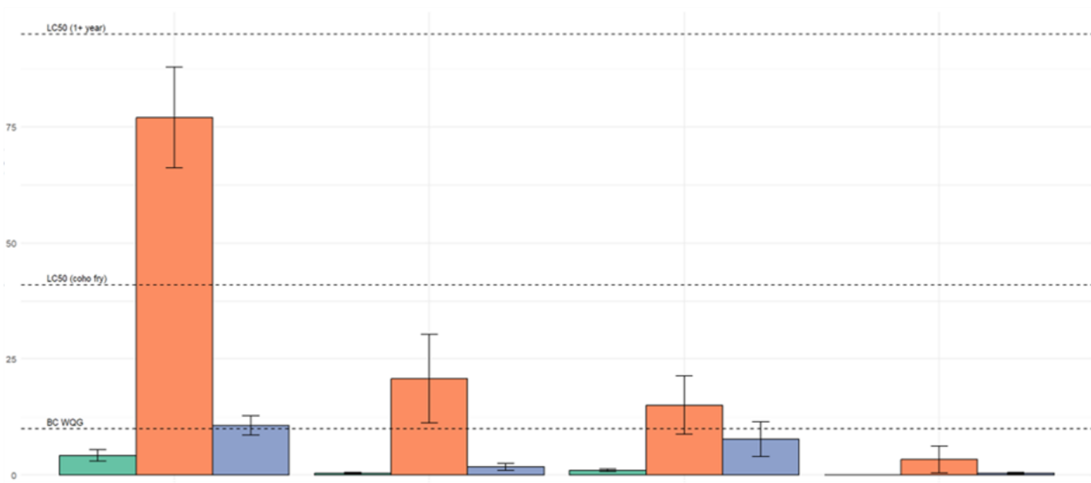

Figure 2. Average 6PPD-Q concentrations in our field samples in urban and semi-urban areas exceed screening values (water quality guidelines) and lethal concentrations for coho salmon.

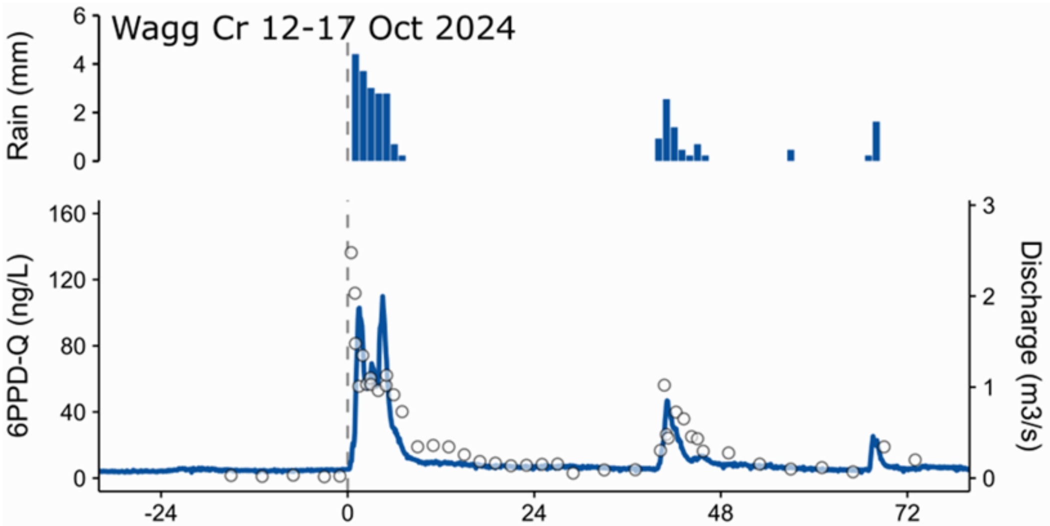

Figure 3. Time series data of rain (top panel), stream discharge (right axis), and 6PPD-quinone concentration (left axis) at Wagg Creek from October 12-17 2024. This type of time series data was obtained and represents the core data of the temporal 6PPD-quinone monitoring research.

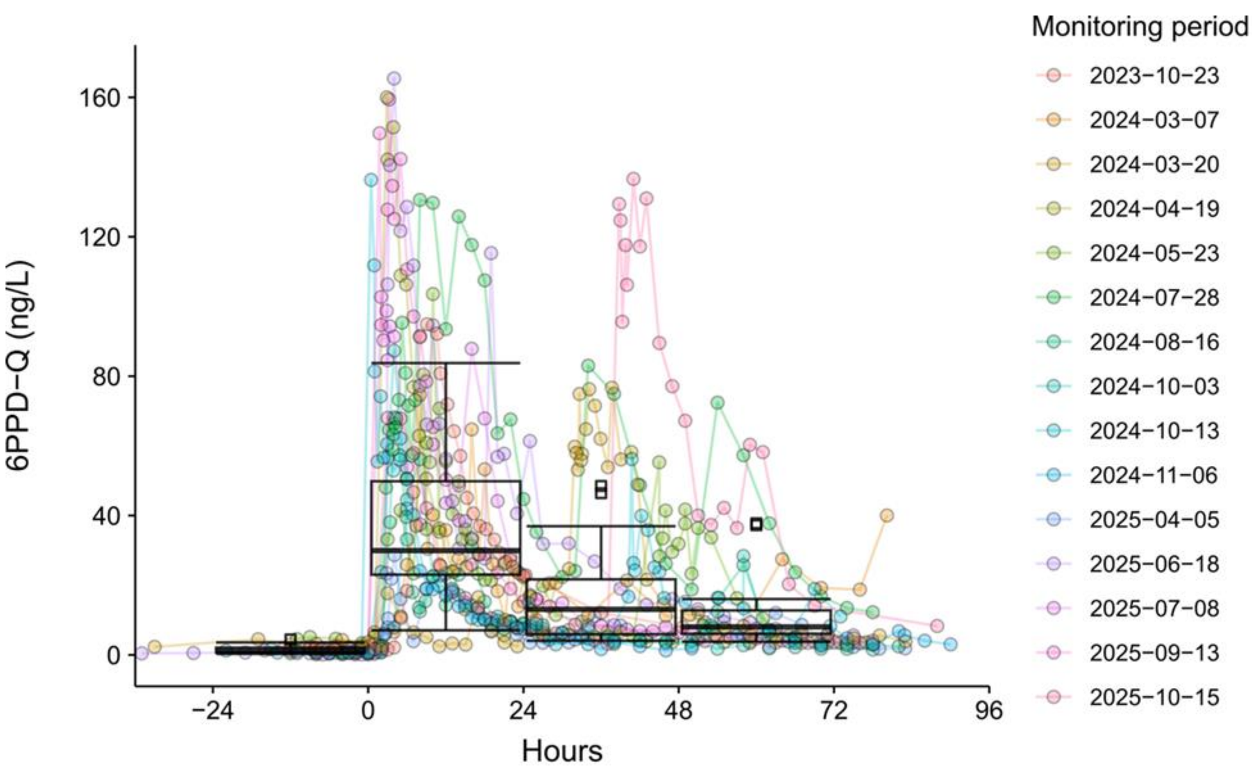

Figure 4. Time series data from temporal 6PPD-quinone monitoring research. Time-harmonized data indicate that, averaged over 24-hour periods, the initial flushing period yields the highest time-averaged concentrations, significantly higher than during the preceding dry weather.

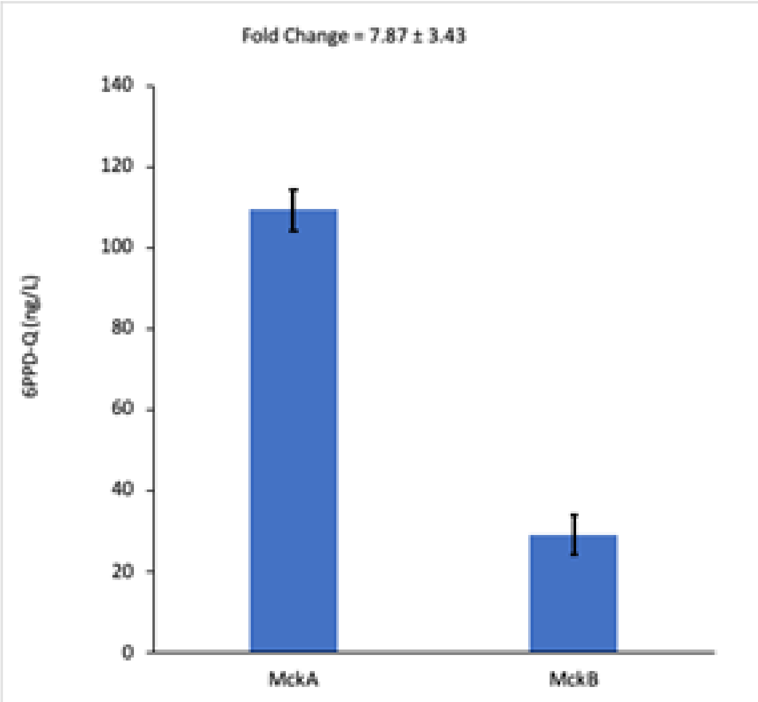

Figure 5. 6PPD-Q concentration at McKenzie Interchange road runoff (MckA) and the bioswale effluent (MckB) for 6 rain events. The graph indicates approximately 7-fold reduction of 6PPD-Q in bioswale effluent compared to the road runoff.

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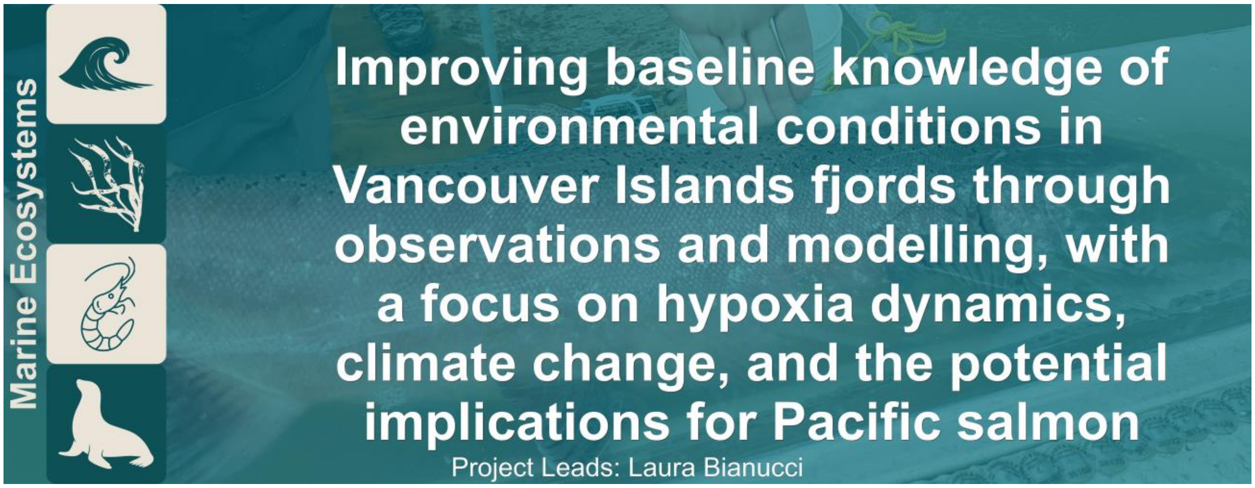
MARINE ECOSYSTEMS

2404 - Environmental Conditions and Hypoxia in Vancouver Island Fjords



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Geng M, Bianucci L, et al (in progress). Assessing climate change in Clayoquot Sound, BC, and potential impacts to Pacific Salmon.

Collaborations: Ahousaht First Nation, Hesquiaht First Nation, Tla-o-qui-aht First Nation, Nuu-cha-nulth Tribal Council, Nature Trust of BC, Maaqutusiis Hahoulthee Stewardship Society

Region: West Coast Vancouver Island

Waterbodies: Clayoquot Sound

Highlights

- Salmon spend a crucial part of their early and late life stages in fjords and are therefore affected by the nearshore environment. This project aims to understand ocean conditions in these coastal areas and how they may change under future climates, using both numerical models and observational datasets. The project focuses on Clayoquot Sound, BC, but the methods are applicable for other regions in the west coast of Vancouver Island (WCVI).
- Clayoquot Sound is comprised of several fjords located in close proximity of each other. Through this project, we were able to identify how and why conditions in these fjords differ. For instance, Tofino Inlet to the south has stronger freshwater inputs, is shallower

and has a weaker connection with the shelf waters than northern fjords like Sydney and Shelter Inlets, leading to a fresher and warmer Tofino Inlet compared to Sydney and Shelter. Furthermore, the role of the sills (particularly the shallow one outside of Herbert Inlet) plays a leading role modulating the deeper waters of the inlets (due to strong tidal mixing at the sill and strong tidal advection).

- Monitoring of oxygen concentrations in Clayoquot Sound showed that oxygen conditions can reach levels that are stressful for Pacific salmon in all seasons and even close to the surface.
- Future scenarios suggest that all of Clayoquot Sound will become warmer, while salinity will not change significantly. Fjords that are generally warmer in present-day simulations, like Tofino, are more at risk of exceeding temperature thresholds that can stress Pacific salmon.

Background

Salmon spend time in fjords and inlets once they leave their rivers and before they venture into the open ocean. The conditions they encounter in these nearshore environments may be crucial for their success at later life stages. But, what are these conditions like and how may they change with climate? This project aims at answering those questions, with a focus on Clayoquot Sound and making use of both numerical models and observations.

We established a monitoring program in this region, in collaboration with local indigenous groups (Ahousaht First Nation, Hesquiaht First Nation, Tla-o-qui-aht First Nation, Uu-a-thluk Fisheries, Nuu-cha-nulth Tribal Council, and Maaqutusiis Hahoulthee Stewardship Society). We supported them with funds, training, and/or materials to sample vertical profiles of temperature, salinity, and oxygen every month in their territorial waters. This project also helped maintain our existing weather station network (mostly installed in finfish farms) and supported the deployment of two moorings inside the inlets to obtain timeseries of currents, temperature, salinity and oxygen. All of these data have supported the development and evaluation of the WCVI model, which can represent observed conditions in the near past (referred to as “present-day”) and represent expected conditions under a future scenario.

Methods and Findings

Our observational methods are traditionally used in oceanographic research, e.g. sampling temperature, salinity and oxygen profiles with a CTD instrument as well as deploying moorings and weather stations. However, the innovative aspect is the collaboration with local communities. These collaborations allowed for sampling at a much higher frequency (~monthly) than anything achievable by DFO alone, but still maintaining DFO’s high-quality data standards (thanks to training and data post-processing and quality control by DFO). As a reference, DFO-led sampling provided 82 CTD profiles in 2019 (mostly from March and October/November) and 122 profiles in 2024 (a well-sampled year through many PSSI projects), while this project’s Nation-led sampling in 2024 provided 150 profiles (mostly monthly from March to December). Beyond the scientific benefits, these collaborations were essential for building long-term relationships with First Nations partners, fostering mutual trust, and creating a framework for ongoing knowledge exchange between Indigenous knowledge systems and western scientific approaches.

In terms of modelling, the WCVI model has been developed and run for 2019, 2024 (to take advantage of the intensive PSSI-related sampling) and one future scenario centered in 2055. Simulations for 2019 and 2024 have been compared against observations and show good agreement, particularly temperature and salinity. Biogeochemical variables (e.g., oxygen, nitrate) show good performance on the shelf, but some further calibration is needed to reach the desired performance inside the inlets. Figure 1 shows the model domain and bathymetry.

Analyses of model outputs in Clayoquot Sound indicate that the inlets towards the south are warmer and fresher than those on the north at all levels of the water column and all three seasons analyzed (spring, summer, autumn). These conditions are due to stronger freshwater inputs, shallower bathymetry and a less direct connection with the shelf waters in southern inlets (Tofino to Bedwell) compared with northern inlets (Herbert to Sydney). In particular, model results allowed to study the role of the sills (particularly the shallow one outside of Herbert Inlet), which play a leading role modulating the deeper waters of the inlets (due to strong mixing at the sill and strong tidal advection).

When comparing model results against temperature values that result in stress responses by Chinook salmon (above 16 to 18°C, personal communication by PSSI colleague Christoph Deeg), we find that the surface waters of all inlets may exceed these thresholds in summer under present-day conditions (Figure 2a). Furthermore, Tofino Inlet shows waters above these thresholds at all depths (Figure 3). When analyzing the same thresholds under the future scenario, they are exceeded mostly everywhere in the Sound in the top 5 meters (Figure 2b,c), and exceeded at depth in the southern inlets (from Bedwell to Tofino).

Once the performance of the biogeochemical module of the WCVI is deemed appropriate, a similar analysis will be performed with oxygen, considering that salmon show signs of stress at environmental values lower than 6 to 8 mg L^{-1} (Christoph Deeg, personal communication). Nevertheless, from the observational record we find that Clayoquot Sound shows throughout the year oxygen concentrations that fall below these thresholds, even near the surface from spring to autumn (Figure 4).

Two peer-reviewed publications are being prepared to discuss these results, while two manuscripts are already published discussing the low near-surface oxygen conditions (Rosen et al, 2022) and describing the model (Foreman et al, 2024). Informal presentations and updates were provided regularly to Gemma Macfarlane, the Stewardship Biologist from Maaqutusiis Hahoulthee Stewardship Society from Ahousaht Nation, as well as to project collaborators. A formal presentation was provided at the last Pacific Salmon Science Symposium in December 2025 and two other ones are scheduled in January and March 2026 to the Maa-nuult Joint Fisheries Committee (JFC) Technical Meeting Series and the State of the Pacific Ocean meeting, respectively.

Insights

This project has added key oceanographic information related to known salmon stressors (temperature, oxygen) to help understand the environment encountered by salmon while migrating towards/from the open ocean. Furthermore, future scenarios provide a management framework to assess how these environments may change over time, allowing for decisions, policy and/or plans to access useful information in case they need to adapt to future conditions. Most importantly, this project created at tool that can be further applied, e.g. by looking into other inlets or sounds as well as by expanding the model or its analysis to include other variables.

In summary, this work has shown that the thermal tolerance of salmon can be exceeded in the southern inlets of Clayoquot Sound (particularly Tofino Inlet and especially in summer). Furthermore, the future scenario we analyzed (based on a “business as usual” scenario centered in 2055) shows an increase in the volume of waters that exceed the thermal threshold throughout Clayoquot Sound. While a less crucial stressor, we studied salinity and its potential future changes, since salmon-affecting bacteria may increase at higher salinities. We are still working on the model improvements needed to extend the analysis to oxygen conditions, which are also vital for salmon health, but observational analysis indicates that concentrations below the optimal range for salmon are ubiquitous in Clayoquot Sound.

Next Steps

The first next step would be to extend current analyses to other Sounds of WCVI, beyond Clayoquot Sound. But it is noteworthy that while this project has focused on temperature and oxygen, the model provides a larger set of environmental variables. Future studies could expand and deepen the analysis of existing model results, investigating the potential role of changes in other ecosystem variables currently modelled (e.g., phytoplankton, zooplankton, nutrients, etc.). Furthermore, future projects could extend the model capabilities by including the carbonate system and/or submerged aquatic vegetation modules. The former would allow for the study of ocean acidification as an environmental stressor and the latter could inform the understanding of climate change in habitat quality. Both modules are available within the modelling framework, but not yet applied to the WCVI model.

Since warming temperatures and declining oxygen concentrations will be issues affecting nearshore environments utilized by Pacific salmon, it would be crucial for salmon conservation and management to consider, mitigate, and adapt to these factors as climate changes.

Tables and Figures

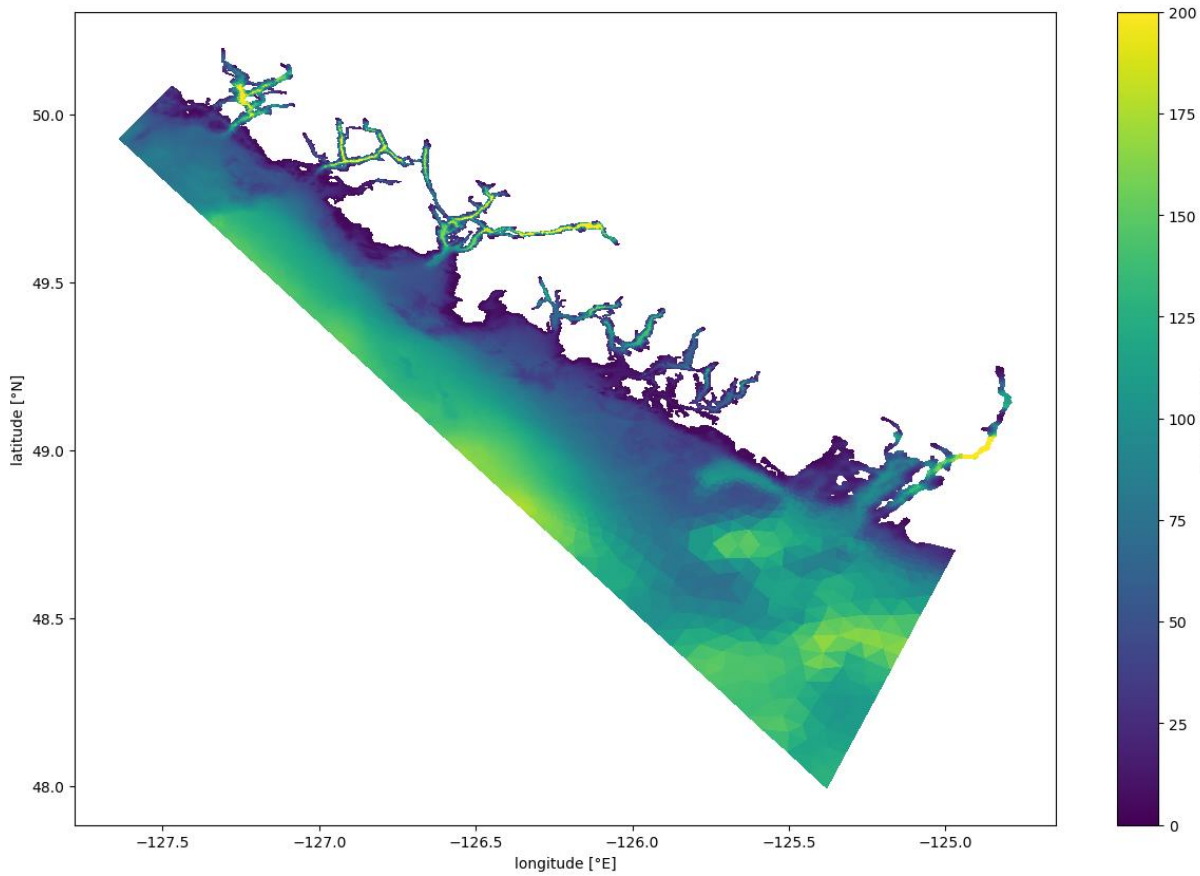

Figure 1. West coast Vancouver Island (WCVI) model domain. Colourscale shows the model bathymetry (in meters)

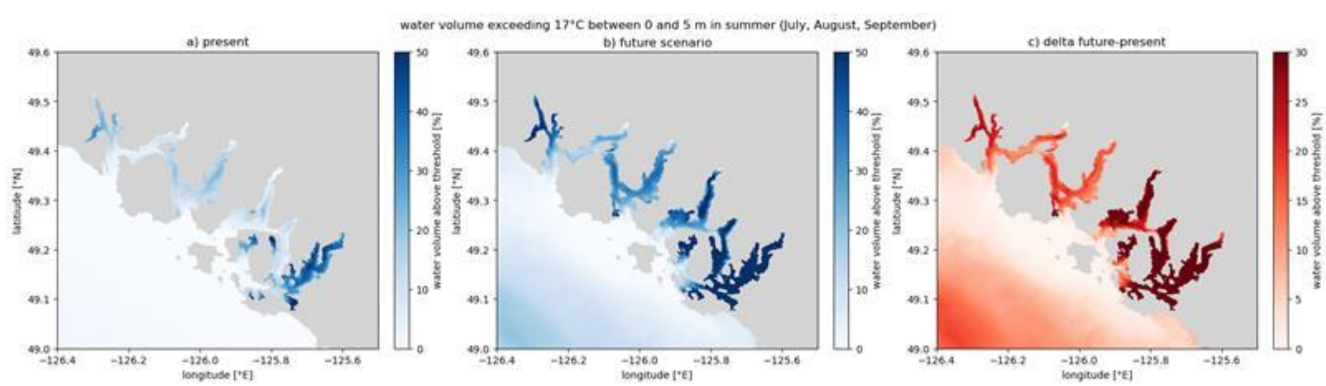

Figure 2. Maps of Clayoquot Sound showing the percentage of the top 5m of the water column exceeding 17°C in summer (July, August and September) in the (a) simulation for 2024 and (b) future scenario. Panel (c) shows the difference between both (future scenario minus 2024 simulation), highlighting the additional percentage of the surface waters that can exceed the temperature threshold in the future scenario.

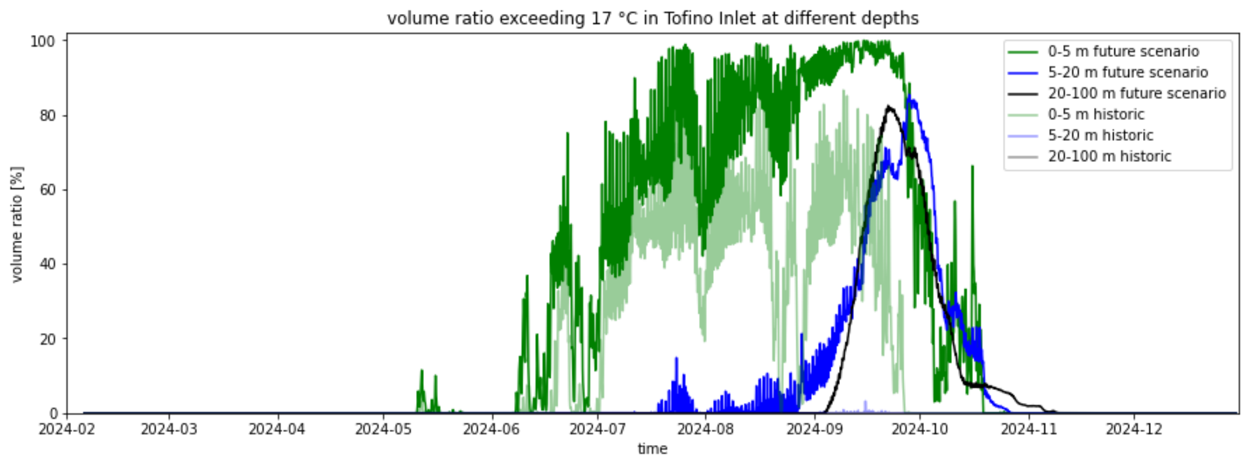

Figure 3. Time series of the percentage of water volume that exceeds 17°C in Tofino inlet at different depth ranges and different simulations. Bold colours indicate the future scenario, while paler colours indicate the 2024 simulation. Green colours indicate the volume in the surface depth range (0 to 5 m), blue colours represent upper waters below the surface (5 to 20 m) and black/grey represent deep waters (20 to 100 m). At surface, both simulations exceed the threshold between spring and autumn, while below 5 m the threshold is exceeded mostly in the future scenario.

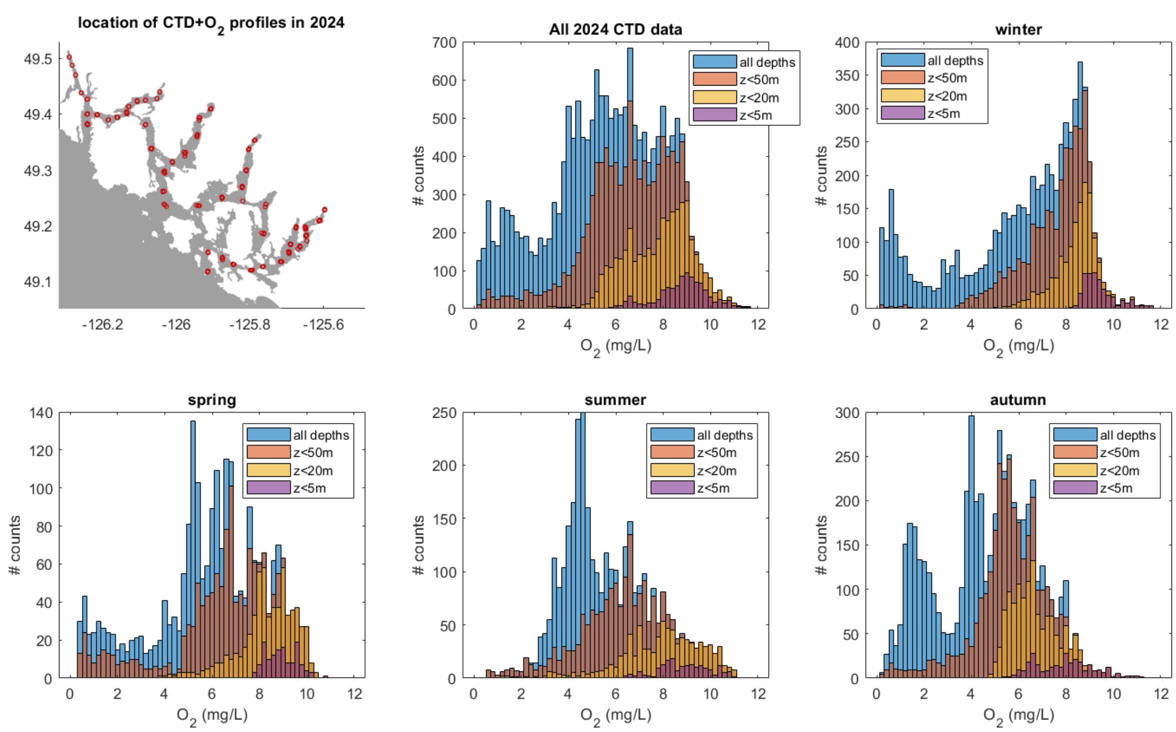

Figure 4. Location of the CTD profiles with oxygen data from 2024. The oxygen histograms show the distribution of oxygen data for the whole 2024 year and four seasons (winter: Jan-Mar, spring: Apr-Jun, summer: Jul-Sep, and winter: Oct-Dec). The different colours show the histograms for four different depth ranges: the whole water column (blue), top 50 meters (orange), top 20 meters (yellow) and top 5 meters (purple).

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2406 - Using Sediment Cores To Study Changing Coastal Productivity

Research paper: Changing productivity in BC coastal inlets (in progress)

CSAS Science Response: Changing productivity in BC coastal inlets (proposed)

Region: BC Coast

Waterbodies: BC Inlets and Salish Sea

Highlights

- This project used sediment core records combined with water properties data to determine whether the bottom of the salmon food web (amount and type of phytoplankton production) had changed in recent decades as a result of climate change.
- Results differ among inlets. The sediment core trends indicate a change toward a longer, less nutritious food web in some inlets but not others. Further work will explore the data more deeply to provide a robust interpretation in the context of climate-linked changes in freshwater inflow, productivity and seawater circulation.
- The final results of this project will be available to inform new, ecosystem-based approach to fisheries management on the BC coast.

Background

Until recently, fisheries models ascribed the decline in Salish Sea salmon populations to a 30% decrease in total primary productivity since the 1970s. Geochemical data (Johannessen et al., 2021, CJFAS) have since shown that total productivity has been constant for the last century in the Salish Sea. However, a change in the type of productivity could have affected salmon, by changing the nutritional value of available food. In addition, it is not known whether total productivity has changed outside the Salish Sea. A change from diatom- to dinoflagellate-dominance is thought to have occurred in nearby Puget Sound, due to a change in the ratios of dissolved nutrients and in the timing of freshwater discharge.

This project relates to drivers of salmon decline. Once complete, the results will be available to inform ecosystem models used to set fisheries catch limits. In the context of the new requirement for ecosystem variability to be included in salmon stock assessment, it will be crucial for fisheries managers to understand changes in the food web and in the physical and chemical properties of coastal seawater.

In addition to interpreting trends in primary productivity, based on sediment cores, the PI will collaborate with a biological oceanographer (Akash Sastri, DFO) and an American chemical oceanographer with data from Puget Sound (Christopher Krembs, Washington State Dept. of Ecology). The collaborations will permit a comparison with a time series of plankton taxonomic data and put the results from BC inlets into a wider regional context. The results will be published in scientific papers and in a proposed CSAS Science Response.

Methods and Findings

This project mainly used sediment cores, with water samples and electronic (CTD) data profiles to support the interpretation of environmental conditions.

Sediment cores

Fourteen new sediment cores 40-50 cm long were collected in BC mainland inlets in 2022-2025 (Figure 1), using a box corer (0.1 m2 cross-sectional area). Cores were subsampled into 1-cm intervals over the top 10 cm, 2-cm intervals for 10-20 cm and 5-cm intervals from 20 cm to the bottom. The sampling resolution was highest near the surface to help define the surface mixed layer. The sediment accumulation rate and mixed layer depth for each core were determined using depth profiles of the radioisotopes Pb-210 and Ra-226. Radioisotopes were analyzed by Flett Research Ltd., in Manitoba, following the procedure of Eakins and Morrison (1978) and Mathieu et al. (1988). The composition of organic matter was determined by analysis of organic carbon and nitrogen at the University of British Columbia, using a CHN analyzer (following Calvert and Pedersen, 1995). Stable isotopes of carbon and nitrogen were determined at the University of British Columbia or at the University of Windsor, using mass spectrometry (Calvert et al., 2001). The proportions of marine-derived and terrigenous organic matter were calculated based on isotopic endmembers previously determined in BC coastal waters (Johannessen et al., 2021; Johannessen et al., 2019). The fluxes of marine and terrigenous organic matter were determined by multiplying the proportions of each by the % total organic carbon and by the sediment accumulation rate. The fluxes were used to determine trends in each type of organic matter over time.

CTD profiles and water sampling

Profile data were collected using a SeaBird SBE911 CTD with sensors for temperature, salinity, dissolved oxygen, transmissivity (red: 660nm, green: 550 nm) and chlorophyll fluorescence. Water samples were collected using a standard 24-bottle rosette collected on the up-cast. Water samples were analyzed unfiltered for nutrients (nitrate, phosphate, silicate) at the Institute of Ocean Sciences, using a Technicon AutoAnalyzer™ II (Barwell-Clarke and Whitney, 1996). Nutrient data will be interpreted by calculating molar ratios of Si:N:P and comparing the ratios with those calculated for the Strait of Georgia and Puget Sound. (In Puget Sound, the Si:N ratio has declined since the 1990s, affecting the phytoplankton species assemblage, while the ratio has remained stable in the Strait of Georgia (unpublished data)).

Data archiving

Following quality control, data were archived in the OSD Data Archive at the Institute of Ocean Sciences and made available through the Waterproperties.ca website.

Delays

There were some unforeseen delays in field work and sample analysis. Two sampling cruises were cancelled, and a change in Coast Guard policy that made it impossible to collect sediment cores and water samples during the same cruise, which meant that the field work portion of the project took longer than anticipated. In addition, three labs that had previously analyzed stable isotopes all stopped offering that service, and it took some time to identify a new lab. As a result, some data were only received this month, with the rest of the outstanding data due by March 31. Consequently, only a preliminary interpretation is possible at this time. Interpretation will be completed in the coming fiscal year.

Insights

Results to date indicate that each inlet tells its own story. Knight Inlet, for example, has about twenty times the terrigenous carbon flux of Roscoe Inlet (Figure 2). However, the marine bloom flux (related to high productivity and a short (nutritious) food chain) is only five times as high in Knight as in Roscoe, and the non-bloom flux is similar in the two inlets. This indicates that the ratio of highly nutritious to less nutritious food at the base of the salmon food web is likely higher in Knight than Roscoe Inlet. In addition, the trends over time are different in the two inlets (Figure 2). It is possible that fisheries management in inlets will require inlet-specific consideration of environmental variables. Once the sediment core interpretation is complete and is put into the environmental context of each inlet, this information will be available to inform the ecosystem models that support salmon stock assessment.

Next Steps

- complete the interpretation of the sediment core data: calculate trends in marine and terrigenous carbon flux in the remaining cores;
- calculate nutrient ratios from water samples for all inlets for spring and autumn/winter, and compare these to the ratios and trends over time in the Salish Sea;
- determine whether differences in marine fluxes among inlets are related to surface nutrients and/or freshwater discharge; and
- work with colleagues in biological oceanography and fisheries to convert this information into an indicator that could be incorporated into the ecological models that inform fisheries stock assessment. Recommended future work:
- Ongoing monitoring of inlets to detect changes due to climate change or local pressures.

Tables and Figures

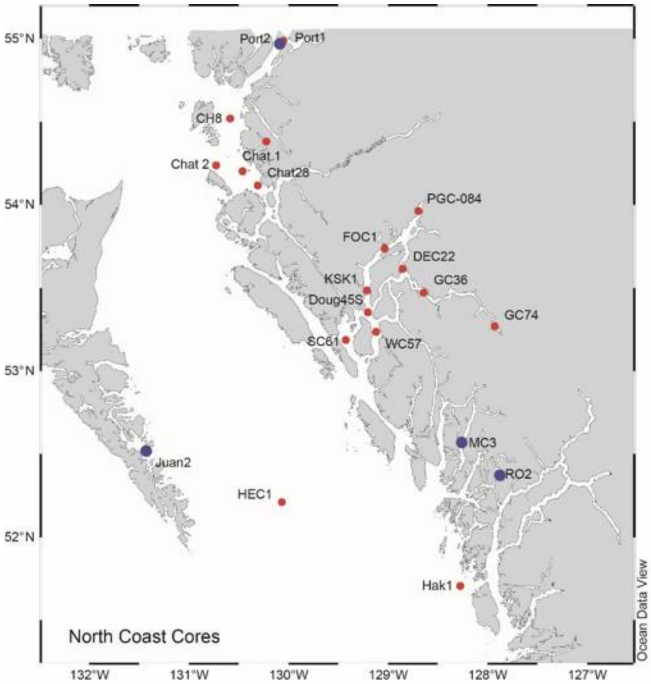

Figure 1. Sediment core location maps. Blue dots: New cores collected in 2022-2025, under PSSI and MCT programs. Red dots indicate existing cores, which will be used to provide context for the new cores.

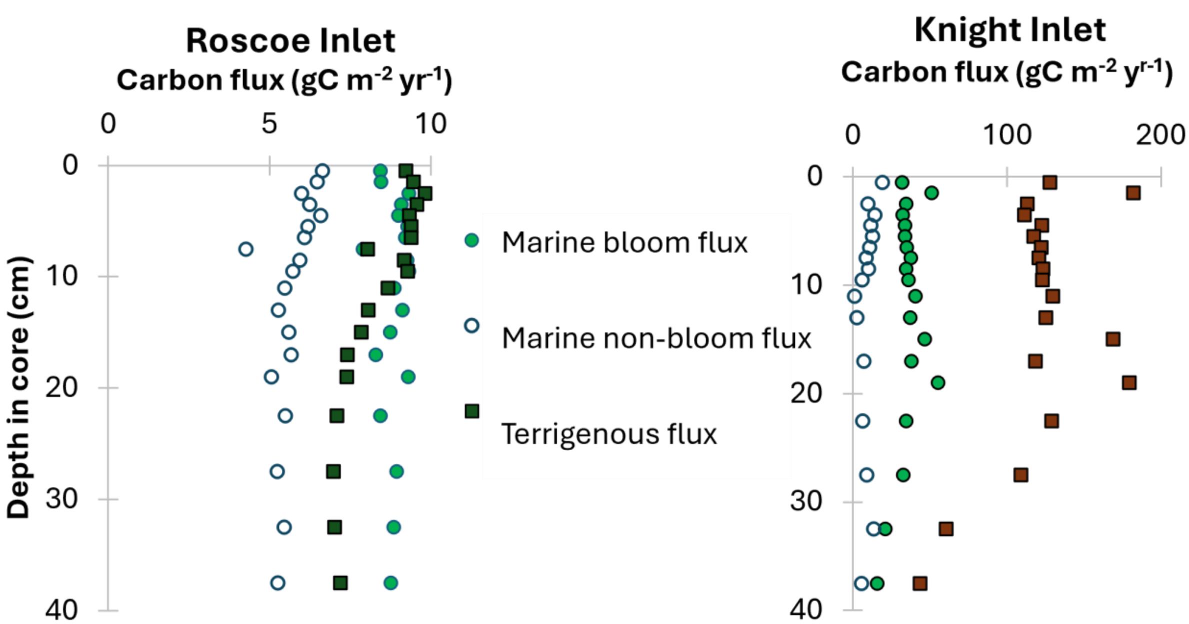

Figure 2. Fluxes of marine-bloom, marine-non-bloom and terrigenous organic carbon in a) Roscoe and b) Knight Inlets. Note that the x-axis scale (carbon flux) for Knight Inlet is 20 times as high as that for Roscoe Inlet. “Marine” represents mainly phytoplankton-derived organic matter. “Bloom” represents organic matter produced under conditions of high productivity, with a short food chain, while “non-bloom” represents low productivity and a long food

chain. The oldest material is at the bottom of the cores, with time progressing toward the surface. Due to the different sedimentation rates, the Knight Inlet core represents about 45 years, while the Roscoe core represents about 270 years.

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2409 - Tagging Study of Sea Lion Predation on Salmon

Fleming, J., King, J.R., Tucker, S., and C. Freshwater 2025. Acoustic and Satellite Tagging of Sockeye Salmon, Oncorhynchus nerka, Off the West Coast of Haida Gwaii, September 30 – August 11, 2024. Canadian Data Report of Fisheries and Aquatic Sciences 1441, 16 p.

Primary publication summarizing sockeye salmon mortality rates and predator vectors (in progress)

Tech report summarizing sockeye salmon behaviour (in progress)

Primary publication summarizing Steller sea lion distribution (analysis underway)

Primary publication summarizing Steller sea lion diet (analysis underway)

Primary publication synthesizing salmon and sea lion data streams to quantify predation risk (anticipated)

Collaborations: DFO: Justin Fleming, Jackie King, Erin Rechisky, , Chad Nordstrom, Ali Bowker Sheena Majewski, Kurt Trzcinski; University of Alaska Fairbanks:Andy Seitz, Michael Courtney ; Vancouver Aquarium: Marty Haulena; ECCC: Christine Rock

Region: BC Coast

Waterbodies: Continental shelf, Queen Charlotte Strait, Johnstone Strait, Strait of Georgia

Species: Sockeye

Highlights

- Increased predation by Steller sea lions (SSL) has been identified as a potential cause of declines in Fraser River sockeye salmon abundance; however, there were previously no relevant data on SSL diets and distribution or sockeye salmon mortality rates to test the hypothesis.
- We found evidence of high sockeye salmon mortality rates; however, the majority of mortality was associated with salmon sharks, not SSL. The SSL predation that did occur was concentrated in Queen Charlotte Strait, not the largest rookery at Triangle Island.

While SSL diet results are pending, SSL tagging data demonstrated evidence of restricted foraging during the initial portion of sockeye salmon migration (as animals are tied to breeding/pupping rookery) followed by rapid dispersal (particularly by males) away from Triangle Island and diverse foraging strategies among individuals. Widespread overlap of the SSL stock with migrating Fraser River sockeye salmon appears to be less than presumed.

- Collectively, these results suggest sockeye salmon may be vulnerable to a broader range of predators than previously considered, and that predator communities, and predation risk, vary through space and time. Thus, previous estimates of SSL consumption rates may be biased high.

Background

Fraser River sockeye salmon productivity has been poor since the early 1990s (Peterman and Dorner 2012). Although the mechanism remains unclear and is likely multifaceted (Cohen 2012), bottom-up processes that reduce juvenile marine survival have been identified as a likely factor (McKinnell et al. 2014, Freshwater et al. 2018, Rechisky et al. 2019). More recently, elevated predation of returning adult Fraser River sockeye salmon by SSL has been hypothesized to be a key factor (Walters et al. 2020). The primary pieces of evidence used to infer SSL impacts are a) large increases in SSL population size coincident with Fraser River sockeye salmon declines, b) the location of large SSL breeding colonies proximate to sockeye migration corridors (e.g., Triangle Island rookery at the northwest tip of Vancouver Island is the largest in northeast Pacific), and c) bioenergetic modeling that estimated significant removals (>1 million individuals) by SSLs if sockeye are 40% of the diet during four weeks in summer and all SSLs at British Columbia rookeries target sockeye during this period (Walters et al. 2020). Yet because there are no published estimates of SSL diet nor foraging distribution from rookeries and haul outs adjacent to sockeye salmon migration corridors, our current understanding of SSL foraging ecology is insufficient to validate key model assumptions. Furthermore, previous empirical estimates of sockeye salmon survival during their marine migrations do not have sufficient resolution to evaluate SSL impacts (Crossin et al. 2007, 2009). As a result, the impact of SSL, and other marine predators, on Fraser River sockeye salmon remains uncertain.

Methods and Findings

We used multiple methods to evaluate SSL foraging ecology, quantify sockeye salmon mortality rates, and ultimately draw inference on the likely impact of SSLs on migrating Fraser River sockeye salmon. The following activities occurred during the 2024 and 2025 field seasons (Figure 1).

Sockeye Salmon Methods

Sockeye salmon were captured aboard a charter purse seine vessel from sites near Rennell Sound (west coast Haida Gwaii; 2024 and 2025) and Queen Charlotte Strait (2025 only). Sockeye salmon were landed and transferred to a flow through seawater trough where biological data, including genetic stock identification (GSI) samples, were collected. Individuals in good physical condition were tagged with either an acoustic or satellite tag before being immediately released. We deployed acoustic transmitters on sockeye salmon (n=625) which allowed individuals to be detected on moored receiver arrays near Haida Gwaii, Triangle Island, Queen Charlotte Strait, throughout the Salish Sea, and the lower Fraser River. The acoustic receiver network included approximately 40 receivers deployed by DFO throughout coastal British Columbia, as well as infrastructure maintained by NOAA, the Ocean Tracking Network, Kintama, and the University of British Columbia. Detections data will be used to parameterize mark-recapture models to estimate survival rates along the migration corridor and identify hotspots of mortality. We also deployed popup archival satellite tags (PSATs) on a smaller number of sockeye salmon (n=35). After releasing from the animal these tags transmit light, temperature, and pressure sensor data that can be used to identify predator taxa (Seitz et al. 2019).

Sockeye Salmon Findings

GSI results are currently only available for the 2024 field season; however, the majority (>98%) of tagged sockeye salmon were identified as belonging to Fraser River populations with Chilko Lake being the dominant conservation unit (~55% of all samples). Only a subset of detections data are currently available for 2025; however preliminary results in both years (Figure 2) indicate overall survival from Haida Gwaii to the Fraser River was poor (<8%). ~50% of individuals tagged at northern sites were detected on Haida Gwaii arrays; however, mark-recapture models that account for imperfect detection probability on these arrays are required for robust estimates of survival. Survival to the Fraser River of tags deployed in Queen Charlotte Strait was markedly higher (~40%). 2% of tags were detected in the study area after deployments were completed, suggesting short-term mortality due to tagging or handling was minimal. Only two tags were detected at Triangle Island (both in 2025), however 46 tags were detected in 2025 at sea lion haul outs throughout Queen Charlotte Strait. Importantly, additional analysis is required to determine how many of these fish were likely consumed by pinnipeds based on subsequent detections. No fish were reported as intercepted by fisheries in 2024, but 5% of tagged fish were recaptured by marine and in-river fisheries and reported in 2025.

We deployed 18 PSATs at Haida Gwaii sites in 2024 and 17 in 2025 (ten in Haida Gwaii and seven in Queen Charlotte Strait). Six of the 2024 PSATs failed to report due to engineering issues. All of the remaining 12 reported before their programmed release data, suggesting the fish were predated. Of the confirmed mortalities, three could not be classified because the tag was not ingested, one was consumed by a benthic ectotherm, and eight were consumed by salmon sharks (Figure 3). In 2025, all PSATs reported and five survived to release, all from the Queen Charlotte Strait study area. Of the ten Haida Gwaii tags, four were consumed by blue sharks, three by a benthic ectotherm, and three by salmon sharks. Neither of the two Queen Charlotte Strait mortalities could be classified (Figure 3).

SSL Methods

We deployed satellite tags (paired head-mounted splash and flipper-mounted spot tags) on adult male (n=7) and female (n=14) SSLs on Triangle Island. Animals were sedated via darting gun and tagged with the assistance of staff from the Vancouver Aquarium. Females were captured near the end of July following pupping; males were captured at the beginning of June as animals staked out territories for the breeding period. Head mounted tags were epoxied to the fur and were shed by fall during the annual moult while the flipper mounted tags should stay affixed for multiple years although tag programming and battery life will ultimately determine transmission duration. The high resolution, yet shorter deployment splash tags will allow for an understanding of foraging behaviour (location and dive profiles) and sex-specific habitat use revealing explicit spatial-temporal overlap with sockeye salmon during their migration through Queen Charlotte Sound. This distribution data is critical in evaluating the relative proportion of the SSL population that has the opportunity to predate sockeye salmon. The longer-term flipper tags (8-16 months; multi-year) will allow for multi-season information on coarse foraging patterns.

We also collected SSL diet information via biochemical tracers and scats from sites on Triangle Island, as well as key haul outs in Queen Charlotte Strait, the southwest coast of Vancouver Island, and the southern Strait of Georgia. The two biochemical tracers we have focused on, fatty acid profiles and stable isotopes, provide estimates of diet composition integrated over weeks to month. The fatty acid analysis (FAA; Budget et al. 2006) will provide more discrete diet estimation (prey-specific proportions) while the stable isotope analysis (SIA; Layman et al. 2012) will be useful to discriminate feeding source (pelagic vs demersal, nearshore vs shelf vs shelf break) such that we can broadly characterize foraging behaviour beyond the satellite tagged individuals. Diets estimated from scats provide a short-term (~ 1 day) estimate requiring far more extensive, repeated sampling to capture temporal variation in diet-particularly if the objective is to capture a potential pulse of a relatively rapidly migrating prey. While we collected scats (n=1,200), there was insufficient funding provided to analyze these, let alone undertake a full-fledged sampling design for scats. These are therefore archived for potential future work and analysis focused on the integrated tracer samples. In total, ~400 sea lion biopsy samples were obtained directly from satellite tagged animals or randomly via a crossbow system. To estimate diet, over 1500 potential fish and invertebrate prey samples were obtained from various DFO research cruises.

SSL Findings

During the 5 - 6-week deployments prior to moult, female foraging was concentrated on the continental shelf (Figure 4a). In the initial weeks, animals used Triangle Island as a central place for short foraging forays. As pups inevitably grew and became more independent, there was a gradual expansion and dispersal away from Triangle east to Cook Bank and Queen Charlotte Strait and south-east to Quatsino Sound with females ultimately moving to sites both east and south of Triangle Island. During the 14 - 16-week deployments prior to moult, males demonstrated very limited foraging activity during the breeding period (Figure 4b). Subsequently by mid-July there was rapid and directed dispersal immediately post-breeding with individuals ranging as far north as southeast Alaska and south to the Washington border. Triangle was not used as major haul out outside of the breeding period for either females or males. More in-depth analysis of distribution and dive behaviour is underway to explicitly parameterize sea lion foraging effort in a spatial context and provide support for interpreting diet results.

Stable isotope and fatty acid datasets for potential prey and sea lions have been completed for 2023-2024 samples; 2025 samples are currently being processed and analyzed. Preliminary analysis of 2023-2024 SI values for known age class and sex animals suggests that males and females are exploiting different prey/habitats diverging further with age (Figure 5).

Insights

Although analyses are underway, there are several key preliminary results. We found that sockeye salmon mortality rates during adult marine migrations may be considerably higher than previously assumed (e.g. Cohen 2012). At the same time, it is clear that the predator community varies along the migratory corridor–while we found some evidence of pinniped predation in Queen Charlotte Strait that warrants additional investigation, we found no evidence of pinniped predation near Haida Gwaii where mortality rates were high and apparently driven by shark predation. Similarly, we found evidence that predation impacts likely vary among and within sea lion haul outs. Despite the large size of the Triangle Island rookery, we found a very small number of tags at this location, particularly relative to Queen Charlotte Strait haul outs.

Steller sea lion satellite tag paths highlight important nuances in foraging behaviour during the months when Fraser River sockeye salmon are available. At this time of year, mature SSL are tied to pupping, nursing and breeding with only intermittent foraging. Peak pupping typically occurs early July. Females stay with their pups fasting for 1-2 weeks after which they make short foraging trips. Females appeared to disperse from Triangle by mid-August to other haul outs around Queen Charlotte Sound and WCVI. Males had very limited movements during the breeding period. Rapid and directed dispersal immediately post breeding (mid-July) was observed. Despite the large number of animals concentrated on Triangle Island during the breeding period (coincident with sockeye salmon migration), adjacent waters do not appear to be a major feeding ground this time of year. These foraging and dispersal patterns generally run counter to blanket assumptions for SSL impacts on sockeye and will have implications for foraging models. Ongoing diet analyses will provide additional information on individual, spatial, and seasonal variability in Steller sea lion foraging.

Our results emphasize the impacts of at least three predator taxa (salmon sharks, blue sharks, Steller sea lions) on sockeye salmon warrant additional consideration. Given a potential latitudinal gradient in shark abundance (Williams et al. 2010, Proudfoot et al. 2024), population level impacts may be sensitive to where Fraser River sockeye salmon intercept the continental shelf during their return migrations. All else being equal, fish making landfall near Haida Gwaii will migrate through a longer gauntlet of predators than those making landfall in Queen Charlotte Sound, which may in turn be at greater risk than those migrating through Juan de Fuca Strait. The location of landfall is uncertain, but if it is correlated with diversion rate, as seems likely, will vary among stocks as well as among years (Grant et al. 2017). If we find evidence of year-specific differences in survival rate, consistent with expected density dependent effects on predator foraging behaviour, this will add substantial additional variability due to sockeye salmon cyclicity. In short, a fixed, average predation rate applied to all stocks is likely inappropriate. Unfortunately, using statistical models to quantify the relative impact of each taxa is not possible given a lack of abundance data for blue and salmon sharks.

Next Steps

Our findings highlight successful ecosystem-based management of sockeye salmon requires careful consideration of factors that are often overlooked when quantifying predator impacts. First, studies on predation impacts have focused on cetaceans and pinnipeds (Chasco et al. 2017a & b, Walters et al. 2020, Nelson et al. 2024), which have robust time series of abundance. However, the effect of pinniped impacts will be biased high if the abundance of multiple predator taxa have increased in synchrony. In this scenario, reducing cetacean or pinniped effects may simply result in the remaining predator taxa increasing in abundance. Second, bioenergetics models are commonly used to quantify the population level impact of predators (Chasco et al. 2017a & b, Walters et al. 2020); however, these methods are sensitive to assumptions about the relative contribution of different species and size classes to the diet (Nelson et al. 2021). These uncertainties are further amplified by seasonal and spatial variability in predator diets, as well as differences among individuals in foraging behaviour. Finally, the total impact on prey species is also sensitive to the proportion of the prey population that is vulnerable to predation. Our findings suggest that each of these components is highly relevant when evaluating Steller sea lion impacts on Fraser River sockeye salmon.

In particular, we suggest ongoing and future work should address the following major dimensions. Seasonal and spatial variability in Steller sea lion diets should be quantified–this work will proceed using collected biochemical tracers. Seasonal, sex-specific variability in Steller sea lion distributions should be used to estimate the relative proportion of the population that is likely to overlap spatially and temporally with migrating sockeye salmon–this work could proceed using existing satellite and overflight survey data. Steller sea lion distributions should be paired with estimates of interannual and stock-specific variability in sockeye salmon migration routes to evaluate relative risk–this work is proceeding using historical catch data, but it is currently unclear whether existing data are sufficient. Since salmon-predator interactions are highly context-dependent (Wells et al. 2025), until the above data gaps are addressed efforts to mitigate predator impacts should proceed with caution and a careful consideration of the associated uncertainties.

Tables and Figures

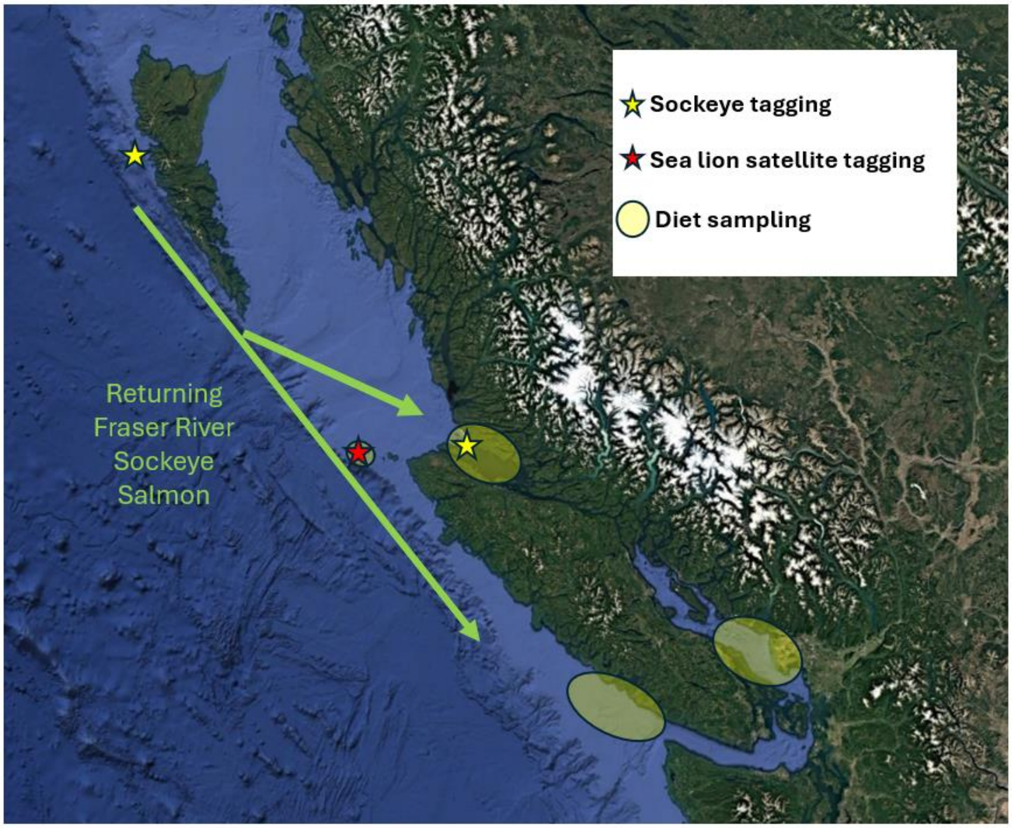

Figure 1. Map of study area showing approximate Fraser River sockeye salmon migration corridor, sockeye salmon and Steller sea lion tagging sites, and diet sampling locations.

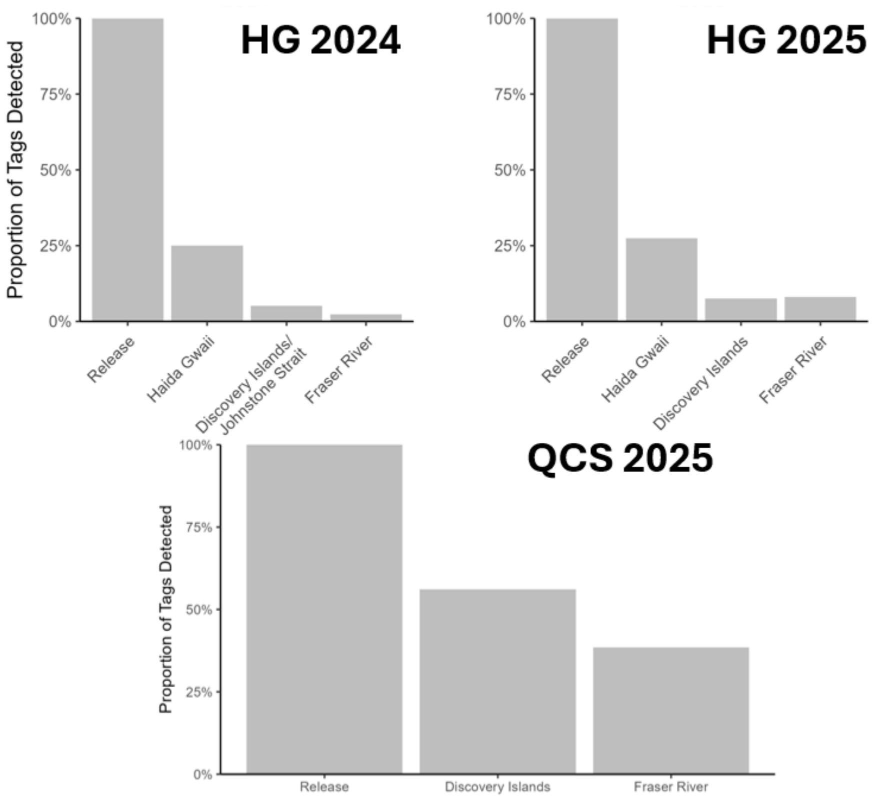

Figure 2. Proportion of tagged sockeye salmon detected along migration corridor by release cohort (HG is Haida Gwaii, QCS is Queen Charlotte Strait). Detections provide an approximate estimate of survival but do not account for imperfect detection probability. Final results require parameterization of mark-recapture model.

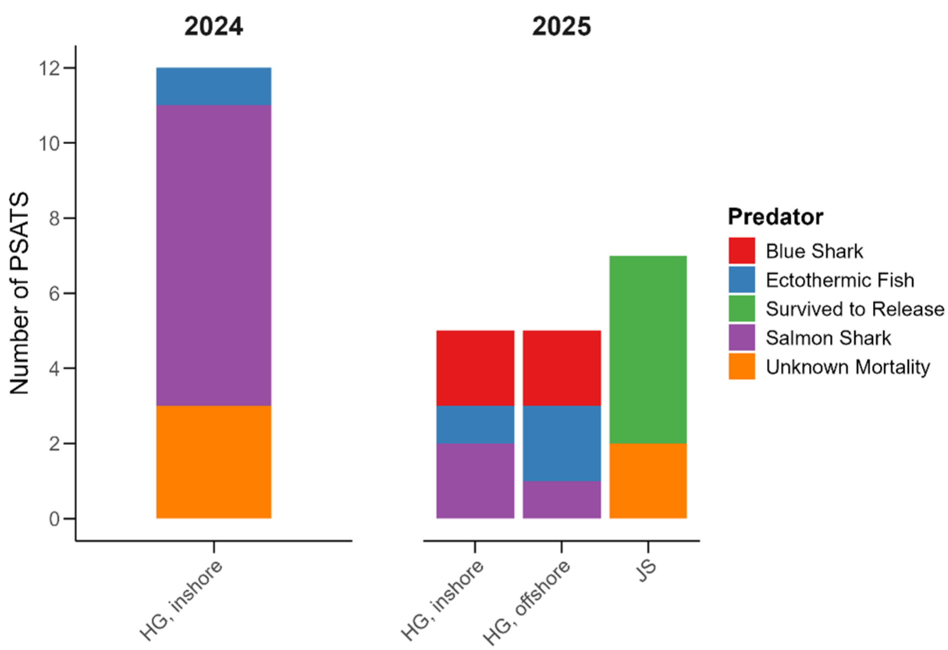

Figure 3. Fates of popup satellite tags stratified by release location. Survival to release represents tags that uploaded data at their release date. All other tags transmitted early indicating they were no longer attached to the tagged animal. Ingested tags could be assigned to a predator guild based on temperature and pressure data while unknown mortalities represent deployments where the tag was removed from the prey, but not ingested by a predator.

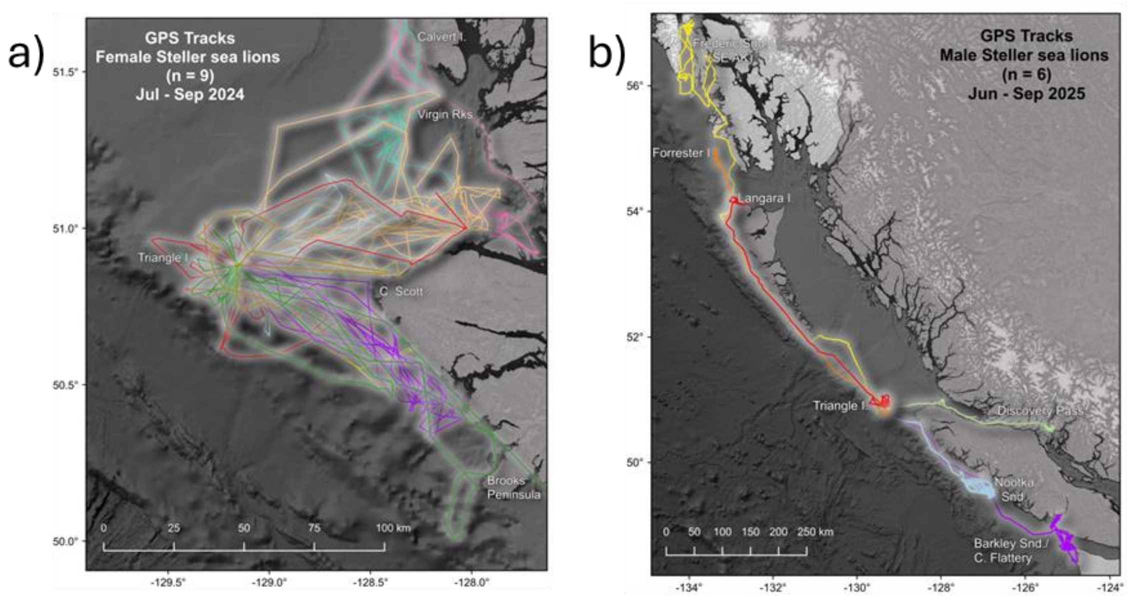

Figure 4. Tracks of individual a) female and b) male Steller sea lions satellite tagged on Triangle Island in 2024 or 2025.

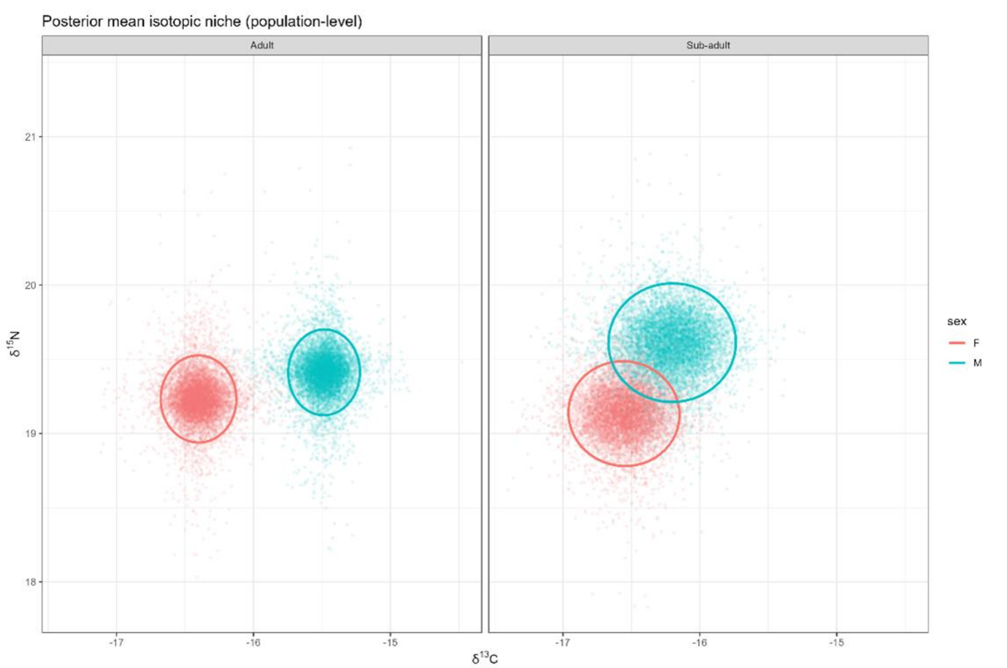

Figure 5. Posterior mean isotopic ($\delta^{13}C$ and $\delta^{15}N$) space for Steller sea lions by age class and sex. Points represent draws from the posterior distribution of population-level mean isotope values from Bayesian hierarchical models. Ellipses denote 95% Bayesian credible regions of uncertainty in mean isotopic values for each group.

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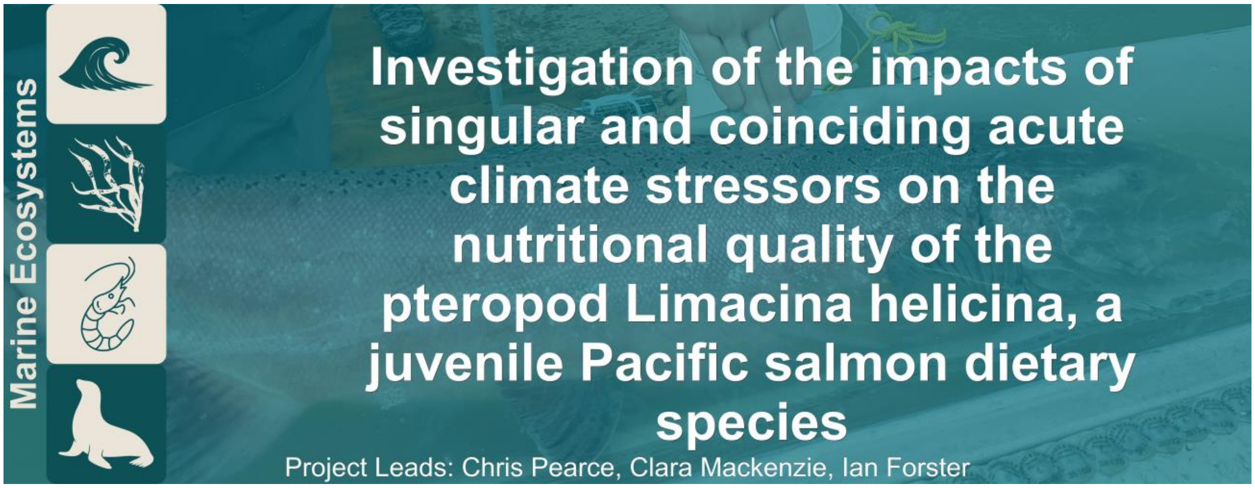
2412 - Climate Stressors and Nutritional Quality of Pteropods



Mackenzie, C.L., Walker, C.Y.V., Miller, M.R., Nomura, M., Spencer, S., Forster, I.P., Neville, C.M., Pearce, C.M. (in review) Impacts of coinciding ocean acidification and warming on the fatty acid profile of the pteropod Limacina helicina within the Northeast Pacific coastal region. Submitted to Frontiers in Marine Science: Global Change and the Future Ocean (in progress)

Collaborations: DFO: Chrys Neville

Region: BC Coast

Highlights

- The nutritional status (*i.e.* fatty acid (FA) profiles) of *L. helicina* was quantified in (a) field samples collected via plankton tow throughout the SOG between 2014 and 2023; and (b) laboratory samples following short-term experimental exposure to coinciding ocean warming and ocean acidification (OA) conditions, in order to investigate how changing oceanic conditions may impact the feed quality of a Pacific salmon prey species.
- Overall, findings suggest that OA may result in altered fatty acid composition in pteropods, potentially leading to shifts in nutritional quality and associated impacts on trophic energy transfer. Additionally, results indicate that temperature stress could pose more immediate threat to pteropod survival.
- We propose that any changes in the nutritive status of *L. helicina* under climate stressor conditions could have carry-over impacts to juvenile salmon growth, health, and survival. However, we highlight that this study represents preliminary findings only and future research is needed to assess multi-trophic impacts.

Background

Under global climate change, co-occurrence of gradual physical changes in seawater and extreme events pose a substantial threat to marine ecosystems (IPCC, 2023). This PSSI-funded project focused on the Strait of Georgia (SOG) within the Northeast Pacific coastal region where steady rises in mean seasonal seawater temperatures and pCO2 levels, and increasingly prevalent acute stressor events such as heatwaves and low-pH upwellings, are already occurring (Bylhouwer et al., 2013; Evans et al., 2019; Okey et al., 2024; Raymond et al., 2022; Talloni-Alvarez et al., 2014). Moreover, the SOG is distinctive as conditions of high pCO2 and aragonite undersaturation persist year-round across a wide extent of the water column (Moore-Maley et al., 2016; Simpson et al., 2024). *Limacina helicina*, a cold-water pteropod well-represented within the region's zooplankton communities, is highly susceptible to climate change stressors, with documented impacts of ocean warming and ocean acidification (OA) on shell development, growth, and survival (Bednaršek et al., 2016, 2022; Lischka et al., 2022; Lischka & Riebesell, 2012). However, there has been minimal investigation of climate change effects on the species' nutritional status (e.g. fatty acid (FA) composition) under regionally-relevant conditions. Given the importance of *L. helicina* as a dietary item for some populations of juvenile Pacific salmon species in the Northeast Pacific (Brodeur et al., 2007; Doubleday & Hopcroft, 2015; Sturdevant et al., 2012), it was proposed that any change in the nutritive status of *L. helicina* under climate stressor conditions could have carry-over impacts to juvenile salmon growth, health, and survival.

The project involved cross-program collaboration between DFO researchers based at the Pacific Biological Station (PBS) and the Pacific Science Enterprise Centre (PSEC) for investigation of the impacts of warming and OA conditions (representative of future conditions in the SOG) on FA profiles of *L. helicina* populations in the region. *Limacina helicina* samples were collected and processed as part of juvenile Pacific salmon survey fieldwork carried out in the SOG during 2014−2023 by the Salmon Marine Interactions Program at PBS (Lead: Neville). The program also supported live collection (within the SOG) of *L. helicina* for a climate change experiment (2023). Subsequent field sample sorting (i.e. extraction of whole pteropods from historical size-fractionated plankton samples) and laboratory experimentation (i.e. conducting of a climate change experiment in the Fisheries and Oceans Climate Change and Ocean Acidification Laboratory (FOCCOAL)), and nutritional analyses (i.e. FA analyses via gas chromatography) were carried out by the Sustainable Invertebrate Aquaculture Program at PBS (Lead: Pearce) and Nutrition Program at PSEC (Lead: Forster), respectively.

Methods and Findings

Climate Change Experiment

Live *L. helicina* (Figure 1) were collected from the SOG in early October 2023 for use in a climate stressor experiment. Collection of approximately 800 pteropods was carried out over a 7-h period across a centrally-located area of the SOG via a series of vertical tows (N=9) using a bongo net collar assembly with two 58-cm diameter Nitex nets (253-μm mesh) deployed to a maximum depth of 300 m. Following, jars with animals were kept in a temperature-controlled cool box (~12°C, dark conditions). Within 24 h of collection, all pteropods were transported to the FOCCOAL at PBS for application to a climate change experiment. A full factorial design was applied to the experiment, resulting in four treatments: Control, OA, Warming, OA+Warming (n=6 tanks per treatment). Treatment conditions were achieved via use of the FOCCOAL, which employs a programmable logic controller and automated seawater and gas mixing systems to tightly control seawater temperature and pCO2, respectively. Pteropods were exposed to singular and coinciding warming (mean summer seawater temperature + 4°C) and OA (Ωaragonite < 1) conditions, with subsequent FA analyses carried out on 48-h and 5-d timepoint samples via gas chromatography (at PSEC). Results indicated a significant impact of OA on nutritional status at 48 h (Figure 2) and a significant impact of temperature on survival at 5 d (Figure 3).

Time-series Analyses (Field Samples)
Additionally, FA analyses of *L. helicina* picked from historical plankton samples collected in the SOG as part of juvenile Pacific salmon survey work (Neville et al., 2025, 2026a, 2026b, 2026c, 2026d, 2026e; Neville & Spencer, 2026) were carried out to examine time-series changes in FA profiles in relation to regional temperature records (e.g. DFO British Columbia Shore Station Oceanographic Program, Chrome Island Lightstation temperature dataset). A subset (N=35) of frozen 1-mm size-fractioned samples covering a 10-year time series (2014–2023) were compiled to carry out pteropod FA profiling. Within a given year (N=7), five sampling stations were selected according to target tow depth and location. Sub-samples of the 1-mm size class samples from each station were used to obtain whole pteropods for FA analyses. FA analyses was carried out at PSEC via gas chromatography with results indicating no significant differences in fatty acid fractions between year groups, though there was suggestion of changing proportion of myristic acid over a number of year groups (Figure 4).

Insights

Project data may be fed into predictive habitat distribution modelling and climate change vulnerability assessments for Pacific salmon species (*e.g.* ACCASP's Fish Stock Climate Vulnerability Assessment Tool (FSCVAT)). This would enable environmental/aquaculture managers and decision-makers to prepare for and respond to the impacts of climate change.

Next Steps

Findings here provide preliminary evidence that *L. helicina* of the SOG region may tolerate persistent OA conditions with minimal impact to survival, but potentially at the expense of energy stores. Moreover, declining aragonite saturation state across the area could pose further detriment to their role as a food source to upper trophic species. In addition, we propose that temperature stress could pose more immediate threat to survival, particularly if warming in upper surface layers extends throughout the wider water column. Results highlight the need for improved understanding of ecological interactions under climate change conditions with regard to food-web dynamics, and the importance of considering multiple stressors when determining vulnerability of *L. helicina* to future climate change conditions. Recommendations for future studies include the development of larger experimental mesocosms for improved pteropod holding facilities and extension of experimental time lines to encompass longer-term exposure periods. The current work could also be followed-up with laboratory-based salmon feeding trials to determine whether (and to what extent) impacts to pteropods relay to juvenile salmon growth/health (*e.g.* multi-trophic impacts).

Tables and Figures

Figure 1. Photograph of Limacina helicina (M. Poerner Loureiro, Vancouver Island University).

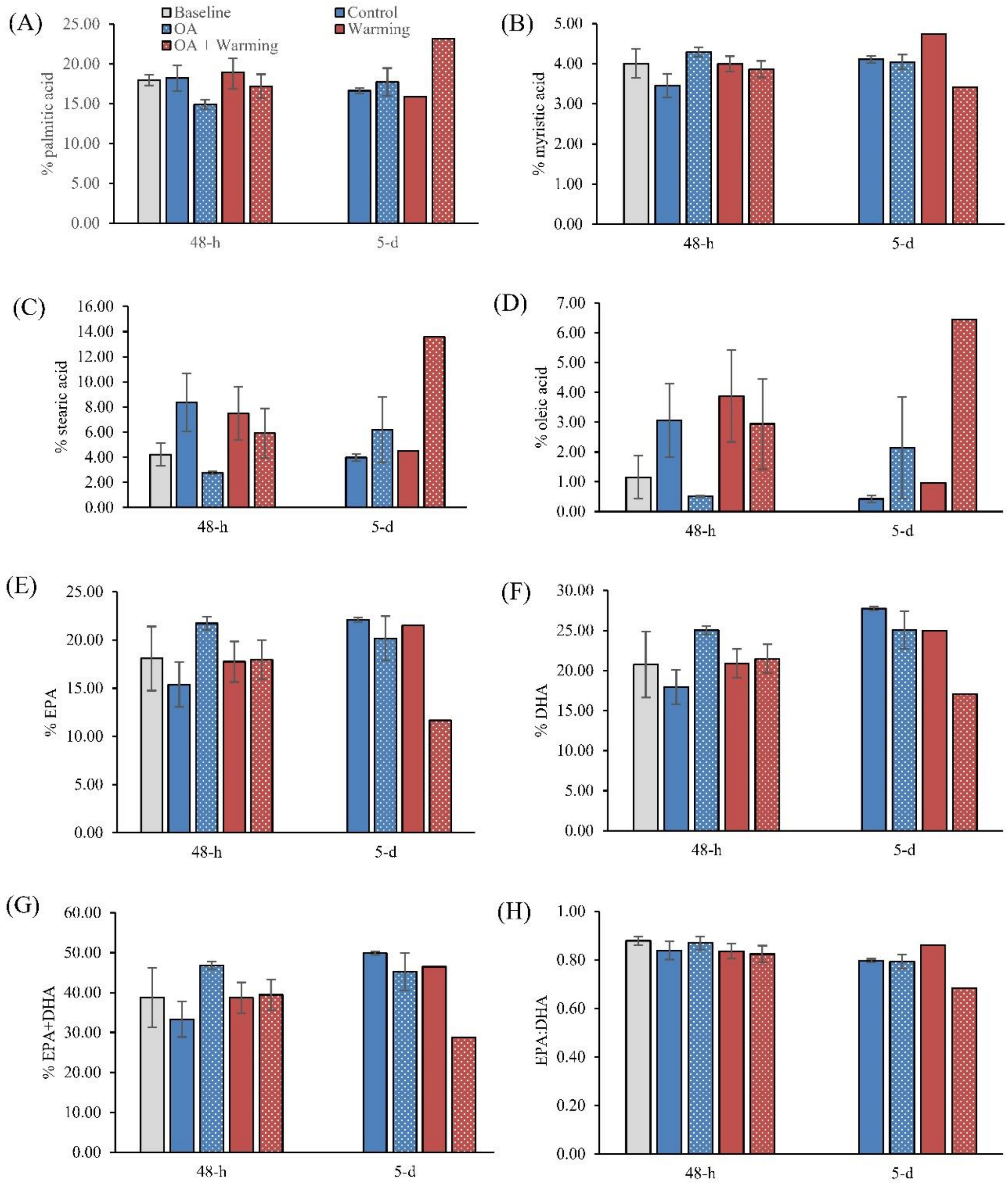


Figure 2. *Mean ± SE percentage (%) of (A) palmitic acid, (B) myristic acid, (C) stearic acid, (D) oleic acid, (E) eicosapentaenoic acid (EPA), (F) docosahexaenoic acid (DHA), and (G) EPA+DHA, and (H) EPA:DHA in Limacina helicina at baseline and following 48-h and 5-d exposures to singular and coinciding temperature and pCO_2 stressors (Control: 10°C, ~650 ppm pCO_2, $\Omega_{arag} > 1$; OA: 10°C, ~1500 ppm pCO_2, $\Omega_{arag} < 1$; Warming: 14°C, ~650 ppm pCO_2, $\Omega_{arag} > 1$; OA+Warming: 14°C, ~1500 ppm pCO_2, $\Omega_{arag} < 1$; n=6 per treatment). Note that all replicates of Warming and OA+Warming treatments at the 5-d timepoint were pooled (resulting in Warming: N = 3 pteropods and OA+Warming: N = 9 pteropods) for analyses due to high mortality across all replicate tanks.*

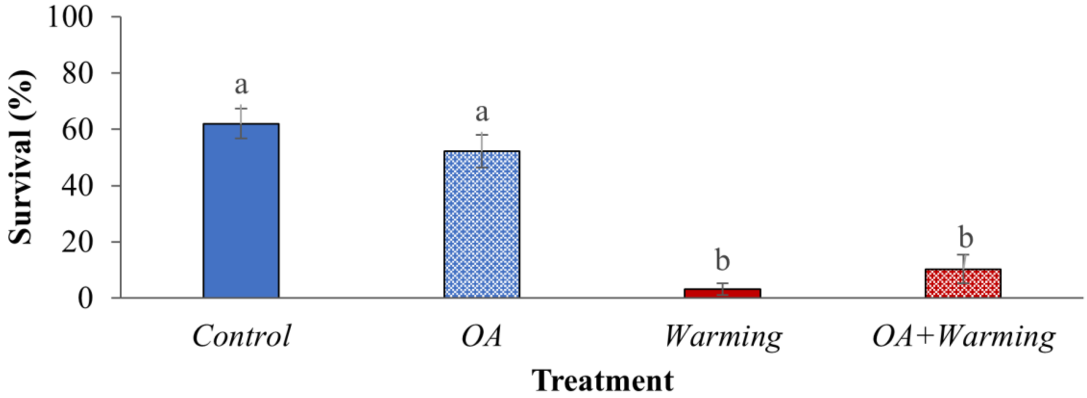


Figure 3. Mean ± SE survival (%) of Limacina helicina following a 5-d exposure to singular and coinciding temperature and OA stressors (Control: 10°C, ~650 ppm pCO2, Ωarag > 1; OA: 10°C, ~1500 ppm pCO2, Ωarag < 1; Warming: 14°C, ~650 ppm pCO2, Ωarag > 1; OA+Warming: 14°C, ~1500 ppm pCO2, Ωarag < 1). Differing lowercase letters above bars denote significant (p < 0.05) differences between treatments.

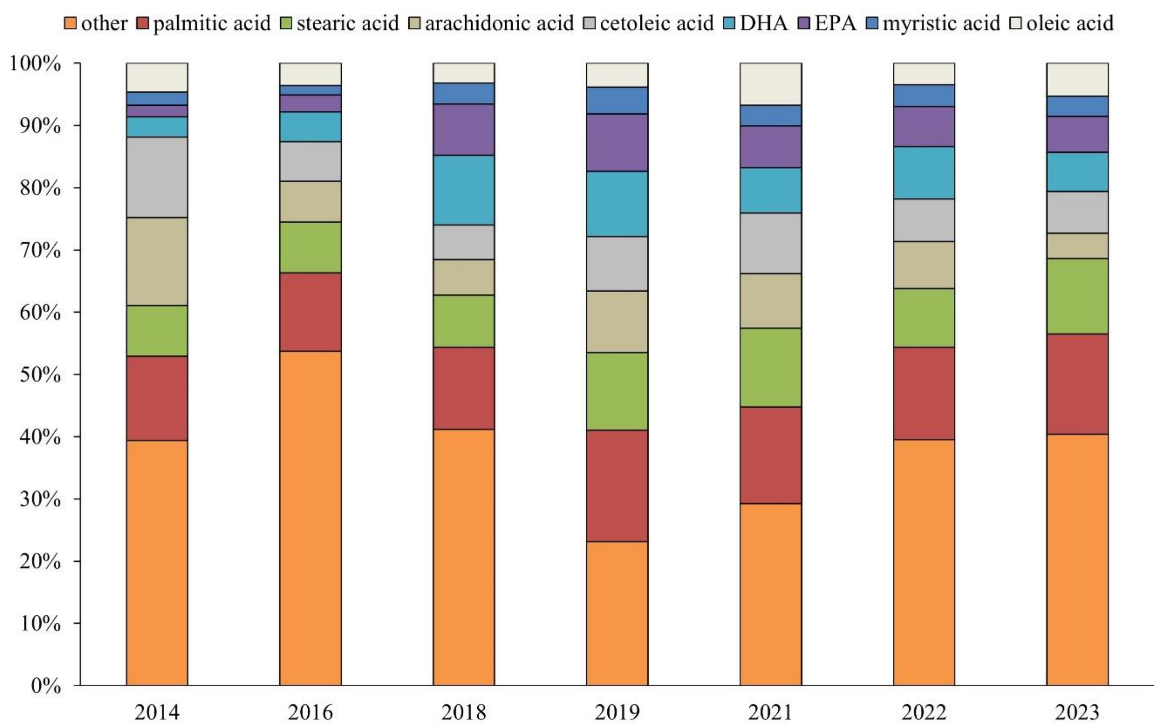


Figure 4. Mean percentages (%) of palmitic acid, stearic acid, arachidonic acid, cetoleic acid, docosahexaenoic acid (DHA), eicosapentaenoic acid (EPA), myristic acid, oleic acid, and remaining fatty acids (other) in Limacina helicina collected at plankton survey stations in the Strait of Georgia (British Columbia, Canada) for the period 2014–2023. Note: Surveys were not conducted in 2015, 2017, or 2020.

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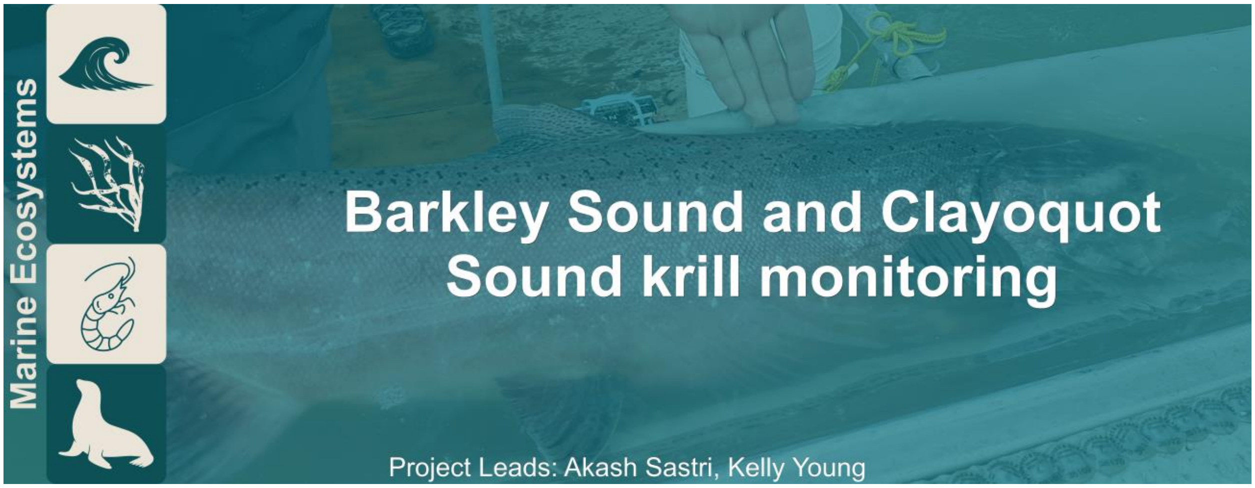
2413 - Krill Monitoring in Barkley and Clayoquot Sounds



Young, K., Galbraith, M., Hennekes, M., Hirst, A., Kafrissen, A., and Sastri, A. Barkley Sound Euphausiid monitoring project. In Boldt, J.L., Joyce, E., Tucker, S., Gauthier, S., and Jackson, J. (Eds.). 2025. State of the physical, biological and selected fishery resources of Pacific Canadian marine ecosystems in 2024. Can. Tech. Rep. Fish. Aquat. Sci. 3687: viii + 337 p. https://doi.org/10.60825/hxdg-q818

Young et al. Physical, Chemical and Biological Data Collected from the DFO-PSSI Barkley Sound Euphausiid Monitoring Project, 2024. Canadian Data Report (in progress)

Young et al. Physical, Chemical and Biological Data Collected from the DFO-PSSI Barkley Sound Euphausiid Monitoring Project, 2025. Canadian Data Report (in progress)

Sastri et al. Interannual and seasonal variation of biomass and phenology of dominant euphausiid species in Barkley Sound, 2022-2025. In preparation for primary publication (in progress)

Sastri et al. Interannual and seasonal variation of lipid, protein, and caloric content of zooplankton in Barkley Sound, British Columbia, Canada. In preparation for primary publication (in progress)

Collaborations: PSSI project, “Follow the Fish” co-investigators; University of British Columbia, Prof. Rich Pawlowicz (Physical Oceanography); Bamfield Marine Science Centre; and Ha’oom Fisheries Society

Region: West Coast Vancouver Island

Waterbodies: Barkley Sound, Clayoquot Sound

Species: Chinook, Coho

Highlights

- To apply a combination of monthly plankton biomass, taxonomy, and oceanographic measurements to enhance understanding and characterize: 1) the variability of zooplankton prey availability for first year ocean phase WCVI Chinook; 2) the variability of prey quality; and 3) the potential for predator-prey match-mismatch events (euphausiid phenology). This study also placed a focus on seasonal and interannual availability of the lipid-rich, northern shelf euphausiid, *Thysanoessa spinifera. Key findings:*

- The amount and annual timing of zooplankton groups common to juvenile Chinook diets followed similar seasonal patterns in both Barkley and Clayoquot Sounds; however, the mean biomass of dominant groups, Calanoid copepods, euphausiids, and decapod larvae was greater in Clayoquot relative to Barkley Sound.
- Recruitment to and subsequent development of *T. spinifera* juvenile stages was sufficiently resolved by monthly sampling in Barkley Sound to estimate cohort development and peak abundance timing.
- The mean annual timing of peak *T. spinifera* abundance was June 12th and interannual timing of peak abundance varied widely (60 day range) between project years (2022-2025)
- The long term annual biomass anomaly time series (1991-2013,2022-2025) of Barkley Sound *T. spinifera* was highly variable with correspondence to both winter sea surface temperature anomalies and Robertson Creek Hatchery two-year old survival indicator. *Implications of these findings for salmon and decision-makers:*
- This project was one of multiple 'Follow the fish' (FtF) projects which sought to identify key biological and environmental factors limiting productivity and survival of natural origin WCVI Chinook. Results of this PSSI project demonstrate that long-term, monthly-resolved, prey (zooplankton) monitoring provides valuable prey availability information relevant to early marine survival of juvenile Chinook and can be used to support annual stock assessment model forecast evaluation.

Background

A Marine Risk Assessment for natural-origin WCVI Chinook (Irvine et al. 2024) was carried out on the basis of expert and community engagement via a series of public workshops convened in 2022. A suite of key limiting factors (LF) focused on all life history stages were assessed and ranked according to current and future risk. Three LFs, prey quality (LF12), prey abundance (LF13), and mis-match with prey (L14) were identified with 'high', 'high', and 'moderate' current risk during first marine year when zooplankton are important to diet. Future risk was elevated for each LF to 'very high', 'very high', and 'high', respectively. This project revived a long-term DFO zooplankton time series (1991-2013) in Barkley Sound and established baseline knowledge for zooplankton in Clayoquot Sound through monthly sampling during the FtF period.

The project focused on identifying the current status of the northern shelf euphausiid, *Thysanoessa spinifera*, a lipid rich euphausiid (Fisher et al. 2020), prominent in the diets of multiple salmonids in Barkley Sound (Tanasichuk 1998, Summers 2003) and the Northeast Pacific more broadly (Feinberg and Peterson 2003; Shaw et al. 2013). This project was designed to fill a sampling gap and take advantage of relatively high frequency surveys in two important foraging areas for WCVI juvenile Chinook and characterize current status of and assess prey availability, prey quality, and euphausiid peak timing (LFs 12-14). The project collaborates and supports research with partners at the University of Victoria, University of British Columbia, Bamfield Marine Sciences Center, Ha'oom Fisheries Society and internal DFO partners including those participating in the 'Follow the Fish' (PSSI) project.

Methods and Findings

Sampling stations in Clayoquot Sound and Barkley Sound are identified in Figure 1. Logistical constraints necessitated different sampling approaches for both areas. In Clayoquot Sound, zooplankton were sampled with a 200 μm mesh, 50 cm ring net towed vertically from near bottom to the surface at ~ 1 m s-1. Core sampling stations were initially chosen in alignment with micro trolling surveys and were moved in 2025 to stations identified by red symbols in Figure 1. Additional stations were also sampled on an opportunistic basis. In Barkley Sound, sampling sought to reproduce field methods of Summers (1993) and Tanasichuk (1998). Briefly, 350 μm mesh, 60 cm mouth diameter Bongo nets, were towed obliquely from near bottom to surface. Ascent rate of the net was ~ 1 m s-1 as the ship moved < 2 knots. Zooplankton were sampled after sunset at the four Barkley Sound stations: Coaster, Swale, Robbers, and Mackenzie. Net contents were concentrated and preserved in 10% sodium-borate formalin-seawater solution. In 2022, the contents of the other Bongo net were preserved in 95% ethanol for molecular analysis and then at Robbers station (2023-2025). Starting in 2023, net contents on the other side were frozen and later size fractionated, freeze dried, massed and prepared for protein, total lipid, and energy content measurement. We are midway through this sample processing. Full water column properties were measured with a Seabird 19+ CTD at Sarita and Swale until September 2023 and then at all stations for subsequent surveys. Discrete seawater samples were collected for nutrients, phytoplankton taxonomy, and chlorophyll *a* (phytoplankton biomass) at all five stations. Surface- and deep salinity and nutrients were also sampled at Sarita and Swale stations.

Zooplankton samples were enumerated by taxonomists based at the Plankton Ecology laboratory, Institute of Ocean Sciences, Sidney, BC, according to Mackas (1992) and Lu et al. (2003). All taxonomic enumeration was resolved to species and stage where possible. For comparing biomass in both Sounds, we focused on the coarse taxonomic categories used for prey identification in stomach contents of juvenile Chinook. The biomass of calanoid copepods and euphausiids dominated in both Clayoquot and Barkley Sound during FtF project years. Peak timing of calanoid copepods was spring and late-summer/autumn for euphausiids in both areas (Figure 2). Decapod larvae biomass followed calanoid copepods and euphausiids. The biomass of these three groups was greater on average in Clayoquot relative to Barkley Sound, whereas, Amphipod biomass was greater in Barkley relative to Clayoquot Sound.

Juvenile and adult euphausiids were measured to the nearest millimeter (total body length) using a stage micrometer. Body length and stage were used for cohort visualization (Figure 3.) and timing estimates. The timing of peak *T. spinifera* abundance was estimated from the regression of cumulative abundance of 5-9 mm juveniles against day of year, where date of maximum abundance corresponded to 50% of maximum cumulative abundance. Interannual variability of peak timing was high (Figure 3.) Peak timing in 2022 was estimated to occur late on July 20th versus early timings of May 20th and June 1st in 2023 and 2024. Timing in 2025 was June 9th and close to the four year mean date, June 12th. The long term time series of *T. spinifera* population biomass (Figure 4.) in Barkley Sound, La Perouse banks, and the Northern Vancouver Island shelf tended to covary. A similar pattern for *Euphausia pacifica* was not evident. The survival of two year old RCH Chinook was significantly correlated ($p < 0.05$) with the Barkley Sound *T. spinifera* population, however, additional analysis suggests that this is not a causal relationship but likely a common response to an unmeasured environmental factor. Similar relationships were found for *T. spinifera* La Perouse Banks and NVI populations; however, they were weaker and non-significant, suggesting the importance local conditions.

Insights

This project provides detailed environmental information including prey availability for a WCVI Chinook salmon life history stage, first marine year, particularly vulnerable to mortality (Irvine et al. 2024). Data collected for this project provides monthly resolved, taxonomically detailed, census of the zooplankton assemblages in two WCVI Chinook foraging grounds, Barkley and Clayoquot Sounds. This type of monitoring is necessary for developing an understanding of what drives variability of the prey (zooplankton) field encountered by juvenile Chinook; and provides important life stage information supporting evaluation of stock assessment forecasts by salmon managers. This program provides the basis for a deeper insight into how variation of physical conditions (e.g. temperature, water mass) influence year to year changes in the timing of a key prey species, *Thysanoessa spinifera*. The method applied here may be applicable to other prey groups but may also provide added information for release timing strategies.

Next Steps

This PSSI funded project provided the basis for demonstrating that routine monthly-resolved sampling in Barkley and Clayoquot Sounds is suitable for capturing variation of zooplankton composition, biomass, and food quality, at scales relevant to the first marine year for WCVI juvenile Chinook. Monitoring in both areas either contributed to the start or revival of ‘prey’ monitoring programs. The utility of the preliminary results presented here makes a good case for maintaining focused plankton monitoring in Clayoquot and Barkley Sounds, but also establishing similar programs in other foraging areas along the WCVI.

Tables and Figures

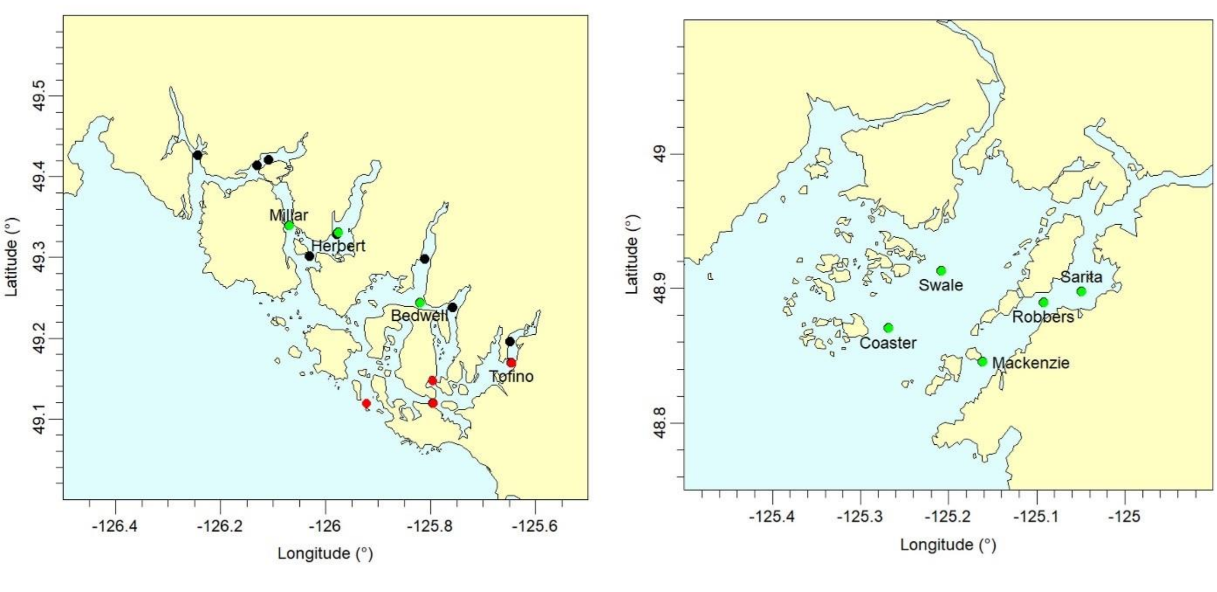


Figure 1. Station map of PSSI plankton monitoring stations in Clayoquot Sound (left) and Barkley Sound (right). Clayoquot Sound stations were sampled on a monthly basis between 2023-2025 and Barkley Sound stations were

sampled on a monthly (February to November) basis, 2022-2025 Core sampling stions in Clayoquot Sound identified with green (2023) and red and black (2025) symbols identify stations sampled opportunistically.

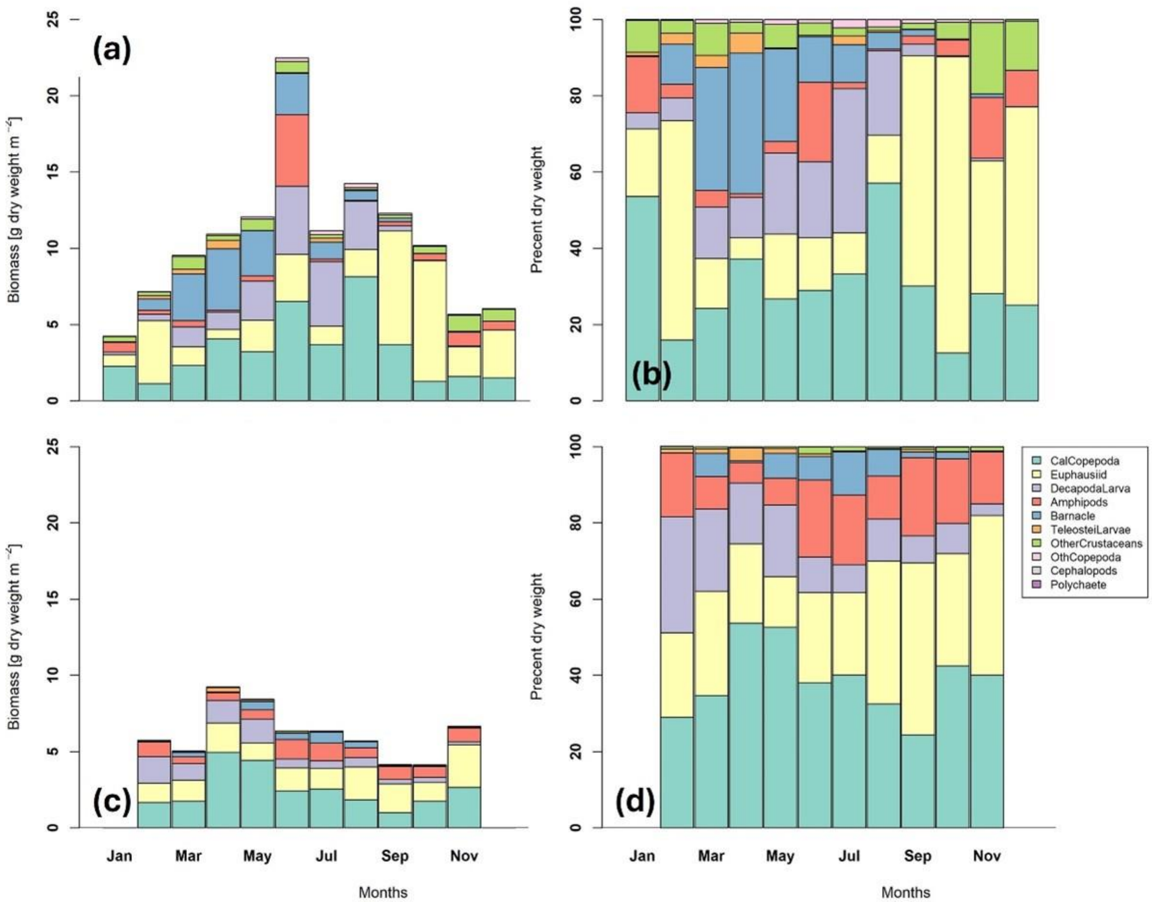


Figure 2. Annual cycle of net zooplankton sampled monthly in Clayoquot Sound (upper panels, 2023-2025) and Barkley Sound (lower panels, 2022-2025), British Columbia. Panels (a) and (c) represent biomass (mg dry weight m^{-2}) averaged within month and partitioned by plankton grouping common to local juvenile Chinook stomach contents and the relative division of biomass among these groups is illustrated in panels (b) and (d).

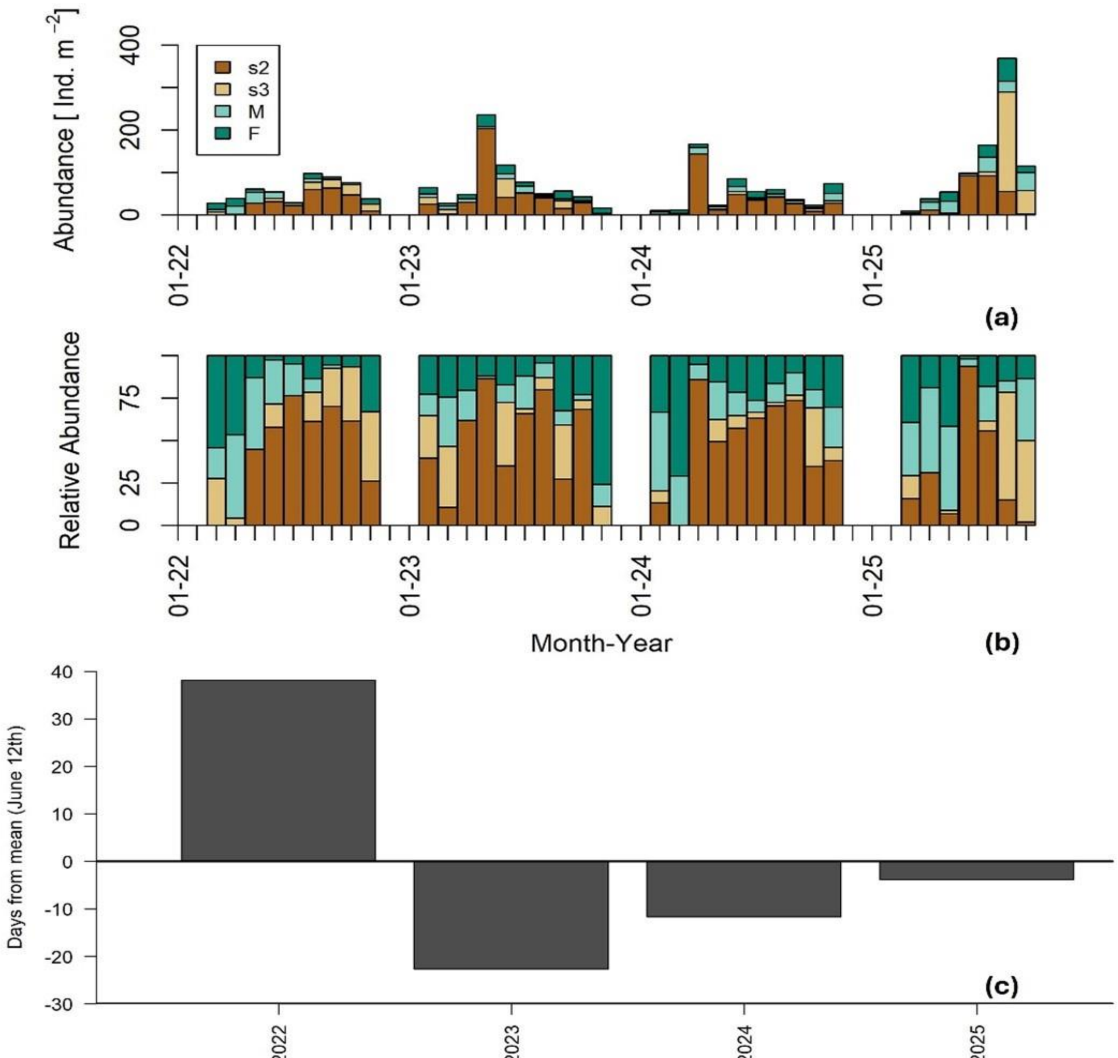


Figure 3. Temporal patterns of the: a) abundance (Number individuals m^{-2}) ; b) relative abundance; and c) relative timing of peak abundance of Thysanoessa spinifera Barkley Sound, British Columbia. Stacked bars represent: 5-9 mm juveniles (s2) ;10-15 mm juveniles (s3); adult males (M); and adult females (F).

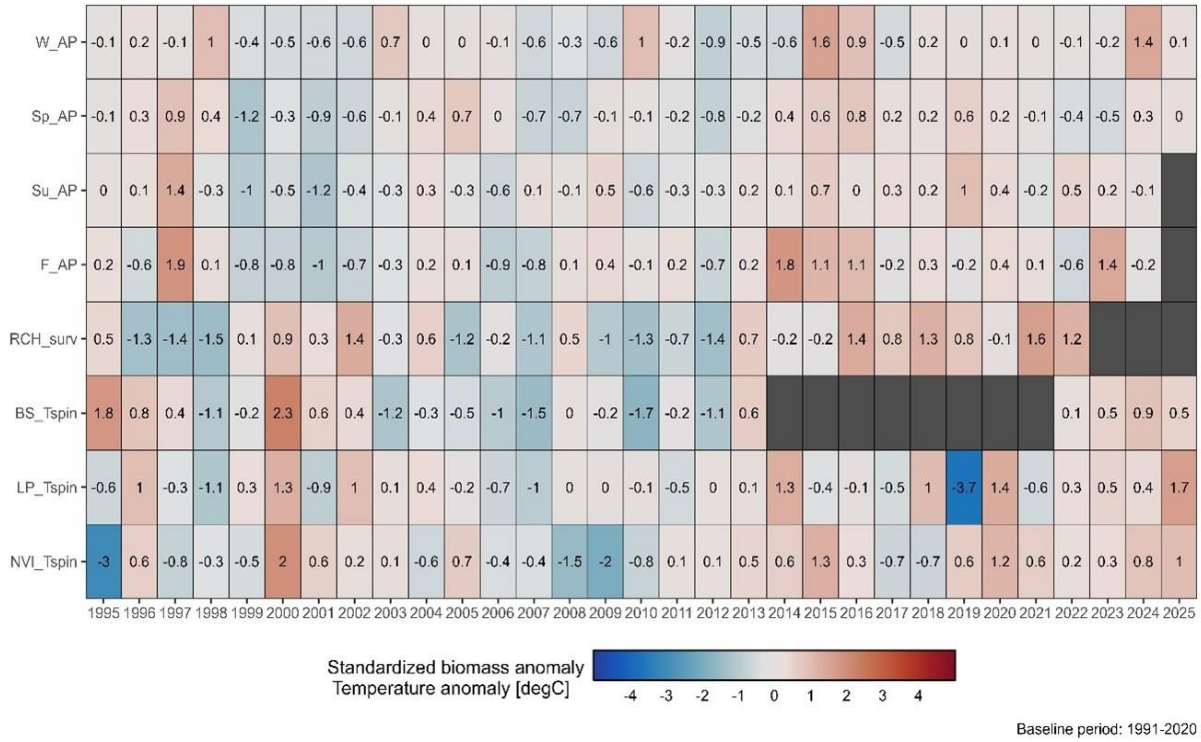


Figure 4. Heatmap of seasonal sea surface temperature anomalies (°C) at Amphitrite Point lighthouse (AP) and standardized annual biomass anomalies for the euphausiid, Thysanoessa spinifera (Tspin) in Barkley Sound (BS), La Perouse banks (LP), and the northern shelf of the West Coast of Vancouver Island (NVI). Standardized time series of estimated survival to age two via Robertson Creek Hatchery (RCH) indicator coded wire tag recoveries (Brown 2024). Biomass and survival anomalies for each time series were standardized to their respective mean. The number of standard deviations from the mean is printed in each box and colour-scaled accordingly. Blue and red shades represent values below and above the climatological mean, respectively.

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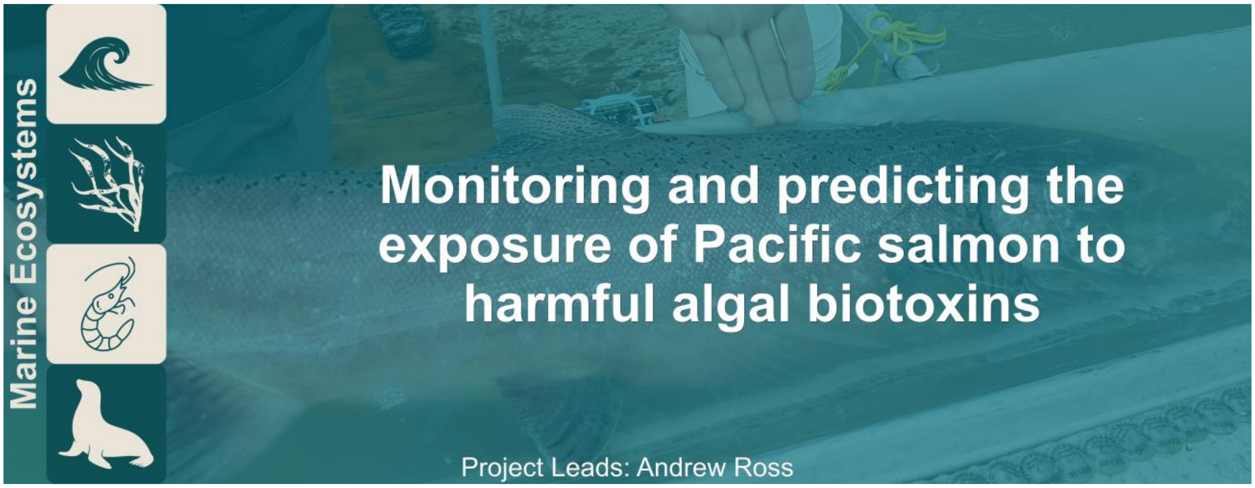
2416 - Predicting Salmon Exposure to Harmful Algal Biotoxins



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Ross, A.R.S., Matthews, N., Mueller, M., et al. Harmful Algal Biotoxin Data Collected from the DFO-PSSI Follow the Fish Project, 2023-2025 (Data Report; in progress).

Mueller, M. et al. Exposure of juvenile west coast Vancouver Island Chinook salmon to harmful algal biotoxins in Barkley Sound (Journal Article describing the key findings of this project; in progress).

Collaborations: Cermaq Canada (Aquaculture Transition/CSRF); Pacific Salmon Foundation (Citizen Science Program/CSRF); and Snuneymuxw First Nation

Region: West Coast Vancouver Island

Waterbodies: Barkley Sound

Species: Chinook

Populations: Sarita, Robertson

Highlights

- Assessed the Risk posed by harmful algal biotoxins to juvenile WCVI Chinook in their critical habitat.
- Juvenile WCVI Chinook salmon are exposed to and take up harmful algal biotoxins in Barkley Sound.
- Biotoxins known to harm fish peak in summer/Fall in Barkley Sound in both water and fish tissues.
- Results suggest that biotoxin exposure/impacts could be mitigated e.g. via timing of hatchery releases.

Background

Biotoxins produced by harmful algae are know to cause illness and mortality in marine animals including juvenile fish (Lefebvre et al., 2005). Regular monitoring of harmful algal biotoxins in B.C. coastal waters since 2020 (Ross et al., 2025b) has revealed significant correlations between climate variables (e.g. water temperature) and the concentrations of these toxins in areas known to be frequented by Pacific salmon. These include at-risk WCVI Chinook salmon populations, for which harmful algae were identified as an emerging threat during the WCVI Chinook Rebuilding Plan Marine Risk Assessment (MRA) Workshop #3 held in April 2022. However, the levels of harmful algal biotoxins to which juvenile WCVI Chinook salmon are exposed in critical habitats such as Barkley and Clayoquot Sounds are unknown. This is an important knowledge gap, given that low early marine survival is contributing to declines in WCVI Chinook and other Pacific salmon populations.

The goal of this PSSI 'Follow the Fish' project was to build upon our Biotoxin Monitoring Program (Ross and Mueller, 2024) by adapting established analytical methods and procedures to measure harmful algal biotoxins in juvenile WCVI Chinook salmon tissues (gill, liver) and habitat (Barkley Sound) using samples collected by 'Follow the Fish' krill and salmon survey teams, in partnership with local First Nations. This information is being combined with environmental data (water properties, eDNA), assessments of fish health and condition (biometrics, gene expression), and information on life history (otolith microchemistry) to help forecast and potentially mitigate early marine exposure of WCVI Chinook salmon to harmful algal biotoxins, and associated impacts on their health and survival.

Methods and Findings

Harmful algal biotoxins were measured in sea water using the method developed for our Marine Biotoxin Monitoring Program (Ross and Mueller, 2024). Surface sea water was collected at 5 locations in Barkley Sound (Fig. 1) during krill surveys carried out at the beginning of each month and filtered on board to obtain filter and filtrate samples, from which biotoxins were extracted and analyzed by liquid chromatography and tandem mass spectrometry to obtain dissolved and particulate biotoxin concentrations (Ross et al., 2025a). These were combined to obtain monthly values of total biotoxin concentration at each location (Fig. 2). To assess exposure to harmful algal biotoxins, juvenile WCVI Chinook salmon captured by purse seining close to krill survey locations were dissected to obtain gill and liver tissue samples, which were pooled as necessary to obtain sufficient material for analysis.

Products and tools developed during this project include a Regional Biotoxin Database (in progress) for organizing, storing and retrieving biotoxin and related environmental, biological, and taxonomic information for sea water and biological samples collected during this project (and the Marine Biotoxin Monitoring Program) with the goal of making it available to co-workers via DMApps.

Advances in methodology during this project include procedures to minimize cross-contamination while dissecting and pooling of tissues for biotoxin analysis, and adaptation of the method for sea water analysis to measure harmful algal biotoxins in very small amounts of tissue, thereby allowing them to be studied in individual fish, organs and/or early life stages (Mueller et al., in preparation).

Examples of communication and knowledge transfer include a Newsletter (Ross and Loseto, 2025) that describes the monitoring of biotoxins and contaminants during the PSSI 'Follow the Fish' project. Results from the monitoring of biotoxins in Barkley Sound during fall 2023 were also included in a report prepared for Snuneymuxw First Nation (Ross, 2024) on the measurement of harmful algal biotoxins near Nanaimo at the same time, to provide context for the interpretation of those results. Knowledge about seasonal trends in biotoxin concentration obtained during this project, and how it can be used to mitigate risks associated with biotoxin exposure in juvenile salmon through the timing of hatchery releases, was presented during a Fish Health & Hatchery Biology Seminar (Ross, 2025).

Key results include:

- detection and identification of seasonal patterns in the concentrations of harmful algal biotoxins in Barkley Sound, including those know to be harmful to juvenile fish (Fig. 2).
- detection of certain biotoxins in the tissues of juvenile WCVI Chinook salmon present in Barkley Sound when those biotoxins are relatively abundant in the surrounding water (June to September).
- recognition that WCVI Chinook are being exposed to harmful algal biotoxins in their critical habitat during early marine life stages.

Insights

This project has revealed that juvenile WCVI Chinook salmon present in Barkley Sound during late summer are exposed to harmful algal biotoxins at levels sufficient to cause uptake in their tissues.

- biotoxins present in Barkley Sound follow seasonal trends similar to those observed elsewhere in B.C. coastal waters (Fig. 2).
- juvenile WCVI Chinook salmon in Barkley Sound are exposed to increasing levels of algal biotoxins from May onwards, particularly at central and outer locations (Coaster, Swale, Mackenzie: Fig. 1).
- exposure of juvenile WCVI Chinook salmon to biotoxins is confirmed by detection of domoic acid, yessotoxin, and the paralytic shellfish poisoning (PSP) toxin saxitoxin in gill and/or liver tissue from purse seined fish caught in Barkley Sound in late summer 2023 and/or 2024.
- Robertson fish appear to accumulate higher levels of biotoxins than Sarita fish caught at the same time and place. For example, only Robertson fish tissues contained PSP toxins, which is consistent with eDNA evidence suggesting that PSP-producing algae (*Alexandrium* spp.) may have been present in Alberni Inlet during their migration to Barkley Sound, and with otolith microchemical data confirming salt-water entry.

- levels of biotoxins detected in tissues seem to correlate with those in the surrounding water (Fig. 3). Results from our Marine Biotoxin Monitoring Program suggest that certain biotoxins including those harmful to juvenile fish are trending upwards in B.C. coastal waters, and that higher biotoxin levels may be associated with climate-related factors such as increasing temperature and/or nutrient limitation due to stratification caused by higher temperatures or freshwater inputs (Ross at al., 2025).

Tools are being developed (CSRF project 2025-26-11-07) to predict future levels of biotoxin exposure and uptake based upon linkages with environmental conditions measured at the same time. This will allow DFO to forecast and potentially mitigate levels and impacts of biotoxin exposure in WCVI Chinook; for example, by timing the release of hatchery fish to minimize exposure (Ross, 2025).

Meanwhile, gene expression analysis is being carried out (Art Bass et al.) to see whether observed levels of biotoxin exposure result in stress responses, biological effects and/or health impacts in juvenile salmon, thereby helping to identify biologically significant thresholds of exposure for these limiting factors.

We are working with the Contaminants group (Lisa Loseto et al.) to investigate the separate and cumulative effects of biotoxins and contaminants on juvenile WCVI Chinook salmon, taking advantage of the observed seasonal trends in biotoxin exposure.

We are also working with the Otolith Microchemistry group (Nicole LaForge, Micah Quindazzi) to relate biotoxin exposure and impacts to life stage and history (e.g. estuary residence time, age at entry) for specific populations (Sarita, Robertson), and with the eDNA group (Christoph Deeg et al.) on interactions of juvenile WCVI Chinook salmon with harmful algae and other marine species.

In addition to providing total biotoxin concentrations, the analysis of filter and filtrate samples (Ross et al., 2025a) allows us to compare biotoxin levels in different salmon tissues with dissolved and particulate biotoxin concentrations in the surrounding water, and to see if the data support a particular pathway of exposure (e.g. uptake via ingestion would likely give a better correlation with particulate biotoxins whereas uptake via gills would likely correlate better with dissolved biotoxins).

The analytical tools used in this project (e.g. high performance liquid chromatography and tandem mass spectrometry) provide a high degree of confidence in the measured concentrations of harmful algal biotoxins in sea water and fish tissues. However, the west coast of Vancouver Island is a highly dynamic environment while the lifecycles of anadromous fish like WCVI Chinook salmon extend beyond the 3-year timeframe of this PSSI project. Consequently, more data is needed to confirm our initial findings. Ideally, this would involve the collection and analysis of samples and data for at least another 2 years, work that is current planned for the CSRF Project “Linking climate variables to algal biotoxin production and impacts on Pacific salmon” (2025-26-11-07) which runs until March 31, 2028.

Next Steps

Remaining knowledge gaps include additional monitoring data with which to establish longer-term trends in biotoxin production in Barkley Sound and how these may relate to climate change. They also include future data on adult returns and indicators of health, recruitment, etc. for salmon that were exposed to the observed concentrations of biotoxins in Barkley Sound during this project (i.e. from July 2023 to November 2025). This will allow long-term risks associated with 'carry forward' impacts of biotoxin exposure to be assessed, along with any early marine life stage impacts revealed by gene expression analysis and/or biometric indicators of fish health in juvenile salmon during this project.

Meanwhile, the findings of this project can be operationalized by incorporating information on the temporal and spatial distributions of harmful algal biotoxins in Barkley Sound (Figs. 1 and 2) into the scheduling of hatchery releases for different populations (Sarita, Robertston) based on knowledge of their migration behaviour (incl. salt water entry and estuarine residence times) to minimize biotoxin exposure and impacts in juvenile salmon. The observed relationships between biotoxin levels in fish tissues and dissolved, particulate and/or total biotoxin concentrations (Fig. 3) in the surrounding water can also be used to help identify pathways of exposure and evaluate current and future risks posed by measured and projected biotoxin concentrations to juvenile WCVI salmon in Barkley Sound.

Tables and Figures

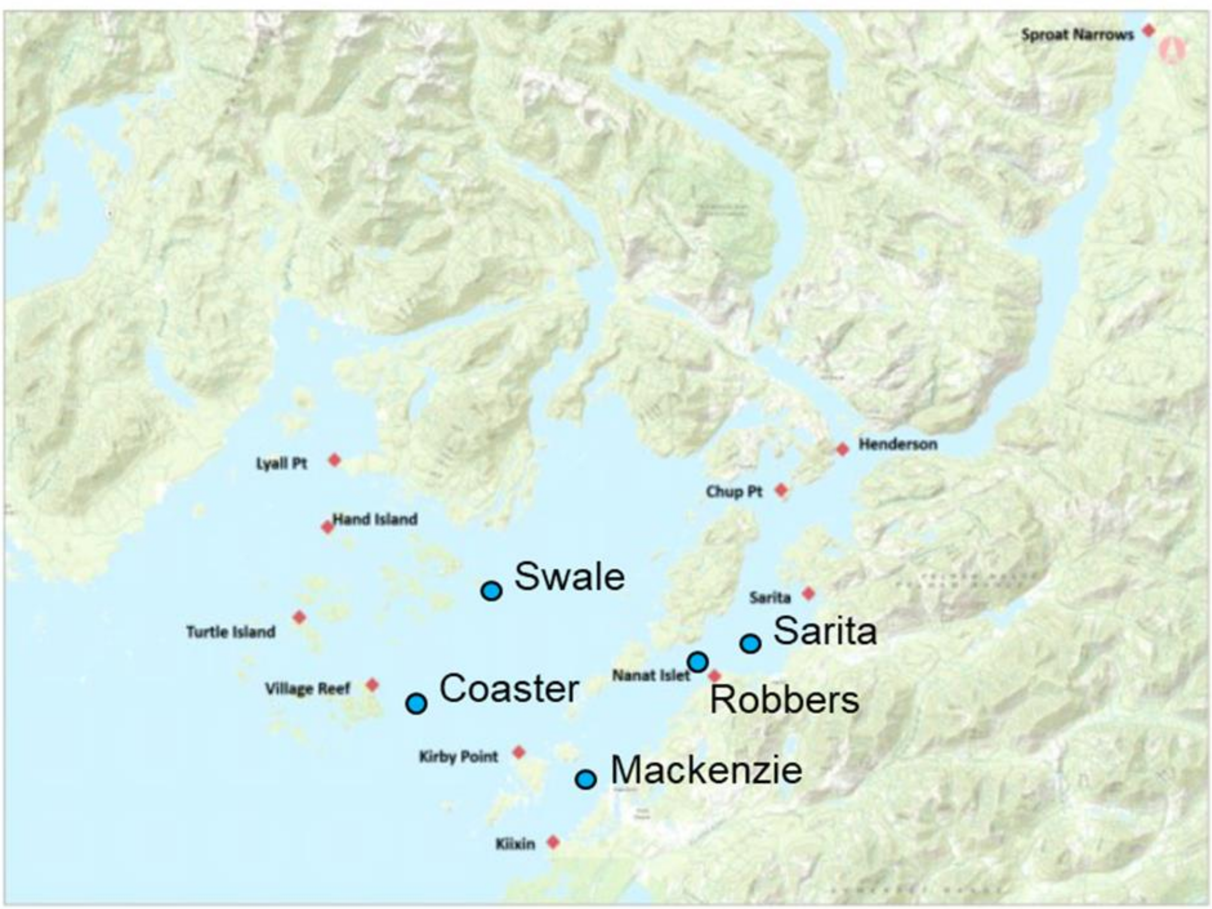

Figure 1. Krill survey sites (blue circles) in Barkley Sound where water samples were collected for biotoxin analysis, and salmon survey locations (red diamonds) including those close to krill survey sites, where juvenile WCVI Chinook were caught and analyzed for biotoxins in gill and liver tissues.

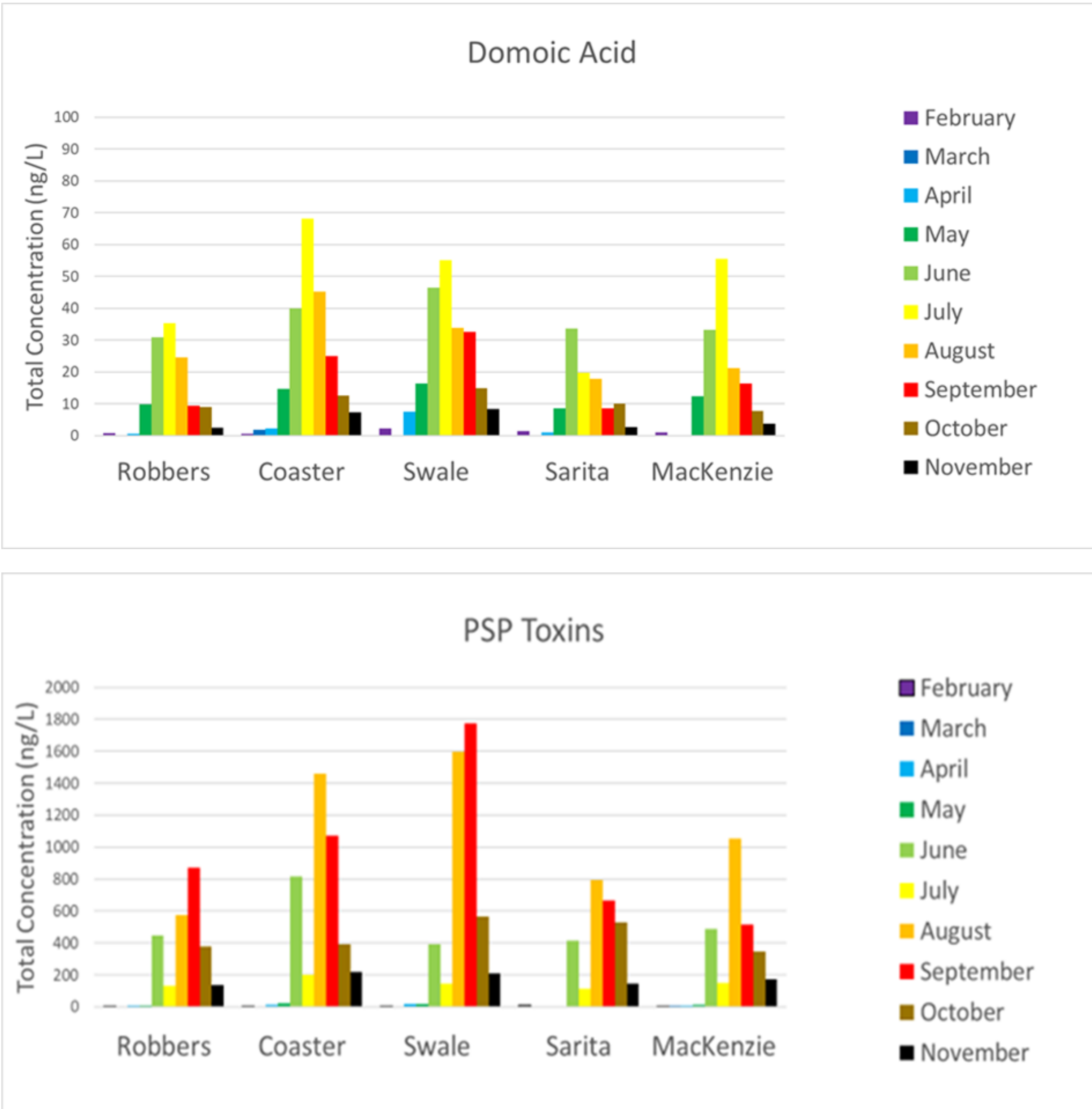

Figure 2. Total concentrations of the harmful algal biotoxin domoic acid (upper panel) and paralytic shellfish poisoning (PSP) toxins (lower panel) at krill survey sites in Barkley Sound during 2024. These toxins, which are known to harm juvenile fish, were most abundant between June and September.

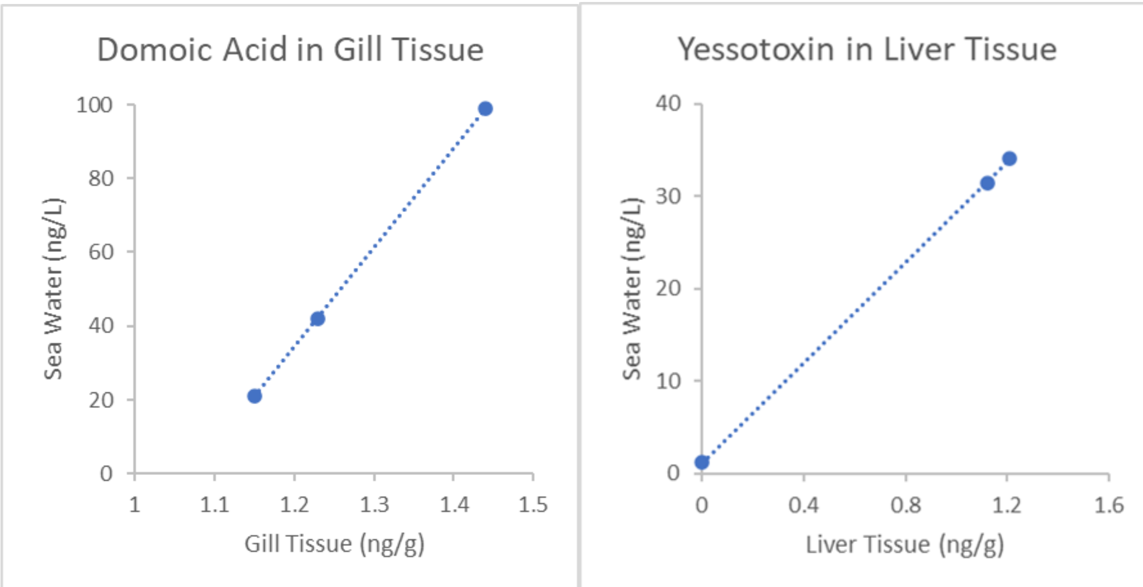

Figure 3. Concentrations in sea water versus gill tissue for domoic acid (left panel) and liver tissue for yessotoxin (right panel) in juvenile WCVI Chinook salmon caught July to September 2023 at Coaster.

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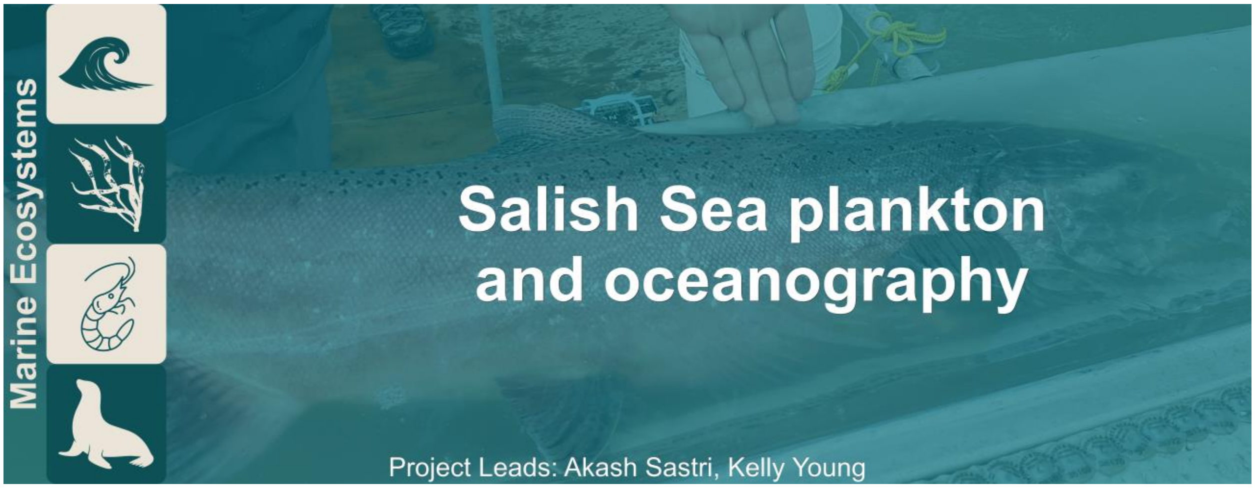
2427 - Salish Sea Plankton and Oceanography Monitoring



Young, K., Galbraith, M., Sastri, A., and Perry, R.I. Zooplankton status and trends in the central and northern Strait of Georgia, 2023. In Boldt, J.L., Joyce, E., Tucker, S., Gauthier, S., and Dosser, H. (Eds.). 2024. State of the physical, biological and selected fishery resources of Pacific Canadian marine ecosystems in 2023. Can. Tech. Rep. Fish. Aquat. Sci. 3598: viii + 315 p

Young, K., Galbraith, M., Sastri, A., and Perry, R.I. Zooplankton status and trends in the central and northern Strait of Georgia, 2024. In Boldt, J.L., Joyce, E., Tucker, S., Gauthier, S., and Jackson, J. (Eds.). 2025. State of the physical, biological and selected fishery resources of Pacific Canadian marine ecosystems in 2024. Can. Tech. Rep. Fish. Aquat. Sci. 3687: viii + 337 p.

Region: Strait of Georgia

Waterbodies: Strait of Georgia

Highlights

- Main idea was to apply a combination of frequent (biweekly-monthly) plankton biomass, taxonomy, productivity, and oceanographic measurements to characterize and enhance understanding of prey availability for early marine phase salmonids in the Strait of Georgia, British Columbia, Canada. *Key findings:*
- Biomass of key prey groups, euphausiids, amphipods, and decapod larvae, was greater than the long-term baseline (1996-2021); but each varied by ~2-3X between project years (2022-2025).
- Total biomass for all zooplankton was also above the long-term mean during 2022-2025 but less variable between years (~1.25X).
- The efficiency of energy transfer (TTE) between phytoplankton and zooplankton was directly measured for the first time in the Strait of Georgia. Seasonal variability was larger than interannual and the pattern was consistent across years. On average, annual upper water column estimates of the proportion of phytoplankton production available to consumers of zooplankton was between ~7-15%. TTE in the central and southern Strait of Georgia was elevated relative to the north during the productive spring/summer seasons. *Implications of these findings for salmon and decision-makers*

- A robust model for juvenile Cowichan Chinook juvenile survival (Perry et al. 2021) is being used to compare against routine FM forecasts. Predictions using this model are highly sensitive to variation of total zooplankton biomass and sea surface properties. We have introduced additional information about food web efficiency which complements this modeling by adding quantitative information facilitating calculation of potential yield based on production at the base of the food web. This information is important to development/refinement of ecosystem-scale approaches to stock assessment.

Background

Management of salmon stocks relies on the success of adult return forecasts, which in turn rely on good census of animals at key stages of their life history. Mortality during early life history stages, freshwater and early ocean, can be high (Beamish and Mahnken, 2001). Factors hypothesized to influence juvenile survival during early ocean phase include size at age, predation, and environmental variability which includes prey availability (amount and timing) and prey quality (Irvine et al. 2024). The Strait of Georgia is an important foraging habitat for all salmon species originating in the Fraser River and some East Coast Vancouver Island watersheds. This large marine estuary is subject to anthropogenic pressures (ship traffic, urbanization) and significant climate variability including increasing frequency of marine heatwaves which can disrupt seasonality and alter the type and amount zooplankton prey available to juvenile salmon.

This project was focused on the zooplankton component of prey availability for out-migrating fish in the Strait of Georgia. Our objective was to take advantage of relatively high frequency (biweekly-monthly) plankton sampling in an effort to characterize seasonal, interannual, and spatial variability of: 1) the biomass of bulk zooplankton and groups targeted by juvenile salmonids; and 2) apply novel methods to measure productivity at the base of the food web and estimate the potential energy available to consumers of zooplankton in the Strait of Georgia. Sampling, development, and implementation of plankton productivity measurements was carried as part of long-term DFO programming in the Salish Sea, supplemented with DFO-PSSI funding support. The project collaborates and supports research with academic partners at the University of Victoria and University of British Columbia as well as the Pacific Salmon Foundations ‘Citizen Science program’ and ‘Bottlenecks’ programs.

Methods and Findings

Zooplankton monitoring

Seasonal monitoring of zooplankton relied on taxonomic enumeration of zooplankton samples collected throughout the Strait of Georgia from one of several vessels, CCG *Neocaligus*, CCG *Vector*, CCG *Tully*, CCG *Franklin*, R/V *Richardson Point* and R/V *John Strickland*, during the 2022-2025 project period (Figure 1). Zooplankton were sampled using vertical tows with ~60 cm mouth diameter, 250 μm mesh SCOR or Bongo nets. Both nets have similar sampling efficiencies (McKinnell and Mackas 2003) and have been used consistently since 2015. Nets were equipped with calibrated flow meters and towed vertically at 1 m s^{-1} from ~ 10 m above bottom to the surface. Net contents were concentrated and preserved in 10% sodium-borate formalin-seawater solution. Samples were enumerated at the Plankton Ecology laboratory, Institute of Ocean Sciences, Sidney, BC, according to Perry et al. (2021).

Crustacean zooplankton composition in the Strait of Georgia was relatively unchanged relative to the years leading up to 2022. Two groups common to juvenile salmon and forage fish stomach contents, were: 1) calanoid copepods, which dominated total biomass most years and regions with biomass developing through late-winter/spring to a seasonal maximum in late spring; and 2) euphausiids were also dominant with a later seasonality, typically reaching annual maxima in late summer, but this pattern varied between region and project years. On annual timescales, biomass anomalies for total biomass and the four common zooplankton prey groups (calanoid copepods, euphausiids, amphipods, and decapod larvae) were greater than their long term mean (1996-2021). Biomass anomalies for all groups have been positive since 2018 and euphausiids, decapod larvae, and amphipods, since 2015 (Figure 2).

Plankton productivity and trophic transfer efficiency

A subset of three deep-water (> 300 m) stations (Figure 1, red symbols) were selected for measurement and comparison of plankton production rates and calculation of energy transfer efficiency (commonly referred to as trophic transfer efficiency, TTE) between phytoplankton and crustacean zooplankton. Both seasonal and annual production rates were measured and TTE estimated as the ratio of crustacean zooplankton to phytoplankton production rates. *Crustacean zooplankton biomass production rates (BPR)*: We used a field application of a biochemical method based on the amount and rate at which the crustacean zooplankton moulting enzyme, chitobiase, is released into the water column (Sastri and Dower 2009). Briefly, seawater samples were collected from multiple standard depths spanning the depth range of net tows; incubated and serially subsampled for 24 hours to follow the rate of enzyme decay. Chitobiase activity in seawater subsamples was measured with a fluorometric assay and depth-specific production rates calculated on the basis of published relationships between zooplankton somatic growth and enzyme activity. *Gross phytoplankton production rates (GPP)*: An active fluorescence approach was used to measure the efficiency with which phytoplankton in seawater samples convert sunlight to chemical energy, photosynthetic yield (Schreiber 1986, Kolber and Falkowski, 1993). Seawater samples were collected at multiple depths within the euphotic zone; each depth-specific sample was incubated for ~30 minutes in a single turnover active fluorescence instrument, LabSTAF. The instrument measures phytoplankton photosynthetic response parameters by varying light exposure during incubation. Measurements of above- and below-surface photosynthetically active radiation (PAR) were then applied to photosynthetic yield curves to estimate GPP.

This is a novel application of plankton productivity measurements in the Strait of Georgia. Similar measurements were carried out by Suchy et al. (2016) and Venello (2021) in Saanich Inlet and the West Coast of Vancouver Island, respectively, but direct estimates of TTE, applicable at ecosystem scales are otherwise rare. This multi-year, seasonally resolved TTE time series for coastal British Columbia is valuable to annual ecosystems assessment. TTE was variable on a seasonal basis, reflecting seasonal trends of both crustacean zooplankton and phytoplankton production rates and biomass. Although production rates for both groups was high in spring, upper water column TTE was typically low (< 10%) because phytoplankton production rates outpaced zooplankton rates. More efficient energy transfer was consistently measured in summer and fall. On an annual basis, TTE varied between 11.75-32.20%. Interannual variation was greater than variation between region-stations. Overall, TTE was greatest at the central station. Deep, basin-scale TTE was 17.14, 21.0, and 23.5% in 2023, 2024, and 2025. These estimates are in the top end of the Ware and Thomson (2005) range (10-20%) and comparable to 23% estimated by Sastri and Dower (2009) for the central Strait of Georgia in 2004 and 2005.

The information generated by these project activities provide ecosystem-relevant metrics of prey availability which are immediately applicable and currently used for statistical juvenile survival models (e.g. Perry et al. 2021) and directly applicable to continued development and 'tuning' of biophysical numerical models (e.g. Pena et al. 2016, Olson et al. 2020). Observation-based validation of these approaches provides valuable reference for evaluating stock assessment forecasts.

Insights

This project provides detailed environmental information on prey availability and ecosystem function for a salmon life history stage particularly vulnerable to mortality. Data collected for this project is valuable because it integrates rate information, productivity at the base of the food web, with state information about prey, type, quality, and availability. Continued application and regular improvement of the Perry et al. (2021) statistical models for juvenile Cowichan Chinook and Big Qualicum coho can continue to be applied in support of DFO forecasting. The original model benefitted from high frequency collections, 2015-2018. This project extends the duration of this information-rich time series to 2025, potentially improving forecasting skill and supporting expansion to other salmonid populations reliant on the SoG as a nursery ground.

DFO adoption of the ecosystem approach to fisheries management (EAFM; Pepin et al. 2023) is currently under review. This approach aims to inform decision making based on traditional single stock assessments with information on climate, oceanographic conditions and predator-prey relationships. This project provided an opportunity to apply and explore the value of measuring lower trophic productivity and transfer efficiencies in keeping with EAFM principles. We have found that the ecosystem-level tools used in this project can be applied as part of a routine monitoring program. Moreover, we have found that rates of plankton production and how they influence resource availability, TTE, vary at temporal (monthly, seasonal, and annual) and spatial (local, region, basin) scales relevant to consumers of zooplankton. Critically, these measurement tools provide information at sea or else within days of sample collection, allowing for *rapid* assessment of ecosystem scale changes (e.g. early/late productivity events or unanticipated changes to plankton) relevant to fisheries management.

Next Steps

Detailed methods development, full results summary, and detailed analyses of the data sets generated by this project are underway and most communication will be via data sharing, technical reporting, and peer reviewed publications. This project was proposed, in part, to fill gaps in our knowledge of spatial-temporal variability of plankton assemblages in the Strait of Georgia. Expansion of productivity stations from regionally representative stations to include areas/stations targeting specific populations of forage fish and juvenile salmonids is an important next step toward refining application and utility of this approach to stock assessment.

Tables and Figures

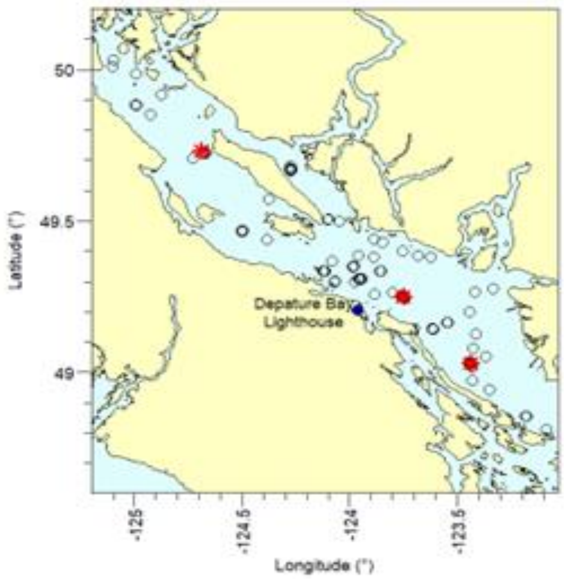


Figure 1. Location of enumerated zooplankton sample stations in the northern, central, and southern Strait of Georgia (2023-2025). Red symbols designate location of productivity stations representing northern, central, and southern regions.

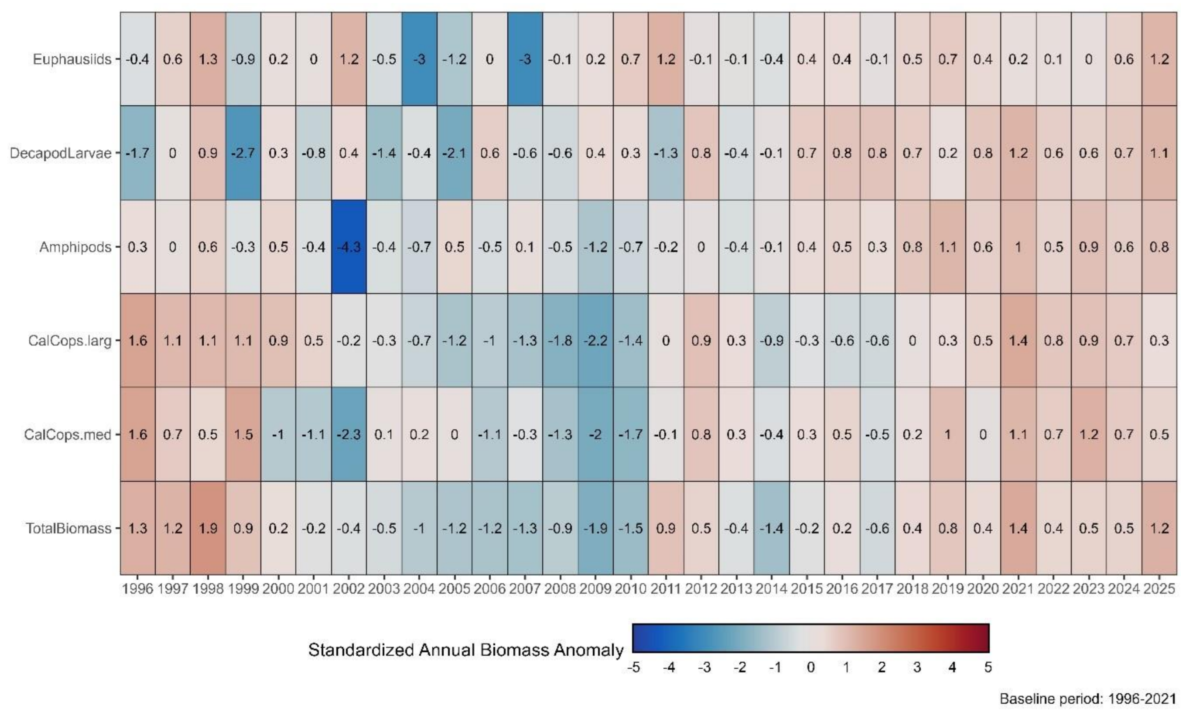


Figure 2. Heatmap of annual biomass anomalies for total zooplankton and crustacean groups common to stomach contents of juvenile salmonids in the Salish Sea (Osgood et al. 2016). Anomalies for each time series are standardized to their respective mean. The number of standard deviations from that mean printed in each box which are colour-scaled accordingly (blue and red shades represent values below and above the climatological mean, respectively.

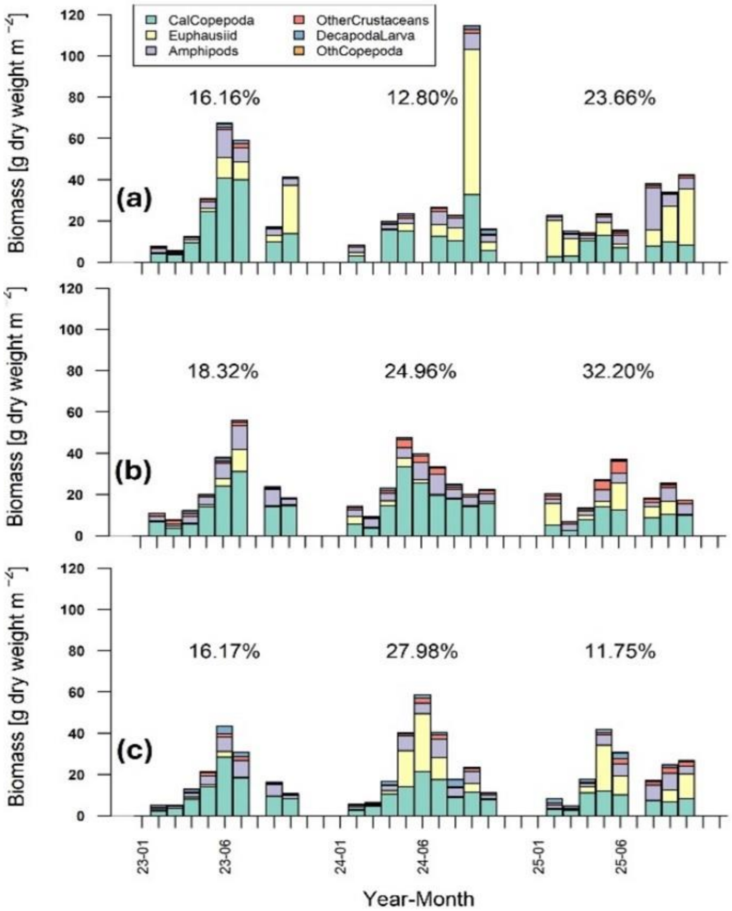


Figure 3. Stacked bar plots of monthly averaged crustacean zooplankton biomass (mg dry weight m^{-2}) partitioned into dominant groups in the Salish Sea (as per Young et al. 2024). Annual trophic transfer efficiencies (%) for each regional station, a) northern Station 12; b) central Station GEO1; and c) southern Station 42, are printed above each annual bar plot.

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2433 - Integrated Salish Sea Acoustic Monitoring

Collaborations: Akash Sastri, Kelly Young, Jennifer Boldt, Chris Rooper, Doug Bertram

Region: Strait of Georgia

Highlights

- Large scale acoustic surveys within the Salish sea indicate the presence of Pacific hake (a significant source of potential predation for juvenile salmon) throughout the northern section of the Salish sea, with increasing biomass over the past years. In the southern area, walleye pollock (another potential predator for juvenile salmon) is also showing sign of increasing biomass.
- Fine temporal scale monitoring in nearshore coastal areas of the Strait indicate low abundance of juvenile salmon compared to juvenile Pacific herring, suggesting high levels of competition for food.
- Nearshore echosounder moorings (including some with cameras) revealed a wide array of potential predators for juvenile salmon, but surface predation from birds and/or marine mammals were not as frequent as observed in nearshore coastal areas of Barkley Sound.
- Deeper echosounder mooring in the central Strait of Gorgia revealed that Pacific hake (predators) were present almost year-round.

Background

Fisheries acoustics can be used to answer a number of questions related to Salmon ecology and dynamics. On large spatial scales, acoustic surveys are used to assess salmon prey (e.g forage fish and krill) conditions within the Salish Sea, identify prey hotspots, key predators of juvenile salmon, and assess changes in productivity through time. On a finer temporal scale, moored autonomous echosounders can provide information on juvenile salmon coastal habitat use, in conjunction with prey availability and predation pressures.

Autonomous echosounder system were used to address key elements affecting juvenile salmon during the first stage of marine life, including juvenile salmon use of coastal areas (time spent in key areas and within the water column), the prey conditions (e.g. euphausiids dynamic) they encounter in the Salish Sea, and the competition and predation pressures that affect them.

Methods and Findings

We used active acoustics methods as a remote sensing tools to assess the salmonsphere (salmon as well as their prey and predators). Large scale fisheries acoustic surveys conducted within the Salish Sea are used to assess marine conditions and the abundance and distribution of key prey species and predators for salmon. On a finer temporal scale, we used moored inverted echosounders to monitor juvenile salmons (and salmonsphere ecosystem components) in nearshore habitats and within the larger Strait of Georgia basin.

This project used the same methods as described for project 2432. More specifically, two autonomous echosounders were moored on the bottom near Departure Bay and French Creek as part of a separate project focused on Pacific herring in 2022-2023. These data were re-analyzed to identify juvenile salmon and associated species. Another mooring was deployed in 2024 in the middle of the Strait of Georgia to assess ecosystem conditions in the deeper larger basin, to provide insight on the dynamic of key salmon prey species (euphausiids) and piscivorous predators (e.g. Pacific hake). Another echosounder mooring was deployed in Malaspina Strait in 2025 (but these data are not available yet).

Insights

- Large spatial scale acoustic data have revealed an increasing biomass of Pacific Hake throughout the Strait, with likely increased predation pressure for juvenile salmon, a sharp contrast to the West Coast, where Pacific hake biomass has drastically dropped over the past years.
- Moorings in nearshore coastal areas revealed the presence of juvenile salmon year-round, but in relatively low abundance. The nearshore habitat in the Salish Sea was largely dominated by Pacific herring (suggesting juvenile salmon are exposed to much higher competition for food).
- Potential predators of juvenile salmon were observed routinely on the moored acoustics as well as on regularly moored camera systems. Surface predation from birds and/or marine mammals were also observed, but far less frequently than on the West Coast (Barkley Sound).
- Moored autonomous echosounder in the central part of the Strait of Georgia further indicated that large predators (Pacific hake) were in the area for most of the year, and there was a strong seasonal signal of euphausiids and epi and mesopelagic communities in the Spring/Summer.

Next Steps

This study was implemented in the second year of PSSI. Acoustic data collected from moored systems are only available once instruments are recovered, in as such, we are just finalizing the processing and analyses of acoustic data from moorings deployed in 2024 and 2025.

Tables and Figures

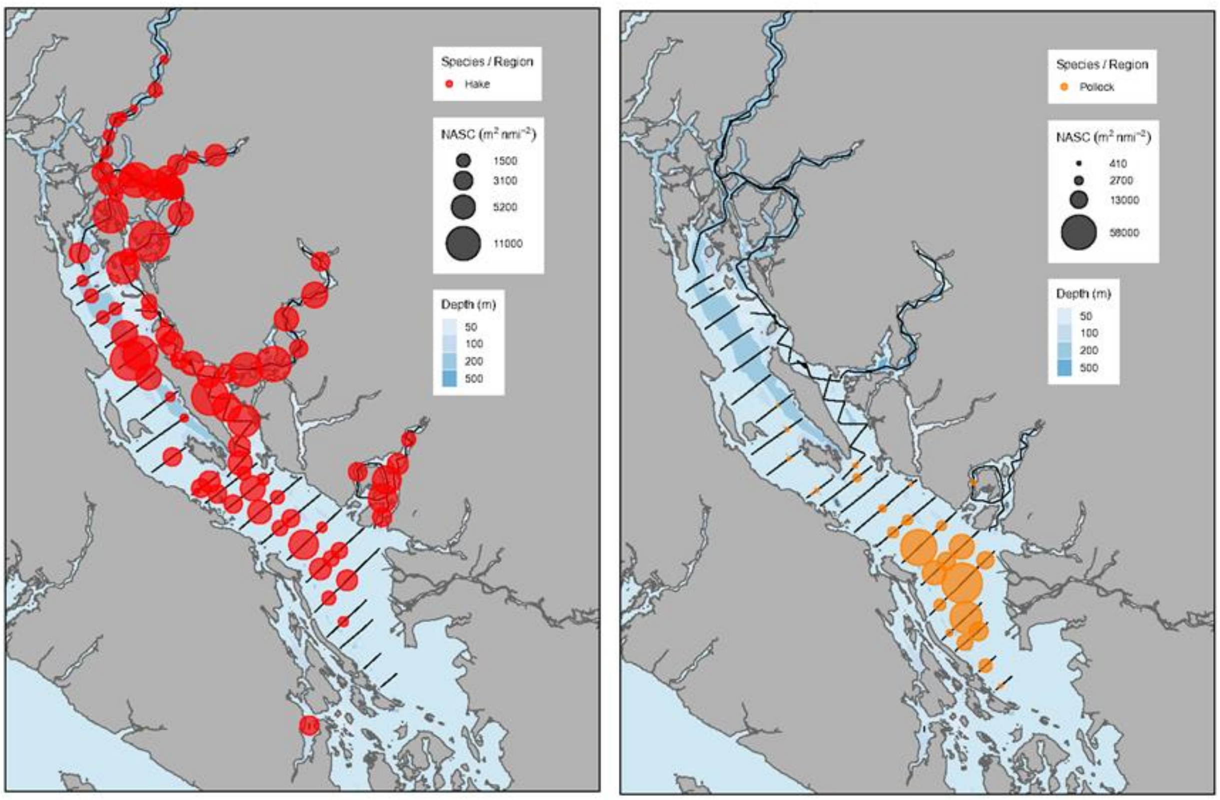
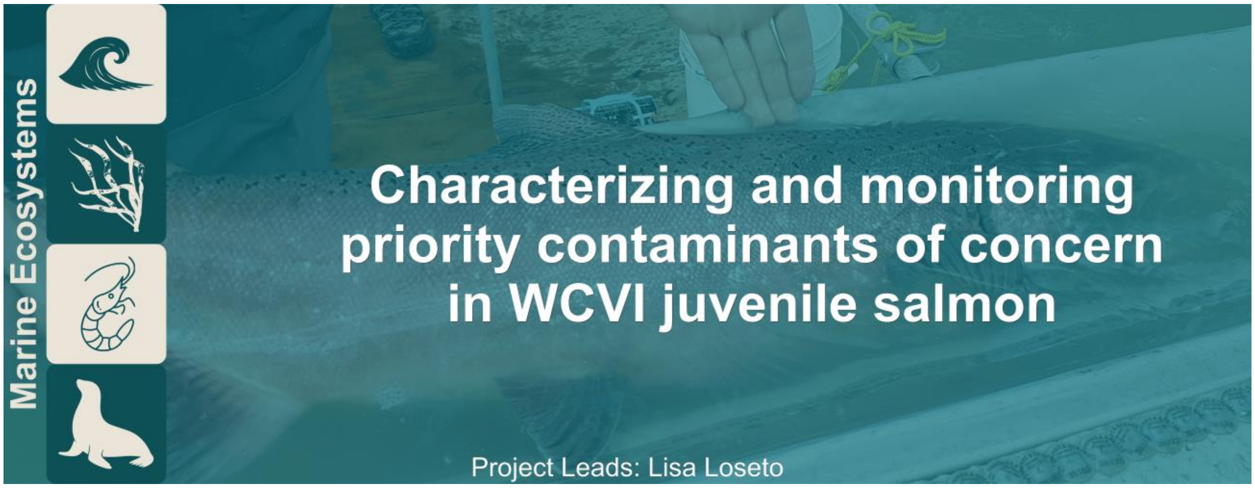


Figure 1. Spatial distribution of potential predators of juvenile salmon within the Salish Sea in Spring 2025, with Pacific hake (Merluccius productus) in red (left panel) and walleye pollock (Theragra chalcogramma) in orange (right panel). The size of the bubble is relative to Nautical Area Scattering Coefficients, a proxy for biomass density.

2513 - Monitoring Key Contaminants in WCVI Juvenile Salmon



Noël, M., Loseto, L.L., Colbourne, K., Bartlett, M., Bokvist, J., and Brown, T.M. 2025. Contaminant concentrations in juvenile Chinook salmon (Oncorhynchus tshawytscha) collected from Barkley Sound, West Coast Vancouver Island, British Columbia, in 2022. Can. Tech. Rep. Fish. Aquat. Sci. 3655: vii + 31 p.

Collaborations: Dr. T. Brown, SFU; **Follow the Fish Program and associated partners and nations/organizations**: Huu-ay-aht First Nation, Toquaht Nation, Uchucklesaht Tribe, Hupačasath First Nation, Yuułuʔiłʔatḥ Government, Tseshaht First Nation

Region: West Coast Vancouver Island

Waterbodies: Barkley Sound, Clayoquot Sound

Species: Chinook

Populations: Robertson

Highlights

- The goal of the project was to better characterize contaminant levels and evaluate their potential impacts on the health of juvenile Chinook from the West Coast of Vancouver Island.
- 12 contaminant classes were analyzed in two composite samples collected in 2022 from Barkley Sound (completed) and polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs) and metals were analyzed in individual fish collected in 2023 and 2024 in Clayoquot Sound and Barkley Sound (in progress).
- Metals, PAHs, and PCBs were the top three contaminant classes detected with the highest concentrations in the two composite samples from Barkley Sound.
- Comparing our results to established effects thresholds, juvenile Chinook salmon from Barkley Sound may be at low risk of exposure to contaminants, specifically PCBs, PBDEs, Dichlorodiphenyltrichloroethane (DDT), PAHs and mercury.

- Concentrations of contaminant classes measured in WCVI juvenile Chinook Salmon range from 3 to 100x lower than levels of contaminant classes documented in juvenile Chinook in the Fraser River. As such contaminant levels in WCVI juvenile provide a benchmark of 'lower' levels reflecting lower urban and industrial associated sources.

Background

The marine environment is under significant anthropogenic pressures including overfishing, habitat degradation shipping, climate change and contaminants (Quinn, 2018). Although declines in Chinook salmon abundance are thought to be linked to freshwater, estuarine and marine environmental conditions, contaminants may also play a role, especially exposure to contaminants during their early life stage. For example, exposure to contaminants in freshwater and/or estuaries have been shown to impact growth and survival of juvenile Chinook salmon (Lundin et al., 2019, 2023; Zabel et al., 2004; Meador et al., 2014).

A variety of contaminants have been detected in adult Chinook salmon collected from the West Coast of Vancouver Island (WCVI) (Holbert et al., 2024). Some of the highest concentrations (on a lipid weight basis) of alkylphenols (APs), total hexachlorocyclohexane (HCH), short chain chlorinated paraffins (SCCPs) and medium-chain chlorinated paraffins (MCCPs) have also been measured in WCVI adult Chinook relative to other stocks (Brown and Holbert, unpublished data). Juvenile salmon are exposed to a variety of contaminants during their seaward migration depending on the characteristics and anthropogenic activities of the watershed. In their study of hatchery-reared Chinook salmon, Meador et al. (2014) found that individuals transiting through contaminated estuaries had a survival rate that was 45% lower than for those transiting through uncontaminated estuaries. To better characterize contaminant levels and evaluate their potential impacts on the health of juvenile Chinook, we collected juvenile Chinook salmon throughout Barkley Sound on the WCVI in July 2022 to evaluate the levels of over 700 compounds from 12 different contaminant classes. In addition, PCBs, PAHs and metals were analysed in individual fish collected in 2023 and 2024 in Clayoquot Sound and Barkley Sound. This project was conducted in partnership with the Follow the Fish program.

Methods and Findings

Field collections

2022: In 2022, the FtF program carried out purse seine surveys to catch and sample juvenile Chinook in the nearshore marine waters of Barkley Sound. Whole fish were frozen in the field using liquid nitrogen and sent to the Pacific Science Enterprise Center, West Vancouver, BC, where they were stored at -80 until further analyses.

2023/2024: In 2023/2024, the FtF program carried out microtrolling surveys to catch juvenile Chinook during their first winter at sea. Surveys were conducted in various sounds along the West Coast of Vancouver Island and we received samples from Barkley Sound (n=19) and Clayoquot Sound (n=30) that were collected between October 2023 and March 2024. In addition, we received samples from the purse seine surveys conducted in Barkley Sound in August (n=16) and September 2024 (n=22). As for the 2022 samples, the subset of captured juvenile Chinook salmon retained were euthanized and had their fork lengths measured and a fin clip taken for genetic stock identification. Samples were frozen in the field and sent to the

Pacific Science Enterprise Center, West Vancouver, BC, where they were stored at -80 until further analyses.

Analytical methods

Samples: In 2022, fish were pooled into two composite samples to have enough material to conduct the analyses of 12 different contaminant classes.

In 2023 and 2024, a muscle subsample from each individual fish was analyzed.

Genetic Stock identification: Fin clips collected in the field were sent to the Molecular Genetics Lab to determine stock of origin of fish using genetic stock identification (GSI) and parentage-based tagging (PBT) methods (Beacham et al., 2018).

Contaminants

Samples from 2022 were analyzed for 12 different contaminant classes: legacy and current use pesticides using high resolution mass spectrometry (HRMS), polychlorinated biphenyls (PCBs) using HRMS, polybrominated diphenyl ethers (PBDEs) using HRMS, dioxins and furans using HRMS, per- and polyfluoroalkyl substances (PFAS) using liquid chromatography mass spectrometry/mass spectrometry (LC-MS/MS) , polycyclic aromatic hydrocarbons (PAHs) using gas chromatography mass spectrometry (GC/MS), pharmaceutical and personal care products (PPCPs) using LC-MS/MS, alkylphenols using GC/MS, hexabromocyclododecane (HBCDD)using LC-MS/MS, polychlorinated paraffins using GC/MS, brominated and chlorinated flame retardants using GC/MS metals using inductively coupled plasma collision reaction cell mass spectrometry (CRC-ICPMS) and mercury using Cold Vapor Atomic Absorption Spectroscopy (CVAAS). All analyses, except metals and mercury which were conducted at ALS Canada Ltd., Burnaby, were conducted at SGS AXYS Analytical Ltd., Sidney, B.C. Samples were run alongside reference samples and blanks to evaluate method performance.

While all samples from 2023 (n=19) and 2024 (n=60) were analyzed for metals and mercury at ALS, a subset was run for PAHs (n=8 and n=16, respectively) and PCBs (n=8 and n=9, respectively) at SGS AXYS.

Stable isotopes: Samples were analyzed for carbon and nitrogen stable isotopes at the Freshwater Institute Biotracers Laboratory as described in Rosenberg et al. (2015). Briefly, subsamples were freeze dried and one mg of sample was loaded into tin capsules and analyzed using a Thermo Advantage V Plus continuous flow Isotope Ratio Mass Spectrometer coupled with a Costech 4010 Elemental Analyzer.

Collaborative Analyses

- Otolith microchemistry: Otoliths were collected from the fish sampled and polished to prepare them for microchemical analysis using a laser and a mass spectrometer, called LA-ICP-MS, or ‘Laser Ablation Inductively Coupled Plasma Mass Spectrometry’. Results of this analysis show how concentrations of elements change in a fish during its entire life and help understand fish growth as well as differentiate between periods spent in the freshwater vs saltwater. This information can provide helpful life history information that can help interpret contaminant concentrations observed in juvenile fish.

- Biotoxins: In addition to chemical pollutants, juvenile Chinook are also exposed to biological contaminants such as biotoxins, poisonous chemicals produced naturally by certain types of marine phytoplankton. A subset of the fish analyzed in 2023 and 2024 were also analyzed for biotoxins by the DFO biotoxin team (Institute of Ocean Sciences). Together with information on chemical pollutants, it will provide a fuller picture of contaminant exposure in these juvenile fish.

Transcriptomics: RNA is being extracted from liver samples from the 2023 and 2024 fish for which we have matching contaminant data. Briefly, tissues are being homogenized with TRIzol reagent and a 3 mm diameter tungsten-carbide bead using a mixer mill. Isolated total RNA is being resuspended in diethyl pyrocarbonate-treated distilled deionized water (DEPC) and stored at -80°C. RNA concentrations are being confirmed through spectrophotometry and 1 µg of each sample is being used to produce cDNA with the High Capacity cDNA reverse transcription kit (Applied Biosystems).

In addition to three normalizer genes (ribosomal protein L8, beta actin and Coil domain-containing protein 84), we are looking at genes known to be impacted by contaminants (aryl hydrocarbon receptor, cytochrome p450, estrogen receptor and vitttelogenin) as well as genes markers of stress response (catalase, heat shock protein 27 and metallothionein).

Key Findings

- In the 2022 juvenile fish from Barkley Sound, metals, PCBs and PAHs were the top three contaminants with the highest concentrations out of the 12 contaminant classes analyzed (Figure 1).
- Overall, the levels of contaminants were generally lower than those reported in previous studies which were conducted mostly in more urban areas like Puget Sound, WA, and Oregon (O'Neil et al., 2020; Anzalone et al., 2022; Lundin et al., 2021; Figure 2) aligning with the fact that the West Coast of Vancouver Island is relatively remote from any major urban or industrial centers.
- A recent study (Lo, 2026) has enabled comparison with juvenile Chinook from Harrison stock collected from the Fraser River at an earlier life stage (March to June) and small size class (ranging from 0.3 to 4.8g) for comparison. Relative to contaminants measured in juvenile Chinook from Barkley Sound in July 2022, the levels of contaminants in Fraser River juveniles were higher for example, levels of PCBs were up to 6x higher, PPCPs were nearly 100x higher, Alkylphenols were approximately 20x higher, and pesticides approximately 10x higher with PFAS and PBDEs approximately 3x higher (Lo, 2026).
- When comparing WCVI Robertson Creek juvenile Chinook concentrations to established effects threshold concentrations for contaminants (PCBs, PBDEs, DDT PAHs and mercury) and in fish (Meador et al., 2002; Berninger and Tillit, 2019; Arkoosh et al., 2017; O'Neill et al., 2015; Beckvar et al., 2005; Johnson et al., 2007), they are below all thresholds and therefore are likely at low risk contaminant associated effects due to these particular contaminants. Even though all fish collected in 2022 were collected at

the same time within Barkley Sound, some differences in concentrations and patterns for some contaminants were observed between the two composite samples and may reflect variability of contaminant exposure related to the locations where they were collected in Barkley Sound or variability amongst individuals selected for each of the composite (influence of size).

- Preliminary results from 2023 and 2024 support this conclusion as monthly variability were observed in mercury concentrations and levels were correlated with length (Figures 3 and 4).

Insights

- We have characterized, for The First time, contaminant concentrations in juvenile Chinook salmon from The west coast of Vancouver Island. Our results indicate a low Risk of contaminant associated health impacts for certain compounds and contaminant classes. however, while concentrations in WCVI juvenile Chinook are lower relative to other regions in B.C. and Washington State, it remains important to evaluate contaminant associated risks in juvenile Chinook inhabiting these waters.

- management questions addressed by This project include those related to Understanding and mitigating a significant stressor (i.e., contaminants) on at-Risk salmon populations. Similarly, The recovery of *endangered* southern Resident killer whales and *Threatened* Northern Resident killer whales requires identifying and mitigating The significant threat posed by contaminants, and largely delivered via their priority prey, Chinook salmon.

Next Steps

- Interpretation of the contaminant results for the 2023, 2024 samples.

- Combine contaminant dataset with transcriptomic dataset to evaluate the impacts of contamination, both chemical and biological (biotoxins) on the health of juvenile Chinook salmon.

- Interpretation with contaminated juvenile Chinook from the Harrison stock collected from the Fraser River (Lo, 2026), that reflect exposure to sources in highly urbanized and industrialized habitats

- Finding from our study may provide benchmarks for low contaminant levels and an associated no to low effects that other managed areas need to strive towards, in particular providing contextual comparisons to the Fraser River stocks.

Tables and Figures

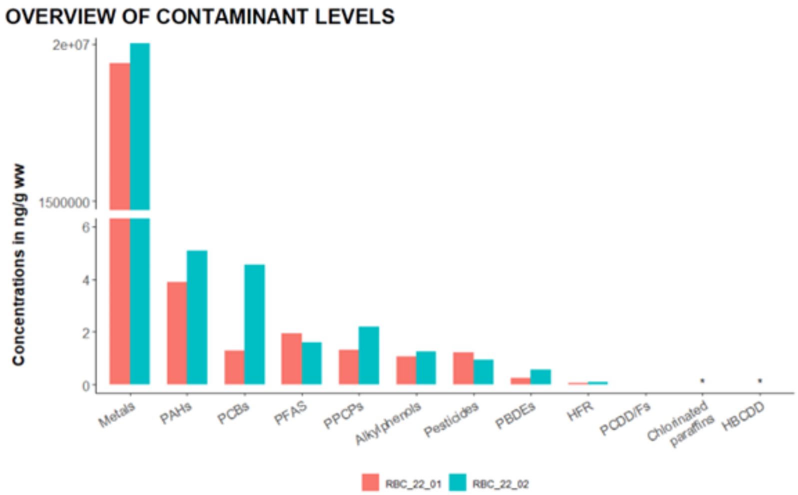


*Figure 1. Total concentrations (ng/g wet weight (ww)) of each contaminant class analyzed in the two juvenile Robertson Creek Chinook salmon composite samples collected in 2022 ranked from highest to lowest. * indicates contaminants not detected*

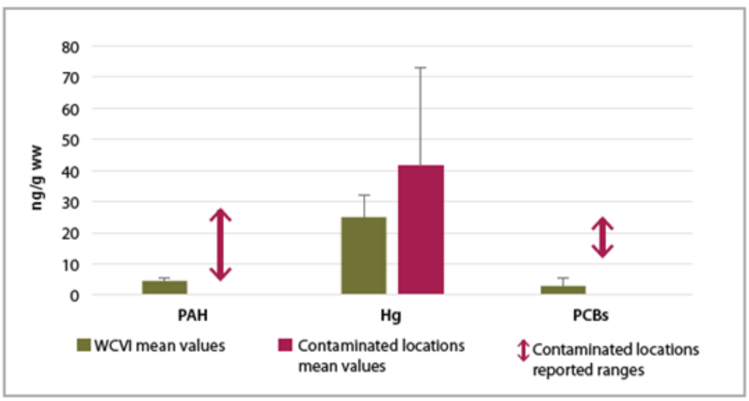


Figure 2. Concentrations in the top three contaminants in WCVI 2 composites relative to published studies of levels in juvenile Chinook salmon living in highly urbanized areas.

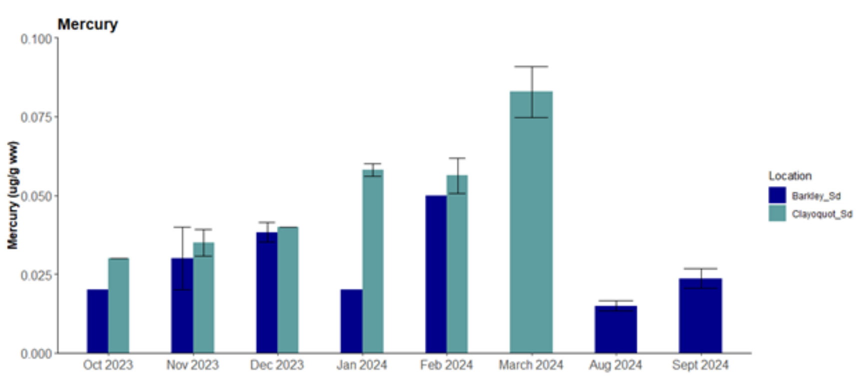


Figure 3. Temporal trends in mercury (ug/g ww) in WCVI juvenile salmon collected in Barkley Sound and Clayoquot sound in 2023 and 2024.

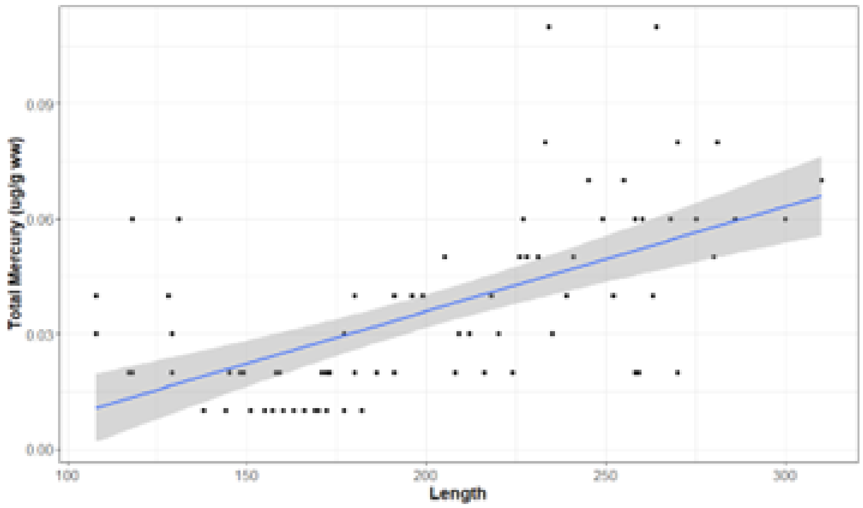


Figure 4. Significant positive relationship with juvenile Chinook salmon whole body mercury (ug/g ww) and length ($p < 0.05$, R - 0.36), for individuals collected from August to March (2023, 2024).

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CLIMATE CHANGE VULNERABILITY

2405 - Biological Models of Salmon Under Future Climates

https://github.com/SiRE-P/PSSI_salmon_climate

Primary publication draft by end of March 2026 with submission in early 2026-27 fiscal year

Collaborations: DFO: Amber Holdsworth and Angelica Pena; Dan Selbie, Howard Stiff, Greig Oldford, and Josie Iacarella

Region: BC

Species: Sockeye

Highlights

- The goal of the project is to estimate how climate related environmental variables are influencing sockeye salmon productivity across different life stages and populations using quantitative models. These estimates will be combined with climate projections to estimate how future conditions may impact salmon populations in future decades.
- Key initial findings, based on the 13 populations model: environmental drivers and life stages influencing future impacts vary among populations; all assessed populations are sensitive to projected changes; and negative impacts are expected to be greatest in southern regions (Columbia, Fraser, WCVI) and driven by increased marine temperatures and freshwater temperatures during adult migrations, while some northern populations may initially benefit from warming.
- These projections will help identify the life stages most vulnerable to climate change and guide management strategies by highlighting population-specific sensitivities.

Background

Many sockeye salmon populations have declined in abundance despite reductions in harvest, suggesting reduced productivity driven by environmental forcing, with poor marine survival identified as a key contributing factor (Peterman and Dorner 2012, Connors et al. 2020). Yet some sockeye salmon populations are stable or increasing (Brown et al. in press, Ogden et al. 2024). The cause of divergent trends in abundance is unclear, resulting in considerable uncertainty about which sockeye salmon populations are most likely to be resilient to changing environmental conditions.

Evaluating future risk requires information on both population-specific stressors and biological responses to those stressors. Although quantitative climate change vulnerability assessments have been performed for a number of Pacific salmon populations, they have largely focused on American Chinook salmon populations from a small number of watersheds (e.g. Crozier et al. 2021). Here we leveraged a unique dataset of juvenile and adult abundance from a network of thirteen sockeye salmon populations extending from the Columbia River to northern British Columbia. We parameterized an age-structured life cycle model that included freshwater and marine covariates to estimate population-specific functional responses, then evaluated how populations fared under various climate change scenarios. Our study incorporated expertise from diverse collaborators, within and outside DFO, with expertise in stock assessment, global climate models, and salmon ecology. Our work can be used to identify Pacific salmon life stages that are most vulnerable to climate change and help prioritize management interventions.

Methods and Findings

Overview of the model

We developed a full life cycle model that consists of two stages: 1) spawner to smolt production and 2) smolt to adult recruit survival (Figure 1). Each stage of the model consists of a Beverton-Holt function, where density-independent production (i.e., survival) is a function of the environmental conditions experienced in that life stage. We modelled each age class separately because sockeye salmon vary in the number of years that they spend rearing in freshwater as well as in the ocean, and covariates were lagged so that each age class was only affected when it overlapped in space and time with a given covariate.

We used a state space approach that linked population dynamics to the observed data and accounted for cyclical feedback among generations. This structure allowed us to account for missing data, observation error, and variation in the life stage that was observed for juveniles (smolt vs. fry). The model was implemented in Stan and fit using Bayesian inference within a hierarchical framework, allowing information to be shared across populations.

Salmon data

Our model is based on thirteen populations of sockeye salmon (Figure 2) where there are estimates of spawner abundance, juvenile abundance (smolt or fry), and adult recruitment. In addition, we have estimates of age structure for juveniles, adult recruits, or both. These populations come from six different watersheds spanning the entire province of BC: Columbia, Somass, Fraser, Skeena, Stikine, Taku. We included data from 1981 to 2024 in our model.

Environmental covariates

We selected environmental covariates based on our understanding of the sockeye salmon lifecycle and when and where the populations experience different conditions. To do this, we developed a directed acyclic graph (DAG; simplified version in Figure 2) that outlines our hypothesized causal effects, as well as our understanding of how environmental covariates influence each other or are influenced by shared drivers (e.g., a common regional climate). We were unable to include all hypothesized covariates, because in many cases we do not have appropriate data for all populations. For example, we know that zooplankton community composition is likely to influence survival (Peterson and Schwing 2003) and that zooplankton dynamics are in turn influenced by temperature and mixed layer depth (Mackas et al. 2012). Thus, based on our model structure, we can interpret any effects of marine temperature and mixed layer depth as being, at least partially due to their effects on zooplankton. In this way, we use the DAG to understand whether our estimated environmental effects are likely to be biased or confounded, and to adjust our model and interpretation accordingly.

The environmental covariates (Figure 3) that we hypothesized could influence spawner to smolt production were: 1) winter (Oct. to Mar.) rearing temperatures (2 or 3 years after spawning), and summer (Apr. to Sep.) rearing temperatures (1 or 2 years after spawning) in nursery lakes. The environmental covariates that may influence smolt to adult recruit survival were: 1) near surface temperature averaged across the juvenile marine migration route for the period of April to June; 2) mixed layer depth averaged across the juvenile marine migration route for the period of April to June; 3) near surface temperatures in the open ocean in summer (Jul. to Sep., 1 or 2 years after ocean entry) and winter (Jan. - Mar.; 1,2, or 3 years after ocean entry); 4) river temperature during upstream migration , 5) river discharge during upstream migration.

Freshwater temperatures and discharge were sourced from the Pacific Climate Impact Consortium (Werner et al. 2019). The juvenile marine migration route is defined as all polygons in Figure 2 from the point of ocean entry for each population and north to Alaska along the continental shelf (i.e., depths less than 500 m). The open-ocean domain was defined by a rectangular polygon in the North Pacific, bounded by 170°W, 145°W, 60°N, and 45°N; areas shallower than 1000 m and regions north of the Aleutian Islands were excluded. Coastal temperature and mixed layer depth were sourced from the BCCM downscaled climate model (Peña and Fine 2024), the HOTSsea model (Oldford et al. 2024) and the GLORYS12 reanalysis (E.U. Copernicus Marine Service Information (CMEMS). Marine Data Store (MDS)). Open ocean temperatures were sourced from GLORYS12.

Future projections

We are still in the process of integrating our model with future climate projections. This will be done by taking the estimated parameters of our model and applying them to averaged historical (1995 to 2025) baseline conditions as well as future projected (2041 to 2070) environmental conditions. This will allow us to estimate how the mean number of adult recruits per spawner is expected to change between these two periods, due to climate change. We plan to contrast the RCP 4.5 and 8.5 future climate scenarios to assess how sensitive our projections are to the specific emission scenario. Future climate projections will be sourced from the BCCM (Pena et al.) model, downscaled CMIP6 model (ACTEA) and PCIC (citation).

Initial results

We find that all populations are sensitive to environmental change at some point in the lifecycle (Figure 4). However, there is considerable variation across populations as to where in the lifecycle environmental conditions have the greatest impact. Southern populations (WCVI and Columbia) appear to be most sensitive to changes in the early marine stage. Fraser and

Columbia populations appear to be most sensitive to warm waters experienced during upstream migration. In contrast, summer temperatures during lake residence had a relatively small effect on recruitment for all populations. Northern populations show greater variability in their responses, and some may even benefit from some degree of warming.

Insights

Although we are still integrating our population model with future climate projections, our preliminary results highlight striking similarities and differences among sockeye salmon populations that are relevant to management. The majority of populations showed marked declines in abundance as marine and freshwater temperatures increase. Yet the life stages and environmental drivers regulating future impacts varied among populations. These patterns suggest management interventions will be most effective if they are applied in a regional or population-specific context and target life stages that have the greatest impact on subsequent recruitment.

More broadly, our findings emphasize the value of leveraging life cycle models when evaluating climate change risk. Climate change vulnerability assessments often rely on predicted changes in putative stressors, rather than population level responses to those stressors. Such frameworks implicitly assume that populations respond similarly to, for example, one degree of warming. Furthermore, without clear linkages to a biological response, it is often challenging to evaluate the relative impact of stressors in different spatial domains (e.g., freshwater vs. marine temperatures) or representing different physical processes (e.g., changes in temperature vs. flow). Although qualitative approaches are necessary in data limited scenarios, uncertainties should be clearly communicated to decision makers.

Despite its complexity, our model only incorporated abundance data from three life stages, limiting our ability to precisely link indicators to biological responses. Marine spatiotemporal distributions are also relatively poorly resolved, particularly for more data-limited northern populations and for all populations during offshore residence. Both of these factors will increase the uncertainty associated with effect size estimates. Additionally, we could only incorporate indicators that were readily available in historical time series and climate projections, and we assumed that ecological responses to environmental drivers would remain constant in the future. Such assumptions are necessary in correlative models where the mechanisms linking, for example, temperature to survival remain unknown, but may lead to biased estimates of life stage-specific effects. Given the complexity of ecological systems (e.g., non-stationarity; Litzow et al. 2019), our predictions should be viewed cautiously and revised as additional data become available.

Next Steps

Our project focused on developing the hierarchical Bayesian model and applying it to thirteen populations with high quality data. Our goal was to estimate the effects of climate-related environmental covariates and make projections of future abundance. Now that this has been done, there are a number of ways that the model could be extended to address key knowledge gaps for DFO.

1. **Extending to data limited populations** - the hierarchical state-space structure of our model means that it should be possible to include populations where we lack juvenile abundance estimates. The model would leverage information from data rich populations to allow us to make inference about more data limited populations. Because DFO only surveys juvenile abundance for a minority of populations, this would allow us to include many more populations. This would greatly increase the ability for managers to use this information to consider climate impacts on sockeye stocks across the region.
2. **Exploring harvest scenarios under future climates** - our model includes the proportion of the recruits that were harvested each year. This means that it would be possible to make projections under different harvest rates to explore the interaction between harvest management decisions and climate change.
3. **Assessing the benefits of stage specific life-cycle modelling vs. traditional spawner recruitment models** - our model estimates could be contrasted against those from a simplified version that only includes spawners and recruits to quantify how the inclusion of the juvenile data improves our ability to estimate the causal effects of the environmental covariates. This analysis would also provide information on the magnitude of bias, if any, in previous analyses that drew inference on environmental effects using only spawner and recruit data.
4. **Assess how much recruitment variation is explained by our environmental covariates** - traditional stock assessment methods often do not incorporate environmental covariates, relying on the abundance of spawners to predict recruitment. Our model could be used to quantify how including environmental covariates may improve our ability to explain interannual variation in recruitment.
5. **Extending to other Pacific salmon species** - the lifecycle structure in our model is specific to sockeye, but it could be adapted to model other species of Pacific salmon. Species with a mix of data-rich and data-limited populations may be most tractable.
6. **Incorporating additional environmental and salmon abundance variables** - model development and refinement indicated that additional environmental variables that are available in historic and projected data could contribute to a further refined model. These include surface wind influencing lake and coastal mixing regimes, related primary production in coastal waters and snowpack coverage in watersheds. Similarly additional time series of salmon abundance (e.g., from juvenile freshwater or marine surveys) could be used to increase the ecological resolution of the life cycle model.

These extensions would support DFO’s implementation of Ecosystem Approach to Fisheries Management. Specifically, they would demonstrate the value of life-cycle modelling, including environmental covariates, and would allow us to link our findings to Fisheries Management by incorporating harvest decision rules.

Tables and Figures

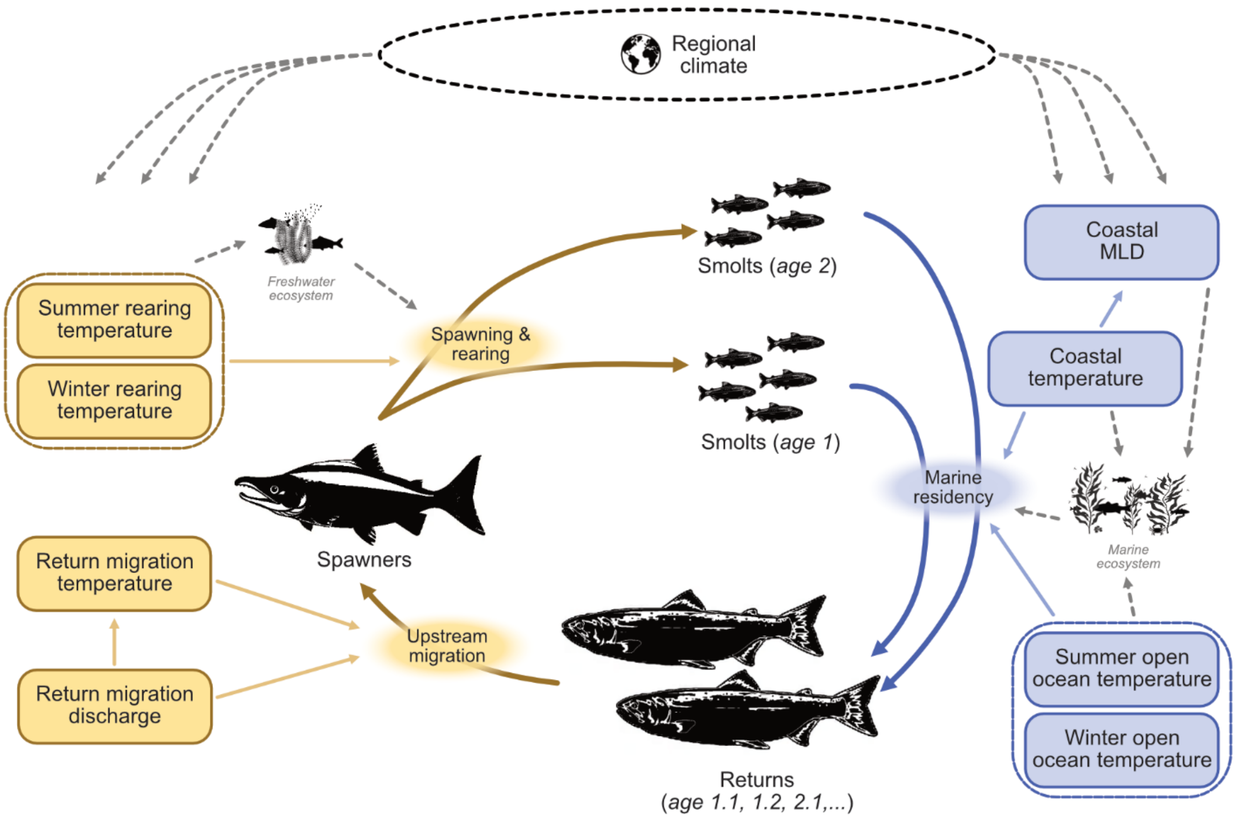

Figure 1. Directed acyclic graph of the lifecycle model linking environmental covariates to salmon productivity and survival. Yellow boxes, freshwater covariates; blue boxes, marine covariates. Solid arrows show direct effects, dashed arrows show indirect effects via unmodelled variables.

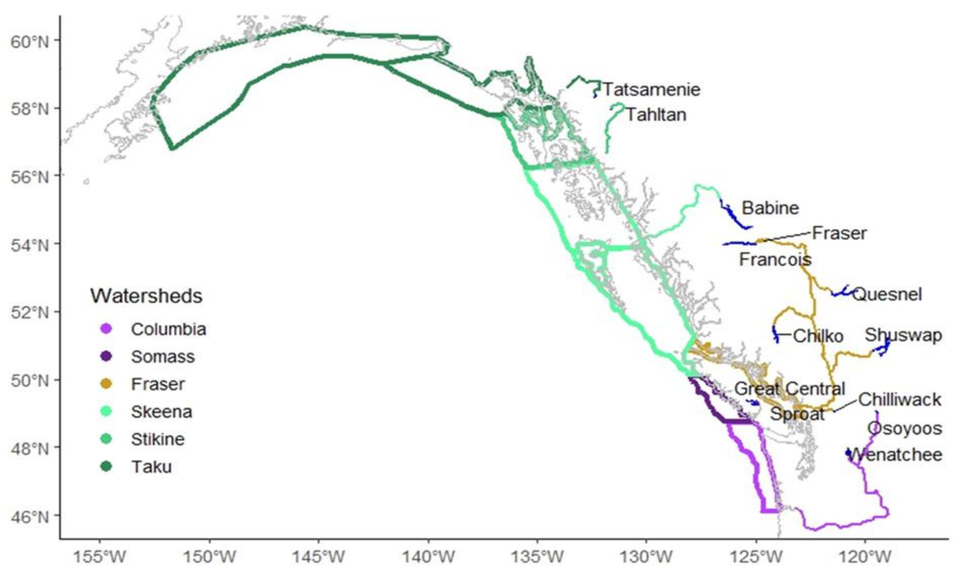

Figure 2. Map of the populations included in the model. This includes the rearing lakes, the rivers, and the polygons that define the coastal shelf migration in the first marine summer. Open ocean domain (not shown) is shared among all populations.

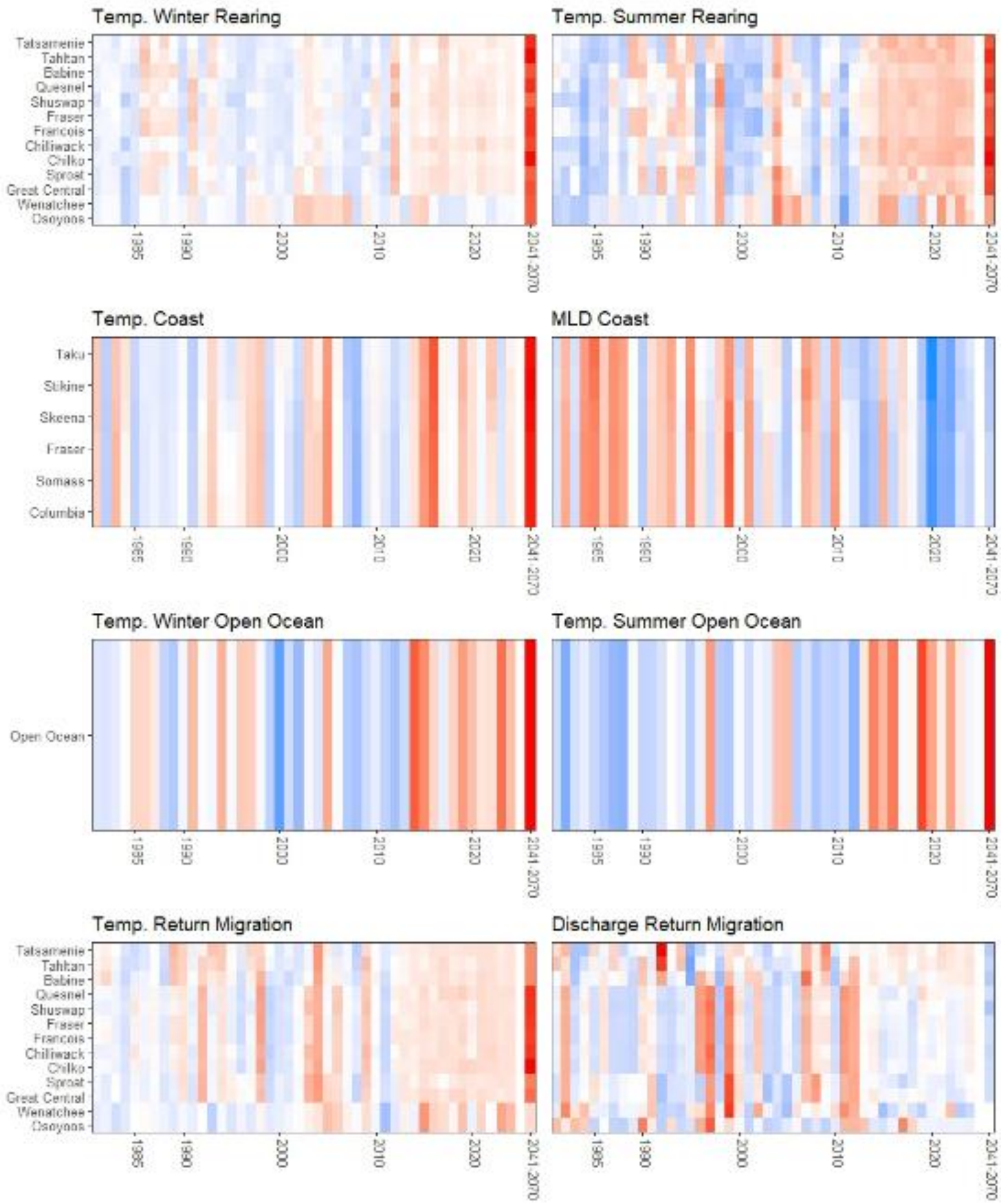

Figure 3. Heat maps of environmental covariates used in the lifecycle model. Red indicates higher values and blue indicates lower values. All time series were standardized to allow direct comparison. Each panel represents one environmental variable, with rows showing different sockeye populations (freshwater variables), watersheds (coastal shelf variables), or the shared open ocean conditions (shared by all populations). MLD represents mixed layer depth on the coastal shelf. The timeseries shows historical values from 1981 to 2024, and then the mean values for the projected future period of 2041 to 2070 as the righthand value.

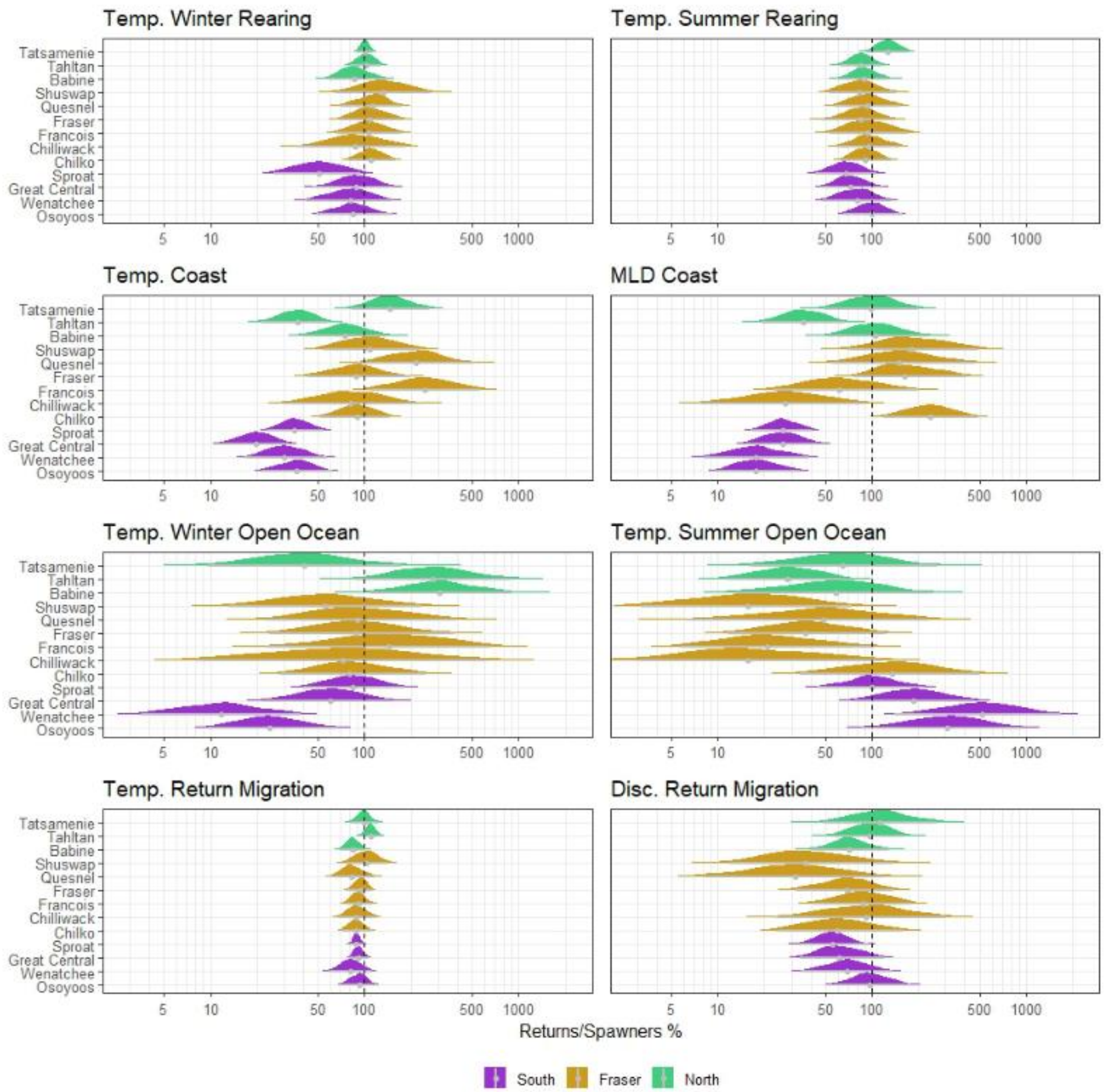

Figure 4. Estimated percent change in returns per spawner for each population in response to a shift of 3 standard deviations (-1.5 to +1.5 SD), calculated relative to the range observed for that population. All other variables were held at their mean, so these represent marginal effects. This analysis highlights the sensitivity of each population to individual environmental drivers.

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2437 - Adaptive Genetic Variation and Salmon Climate Resilience

🔄 Genotype-environment associations and genomic offsets in Sockeye Salmon (Oncorhynchus nerka) (in progress)

🔄 Comparison of high-density reduced representation sequencing, low coverage resequencing and genotype imputation for population genomics in Chinook Salmon (Oncorhynchus tshawytscha) (in progress)

🔄 Parallel variation in genomic offsets across two species of Pacific Salmon (in progress)

🔄 Genotype-environment associations and genomic offsets among even- and odd-year Pink Salmon (Oncorhynchus gorbuscha) (in progress)

🔄 Genome-wide patterns of variation and genomic offsets in Chum Salmon (Oncorhynchus keta) (in progress)

Collaborations: GRDI GenARCC program

Region: BC & Yukon

Species: All *Oncorhynchus* spp.

Highlights

- Pacific salmon are found across a Large geographic range, which covers substantial variation in environmental conditions
- salmon from different locations are putatively adapted to The conditions that occur in their local habitats, particularly in freshwater
- Whole-genome sequencing allows adaptive genetic variation to be resolved and associated with variation in The environment across locations
- This not only provides insights into The environmental conditions that have played Key roles in The shaping adaptation in these species, but also allows estimation of The amount of genetic change that would be predicted to track forecasted climate change scenarios

- Our main findings suggest that changes in maximum temperature are consistently important in predicting The amount of genetic change required to track climate change across species, suggesting that relatively high levels of genetic change will be necessary in The Fraser and Thompson Rivers
- This project provides genetic insights into how Pacific salmon may respond to their changing habitats, which characterizes another Risk factor to account for in climate change conservation and mitigations efforts and decision making

Background

Pacific salmon are broadly distributed across western Canada and the northern Pacific Ocean with spawning grounds located over a wide diversity of freshwater habitats. In general, Pacific salmon return to their natal spawning grounds to reproduce, and not surprisingly this has resulted in substantial genetic variation among different salmon populations throughout the Canadian range. Genetic variants among and within populations of the majority of Canadian Pacific salmon have been characterized using relatively few genetic markers, and this characterization has enabled the development of the genetic-stock identification and parentage-based tagging programs within Fisheries and Oceans Canada, which both provide vital information for management of fisheries and hatcheries. Despite the utility of these developments, low-density genetic markers are insufficient to assess adaptive genetic variation in these species, leaving critical gaps for conserving fitness-associated genetic diversity and for assessing potential resilience to climate change.

Until recently, the costs of next-generation sequencing were prohibitive for assessing genome-wide genetic variation in species with large genomes such as salmonids. However, reductions in these costs combined with publication of reference genome sequences for the Pacific salmonids has opened novel opportunities to address these gaps. This project utilized low-coverage whole-genome resequencing to assess genome-wide patterns of genetic variation among and within populations of Pacific salmon (Figure 1). The data generated by this project feed into several analyses to identify genomic regions and variation involved in environmental adaptation, to reassess the genetic support for currently defined conservation unit boundaries, and to estimate the relative genetic change predicted to track climate change across different populations of Canadian Pacific salmon. Additionally, these high-density genomic data can be leveraged to improve the resolution of genetic variation among and within stocks of Pacific salmon to support rebuilding efforts and the development of biomarkers to support future development of specific stock-identification tools.

Methods and Findings

Samples for this project were obtained by leveraging thousands of archived tissues samples that are maintained within the Molecular Genetic Section. DNA was isolated using standard laboratory protocols, and after quantification and quality control, samples were sent to Genome Quebec for low-coverage whole-genome resequencing using Illumina NovaSeq platforms. The resulting sequencing reads were trimmed, aligned to the corresponding species-specific reference genome, and quality filtered. Genotype likelihoods were obtained with angsd v0.940, and genotypes were imputed with Beagle v4.1. The imputed genotypes were then used in all downstream analyses for principal component analyses, FST calculations, genotype-environment associations by redundancy analyses, and genomic offsets by gradient forests. All bioinformatic analyses were conducted with standard tools and custom pipelines established for the project, and computing resources were provided through the Government of Canada's Genomic Adaptation and Resilience to Climate Change (GenARCC) program.

The final analyses for the project, and publication of species-specific manuscripts and a manuscript validating the use of genotype imputation in Chinook salmon are in progress. All sequencing reads and called genotypes will be submitted to field-specific public repositories on publication of the associated manuscripts. Additionally, all bioinformatic pipelines and associated script files will be available through the GitHub platform.

For each species, thousands of genomic regions were identified as outliers consistent with adaptation either in comparison to background genetic variation or by association with environmental variation among locations (Figure 2). These data provide novel insights on genetic variation among stocks of Pacific salmon, and resolve fine-scale differences among stocks which can support future development of dedicated genetic stock identification tools. In this project, these data were utilized to generate two metrics of genomic variation relevant to conservation efforts, particularly in the context of climate change. First, environmentally associated genetic outliers were used to predict the amount of genetic change required to track climate change forecasts among locations. Consistent importance of changes in maximum temperature were observed, driving high estimates of genetic change necessary in the Fraser and Thompson Rivers across species (Figure 3). Second, genome-wide genetic variation was used to estimate heterozygosity, which is a metric of the proportion of sites in the genome that carry two different alleles within an individual, capturing variation in within-population genetic diversity among locations (Figure 4). These two metrics can feed into assessments of potential climate change impacts on Pacific salmon, as higher levels of genetic change required to track climate change and lower levels of genetic diversity have the potential to increase the climate change vulnerability of a population.

Insights

The project provides the highest resolution genetic datasets currently available for all of the Pacific salmon across the Canadian portion of each species' range, and characterizes putatively adaptive variation particularly in the context of freshwater environmental variation and climate change. These data are directly relevant for management of Pacific salmon in the context of conservation and rebuilding decisions as many Pacific salmon populations continue to face declines in abundance due to changing climate. The main results of the project emphasize the impacts of maximum temperatures on Pacific salmon, and highlight the degree of these potential impacts on systems like the Thompson River across species. In addition, the high-density of whole-genome genetic data and characterization of adaptive variation facilitates resolving among stock differences and supports development of genetic monitoring tools both for rebuilding and fisheries management applications, and improves the genetic resources available to support conservation unit delineation consistent with Canada's Policy for the Conservation of Wild Pacific Salmon (DFO 2005).

The primary sources of uncertainty associated with the project come from four aspects of the study design. First, although the datasets generated by the project represent some of the most comprehensive available for Pacific salmon, the sampling strategy prioritized the number of locations assessed rather than the number of individuals represented per location. This strategy is advantageous for performing associations with environmental variation among locations, but comes at the cost of reduced precision of estimates of genetic variation for each location. Second, low-coverage resequencing maximizes the number of individuals sequenced, but reduces the precision of genotype estimates for each individual, which again reduces the precision of estimates of genetic variation for each location. Third, the genotype-environment association analyses performed in this project require consistent and complete environmental data for each location in the study, and climate change forecasts are also necessary to predict the amount of genetic change that tracks climate change. Given the range of locations included, the only available dataset meeting these requirements at the time of the analyses was the BioClim database, which includes variables summarizing air temperature and precipitation variation. Although useful, these variables are only indirectly tied to the water conditions experienced by Pacific salmon. Moreover, a lack of understanding of stock-specific ocean distributions meant the analyses in this project only captured environmental variation among freshwater habitats. Fourth, the amount of genetic change required to track climate change for a population (i.e., the genomic offset) is not a direct measurement of risk or change in fitness, such that the relative variation in genomic offsets among locations is unlikely to fully capture the potential impacts of climate change. Additionally, these analyses rely on genotype-environment associations produced by evolution in the past, which may not capture the mechanisms through which evolution will proceed in the future, and may require extrapolation of associations beyond current conditions as climate change produces conditions that are completely novel for Pacific salmon. Together, these uncertainties emphasize the importance of considering genomic offsets in the context of holistic climate change vulnerability assessments rather than independently.

Next Steps

This project generated large genomic datasets for each of the five Pacific salmon, which substantially increased the genetic resources available to guide management of these species. However, archival samples in the Molecular Genetic Section were collected over approximately the last 40 years, and did not include samples from all key locations through BC and the Yukon for each species. Future studies should assess the extent to which archived samples continue to capture extant genetic variation for these locations, particularly for those which only have archived samples from before 2000. These studies should also capture unrepresented conservation units, and samples with detailed metadata on life history factors, such as run timing or spawn timing, would provide a major benefit for future analyses such as those conducted in the project.

Future studies should also address the sources of uncertainty described in the previous section. Firstly, to improve precision of estimates of genetic diversity for locations of high conservation concern or locations for which precise information on within-population genetic diversity is necessary, efforts to sequence additional individuals at potentially higher genomic coverage should be undertaken. Secondly, to improve confidence in genotype-environment associations and genomic offset predictions functional studies should be conducted to validate these associations and provide evidence that putatively adaptive genetic variants are also associated with trait variation in these species. Thirdly, watershed-specific analyses will provide opportunities to use environmental data that is more directly tied to the conditions experienced by Pacific salmon, which will allow regional validation of the patterns detected in this study, and may provide additional insights on environmental adaptation and climate change responses.

Tables and Figures

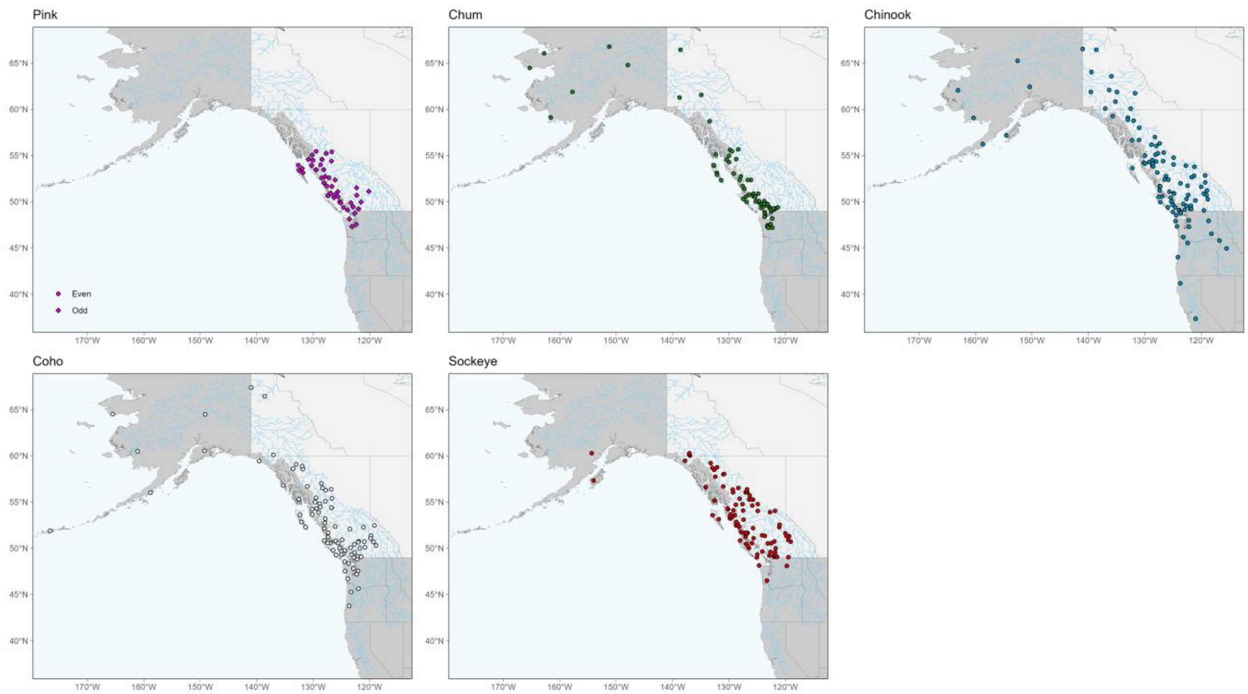

Figure 1. Collection locations for each Pacific salmon species used for low-coverage whole-genome resequencing, genotype-environment association analyses and genomic offset calculations. Panels and colours display the locations for each species (pink salmon - magenta; chum salmon - green; Chinook salmon - blue; coho salmon - white; sockeye salmon - red). Circles and diamonds for pink salmon correspond to collections of even-year and odd-year spawners, respectively.

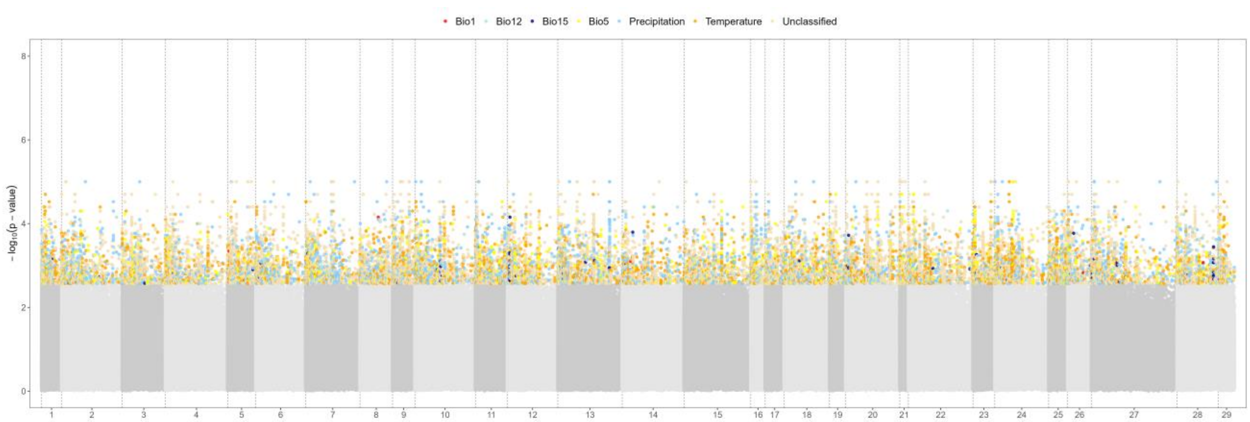

Figure 2. Genotype-environment associations for approximately five million genome-wide single-nucleotide polymorphisms (SNPs) in sockeye salmon. Allele frequencies at these SNPs were associated with four BioClim environmental variables using a partial redundancy analysis conditioned on the two main axes of genetic variation. The y-axis displays the inverse logarithm of the significance value for environmental associations for each SNP. Grey SNPs reflect those without a significant association, and alternating grey colours and dotted vertical lines show

chromosomal boundaries across the genome. Coloured points represent significant associations classified as most consistent with variation in one or more environmental variable based on correlations (red, Bio1 - annual mean temperature; yellow, Bio5 - maximum temperature of warmest month; pale blue, Bio12 - annual precipitation; navy, Bio15 - precipitation seasonality; orange, Bio1 and Bio5 - temperature; blue, Bio12 and Bio15 - precipitation; tan - unclassified).

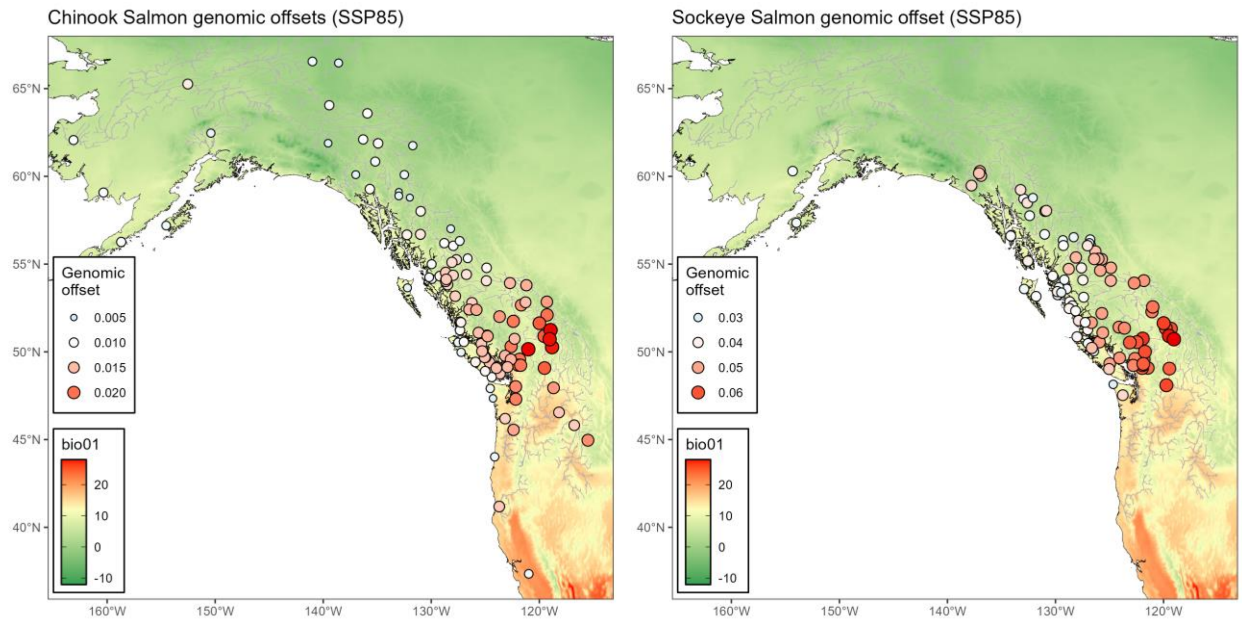

Figure 3. Genomic offsets for Chinook and sockeye salmon calculated using projected climate conditions from the shared socioeconomic pathway (SSP) 8.5 under the CMIP6 model. Offset estimates are projected on top a raster indicating variation in annual mean temperatures under the same SSP8.5 model. Offsets are indicate by circle diameter, and by blue to red colour indicating low to high offsets.

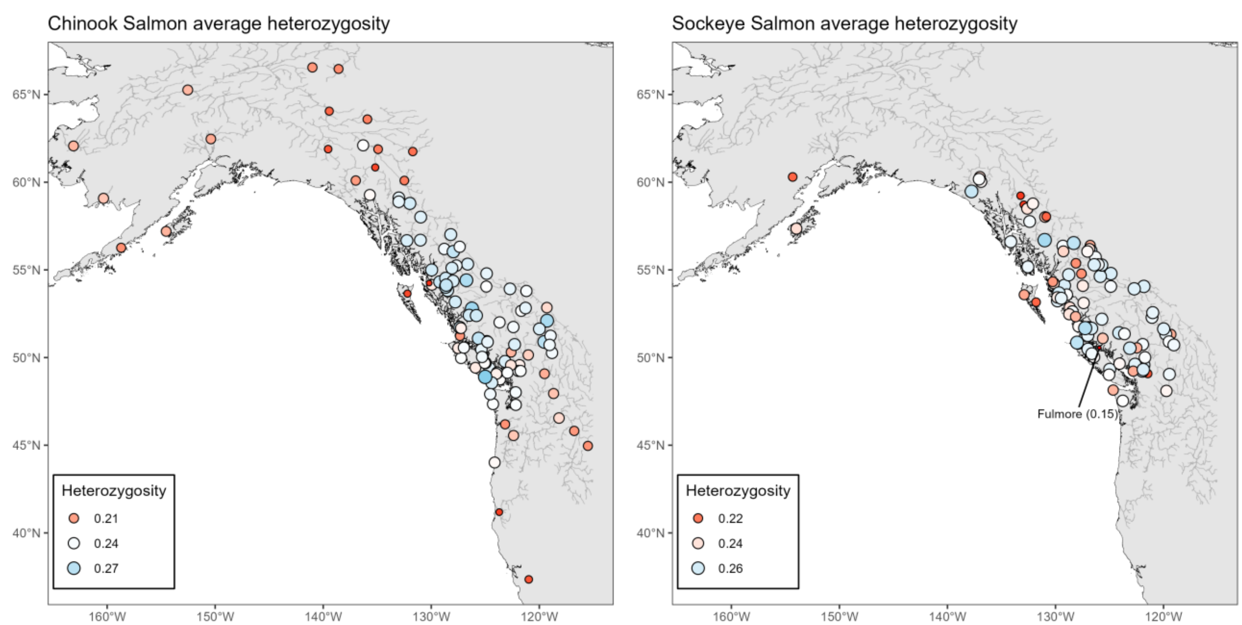

Figure 4. Average genome-wide heterozygosity estimates for each collection location of Chinook and sockeye salmon. Heterozygosity is shown by circle diameter, and by red to blue colours indicating low to high heterozygosity.

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9001 – Climate Vulnerability Indicators for Salmon (CVIS)

Collaborations: DFO: Michael Arbeider, Colin Bailey, Josephine Iacarella, Timothy Healy; External:Pacific Salmon Foundation, Pacific Climate Impacts Consortium, ECCC, University of Victoria

Region: Fraser River Basin

Species: *Oncorhynchus* spp.

Highlights

- The Climate Vulnerability Indicators for Salmon (CVIS) framework, is a quantitative approach for evaluating climate vulnerability for Pacific salmon conservation units (CUs) across freshwater, migration, nearshore marine, demographic, and genetic factors. The framework provides a transparent and reproducible basis for comparing climate-related risk among CUs by identifying which mechanisms and life stages most differentiate vulnerability.
- CVIS was applied to 5 species and 50 Pacific salmon CUs in the Fraser River basin to assess relative climate change vulnerability using data from downscaled climate projections, cumulative habitat stressor models, life-history timing, status assessments, and whole genome sequencing.
- Preliminary findings show considerable variation in indicator values and standardized scores across CUs, with risk generally the highest among CUs of sockeye and Chinook salmon rearing in the lower Fraser and Thompson-Nicola basins with summer migration timing, while Fraser pink, chum, and Coho salmon CUs were among the least vulnerable. Relative vulnerability scores and CU rankings only varied somewhat across different emissions scenarios, time periods, global climate models, but were more sensitive to the choice of scoring method for aggregating vulnerability indicators.

Background

Climate change is contributing to declines and increasing variability in Pacific salmon productivity across their Canadian range, but impacts are heterogeneous across species and among the hundreds of Pacific salmon conservation units (CUs). Despite a wealth of scientific studies on climate stressors in freshwater and marine environments (Crozier and Siegel 2023), broad-scale assessments that compare climate vulnerability across multiple species and wide geographic areas remain limited for Canadian Pacific salmon. This gap constrains systematic incorporation of climate considerations into conservation planning and management decisions, which may limit their effectiveness since any benefits of these activities can be moderated or outweighed by climate-driven changes (Beechie 2023).

The CVIS framework was developed to address this need through a quantitative, indicator-based approach that can evaluate a broad suite of mechanisms that determine climate vulnerability. The approach integrates multiple data products and modelling efforts, including downscaled climate models in freshwater and marine domains, cumulative habitat stressors models, CU status assessments, CU-specific life history timing, and environmental niche and genetic analyses. The framework is designed to be scientifically robust, transparent, and reproducible to support decision-making. The application presented in the report focuses on the Fraser River basin, an area of high life-history diversity where climate change is recognized as a major threat for many CUs.

Methods and Findings

Framework and indicators. CVIS consists of 17 quantitative indicators grouped into five categories aligned with mechanisms and life stages: (1) freshwater spawning and rearing, (2) upstream migration, (3) nearshore marine, (4) demographics, and (5) genetics (Table 1). Each indicator is derived from a quantitative or categorical metric (e.g., projected August stream temperature, proportional change in seasonal flow, migration distance, WSP status category). Indicators are standardized to a common 0–1 risk scale using response functions (Boyce et al. 2022), enabling comparison of risk across indicators and CUs. Where applicable, physiological/ecological thresholds (e.g. 15°C lower thresholds used for some temperature risk normalizations) are used to map raw indicator values into risk scores.

Freshwater spawning and rearing indicators. Vulnerability indicators for freshwater spawning and rearing life stages represent changes in stream temperature and flow, as well as cumulative threats to stream habitats (Iacarella et al. 2025), freshwater residency times, and environmental niche model predictions of changes in habitat favourability (Iacarella and Weller 2023). For each CU, an indicator is calculated as the mean value of model estimates across all stream segments within a CU boundary (e.g. see Figure 1), filtered to accessible streams with intrinsic habitat potential using the BCFishPass accessibility and habitat models (Hillcrest Geographics, 2025). Variation in environmental change indicators for each CU was summarized using 80% quantile ranges of values from global climate model projections.

Upstream migration indicators. Upstream migration indicators combine CU run and spawn timing (Wilson and Peacock 2025) with the migration path from river mouth to spawning sites to estimate average projected temperature and changes in flow during the upstream migration period. Temperatures and flows were summarized from projections by the Variable Infiltration Capacity with Glaciers model (VIC-GL, Schnorbus 2020), while spawning sites were selected from NuSEDS sites.

Nearshore marine indicators. Marine indicators represent changes to sea surface temperature and cumulative habitat impacts (Murray et al. 2024) within marine adaptive zones during the period of marine entry for each conservation unit. Sea surface temperature projections from global climate models were averaged over a 4 month period from April to July, representing the typical period of marine entry for most Fraser CUs (Mueter et al. 2002; Wilson and Peacock 2025). Because all CUs within the Fraser Basin belong to the same marine adaptive zone, scores were standardized across all marine adaptive zones of British Columbia to provide a more informative relative risk score.

Demographic and genetics indicators. Demographic indicators are derived from spawner abundance data and recent Wild Salmon Policy assessments of CU status in the Fraser Basin.

The CU status indicator represents the categorical status designation (Red, Amber, Green) using the Rapid Status Assessment Approach in 2022/23 (Pestal et al. 2023) while the recent generational average of spawners is determined based on the geometric average of the number of spawners over the most recent generation with available estimates. Genetic indicators assess the genetic differences among populations to evaluate the raw material for future selection (heterozygosity) and the differences between current genetic composition and optimal genetic composition under future conditions (genomic offset). The genetic indicators described here come from a whole genome analysis of Pacific salmon populations across their North American range (Healy et al, in prep).

Overall vulnerability scoring and sensitivity analysis. To translate individual indicators into overall vulnerability, a few scoring methods are applied reflecting different assumptions about how indicators combine to determine vulnerability risk. Overall scoring methods include: (i) an average of categories, giving equal weight to each indicator category (ii) an average across all indicators, giving equal weight to each indicator and (iii) an average-of-cubic means by category that places greater weighting on high indicator scores. Results are presented with emphasis on mid-century (2041–2060) under the representative concentration pathway 4.5, reflecting a moderate emissions mitigation scenario. Relative changes in CU vulnerability rankings were evaluated by changing the emissions scenarios (RCP 4.5 vs 8.5, representing moderate and minimal emissions mitigation), time periods (mid- vs end-century), global climate models, and scoring frameworks.

Results. Preliminary findings show considerable variation in indicator values and standardized scores across CUs (Figure 3), with risk generally the highest among CUs of sockeye and Chinook salmon rearing in the lower Fraser and Thompson-Nicola basins with summer migration timing. Fraser pink and chum, and most Coho CUs were generally among the least vulnerable of CUs on account of several factors. Demographic risk tended to be lower for these CUs because they have larger numbers of mature individuals and few of these CUs have a red, or poor, conservation status. Migration risk was lower due to their migration being shorter distances and occurring during the fall when temperatures do not exceed negative thresholds. Vulnerability scores for freshwater indicators were variable but tended to be lower for Pink, Chum, and Coho compared to some Chinook and Sockeye with smaller CU boundaries that are projected to experience greater environmental change. CUs with the highest vulnerability scores tended to be those with smaller numbers of spawners, poor conservation status, summer migration timing, and occurring in the lower Fraser and Thompson basins (E.g. CK-16 South Thompson 4.2; CK-06, lower Fraser summer run 5(2); CK-07 Maria Slough summer 4(1); SEL-03-03 Harrison downstream migrating late, SEL-03-02 Cultus Lake sockeye, and SEL-03-01 Chilliwack sockeye). Among those CUs with intermediate vulnerability scores were Chinook and Sockeye CUs spawning in the mid and upper Fraser watersheds, and Fraser canyon Coho. Marine indicator values were the same across all CUs with high standardized scores reflecting higher projected sea surface temperature and cumulative habitat impacts within the Strait of Georgia compared to other areas of coastal BC.

Relative vulnerability scores and CU rankings only varied somewhat across different emissions scenarios, time periods, global climate models, but were more sensitive to the choice of scoring method (Figure 4). The CUs with lower vulnerability ranks remained relatively consistent across all scenarios and sensitivity analysis, while higher vulnerability ranked CUs shifted positions among different scoring methods and among some global climate models.

Insights

This analysis leverages several recently developed models and assessments to provide a comprehensive, quantitative synthesis of risk factors that are important for understanding climate change vulnerability. The impact of climate change on Pacific salmon will depend on multiple interacting mechanisms whose influence will be mediated by life history, habitat condition, phenology, and other factors that vary across CUs. The indicator-based approach allows for multiple sources of information to be considered and specific scenarios, life stages or mechanisms to be examined in more detail depending on the question of interest or application. The scope of the analysis, consisting of 50 CUs compared within a consistent framework, can support more systematic consideration of climate vulnerability for conservation planning in the Fraser basin.

Preliminary findings largely correspond with published literature and studies that show Fraser sockeye at high risk from climate change, particularly due to temperatures during upstream migration (Rand et al. 2006; Martins et al. 2011). They also correspond with high climate vulnerability assessments for sockeye and Chinook salmon during recent recovery potential assessments (Dionne et al. 2023; Doutaz et al. 2023). There has been less research towards climate vulnerability for Fraser pink, chum, and coho salmon, but findings suggest their vulnerability is relatively lower than most Chinook and sockeye CUs.

Vulnerability of the marine life phase and the effects of increasing sea surface temperatures was not well distinguished for Fraser CUs in this model and remains an important area for further research. In addition, not all CUs and life history types are equally well represented by the indicators. For example, freshwater indicators represent stream conditions but do not represent rearing conditions for sockeye in lakes due to a lack of models projecting future lake conditions across the Fraser basin.

Next Steps

The CVIS framework provides a more systematic manner for incorporating climate change risk into assessments and planning activities for Pacific salmon. Given the serious implications of climate change for Pacific salmon, conservation planning and management processes should consider climate change vulnerability to contextualize the risks and benefits when making decisions. The framework could be expanded to other regions and CUs over time to support broader regional planning decisions and investigate how vulnerability and climate change impacts varies among CUs across their distribution within BC.

Tables and Figures

Table 1. The 17 indicators included in CVIS and their abbreviation used in this report.

Abbreviation	Description
	Demographics
CUstatus	Wild Salmon Policy CU status
CUnmat	Number of mature individuals (spawners)
	Freshwater
favchange	Ecological Niche Model Change in favourability from baseline
cthr	Standardized cumulative threats to freshwater streams
tw8rate	Rate of change in August Temperature (°C/decade)
tw8proj	Projected August Temperature (°C)
flow8pdelta	Proportional change in August flow from baseline
flow18pdelta	Proportional change in Nov-Jan flow from baseline
fwres	Freshwater residency time (days)
	Genetics
hetzyg	Genetic heterozygosity
genoff	Genomic offset
	Nearshore Marine
SSTproj	Projected nearshore SST during ocean entry (°C)
SSTrate	Rate of change in nearshore SST (°C/decade)
CImpact	Cumulative impacts to marine nearshore habitat
	Upstream Migration
migrTproj	Projected temperature during upstream migration (°C)
migrQpdelta	Proportional change in discharge during upstream migration
migrdist	Length of upstream migration (km)

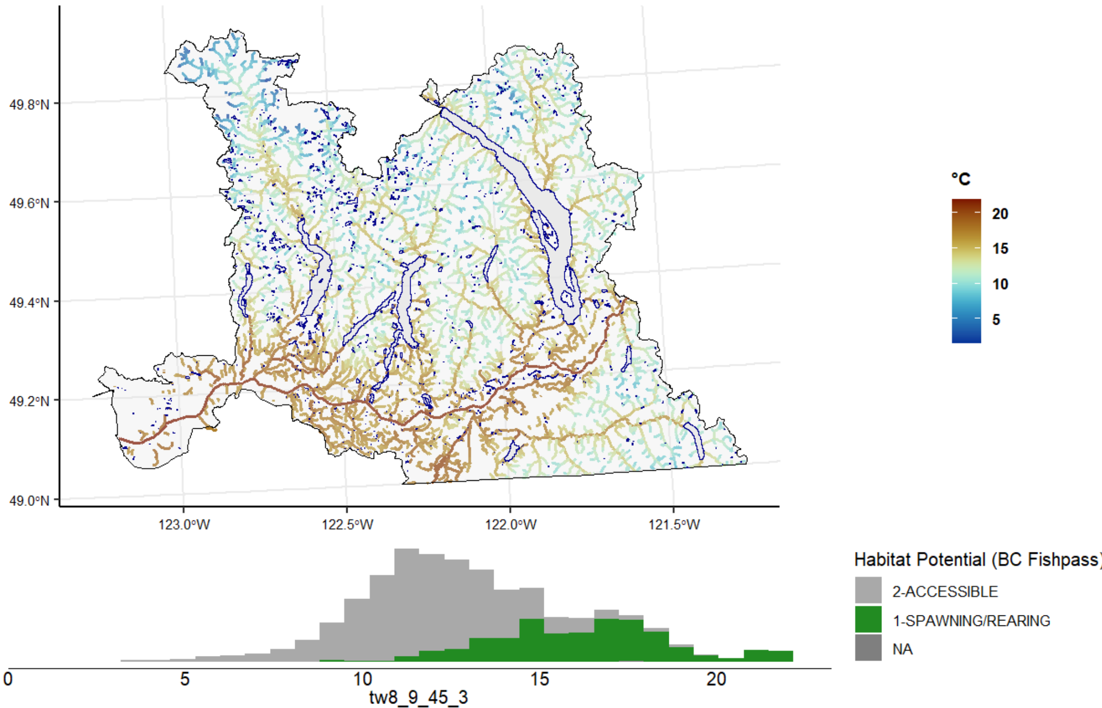

Figure 1. Map and histogram of projected August stream temperatures for the mid-century period (2041-2060) for lower Fraser Coho (CO-47). The mapped stream network is limited to accessible streams while indicator values are averaged from streams with habitat potential for spawning/rearing (green bins in the histogram).

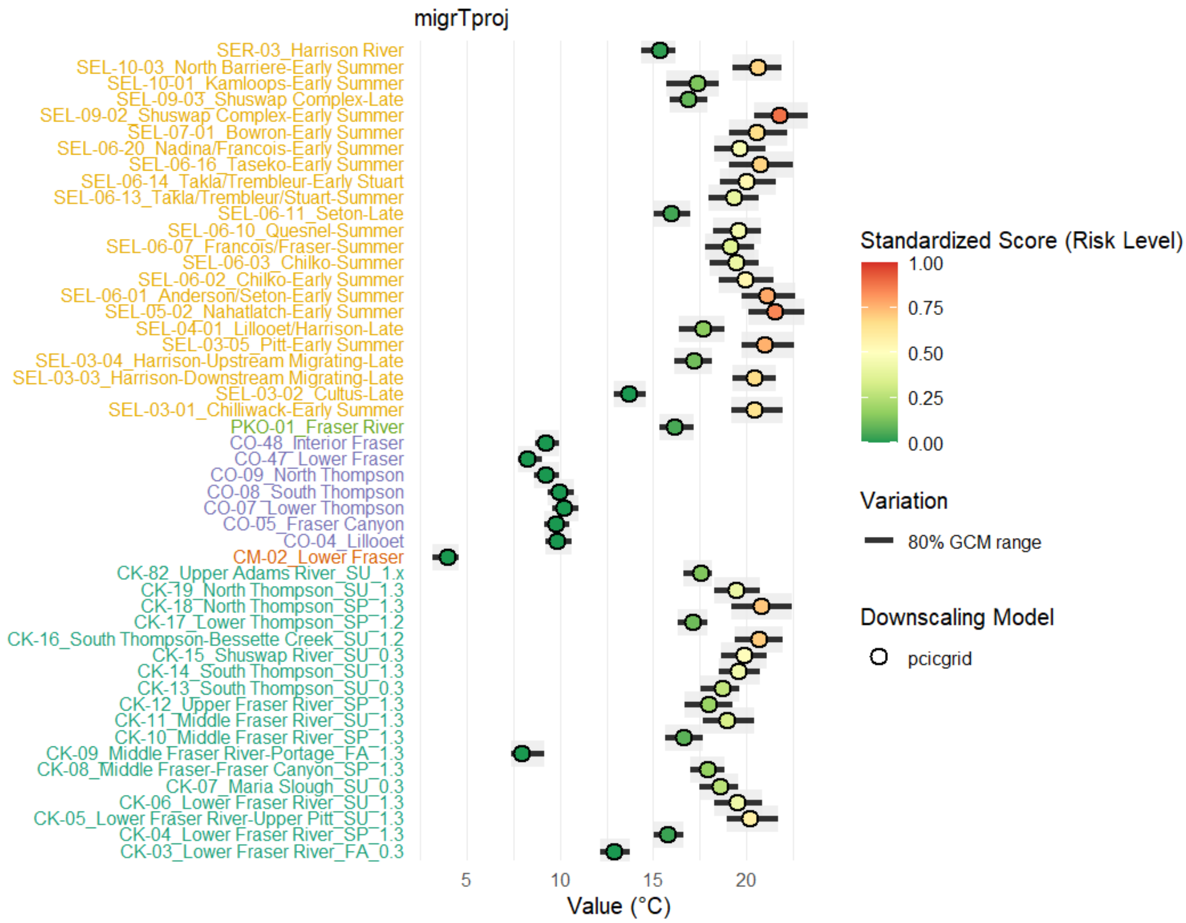

Figure 2. Indicator values of projected migration temperatures (migrTproj) for 50 CUs in the Fraser basin for the mid-century period (2041-2060) and RCP 45 emissions scenario. Circle fill colour represents standardized risk scores from 0 to 1 and black line segments show 80% quantile ranges of variation in projected temperature across global climate models.

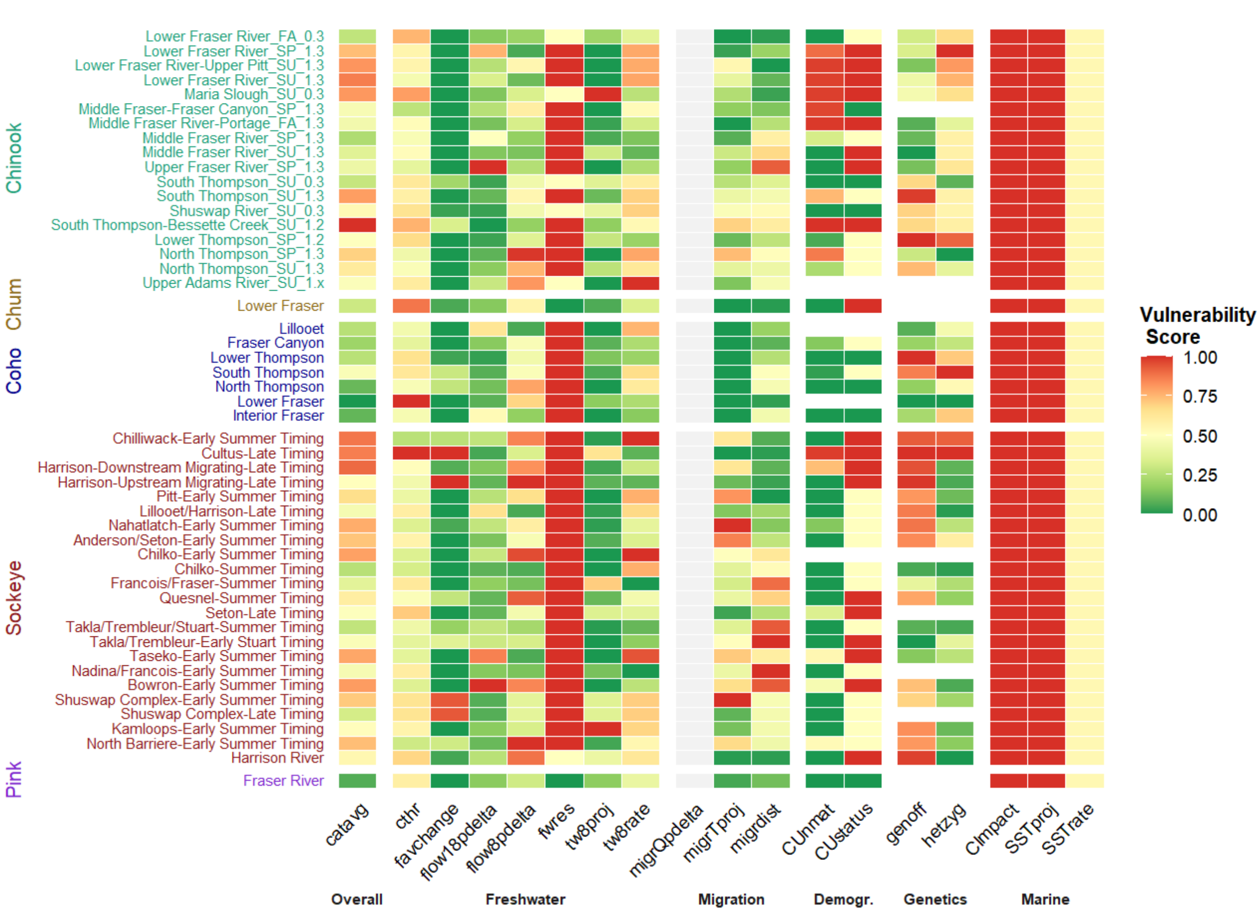

Figure 3. Standardized vulnerability scores of all indicators for 50 CUs in the Fraser basin including an overall vulnerability score taking the average of each indicator category (catavg column). Refer to Table 1 for indicator names corresponding to abbreviations. For environmental change indicators, scores shown here use the ensemble mean of global climate models averaged over the mid-century period (2041-2060) under the emissions scenario of representative concentration pathway 4.5.

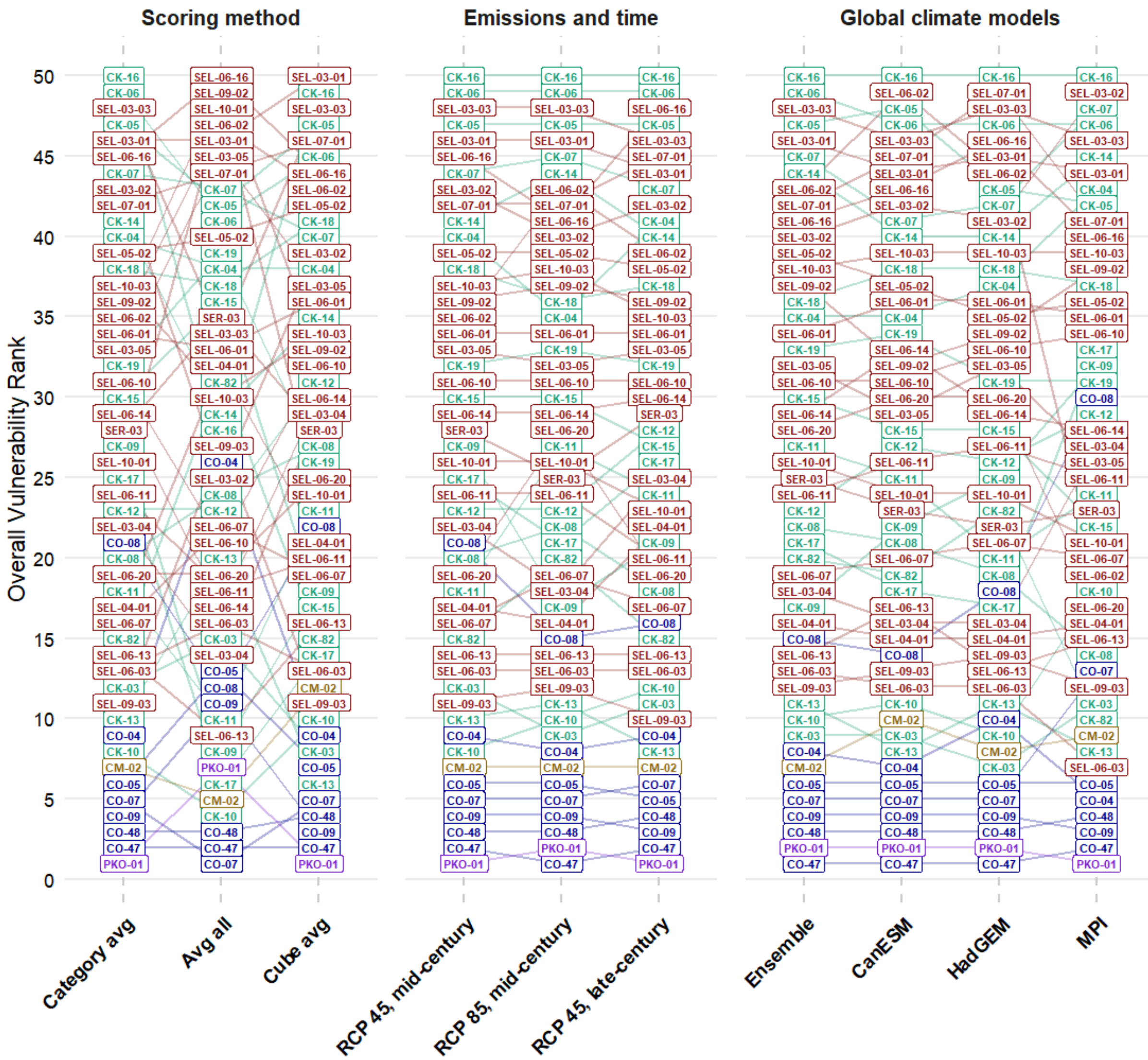

Figure 4. Relative vulnerability rankings (higher rank = more vulnerable) for the 50 CUs in the Fraser basin across different scoring methods (average of category scores, average of all indicators, and average of cubic mean), emissions scenarios (RCP 45 and RCP 85), time period (2041-2060 and 2081-2100) and global climate model (ensemble mean versus three individual models). CU abbreviations are colour-coded by species (red = sockeye, green = Chinook, purple = pink, blue = coho, gold = chum) and lines between scenarios show relative change in rank among methods.

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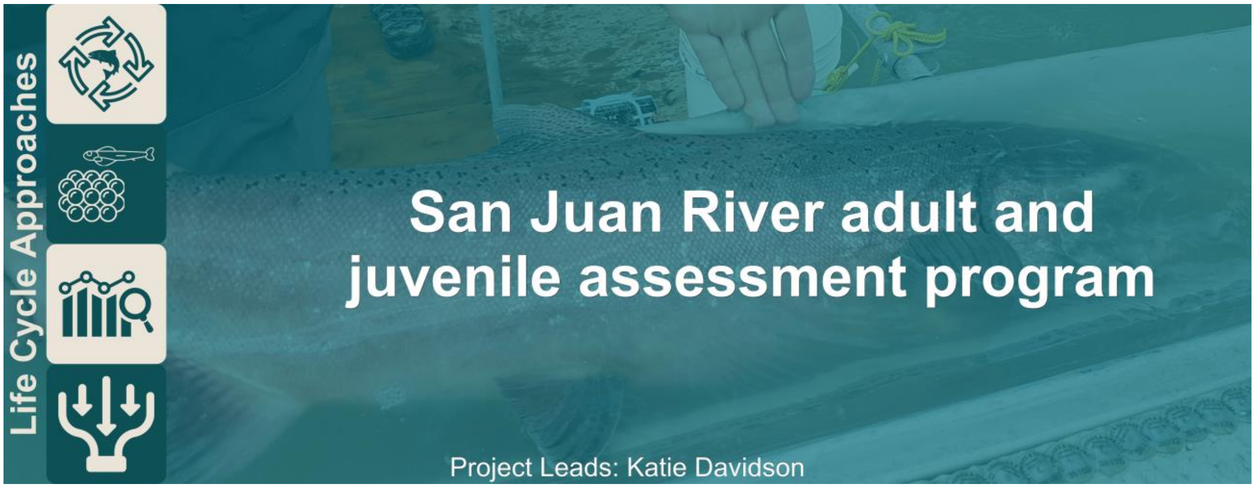
LIFE CYCLE APPROACHES

2403 - San Juan River Adult and Juvenile Assessment Program



https://github.com/SCA-stock-assess/WCVI-SanJuan-Juvenile

Tech report to be published March-April

Dataset to be published on the Salmon Portal March-April

Collaborations: Pacheedaht First Nation, 4 Mile Hatchery, Follow The Fish

Region: West Coast Vancouver Island

Waterbodies: San Juan River, Gordon River

Species: Chinook, Coho, Chum

Populations: San Juan Chinook

Highlights

- San Juan Chinook are a unique population part of the WCVI Fall Chinook CU that has recently received a rebuilding plan. Risk assessments have noted knowledge gaps related to juvenile life stages in the freshwater, estuary and early marine stages. This project aims to fill some of these data gaps.
- The results from this project will inform a revised risk assessment process for WCVI Chinook in 2026, as well as provide Pacheedaht First Nation with data upon which to base their rebuilding plan for San Juan Chinook and to inform restoration efforts in the watershed.

Background

These activities will all inform the San Juan Chinook Rebuilding Plan in development by PFN, which will be linked to the broader WCVI Chinook Rebuilding Plan recently developed by DFO (required under the Fish Stock Provisions Act for naturally-produced WCVI Chinook) (DFO 2025). This project will also inform a risk assessment re-scoring expected to happen in 2026, where new information from PSSI projects will be used to re-evaluate the most prominent bottlenecks to WCVI Chinook survival and recovery. The first round WCVI Chinook risk assessment process identified several knowledge gaps, mostly related to early freshwater and marine life cycle stages. For San Juan Chinook specifically, juvenile data from these life stages (and interactions between hatchery and wild juveniles) are sparse, and biological data on natural spawners (e.g., age, origin) are limited.

These reasons made the San Juan River a good candidate to develop an integrated life history monitoring program in alignment with the larger Follow The Fish program. We focused on activities complemented Pacheedaht First Nation's established juvenile monitoring programs. First, we operated a rotary screw trap program to enumerate and sample naturally-produced out-migrating juveniles (all species, but focused on juvenile Chinook migration timing) in the freshwater environment, allowing us to compare natural migration timing to hatchery release timing, gather baseline biological traits relative to hatchery releases (e.g., size, condition), and estimate fry outmigration abundance. Otolith and stomach samples are also collected from a sub-sample of individuals to assess size-specific survival and diet contents. Second, we collected samples from Pacheedaht's estuary beach seine program to continue examining diet differences and estuary residency (via otolith microchemistry) between hatchery and natural-origin Chinook. Finally, we conducted biweekly purse seining in Port San Juan (PFMA 20-2) through the late spring, summer and fall months (~May-October) to collect mixed-stock information, including hatchery/natural-origin of juvenile Chinook, stock ID, biological traits, relative abundance, and information on other species schooling with Chinook (e.g., Coho, Pacific Herring). As with the RST and beach seine, we also collected otoliths and stomach contents from a sub-sample of Chinook encountered. Finally, we developed a biosampling plan to assess age and stock composition of naturally-spawning adult Chinook (a deadpitch program). Current information on the Proportion of Natural Influence (PNI) is limited only to broodstock sampling, but it is unknown whether these samples are biased and whether they are representative of the river spawning component of the population. It is critical to have an accurate representation of PNI and age and composition-at-return to assess productivity trends and hatchery release strategies for rebuilding San Juan Chinook.

All work was done in collaboration with Pacheedaht First Nation. Their Fisheries Team lead the majority of the field work and sample collection, as well as advised on sampling designs and salmon dynamics to improve the study design of the project.

Next Steps

The key finding of this project will be the specific differences in dynamics between hatchery and natural-origin San Juan Chinook, and using this information to both improve the survival and health of natural-origin juveniles while producing hatchery fish that complement, rather than compete with, the natural population. These findings may be applicable to other systems, although collecting stock-specific information is critical to ensure that any future "indicator" populations are in fact indicative of dynamics in other systems.

Future studies should further examine specific indicators of early mortality in juvenile salmon, primarily in the freshwater and estuarine stages which are largely unmonitored by DFO. In addition, consideration should be given as to how hatchery release strategies change the life history dynamics of juvenile salmon.

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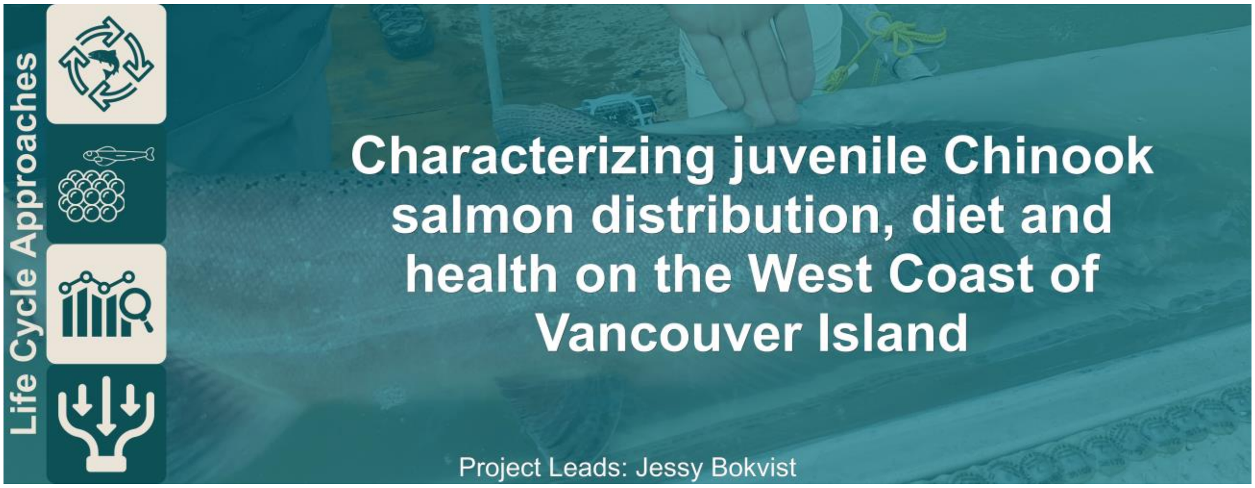
2407 - Juvenile Chinook Distribution, Diet, and Health on WCVI



Characterizing juvenile Chinook salmon overwinter distribution, health, and diet in nearshore marine areas on the West Coast of Vancouver island, 2020-2025 (Canadian Manuscript Report, in progress, Fisheries and Oceans Canada Library - Canada.ca)

The early marine distribution, health and diet of juvenile Chinook salmon in Barkley Sound on the West Coast of Vancouver Island, 2022-2025 (Canadian Manuscript Report, in progress, Fisheries and Oceans Canada Library - Canada.ca)

Contact: Jessy.Bokvist@dfo-mpo.gc.ca

Collaborations: Ahousaht First Nation; Coal Harbour Ltd.; British Columbia Conservation Foundation; Cedar Coast Field Station; Charter Tofino; Ditidaht First Nation; Ehattesaht/Chinehkint First Nation; Ha'oom Fisheries Society; Hesquiaht First Nation; Hupačasath First Nation; Huu-ay-aht First Nations; The Juanes Lab (University of Victoria); Ka:'yu:'k't'h'/Che:k:tles7et'h' First Nations; LGL Limited; Maaqutusiis Hahoulthee Stewardship Society; M.C. Wright and Associates Ltd.; Mowachaht-Muchalaht First Nations; Nootka Sound Watershed Society; Nuu-Chah-Nulth Tribal Council; Nuchatlaht Tribe; Pacheedaht First Nation; Pacific Salmon Foundation; Quatsino First Nation; Redd Fish Restoration Society; Thornton Creek Enhancement Society; Tla-o-qui-aht First Nation; Toquaht Nation; Tseshaht First Nation; T'Sou-ke Nation; Uchucklesaht Tribe; Yuułuʔiłʔatḥ Government

Region: West Coast Vancouver Island

Waterbodies: Sooke Basin, Port San Juan, Nitinat Lake, Barkley Sound, Clayoquot Sound, Nootka Sound, Kyuquot Sound, Quatsino Sound

Species: Chinook

Populations: WCVI Chinook

Highlights

- This project aimed to characterize the distribution, diet and health of WCVI origin juvenile Chinook during their first year at sea. From 2020-2025, Juvenile Chinook were caught and sampled during their outmigration from natal rivers, in the summer, and overwinter within marine sounds on the WCVI.

- We found that nearshore marine areas on the WCVI are important rearing habitats for local juvenile Chinook during their first year at sea. Microtrolling surveys revealed shifting habitat distributions, as some individuals were observed to distribute into sounds along presumed northernly migration, well others persisted within locals sounds for the duration of their first year at sea. Juvenile Chinook utilized a variety of high quality prey sources throughout the summer and winter, however, a decline in stomach fullness and fish condition over the winter may indicate nutritional stress that requires further investigation. The distributional and diet overlap of juvenile Chinook stocks of hatchery and natural origin through space and time indicate potential for intraspecific competition if resources are limited.
- Decision makers should examine the importance of WCVI nearshore marine areas for juvenile Chinook during their early marine phase. Area based management decisions should consider that local juvenile Chinook may stay in nearshore sounds for the entirety of their first year at sea and management action can impact local residents and northern migrating juvenile Chinook from the WCVI, other parts of BC, and the USA. Management should consider action to maintain the availability and quality of prey items we found utilized by WCVI juvenile Chinook stocks. Fish were the most important prey source for WCVI juvenile Chinook during the summer and winter suggesting the importance of forage fish management within nearshore areas to maintain high-quality prey resources. Finally, decision makers should consider how to mitigate potential for competition of resources between hatchery and natural-origin juvenile Chinook in management decisions.

Background

Chinook salmon from the West Coast of Vancouver Island are an important natural resource of high conservation concern. In 2022, WCVI Chinook were included in the Fish Stock Provisions of Canada's Fisheries Act, triggering the development of a rebuilding plan. Risk assessment workshops were held in 2021-2022 to identify key risks to WCVI Chinook across their lifecycle to inform rebuilding efforts and development management actions to address risks of highest concern. The first year at sea was assessed as the period of highest risk for WCVI Chinook, yet many knowledge and data gaps existed that limited understanding of what key factors are limiting survival and productivity of juvenile Chinook (Irvine et al, 2024). In 2023, DFO's Pacific Salmon Strategy Initiative funded the *Follow the Fish* program to investigate factors that are limiting the health and survival of WCVI Chinook. One of twelve projects under Follow the Fish, this project aimed to address knowledge gaps pertaining to the distribution of juvenile Chinook in nearshore marine sounds and nutritional stress, including competition for and access to abundant and high quality prey during the first year at sea.

This project was highly collaborative and relied on the combined efforts and partnership between DFO, 17 First Nations and 12 Non-Governmental Organizations (NGOs) to achieve project objectives. Outmigration and winter salmon surveys funded under this project were largely carried out by local First Nation and NGO partners fishing in the Ha'houlthee or traditional territories of local First Nations from Sooke Basin through Quatsino Sound. Summer purse seine surveys in Barkley Sound were co-funded and carried out with Huu-ay-aht First Nation under their British Columbia Salmon Restoration and Innovation Fund project focused on Sarita River Chinook.

Methods and Findings

Under this project we used catch and effort, fish, and environmental data collected from 2020-2025 to characterize juvenile Chinook distribution, diet, and health. We processed tissue samples from juvenile Chinook to obtain stock of origin information using GSI and PBT methods (Beacham et al, 2018) and assigned WCVI-origin fish to nine stock aggregates (Figure 1). We collected fork length (mm) and weight (g) measurements from sampled Chinook to estimate an index of condition from the residuals of a log-log length-weight linear regression. Chinook were lethally sampled to collect stomachs to determine diet composition and investigate nutritional stress. Prey items were taxonomically identified to the lowest practicable level and the frequency of occurrence and the mean contribution of prey groups to the diet composition and fullness of a stomach were calculated across spatial and temporal scales. To characterize the winter distribution of WCVI juvenile Chinook we used geostatistical models to investigate the spatial, temporal and environmental factors associated with catch per unit effort (CPUE). We ran several inlet specific and WCVI wide models to investigate the association of CPUE with various predictors, including ocean entry year, day of year, time of day, capture depth, and fish origin (stock and hatchery vs natural). We investigated CPUE associated with temperature, salinity, and chlorophyll A at surface and capture depths using measurements collected during field surveys and via satellites.

This project found that nearshore marine areas on the West Coast are important rearing habitat for local juvenile Chinook who may reside in these areas for the duration of their first year at sea. Summer surveys in Barkley Sound showed local stocks distributed throughout the Sound with southern Chinook from Nitinat, Sooke and Port Renfrew migrating into Barkley Sound by early summer (Figure 2). This northward migration through nearshore sounds continued during the winter, as seen by the detection of fish from southern areas within northern sounds over time (Figure 2). WCVI Chinook also stayed within their natal area (sound, inlet or basin where natal river tributaries drain into) for the duration of their first winer at sea. For example, Inner Barkley juvenile Chinook originating from Robertson Creek/Stamp River were detected within Barkley Sound throughout the summer and winter, as well as in Clayoquot, Nootka, Kyuquot and Quatsino Sounds (Figure 2). During the winter period, geostatistical modelling showed that WCVI Chinook CPUE was highest in the fall and dropped quickly by November (Figure 3 A), which could reflect a change in abundance of fish, either through emigration out of sounds, mortality, or a change in fish behavior leading to less captures. This drop was reflected primarily in the CPUE for hatchery-origin fish, whereas CPUE of natural origin fish was relatively consistent across the winter. CPUE was lowest at the surface and increased deeper into the water column (Figure 3 B) and was also positively associated with temperature and salinity at depth. This indicated that juvenile Chinook were distributed at deeper depths during the winter and associations with higher salinity and temperatures may reflect movement in relation to thermal and salinity preferences or other behaviors.

WCVI Juvenile Chinook consumed a variety of prey sources during their first marine year. Stomach samples were obtained from juvenile Chinook during their spring rearing in the Somass Estuary and Nitinat Lake (2024), during summer rearing in Barkley Sound (2022-2025) and overwinter in nearshore sounds along the WCVI (2020-2025) to investigate diet composition. Juvenile Chinook from the Somass Estuary and Nitinat Lake consumed insects, barnacles and amphipods during the spring (Figure 4). In Barkley Sound during the summer, diet composition was primarily composed of fish and decapod (crustacean) larvae alongside a variety of other prey sources (Figure 4). As juvenile Chinook overwintered in nearshore sounds along the WCVI their diet was largely comprised of fish with contributions from amphipods, krill and crustacean larvae (Figure 4). Hatchery and natural origin juvenile Chinook utilized similar prey resources over space and time during the first marine year (Figure 4). High quality prey appeared to be available to juvenile Chinook through the summer and winter, such as fish (Daly et al, 2010), decapod larvae (Weil, Duguid, Juanes, 2020), krill (Davis et al, 2020) and Hyperiidea amphipods (Hiltunen et al, 2022; Weil et al. 2020). In particular, the consumption of fishes in juvenile salmon has been linked to higher growth rates (Duguid et al, 2021, Davis et al, 2020) which can lead to higher marine survival (Claiborne et al, 2021; Duffy, Beauchamp, 2011). As winter progressed, fish condition and stomach fullness declined despite the large contribution of fish in the diets of juvenile Chinook, which could suggest prey availability becomes limited in the winter and leads to nutritional stress. However, these patterns may also be explained by changes in fish behavior to prioritize migration, predator avoidance over feeding activities, or decreased prey consumption resulting from slowed metabolism in cooler waters (Plumb, Moffitt, 2015). Next steps under this project include investigating how variation in fish growth (being measured from collected scales) and condition relate to diet composition to investigate how dominant prey groups influence juvenile health.

Juvenile Chinook distributional patterns and diet indicate potential for intra-specific competition within WCVI Sounds if resources are limited. Within a sound, juvenile Chinook face competition for resources from local stocks and with Chinook from neighboring sounds who arrive during their northward migration (Figure 5). Chinook from other parts of BC and the USA arrive in WCVI Sounds as winter progresses, these fish are comparable in size to local juvenile Chinook and therefore may target and compete for the same prey sources. Of the local WCVI juvenile Chinook present in nearshore areas, majority are of hatchery origin compared to their natural origin counterparts (Figure 5). The productivity and growth of natural origin salmon can be negatively impacted by competition with hatchery conspecifics (Weber, Fausch, 2005; Metcalfe, Valdimarsson, Morgan, 2003), however, this outcome is highly variable and is influenced by environmental conditions (Garzke et al, 2023; Daly, Brodeur, 2015), density dependent interactions (Grossman, Simon, 2019), and the fitness of hatchery reared salmon (Araki et al, 2008; Metcalfe, Valdimarsson, Morgan, 2003). Overlap in distribution and diet between hatchery and natural origin juvenile Chinook observed in this project does not confirm that competition is occurring but rather that competition is likely if resources are limited.

Insights

Our objectives were to improve understanding of exposure to and risk of factors that may be limiting the survival of WCVI Chinook salmon. WCVI Chinook are thought to stay nearshore for their first year at sea but there is limited understanding of overwinter distribution due to few winter surveys carried out in WCVI Sounds. This project improved understanding of how natural and hatchery origin juvenile Chinook utilize nearshore marine areas on the WCVI and the movement of local, USA, and other BC Chinook through sounds during the winter. Knowledge of distributional patterns of juvenile Chinook can be used to characterize when and where fish are exposed to different factors limiting their survival (e.g. pathogens, contaminants) and aid in area-based management decisions to limit risk exposure. Under this project we provided data and insight into whether WCVI juvenile Chinook are limited by competition for, access to and quality of prey during their first year at sea, which were outstanding data gaps from risk assessment processes (Irvine et al, 2024). Results and data from this project can be used by decision makers for area-based management actions related to rebuilding Chinook salmon and managing risks associated with nutritional stress and competition.

Sources of uncertainty relate to sampling design and survey methodologies employed under this project. Survey efforts were focused on “following” juvenile Chinook that originated primarily from Nitinat River, Sarita River, and Stamp River as these populations are of relatively high abundance in these areas which enables high catch and sampling rates over space and time. Outmigration beach seine surveys were limited to sampling Chinook in Nitinat Lake and the Somass Estuary and summer purse seine surveys occurred in Barkley Sound, which led to captures of Chinook originating from Nitinat+Sooke, Inner Barkley, and Sarita River. While these populations can provide insight into risks to WCVI Chinook during the early marine phase further research is needed to understand population and area specific risk associated with nutrition and competition. Winter surveys achieved sampling in all WCVI Sounds and intercepted multiple stocks leading to a more representative sample of WCVI Chinook, however, this sampling involves hook and line fishing (microtrolling) for juvenile Chinook which may bias captures to larger fish that are actively feeding. If juvenile Chinook are in good health they are more likely to participate in feeding behaviors than those in poor health, so results from winter surveys should be interpreted understanding this limitation. Due to variation in populations and areas sampled and differing capture methodologies, comparisons of fish diet and condition across seasons should be made cautiously.

Next Steps

Future work building on this project’s findings should be aimed at understanding migration patterns, where and when prey availability is limited and linkages between diet, competition and Chinook health. Under this project we demonstrated movement and residency within Sounds throughout the winter but it is not clear what proportion of the WCVI Chinook population this represents. A future telemetry study could answer many outstanding questions on migration behaviors including migration timing, fish movement between Sounds (e.g. utilize multiple or choose one), and when fish are emigrating from nearshore Sounds into open waters on the continental shelf. Outstanding questions also remain around fine-scale distribution of local juvenile Chinook within WCVI Sounds, a stratified systematic sampling approach should be pursued in future research to characterize these patterns. To better understand if WCVI Chinook are experiencing nutritional stress, measurements of fish health (e.g. growth, condition, genetic signatures of starvation) should be analyzed in relation to diet composition to understand how dominant prey groups directly influence juvenile health. Finally, to better understand the potential for intraspecific competition, future research should examine if prey items are being preferentially selected or reflective of prey availability within the environment. This information would provide insight into how and when we might see competition arise as prey availability changes.

Outcomes of this projects should inform rebuilding efforts for WCVI Chinook salmon and future assessment and monitoring programs. Project results will be maintained long term by informing upcoming revisions of the rebuilding plan for WCVI Chinook salmon (Fisheries and Oceans Canada, 2025). This project improved understanding of limiting factors related to prey availability, quality, and intra-specific competition that can be used by management to update relative risk ranking of marine limiting factors that inform the rebuilding plan. Results from this project should be used as guidance on where and when potential for intraspecific competition and nutritional stress are risks to juvenile Chinook to develop management actions that mitigate risks. These results can be used by local stakeholders and decision makers to inform stock and area-specific local management of juvenile Chinook and provide guidance on outstanding data gaps for further assessment programs.

Tables and Figures

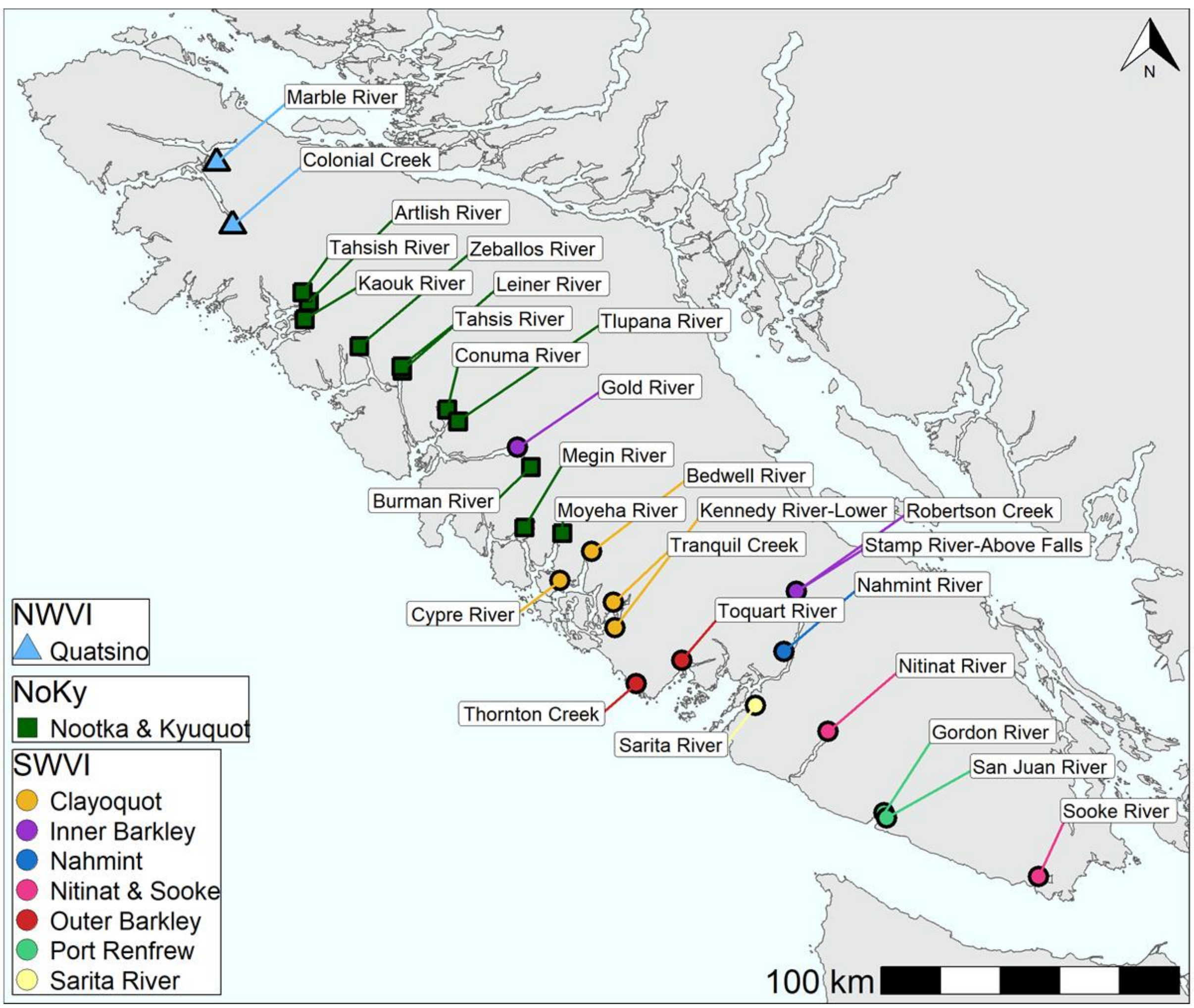


Figure 1. Chinook-bearing river systems on the WCVI that have been genetically sequenced and included in the library for stock assignment with GSI and PBT. Color coding indicates how populations were aggregated for individual

stock assignments and shapes indicate how river systems fall in the South-West Vancouver Island (SWVI), Nootka-Kyuquot (NoKy) and North-West Vancouver Island (NWVI) Conservation Units.

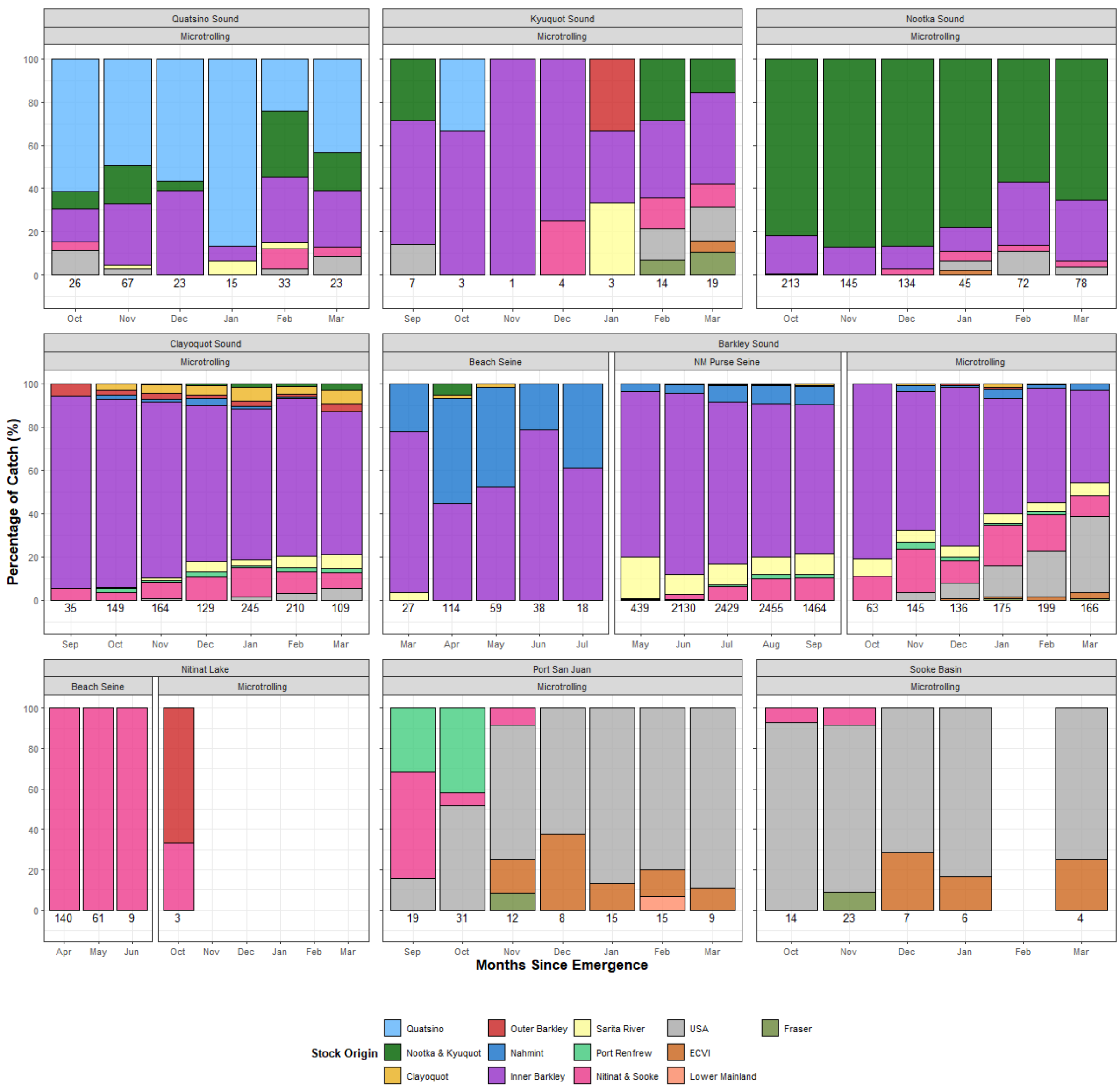


Figure 2. Stock composition of juvenile Chinook caught during summer and winter salmon surveys summarized by fishing area and month across field season (2020-2025). Chinook are considered juvenile based on PBT brood year information or have a fork length ≤350mm. WCVI Chinook are assigned to stock aggregates based on Figure 1 and non-local Chinook are assigned to areas representing the Lower Mainland, Fraser, East Coast of Vancouver Island (ECVI), and the United States of America (USA). Individual fish are assigned to a stock of origin based on a

probability of assignment ≥80% and numbers below bars represent sample sizes.

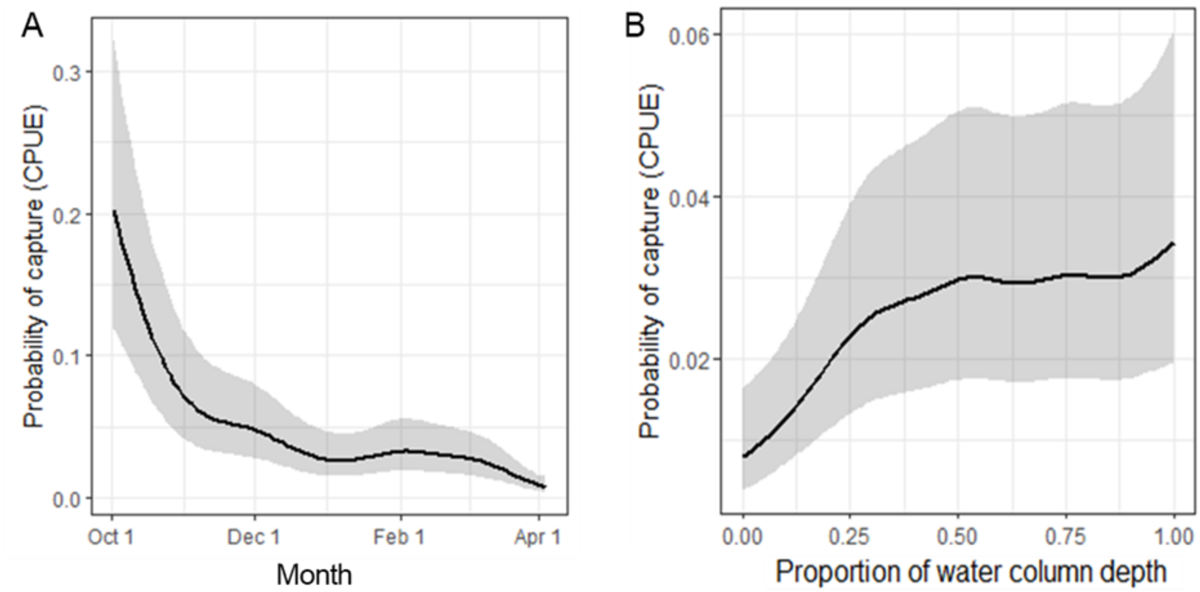


Figure 3. Geostatistical modelling predictions of CPUE as a function of A) varying date of winter microtrolling season and B) depth proportion with all other variables held constant. Models were built using winter microtrolling data from 2020-2025 across all areas surveyed.

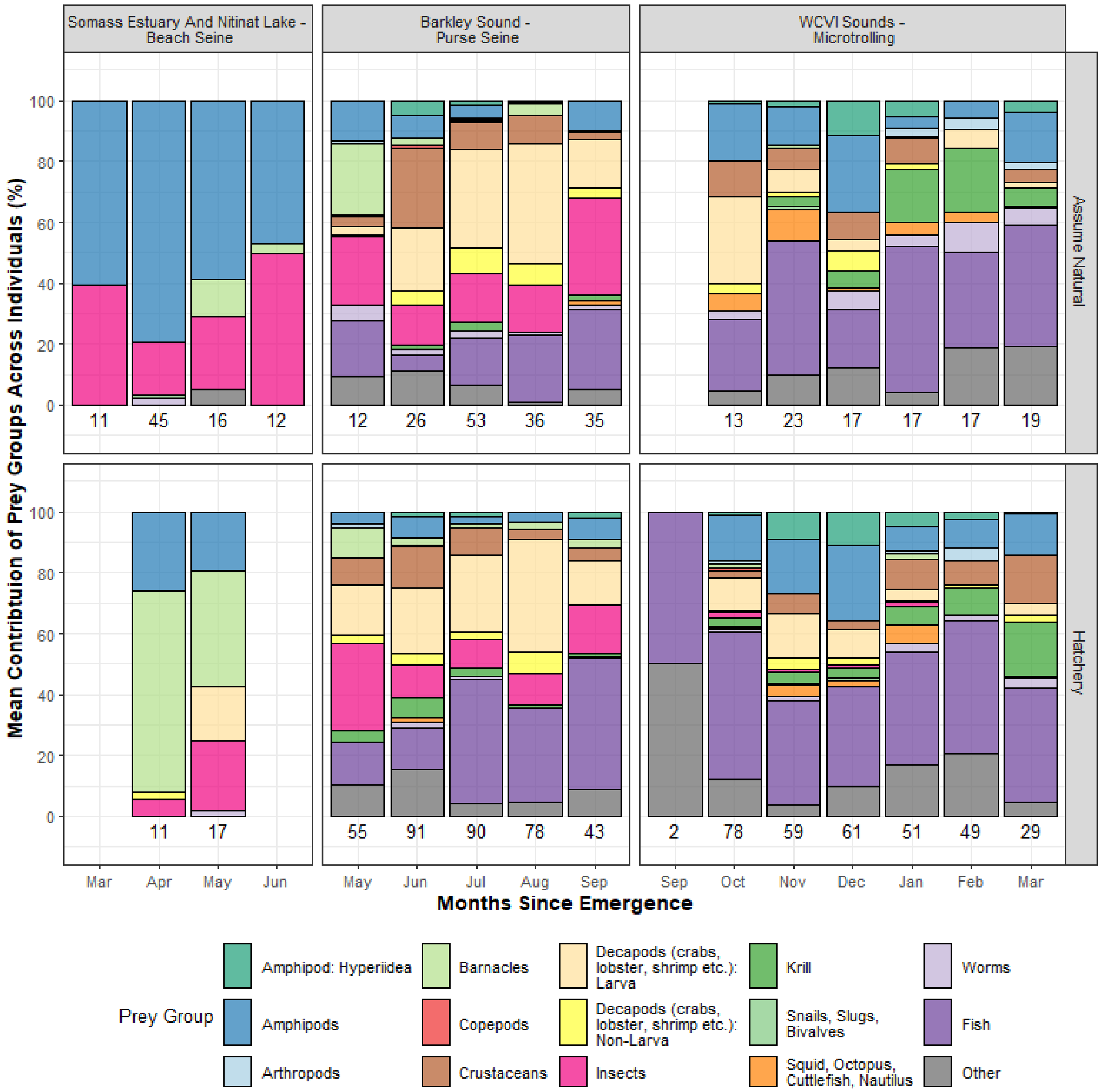


Figure 4. Mean contribution of prey groups to the diet composition of hatchery and natural origin WCVI juvenile Chinook during spring outmigration (Nitinat Lake and Somass Estuary, 2024), summer (Barkley Sound, 2022-2025) and winter (Port San Juan through Quatsino Sound, 2020-2025) salmon surveys. Prey groups were categorized to lowest practicable levels of distinguishable items, with the 'other' group composed of relatively rare items (bryozoans), or items that were indistinguishable to a particular taxonomic prey group (such as parts, eggs, fragments, organic mush). Numbers below bars represent sample size. Surveys were biased toward specific stocks based on timing and survey location with dietary information shown for Beach Seine panel: Inner Barkley, Nahmint, and Nitinat & Sooke, Purse Seine panel: Inner Barkley, Nahmint, Nitinat & Sooke, and Sarita River, Microtrolling panel: Clayoquot, Inner Barkley, Nahmint, Nitinat & Sooke, Nootka & Kyuquot, Outer Barkley, Port Renfrew, Quatsino, and Sarita River.

Figure 5. Catch demographics linking hatchery origin and population aggregate of fish captured relative to a particular sound by month and across field seasons (2020-2025). Hatchery origin was designated if an individual had PBT stock assignment, adipose fin clip, and/or a CWT was detected, individuals matching none of these descriptions were assumed to be natural-origin. Chinook were considered juvenile based on PBT brood year or were of a juvenile size class (≤350mm). Local and non-local status describes WCVI stocks in relation to each Sound, where stock aggregates whose river of origin is within a Sound are deemed local and non-local fish are those present in a Sound that does not contain their river of origin (i.e. migrating WCVI fish). For example, a Quatsino fish was only categorized as 'local' when captured within Quatsino Sound. Comparatively, Inner Barkley populations were considered local when present in Barkley Sound and Nootka sound, as system genetically indistinguishable in both sounds form a stock aggregate (see Figure 1). Likewise, the "Nootka & Kyuquot" stock aggregate has systems within Clayoquot Sound, Nootka Sound, and Kyuquot sound, and therefore any fish matching to "Nootka & Kyuquot" genetics, may be considered local if caught in these three sounds. Populations outside of WCVI were aggregated into broad generic groups identified either to BC or USA origin.

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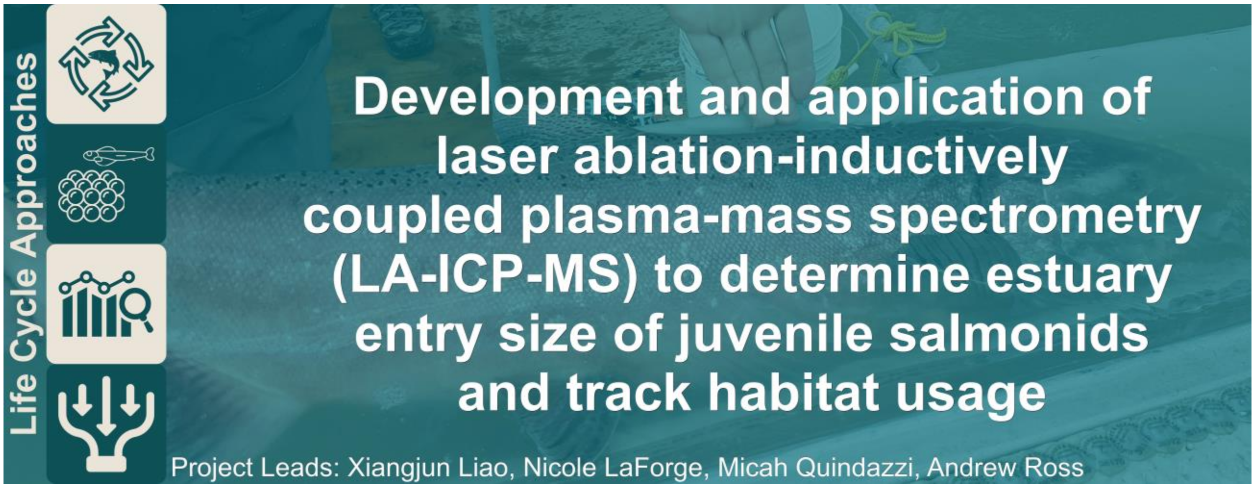
2422 - LA-ICP-MS for Estuary Entry Size and Habitat Use



Using Otolith Microchemistry to Identify Life-History Specific Survival Rates of Sarita River Chinook Salmon, Trans. Am. Fish. Soc. [in review]

Robertson Creek/Stamp River Chinook Salmon Tech Report [in prep]

Nitinat River Chinook Salmon Tech Report [in prep]

Bedwell River Chinook Salmon Tech Report [in prep]

Assessment of Life-History Specific Utilization of the Nearshore Environment manuscript [in prep]

Collaborations: LGL Ltd, Huu-ay-aht First Nation

Region: West Coast Vancouver Island

Waterbodies: Barkley Sound, Clayoquot Sound, Nitinat Lake, San Juan River, Sarita River, Stamp River, Bedwell River

Species: Chinook

Populations: Sarita, Stamp/Robertson, Nitinat, San Juan, Bedwell

Highlights

- **Goal**: Develop internal DFO capacity to analyse otolith microchemistry using LA-ICP-MS and use it to compare juvenile Chinook sizes at estuary entry and estuary residence times by back-calculating the fork lengths (FL) from the microchemically derived otolith radii.

- **Findings**: We measured the otoliths of outmigrating Chinook and constructed FL-otolith radii regression relationships: determined that they were segmented break-point models and river system specific. We focused on PSSI priority WCVI systems: identified population specific patterns of estuary entry and residency for the Sarita, Nitinat, Stamp, Bedwell and San Juan systems.

- **Implications**: Microchemistry analysis reveals that Chinook Salmon in each river system have a unique proportion of several life-history patterns, including whether they leave as fry or parr, use the estuary for an extended period of time or merely transit through it, and then either remain in the marine environment or return for a duration of time to their own or another river's estuary.

Background

Impetus: WCVI natural-origin (NO) Chinook are very important for the economic, social and cultural well being of many coastal communities, including First Nations, and both freshwater & marine ecological communities. Low early marine survival has been identified as a threat for rebuilding these stocks and has been understudied in NO Chinook

Knowledge gap: A method was needed to identify successful life-history types in returning adults in order to determine how best to rebuild them. Analysis of otolith microchemistry can fill this gap because otoliths are inert once incorporated and preserve chemical signals related to environmental patterns (e.g. transition from fresh to saltwater) unlike other tissues such as bone and scales. This means analyzing the chemistry across the otolith can reveal where salmon were through time at some size and stage.

Partnerships: Otoliths have been stored by DFO from collections undertaken by many programs including Stock Assessment and the more recent Follow the Fish program. Collaboration with these programs can provide a large archive of both current and historical otoliths to analyze microchemically and track the changes across the life spans of individual fish and the changes in life-history patterns of populations from past to present.

Methods and Findings

This project is the first to develop the capacity to use otolith microchemistry analysis by Laser Ablation-Inductively Coupled Plasma-Mass Spectrometry (LA-ICP-MS) internally within DFO. With the existing instruments and expertise housed in the Mass Spectrometry Lab at IOS, we have the capacity to microchemically analyse thousands of otoliths per year in a cost effective manner and use the life-history knowledge gleaned from them to inform fisheries and conservation policy.

This technique involves polishing otoliths to expose the earliest layers, which are formed before the fish hatches, and then vaporising a line transect from the core to edge with a tiny, precise laser connected to a mass spectrometer. The spectrometer counts and identifies the changing elemental composition of the otolith material over each fish's life-span, and the timing of these changes can be calculated based on the known speed and position of the laser beam and applied to real world times and locations of relevance.

Findings:

- Otolith microchemistry of WCVI Chinook shows evidence for freshwater to marine carry-over effects
- Most NO juveniles leave the estuary early and small as fry, but the small percentage of later, larger parr outmigrants have a much higher survival rate, although the proportions differ by year and river system

- While hatchery origin (HO) outmigrants have a higher survival rate overall than NO outmigrants, the larger, later NO outmigrants survive better than their similarly sized HO counterparts
- The largest, oldest returning spawners tend disproportionately to have been early, small outmigrants. Therefore, releasing hatchery juveniles as late, large outmigrants appears to be promoting the return of spawners as younger, smaller adults which may be driving follow-on effects such as lower fecundity, fewer eggs per female, smaller average egg sizes and increased competition for optimal redd sites.

Insights

Our research has really highlighted the need to address Pacific salmon stocks from the perspective of life history types, rather than as monoliths. By identifying what life-history types leave the river and what life-history types return, we can identify differential survival across these life-history types and start getting at what makes a successful Pacific salmon. This can improve Pacific salmon management by providing assessments of how habitat, such as freshwater rearing habitat, may improve the overall survival of stocks by allowing more members of the population to make use of a more successful life history type. We have also shown that there are different ages at return amongst life history types, which could improve management by addressing not only changes in survival, but changes in fitness. By addressing carry over effects of early life history decisions, we can start to better address where the bottlenecks to survival exist and how targeted restoration could be rolled out.

Next Steps

As we study more systems, it is clear that each system has its own unique set of circumstances. An early life history type that may be successful in Sarita may not be successful elsewhere. We have also found that brood year specific analyses are more helpful to pinpoint certain problematic years which can then be investigated further to find a cause. We are working on finishing up these reports on various systems highlighted above, as well as working with other members of FTF to provide details about how these carry over effects may be manifesting in biological data we already have collected.

We are planning to, in the future, investigate more and more systems including ECVI and Fraser River stocks.

Tables and Figures

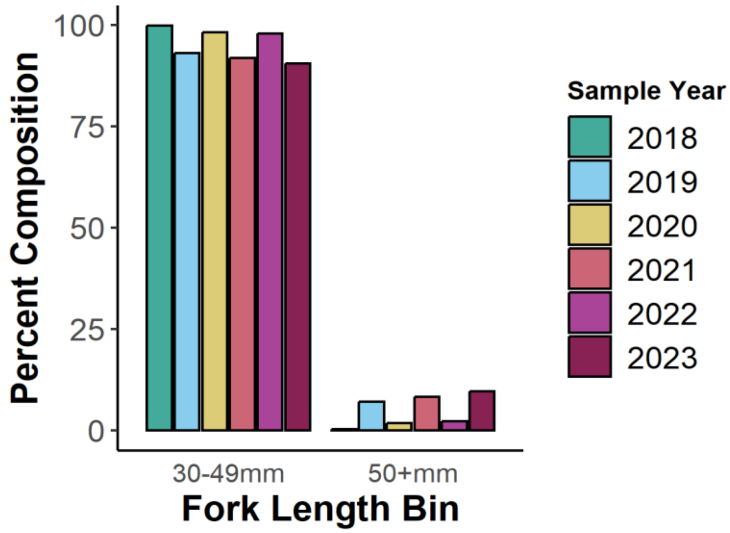


Figure 1. Outmigration life-history types of Sarita River Chinook salmon smolts captured in an RST located in the lower Sarita River.

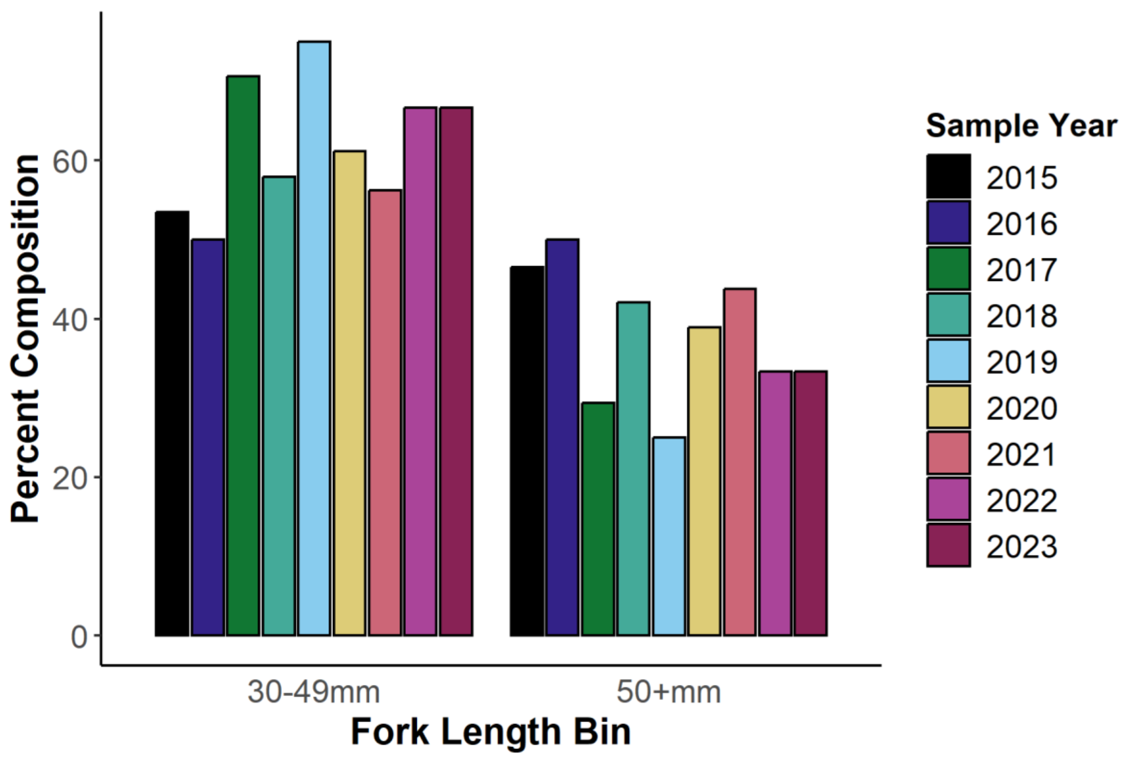


Figure 2. Outmigration life-history types of Sarita River Chinook salmon as identified in returning adults through LA-ICP-MS. Fry outmigrants that made up 95% of the outmigrating smolts only constituted around 63% of returning adults.

2432 - Barkley Sound Acoustic Monitoring of Salmon and Prey

Linking oceanic variability, euphausiid hotspot persistence and marine predator distribution along the Pacific coast of Canada. 2026. Evans, R. Gauthier, S., Robinson, C.L.K., English, P.A., Stanley, C., Wright, B.M., Nichol, L. Ecological Application 2026;36:e70141. https://doi.org/10.1002/eap.70141

Collaborations: Follow The Fish team

Region: West Coast Vancouver Island

Highlights

- Large scale acoustic surveys off the BC coast revealed persistent euphausiids hotspots - such data (along with further work on forage species) could ultimately inform on conditions critical for adult salmon marine survival.
- Fine temporal scale monitoring in nearshore coastal areas of Barkley Sound revealed year-long habitat use by juvenile salmon, with clear pulses in late Summer and early Fall.
- These juvenile salmon densities are linked to densities and availability of euphausiids.
- Competition and predation pressures from other fish species (Pacific herring and demersal predators like walleye pollock/Pacific hake) are present year-round and are found near surface water at night (co-occurring with juvenile salmon). Predation events from birds/marine mammals have been recorded multiple times at these sites, and did not appear to be density dependent.

Background

Fisheries acoustics can be used to answer a number of questions related to Salmon ecology and dynamics. On large spatial scales, acoustic surveys are used to assess salmon prey (e.g forage fish and krill) conditions along the BC coast, identify prey hotspots, and assess changes in productivity through time. On a finer temporal scale, moored autonomous echosounders can provide information on juvenile salmon coastal habitat use, in conjunction with prey availability and predation pressures.

Autonomous echosounder system were used to address key elements affecting juvenile salmon during the first stage of marine life, including the timing of juvenile salmon use of coastal areas (time spent in key areas and within the water column), the prey conditions (e.g. euphausiids dynamic) they encounter in these areas, and the competition and predation pressures that affect them.

Methods and Findings

We used active acoustics methods as a remote sensing tools to assess the salmonsphere (salmon as well as their prey and predators). Large scale fisheries acoustic surveys conducted along the BC coast over the continental shelf and slope are used to assess marine conditions and the abundance and distribution of key prey species for adult Chinook salmon (e.g. Pacific herring and euphausiids). On a finer temporal scale, we used moored inverted echosounders to monitor juvenile salmons (and salmonsphere ecosystem components) in coastal areas within Barkley Sound.

Two autonomous systems were moored on the bottom of Barkley Sound nearshore areas with the transducers facing upward toward the sea surface, detecting juvenile salmon and all marine organisms as they go through the acoustic beam. Previous work in coastal areas using direct sampling methods (e.g. purse seine) combined with such moorings, as well as libraries of acoustic-trawl surveys and frequency-based signal processing techniques is enabling the classification of acoustic backscatter into species group (juvenile salmon, Pacific herring, walleye pollock and similar demersal fish, euphausiids) to obtain fine scale temporal data on their prevalence and relationship over more than a year of continuous data collection. In addition, surface predation events (from diving birds and/or marine mammals) are documented for the entire time-series. Acoustic methods are not capable of identifying juvenile salmon to species. To achieve species-specific interpretations the data will rely on other available sampling and ancillary data (seine, micro-trolling, eDNA, hatchery release timing) to further partition the acoustic information that was attributed to juvenile salmon.

Insights

- Large spatial scale acoustic data have revealed persistent hotspots of euphausiids (a key salmon prey) along the BC coast - expansion of this work will include key forage fish species.
- Moorings in nearshore coastal areas of Barkley Sound reveal the presence of juvenile salmon year-round, but having a clear pulse of activity and density in Late summer-early Fall. Although juvenile salmon have been detected throughout the top 50 m of the water column, they predominantly occupy the top 15-20 m of the water surface.
- Pulses of juvenile salmon were closely linked to the availability and density of a key prey, euphausiids (krill). Krill display distinct diel vertical migrations (prey are at depth during the day and near surface at night).
- Key competitors (Pacific herring) and fish predators (walleye pollock and/or Pacific hake) are present throughout the year, and also exhibit diel migration (mixing with juvenile salmon in the surface layer at night).

- Further predation pressure from birds and/or marine mammals were identified throughout the time-series (documented daytime surface attacks), and does not appear to be density dependent, with many events occurring in the Winter when fewer surface schools are observed.

Next Steps

This study was implemented in the second year of PSSI. Acoustic data collected from moored systems are only available once instruments are recovered, in as such, we are just finalizing the processing and analyses of these acoustic data - integration with other sampling (micro-trolling, eDNA, etc) that occurred while the instrument were collecting data will be a critical step to fully interpret these data and publish the findings.

Tables and Figures

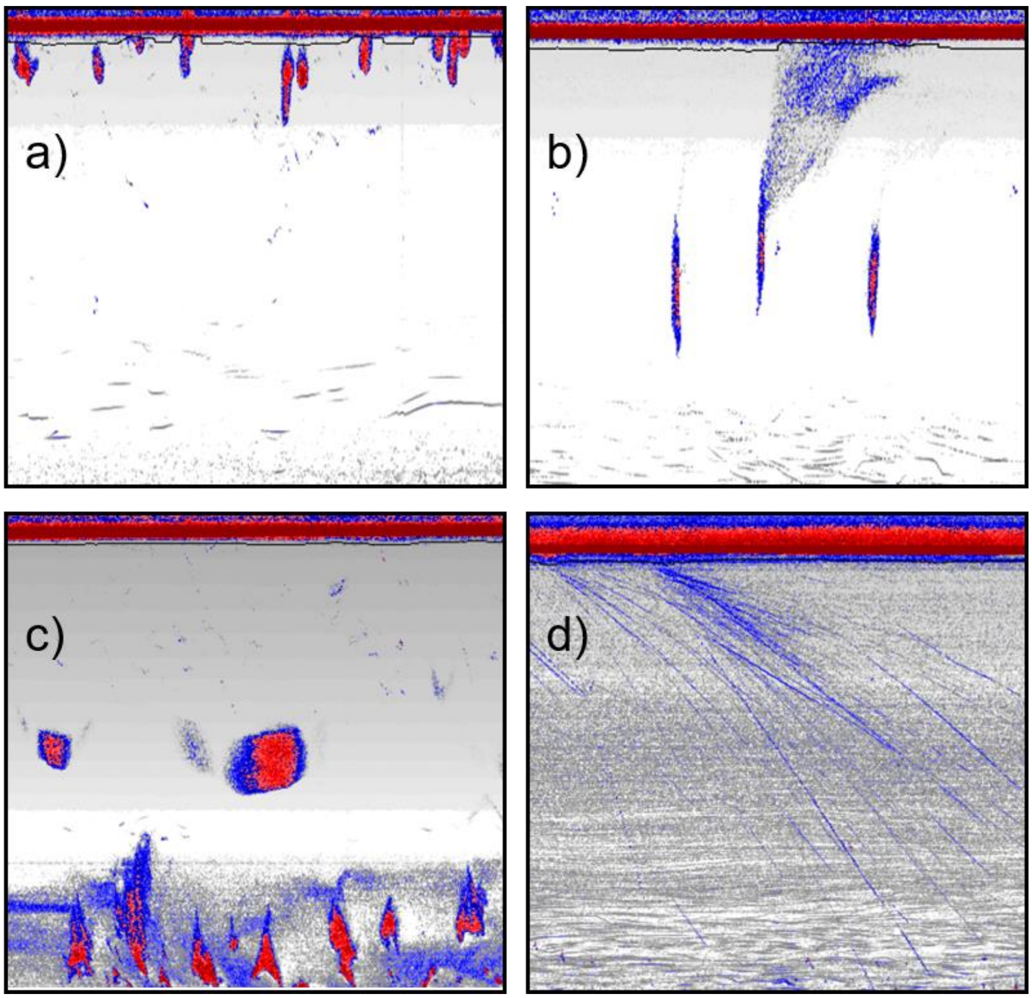


Figure 1. Typical echogram observed in Barkley Sound, where the top red band indicate the water surface, total depth displayed is around 80 m. a) dense juvenile salmon schools near the surface, b) typical herring schools, with one displaying the release of gas bubbles, c) demersal fish schools (likely walleye pollock within the deeper krill layer, d) example of a surface predation event, showing multiple animals/fish diving deep.

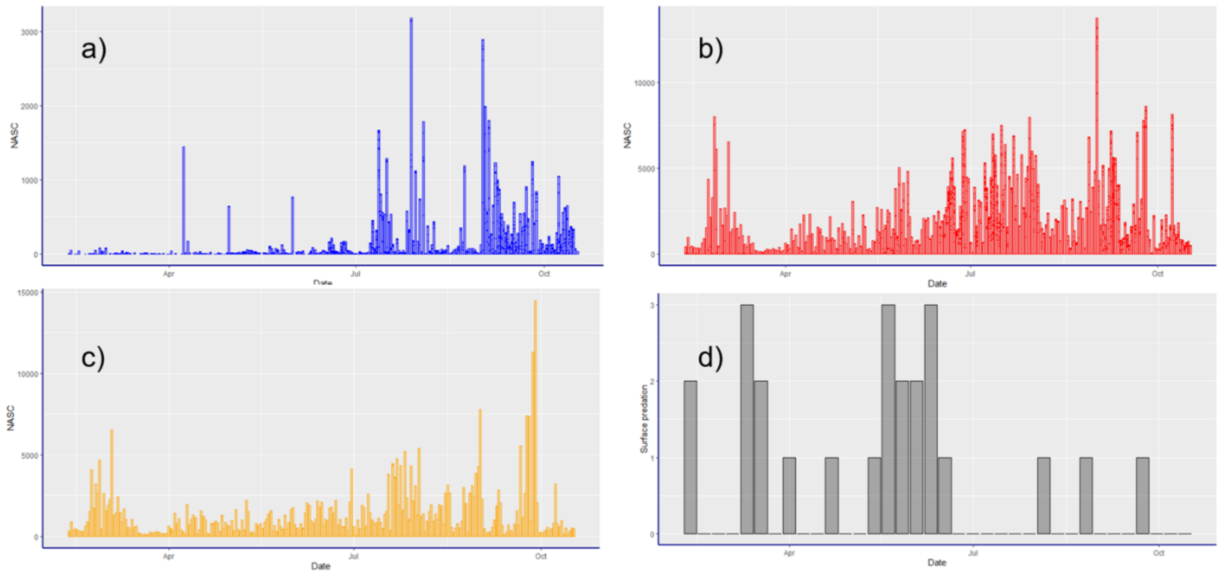


Figure 2. Time series of the Mackenzie Anchorage mooring site in Barkley Sound (only including first deployment from February to October 2024): a) juvenile salmon, b) Pacific herring, c) walleye pollock, d) detected surface predation events from diving birds/marine mammals.

2447 – Cumulative Stressors Identification Using Fit-Chips and eDNA

Follow the Fish microtrolling and purse seine reports

Peer-reviewed publication on Tenacibaculum maritimum on WCVI

Other publications on WCVI Chinook Fit-Chips and eDNA (pending)

Collaborations: Follow The fish

Region: West Coast Vancouver Island

Waterbodies: WCVI sounds

Species: Chinook

Populations: WCVI Chinook

Highlights

- This project uses advanced molecular tools to evaluate the cumulative effects of environment and individual condition on juvenile Chinook salmon in their ocean entry year (OEY). This is done directly on the individual level by assessing stress and infectious agents in fish using salmon Fit-Chip on minimally invasive gill biopsies as well as on ecosystem level by assessing community composition from salmon pathogens to predators by analyzing concurrent environmental DNA samples. *Key findings - Fit-Chips*
- Multiple factors, including thermal stress, hypoxia, and several infectious agents, were associated with survival impacts in the OEY for Chinook salmon.
- Thermal stress, the occurrence of which we expect will increase with climate change, was common in Barkley Sound in July and August, and may occur in other sounds. Our data and many previous studies indicate that thermal stress at ocean entry (and/or associated factors) are negatively associated with survival for salmonids.
- Hypoxia stress was apparent in 25% of OEY fall-winter Chinook salmon.

- The Fit-Chip “food deprivation” panel provided very limited (<2%) evidence of starvation during the study period.
- As “aquaculture pressure” increases, OEY Chinook salmon are more likely to test positive for several infectious agents, some of which were positively associated with imminent mortality. *Key Findings - eDNA*
- Community composition across the west coast of Vancouver Island shows spatial differentiation from north to south, but environmental drivers of temperature, oxygen saturation, and salinity have a higher impact that spatial gradients alone and show repeating seasonal patterns.
- Salmon was associated with annual migration cycles and we were able to highlight key salmon habitat based on reoccurring distribution patterns.
- Analysis of prey and predator distribution suggested that high prey abundances are also associated with high predator abundances. Similarly, many high prey abundance locations also experience high densities of harmful algae bloom (HAB) producing species as well as pathogens. Together this suggest that OEY Chinook salmon must balance feeding opportunities with predation, pathogen, and toxin risks.
- Atlantic salmon aquaculture was positively associated with several pathogens of concern for OEY Chinook as were Chinook themselves. This suggests that Chinook may be attracted to aquaculture sites where they are exposed to pathogens. *Implications*
- Thermal stress and hypoxia already impact OEY Chinook salmon and these impacts are likely to increase as climate change progresses.
- OEY Chinook may be exposed to critical temperature, oxygen, and algae toxins as well as elevated pathogen and predators pressuere when foraging.
- Netpen aquaculture is associated with increased pathogen levels and likely increases pathogen exposure for OEY Chinook salmon in WCVI inlets.
- Prey limitation seems to be a factor of limited impact to OEY Chinook over the assessed time period.

Background

Natural-origin Chinook salmon in West Coast Vancouver Island (WCVI) inlets have experienced population declines in recent decades, to the extent that some WCVI spawning streams with intact habitat are seeing very low returns of natal fish and are dependent on hatchery strays. A recent WCVI Chinook risk assessment process identified several factors associated with OEY residence that can be examined using molecular tools. These include prey availability, pathogens, harmful algae, predation, high temperatures and hypoxia. We deploy molecular tools to address these factors as part of the “Follow the Fish” (FTF) program (Project 2407), which was a collaborative effort among several DFO scientists, many WCVI First Nations, and several coastal NGOs. Salmon Fit-Chips are a molecular-based method for examining the physiological response to stressors and quantifying pathogens on the level of individual fish from minimally invasive gill biopsies and were deployed on fish collected by the FTF program. Additionally, we collected water samples alongside FTF sampling for e(nvironmental)DNA analysis, where we reconstruct the ecosystem based on the nucleic acids detected in the water. With this data we are able to detect salmon and assess where they interact with salmon pathogens, their prey and predators as well as where they are exposed to harmful algae bloom species.

Methods and Findings

Salmon Fit-Chips Methods

Chinook salmon gill biopsies, collected from purse seine, beach seine, and microtroll collections as part of the Follow the Fish project, were run on the Fluidigm Biomark nanofluidic qPCR platform. Within a single analytical run, this platform allows for assays of 13 infectious agents and 70 salmon genes to be run against 80 gill samples, known as a salmon Fit-Chip. The salmon gene expression can be statistically analyzed to provide probabilities (0-1) for certain salmon “stressor states” including: food deprivation, imminent mortality, viral disease, smoltification, hypoxia, inflammation, and immune stimulation. Detailed methods for the Fit-Chip laboratory and statistical analysis can be found in Akbarzadeh et al. (2024).

Because there is no measure of survival for the Follow the Fish project until PIT-tagged adults return over the next few years, we used the “imminent mortality” panel from the Fit-Chips as a proxy for survival. The imminent mortality panel is based on the gene expression of fish that were sampled in the laboratory in a moribund state or within 72 hours of dying, thus fish in the wild that show such a pattern are likely experiencing severe physiological stress, although we are unable to determine their actual fate. Probability of imminent mortality was used as the response variable for a geostatistical model (Anderson et al. 2024) that included all the pathogens detected at adequate prevalence and all of the Fit-Chip stressors. Some confounding factors such as sample year, day of year, capture method, and location were included as predictors or random effects. We ran another geostatistical model with all the same predictor variables but with Fulton’s K (mass relative to length) as the response, with the expectation that skinnier fish are at a physiological disadvantage relative to heavier fish.

For the analysis of infectious agent detections in salmon gill relative to “aquaculture pressure” we once again used geostatistical models where infectious agent copies RNA/DNA was the response variable and aquaculture pressure and confounding variables as mentioned above were the predictors. To determine aquaculture pressure, we used an approach often applied in the sea lice literature, where kernel density weights from active farms were summed for each fish collection location (Nekouei et al. 2018). Where counts of sea lice were multiplied by the kernel density estimate in previous studies, we instead multiplied the farm salmon biomass with the assumption that as biomass increases, the potential for infectious agents to be dispersed away from farms at greater concentrations also increases. We ran these models for both Atlantic Salmon and Chinook salmon farms (only using Clayoquot data for Chinook farms since those only exist in Clayoquot Sound).

Salmon Fit-Chips Products and tools produced / Advancements in methodology, technology, and application

For this study we developed a tailor made dedicated Chinook Fit-Chip to target the most important factors for juvenile WCVI Chinook.

Key Salmon Fit-Chips Findings

- Very few (<2%) of samples run indicated that Chinook salmon were food-deprived, indicating that food availability might not be a limiting factor, at least in the populations/years/regions represented by our sampling efforts.
- Chinook captured in their first Fall-winter in the ocean showed a 25% incidence of hypoxia stress, indicating a substantial proportion of the population is exposed to low oxygen environments.
- In Barkley Sound, in July and August of each study year, 30% of Chinook exhibited thermal stress - indicating that they were exposed to elevated water temperatures near the surface. Prevalence of *Tenacibaculum maritimum,* a bacterium of interest from previous studies, was also close to 100% among fish during this period (Figure 1). These factors combined may represent a particularly high stress period.
- Spatial models where the imminent mortality Fit-Chip panel served as the response variable revealed positive associations between "imminent mortality" and hypoxia, thermal stress, PSNV1, *T. maritimum, Ca.* B. cysticola, and *L. salmonae* (Figure 2). Two pathogens, PSNV1 and *L. salmonae,* were negatively correlated with Fulton's K (body condition) (Figure 2). The imminent mortality panel and body condition are our best proxies for survival until we have PIT tag returns from the Somass River PIT array.
- In sounds with active netpen aquaculture, there was a positive association between "aquaculture pressure" from Atlantic Salmon farms and the PCR detections (in Chinook salmon gill) of Piscine orthoreovirus 1a, *Loma salmonae, Tenacibaculum maritimum*, and *Ca.* Branchiomonas cysticola. For Chinook farms, the association was positive for Pacific salmon nidovirus 1 (PSNV1), *Loma salmonae, Ichthyophthirius multifiliis,* and *Paranucleospora theridion* (Figure 3). PSNV1 was extremely abundant at two WCVI hatcheries but quickly disappeared as fish entered the marine environment. This pattern is consistent with the virus causing high mortality or being cleared as fish enter seawater.

eDNA Methods

5L replicate water samples were collected via transect from 8m depth and filtered onboard the research vessel through hollow membrane filters. In total, 856 eDNA samples from 131 sites from all WCVI Sounds were analyzed in this study. Nucleic acids were extracted in a dedicated clean laboratory and quantified. Samples were then analyzed in two separate workflows: First, nucleic acids of key salmon pathogens, salmon, and prominent forage fish were quantified on the Fluidigm Biomark nanofluidic qPCR platform with targeted assays. Second, metabarcoding to elucidate community composition targeting bony fish, salmonids, cephalopods, rock fish, vertebrates, and invertebrates was performed by sequencing. Sequence data were analyzed using a custom-built pipeline. Statistical analysis of both datasets was performed in R. “Aquaculture pressure” was assessed via kernel density as described above.

eDNA Products and tools produced / Advancements in methodology, technology, and application

Custom analysis pipeline: (https://github.com/ViralChris/eDNA_metabarcoding_pipeline_V2)

WCVI eDNA database with >20 billion reads of 2116 operational taxonomic units.

Key eDNA Findings

- eDNA is a valuable tool to describe the entire ecosystem from viruses to whales and was able to describe the spatiotemporal distribution of numerous species relevant for salmon survival. Key observations contain viruses such as Piscine orthoreovirus 1a, pathogenic bacteria like *Tenacibaculum maritimum*, key prey items including Euphausiids and herring, all Pacific salmon species, predators of juveniles (auks and rockfish) as well as adults (sealions and dogfish) and even harmful algae species such as *Heterosigma akashiwo* (Figure 4).
- Community composition along WCVI sounds was influenced by spatial gradients, but seasonal reoccurring trends were overriding these influences. Temperature, salinity, and oxygen concentration were the key environmental drivers of community composition.
- Abundance of prey items of juvenile Chinook showed strong seasonal and inter-seasonal variation (Figure 5). Crucially, high prey abundances were often associated with high predator abundances, pathogens and potentially harmful algae in the summer, suggesting that salmon may subject themselves to hazardous conditions to avail themselves to feeding opportunities (Figure 4). We are currently addressing the impact of harmful algae by combining the eDNA dataset with the toxicological data collected by Dr Andrew Ross under the FTF project. Several pathogens of interest were positively associated with Atlantic salmon aquaculture, including Piscine orthoreovirus 1a, *Tenacibaculum maritimum*, *Paranucleospora theridion, Moritella viscosa, Loma salmonae, Ichthyophthirius multifiliis, Ca.* Branchiomonas cysticola, *Tenacibaculum finmarkense*, and *Piscricketsia salmonis.* Notably, Chinook, Dolly Varden and rainbow trout, all species with a coastal residency in their life history, were also positively associated with Atlantic salmon aquaculture, suggesting that farms attract such salmonids and could lead to pathogen exposure (Figure 6A). *Tenacibaculum maritimum* was observed at higher concentrations and longer in sounds where salmon net pen aquaculture is practiced (e.g. Nootka and Clayoquot) than in sounds without aquaculture (Barkley) where it occurred primarily in the summer (Figure 6B).

Insights

This dataset constitutes one of the largest and most comprehensive surveys of stress and infectious agents in Chinook salmon in their first marine year. Many questions in addition to the original goals of the project (and which may not yet be apparent) could be asked of these data.

Therefore, the full potential contributions to policy and planning are expected to expand beyond the suggestions below:

Findings from this study are most relevant to policy and planning regarding netpen salmon aquaculture and SEP hatcheries. For SEP hatcheries, the finding of higher hatchery (relative to migrating fish) prevalence of PSNV1, a little-known virus with potential to have negative impacts, provides an opportunity to improve animal welfare and biosecurity, depending upon the outcome of further research on the pathogenicity of PSNV1.

For net-pen salmon aquaculture, our study added to previous work demonstrating that WCVI aquaculture facilities elevate sea lice levels in wild Pacific salmon (Nekouei et al. 2018, Jeong et al. 2025) by providing evidence of a positive association between aquaculture pressure and several infectious agents in free-living Chinook salmon (using similar statistical methods as those sea lice studies). The list of infectious agents associated with netpen aquaculture in seawater detected via eDNA has many commonalities with what was associated in fish - suggesting a causal link between exposure and infection. The combination of these findings suggests that netpen aquaculture elevates parasites and pathogens in the environment and in free-living Chinook salmon, particularly in Clayoquot Sound where netpen aquaculture is abundant and several spawning streams with seemingly pristine habitat are characterized by very poor survival of outmigrant juvenile salmon.

eDNA data showed that salmonids with coastal resident life histories such as Chinook were associated with salmon aquaculture sites, potentially because they are attracted to the high biomass and/or feed off the farms, which could lead to pathogen exposure. Similarly, eDNA data also indicated that while key prey groups were readily detectable, they were patchily distributed in space and time. Juvenile salmon may be forced to expose themselves to harmful algae, pathogens, and predators in order to access prey resources, as these often co-occurred at the same sites.

With research objectives intertwined with the WCVI Chinook risk assessment process, our study contributed significantly to our understanding of limiting factors. While not ruling out the potential for prey availability as a limiting factor, the Salmon Fit-Chip food deprivation panel did not provide evidence that many fish are experiencing sparse prey fields. As demonstrated many times in other studies, we found evidence that sea surface temperature is a limiting factor for WCVI Chinook salmon. Hypoxia also appeared as a limiting factor, perhaps effecting a higher proportion of the population than previously expected.

Next Steps

Future Studies

- The impacts of the various parameters measured by Salmon Fit-Chips will be best evaluated once PIT-tagged adults have returned to the Somass River over the next few years. The Pacific Salmon Foundation and University of Victoria have established a PIT reader in the Somass River and will be applying some of the Salmon Fit-Chip data described in this report to test for associations between factors like thermal stress, hypoxia, and infectious agents and true survival (rather than the probability of imminent mortality).

- As we observed seemingly stressful conditions for Chinook salmon during the summer in Barkley Sound, it would be important to know whether or not these conditions occur in all WCVI inlets. Repeating the purse seine sampling program in Clayoquot and Nootka Sounds during the summer months would be highly informative.
- Further research into the Pacific Salmon Nidovirus 1, most likely in the form of controlled laboratory challenge studies, would provide vital information regarding this little-known virus. PSNV1 appeared to be positively associated with imminent mortality and negatively associated with body condition. We know from this study and others that this virus reaches very high prevalence in hatcheries but is rarely observed in the wild, particularly in the marine environment. Knowing whether the disappearance of the virus in marine waters is due to clearance or mortality would indicate whether or not mitigation at hatcheries is required.
- Several infectious agents were positively associated with aquaculture pressure. Future studies that investigate potential impacts of those pathogens on natural-origin fish would be valuable since aquaculture management is one of the few “levers that can be pulled” on a relatively short timescale.
- Current eDNA work is focuses on completing the sample analysis (estimated time of completion Mid-February 2026) and final statistical analysis of the complete dataset (estimated time of completion March 2026)
- Collaboration with the otolith microchemistry group (Nicole LaForge, Micah Quindazzi) will allow for investigation of the carry over effects and other impacts of different Chinook juvenile life history types through the lens of Fit-Chip stressor panels and pathogens.
- Collaboration with Andrew Ross’ group under FTF will merge eDNA data on harmful algae with algae toxin levels measured in water and salmon tissues to create a complex framework for algae toxin exposure risks in juvenile Chinook
- Collaboration with Akash Sastri and Kelly Young under FTF will merge eDNA data on zooplankton species with conventional zooplankton survey data by analyzing sequence data on physical composition
- In collaboration with Tim Healy’s group, we will utilize age specific methylation markers to determine the age composition of Chinook salmon eDNA detections in order better understand the specific habitat usage criteria of juvenile and adult Chinook *Applying study results to salmon conservation and management*
- The data and results from this project will be used to inform the WCVI Chinook Marine Risk Assessment process. It will also feed into additional studies (otoliths, biotoxins, plankton) that will further inform the Risk Assessment.

- Our data provides further evidence-based data on the impact of open net-pen salmon aquaculture on wild salmon and supports "the implementation of a ban on open net-pen salmon aquaculture in B.C. coastal waters by June 30, 2029," as committed to in official Canadian government policy (Government of Canada 2024).
- Cumulative stressors throughout the summer, such as temperature, hypoxia and pathogen loads (specifically *Tenacibaculum spp*.) could be integrated into the management of recreational fisheries to minimize mortality from catch and release practices during critical times (Hinch et al 2024).

Tables and Figures

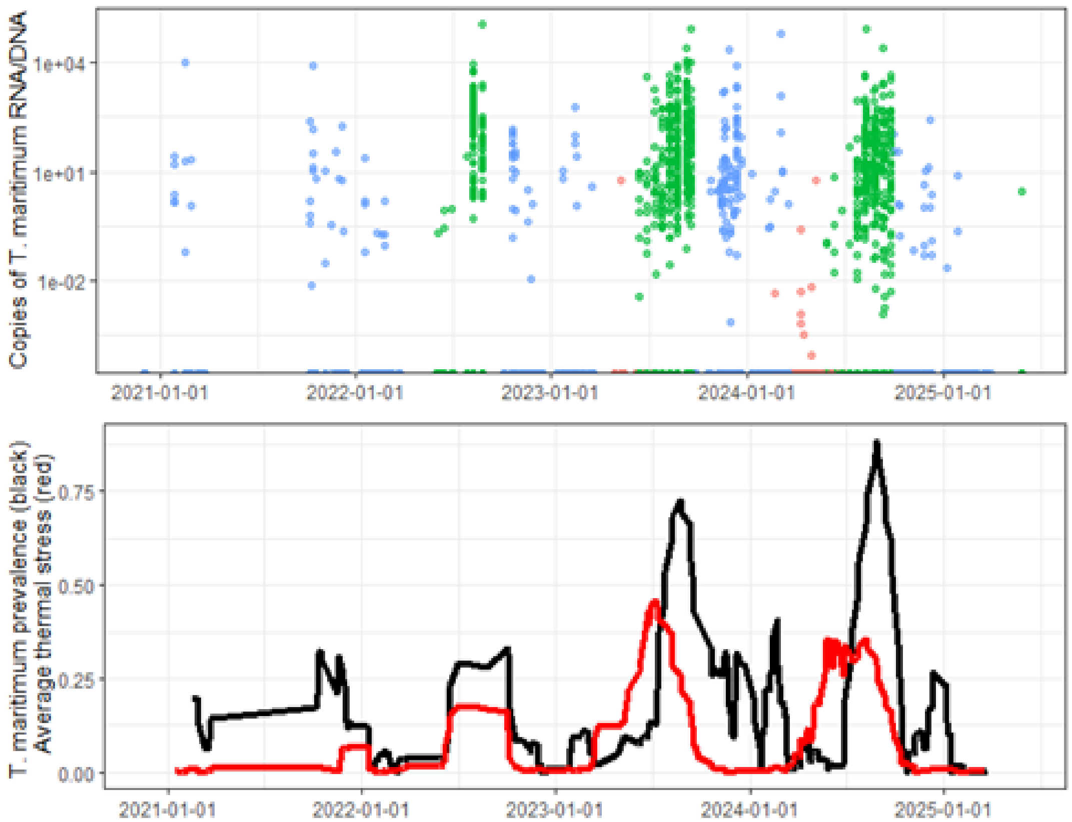


Figure 1. Tenacibaculum maritimum was prevalent in ocean entry year Chinook salmon collected in July and August each study year in Barkley Sound, and the period when infections rapidly increased coincided with thermal stress as revealed by Salmon Fit-Chips. Top panel: each point represents an individual Chinook salmon captured by beach seine (red), purse seine (green), or microtroll (blue) in Barkley Sound. Points at bottom of y-axis indicate non-detections. Bottom panel: Daily prevalence of T. maritimum (black line) and averaged daily probability of thermal stress (red line). Both are averaged over adjacent 10 days to smooth for presentation.

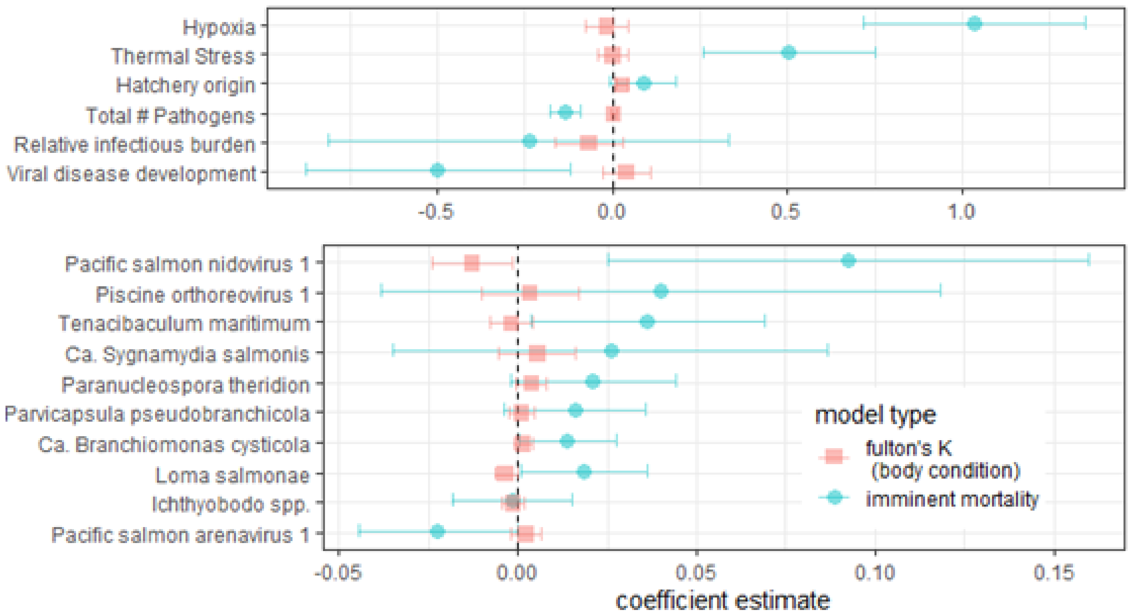


Figure 2. Model results from geostatistical models of imminent mortality and body condition. If blue points and associated 95% confidence intervals are entirely to the right of the vertical dashed line, that variable is positively associated with the probability of imminent mortality, where as to the left of the line would indicate a negative association. If red points and associated 95% confidence intervals are entirely to the left of the vertical dashed line, that variable is negatively associated with body condition, indicating high levels of that variable are associated with skinnier fish. Note the different scales (x-axis) of the two plots.

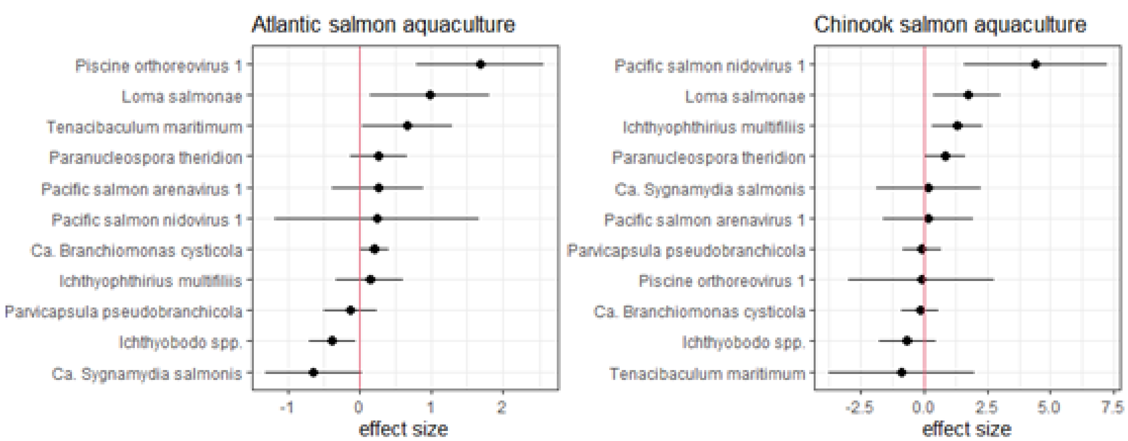


Figure 3. Aquaculture pressure (Atlantic Salmon farms left, Chinook salmon farms right) was positively associated with copy number of several infectious agents in microtroll-caught Chinook salmon in WCVI inlets. Each row represents a geostatistical model where pathogen copy number was the response variable.

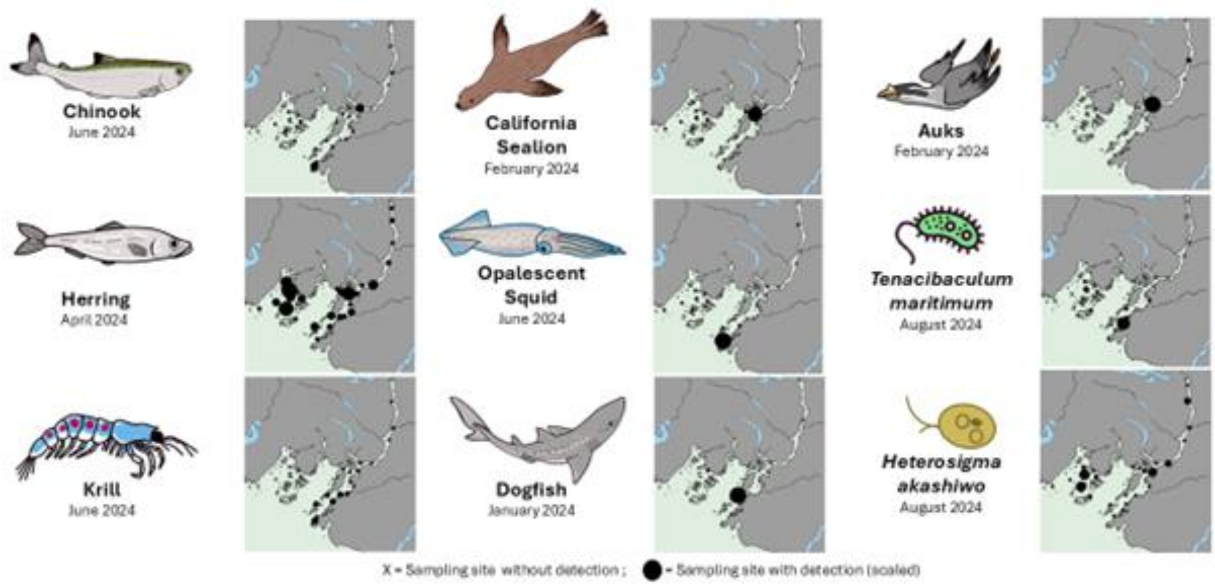


Figure 4. Community composition of Barkley Sound in Summer 2024: Selected species detected by eDNA shown in proportionally scaled circles. "X" represents samples collected without detection of the respective species.

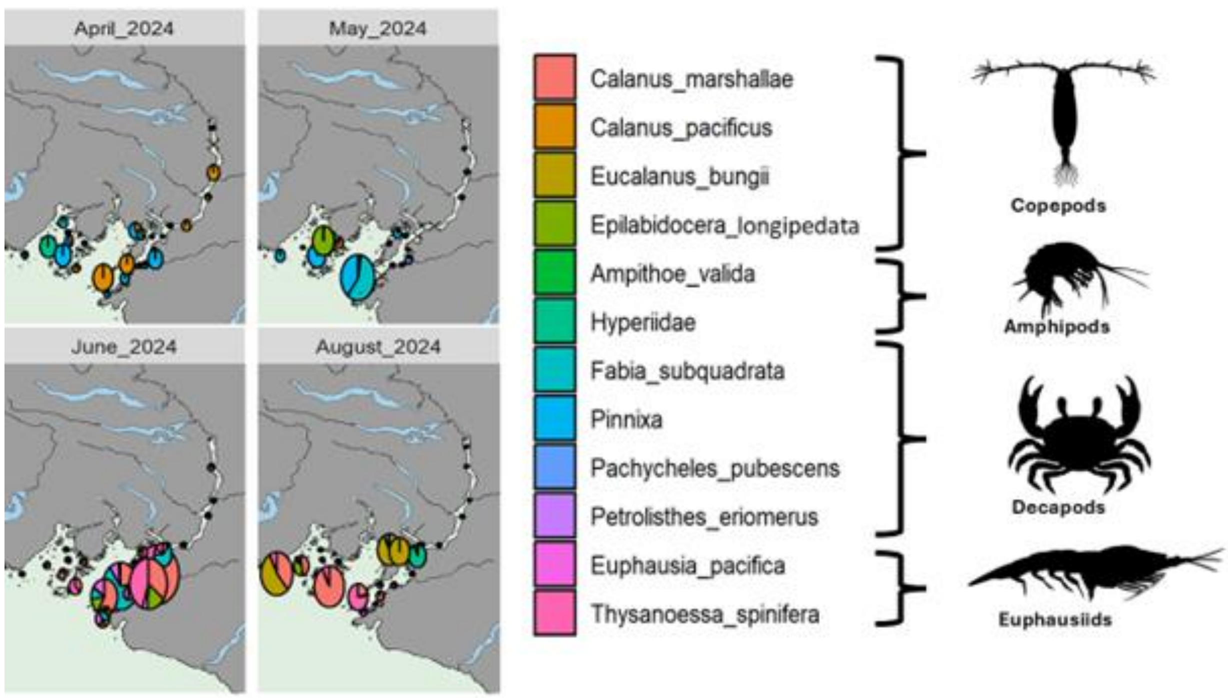


Figure 5. OEY Chinook early marine prey species relative abundance and composition in Barkley sound during spring and early summer 2024 before they transition to piscene prey (Aproximatley in July to August). Prey sources are spatotemorally heterogeniously distributed. Alberni Inlet represents as a prey depletd region throughout spring.

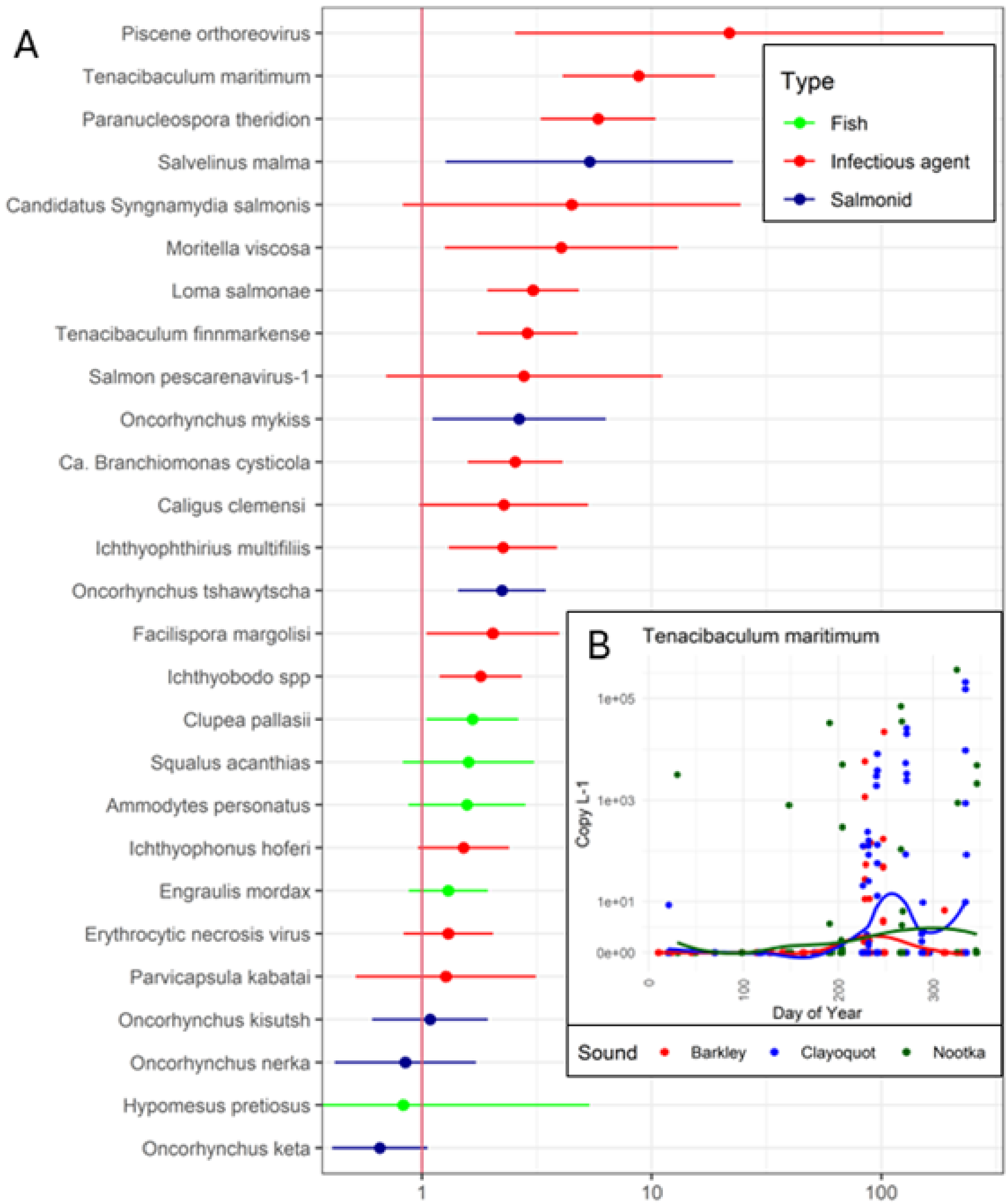


Figure 6. eDNA detections and salmon aquaculture: A: Atlantic Salmon quaculture (detection of Atlantic salmon in eDNA) was positively associated with copy number of several infectious agents in eDNA in WCVI sounds. Each row represents a geostatistical model where pathogen copy number was the response variable. B: Time of year and quantity of detection of Tenacibaculum maritimum in the eDNA dataset per Sound. Salmon aquaculture is not found in Barkley sound. Every data point repesents a sample and a trend line is added.

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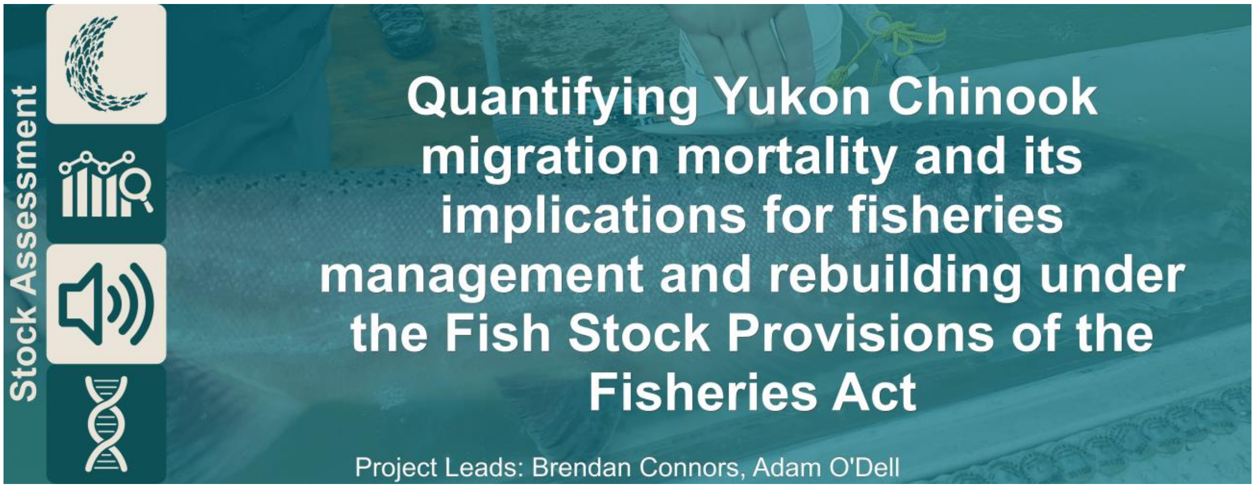
SALMON POPULATION MONITORING

2402 - Yukon Chinook Migration Mortality



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Connors, B.M., O'Dell, A., Hunter, H., Glaser, D., Gill, J., Rossi, S., and Churchland, C. 2025. Stock status and biological and fishery consequences of alternative harvest and rebuilding actions for Yukon River Chinook salmon (Oncorhynchus tshawytscha). DFO Can. Sci. Advis. Sec. Res. Doc. 2025/nnn. iv + 130 p.

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Collaborations: Alaska Department of Fish and Game, Yukon First Nations

Region: Yukon

Waterbodies: Yukon River basin

Species: Chinook

Populations: Yukon Chinook and Porcupine Stock Management Units

Highlights

- Yukon River Chinook salmon returns have remained critically low in recent years, causing immense hardship for Yukon river communities that have relied on salmon for subsistence, cultural practices, and food security for generations.
- The causes of these declines are likely multifactorial; however, in recent years, large numbers of returning adults have gone “missing” during their freshwater migration in Alaska. This has raised concerns that mortality may be occurring after assessment programs enumerate Chinook passage from Alaska into Canada, potentially undermining the efficacy of fisheries management measures.

- An international collaboration among DFO Science, Yukon Rivers Transboundary Area, Yukon First Nations, and the Alaska Department of Fish and Game tagged and tracked adult Chinook during their freshwater spawning migration to quantify migration related mortality.
- Insights from this work can be used to inform precautionary buffers for a border passage goal (i.e., to account for post-border mortality) and in season management of total mortality (fishing and environment) all to support rebuilding and recovery efforts.
- More broadly, the project has established significant infrastructure and catalyzed collaborations that will support continued monitoring and assessment for at least three more years.

Background

Returns of Chinook Salmon to the Yukon River have been declining for over 30 years, with 2020 - 2024 seeing five of the lowest returns of Canadian-origin Chinook Salmon on record (Figure 1, Figure 2a). Coincident with these declines, substantial en-route freshwater migration mortality has been observed in some years before fish reach Canada. Estimates from assessments sites near the river mouth and at the international border suggest that, in certain years, more than 40% of Canadian-origin Chinook may have died prior to reaching Canadian waters (Figure 2b).

Estimates of natural mortality during the spawning migration in Canada are not available. As a result, fisheries managers work under the assumption that annual spawning escapement is equal to border passage minus any in-river harvest. Given the high levels of mortality observed in the Alaskan portion of the drainage in some years, this assumption has become increasingly tenuous and if violated has the potential to severely undermine fishery management measures and rebuilding and recovery. To help fill the knowledge gap, DFO Science and the Yukon Rivers and Transboundary Area partnered with the Yukon First Nation Salmon Stewardship Alliance (supported by Council of Yukon First Nations), Yukon First Nations, and the Alaska Department of Fish and Game to tag and track the fate of adult Yukon River Chinook salmon throughout their extensive freshwater spawning migration.

Methods and Findings

This project complimented tagging, telemetry tracking, and statistical models to estimate spawning migration mortality, alongside assessment of stock abundance and Conservation Unit (CU) status. Details of the latter are described in Connors et al. 2025 and here we briefly describe the tagging components of the work.

Adult Yukon River Chinook salmon were tagged in the lower Alaskan portion of the Yukon River in 2023 and 2024. Migration rates and fate of tagged fish were monitored using a network of remote tracking stations (RTS) deployed throughout Alaska and the Yukon Territory, supplemented by aerial telemetry surveys. Tissue samples were collected from each tagged fish and analyzed by the DFO Molecular Genetics Lab to assign individuals to Canadian Yukon River CUs. These genetic assignments identified the CU each fish was expected to reach. Tagged fish were also aged by the Alaska Department of Fish and Game ageing lab via scale samples. Sex of individual fish was determined by combined visual and genetic methods.

Remote tracking of Chinook salmon in the Canadian portion of the Yukon River was conducted using ATS R4500 receivers deployed at RTS sites. Beginning in 2023, DFO deployed four RTS: three along the mainstem Yukon River and one on the Porcupine River near Old Crow. During 2024, monitoring expanded substantially through a coordinated effort between DFO and the Yukon First Nations Salmon Stewardship Alliance (YFNSSA), undertaken with guidance from Yukon First Nations. This collaboration resulted in the deployment of 20 RTS towers across the basin (Figure 3). The RTS were strategically positioned throughout the Canadian drainage to monitor fish passage at key assessment locations. Stations at Dawson City and Rampart House detected Chinook salmon entering the Yukon Chinook Stock Management unit (SMU) and the Porcupine Chinook SMUs, respectively. Each RTS consisted of a 20 ft tall aluminum mast with antennas mounted at the top to maximize detection range and was installed on elevated riverbanks. Solar powered systems enabled continuous, autonomous operation throughout the migration period. The RTS network provided high-resolution data on movement patterns, timing, and fate of tagged Chinook salmon.

Aerial telemetry surveys were conducted using a Maule M-7 fixed wing plane flying at 300–600 m altitude and approximately 160 km hr $^{-1}$. An ATS R4520 receiver was operated onboard with dualH antennas mounted to the wings. Flights followed the Yukon River mainstem and its major tributaries to detect tagged fish. Aerial surveys expanded spatial coverage and provided finer-scale movement information, including identification of migration dropouts and verification of spawning locations, thereby enhancing the spatial resolution and completeness of the telemetry dataset.

A hierarchical Bayesian mark-recapture model is in development to estimate survival by river segment and CU. This framework explicitly accounts for imperfect detections, small sample sizes, and uncertainty in genetic assignments. It will be used to derive annual and multi-year estimates of migration mortality by CU in relation to environmental conditions experienced during spawning migrations.

Preliminary analysis of the tagging data suggest Yukon Chinook migrate at an average of 51 km d-1 (range 38-63 km d-1), and the furthest distance travelled was over 3200 kms. In 2024, an estimated 85% of tagged Chinook likely reached their assigned CU spawning grounds. This compares to an estimate of 84% survival of migrating Chinook in the Alaskan portion of the river (as estimated by sonar projects at the river mouth and Yukon/Alaska border) in 2024 which is remarkably similar. If this relationship persists in subsequent years, in-season estimates of migration mortality derived in Alaska may help inform expected migration mortality in Canada and support development of precautionary buffers for bilateral border passage goals under the Yukon River Agreement.

Insights

This project has helped develop infrastructure, and catalyze international science based collaboration, to understand the ecology of spawning migration in Yukon Chinook that undergo one of the longest freshwater migrations of any Pacific Salmon. Through tagging, tracking, and statistical analyses we have started to be able to shed light on rates of freshwater migration and the magnitude of spawning migration mortality, by Conservation Unit. These insights can then be related to analysis that characterize population dynamics, estimate biological benchmarks, assess Conservation Unit statuses, and quantify expected biological and fishery consequences of current and alternative harvest management measures for Yukon Chinook.

The establishment of a network of water temperature monitoring stations that this project helped establish will help support water temperature monitoring for years to come and linking freshwater conditions to migration mortality.

Preliminary analyses suggest migration mortality can be well estimated by Conservation Unit and that tagging and telemetry based estimates of mortality in the Canadian portion of the river basin correlated with sonar based estimates in the Alaskan portion of the river. If this pattern holds with more years of data annual estimates of migration mortality in the Alaskan portion of the river can be used in-season to adjust expected migration mortality in the Canadian portion of the river and inform precautionary buffers for the border passage goal used bilaterally under the Yukon River Agreement.

Next Steps

Key next steps include:

- development of hierarchical Bayesian mark-recapture models to estimate survival by river segment and CU in a statistically integrated manner that accounts for imperfect detections, small sample sizes, and uncertainty in genetic assignments and that can be scalable to incorporate future years' data.
- continued tagging and tracking over at least three additional years, in collaboration with Yukon First Nations and the Alaska Department of Fish and Game, will expand sample sizes and strengthen inference across CUs and environmental conditions.
- leveraging the insights from continued assessment to inform in-season precautionary buffers for border passage goals that reflect expected migration mortality in Canadian portion of river after Chinook salmon migrate past border.

Tables and Figures

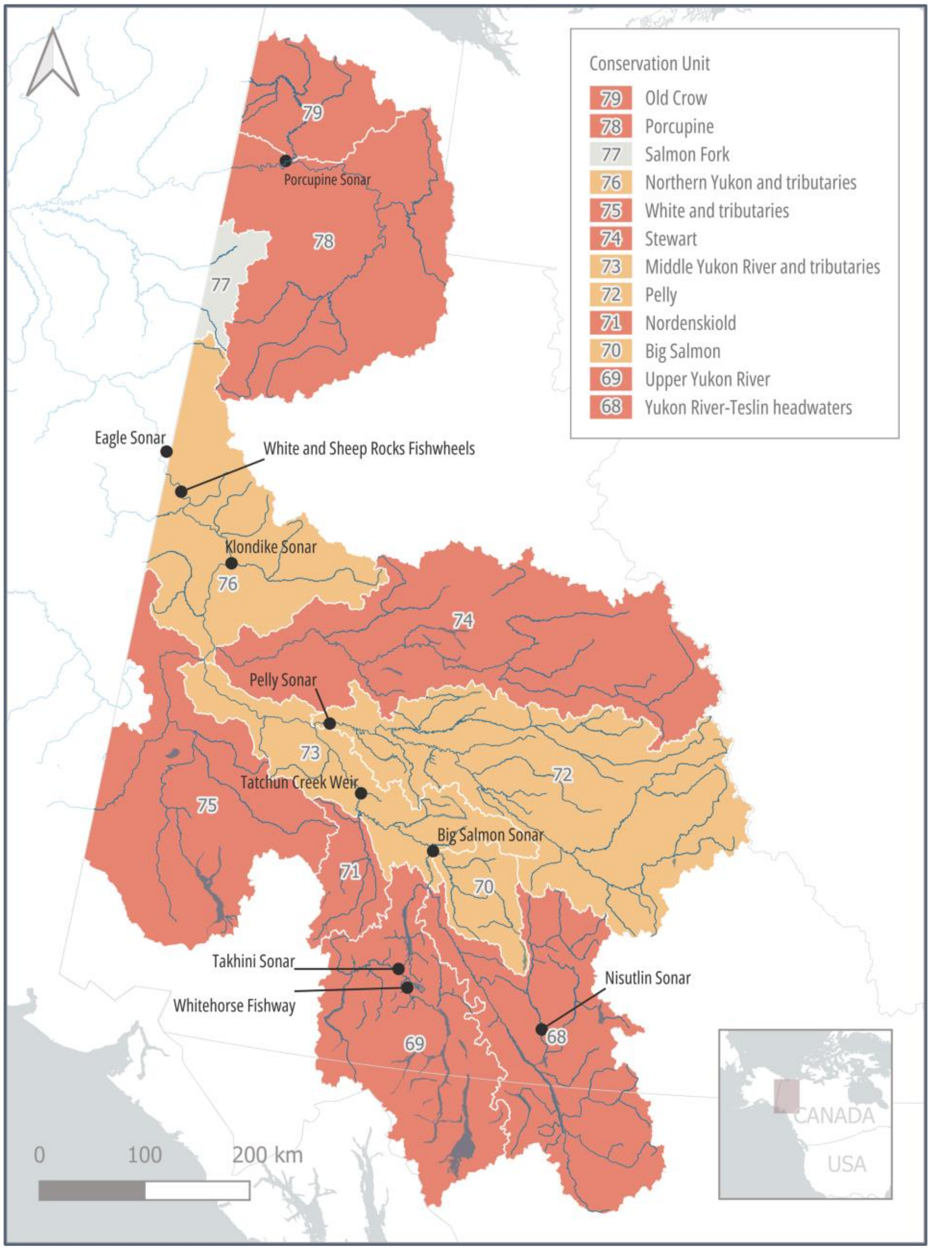


Figure 1. Yukon River Chinook salmon Conservation Units and their corresponding Wild Salmon Policy biological statuses, as well as major contemporary adult assessment sites. Biological status are based on assessment described in Connors et al. 2025.

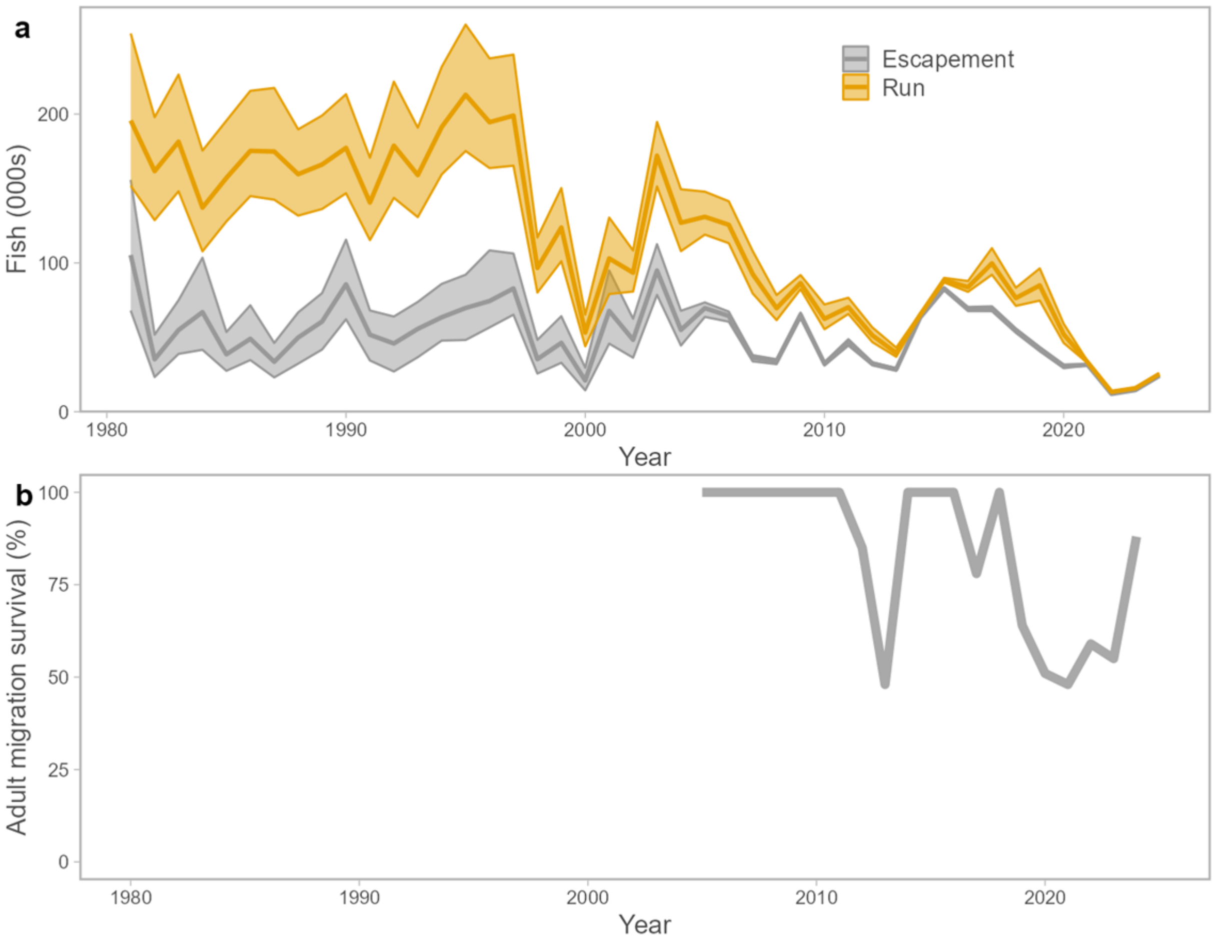


Figure 2. (a) Reconstructions of total returns, and spawning escapement, of Canadian-origin Yukon Chinook and (b) estimates adult freshwater migration survival between Pilot Station (near mouth of river) and Eagle (at Alaska-Yukon Territory border) sonar assessment sites for years where it was estimable (2005 to present).

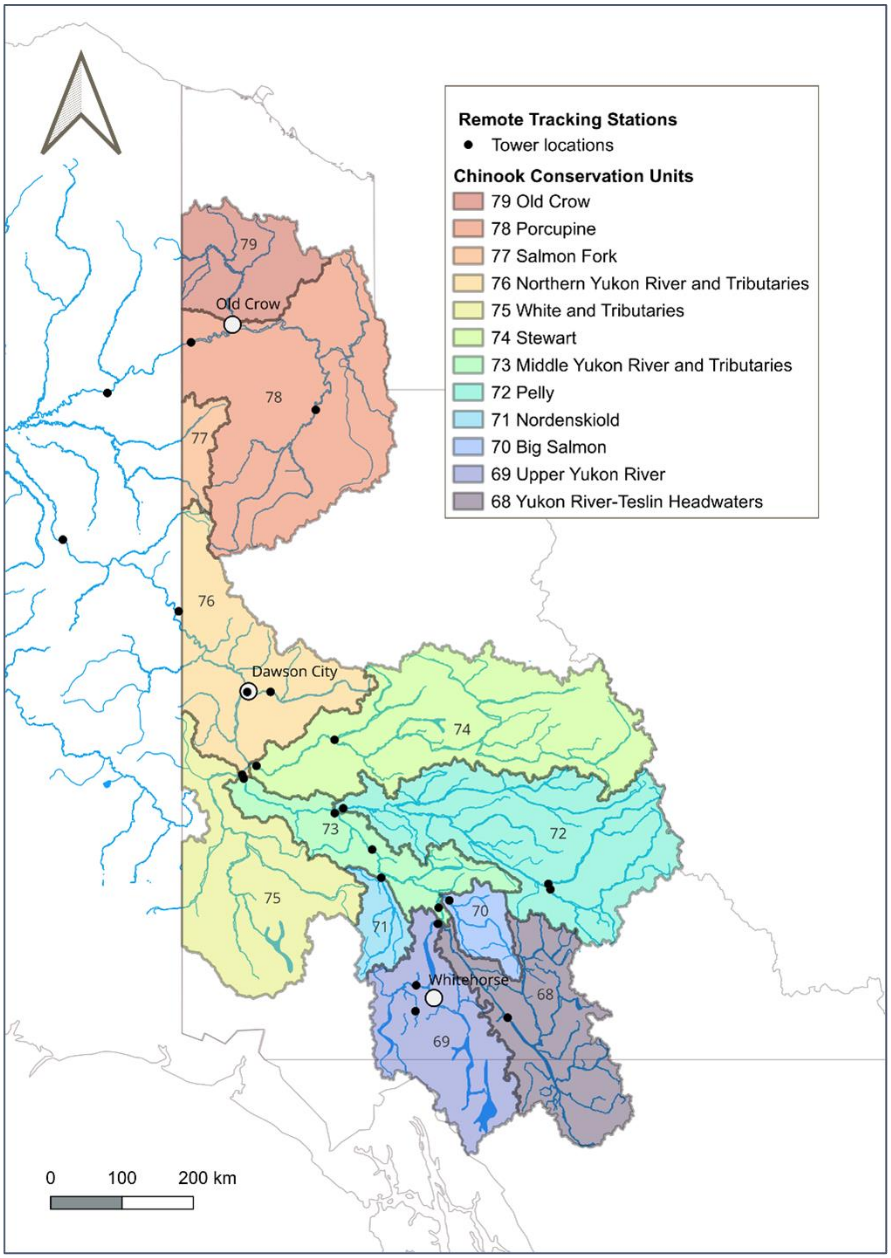


Figure 3. Yukon River Chinook Salmon Conservation Units and locations of the 2024 remote tracking stations.

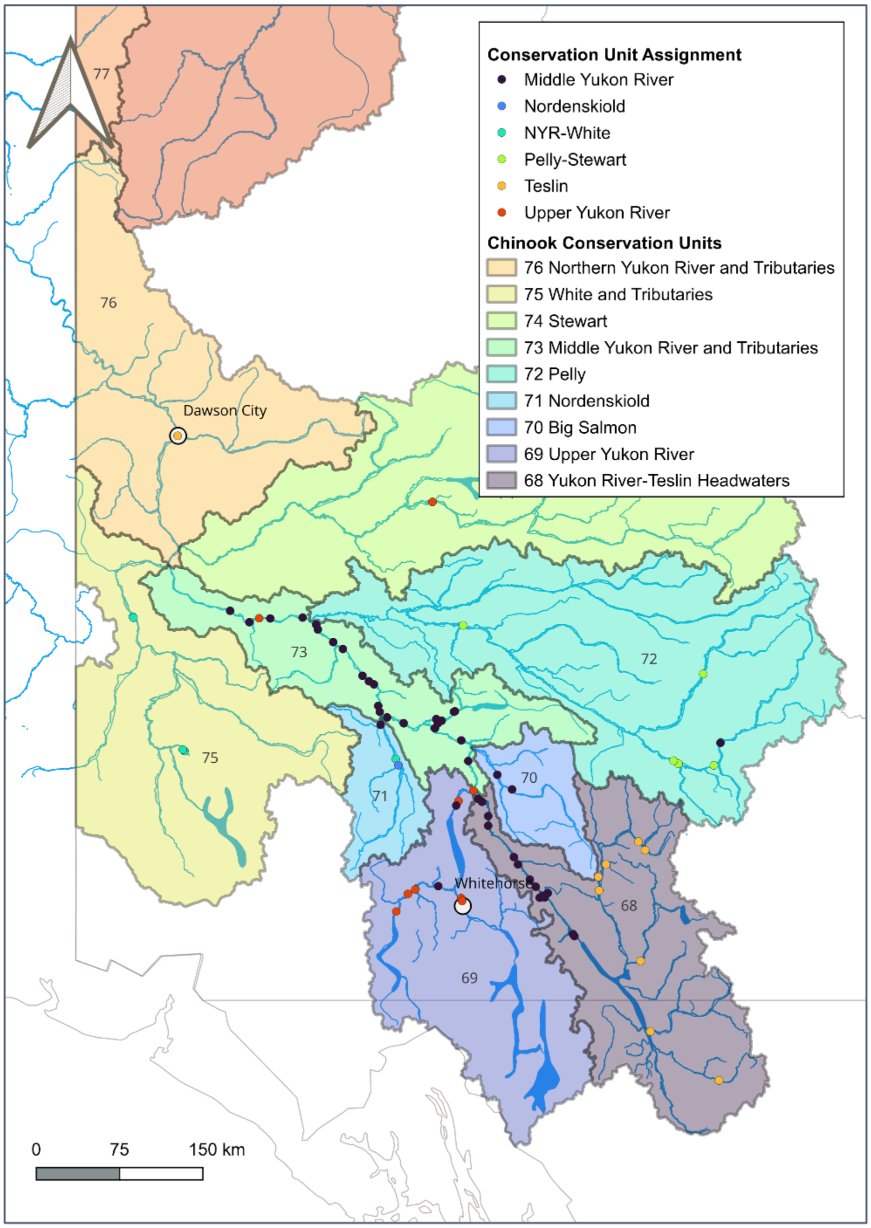
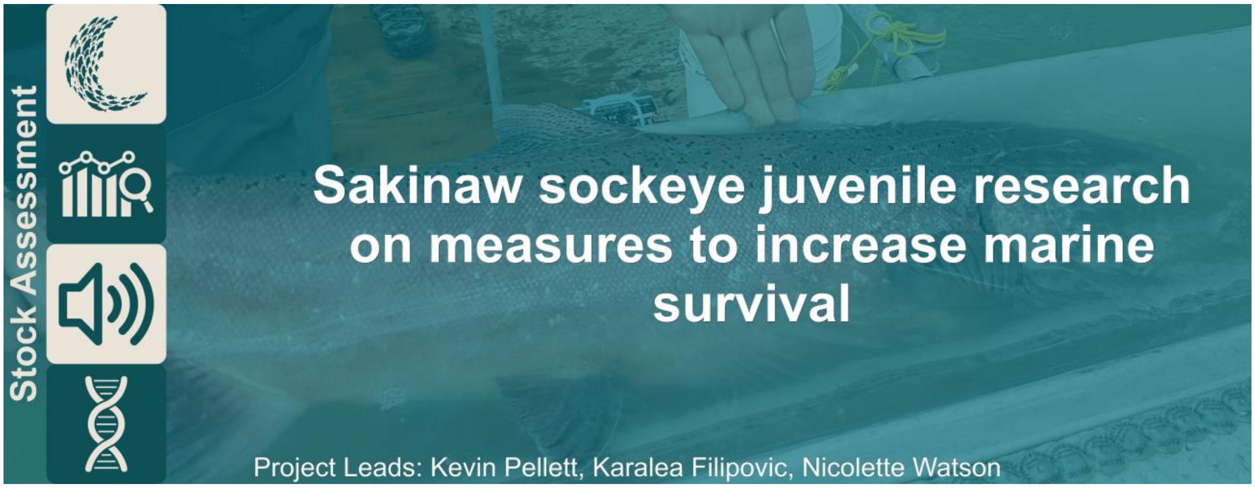


Figure 4. Yukon River Chinook Salmon Conservation Units and location of aerial tracking detections of tagged Chinook Salmon and their individual genetic assignments.

References

Connors, B.M., O'Dell, A., Hunter, H., Glaser, D., Gill, J., Rossi, S., and Churchland, C. 2025. Stock status and biological and fishery consequences of alternative harvest and rebuilding actions for Yukon River Chinook salmon (*Oncorhynchus tshawytscha*). DFO Can. Sci. Advis. Sec. Res. Doc. 2025/nnn. iv + 130 p.

2426 - Sakinaw Sockeye Marine Survival



Sakinaw Sockeye Juvenile Research on Measures to Increase Marine Survival (**in progress**)

Collaborations: shíshálh Nation

Region: Mainland Inlets

Waterbodies: Sakinaw Lake, Malaspina Strait

Species: Sockeye

Populations: Sakinaw (SEL-11-07)

Highlights

- This project tests the hypothesis that early marine survival of Sakinaw sockeye is negatively impacted by local predation at the Hodgson Island pinniped haul-out shortly after smolts enter the marine environment. If correct, smolts transported via boat past Hodgson Island, into Malaspina Strait, would have higher marine survival than smolts that outmigrate from Sakinaw Lake and pass the haul-out on their own. Marine survival is assessed by comparing the adult returns from PIT tagged transported smolts and hatchery PIT tagged fry and smolts released in the lake.
- PIT tagging sample size objectives were achieved (1000-2500 tags)
- Transporting via aerated tanks on a boat is a successful method for moving smolts past the pinniped haul-out (Hodgson Island). Survival to release was over 99% and release condition and behavior was observed to be excellent.
- Marine survival comparisons are still being monitored, with the 2024 transport group returning as adults in summer 2026. Preliminary results from the 2023 transport group indicate that survival was not improved for the transported smolts, with only 1 PIT tagged transport fish returning to the lake as an adult. *Implications*
- Early marine survival may not be the limiting factor for this population. If transport returns continue to be low in the 2026 adult return, the recommendation would be to not pursue

smolt transport as a restoration tool for Sakinaw sockeye. See Insights and Next Steps for more detail.

Background

Sakinaw sockeye have been listed as endangered with COSEWIC since 2003, and a *Species at Risk Act* Recovery Potential Assessment (RPA) was completed in 2017 (Ramshaw et al. 2019). The RPA cited low marine survival as the greatest limiting factor in recovery, with predator abundance and assumed predation on smolts and adults ranked as high risk, with a critical level of impact. Perpetually low marine survivals are preventing recovery such that the persistence of the population is entirely dependent on a captive brood program.

Sakinaw sockeye smolts out-migrate from Sakinaw Lake each spring into the Malaspina Strait and Strait of Georgia. Localized marine predation is considered a major limiting factor for the survival of this stock. On water surveys (since 2019) of pinnipeds from the estuary to the seal haul-outs on Hodgson Islands (approximately 2km from the estuary, Figure 1) have observed approximately 100-350 harbour seals in the area during the spring out-migration.

This project was started as a pilot (2022) in collaboration with shíshálh Nation to test the hypothesis that the Hodgson Island harbour seal population is negatively affecting smolt survival, and subsequently adult returns. The goal of the project is to transport and release smolts past the seal haul-out and then compare marine survival rates between transported smolts and those out-migrating naturally. The pilot project began with a low number of smolts transported in small trial releases to test the effect of handling, Passive Integrated Transponders (PIT) tagging, and increased osmoregulation on fish.

The initial proposal indicated a minimum of 1,000 and up to 2,500 PIT tagged sockeye are recommended per year such that a 1% survival will yield a total of 10-25 tag returns. Return rates of less than 1% may be too low to justify operationalizing this activity long term. Return rates for smolts entering the estuary naturally are well documented through annual census programs so additional tagging of a control group is not necessary.

Methods and Findings

Methods

All sockeye smolts outmigrating from Sakinaw Lake encounter a smolt fence with a slide and overhead camera. A portion or all smolts can be directed into a trap box (6x6x3’ aluminum framed) depending on slide configuration (Figure 2). For the purpose of this project the slide was set to 100% capture to meet tagging goals.

Smolts were tagged with Biomark APT12 PIT Tags (12 x 2.12 mm, 0.1 g). Following sedation with TMS (Tricaine methanesulfonate), the tags are injected into the body cavity with an individual pre-loaded 12-guage needle and a Biomark MK 25 implanter. Tagged fish were then scanned and recorded via Biomark BioLogic DCM digital board, Biomark hand scanner, and a bluetooth connected tablet (Figure 3). Tag insertion and fish handling techniques described in the Columbia River PIT Tag Marking Procedures Manual (Columbia Basin Fish & Wildlife Authority PIT Tag Steering Committee, 1999) were modified slightly. As per recommendations from the DFO Veterinarian, the procedure for tagging was to insert the needle ahead of the pelvic girdle along the midline and inject the tag forward. Air bubblers and ice were used in each tagging bin to keep water temperatures cool and well oxygenated. Following tagging, smolts were returned to the trap box for recovery.

Smolts were held in recovery for a minimum of three hours before the transportation process began. At high-tide, shíshálh Nation's 30' Landing Craft was brought into the estuary, where six large plastic garbage bins on board were filled with saltwater and frozen water bottles (500ml). At the smolt fence & trap box, eight waterproof backpacks (dry bags) were filled with ~5 gallons of water and 50 smolts (Figure 4). Smolts were carried 900 m down to the beach, where they were transported to the Landing Craft via 12' skiff with electric motor. Smolts were then poured into the garbage bins with 20 mg/L of O2 from an oxygen tank (Figure 5). Smolts were then transported and released in the Malaspina Strait.

Key Results

- PIT tagging sample size objectives were achieved (1000-2500 tags). It was determined that sample size objectives could be met during the peak of smolt outmigration under normal operating conditions, as seen in 2023 & 2024, with the number of fish PIT tagged exceeding the goal of 2500 (Table 1).
- Transporting via aerated tanks on a boat is a successful method for moving smolts past the pinniped haul-out (Hodgson Island). Survival to release was over 99% and release condition and behavior was observed to be excellent. Challenges included high water temperatures during tagging and transport. This was mitigated with ice and a start date earlier in May.
- Marine survival comparisons are still being monitored, with the 2024 transport group returning as adults in summer 2026. Preliminary results from the 2023 transport group indicate that survival was not improved for the transported smolts, with only 1 PIT tagged transport fish returning to the lake as an adult.

Insights

This project was an exploration of new options to restore the Sakinaw sockeye population to a self-sustaining run. It was conducted at a pilot scale to avoid making large investments in equipment or infrastructure before understanding the effectiveness of smolt transport as a tool to increase adult returns.

Given the timelines of the project in relation to the biology of the population we don't yet have all of the results in hand. Preliminary findings from the first group of ~2,600 smolts suggests this is not an effective tool at increasing survival due to low (1) returns in 2025. A second cohort of over 5000 tags is expected to return in summer 2026 and will confirm these results.

Assuming a similarly low return in 2026 the recommendation is to not pursue smolt transport as a restoration tool for Sakinaw sockeye. If the results are taken at face value they do raise some important discussion points and potential future directions. For example, early marine survival may not be the limiting factor for this population and later stage mortality may be more important than previously thought. Further investigations should focus on the hypothesis that late stage mortality is an important factor for this population based on the known milling behavior in the terminal area. It has been well documented that Sakinaw sockeye adults school and stage in the bay while waiting for optimal migration conditions. These are typically described as a high tide at night with sufficient water levels which only occur on specific days within key migration months (e.g. July). Prolonged staging could be exposing this population to higher levels of predation than for example Fraser bound sockeye and should be specifically evaluated.

Moreover; stock composition data from the Johnstone Strait test fishery indicate Sakinaw sockeye are regularly encountered each season. Although numbers are low (<10/yr) the probability of this occurring should be near zero when comparing current escapements (low hundreds) to Fraser River run size (low millions; or 1 in 10,000). This suggests there are more adults enroute to Sakinaw than expected providing additional support for the above hypothesis.

Next Steps

Following the recommendations above, below are a few directions to go with respect to future work.

- Revisit sockeye test fishing data and conduct a run reconstruction to estimate the pre-terminal abundance of Sakinaw sockeye relative to escapement.
- Work with test fishing crews in 2026 to scan some or all of the test fishing catch with a PIT antenna as sets are spilled during enumeration (underway). Tags in adults should be at a maximum this year and any IDs detected can be compared to results from the river to estimate survival.
- Increase monitoring of staging behavior in the bay particularly in the month of July (peak season). Consider installation of fixed SONAR stations in the bay to look for evidence of predation, particularly at night as fish attempt river entry. Overhead camera installations with zoom capability may also be useful.
- Consider PIT tagging clipped adults in the test fishery to test the above hypothesis. This should be combined with DNA sampling to ensure they are Sakinaw origin fish. Alternatively; consider applying acoustic tags and receivers to see where mortality is occurring. Sakinaw sockeye may stand out in the catch given their relatively small size and adipose clip. Dip netting individuals out of the bunt could be explored. Sorting entire sets is not feasible unless the boat is chartered specifically for that activity. At this time the recommendation is to avoid operationalizing smolt transport activities to support recovery of Sakinaw sockeye. It also brings into question the utility of similar activities that are designed to mitigate high early marine survival (e.g. net pens).

Tables and Figures

*Table 1. The number of PIT tagged and transported Sakinaw sockeye smolts each year of the project and the dates of releases. * Infrastructure issues at the Sakinaw Lake dam prevented enough smolts from being trapped for the project.*

Year	Date	PIT Tagged & Transported
2023	May 15-17	2659
2024	May 6-9	4845
2025	May 6-8	326*

Figure 1. Map of the study area with the Hodgson Island haul out and Sakinaw Lake counting fence.

Figure 2. Smolt dewatering slide at the Sakinaw Lake outlet with flash board for camera counts (left) and trap box with smolts ready to be tagged (right).

Figure 3. PIT tagging process at the Sakinaw Lake fence with pre-loaded trays and marking gun.

Figure 4. Smolts being transferred into a waterproof backpack for transport to the skiff and landing craft.

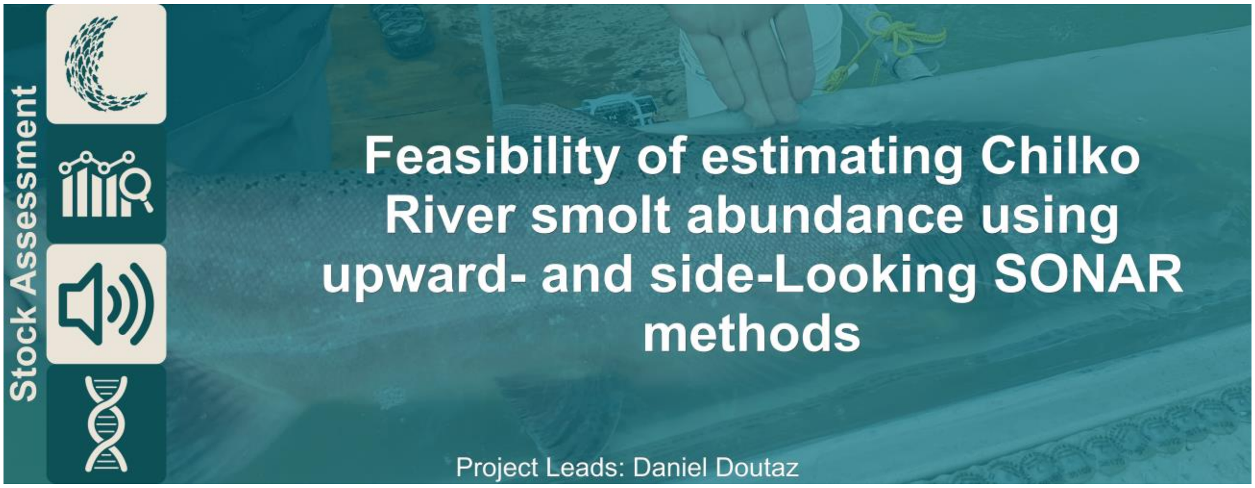
Figure 5. Transporting and releasing fish aboard the landing craft.

References

Columbia Basin Fish and Wildlife Authority PIT Tag Steering Committee. 1999. PIT tag marking procedures manual. Available from https://wiki.ptagis.org/images/6/60/MarkingProceduresManual.pdf

Brock Ramshaw, Wilf Luedke and Josh Korman. 2019. Recovery Potential Assessment for the Sakinaw Lake Sockeye Salmon (*Oncorhynchus nerka*). Can. Sci. Advis. Sec. Res. Doc. ISSN 1919-5044.

2430 - Estimating Chilko Smolt Abundance with SONAR Methods



Collaborations: Aquacoustics Inc., Tŝilhqot'in National Government (TNG)

Region: Fraser

Waterbodies: Chilko River

Species: Sockeye

Populations: Chilko ES/S Sockeye

Highlights

- The main goal of the project was to test the use of SONAR technology to enumerate sockeye salmon smolt outmigration, while concurrently running a counting fence to evaluate its performance over a four year period.
- Over the course of three years (2025 results are pending), the difference in the total number of sockeye smolts estimated with SONAR when compared to estimates generated at the enumeration fence ranged from 5-33% (5% in 2024, 8% in 2023, 33% in 2022).
- This method has been shown to be effective at enumerating sockeye smolts, which is an important and often lacking piece of information in salmon stock assessments (e.g. estimating early freshwater survival, generating stock-recruit relationships). However, using SONAR in this configuration is highly dependent on site selection, stream morphology, flow conditions, and the ability to adequately sample smolts for size measurements used in the analysis.

Background

Chilko sockeye salmon represent the only wild sockeye indicator stock in the Fraser watershed. The annual Chilko Lake sockeye smolt assessment (1951-present) comprises the only long-term time series data available to assess juvenile recruitment, and freshwater and marine productivity for wild Fraser River sockeye salmon. Since program inception, sockeye smolts have been enumerated during their out-migration from Chilko Lake using a traditional fish counting weir and photographic sampling/counting techniques. During the first six decades of the program (1951-2012), interruptions in weir operation were relatively rare: in only three years (1979, 1993, 2006) did early freshets necessitate removal of the weir before the vast majority of smolts had migrated from Chilko Lake.

Recently, unusually early freshets have been experienced in the Chilko watershed that have translated into high and variable water conditions much earlier in the season. As such, DFO Stock Assessment crews were not able to operate the weir in 2015 due to high water flows, and have had to remove the weir structure prior to the completion of smolt migration on numerous other recent years (e.g., 2019). The observed increase in the frequency of early freshets in the Chilko watershed is consistent with predicted hydrographic changes for interior BC streams as a whole in response to climate variability, with the average timing of the spring freshet expected to continue shifting earlier as air temperatures rise. The future of operating the Chilko sockeye smolt weir is in jeopardy given the current trend related to the timing, frequency, and strength of the spring freshets. If proven effective, the SONAR method would provide an alternate assessment method for the Chilko watershed that could be quickly employed in years when high flows either prevent the installation of the weir at the beginning of the migration, or necessitate the removal of the weir before the smolt migration is largely complete.

The objective of this work was to:

- test the feasibility of using upward-looking SONAR technology to assess daily abundances of Chilko Lake sockeye smolts as they migrate downstream through the Chilko River, and
- evaluate the reliability of using daily SONAR-derived abundance indices predict the daily migration totals observed at the counting weir that is deployed annually on the Chilko River.

This work was conducted in collaboration with the Tŝilhqot'in National Government (TNG).

Methods and Findings

Acoustic data were collected with two Simrad WBT Mini SONAR systems deployed approximately 2 km downstream of the Chilko River smolt enumeration fence. Each SONAR system operated with a 7° circular 120 kHz split-beam transducer. For the up-looking system, the transducer was mounted on the river bottom, in the thalweg, aimed straight up towards the water surface. For the side-looking system, the transducer was mounted nearshore on the left bank of the river, with its center approximately 15 cm below the surface, aimed across the river with a transducer tilt angle of approximately 3° down from horizontal. Data were recorded with a ping rate of 20 pings per second on the up-looking (maximum range 4 m), 12 pings per s on the side-looking system (maximum range 12 m). Both systems were set to 50 W power output. For all four years of the study, SONAR data were collected from mid-April to late-May during the entire Chilko sockeye smolt outmigration period.

SONAR data was manually reviewed and edited using Echoview software to remove noise, and echo integrated in 1 hour x 1 m range cells (side-looking) or 1 hour x 0.2 m range cells (up-looking). The results were exported as csv files, and all echo integration csv files belonging to the same transducer and site were concatenated for further analysis in Microsoft Excel. Excel was then used to convert the echo integration results to smolt passage estimates, which were then compared to the estimates generated at the Chilko River smolt enumeration fence.

In 2023 and 2024 (2025 results pending), daily estimates of smolt passage showed close correspondence (5% in 2023, 9% in 2024) between fence counts and independent acoustic estimates both in time and magnitude. In the first year of the study (2022), daily SONAR estimates were in good agreement with the fence counts over the first 9 days of the study, but consistently higher over the last 9 days (May 3rd and thereafter). At present, the source of this divergence is unclear.

This project is one of few that have used split-beam SONARs configured in this manner to enumerate outmigrating salmon smolts. While further testing needs to be conducted in both the Chilko River where the study was conducted, and in other candidate systems, the preliminary results of this study are promising. These methods could be modified and applied to a variety of salmon stock assessment programs to gain crucial information on survival in the early freshwater life stages (egg to smolt survival), however, considerable planning and care needs to be taken when selecting a suitable site.

Insights

This project has shown sockeye salmon at the smolt life stage can be effectively enumerated using SONAR, and is an easily-deployed and operated alternative to installing large enumeration fences which are typically labor-intensive and may disturb stream substrates. Many salmon stocks are solely assessed through adult escapements, which does not capture survival during the early freshwater life stages, and creates additional challenges when investigating individual stock recruitment and forecasting returns that are used in fisheries management and planning.

Using SONAR to enumerate salmon at the smolt stage enables researchers to investigate survival metrics during the early freshwater period in which there is often little or no data at the population or Conservation Unit (CU) level. In systems where there is ongoing juvenile enumeration work (e.g. with counting fences, rotary screw traps (RST), incline plane traps (IPT), etc.), this method may provide a suitable, and less invasive alternative to conventional methods. Further to this, the observed increase in frequency of early freshets and hydrographic changes in response to climate variability may preclude the operation of some juvenile assessment methods, leading to the need for other means of collecting juvenile salmon data.

Sources of uncertainty raised from this project include discrepancies in SONAR counts when compared to fence counts (particularly in the 2022 study year), which at this time are unresolved. Additionally, there is uncertainty how the system deployed would operate under heavy flow conditions, in systems with different stream characteristics, and in systems with multiple species of Pacific salmon with overlapping outmigration timing.

Next Steps

This work describes how split-beam SONAR systems can be deployed and configured to enumerate outmigrating salmon smolts, which can provide crucial information on egg to smolt survival, stock recruitment, and freshwater habitat conditions and quality. This additional information can then be used to inform management strategies or mitigations for stocks below conservation benchmarks, or inform enhancement work conducted by the DFO Salmonid Enhancement program where no metrics exist other than adult escapements to evaluate performance (e.g. Bowron, Pitt, Taseko rivers).

Tables and Figures

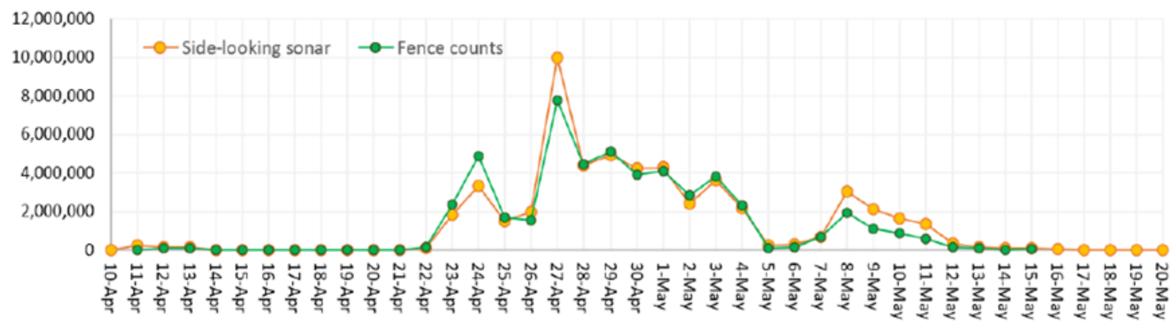


Figure 1. 2024 daily estimates of Chilko River sockeye smolt passage: side-looking SONAR estimates versus fence counts.

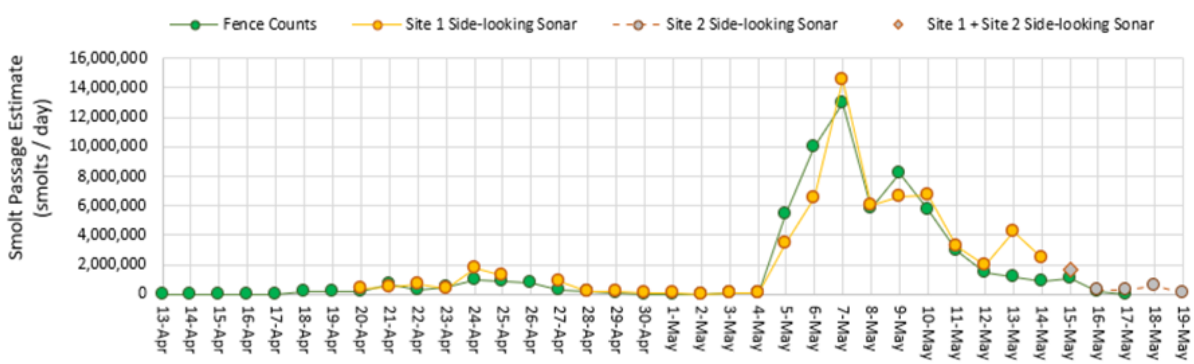


Figure 2. 2023 daily estimates of Chilko River sockeye smolt passage: side-looking SONAR estimates versus fence counts.

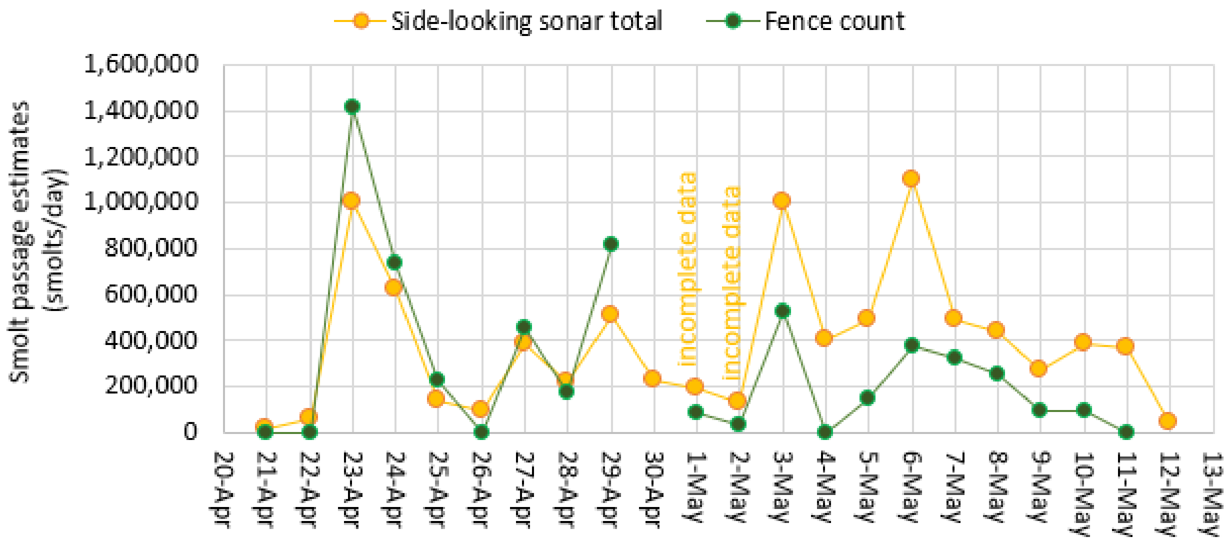


Figure 3. 2022 daily estimates of Chilko River sockeye smolt passage: side-looking SONAR estimates versus fence counts.

GENETICS

2434 - Rapid Genotyping Using SHERLOCK Assay

Evaluation of a SHERLOCK assay for improved management of Chinook Salmon in BC. DFO Tech Report (In progress)

Collaborations: Salmonid Enhancement Program

Region: East Vancouver Island

Waterbodies: Puntledge River

Species: Chinook

Populations: ECVI Georgia Strait Summer Chinook

Highlights

- The objective of this project was to test the use of SHERLOCK lateral flow-type assays to assess their suitability for rapid, field-deployable genetic assays for use in SEP management applications.
- We found excellent performance of the tool under ideal laboratory conditions, but inconclusive and inconsistent results when attempting field deployment of the tool.
- Further optimization and simplification of the procedure will be required for this tool to improve management practices.

Background

GREB1L is a gene that explains a large amount of the variation in run timing for Chinook Salmon. Specific SNPs in the GREB1L gene are currently used as diagnostic genetic markers to retroactively distinguish between summer and fall runs of Chinook in the Puntledge River Hatchery. These markers have two alleles one of which is primarily carried by early returning Chinook salmon and the other by late returning salmon. Current management of enhancement at the Puntledge River Hatchery uses a date threshold to ensure most “summer run” fish carry the early-run allele to preserve the genetic integrity of this population segment. Rapid in-season genotyping results would allow more accurate and expanded use of available broodstock for the Puntledge summer run. SHERLOCK assays are field deployable genotyping assays that can generate a result in under an hour and may provide this capacity to enhancement efforts in the Puntledge River. The technology has previously been demonstrated for rapid genotyping purposes including GREB1L markers in California populations of Chinook salmon.

Methods and Findings

We used existing qPCR assays and data generated by the DFO GSI program for routine broodstock screening for Puntledge Chinook salmon as the ground truth for underlying greb1l genotypes. We then tested a published SHERLOCK assay (Baerwald et al. 2025) to validate its efficacy for genotyping greb1l in Puntledge Chinook. Lab samples assayed with SHERLOCK were successfully genotyped (Figure 1) and had a high concordance with SNP genotyping results (99%, Table 1) indicating that the tool can accurately genotype samples and is consistent with existing SNP genotypes in Puntledge River Chinook. A test field deployment of the tool using lateral flow strips for genotype detection (Figure 2) resulted in only an 80% concordance rate (4/5), but had a majority of assays fail (19). These results suggest that the tool has promise, but that further optimization and simplification of the methodology is required before the tool could be adopted to improve management.

Insights

The project has demonstrated that SHERLOCK assays could accurately genotype Chinook Salmon in the Puntledge River, but that reliability of the tool must be improved before it can be adopted.

Next Steps

Future studies could continue to optimize and stabilize the reagents for field delivery, but alternative techniques to rapidly genotype GREB1L should be explored and considered. There remains a clear use-case and a real benefit to increase the number of Summer run fish for broodstock that such tools could enable.

Tables and Figures

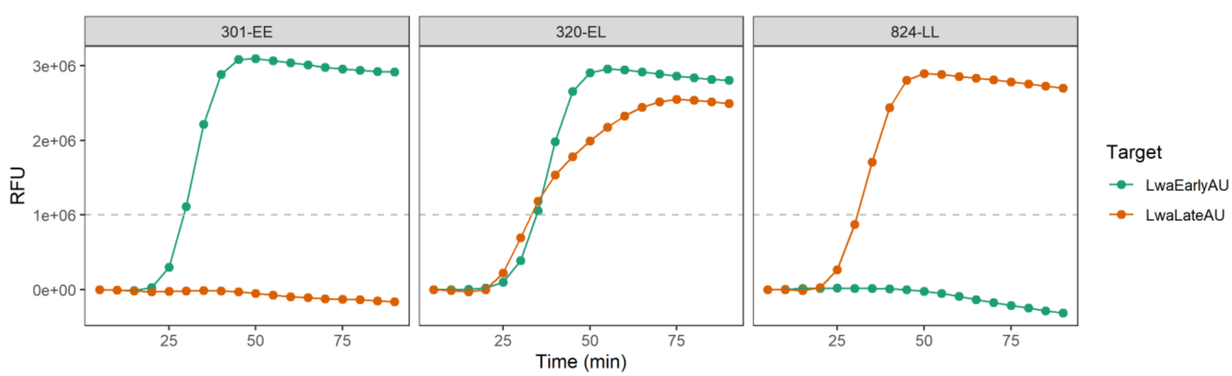


Figure 1. SHERLOCK genotyping of greb1l early (green) and late (orange) alleles in individuals known to be homozygous for the early allele (301-EE), heterozygous (320-EL), and homozygous for the late allele (824-LL). Accumulation of fluorescence (RFU) over time indicates the presence of the allele in the DNA sample tested.

Figure 2. Lateral flow strips used for detection of greb1l genotypes using SHERLOCK assays.

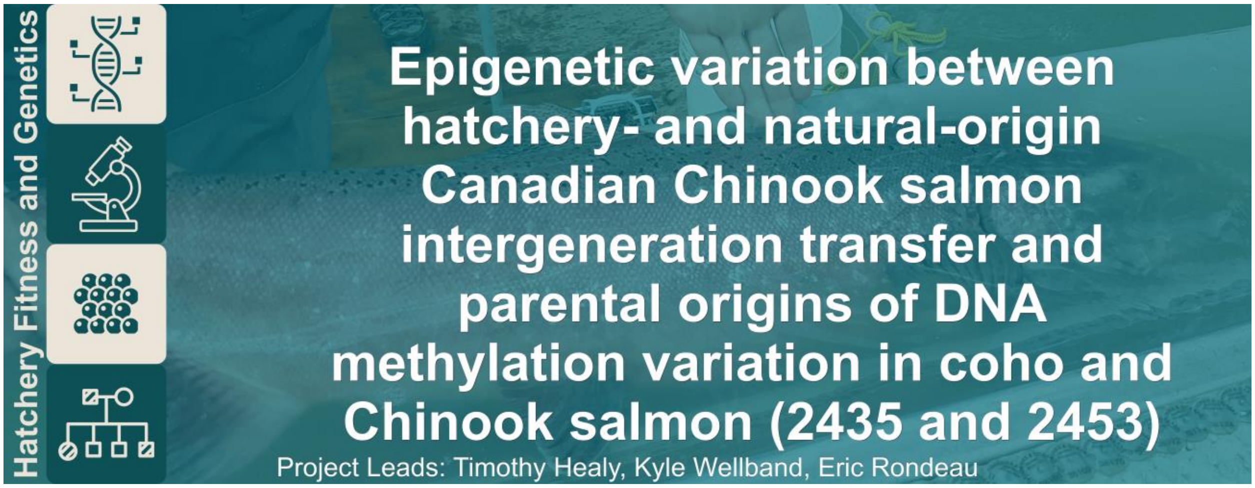
SHERLOCK Genotype	SNP Genotype		
	EE	EL	LL
EE	44		
EL	1	8	
LL			42
No call			1

Figure 3. Concordance of greb1l genotyping approaches using qPCR (SNP) and SHERLOCK assays for individuals with known early-early (EE), early-late (EL), and late-late (LL) genotypes.

References

Baerwald M.R., Funk E.C., Goodbla A.M., Campbell M.A., Thompson T., Meek M.H. Schreier A.D. 2025. Rapid CRISPR-Cas13a genetic identification enables new opportunities for listed Chinook salmon management. Mol. Ecol. Resour. 25(5): e13777. doi:10.1111/1755-0998.13777.

2435/2453 - Epigenetic Variation between Hatchery and Wild Salmon



Variation in DNA methylation between hatchery- and natural-origin Chinook Salmon (Oncorhynchus tshawytscha) across hatcheries in British Columbia (in progress)

Effects of hatchery rearing strategies on whole-genome DNA methylation in Sarita River Chinook Salmon (Oncorhynchus tshawytscha) smolts (in progress)

Cross-tissue differences in DNA methylation and gene expression between hatchery- and natural-origin Chilliwack River Chinook Salmon (Oncorhynchus tshawytscha) (in progress)

Region-specific inheritance of parental DNA methylation patterns in Coho Salmon (Oncorhynchus kisutch) (in progress)

Technical report / CSAS document contribution: Genome-wide genetic variation among West Coast Vancouver Island stocks of Chinook Salmon (Oncorhynchus tshawytscha) (in progress)

Collaborations: Salmonid Enhancement Program, University of British Columbia, Genome British Columbia

Region: BC

Waterbodies: Atnarko River, Cheakamus River Chehalis River, Chilliwack River, Conuma River, Nanaimo River, Nicola River, Quinsam River, Salmon River, Sarita River, Wannock River, Yakoun River

Species: Chinook, Coho

Highlights

- Hatchery and natural habitats favour different traits in Pacific salmon, and consistent with this, performance differences between hatchery- and natural-origin salmon are often observed in nature with natural-origin fish tending to outperform their hatchery counterparts.
- Despite this, when hatchery programs are integrated with the natural component of the population, detection of genetic differences between hatchery- and natural-origin fish is rare.

- In contrast, epigenetic differences, such as the addition or removal of methyl groups from DNA (i.e., DNA methylation), between hatchery- and natural-origin salmonids have recently been characterized in several species and populations.
- These epigenetic differences may underlie hatchery effects on performance in Pacific salmon, and have the potential to be inherited across generations, which would pose a long-term fitness risk to enhanced populations.
- These projects represent the most comprehensive study of variation in DNA methylation across hatcheries in Pacific salmon to date, assessing (1) the consistency of differences in DNA methylation across hatcheries, (2) the extent to which these differences are inherited by the offspring of hatchery-origin fish, and (3) the potential for development of epigenetic biomarkers for the management of hatchery effects in enhanced populations.
- Differences in DNA methylation between hatchery- and natural-origin Chinook or Coho Salmon were observed in every population examined, but essentially all patterns with population- or hatchery-specific.
- In outmigrating smolts, hatchery rearing strategies impacted DNA methylation patterns with juveniles reared with slower growth rates and released at smaller sizes showing patterns less divergent from natural epigenetic signatures than those observed in traditional hatchery releases.
- As expected, tissue-type had substantial effects on DNA methylation even between different fins, and although fin tissue captured some of the differences in methylation detected in other tissues, the majority of patterns were tissue-specific.
- Consistent with potential long-term effects of hatchery-mediated epigenetic variation, there was evidence of inheritance of DNA methylation patterns from hatchery parents to their offspring in controlled crosses, but the mode of inheritance varied depending on the region of the genome assessed.
- Taken together, these projects clearly confirm that epigenetic effects of hatchery rearing are likely mechanisms underlying hatchery effects on performance in Pacific salmon, although these patterns are generally population-specific such that development of widely applicable epigenetic biomarkers for hatchery-origin is unlikely to be possible.
- Instead the findings of these projects suggest that understanding how hatchery practices modify epigenetic variation in Chinook and Coho Salmon may guide modifications to reduce hatchery impacts in the future, and that population-specific biomarkers are likely to have utility when desired.

Background

Enhancement of Pacific salmon through hatchery production is a key component of supporting salmon populations. Objectives of hatchery enhancement span conserving at-risk stocks, rebuilding lower abundance stocks, providing harvest opportunities and increasing public awareness through outreach and education. However, there are also risks associated with hatchery enhancement; differences between a hatchery and a natural habitat affect both the genetic and environmental factors that shape the performance and fitness of salmon. Consequently, hatchery-origin salmon may be less suited to wild habitats than their natural-origin counterparts, and the presence of hatchery-origin fish on a natural spawning ground may reduce the fitness of a population overall. Despite the known risks and consequences of hatchery enhancement, major genetic differences between hatchery- and natural-origin salmonids as a result of hatchery-mediated selection or relaxed selection have generally not been observed in integrated populations. In contrast, substantial epigenetic differences have been detected between hatchery- and natural-origin Pacific salmonids.

Epigenetic variants are structural changes to DNA without a change in the DNA sequence itself. For example, DNA methylation is a commonly studied epigenetic mechanism in which a methyl group (-CH3) is covalently added to a cytosine residue. These modifications to DNA can alter the function of the genome, particularly through the regulation of gene expression. Given the extent of previously observed variation in epigenetic signatures between hatchery- and natural-origin salmon, the functional effects of epigenetic variants are excellent candidates to underlie the fitness consequences associated with hatchery enhancement. Additionally, it is possible for hatchery epigenetic variants to be inherited by the offspring of hatchery-origin fish, which aligns with the potential for long-term reductions in population fitness as hatchery-origin fish spawn in natural habitats. The study of epigenetic variation in Pacific salmonids is relatively in its infancy, but epigenetic biomarkers are a promising tool to facilitate managing hatchery enhancement specifically and salmon fisheries generally. Critical knowledge gaps in the generation of these tools are that epigenetic differences between hatchery- and natural-origin Chinook Salmon have not been well-characterized and the extent to which these patterns are inherited in Pacific salmon is unknown. These projects address both of these gaps using data for Chinook and Coho Salmon populations enhanced by the DFO Salmonid Enhancement Program (SEP).

Methods and Findings

Samples for these projects were obtained from fin tissues submitted to the Molecular Genetics Section as part of the parentage-based tagging (PBT) program in the SEP, or from additional sampling efforts for the Chehalis, Chilliwack and Sarita Rivers. DNA was isolated from all samples using standard laboratory protocols, and for a relatively small number of Chilliwack River Chinook tissues RNA was also isolated with standard protocols. All isolations were quantified and quality controlled prior to use in data generation. For whole-genome data, DNA or RNA was sent to Genome Quebec for enzymatic methylation sequencing or RNA sequencing, respectively. For screening of methylation patterns in candidate genome regions, high-resolution melt analyses were conducted following quantitative polymerase chain reactions (qPCR).

Sequencing reads were trimmed, aligned to the corresponding species genome sequence, and filtered for alignment quality and duplicated sequences. Final alignments were used to call variation in DNA methylation at CpG sequences using MethylDackel v0.6.1. Differences in methylation were then assessed by multidimensional scaling analyses and differential methylation tests with DSS v2.50.1 using custom analysis scripts established for the projects.

The final analyses and manuscripts for these projects are in progress. The sequencing reads, methylation results and all other datasets will be submitted to public repositories on publication of the corresponding manuscripts. Similarly, all bioinformatic pipelines and scripts files will be publicly available through GitHub.

Methylation patterns demonstrated substantial variation among different populations, and were also highly dependent on the tissue from which DNA was isolated even between adipose and caudal fins (see Figure 1 for example for Chinook Salmon). In all populations and tissues, approximately 50-500 regions of the genome displayed differences in methylation between hatchery- and natural-origin fish (see Figure 2 for example for Atnarko River Chinook Salmon), but these differences were essentially all population-specific. Within the Chilliwack River Fall Chinook population, differences in methylation between origins showed some consistency across two brood years, and although many differences in methylation were tissue-specific, a subset of patterns observed in fin tissues were detected in other tissues as well. Inheritance of parental methylation patterns was examined in Chehalis River Coho Salmon by assessing candidate regions with known differences between hatchery- and natural-origin parents. Inheritance of parental patterns was observed with some regions showing offspring methylation consistent with additive inheritance (intermediate between the parents) and other regions showing methylation patterns consistent with paternal dominance (methylation inherited from the father) (Figure 3).

Insights

These two projects provide several novel insights into epigenetic variation in Pacific salmon. The Chinook Salmon datasets summarized above represent the most comprehensive efforts to date to characterize differences in DNA methylation between hatchery- and natural-origin fish in this species and have clearly established that common effects of hatchery rearing across facilities are rare. The Coho Salmon study is the first, to our knowledge, to assess inheritance of epigenetic variation in Pacific salmon, confirming the potential for persistence of hatchery-mediated epigenetic effects across generations in enhanced populations. These results highlight the key need to develop understanding of the relationships between hatchery practices and different methylation patterns, the functional consequences of differences in methylation, and the potential adjustments in hatcheries that could mitigate these effects.

There are four main sources of uncertainty for the findings of these projects. First, although the results above are suggestive that epigenetic differences are an important consequence of hatchery rearing and differences in performance between hatchery- and natural-origin salmon, the functional effects of the methylation differences summarized above remain to be established. Second, the extent to which methylation patterns in fin tissue capture those that may underlie differences in performance also remain to be established. Third, the inheritance of DNA methylation patterns demonstrated above requires testing and validation under hatchery and natural conditions; this validation is a key aspect of linking hatchery-mediated epigenetic changes to potential long-term fitness impacts. Fourth, the utility of epigenetic biomarkers for tracking hatchery origin or age in Chinook and Coho Salmon remains to be tested, as the high degree of population-specific patterns detected in these projects delayed biomarker development.

Next Steps

Future studies should address the uncertainties described above by performing physiological tests of the impacts of DNA methylation on performance in Chinook and Coho Salmon, and by using parentage-based tagging to assess parent-offspring methylation patterns outside of laboratory settings. Additionally, a proof of concept study for epigenetic biomarkers of hatchery origin and age in a key population would further improve the utility of the results summarized here. Operationalization of these findings will require not only proof of concept efforts, but also manipulative experiments to assess alternative rearing strategies and their impacts on DNA methylation, which will then inform scientific best practices that mitigate the fitness risks associated with enhancement in Pacific salmon.

Tables and Figures

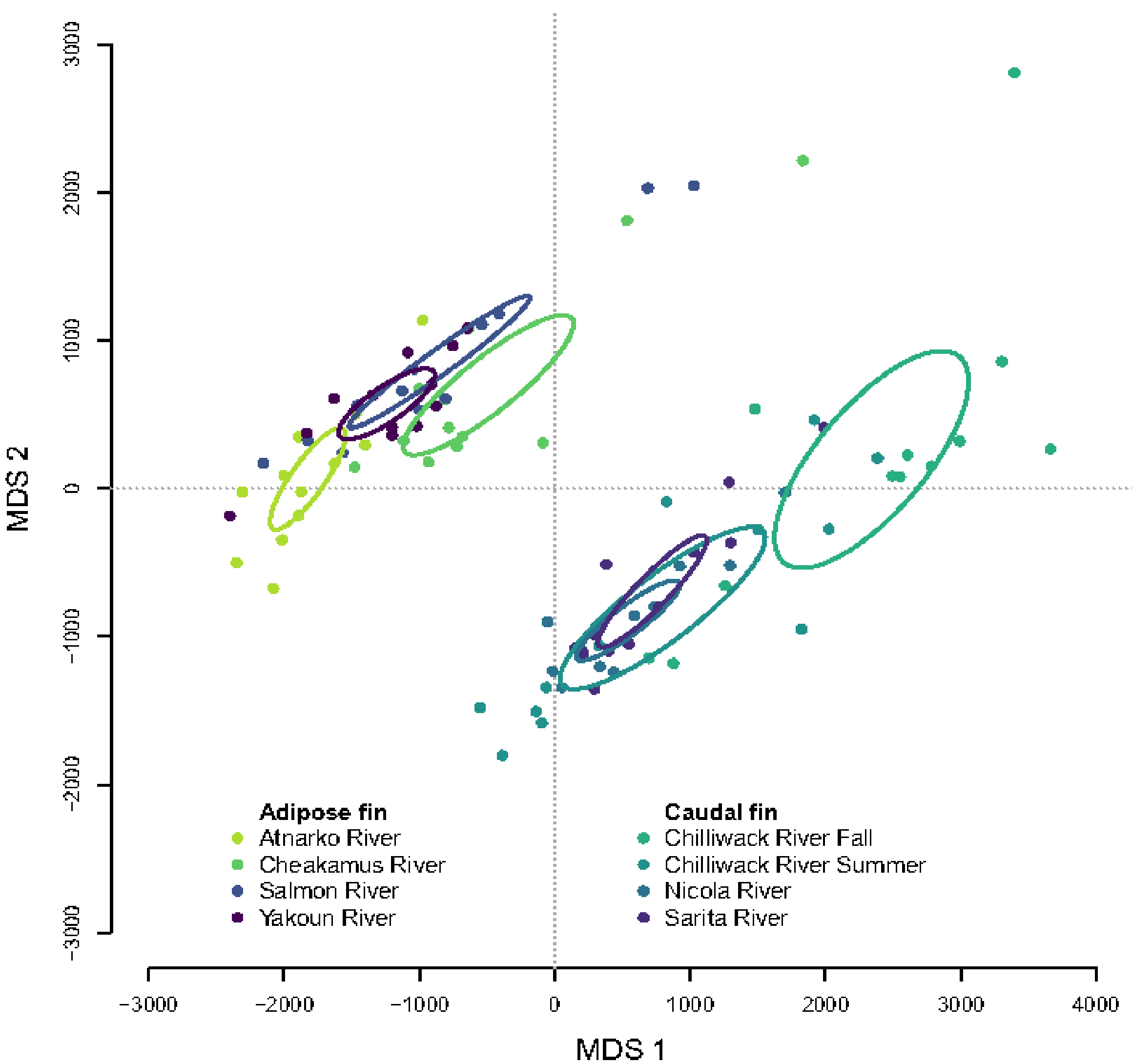


Figure 1. Multidimensional scaling plot of variation in genome-wide DNA methylation among integrated populations of Chinook Salmon. Points represent individual fish, and colours indicate populations. Ellipses show the 95% confidence limits for the distributions. DNA was isolated from adipose or caudal fins (adipose - Atnarko, Cheakamus, Salmon, Yakoun; caudal - Chilliwack Fall, Chilliwack Summer, Nicola, Sarita).

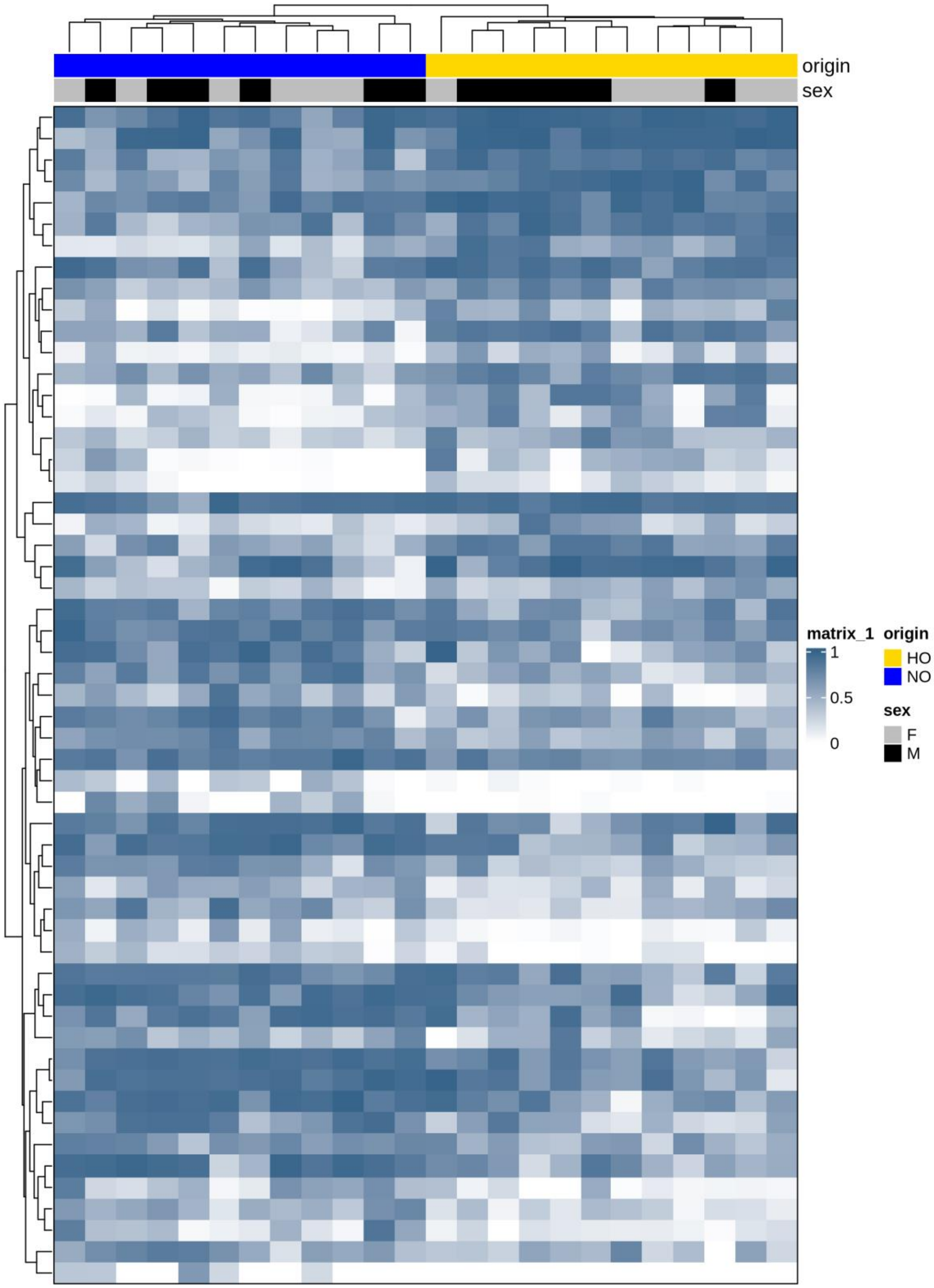


Figure 2. Heatmap of differentially methylated regions between hatchery- (yellow) and natural-origin (blue) fish. Columns correspond to individuals and rows correspond to genomic regions. Methylation levels are shown by the white to steel blue colour scale. Females (grey) and males (black) are indicated by the top bar.

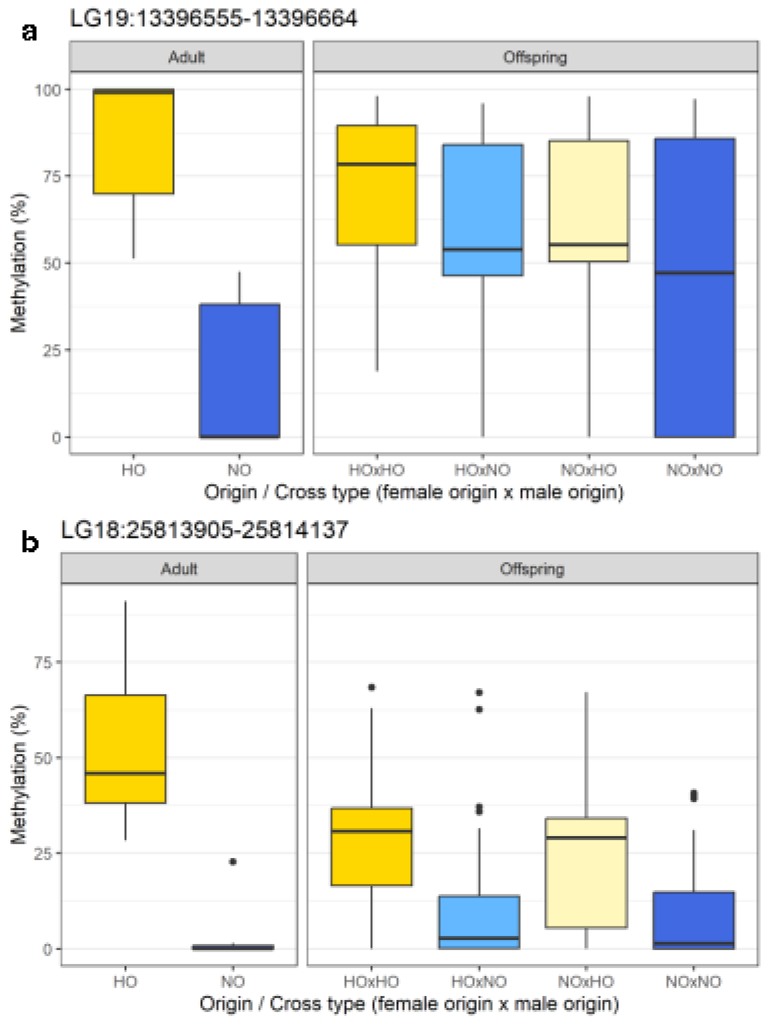
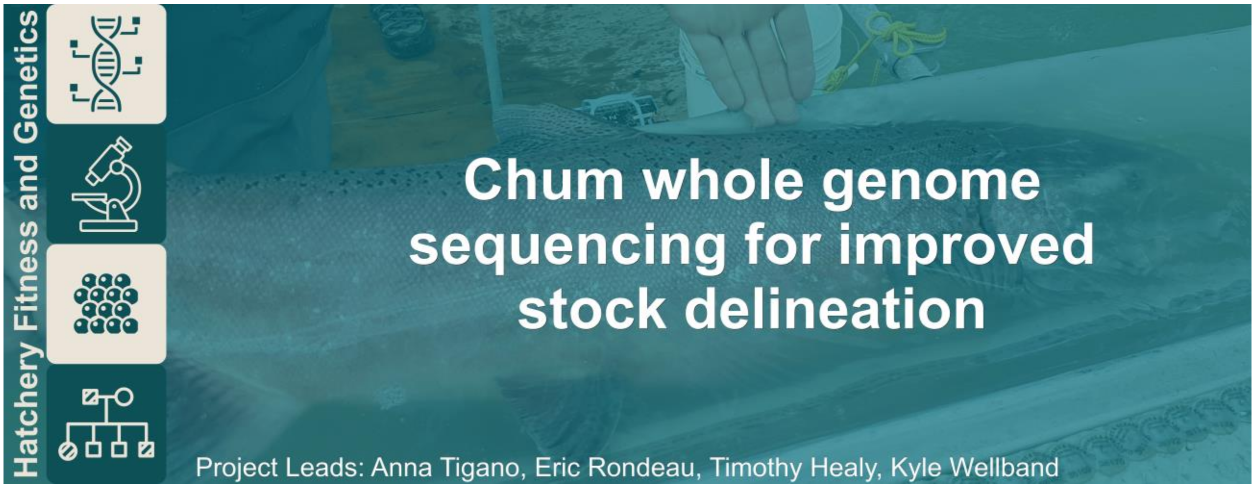


Figure 3. Box plots for high-resolution melt analyses of offspring methylation patterns compared to parental methylation for two genomic regions. Offspring cross-types are shown as female x male parent with hatchery-origin x hatchery-origin (yellow), hatchery-origin x natural-origin (pale blue), natural-origin x hatchery-origin (pale yellow), and natural-origin x natural-origin (blue). Panel a displays a region showing a pattern similar to additive inheritance, whereas panel b displays a region demonstrating paternal dominance.

2436 - Chum Whole Genome Sequencing for Stock Delineation



Tigano A, Long K, Healy T, Wellband K, Rondeau E. Increased genetic resolution in southern BC chum enabled by whole genome data. In preparation.

Region: Southern BC

Waterbodies: Fraser, Strait of Georgia, Puget Sound

Species: Chum

Populations: Fraser, Howe and Georgia Strait - Southern Fjords

Highlights

- The Genetic Stock Identification (GSI) of chum in southern BC, especially in the Fraser River and the Strait of Georgia ("SOG" hereafter), has poor resolution.
- We identified informative genetic markers (single nucleotide polymorphisms, SNPs) to improve the current SNP panel for GSI ("GSI panel" hereafter) and increase genetic resolution in the Fraser and SOG. In particular, we were able to differentiate 1) chum returning to the Chilliwack River versus the rest of the Fraser and 2) chum from spawning location in the SOG west versus SOG east. These improvements will improve stock assessment in those two areas.

Background

GSI is routinely used in the Northeast Pacific to inform the management of Pacific salmon species, especially Chinook (*Oncorhynchus tshawytscha*), sockeye (*Oncorhynchus nerka*), coho (*Oncorhynchus kisutch*), and chum (*Oncorhynchus keta*). Of these four species, chum is the most widely distributed in the Pacific Ocean, and displays the weakest population structure across its range. Chum is managed jointly by Canada and the United States under the Pacific Salmon Treaty to ensure that the fishery is sustainable on the long term, and GSI has become a pillar of effective stock assessment and management. Bilateral efforts between Canada and the USA have led to the development of GSI panels in each of the two countries, with bilateral collaboration ensuring a large overlap of SNPs between the panels developed in the two countries to foster exchange of data and results. The Canada chum GSI panel consists of 535

SNPs originally sourced from a series of RAD-seq (a genomic method to genotype thousands of genome-wide SNPs) studies targeting different parts of the range, but limited to Washington and Alaska (to be refined Small et al PSC report, Mckinney et al. 2020; Mckinney et al. 2022), and subsequently optimized independently from the USA counterpart. The Canadian baseline, the genetic database used as reference to assign samples of unknown origin to their stock of provenance, includes genotypic data for over 32,000 individuals from 384 collections across the species range (October 2025).

Despite the genotyping efforts, some areas in southern BC remain poorly resolved, with two areas being of particular interest: the lower Fraser and SOG. In the Fraser, the Albion test fishery, which provides crucial information on chum returns for stock assessment, relies on accurate separation of Chilliwack River returns from the rest of the Fraser, but it is currently challenging. To avoid misassignment and increase accuracy, albeit at the cost of resolution, all collections from the Fraser are lumped into a single reporting unit. In the Strait of Georgia, two main reporting units are currently recognized: Howe-Burrard, including collections from Howe Sound and Burrard Inlet; and Strait of Georgia, including collections from the west and east side of the strait that are not included in the Howe-Burrard reporting unit. Even though assignment accuracy between these two reporting units is low with the current SNP panel, the analysis of the baseline samples suggest that additional efforts may help discriminate collections from the east and the west side of the Strait, thus increasing overall resolution in the SOG.

Methods and Findings

We used whole genome sequencing to fully characterize genome-wide sequence variation within the Fraser, SOG and adjacent areas, including Puget Sound, Johnstone Strait, and West Coast Vancouver Island. We sequenced 15 individuals from each of 45 collections in these areas (Fig.1), and called variants using stringent quality filters. We identified more than 11 million SNPs (excluding rare variants) across 594 individuals, which is 21,000X the number of SNPs included in the current GSI panel (535 SNPs). We performed Principal Component Analyses (PCAs) to investigate population structure. Analyses based on 100,000 randomly selected SNPs, a subsample of the full catalogue of genomic variation, showed great resolution improvement compared to the reference baseline including data from the 535 SNPs of the GSI panel (Fig.2): the Fraser, SOG and Puget Sound were markedly differentiated from each other, the North Puget collections were clearly separated from the rest of the individuals, and we started to observe differentiation between Chilliwack and Fraser, and SOG east and west. More focused analyses including only Fraser-Chilliwack or SOG samples revealed significant differentiation within those two areas. To identify a set of highly informative SNPs to add to the GSI panel, we calculated FST, a measure of genetic differentiation, across all SNPs within each of the two areas and selected the 100 SNPs showing the highest differentiation in each area (Fraser and SOG).

We extracted the genotype data from the whole genome sequencing dataset for the SNPs in the GSI panel and the 200 highly differentiated SNPs in the Fraser and the SOG. 121 of the 535 SNPs in the GSI panel were not present in the whole genome dataset because they were either excluded due to quality and/or low minor allele frequency filters, or because they were not variable in the target geographic area. Using Leave-One-Out (LOO) analyses we tested for changes in GSI accuracy between the current GSI panel (414 SNPs) and the improved panel that includes the GSI panel and the 200 differentiated SNPs (614 SNPs). The addition of the 200 SNPs resulted in much improved assignments (Fig.3 and 4). When we tested the current GSI panel, assignments to the SOG had low true positive rates, indicating low assignment probabilities or misassignments, and individuals from each side of the strait showed similar probabilities to be assigned to SOG east or west (Fig.3). In the Fraser, Chilliwack individuals tended to be assigned to the rest of the Fraser, resulting in high false positive rate when the Fraser was the target reporting unit, and low true positive rates when the Chilliwack was the target reporting unit (Fig.3). In contrast, when we used the improved panel, all analyses showed low false discovery rate (FDR < 0.05) and high true discovery rate, hitting the target accuracy threshold of 80% of individuals assigned with 80% probability assignment, except for Chilliwack, which showed great improvement but fell slightly short on the true positive rate (70-75% instead of > 80%, Fig.4) . True positive rate of assignment to Chilliwack is likely to increase with greater sample sizes, which are generally targeted for the construction of the reference baseline. Overall, by adding 200 highly differentiated SNPs, true positive rate increased by 48% on average at a 80% of assignment probability threshold in the four target areas, with the greatest increases in Chilliwack (66%) and SOG west (63%), followed by SOG east (49%; Figs.3 and 4). The Fraser had the lowest increase in true positive rate as it was already high in the original GSI panel, even though its false discovery rate was the highest (10%) due to Chilliwack individuals tending to assign to the Fraser (Figs.3 and 4). Similarly, false discovery rate decreased by 5% and accuracy increased by 10% on average.

Finally, with funding from PSSI we expanded our whole genome dataset to include one collection from each designated Conservation Unit (CU) in BC and additional collections from Alaska, for a total of 512 individuals from 44 collections/CUs from Washington to Alaska. This dataset will be used to further characterize population structure across the BC range and beyond, investigate signatures of local adaptation and the environmental factors driving it, assess variation in genomic vulnerability to climate change across the NE Pacific range, estimate genetic diversity, reconstruct past changes in effective population size, and potentially further improve the GSI panel to increase geographic resolution of GSI.

Insights

A good understanding of population structure is crucial for the effective management of Pacific salmon, including chum. The latest study investigating population structure in BC and Washington is almost 20 years old, and was based on only 89 SNPs, granting rather limited resolution, especially in the Fraser and SOG (Small et al. . Additionally, the genomic data used to develop the current GSI panel were collected from American spawning locations only, and the genomic variation that is unique to Canadian stocks was not captured. With our work on chum funded by PSSI we have characterized population structure in southern BC and Puget Sound and identified SNPs that are highly differentiated and informative of population differentiation in the areas of interest. An improved GSI panel based on our results will greatly improve GSI resolution and accuracy in the Fraser and SOG, and beyond.

We have been contacted multiple times in recent times for information on population structure in chum, both internally within DFO and by American agencies, to better inform stock assessment and management and hatchery practice. For example, apparent lack of population structure in the Fraser has led to the movement of chum of different origins among hatcheries. Our results provide evidence of population differentiation within the Fraser, which should be kept into account in hatchery practice to ensure the preservation of unique genetic diversity and potentially local adaptations to different parts of the Fraser watershed.

Our NE Pacific range whole genome sequencing dataset will provide additional information on population structure across the chum North American range and a suite of ad hoc genomic analyses, including assessment of genetic diversity, demographic reconstructions, measures of genomic vulnerability to climate change, will provide information to prioritize conservation efforts and ensure long-term sustainability of fisheries.

Next Steps

- In the coming months, we will perform additional assignment tests using individuals that were not originally included in the SNP discovery and GSI panel improvement analyses, and eventually add the informative SNPs identified to the current chum GSI panel.
- Dissemination of results at the Pacific Salmon Initiative Symposium has spurred interest into further characterizing fine population structure of chum in the Fraser and preliminary results are encouraging in this regard. We are also working on characterizing genomic areas of differentiation that could be associated with traits of interest, such as timing of migration. Finally, we'll expand our investigations to the rest of the BC range and beyond as described above.
- The results of our study will result in an improved GSI panel that will help differentiate chum from different areas in southern BC at an unprecedented resolution, thus informing and improving hatchery practices and stock assessment.

Tables and Figures

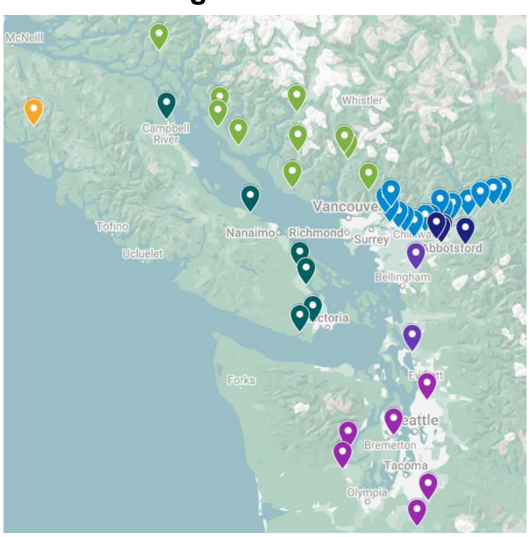


Figure 1. Map showing the spawning location of the collections used to increase GSI resolution in the Fraser River and in the Strait of Georgia.

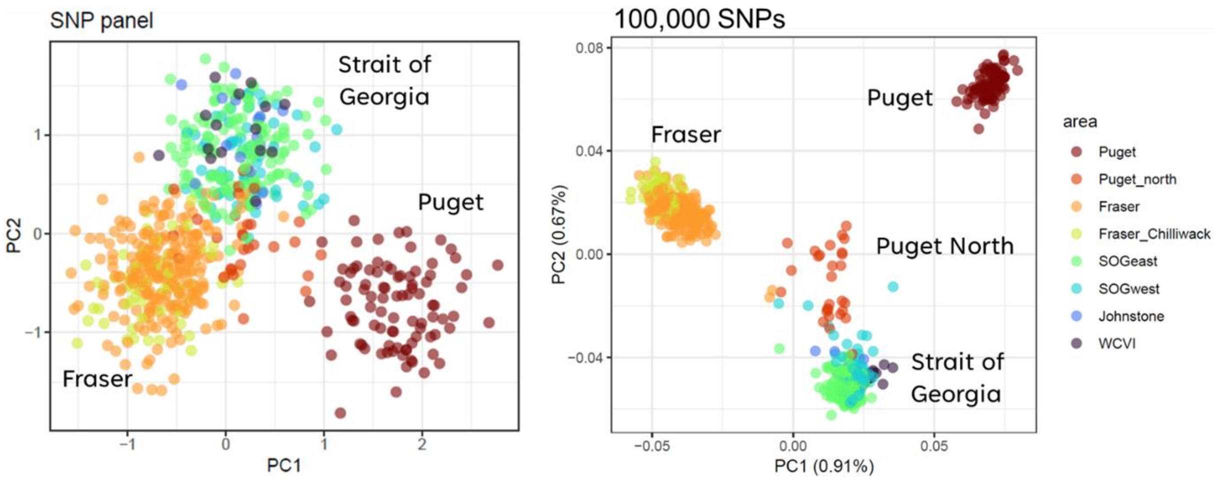


Figure 2. PCA plots showing population differentiation based on either the 535 SNPs included in the GSI panel (on the left) or 100,000 SNPs sampled randomly from a catalogue of 11 million SNPs from across the genome (on the right). The comparison shows higher genetic resolution when using more SNPs identified from the collections on interest.

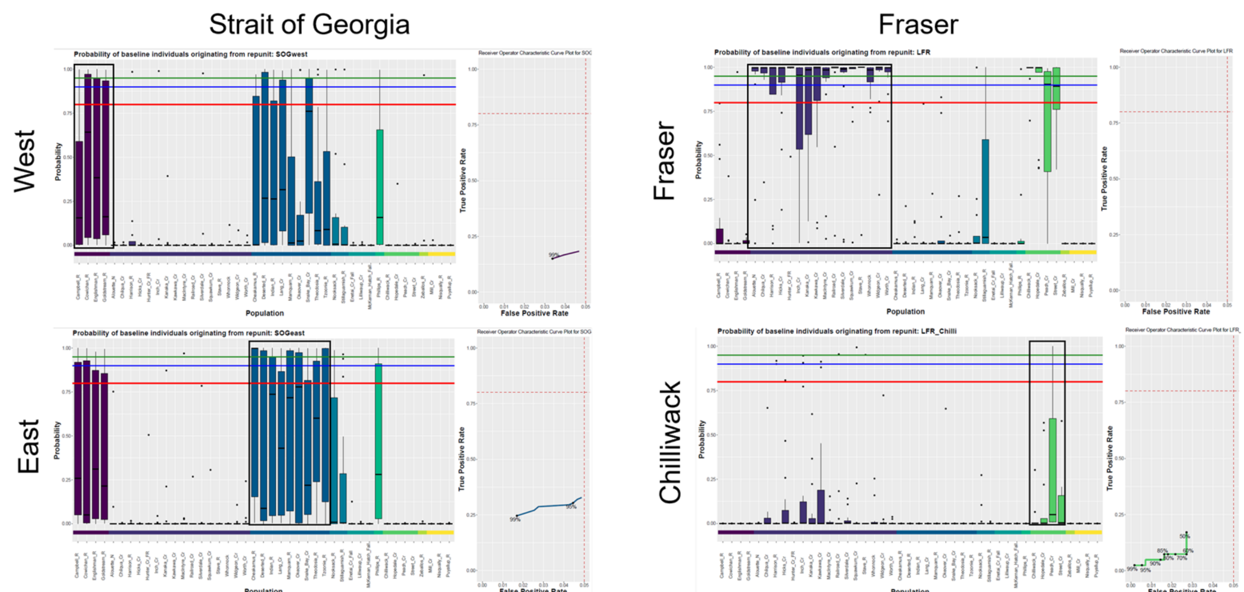


Figure 3. Plots summarizing LOO analyses results for the current GSI panel for each of the four target geographic areas: Strait of Georgia on the left (West and East) and Fraser on the right (Fraser-excluding Chilliwack and Chilliwack).

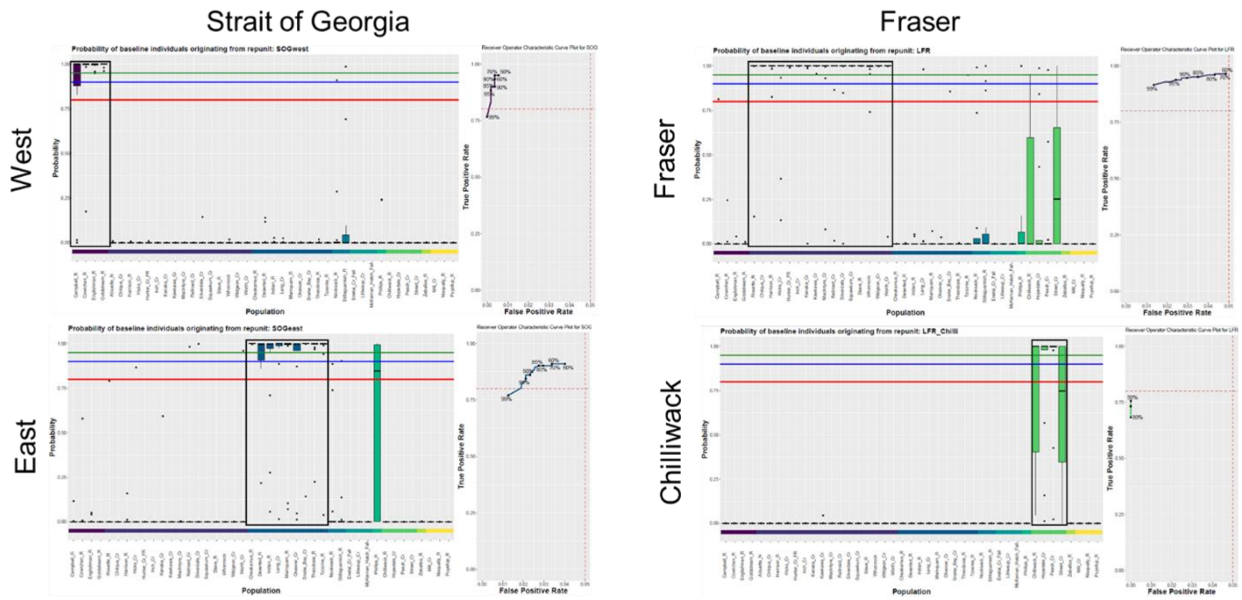


Figure 4. Plots summarizing LOO analyses results for the improved GSI panel (current + 200 highly differentiated SNPs) for each of the four target geographic areas: Strait of Georgia on the left (West and East) and Fraser on the right (Fraser-excluding Chilliwack and Chilliwack).

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2451 - Relative Reproductive Success of Hatchery Vs Wild Salmon

Technical report: Assessing feasibility of relative reproductive success studies between hatchery- and natural-origin Pacific salmon in British Columbia with parentage-based tagging (PBT) (in progress)

Region: West Coast Vancouver Island

Waterbodies: Sarita River

Species: Chinook

Populations: Sarita River

Highlights

- Hatchery-origin Pacific salmon spawn and spend their early lives in a different environment than natural-origin fish, which likely unintentionally reduces their performance in natural habitats
- The size of this effect is often assessed by the relative reproductive success (RRS) of hatchery- and natural-origin fish in natural habitats
- RRS is estimated by the family sizes of hatchery- or natural-origin parents in the subsequent generation, which can be determined by the application of genetic tags (i.e., parentage-based tagging or PBT)
- These experiments rely on high proportions of genotyping of both hatchery- and natural-origin spawners, whereas only the former group are routinely genotyped at high frequency in Canada
- As a result, no RRS estimate has been made for any population enhanced by DFO's Salmonid Enhancement Program (SEP), which is a key knowledge gap for management and mitigation of genetic risks of enhancement
- In this project, genetic sampling of naturally spawning Chinook salmon in the Sarita River was increased to a target of 50% of the escapement to assess the use of PBT to

estimate RRS in this river, and to begin building a database of genotypes for escapement spawners and their offspring

- Genotyping targets were met as planned, but the total escapement was approximately double the expected size, which meant the tagging rate of spawners was substantially lower than necessary to support a RRS study
- Despite this reduced tagging rate, genotyping of outmigrating smolts confirmed that tagging rates in RRS studies can be approximated assuming random mating of escapement spawners with respect to origin
- The results of this project suggest that it is likely unfeasible to estimate RRS in even the most tractable Pacific salmon populations in Canada by PBT alone
- Alternatively, development of grandparentage-based tagging for application in systems enhanced by SEP has the potential to allow widespread estimation of RRS through future use in the broodstock genotyping program

Background

Enhancement of Pacific salmon through hatchery production is a key component of supporting salmon populations. Objectives of hatchery enhancement span conserving at-risk stocks, rebuilding lower abundance stocks, providing harvest opportunities and increasing public awareness through outreach and education. However, there are also risks associated with hatchery enhancement; differences between hatchery and natural habitats affect both the genetic and environmental factors that shape the performance and fitness of salmon. Consequently, hatchery-origin salmon may be less suited to wild habitats than their natural-origin counterparts, and the presence of hatchery-origin fish on natural spawning grounds may reduce the fitness of populations overall. The relative fitness of hatchery-origin compared to natural-origin salmon has been estimated in a handful of systems through determination of relative reproductive success (RRS). In these studies, returning adults are assigned back to their parents using genetic tags, and RRS is inferred by the number of returns per family from hatchery-origin compared to natural-origin parents. In general, the results of RRS studies suggest that hatchery-origin fish have lower natural reproductive success than natural-origin fish, and that reduced RRS is potentially transferred across generations.

The extent to which hatchery-origin fitness is lower than natural-origin fitness is likely dependent on current and historical factors impacting specific systems, including hatchery practices. To date, no study has estimated the RRS of hatchery- and natural-origin Pacific salmonids in integrated populations enhanced by the DFO Salmonid Enhancement Program (SEP). This is a critical knowledge gap for effectively managing hatchery production, as genetic management of these systems currently assumes a RRS of 0.8. This value is a reasonable consensus value from published estimates for rivers in the USA, but the SEP has had clear guidelines for genetic management since at least the 1980s, and it is possible that RRS estimates from the USA are inaccurate for SEP hatcheries. Utilization of an inaccurate RRS estimate could result in mismanagement of genetic risks associated with hatchery production, because the number of hatchery-origin fish that are predicted to utilize the natural spawning grounds increases as RRS increases, but a high RRS also suggests relatively low negative consequences for fitness associated with hatchery-origin spawners. Therefore, accurate estimation of RRS is important for effective genetic management of SEP hatcheries, particularly in the context of managing the influences of the hatchery and natural environments on the adaptive trajectories of integrated populations (i.e., proportionate natural influence or PNI).

Methods and Findings

Fin tissue samples from Sarita Chinook salmon adults from the 2023 escapement and smolts from the following outmigration were submitted to the DFO Molecular Genetic Section for DNA isolation and genotyping. DNA was isolated with standard protocols within the laboratory and all samples were genotyped at 547 single-nucleotide polymorphisms (SNPs) by Ion Torrent sequencing with a custom Agriseq panel, which is the current DFO standard for parentage-based tagging (PBT). Resulting genotypes were analyzed with Colony and CKMRsim to determine one- and two-parent assignments for outmigrating smolts back to escapement spawners using custom scripts that apply these tools as part of the PBT pipeline used by the Genetic Stock Identification Program. All genotypes, parentage assignments and analysis scripts will be submitted to public repositories, and a final technical report for the project is in progress.

788 Chinook salmon from the Sarita River escapement were successfully genotyped, which was expected to represent 39.4% of a forecasted escapement of approximately 2,000 spawners. However, the 2023 escapement was substantially larger than forecasted with a post-season estimate of 4,127 fish. As a result, the predicted tagging rate of natural spawners was 19.1%. This tagging rate is too low to support a long-term assessment of RRS, because another generation of spawning and tagging is required is compare hatchery- and natural-origin spawners. However, smolt genotyping was used to validate this estimated tagging rate to support the design of future RRS studies. Genotypes were obtained for 996 outmigrating smolts. 23 smolts were successfully assigned back to two parents, and 163 smolts were assigned back to one parent. Assuming random mating, these assignment rates suggest that the tagging rate of spawners in the escapement was 15.2% and 9.0%, respectively. The higher estimate based on two-parent assignments likely reflects higher confidence in these assignments compared to one-parent assignments, and suggests that 15.2% may be the more accurate of the two tagging rates based on genetic assignments. Furthermore, the estimated spawner tagging rate based on two-parent assignments was relatively similar to the estimated rate based on the number of spawners sampled out of the escapement (Table 1). Despite this, the slightly lower assignment rate in smolts than predicted based on adult tagging rate may reflect either an underestimation of the total size of the escapement or reduced contributions of genotyped fish in spawning than ungenotyped adults, which could be investigated further. Regardless, the results of this project suggest that future RRS studies can be designed assuming random mating and using the sampling rate of escapement spawners as the predicted tagging rate.

Insights

This project has confirmed the sampling requirements to estimate RRS in Chinook salmon populations enhanced by the SEP, and these findings likely extend to other Pacific salmon species as well. The results summarized here highlight that, even in rivers with extensive genetic tagging of escapement spawners, genotyping rates are likely insufficient to support long-term application of these approaches with parentage-based tagging alone. This is partially due to the difficulty of obtaining near comprehensive sampling, and partially due to variation in escapement sizes making it challenging to predict annual tagging rates. However, this project also highlights the ongoing need to address this knowledge gap regarding RRS and the genetic risks of enhancement in Pacific salmon populations integrated with a SEP hatchery. These results strongly suggest that development of genotyping techniques to support grandparentage tagging would provide a substantial benefit for future monitoring and assessment of hatcheries in the Pacific Region.

The main source of uncertainty in this project is the low sample size of tagged fish among the offspring of naturally spawning Chinook salmon in the Sarita River. Despite large efforts to handle and sample potential escapement spawners, smolt tagging rates were estimated at ≤15.2%, which gives sufficiently low power that any differences between hatchery- and natural-origin spawners would be impossible to resolve. Additionally, the results of the project were collected over a single spawning year. Repeating the experiment across several spawning years would provide more confidence in the patterns of expected versus observed tagging rates. These efforts were not conducted as part of this project, because escapement sizes were sufficiently large that tagging rate was likely to remain low regardless of escapement sampling efforts.

Next Steps

The key knowledge gap identified prior to this project still remains: an estimate of RRS between hatchery- and natural-origin Pacific salmon in a population enhanced within the SEP. However, as intended, this project has provided information to facilitate addressing this gap with future work. The results of this project emphasize that development of grandparentage tagging to support hatchery assessment and monitoring is a critical next step for the broodstock genotyping program. Future studies should examine alternate approaches to support these developments (e.g., expanding SNP panels, maintaining cross records or genotyping microhaplotypes), and should assess the feasibility of deployment as part of routine broodstock genotyping that happens annually for the majority of Chinook and coho salmon brood spawners. It may also be possible to return to archived broodstock tissues samples maintained by the Molecular Genetics Section to provide a jumpstart on assigning escapement samples back to hatchery grandparents. These efforts would allow linking escapement samples indirectly to their hatchery- or natural-origin parents that spawned in natural habitats, and would potentially allow RRS estimation across a wide range of populations enhanced by SEP. Estimation of RRS, and the extent to which RRS is inherited, would then allow refinement of approaches to manage genetic risks in enhanced populations such as the application of proportionate natural influence (PNI).

Tables and Figures

Table 1. Alternative estimates of escapement genotyping rate based on estimated escapement size, one-parent genetic assignments and two-parent genetic assignments. Estimates from genetic assignments assume random escapement genotyping with respect to sex, and random mating in natural spawning.

Data source used	Estimated escapement genotyping rate
Estimated escapement size	0.191
One-parent genetic assignments	0.09
Two-parent genetic assignments	0.152

2452 - Genetic Associations with Chinook Male Return Age

Genetic associations with age of return in Chinook Salmon (Oncorhynchus tshawytscha) in British Columbia (in progress)

Collaborations: Salmonid Enhancement Program

Region: BC

Waterbodies: Atnarko River, Chilliwack River, Big Qualicum River, Puntledge River

Species: Chinook

Populations: Atnarko River, Chilliwack River Fall, Big Qualicum River, Puntledge River Fall

Highlights

- Chinook salmon males display a range of ages of return in Canada
- Generally older and larger males are competitively dominant in spawning, but the youngest males that return at younger ages than females, known as jacks, display an alternative "sneaker" strategy in spawning.
- Although the reproductive output of jacks is lower than larger males, the extent of this reduction is dependent on the relative frequency of jacks in the population, and returning at younger ages reduces exposure to predation pressures in the ocean potentially providing a benefit.
- Hatcheries remove or reduce the size selection against jacks in spawning, and there are concerns that hatchery enhancement may increase the abundance of jacks in a population through either genetic or environmental mechanisms.
- This project utilizes a reduced representation sequencing and genotyping approach to assess genetic associations with age of return in Chinook salmon in British Columbia to understand potential genetic effects of enhancement and how those effects might be mitigated.

- Unlike studies from the USA, the results of this project provide little evidence of genetic variants, particularly versions of the Y-chromosome, that are specifically associated the jack life history in four enhanced populations in British Columbia.
- Despite this, genetic associations with age of return more generally suggest largely population-specific patterns, and putative Y-chromosome variation effects on age of return overall in the Atnarko River.
- These results are consistent with heritable variation in age of return in these populations indicating that continued management of different age individuals in broodstock will be beneficial, and suggest any hatchery-mediated increase in jacks in these populations may not have been driven by overrepresentation of jack-specific genetic variants in broodstock.

Background

Chinook salmon males display a wide range of ages of return, including a life history strategy of returning one year earlier than the earliest returning female. These early-returning males or "jacks" are relatively small, and participate in spawning by employing an opportunistic "sneaker" strategy to fertilize small numbers of eggs from many spawning events involving females and larger, more dominant, males. In general, spawning success in Chinook salmon is closely related to size; however, jacks experience the risk of marine predation for at least one less year than other males, and the success of jacks is a product of negative frequency-dependent selection (Berejikian et al. 2010). The natural occurrence of low frequencies of jack males in Chinook salmon populations is likely beneficial, despite the negative effects of small size on individual spawning success and fisheries value.

Both genetic and environmental factors contribute to the tendency of a male Chinook to return as a jack. For instance, high growth rates at early life stages that interact with size-at-age thresholds are thought to play key roles in the likelihood of observing the jack phenotype later in life (Larsen et al. 2006). Given these factors, hatchery enhancement may risk an unnatural increase in the proportion of jacks in a population due to both genetic and environmental effects. Hatcheries reduce or remove the negative size selection against jacks in spawning, and juvenile feeding regimes often produce high growth rates in the hatchery. Of these possible impacts, genetic effects likely pose a greater long-term risk to the age structure of the population as the genetic tendency to return as a jack would be inherited when the hatchery-origin jacks return and spawn in nature. To mitigate these effects, DFO's Salmonid Enhancement Program (SEP) has strict guidelines for the use of jacks in broodstock (DFO 2016). However, little is known about the genetic basis for early return in male Chinook salmon in Canada, and thus it is challenging to assess the relative impacts of genetic and environmental factors on the frequency of jacks in enhanced populations.

Recent work from the USA has shown that genetic variation consistent with differences in the Y-chromosome can be strongly associated with differences in age of return of Chinook salmon, particularly the tendency to jack (McKinney et al. 2020, 2021; Hoffman et al. 2025; Willis et al. 2025). However, these genetic differences have been specific to each system examined. Consequently, the main objectives of this project were characterizing putative Y-chromosome variation in populations of Chinook salmon from British Columbia, associating that variation with differences in age of return, and assessing the potential for enhancement activities to impact the frequency of age-associated genetic variants.

Methods and Findings

Samples for this project were collected as part of the Chinook salmon parentage-based tagging program with the SEP. Fin tissues from essentially all Chinook salmon used are brood are submitted to the Molecular Genetics Section for DNA isolation and genotyping. This genetic tagging allows hatchery offspring to be assigned back to their parents in support of monitoring and assessment. Returning offspring that are also used as broodstock can similarly be assigned back to their parents, which allows determination of age of return. Isolated DNA from broodstock samples of known age were quantified and quality controlled, and then were sent to the Plate-forme d'Analyses Génomiques de l'Université Laval and Genome Quebec for double-digest restriction site associated DNA sequencing. Obtained sequence reads were trimmed, aligned and quality filtered using standard bioinformatic tools and custom pipelines established for the project. Genotypes were called using the Stacks v2.65 pipeline (Catchen et al. 2013). Genetic associations with age of return were conducted using the approaches of McKinney et al. (2021), and redundancy analysis.

Preparation of the manuscript resulting from this project is in progress. All sequencing reads and called genotypes will be submitted to field-specific public repositories on acceptance of the manuscript, and all bioinformatic scripts used in the data preparation and analyses will be available through the GitHub platform.

Consistent with studies from outside of Canada, genetic associations with age of return in male Chinook salmon were largely population-specific in this project. Few genetic loci were associated with age of return independently with the exception of loci on the sex chromosome (Ots17; example for the Atnarko River see Figure 1). In each population, novel putative Y-chromosome variation was detected consistent with different haplotypes segregating in each population, and the effects of this Y-chromosome variation on age of return were also dependent on the population examined. In Chilliwack River Fall, Puntledge River Fall and Qualicum River Chinook, Y-chromosome variation had no effect on age of return. In contrast, in Atnarko River Chinook, three haplotypes were found predominantly in age 3 and 4 males, whereas one haplotype was found predominantly in age 4 and 5 males (Figure 2). Despite this association between putative Y-chromosome variants and age of return in the Atnarko River, no population displayed a Y-chromosome haplotype specifically associated with the jack phenotype as has been observed in systems in the USA. Multivariate analyses suggest there are polygenic effects on male age of return in all of the populations assessed with 445-572 genetic loci associated with trait variation depending on the population considered (example for the Atnarko River see Figure 3). Taken together, the results of this project highlight genetic mechanisms underlying the jack phenotype consistent with previous demonstrations of heritability in this trait (e.g., Heath et al. 2002), but these mechanisms are largely population-specific with little evidence supporting jack-specific versions of the Y-chromosome.

Insights

This project is the first to characterize genome-wide associations with age of return in Canadian Chinook salmon, and to suggest functional consequences of putative Y-chromosome variation within enhanced populations. These data are relevant to ongoing and future broodstock management, and highlight that genetically informed management of age of return in hatchery-origin fish will require population-specific assessments to understand both loci of major effect (e.g., the Y-chromosome), and polygenic effects across many loci. Furthermore, these data suggest that environmental factors may have played a larger role than genetic factors in any change in the frequency of jack males in populations of Chinook salmon enhanced from SEP major facilities.

There are four main sources of uncertainty associated with this project. First, previous studies from the USA have consistently shown that genetic effects on age of return, particularly Y-chromosome effects, are stronger in wild or natural-origin Chinook salmon than they are in hatchery-origin fish (McKinney et al. 2021; Willis et al. 2025). This is likely a consequence on hatchery-mediated environmental effects interacting with and reducing the relative genetic influences on the jack phenotype. The current project only examined hatchery-origin Chinook salmon, because a sufficiently large set of natural-origin males with known ages was not available, which may have reduced the ability to detect genetic associations with age of return in this project. Second, the currently available version of the Chinook salmon genome was sequenced from a female fish, and therefore does not contain an assembled version of the Y-chromosome. As a result, the putative Y-chromosome haplotypes detected in this project are based on putative Y-chromosome sequencing reads that successfully mapped to a X-chromosome in the genome. Although this approach was successfully used both here and elsewhere (McKinney et al. 2021), the use of heterologous mapping reduces the precision and resolution of the called haplotypes. Third, the sample sizes used in the current project were optimized for efficient detection of major effect genetic loci on the jack phenotype based on the substantial Y-chromosome effects observed in other populations. However, these sample sizes are relatively low for the detection of smaller genetic effects, such as polygenic associations. Fourth, reduced representation sequencing is a useful approach to assess genome-wide associations in a large number of individuals, particularly to assess haplotype variation. Yet, these approaches have the potential to miss important genomic regions associated with trait variation, and may also produce false associations as well.

Next Steps

The most critical knowledge gap remaining after this project is understanding differences between genetic associations with age of return in hatchery- and natural-origin Chinook salmon. Understanding genetic associations in natural-origin fish would provide a substantial improvement in the ability to interpret the results of this project. Future studies could then focus on the interactions between hatchery environments and genetic variation to better understand how enhancement influences the expression of different life history traits in Chinook salmon. These efforts may also clarify the high degree of population specificity detected in this project, as common genetic effects may have been masked by differential environmental effects across facilities. Additional work to characterize patterns across facilities may be necessary, particularly for populations with concerns regarding shifts to earlier ages of return.

Ultimately, better understanding of the mechanisms underlying age of return variation in Chinook salmon can be operationalized through development of biomarkers or adjusted guidelines for broodstock management in SEP facilities. Environmental effects may be less likely to persist long-term when hatchery-origin jacks spawn in the natural habitat, whereas genetic effects may pose a greater long-term risk. Refining the ability to manage jack influences within hatchery broods could both improve access to broodstock and reduce the genetic risks of enhancement.

Tables and Figures

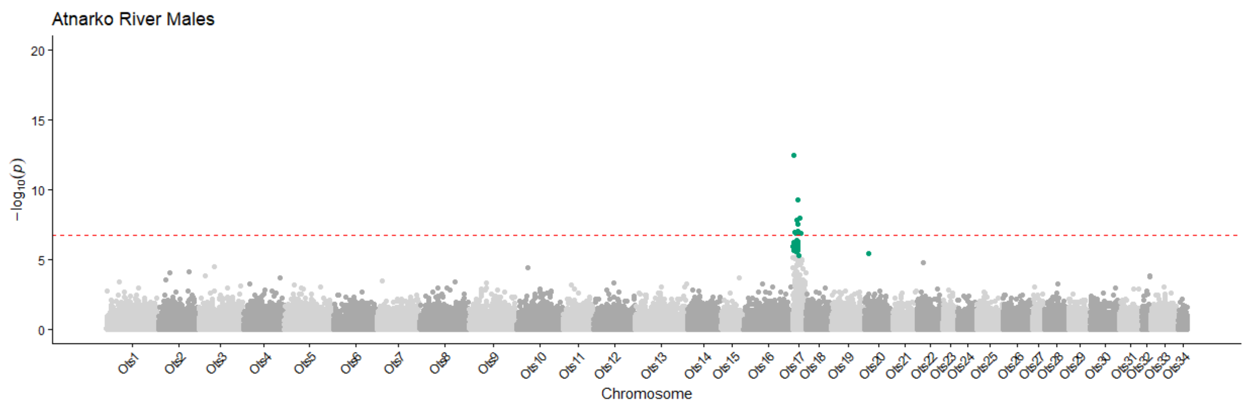
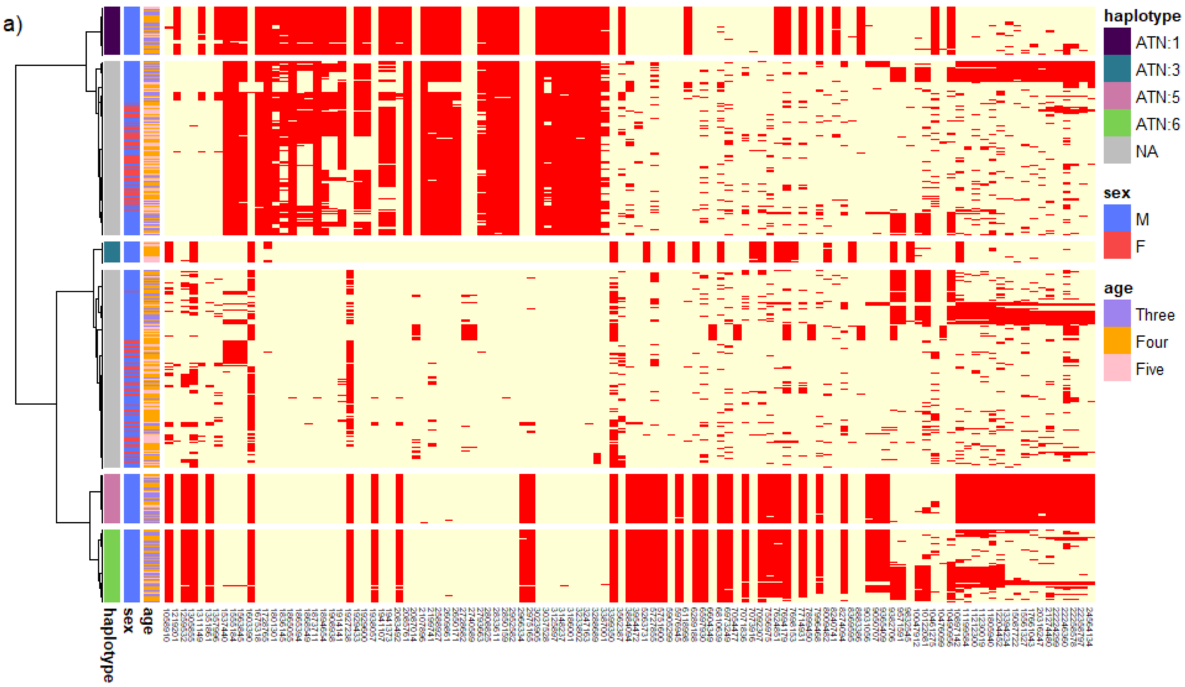


Figure 1. Association results between individual single-nucleotide polymorphisms (SNPs) and variation in age of return in male Chinook salmon from the Atnarko River. The vertical axis displays the inverse logarithm of the p-value for each statistical test, and the horizontal axis displays the chromosomes in the Chinook salmon genome. Non-significant SNPs are shown as grey circles with alternating grey colours corresponding to chromosomal boundaries. Green circles correspond to significantly associated SNPs based on a false discovery rate correction, and the red dotted line indicates the threshold for significance after a Bonferroni correction.

a)



b)

Classification	Male observed	Male expected	Female observed	Female expected
XX	38	0	61	61
XY	207	245	0	0
YY	0	0	0	0

c)

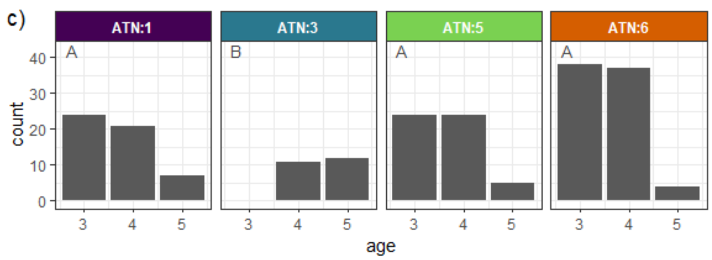


Figure 2. Identification of putative Y-chromosome haplotypes on chromosome Ots17 and their effect on age of return in male Chinook salmon from the Atnarko River. a) Haplotype clustering on Ots17 using single-nucleotide polymorphisms (SNPs) with high linkage disequilibrium (LD) reveals four male-specific clusters, ATN:1 (dark purple), ATN:3 (teal), ATN:5 (dark pink), and ATN:6 (green), representative of putative Y-chromosome haplotypes. Each individual is represented by two haplotypes along the vertical axis of the heatmap and is coloured by sex (males, blue; females, red) and age of return (three year old, purple; four year old, orange; five year old, pink). The horizontal axis of the heatmap displays SNPs by position across Ots17 with the higher frequency allele coloured yellow and the lower frequency allele coloured red for each SNP. b) The number of individuals classified as male or female using putative X- or Y-chromosome assignments from the heatmap clusters compared with the expected number of each sex based on the samples sequenced. c) The distribution of age of return associated with each putative Y-chromosome haplotype in males. Significant differences in age distributions between haplotypes are denoted by different letters (A, B).

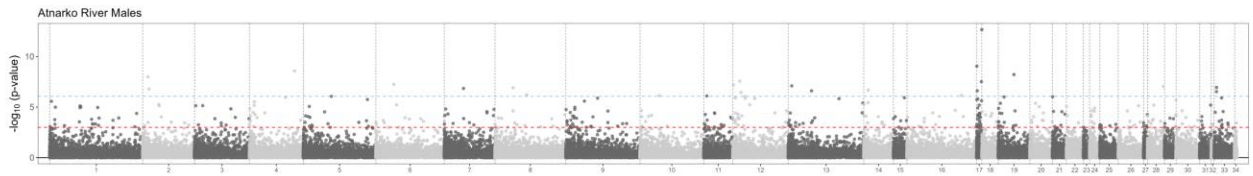


Figure 3. Multivariate association results between single-nucleotide polymorphisms (SNPs) and variation in age of return for male Chinook salmon from the Atnarko River as assessed by partial redundancy analysis (RDA). The vertical axis displays the inverse logarithm of the p-value for results for each SNP, and the horizontal axis displays the chromosomes in the Chinook salmon genome. Grey circles display the results for each SNP across the genome with alternating grey colours and vertical dotted lines corresponding to the chromosomal boundaries. Two thresholds for identification of associated SNPs are indicated by the horizontal dashed lines: Bonferroni correction (blue) and SNP loadings greater than three standard deviations from the mean loading on the first RDA axis (red).

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2545 - Genetic Stock ID and Parentage-Based Tagging of Salmon

Collaborations: Multiple collaborators

Region: BC & Yukon

Species: All *Oncorhynchus spp*

Highlights

- Stabilized funding for core Genetic Stock Identification work enabled the genotyping of over 60,000 individuals as directed by regional stock assessment teams.
- Genotyping of 100% of Canadian Chinook and Coho broodstocks enabled the development of genetic-based monitoring of enhanced individuals and near complete PBT recovery.

Background

The Genetic-stock identification program had developed amplicon-based genetic techniques for genetic-stock identification (GSI) and parentage-based tagging (PBT) in Pacific salmonids over the 10 years preceding the Pacific Salmon Strategy Initiative. Use of the methods, however, were often sporadic and funding dependent, leading to incomplete datasets, incomplete PBT brood genotyping and inefficient per-sample costs. The funding made available under PSSI aimed to change this by supporting the up-front costs of core stock assessment GSI analyses, while providing the personnel funding to support additional capacity for internal and external collaborators to lead to per-sampled cost efficiencies. Funding aimed to cover full brood genotyping for Chinook and Coho, for near 100% tagging of broodstock in Canada.

Methods and Findings

Both parentage-based tagging (PBT) and Genetic Stock Identification (GS) rely on the same underlying method - an amplicon-based SNP panel. For each of the Pacific salmon species, a ThermoFisher IonTorrent AgriSeq-based amplicon panel has been developed to enable the technique, with sockeye and sink being developed with in-kind support over the PSSI timeline. Once an amplicon panel is ready, each technique requires a reference. For GSI, this is primarily baseline individuals collected from spawning locations to represent a region genetically. Over the course of the project, PSSI has allowed for bolstering baselines in each species. In particular, a concerted effort in North Coast and Transboundary rivers by stock assessment and first nation collaborators has greatly expanded the coverage of coho and sockeye spawning sites previously missing or data deficient within the baseline. For PBT, the reference is composed of spawning adults used as broodstock, and for Coho and Chinook, PSSI has provided the support to achieve near 100% tagging. In the most recent year complete, 21,862 individuals were received for Chinook (Table 1), and 8,163 for Coho (Table 2). In-kind support to additional projects has allowed expansion of PBT to Lower Fraser chum, and conservation enhancement in sockeye within the upper Fraser River.

With both underlying reference datasets available, the combined techniques of PBT and GSI can be performed on samples submitted from across the Pacific region. Once genotyped, an individual of unknown origin can be screened for matches to the reference genotypes for PBT, and if a match is made, this individual can be reported to stock, brood year, release group and specific dam and sire. All individuals can subsequently be included in a fulsome analysis, with mixed stock proportional assignment estimates for reporting units under evaluation returned to the sample submitter. Yearly over PSSI, we received up to 31,000 individuals from South Coast, 14,000 from North Coast, 8,000 from Yukon-Transboundary, and 5,000 from Fraser-Interior region. In Chinook, these submissions led to the recovery of 13,213 PBT tags from 38,223 screened Chinook from all non-brood sources - a further 14,610 individuals collected as brood in 2024 could be assigned back to origin with prior years' broodstock.

Insights

The combination of parentage-based tagging and genetic-stock identification provides salmon managers with a single data-source that can yield many different pieces of information. Thru PBT, it can provide age, release strategy, individual family success, estimates of PNI. Unlike other tagging methods, GSI can step in and provide information where direct tagging didn't occur, such as by genetic sex screening, or estimating origin to regional reporting unit. Additional quality control steps can provide estimates of species misidentification or sample contamination to ensure numbers are reported accurately.

The applications of data usage are broad, and often regionally or project specific. They have included, but not limited to:

- Stray recoveries identified by PBT in natural systems.
- Genetic mark-recapture to inform system-wide escapement estimates.
- Stock identification to inform estuary use in out-migrating juveniles.
- High-seas stock-specific marine distribution in International Year of the Salmon expedition recoveries.
- In-season rapid genetic stock identification to inform real-time decision making.
- Assignment to origin by PBT of >98% of Canadian Coho heads returned to MRP's head recovery program.

Next Steps

With the conclusion of PSSI, the primary gap will be the maintenance of the datasets that underlie the techniques performed. In particular, Parentage-based tagging is only effective with complete brood genotyping, and requires yearly sampling, genotyping and curation to perform effectively. With lack of funding clarity, long-term operationalization of PBT is at risk of failure.

Should PBT data collection be maintained, a longer-term goal is to harmonize the markers underlying the technique with US-based laboratories performing the same technique. Providing the reference genotypes in a bilaterally accessible format will allow for integration of PBT recoveries in any jurisdiction they are genotyped, not just Canadian.

Tables and Figures

Table 1. The count of Canadian-origin Chinook broodstock recorded as used, along with count of brood and proportion received for PBT from 2013 to 2024 (final counts for 2025 not yet available).

Year	Brood Recorded	Brood Received	% Brood Received
2013	17475	10198	58.4
2014	19376	10560	53.9
2015	21196	12201	57.6
2016	21367	13743	64.3
2017	21973	14072	64
2018	21795	14993	68.8
2019	22550	20298	90
2020	21184	20639	97.4
2021	22249	21477	95.8
2022	22757	21079	92.6
2023	24068	23040	95.6
2024	21777	21862	100+

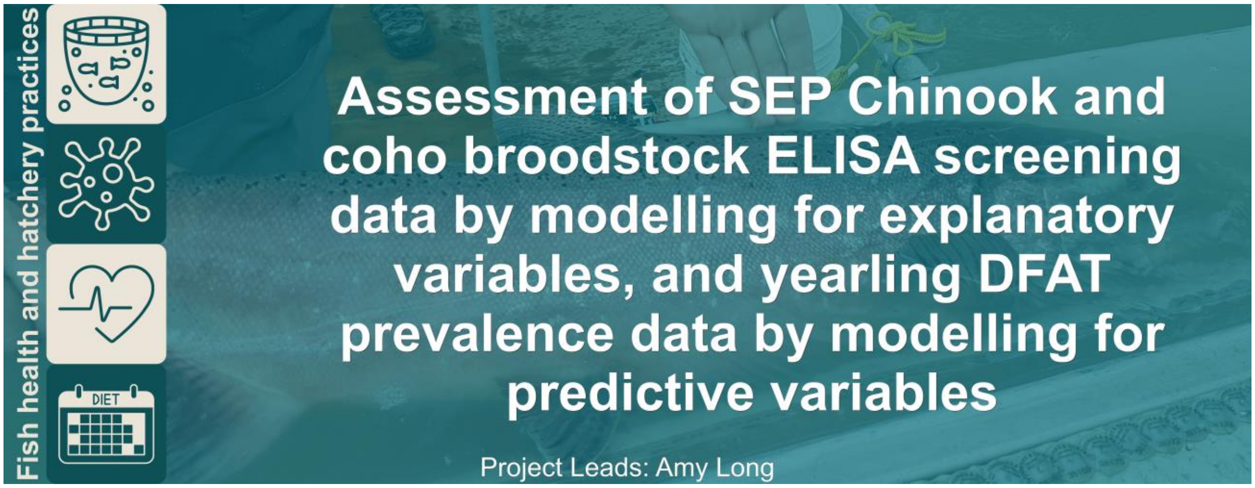
Table 2. The count of Canadian-origin Coho broodstock recorded as used, along with count of brood and proportion received for PBT from 2014 to 2024 (final counts for 2025 not yet available).

Year	Brood Recorded	Brood Received	% Brood Received
2014	9998	5995	60
2015	10359	7558	73
2016	9283	6893	74.3
2017	9390	7075	75.3
2018	9253	7429	80.3
2019	9375	7726	82.4
2020	8759	6639	75.8
2021	9096	7712	84.8
2022	8739	7178	82.1

Year	Brood Recorded	Brood Received	% Brood Received
2023	9162	7957	86.8
2024	8182	8163	99.8

FISH HEALTH

2400 - Modeling Chinook and Coho Broodstock Disease Screening



Collaborations: DFO: Derek Price, Ian Keith, Cheryl Lynch, Anne Nguyen, Ali Manochehri

Region: BC

Species: Chinook, Coho

Populations: Puntledge, Nitinat, Coldwater River, Spius Creek, Nicola River, Chilcotin River, Chilko Ricer, Salmon River, Eagle River

Highlights

The study explored the relationship between parental BKD levels on individual salmon results while controlling for the impact of environmental factors such as thermal regime using previously collected data including broodstock disease levels, environmental parameters, and progenitor disease status.

BKD levels in returning adults do not demonstrate a significant association with the OD levels of their progenitors. Instead, the relationship appears to be confounded by environmental and population-level factors, including water temperature, specific watershed characteristics, and the overall BKD prevalence within the returning population.

The findings reveal key knowledge gaps in understanding BKD dynamics, suggesting the need for further research to build a fuller picture of the factors influencing disease transmission and prevalence.

Background

Renibacterium salmoninarum, the causative agent of bacterial kidney disease (BKD), is endemic to the Pacific Northwest. Infection with this bacterial pathogen can result in significant morbidity and mortality in cultured juvenile Pacific salmon. Current BKD management relies on screening brood stock using an enzyme-linked immunosorbent assay (ELISA) and excluding eggs from females exceeding the defined optical density (OD) threshold. This approach has significantly reduced the incidence of disease in both hatchery-reared juveniles and returning adult fish. The Salmonid Enhancement Program (SEP) maintains an extensive dataset that includes 16 years of ELISA broodstock screening results for many Vancouver Island and mainland Coho and Chinook stocks.

These datasets have not been previously subjected to a comprehensive epidemiological analysis to identify potential explanatory variables for BKD prevalence in stocks of concern. This project sought to address that knowledge gap by integrating ELISA data and linking broodstock ELISA values to Parental Based Tagging (PBT) information enabling stock-specific analyses. The work was conducted through a collaborative partnership among the Science Branch, SEP, and Aquaculture Management.

Methods and Findings

The study explored the relationship between parental BKD levels on individual salmon results while controlling for the impact of environmental factors such as thermal regimes by incorporating various temperature metrics, such as average temperature, minimum and maximum temperatures, degree days, and the number of days within specific temperature thresholds (6°C to 10°C). While Nitinat's temperature data was based on monthly or daily mean temperatures (depending on the year), Puntledge and Spius provided daily mean, maximum, and minimum temperatures. For each stock year, temperature data were filtered to include dates that a stock occupied the hatchery, e.g. the day of first broodstock captured to the day of last juvenile release. Juveniles of Chinook stocks were released less than a year of holding at the hatchery at Puntledge and after two years at Spius, while Coho stocks were released after 1 year and 2 year but temperature measurements were calculated based on the 2 year release for Coho stocks.

Data used in the analysis was from 2014 through 2023, and was dependent on data available in E-PRO and temperature data (Table 1). Only individuals with BKD value and maturity class information were included. Incomplete data points were filtrated out in each analysis. Dam's BKD optical density (OD) value and BKD level were attached to E-PRO records for progenies by matching progenies' dam DNA code to the dam's data in the report. This step was only possible for progenies with dam's DNA code and BKD OD value.

To guide the modelling of the vertical transmission path, we collaborated with an expert panel to develop a causal diagram (Figure 1). This exercise facilitated the identification and characterization of relationships across multiple scales, including the watershed, hatchery, and individual fish levels, while specifically assessing variables for their potential to confound the results. We evaluated these factors using a mixed-effects generalized linear model framework, designating the OD from the BKD ELISA as the outcome of interest and the OD of the progenitor (the dam) as the primary predictor. Temporal variation was integrated as a random effect to account for annual fluctuations. The final model incorporated several confounding factors, most notably the specific watershed of origin. We also included terms for interactions between mean temperature–which was scaled and centered by creek–and BKD prevalence at the stock level. For the purposes of this analysis, a stock was defined as a cohort of brood fish of the same species returning to the same creek during the same season, such as Nitinat Spring Coho. While species and season were initially tested, they were excluded from the final model as they were not statistically significant and did not meet the criteria for confounders; their observed effects were largely captured by spatial and temporal variables.

Research Findings

The primary analysis indicates that BKD levels in returning adults do not demonstrate a significant association with the OD levels of their progenitors. Instead, the relationship appears to be confounded by environmental and population-level factors, including water temperature, specific watershed characteristics, and the overall BKD prevalence within the returning population. For instance, while the watershed variable was not statistically significant in isolation, its inclusion in the model resulted in a measurable change in the coefficient of the primary predictor, suggesting a latent environmental influence. A more notable finding was the negative association between BKD levels and scaled temperature, which suggests that OD levels generally decrease as temperatures increase. However, a significant interaction between temperature and BKD prevalence indicates a modulating effect on this relationship (Figure 2). While lower temperatures appear to provide a more suitable environment for the transmission of BKD, a higher proportion of infected individuals within a population further intensifies this effect.

It is important to note, however, that the statistical model demonstrated a relatively low goodness-of-fit, indicating that a substantial portion of the variance in BKD levels remains unexplained by the variables currently under study. This suggests that the dynamics of BKD in these ecosystems are influenced by a complex array of factors–potentially including individual host immunity, varying hatchery practices, or additional environmental stressors–that were not fully captured in the present framework. Consequently, while the identified trends regarding temperature and prevalence offer valuable directional insights, they should be interpreted with caution and viewed as preliminary findings within a highly variable biological system.

Insights

This project contributes significant clarity to the understanding of BKD transmission by identifying that environmental and population-level factors often overshadow direct parent-to-offspring transmission in wild and enhanced stocks. By demonstrating that BKD levels in returning adults are more closely associated with watershed characteristics and thermal regimes than with the status of their progenitors, this research shifts the focus toward environmental stressors as primary drivers of disease expression. These findings highlight a critical pathway of effect where colder water temperatures facilitate higher pathogen loads, a relationship that is further intensified by the cumulative impact of high disease prevalence within the population. This identification of thermal and density-dependent “modulating effects” provides a more nuanced understanding of how multiple stressors interact to influence the health of salmon cohorts.

From a management and policy perspective, these insights inform risk assessment and hatchery planning by emphasizing that individual-level screening of broodstock may be insufficient without considering broader ecological context. The study provides a framework for evidence-based decisions regarding stock transfers and watershed-specific management, suggesting that biologically significant thresholds for disease may vary depending on local environmental conditions. By accounting for these spatial and temporal variables, managers can better navigate the trade-offs between enhancement goals and the risks of disease outbreaks.

A primary source of uncertainty in this analysis, however, stems from the operational protocols used to manage BKD in hatcheries. The standard practice of utilizing OD thresholds to cull high-risk eggs creates a filtered data set, as the most heavily infected vertical transmission paths are often removed from the population before they can be assessed in returning adults. Furthermore, when conservation concerns for at-risk populations supersede these culling protocols, it introduces additional variability into the transmission pathway. This management-induced selection bias limits our ability to fully quantify the role of vertical transmission, as the observed returning population primarily represents individuals that either passed through a selective screening process or were spared due to conservation priorities.

The findings reveal key knowledge gaps in understanding BKD dynamics, suggesting the need for further research to build a fuller picture of the factors influencing disease transmission and prevalence. The low goodness-of-fit of the current model indicates that additional variables, such as hatchery practices, genetic diversity, or other environmental and anthropogenic stressors, may play significant roles in shaping BKD dynamics. A promising avenue for research includes the use of simulation models to assess the impact of altering management practices, such as raising or lowering the positive-negative culling threshold OD value. This approach could help predict how adjustments to culling thresholds might influence disease prevalence and population outcomes under varying environmental conditions. Research should also focus on understanding potential thresholds or tipping points where environmental conditions, such as temperature extremes, significantly influence disease prevalence and outcomes.

The study’s findings can inform proactive strategies for salmon conservation and management, particularly concerning how environmental conditions affect BKD prevalence. Managers could prioritize monitoring in watersheds where conditions, including temperature and BKD prevalence, elevate disease transmission risks. Additionally, the insights from simulations examining the effect of changing the positive-negative culling threshold OD value could guide policy and operational decisions to strike a balance between limiting disease spread and optimizing population sustainability.

Next Steps

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Tables and Figures

Table 1. Stocks and cohorts used in this analysis as well as the years of available data for BKD screening, progenitor DNA, and temperature.

Stock Name	Cohort	BKD screening	Progenitor DNA	Temperature Data
Puntledge Fall Coho	*	2018, 2020	None	2014-2023
Puntledge Summer Chinook	*	2014-2023	2017-2023	2014-2023
Nitinat Fall Coho	*	2014-2022	2016-2020, 2022	2014-2023
Coldwater River Spring Chinook	Spius 1	2014-2023	2019, 2022, 2023	2017-2022
Spius Creek Spring Chinook	Spius 1	2014-2023	2019, 2022, 2023	2017-2022
Nicola River Spring Chinook	Spius 1	2014-2023	2019-2022	2017-2022
Chilcotin River Spring Chinook	Spius 3	2021, 2022	None	None
Chilko River Summer Chinook	Spius 4	2014-2023	2021	None
Coldwater River Fall Coho	Spius 1	2014-2023	2017, 2020-2022	2017-2022
Spius Creek Fall Coho	Spius 1	None	None	2017-2022
Salmon River Fall Coho	Spius 2	2014-2015, 2017-2023	2017-2018, 2020, 2022-2023	None
Eagle River Fall Coho	Spius 5	2015-2023	2018-2020, 2022	None

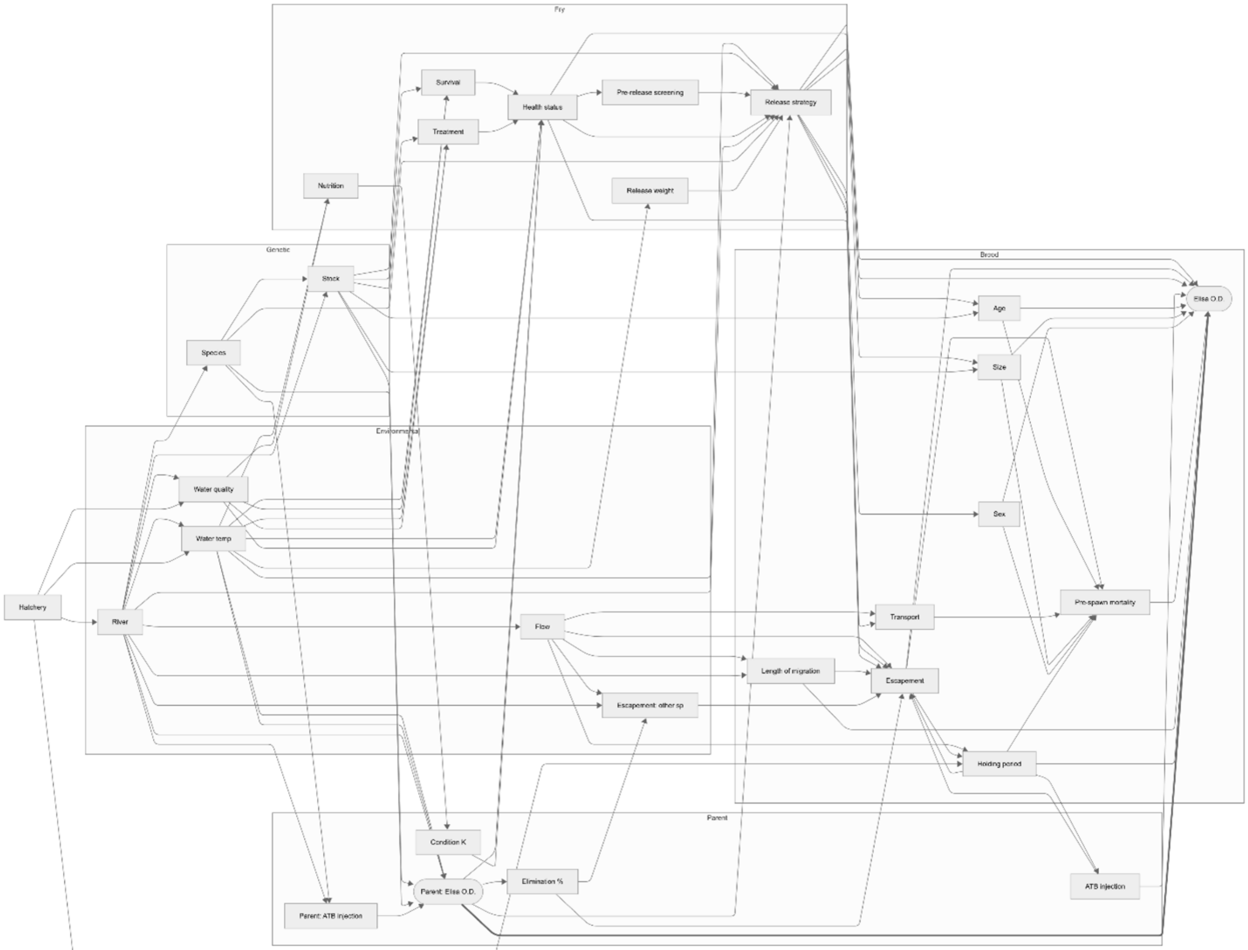

Figure 1. Directed Acyclic Graph (DAG) of the causal web explaining OD results for BKD. Arrows represent plausible unidirectional associations between factors considered for the epidemiological model as identified and characterized by the experts panel.

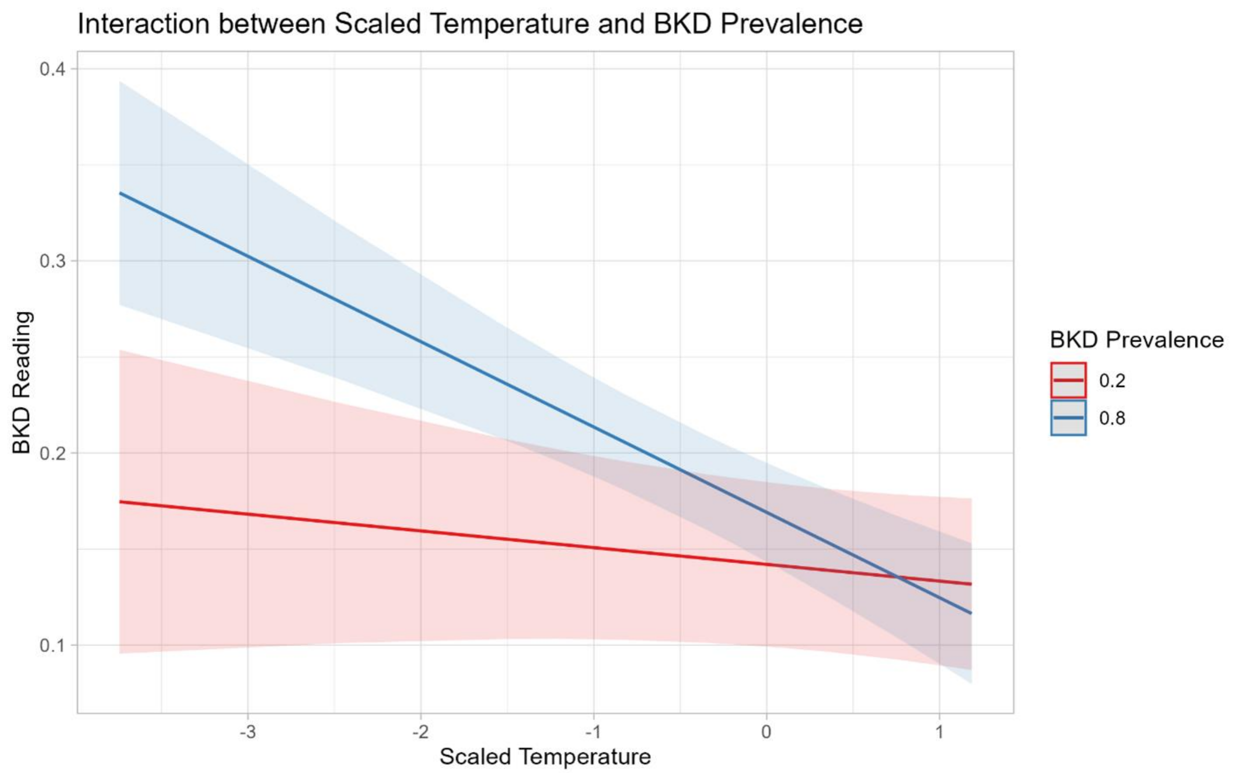

Figure 2. Interaction between the effects of Scaled Temperature and BKD Prevalence. Predicted values are derived from our linear mixed-effects model accounting for year to year variation. The scaled temperature is plotted on the x-axis against the OD for BKD (y-axis), with separate lines representing 20% (red) and 80% (blue) BKD prevalence in the returning population. Shaded regions of corresponding colours represent 95% confidence intervals.

2401 - IHNV Epidemiological Modeling in Sockeye Salmon

Garver, K.A., Hawley, L.M., Thiessen, L., Harborne, M., Berdan, C. and Lofthouse, D. 2022. Report on the occurrence of infectious hematopoietic necrosis disease in out-migrating Sockeye Salmon fry at Pinkut Creek Spawning Channel in the spring of 2021. Can. Tech. Rep. Fish. Aquat. Sci. 3478: iv + 17 p.

Region: BC

Waterbodies: Weaver Creek, Nadina River, Fulton River, Pinkut Creek

Species: Sockeye

Highlights

This study examined IHNV prevalence across different watersheds, sockeye stocks, and environmental conditions to identify those factors responsible for driving IHNV prevalence and/or influencing disease within sockeye salmon populations.

Background

Infectious hematopoietic necrosis virus (IHNV) is a deadly virus of sockeye salmon, causing catastrophic losses during the early lifestages. Long-term monitoring of IHNV infections across multiple stocks of sockeye salmon has revealed the prevalence of IHNV infections can vary annually within and between stocks; however, the factor(s) responsible for such fluctuations in IHNV prevalence in sockeye salmon stocks in British Columbia remain unresolved. Understanding the drivers behind the occurrence and perpetuation of IHNV in sockeye salmon is instrumental in managing and mitigating the risk of this endemic pathogen. Utilizing epidemiological analytical approaches to study the patterns of IHNV in sockeye salmon we'll identify the factors which influence the prevalence of the virus in BC sockeye salmon stocks.

Methods and Findings

METHODS:

Adult and fry sockeye salmon were each collected annually from 1987 to 2018, from each of four spawning channel populations, representing two stocks within the Fraser River watershed and two within the Skeena River watershed (Figure 1). Samples were screened for the presence of infectious hematopoiectic necrosis virus (IHNV) using cell culture methodologies. Characteristic cytopathic effects (CPE) observed in cells indicated the presence of viable replicating IHNV. Prevalence of IHNV was calculated by dividing the number of samples with CPE by the total number of samples screened.

We used statistical methods to understand how IHNV prevalence in adult fish relate to infection levels in fry, and how infection in fry affects infection in adults that return 3-4 years later.

To compare how infection levels changed over time, we looked at timeseries data for each project site (Fulton, Pinkut, Nadina, Weaver) and for each life stage (fry, adult males, adult females). We used a clustering method that can line up patterns even when the timing doesn't match perfectly (a technique called dynamic time warping) to measure how similar the trends were.

To study how infection in returning adults affects IHNV prevalence in fry, we used a mixedeffects binomial model for proportions that accounted for differences between spawning years and project sites.

To study how fry infection affects infection in adults 3-4 years later, we used a similar model along with escapement data to calculate a weighted average of fry infection that matched the makeup of the returning adult population. Because the relationship wasn't linear, we also added a quadratic term to better capture the pattern.

RESULTS:

From 1987 to 2018, a total of 56,692 sockeye salmon were screened for IHNV. Over this 32 year timeframe, the prevalence of IHNV infections varied annually within and between the four stocks sampled (Figure 2). Across the entire dataset, there was a positive correlation between the detection of IHNV in male and female samples; with the prevalence being generally higher in females than in males (Figure 3). Nonetheless, this prevalence in spawned females was not demonstrative of what was observed in fry, as there were numerous years where IHNV was not detected in the fry despite high prevalence in the broodstock. However, it appears as though the IHNV prevalence in fry is a strong predictor of the population's IHNV status upon returning adults 4 years later. For instance, fry with 50% IHNV prevalence are predicted to return as adults with a prevalence of 30 to 80% (Figure 4).

Insights

This work provides the first long-term dataset of infectious hematopoietic necrosis virus (IHNV) prevalence among various sockeye salmon stocks in British Columbia and reveals a highly dynamic nature of this deadly virus. From this data, it was learned that when surveying adult fish, it is best to sample females as they have the highest prevalence. In naturally spawning populations of sockeye salmon, it was found that the IHNV prevalence in broodstock offers little insight into the infection status of fry, as true parent to progeny transmission is unlikely. In many instances, high IHNV prevalence in adults did not result in the occurrence of virus in fry. However, unexpectedly it was discovered that IHNV prevalence in fry is significantly correlated to the prevalence of returning adults, suggesting IHNV in adults is partially explained by their status as fry and supports the role of a lifelong IHNV carrier state in perpetuating IHNV in sockeye salmon populations.

Next Steps

This work illustrates the importance of long-term datasets in differentiating genuine trends from short term fluctuations and to uncover complex ecological dynamics. Analysis of IHNV prevalence across the four stocks over the 32 year timeframe revealed that prevalence across stocks is most similar within a river system, suggesting watershed or regional specific factors may influence level of IHNV in the system (Figure 5). Nonetheless, a shared prolonged reduction of IHNV observed across both Fraser and Skeena watersheds, suggests broader oceanic factor(s) are contributing to the occurrence of IHNV in sockeye salmon (Figure 2). Given these trends, we are presently gathering environmental, management and other data to determine if there are correlates that are explanatory for these trends. In particularly, we are employing Pacea, an R package of ecosystem information, to link biological data with environmental variable to generate models and visualizations.

Tables and Figures

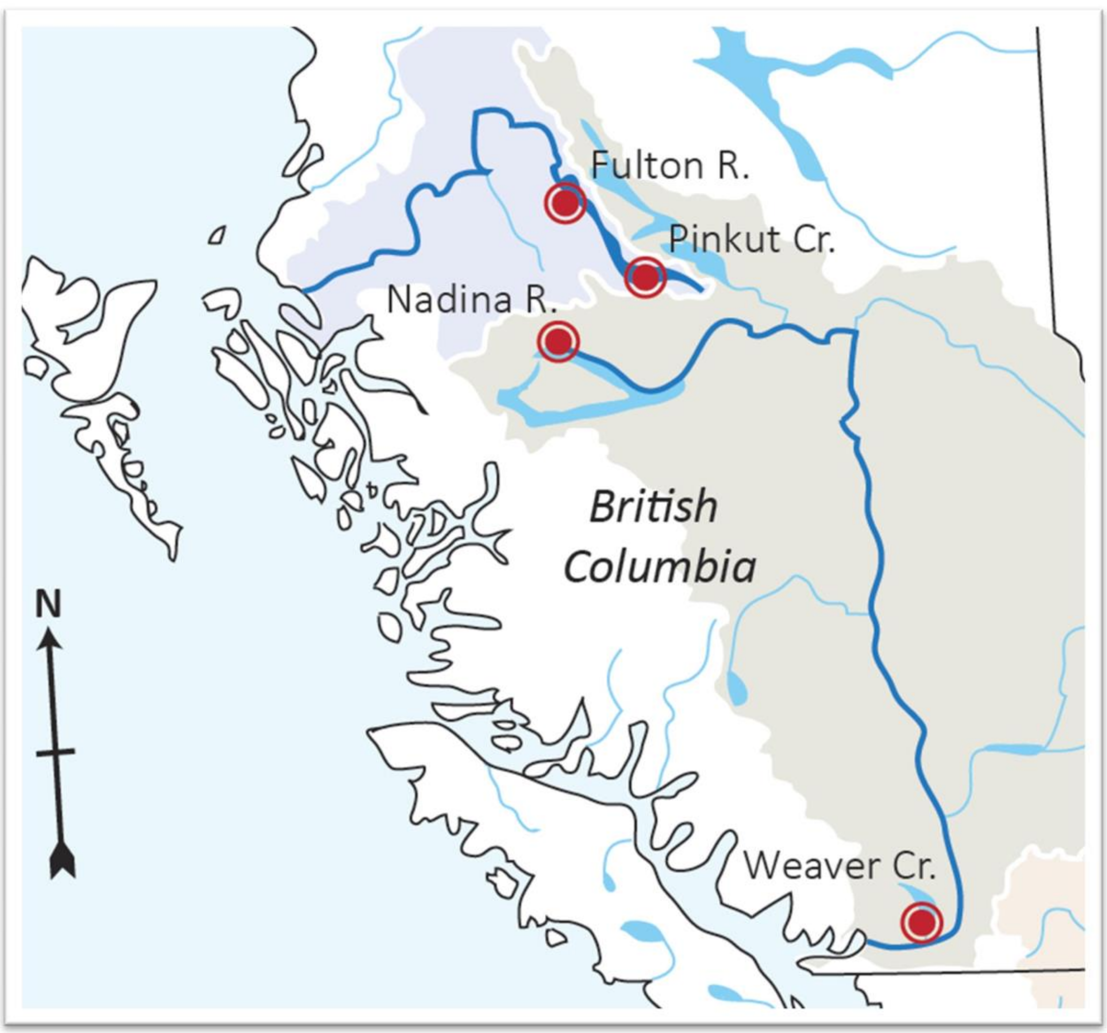

Figure 1. Map showing the locations of the sockeye salmon spawning channels (red circles) within the Skeena and Fraser River watersheds, revealed by blue and olive shading; respectively.

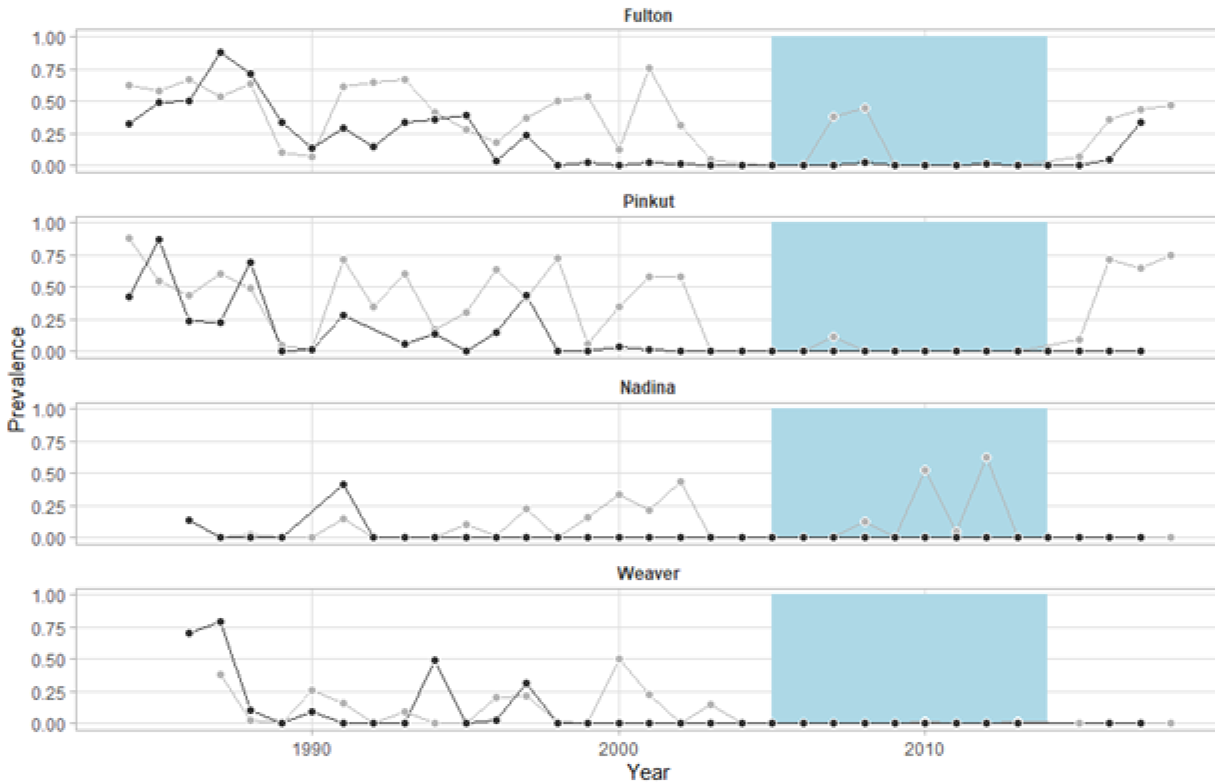

Figure 2. Annual prevalence of IHNV in adults (grey) and fry (black) sockeye salmon collected over 32 years from spawning channels located at Fulton River, Pinkut Creek, Nadina River and Weaver Creek. Blue shading highlights years where IHNV prevalence was generally lower across all four collection sites.

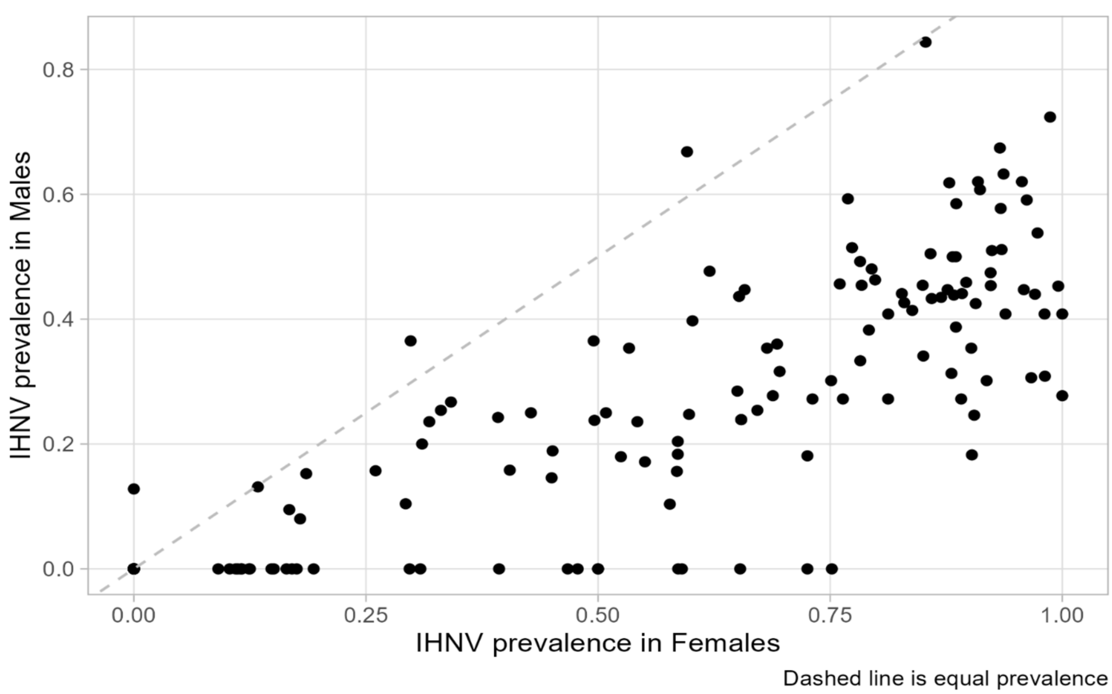

Figure 3. Plot illustrating a positive relationship between IHNV prevalence in males (y-axis) and females (x-axis)

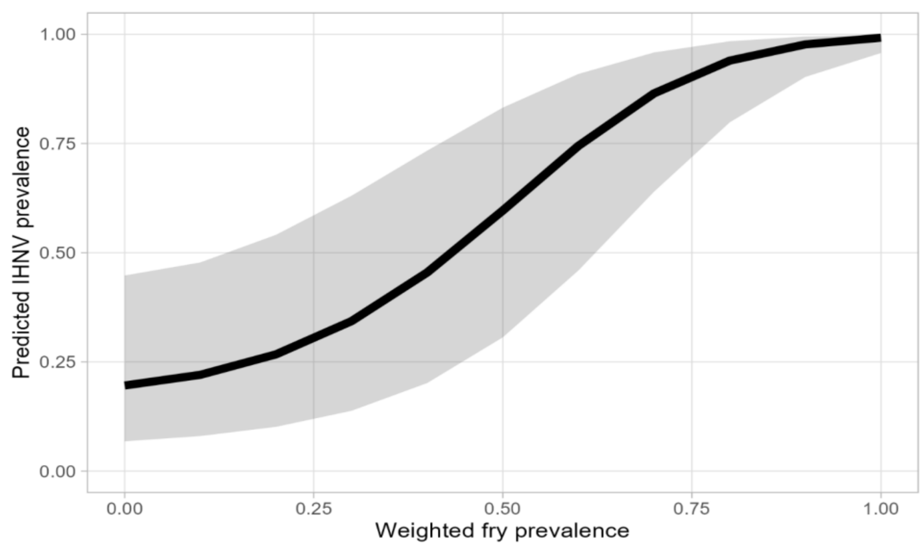

Figure 4. Plot illustrating the predicted IHNV prevalence in returning adult sockeye salmon to Fulton River Spawning Channel based on IHNV prevalence in fry. Grey shading represents 95% confidence intervals.

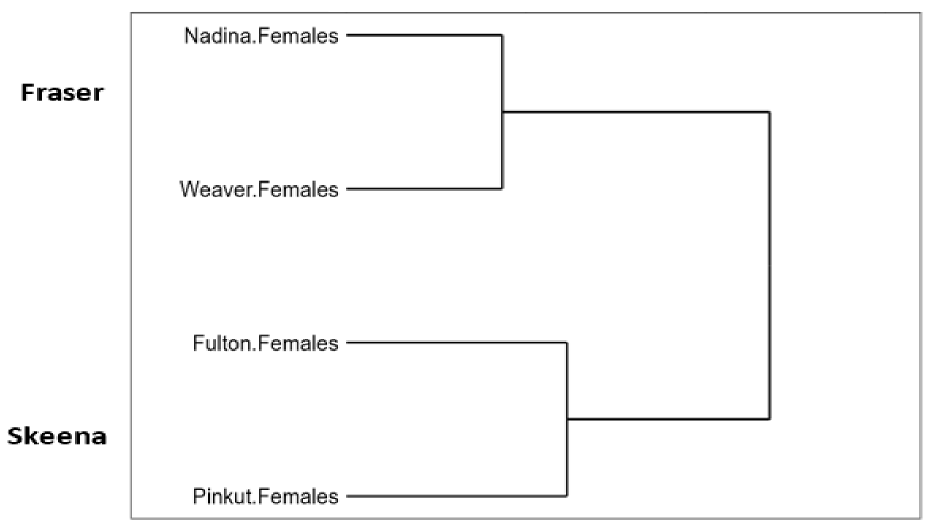

Figure 5. Cluster diagram illustrating similarities in IHNV prevalence of adult female sockeye salmon across spawning channels over a 32 year time period.

2408 - Modernizing Salmonid Health Diagnostic Services

Long, A., Sadler, H. and Thompson, C. Prevalence of Flavobacterium psychrophilum in Chinook salmon (*Oncorhynchus tshawytscha*) in British Columbia (in progress).

Joint Aquatic Drug Approval Coordination, Western Fish Disease, & AFS Fish Health Section Annual Meeting, Bozeman, MT. June 2025.

Collaborations: Kyle Garver, DFO; Ahmed Siah, BC Centre for Aquatic Health Sciences

Region: BC

Species: Chinook, Coho, Sockeye

Highlights

- The project focused on developing, validating, and implementing quantitative PCR (qPCR) assays for seven endemic fish pathogens in British Columbia to improve disease detection and support salmon health management.
- Targeted surveillance revealed differences in pathogen prevalence among salmon stocks and tissues, with *F. psychrophilum* more frequently detected in spleen samples than kidney, alongside observed genetic diversity in isolates. For *R. salmoninarum*, ELISA testing was more reliable than qPCR, with non-lethal sampling methods under ongoing evaluation.
- Improved diagnostic tools enhance pathogen detection and understanding of disease prevalence, aiding targeted interventions in salmon hatcheries.

Background

Historically, Fisheries and Oceans Canada's (DFO) Salmonid Enhancement Program (SEP) has worked closely with the Science Branch's Aquatic Animal Health (AAH) Section to implement disease monitoring and mitigation programs aimed at reducing the impacts of endemic diseases in salmonid hatcheries. These efforts are critical for maintaining hatchery productivity and supporting broader salmon conservation and enhancement objectives. However, reductions in funding for salmon health research within both SEP and the Science Branch have limited the ability of the Finfish Diagnostic Laboratory (FDL) at the Pacific Biological Station (PBS) to modernize and adopt emerging diagnostic technologies. As a result, diagnostic capacity has not kept pace with current best practices, and opportunities for effective technology transfer between Science Branch and SEP have diminished.

This project sought to address these knowledge and capacity gap by re-establishing strong linkages between SEP and the Science Branch and leveraging scientific expertise to improve, expand, and modernize the FDL. The demand driving this work is the need for timely, accurate, and advanced diagnostic information to support proactive salmonid hatchery health management. Through strengthened collaboration among SEP, BC Centre for Aquatic Health Sciences, and Science Branch, a multi-year initiative was implemented that will result in sustainable disease monitoring and mitigation, ultimately improving hatchery health outcomes across SEP facilities.

Methods and Findings

Validation and transfer of diagnostic assays for endemic pathogens

In consultation with SEP veterinarians and fish health staff, the project identified seven endemic pathogens for which there was a need for improved diagnostic assays. Due to the need for high-capacity and rapid diagnostics, quantitative PCR (qPCR) assays were chosen for their accuracy and reliability. The targeted pathogens were as follows: *Tetracapsuloides bryosalmonae* (Bettge et al., 2009), *Flavobacterium columnare* (Gibbs et al., 2020), *Flavobacterium psychrophilum* (Ma et al., 2019; Marancik & Wiens, 2013), *Renibacterium salmoninarum* (Richmond & Plant, 2021), *Ichthyophthirius multifiliis* (Howell et al., 2019), IHNV (Purcell et al., 2013), and *Nucleospora salmonis* (Badil et al., 2011). Where pathogen nucleic acids were unavailable, synthetic double-stranded DNA fragments (gBlocks™) were used for validation work, e.g. limits of detection and quantification. In collaboration with BC Centre for Aquatic Health Sciences, the *R. salmoninarum* qPCR assay underwent interlaboratory validation in which both labs screened 170 samples. The results showed substantial agreement between labs (Cohen's kappa=0.68), confirming the reliability of assay transfer. Post-validation, assays were implemented to assist the FDL in disease investigations.

To ensure effective knowledge transfer, standard operating procedures were developed by the AAH team and shared with FDL staff. Training sessions covered all aspects of assay implementation, enabling FDL personnel to independently conduct analyses.

Deployment of assays for pathogen surveillance

In addition to assay validation and technology transfer, this project also focused on collection and analysis of longitudinal data on two high-priority pathogens: *F. psychrophilum* and *R. salmoninarum*. *F. psychrophilum* is the causative agent of bacterial coldwater disease and infections can cause significant disease and mortality in juvenile, hatchery-reared salmonids. Identified knowledge gaps for *F. psychrophilum* in BC include overall prevalence in broodstock, and the linkage between female broodstock bacterial load and outbreaks in fry. While outbreaks are common at most SEP facilities rearing salmonids, outbreaks are notably acute in Harrison River Chinook salmon (HRCS).

Surveillance conducted between 2023 and 2025 determined that prevalence was approximately 40% in HRCS broodstock during 2023–2024, with a significant reduction in 2025 ($\chi2=12.6$, $p < 0.01$) (Table 1). It is possible that prevalence is cyclical in this stock but additional screening is necessary. Chehalis River broodstock, reared under similar conditions, showed comparable infection rates to HRCS in 2024, suggesting genetic differences between stocks may influence outbreak intensity.

Both kidney and spleen were collected to determine which tissue would be best for routine sampling. Agreement between the two tissues was slight (Cohen's kappa=0.16). The number of positive fish based on spleen results was more than double that of kidney indicating that spleen is more likely to result in a positive detection. Tissues were also streaked on bacterial agar and evaluated for growth of yellow-pigmented bacteria morphologically similar to *F. psychrophilum*. Using novel sequencing techniques, we identified unexpected genetic heterogeneity within *F. psychrophilum* isolates from BC.

In 2024, the SEP Fish Health group conducted a pilot study to evaluate the effectiveness of pre-fertilization egg disinfection in reducing bacterial loads. Unfertilized eggs from 20 HRCS females were treated in an Ovadine®:saline solution (100 ppm:0.75%) for 15 minutes. Egg disinfection is typically carried out post-fertilization; however, iodophor cannot penetrate eggs to eliminate bacteria already present within. A previous study by Lennox et al. (2023) suggested that pre-fertilization disinfection in an iodophor:saline solution may decrease intra-egg bacterial concentrations, supporting the basis for this pilot. Eggs from each female were sampled at three key stages (pre-fertilization and pre-treatment, pre-fertilization and post-treatment, and post-fertilization and post-treatment) and screened for *F. psychrophilum* by AAH staff. The number of positive samples decreased from eight (pre-treatment and pre-fertilization) to one (post-treatment and post-fertilization). Fish were not monitored post-hatch, so long-term effectiveness of the treatment could not be assessed, though no adverse impacts on fertilization or hatching were noted.

The study was repeated in fall 2025, expanding to include all HRCS eggs as well as all chum salmon eggs at the Tenderfoot hatchery. Samples from the HRCS eggs were collected and will be analyzed using qPCR before the end of the fiscal year to further evaluate the efficacy of this treatment approach.

R. salmoninarum is the causative agent of Bacterial Kidney Disease (BKD), and is vertically transmitted from female broodstock to progeny. As such, kidney is collected from spawning female broodstock and submitted to the FDL for BKD screening using an enzyme-linked immunosorbent assay (ELISA). In the current study, 637 samples were screened by ELISA and qPCR. Assay agreement was slight (Cohen's kappa=0.20), and overall, more samples were positive by ELISA as compared to qPCR. The ELISA measures bacterial antigen concentrations and serves as a proxy for previous *R. salmoninarum* exposure. Conversely, the qPCR measures the total amount of nucleic acid present, i.e. an active infection. Therefore, although the *R. salmoninarum* qPCR assay is sensitive and specific, the ELISA remains the gold standard method for broodstock screening. Longitudinal surveillance of select stocks was also conducted from 2023 through 2025 (Table 2). Prevalence, as determined by ELISA, is high at these facilities every year. Results from 2025 are pending but will be available by the end of this fiscal year.

This project also explored the use of non-lethal sampling methods for *R. salmoninarum*. To do so, lethal (kidney) and non-lethal (mucus, gill clip, anal fin clip, and ventral swab) samples were collected from female broodstock at Nitinat and Big Q hatcheries. All samples were screened by the qPCR assay and kidney was also screened by ELISA (Table 3). In 2024, results showed limited agreement between non-lethal samples and kidney, with mucus samples providing the highest detection rates. Given the amount of handling during the spawning process, mucus also has the highest risk of contamination. Consequently, mucus sampling was excluded in 2025, with evaluation ongoing for gill clip and anal fin sampling methods.

Insights

This project has provided new information about salmon populations and their health by generating data on the distribution and detection of various pathogens. By employing molecular diagnostic tools like qPCR, the study has documented pathogen presence in juvenile and broodstock salmon populations, contributing to an improved understanding of pathogen dynamics in these systems. The longitudinal data gathered offers insight into how pathogen prevalence varies among different salmon stocks and over multiple years.

The results of the project can inform certain aspects of salmon management. For example, the findings regarding pathogen screening in broodstock populations may assist in reviewing fish movement protocols or stock enhancement practices. Additionally, evaluation of pre-fertilization egg disinfection suggests a potential approach that could be further explored as a disease prevention tool for hatcheries, particularly in relation to bacterial coldwater disease. The study also identified important considerations related to tissue type variability in pathogen detection, which highlights potential trade-offs when exploring non-lethal sampling methods screening broodstock for *R. salmoninarum*. These findings are relevant for hatchery planning and emphasize the importance of balancing disease mitigation efforts with the logistical and operational constraints of hatchery facilities.

This research also provides additional information about factors influencing salmon health, such as stressors and potential risk pathways related to pathogen transmission, hatchery practices, and environmental conditions. While the findings highlight areas for further research or development, the project offers practical data that may aid in specific management decisions, operational guidelines, and planning for salmon conservation efforts.

Next Steps

The findings from this project have identified several knowledge gaps and areas for further study. With respect to *R. salmoninarum*, future efforts should focus on analyzing existing data to evaluate prevalence trends across different stocks over time, refining qPCR assays to improve diagnostic reliability, and optimizing non-lethal sampling methods. For *F. psychrophilum*, additional research is needed to investigate genomic differences among BC-specific isolates and potential influence on virulence. Continued investigation into stock- and year-specific variations in pathogen prevalence, particularly in high-risk stocks, will further clarify susceptibility patterns and inform management strategies. Additional work on evaluating the efficacy of pre-fertilization egg disinfection is necessary to assess its role as a disease prevention tool.

This project also emphasizes the need for standardized diagnostic practices and improved methods for pathogen detection to reduce uncertainties in disease monitoring. Strengthening partnerships between the Science Branch and SEP is vital to hatchery health management. By improving access to advanced diagnostic technologies, and supporting the capacity of the FDL through ongoing training and collaboration, improved disease monitoring and response strategies can be developed. The integration of these findings into hatchery operations and broader conservation strategies may help address emerging risks and ultimately support salmon stock sustainability.

Tables and Figures

Table 1. Longitudinal surveillance results for Flavobacterium psychrophilum. Broodstock were classified as positive if the bacterium was re-isolated from tissue samples or if tissues tested positive by qPCR. Total prevalence was calculated as the number of unique positive broodstock identified by qPCR and/or culture divided by the total number of samples collected. Subscripts denote statistically significant differences in prevalence among years ($\chi 2=12.6$, $P < 0.01$).

Stock	Year	Total prevalence (No. screened)
Harrison River	2023	0.43^{a} (121)
	2024	0.44^{a} (122)
	2025	0.25^{b} (125)
Chehalis River	2024	0.2 (60)

Table 2. Longitudinal surveillance results for R. salmoninarum at select facilities. Broodstock were classified as positive if the ELISA optical density value was greater than the mean optical density of the negative control or kidney tested positive by qPCR. ELISA prevalence estimates included samples classified as 'low level of detection' as these samples are considered positive but are often kept by facilities.

Facility	Species	2023			2024		
		No. of samples	ELISA prevalence	qPCR prevalence	No. of samples	ELISA prevalence	qPCR prevalence
Big Q	Coho	30	0.93	0.03	60	0.83	0.05
Chehalis	Coho	30	0.93	0.13	60	1	0.07
Inch Creek	Coho	20	0.95	0.05	60	1	0.02
Nitinat	Coho	40	1	0.55	45	1	0.18
Puntledge	Coho	20	1	0.35	88	0.86	0.25
Puntledge summer	Chinook	11	1	0.09	18	0.94	0

Table 3. Non-lethal BKD screening samples. Female Coho salmon broodstock were sampled at both facilities. Agreement values were calculated using Cohen's kappa analysis and all tissues were compared to kidney.

Year	Facility	No. sampled	Samples collected	Sample agreement
2024	Nitinat	40	Kidney	Gill: <0
			Gill clip	Mucus: 0.11
			Mucus	Ventral swab: 0.085
			Ventral swab	Anal fin clip: <0
			Anal fin clip	
2025	Nitinat	40	Kidney	
			Gill clip	
			Anal fin	
	Big Q	40	Kidney	
			Gill clip	
			Anal fin	

Table 4. Stock and species sampled.

Stock	Species
Big Q	Coho
Chehalis	Coho
Chehalis	Chinook
Chilko	Chinook
Chilliwack	Coho
Fraser	Sockeye
Fulton	Sockeye
Inch	Coho
Kitimat	Coho
Maria Slough	Chinook
Nanaimo River	Chinook
Nitinat	Coho
Norrish (Inch)	Coho
Puntledge	Coho
Puntledge Fall	Chinook
Puntledge Summer	Chinook
Quatse	Coho
Robertson	Chinook
Skeena	Sockeye
Sooke	Chinook
Thornton	Chinook
Viner River	Chum

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Richmond, Z., & Plant, K. 2021. Quantitative PCR (RT-qPCR) for Detection of *R.sal* using AgPath-ID One-Step RT-qPCR kit in Multiorgan tissue of Finfish Species. BC Centre For Aquatic Health Sciences, SOP 83-v5.1.

2417 - Optimizing Hatchery Feeds for Pacific Salmon Production

Technical Report: Effect of transition diet on smoltification, growth and survival in Chinook salmon (in progress)

Collaborations: Salmon Enhancement Program Hatcheries

Region: BC

Species: Chinook

Populations: Stream-type and ocean-type chinook from Chilliwack River Hatchery

Highlights

- Given that early marine survival can be very low for hatchery-reared salmonids, the present study investigated the effects of a transition diet on the smoltification, growth and survival of stream-type and ocean-type Chinook salmon during the transition from freshwater to seawater.
- Fish fed the transition diet did not show any apparent advantages over fish fed the control diet, in terms of smoltification (enzymatic activities of gill Na+, K+ ATPase), growth performance or survival.
- We do not recommend broadscale adoption of transition diets at DFO hatcheries at this time, given that they do not appear to be an effective way to improve early marine survival.

Background

The main objectives of salmon hatcheries in Canada are to enhance wild populations and support salmon fisheries, but are often hindered by low early marine survival of salmon after release (Beamish et al. 2010, 2012). While low early marine survival can be attributed to various factors, smoltification [the morphological, behavioural, and physiological changes salmon undergo to enable them to adjust to the marine environment (McCormick 2012; Brauner and Richards 2020)], is potentially a major bottleneck. During smoltification, one of the key changes is elevated enzyme activities of gill Na+, K+ ATPase (NKA), which plays a crucial role in facilitating primary salt secretion at the gills (McCormick 2012; Brauner and Richards 2020). Both elevated gill NKA levels (McCormick and Saunders 1987; Stich et al. 2015b, 2015a) and high survival post seawater transition (Clarke 1982) are considered valid indicators of smoltification development of salmonids.

In hatchery settings, a change in photoperiod (increasing daylength) can trigger smoltification, while temperature (warming) can accelerate its development in salmonids (Clarke et al. 1989; Muir et al. 1994; Duston and Saunders 1995; Ban 2000; Strand et al. 2018). In addition, past studies have also reported that salt supplementation in the diet could facilitate smoltification development of salmonids (positive effects: Zaugg et al. 1983; Trombetti et al. 1996; Staurnes and Finstad 2000; Hanson et al. 2016); but also negative effects see: Trombetti et al. 1996; Hanson et al. 2016). Manipulating the diet represents a feasible and relatively simple approach to further improve the smoltification success and thus early marine survival of hatchery salmon in BC. In collaboration with the DFO Salmon Enhancement Program, the objective of the present study was to investigate the impact of a seawater transition diet (Adapt Flex-transition diet vs control diet), on the smoltification, growth and survival of stream-type (ST, typically resides in freshwater for >1 year prior to migrating to the ocean) and ocean-type (OT, typically resides in freshwater for <6 months) Chinook salmon (*Oncorhynchus tshawytscha)* during the transition from freshwater to seawater.

Methods and Findings

On March 18th 2025, stream type (ST) and ocean type (OT) Chinook salmon from Chilliwack hatchery were transferred to 200 L indoor tanks (N=4 tanks per treatment, per strain) at 10°C under natural photoperiod at Pacific Science Enterprise Centre (PSEC), in West Vancouver, BC. Fish were fed control diets to satiation 3-4 times daily until the start of the experiment. The experiment started on April 2, 2025 for ST Chinook (control: 4.96 ± 0.02 g, 7.58 ± 0.01 cm; treatment: 4.87 ± 0.05 g, 7.55 ± 0.03 cm) and April 30, 2025 for OT Chinook (control: 4.29 ± 0.03 g, 7.30 ± 0.02 cm), respectively. These timings were also around 5 weeks before the time when the fish would usually be released by the hatchery to begin their outmigration. Fish (N = 55 per tank for ST, and N = 50 per fish for OT; 4 tanks per diet treatment per life stage) were fed one of two diets to satiation daily during a 5 week growth trial in freshwater: control (BioClark's Fry, 3.0 mm, Bio-Oregon, Canada) or treatment transition diet (Adapt Flex 3 mm, EWOS, Canada), which contained 5% NaCl, and additional other proprietary ingredients (e.g. an immunostimulant compound and mix of exclusive nucleotide). Fish were maintained on their treatment diets for an additional 34 days (ST) and 7 days (OT) until the seawater transition. The timing of the seawater transition was determined when the majority of the fish in experiment tanks showed visual cues of smolt transformation, specifically the development of silvering body colour, and fading of parr marks. The fish were transitioned to seawater over 1 day, and then all fish were fed the same control diet for 4 weeks, after which the experiment was terminated and all remaining fish were euthanized (TMS at 0.2 g/L).

Fish were sampled for body size (mass and fork length) and gill Na^+, K^+ ATPase (NKA; 5 - 8 fish per tank per sampling time, except on day 0, when total 30 fish were sampled prior to tank stocking) on: (1) day 0; (2) after 5 weeks on the experimental diets in freshwater; (3) 1 day after seawater transition; and (4) after 4 weeks in seawater. The Specific growth Rate (SGR) for each replicate tank was calculated for 2 periods: (1) the 5-week freshwater trial; (2) from the end of freshwater trial to the end of the seawater trial, using the formula below:

$$SGR (\%) = [\ln (F) - \ln (I)] \times 100 / T$$

- Where I = initial mean fish weight per tank (g), F = final mean fish weight per tank (g), and T = experiment duration (days)
- Enzyme activities of gill Na^+ K^+ ATPase (NKA) were analyzed using methods as described by Mccormick (1993).
- Fish growth and gill NKA levels were analyzed using two-way analysis of variance (ANOVA) using Sigmaplot 14. A statistical level of 0.05 is considered significant, and all data were expressed as mean ± standard error of the mean (SEM).

Overall, there were no differences in the trends between OT and ST Chinook salmon. Survival was excellent for both ST and OT Chinook salmon throughout the entire study (>91% across Chinook strains and diet treatments; Table 1). As expected, gill NKA activity increased during the experiment, indicating that smoltification processes were progressing over time (Figure 1; significant main effect of sampling stage; ST $p = 0.002$; OT $p<0.001$). However, there were no differences in gill NKA levels between diet treatments (ST: $p = 0.21$; OT: $p = 0.30$). For growth, fish grew faster on the control diet compared to the transition diet, but only in freshwater (Figure 2; significant interaction between diet and sampling stage; ST: $p < 0.001$; OT: $p = 0.028$). In freshwater, control fish had significantly higher SGR than the treatment fish. However, in seawater, SGR were similar for both groups, when all fish were fed the same control diet. Notably, SGR levels were much lower (up to 50% reduced) in seawater compared to freshwater (Figure 2).

Insights

This study investigated the effects of a transition diet on the smoltification development, growth and survival of ST and OT Chinook salmon during the transition from freshwater to seawater with the overall goal to improve early marine life survival. Throughout the lab experiment, all fish appeared robust, as they were able to handle multiple handling and sampling events without showing obvious adverse effects such as post sampling mortalities. By the end of the study, regardless of the diet, both ST and OT Chinook salmon apparently smolted well, as indicated by the elevated Gill NKA levels after the experiment started (Fig. 1), and the high survival 24-h and 4-weeks post seawater transfer (Table 1). Moreover, the overall data trends are highly similar between ST and OT Chinook salmon, indicating that both life history types responded comparably to the diet treatment and seawater transfer.

Overall, the results of this study showed no apparent advantage of using the transition diet over the control diet in rearing Chinook salmon. First, for each strain of Chinook salmon, fish fed both the transition diet and control diet reached very similar smoltification status in terms of gill NKA activities and exhibited high survival post seawater transition. Secondly, compared to the control diet, the transition diet did not show an advantage on fish growth performance. In fact, for both ST and OT Chinook salmon, the control fish grew significantly faster in freshwater (Figure 2), and this is also in agreement with other studies (Salman and Eddy 1988; Hanson et al. 2016). In the present study, the growth differences observed may be related to the fish appetite for the feed, which was reflected by the amount of food fed to reach visual satiation. Particularly for ST Chinook salmon, the control fish consistently displayed a bigger appetite for feeding, and were thus offered more feed than the treatment fish throughout the study; this behaviour might thus translate into the observed larger body mass gains in control fish than treatment fish.

Despite high survival, transition to seawater resulted in compromised growth rates for both ST and OT Chinook salmon. While all fish were fed the same control diet in seawater, the SGR of all fish decreased to a similar rate of 1 – 1.08 % after 4 weeks in seawater (Figure 2); indeed, the SGR of control ST Chinook salmon, which was the highest in freshwater (2.11 ± 0.00% per day), had the largest reduction of almost 50%. This slower growth of Chinook salmon post seawater transfer has been reported by other studies as well (Clarke et al. 1981; Morgan and Iwama 1991). With the increased metabolic rate of Chinook salmon in increased salinity (Morgan and Iwama, 1991), the fish may thus have less net energy for supporting growth (Brauner and Richards 2020), resulting in slower SGR at this stage. While the seawater growth phase was only 4 weeks in the present study, these Chinook salmon might need more time to physiologically adjust for the seawater condition, before compensating for their growth. In a wild setting, elevated metabolic rates and incomplete smoltification processes leading to reduced SGR could contribute to early marine mortality. In this regard, sufficient estuary rearing areas could be pivotal to support smoltification processes, feeding opportunities and protection from predation during this critical transition stage (McNatt et al. 2016; Moore et al. 2016; Chalifour et al. 2021).

Interestingly, the smoltification development rates likely differed between the strains. At the start of the present study, the gill NKA levels (unit: μmol ADP·mg protein−1·h−1) of ST Chinook salmon (2.02 ± 0.26) are comparable to those reported from Chinook salmon at the beginning of river migration (mean 1.34 – 1.64; Ewing et al. 2001), while OT Chinook salmon (3.48 ± 0.22) had already reached a similar level of those caught in estuaries (3.8 ± 0.32; Ewing et al., 2001). This finding suggested that while OT Chinook salmon were held for 4 weeks longer until experiment start, they were also in more advanced smoltification development, which was also supported by fish morphology observation during initial tank stocking. After 4 weeks in seawater, the gill NKA levels of OT Chinook salmon were still higher than ST Chinook salmon (mean value of control and treatment; OT: 5.30 ± 0.24; ST: 3.78 ± 0.24); these levels are comparable to those of Chinook salmon smolt at early stage of seawater transfer at 34 ppt (mean around 4; Quinn et al. 2003), but lower than those observed after 10 days in seawater (mean: 6; Quinn et al. 2003). In fact, Houde et al. (2019) reported even higher gill NKA levels from Chinook salmon smolt both in freshwater (5.0 ± 2.5) and seawater (9.6 ± 2.8).

It is possible that the positive effects of a transition diet on smoltification were masked by other factors, such as temperature. Increasing temperature has been reported to accelerate smoltification processes, in terms of earlier elevation and higher gill NKA activities in Atlantic salmon (Solbakken et al. 1994; Mccormick and Moriyama 2000; McCormick et al. 2002), Chinook salmon (Muir et al. 1994), and sockeye salmon (Ban 2000). In the present study, all fish experienced an increase of water temperature during transfer from the hatchery (5.8 ± 0.4oC for ST, and 7.4 ± 0.2oC for OT) to PSEC (10°C). Therefore, it is possible that smoltification development had already been accelerated soon after they were introduced to the holding tanks, before the experiment started. In this case, the effects of the transition diet may have been masked, as both control and treatment fish would show accelerated smoltification development. While the initial higher gill NKA levels of OT Chinook salmon discussed above, seemed to support this hypothesis, more concrete evidence are still needed. To mitigate the potential interference of a water temperature effect, future studies could design similar experiments so that the fish would not experience a significant change in water temperature, such as running the entire study at the hatchery as reported by Hansen et al. (2016).

Next Steps

We found no evidence to suggest that using seawater transition diets (Adapt Flex by EWOS Canada Ltd.) will improve early marine survival for hatchery fish. The results of the present study showed that there were no apparent advantages of using this seawater transition diet over the routine control diet on rearing ST and OT Chinook salmon in terms of smoltification, growth and seawater survival. Indeed, all these performance parameters measured in the present studies showed very similar trends between ST and OT Chinook. As such, we do not recommend broadscale use of these transition diets at DFO hatcheries at this time.

On the other hand, future studies are encouraged to investigate knowledge gaps revealed here. One recommendation is to conduct a similar study in a hatchery setting, in order to have the most direct insights into how a transition diet may benefit the hatchery production of salmon at DFO. Hatchery and lab conditions vary in several aspects, including water source, fish density, temperature, and rearing environment. In the present study, it was speculated that the inevitable change in water temperature from hatchery to the lab might have accelerated the smoltification development in both control and treatment fish, thus masking the effects of transition diet. Conducting a similar study in a hatchery setting could reveal the effects of the transition diet, while eliminating similar potential interfering factors that may exist in lab environment. Moreover, while the present study focused on growth and gill NKA as traditional development indicators, future studies could further investigate dietary effects on the physiological and behavioural performance parameters relevant to survival post hatchery-release. For example, swimming or migration performance (Pedersen et al. 2008; Serrano et al. 2009; Wilson et al. 2021), standard and maximum metabolic rates (Farrell 2009; Auer et al. 2015) and predator avoidance behaviours (Olla et al. 1998; Jackson and Brown 2011) are known to be critical to salmon survival in the early marine environment. Finally, given that the transition diet does not appear to be effective at improving early marine survival, we recommend considering how alternative diets could confer other desirable traits in fish, such as the possibility that high lipid diets could reduce the jacking rate in salmon.

Tables and Figures

Table 1. Survival of stream-type (ST) and ocean-type (OT) Chinook salmon at different stages of the experiment.

Diet	Sampling Stage for ST Chinook salmon		
	Stage 1: 5-Week Diet Trial In FW	24-h post SWT	Stage 2: 4-Week Growth In SW
Control	100%	100%	99 ± 1.3%
Treatment	100%	100%	99 ± 1.3%
	Sampling Stage for OT Chinook salmon		
	Stage 1: 5-Week Diet Trial In FW	24-h post SWT	Stage 2: 4-Week Growth In SW
Control	100%	100%	100%
Treatment	99 ± 0.6%	100%	91 ± 7.6%

**Values are expressed as mean ± standard error of mean (SEM). FW: freshwater; SWT: seawater transition; SW: seawater.*

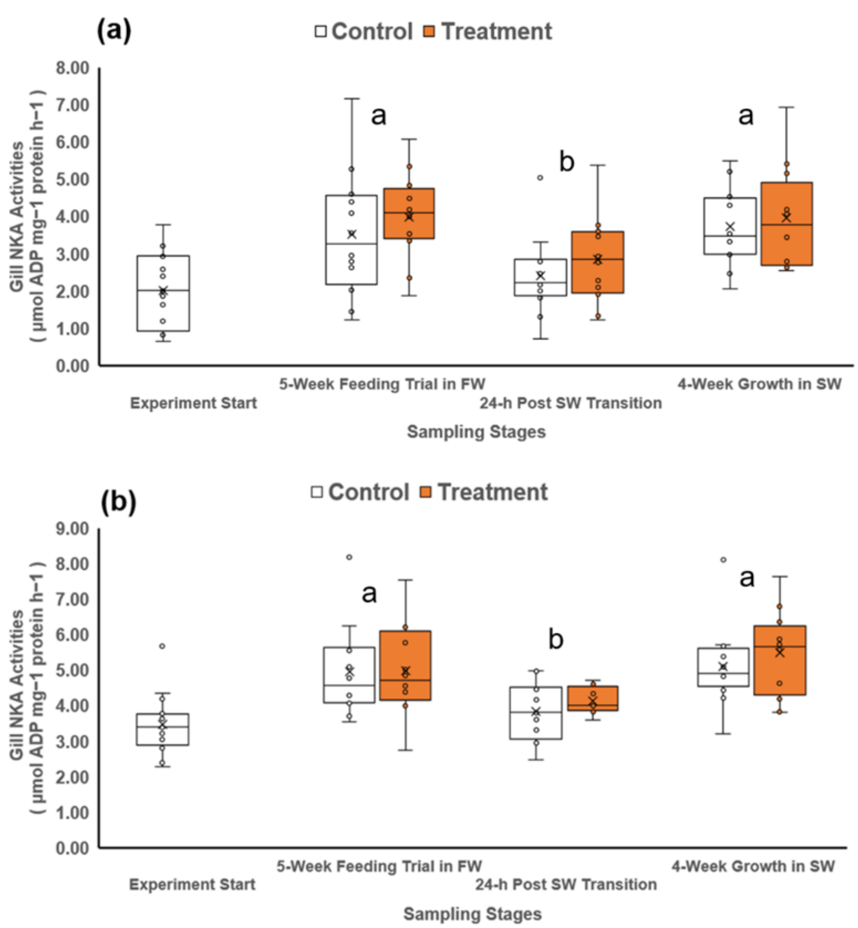

Figure 1. Gill Na+ K+ ATPase (NKA) activities of (a) stream-type chinook salmon, and (b) ocean-type chinook salmon from the control or treatment diet group at different experiment stages (n = 12 per sampling time per diet group). The cross symbol (×) in the box plot indicates mean values within each group. Different superscripts denote significant

differences among each sampling stage (p < 0.05, two-way ANOVA, followed by all pairwise multiple comparison tests with the Holm-Sidak method).

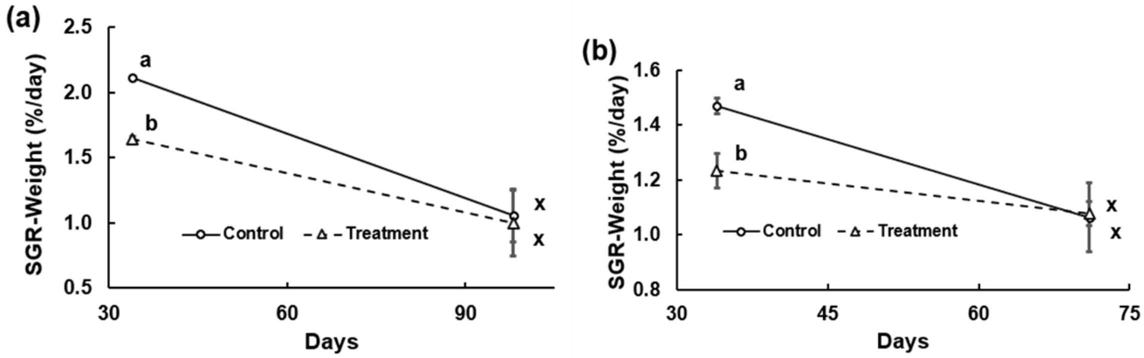

Figure 2. The mean specific-growth rates (SGR) of (a) stream-type (ST) Chinook salmon, and (b) ocean-type (OT) Chinook salmon from the control or treatment diet group at the end of the freshwater growth trial (day 34) and seawater growth trial (ST = day 98; OT = day 71) There was a significant interaction between diet and sampling stage on the SGR of both ST and OT chinook. Different superscripts denote significant differences between data within the each experiment stage (p < 0.05, two-way ANOVA, followed by all pairwise multiple comparison tests with the Holm-Sidak method). The error bars indicated standard error of the mean (SEM).

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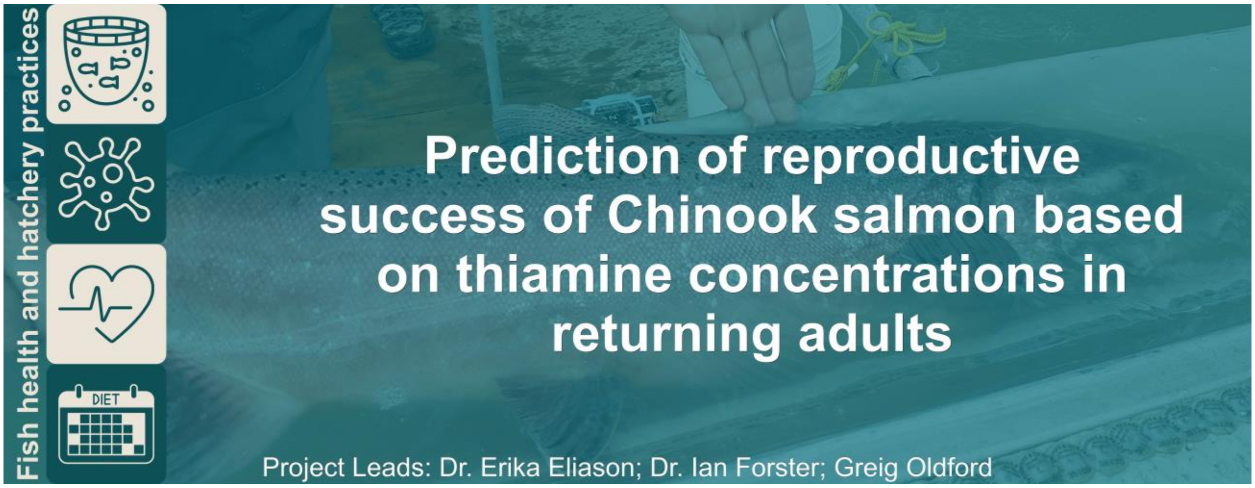
2418 – Thiamine Influence On Chinook Reproductive Success



Collaborations: Salmon Enhancement Program Hatcheries, University of British Columbia (Dr Brian Hunt), DFO environmental Watch (EWATCH)

Region: BC

Species: All *Oncorhynchus* spp

Populations: Capilano early and mid Coho, Chilliwack Fall Chinook, Cheakamus Chinook, Harrison Sockeye, Chilko Sockeye, Weaver Creek Sockeye, Chehalis Pink

Highlights

- Thiamine deficiency complex (TDC) is an emerging concern in Pacific salmon, potentially contributing to en route and prespawn adult mortality and elevated fry mortality, yet little is known about the prevalence of TDC in Canadian Pacific salmon populations.
- This project established thiamine analysis capability for fish tissues (e.g. eggs, plasma, muscle, liver) by the Nutrition lab at the DFO Pacific Science Enterprise Centre (PSEC).
- Preliminary data discovered that total thiamine levels in eggs of both coho and Chinook salmon in BC generally ranged from 6 - 13 nmol/g, most pink Salmon contained 4 - 8 nmol/g, but most sockeye salmon eggs only contained 2 - 6 nmol/g, which suggests that some Pacific salmon populations in BC may exhibit TDC and warrant further monitoring.

Background

Thiamine (Vitamin B1) is an essential water soluble vitamin for fish, supporting physiological functions such as metabolism, immune, neuron and cardiac functions (Bâ 2008; Manzetti et al. 2014; Roman-Campos and Cruz 2014; Whitfield et al. 2018), normal development (Carvalho et al. 2009), growth (Reed et al. 2023; Lee et al. 2026) and reproductive success (Fitzsimons et al. 2005; Honeyfield et al. 2005; Mantua et al. 2025). In aquatic systems, thiamine is synthesized by bacteria and phytoplankton at the base of the food web (Croft et al. 2007; Tang et al. 2010;

Paerl et al. 2015; Hylander et al. 2024; Suffridge et al. 2024), and fish obtain thiamine exclusively through their diet (Fridolfsson et al. 2018; Harder et al. 2018; Ejsmond et al. 2019; Hylander et al. 2024). Thiamine deficiency complex (TDC) is a syndrome that is caused by a chronic deficiency in thiamine, impacting salmon across the life cycle. In adult salmon, reduced swimming and migratory ability, and increased pre-spawn mortality have been linked to TDC (Brown et al. 2005a; Fitzsimons et al. 2005). For early-stage salmon fry hatched from thiamine-deficient eggs, symptoms include loss of equilibrium (Fitzsimons et al. 2005), abnormal swimming behaviour (i.e. swimming in a corkscrew pattern) (Mantua et al. 2025), impaired vision and foraging ability (Carvalho et al. 2009), and high mortality (Koski et al. 1999; Mantua et al. 2025). TDC is caused by low availability of thiamine in the diet and/or ingestion of prey high in thiaminase (enzyme that degrades thiamine, Fisher et al. 1998; Brown et al. 2005a; Honeyfield et al. 2005; Houde et al. 2015; Mantua et al. 2025). Both extrinsic (e.g. changing environmental conditions, variation in the migration experience) and intrinsic factors (e.g. species, size, sex, disease state) could further modulate fish thiamine levels.

TDC has been linked to salmonid population declines globally, including Atlantic salmon *Salmo salar* in the Baltic Sea (Amcoff et al. 1999), lake trout *Salvelinus namaycush* in the Great Lakes (Ladago et al. 2020), and Chinook salmon in Alaska (Strasburger et al. 2023) and California (Mantua et al. 2025). However, there is little published information about the status of TDC in Pacific salmon, especially in British Columbia (BC), Canada (but see Welch et al. 2018). More research is thus urgently needed to investigate how thiamine status has been impacting Pacific salmon in BC, Canada. The objectives of this project were to: (1) establish thiamine analysis capacity at DFO to support studies and programs investigating the thiamine status of salmonids in Canada. Until this project, there were no Canadian labs providing thiamine analysis services, thus Canadian projects must rely on a few labs in the USA, creating a bottleneck (costly, delayed, sample loss risk) in thiamine analysis. (2) determine preliminary thiamine status in eggs collected from both wild and hatchery-derived stocks of Chinook salmon, coho salmon, pink salmon and sockeye salmon in BC. And (3) assess the effectiveness of thiamine treatment practices being tested at some DFO hatcheries. This research was conducted in collaboration with the Pelagic Ecosystem Lab at University of British Columbia (UBC), DFO Salmon Enhancement Program (SEP) and DFO Environmental Watch Program (EWATCH).

Methods and Findings

Thiamine analysis capacity was established by researchers in the Nutrition lab at the DFO Pacific Science Enterprise Centre (PSEC), based on the methodology of Brown et al. (1998) with expert advice from Dr. Jacques Rinchard from SUNY Brockport and Dr. Cody Pinger from National Oceanic and Atmospheric Administration (NOAA). To confirm the reliability of our analysis protocol, we analyzed 27 Chinook salmon egg samples collected in 2023 by Pelagic Ecosystem Lab at UBC and compared our results with those provided to UBC by the lab at SUNY Brockport. There was a strong and significant linear relationship (Fig 1; $y = 0.8183 x - 0.4131$) between SUNY Brockport and PSEC's results on total mean thiamine levels ($p < 0.001$) providing confidence that the methodology employed by PSEC is reliable and accurate. Overall, PSEC reported consistently lower total mean thiamine levels, especially lower TPP levels, compared to SUNY Brockport. This is not surprising given that PSEC conducted the analysis in 2025, almost 2 years later than SUNY Brockport. Given the sensitivity of thiamine (temperature, light, pH; Brown et al. 1998; Wright et al. 2005; Edwards et al. 2017; Rocchi et al. 2022), thiamine degradation in tissues is expected to occur over time with prolonged storage and multiple sample handing events.

Additional salmon samples from both hatcheries and the wild were collected to obtain baseline, preliminary data on the thiamine status of salmon in BC. Sample collection included: Chilliwack River hatchery coho salmon (N=10 females; eggs, plasma), Chilliwack River hatchery Chinook salmon (N=10 females; eggs, plasma), Capilano hatchery mid coho salmon (N=10 females; eggs), Harrison River sockeye salmon (N=10 females; eggs, ventricles, plasma), Chilko River sockeye salmon (N=10 females; eggs, ventricles, plasma), Weaver Creek sockeye salmon (N = 9, eggs, ventricles, plasma), Chehalis pink salmon (N = 11 females; eggs). Tissues were immediately frozen (dry shipper or dry ice) and stored at -80oC until analysis. Ventricle and plasma analysis is ongoing, only egg data are presented here. Total thiamine levels were very similar in the Chinook and coho eggs assessed here (Figure 2), mostly ranging between 6 – 13 nmol/g. However, sockeye salmon eggs had much lower total thiamine levels of mostly 2 – 6 nmol/g, while total thiamine in pink salmon eggs mostly ranged from 4 – 8 nmol/g. Using the thiamine thresholds as established by Mantua et al. (2025), 20 – 40% of each coho and Chinook salmon population are considered as being likely impacted by thiamine deficiency to some degree (< 7.7 nmol/g; Figure 3). However, all sockeye salmon samples are below 7.7 nmol/g, with over 50 – 100% of eggs considered having low (2.7 -5.9 nmol/g) or critically low thiamine (< 2.7 nmol/g) levels. For the Chehalis pink salmon population, 72% of samples are considered to be likely thiamine deficient (< 7.7 nmol/g), with 45% of eggs in the low category (2.7 – 5.9 nmol/g; Figure 3).

To counteract the effects of TDC, thiamine supplementation is seen as an effective strategy to improve salmon reproduction success in hatcheries (Harder et al. 2025) and is currently implemented at a few DFO hatcheries. Current practices include injecting thiamine (500 mg thiamine hydrochloride) into broodfish ~12-25 days prior to spawning (Shuswap River hatchery) or immersing fertilized eggs in a static bath made of 1000 ppm thiamine mononitrate for 1 hour (Tenderfoot Creek hatchery, Capilano hatchery). We sampled thiamine-injection-treated eggs from Middle Shuswap Chinook salmon at Shuswap River hatchery (N=6, no control fish were available).We sampled both untreated (control) and thiamine-bath-treated eggs (immediately after the 1 h bath) from Cheakamus Chinook salmon at Tenderfoot Creek hatchery (N=4 females), early coho (N=20 females) , mid coho salmon (N=20 females) and late coho salmon (N=20 females) from Capilano hatchery. In addition, thiamine-bath treated eggs were sampled ~1 month post-fertilization in coho salmon from Capilano hatchery (N= 400 eggs each for early, mid and late coho; eggs from different females were mixed; no control fish were available).

Thiamine injection-treatment (Middle Shuswap Chinook salmon at Shuswap River hatchery) produced eggs with total thiamine levels ranging between 16-27 nmol/g (Table 1). While there are no control fish for comparison, these levels are above egg thiamine levels in untreated eggs from other locations (Tenderfoot and Chilliwack hatchery Chinook salmon, Figure 2). This suggests that the thiamine injection treatment likely was effective at increasing total thiamine levels in the eggs. Unfortunately, the effectiveness of the thiamine bath treatment (Tenderfoot Creek hatchery and Capilano hatchery) could not be resolved here. Sampling eggs immediately following the 1 h thiamine bath treatment resulted in extremely elevated and highly variable total thiamine levels (range = 256.8 – 327.0 nmol/g). In fact, we were unable to determine accurate total thiamine levels for the bath-treated samples from Capilano, as the results were contradictory (i.e. varying from 0.95 – 291.20 nmol/g). While we reported consistently high total thiamine from bath-treated eggs from Tenderfoot Creek Hatchery, these levels are not biologically reasonable and were likely produced by excess thiamine associated with the bath. Given this, we sampled some eggs ~1 month post bath treatment from Capilano Hatchery and found levels to vary among batches (early coho batch#1: 0.90 ± 0.06, batch #2: 2.49 ± 0.60; mid coho batch#1: 3.86 ± 1.18; N=5 tests, unit = nmol/g). However, without control, un-treated eggs at the same life stage, we are unable to assess whether the thiamine bath treatment was successful at increasing thiamine levels in these eggs.

Insights

This project successfully established thiamine analysis capability at PSEC, which is currently the only known laboratory in Canada conducting these analyses. A detailed protocol outlining the equipment, consumables and procedural steps is available for distribution to other research groups at DFO to set up the same analysis capacity. Our lab at PSEC is currently welcoming thiamine analysis requests and collaborative projects to support research programs monitoring the thiamine status of Pacific salmon and their prey in Canada.

The thiamine levels in coho and Chinook salmon eggs were within the expected range, consistent with previous work on Chinook salmon in Alaska (Honeyfield et al. 2016; Larson and Howard 2019) and California (Mantua et al. 2025), and preliminary data available for BC (Lerner and McLaskey 2024). Notably, the relatively wide range of thiamine levels suggests considerable variation among individuals within each population. Future studies should consider increasing the sample size from each population (i.e. >10 fish per population) to have a more precise estimate of salmon thiamine status. In contrast, the total thiamine amounts in sockeye salmon eggs from Weaver Creek, Harrison and Chilko River were less variable, but also had lower levels (mostly within 2 - 6 nmol/g). While the Harrison River samples were considered not fully ripe, the thiamine levels in these eggs were similar to those of fully ripe fish in Chilko River. Notably, a previous study found much higher total thiamine levels in eggs of sockeye salmon from Harrison River, and pink salmon from Seton River in 2015 (sockeye: 10.9 ± 1.2 nmol/g, n = 5; pink: 19.5 ± 2.3 nmol/g, n=20; Welch et al., 2018). The cause of these differences in thiamine levels between studies of the same population conducted ~10 years apart is unknown, but may be related to changes in prey (and thus dietary thiamine/thiaminase levels), changing ocean or migration conditions or other factors not identified.

Based on the thiamine thresholds by Mantua et al. (2025), 20 - 40 % of the eggs analyzed from each coho and Chinook salmon population in this study, are considered to be likely impacted by thiamine deficiency (Figure 3). However, the total thiamine in all eggs from sockeye salmon from both Harrison and Chilko River are well below this threshold, and only 27% of Chehalis pink salmon eggs were above it. It must also be noted that the threshold from Mantua et al. (2025) is set based on Chinook salmon, but the susceptibility to TDC, or thiamine threshold, is likely species-specific (Brown et al. 2005b; Fitzsimons et al. 2007; Honeyfield et al. 2008; Harder et al. 2018). To our knowledge, there are no published data on thiamine status of sockeye and pink salmon other than Welch et al. (2018). Future research should track thiamine status of Pacific salmon in BC, especially sockeye salmon.

The broodfish-thiamine-injection method appeared to effectively improve the total thiamine levels, mostly in form of TH, in Chinook salmon eggs. Although there were no untreated, control eggs available as a comparison at Shuswap River Hatchery, the injection-treated eggs (20.5 ± 4.8 nmol/g, range from 16 - 27 nmol/g) contained up to 2 - 3 times the usual thiamine amount in untreated eggs of other Chinook salmon stocks (Figure 2 and 3, 6 - 13 nmol/g). The total thiamine levels in eggs from these injection-treated fish are within the range reported for similar studies on coho salmon (21.925 ±1.694 nmol/g, Fitzsimons et al., 2005) and steelhead trout *Oncorhynchus mykiss* (total thiamine 20.4 ± 11.3 nmol/g; Futia et al 2017; mean total thiamine: 33.5 nmol/g, range: 15.4 - 51.1 nmol/g; Reed et al 2023). Unfortunately, our study could not resolve the effectiveness of thiamine bath-treated eggs because of supra-biological and varying levels measured in eggs sampled immediately after the 1 h treatment bath (e.g. 302.5 ± 31.2 nmol/g in Chinook salmon at Tenderfoot Creek hatchery; 0.95 - 291.20 nmol/g in mid Coho salmon eggs at Capilano Hatchery). Thus, it was unknown how much of the thiamine was actually retained and biologically available to the eggs over time. Future work should resolve the effectiveness and necessity of these thiamine treatments, as these methods could prove highly valuable in both minimizing the potential negative impacts of TDC on early fry and optimizing hatchery salmon production (Futia et al. 2017; Reed et al. 2023; Harder et al. 2025).

Next Steps

With the thiamine analysis capacity established at PSEC, DFO can now further expand research relevant to thiamine and fish in Canada. First of all, more research is urgently needed to determine the status of TDC across stocks of all 5 species of Pacific salmon in BC and the Yukon, across the life cycle (especially adults and eggs). Second, we need to establish how thiamine levels vary across tissue types (e.g. muscle, ventricle, liver, plasma, eggs) and identify whether plasma thiamine levels could be used as a non-lethal indicator of adult salmon thiamine status. Third, we need to establish the thiamine and thiaminase status of the primary prey species in both ocean and freshwater habitats and how these may be changing over time. As such, a next step for the Nutrition lab at PSEC is to establish a protocol for thiaminase activity and begin collaborating with other groups to collect and assess prey. Fourth, we need to determine TDC thresholds for impairment for all 5 species of Pacific salmon species, in both eggs and migrating adults. Finally, we need carefully controlled experiments to assess the effectiveness and necessity of thiamine treatment (both bathing eggs and injecting broodstock) for hatcheries in BC.

Tables and Figures

Table 1. Results of total thiamine levels detected in chinook salmon eggs treated or untreated with thiamine. The results shown were the mean of duplicates. Each test represented results of eggs collected from an individual fish of each population. Note that for Cheakamus chinook salmon, each pair of control and treated eggs (same row) was collected from the same fish. All Middle Shuswap chinook salmon were treated with injection prior to spawning, and thus untreated eggs were not available for sampling. The bath-treated eggs were all fertilized, while the untreated eggs, and the injection-treated eggs were not fertilized.

Analysis ID	Total Thiamine Levels in Eggs (nmol/g)		
	Cheakamus Chinook Salmon		Middle Shuswap Chinook Salmon
	Control - Untreated	Thiamine-Bath Treated	Broodfish Injection-Treated
Test-1	11.4	256.8	16.1
Test-2	4.2	313.9	20.1
Test-3	13.9	327	27.2
Test-4	14	312.4	18.7
Mean ± SD	10.8 ± 4.6	302.5 ± 31.2	20.5 ± 4.8

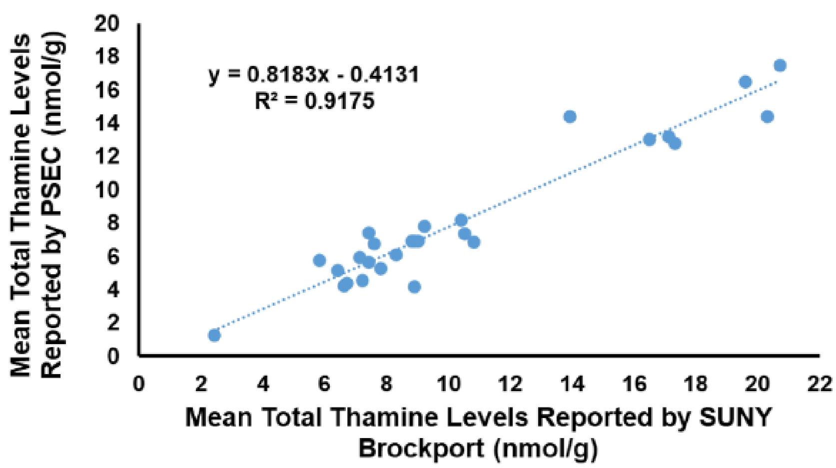


Figure 1. Results of linear regression analysis on the total mean thiamine level results reported by SUNY Brockport and PSEC on the same set of Chinook salmon eggs. Each dot represents an individual sample.

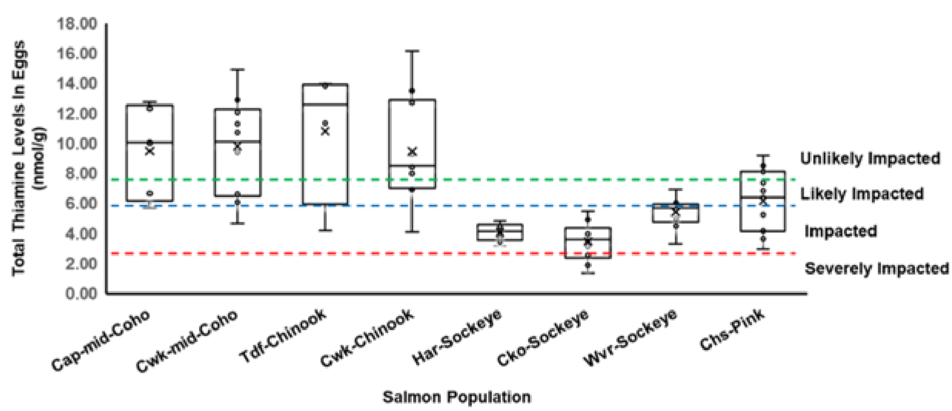


Figure 2. Results of the total thiamine levels in untreated and unfertilized eggs collected from Capilano mid coho (Cap-mid-Coho, n=5), Chilliwack mid coho (Cwk-mid-Coho, n=10), Tenderfoot Cheakamus Chinook (Tdf-Chinook, n=4), Chilliwack fall Chinook (Cwk-Chinook, n=10), Harrison sockeye (Har-Sockeye, n=10), Chilko sockeye (Cko-Sockeye, n=10), Weaver sockeye (Wvr-Sockeye, n=9) and Chehalis pink (Chs-Pink, n=11). Note that the Harrison sockeye eggs were considered not ripe during sample collection; Tenderfoot Cheakamus Chinook data came from results of untreated eggs reported in Table 1. The dash lines represent thiamine level thresholds established by Mantua et al. (2025) to illustrate the likelihood of being impacted by thiamine deficiency: high - unlikely impacted (> 7.7 nmol/g), intermediate - likely impacted (5.9-7.7 nmol/g), low - impacted (2.7-5.9 nmol/g) and critically low - severely impacted (< 2.7 nmol/g). The cross symbol (×) in the box plot indicates mean values within each group.

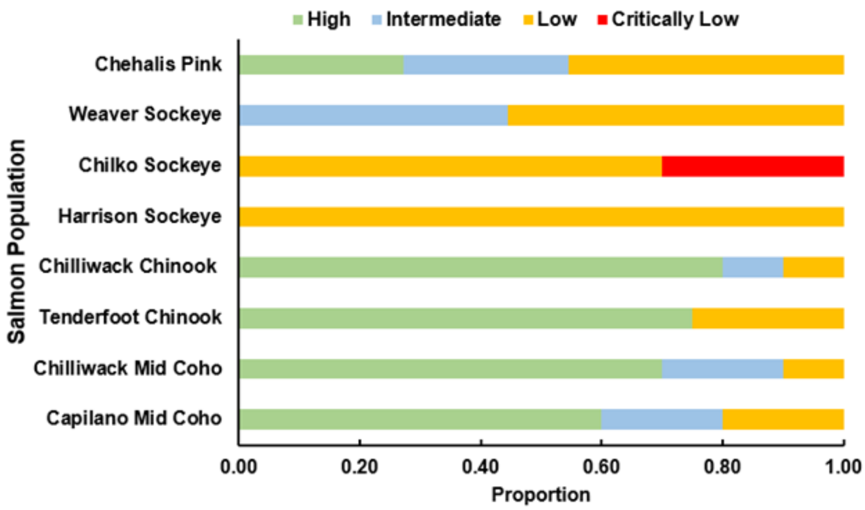


Figure 3. Proportion of salmon eggs from different populations measured by the thiamine level thresholds established by Mantua et al. (2025). Different category of total thiamine level represents different likelihood of being impacted by thiamine deficiency: high - unlikely impacted (> 7.7 nmol/g), intermediate - likely impacted (5.9-7.7 nmol/g), low - impacted (2.7-5.9 nmol/g) and critically low - severely impacted (< 2.7 nmol/g). Eggs were collected from different salmon species and population: Capilano mid coho (n=5), Chilliwack mid coho (n=10), Tenderfoot Cheakamus Chinook (n=4), Chilliwack fall Chinook (n=10), Harrison sockeye (n=10), Chilko sockeye (n=10), Weaver sockeye (n=9) and Chehalis pink (n=11).

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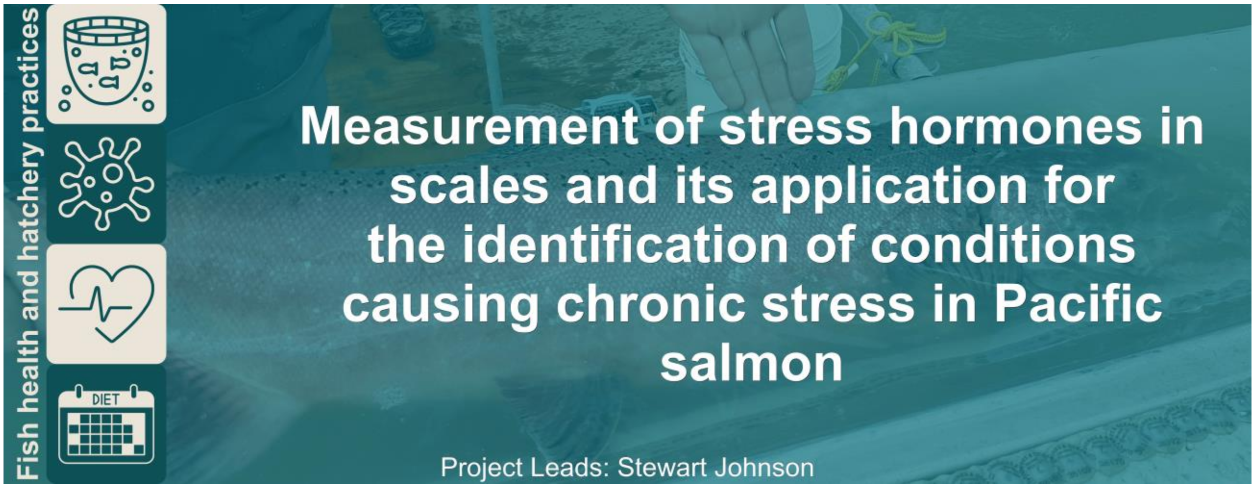
2421 – Testing Scale Hormones to Assess Chronic Stress



Collaborations: University of Guelph: Reid Williams, Dr. Nicholas Bernier, Dr. Fredrick Laberge

Region: BC

Species: Chinook

Highlights

Main idea

- Determine the usability of scale corticosteroids as biomarkers of chronic stress in Pacific salmon.
- Scale corticosteroid content can differ by underlying factors such as sex or life-stage. Furthermore, both cortisol and cortisone content rapidly increases in scales following a single acute stressor and returns to baseline levels within 72 hours. Both corticosteroids can also decrease at increasing rates while under chronic stress. Finally, the dynamics of scale corticosteroids can differ depending on the type of prolonged stress.

Implications

- As scale corticosteroids can be elevated while plasma values are normal following acute stress, and the opposite can occur during chronic stress, we do not currently recommend using scale cortisol, nor cortisone, as biomarkers of chronic stress in Chinook salmon.

Background

Exposure of fish to stressors can elicit physiological changes at multiple levels of animal organization, these alterations are collectively known as the stress response. The hypothalamic-pituitary-interrenal (HPI) axis which is activated in response to most forms of stress in fish, initiates and regulates the stress response. In fish cortisol is the predominant glucocorticoid released as part of the primary stress response, and is critical for mediating adaptive metabolic, physiological, and behavioral adjustments. However, prolonged elevation of cortisol, due to extended or repeated exposure to stressors, caused chronic stress that can negatively affect fish behavior, growth, reproduction, and immune functions (reviewed in Schreck and Tort, 2016).

With respect to salmon, the period of parr-to-smolt transition (smoltification) is one of the most sensitive periods to stressors, with chronic stress resulting in impaired ability to smolt (Bernard et al., 2019; Vehanen et al., 2023). For these reasons, there is a significant need to identify and validate biomarkers of chronic stress in different stages of Pacific salmon, which can be used to identify and where possible control/manage factors lo reduce levels of chronic stress.

The analysis of circulating (serum/plasma) cortisol is the most common method used in stress response assessments in fish. This method works well under controlled situations, where fish can be caught and rapidly sampled (within minutes to avoid the rapid increase in cortisol which occurs in response to capture stress) and it provides information on the acute stress response at the time of collection (immediate state of stress). To understand chronic stress the past cortisol history of individuals needs to be understood, Unfortunately, due to how cortisol is physiologically regulated, circulating cortisol levels are well recognized as poor predictors of chronic stress (Aerts et al., 2015).

In higher vertebrates, measurement of cortisol in hair (Raul et al., 2004) and feathers (Macbeth et al., 2010), has been demonstrated to allow for retrospective assessment of levels of stress. Building upon these studies fish scales were identified as a biomaterial that accumulates cortisol, and other physiologically important hormones including cortisone, over long periods of time. The measurement of scale cortisol content was proposed as a way to determine past cortisol history in fish, and for use as a biomarker of chronic stress (Aerts et al., 2015; de Vrieze et al., 2012). However, unlike hair and feathers in which cortisol levels remain fixed after deposition, the exchange of cortisol between the circulatory system and scales is an ongoing dynamic process, which is poorly understood, Moreover, scale cortisol levels appear not to be affected by single acute stress events such as those associated with capture (reviewed in Laberge et al. 2019; Kennedy and Janz, 2023).

This project examined the usefulness of the measurement of scale stress hormone content (SSHC) as a biomarker of chronic stress in Pacific salmon. Laboratory and hatchery-based studies were conducted to determine and validate/optimize: 1) sampling methods (e.g. study spatial heterogeneity of scale stress hormone content (SSHC)), 2) effects of acute vs. chronic stress on SSHC, 3) relationship between plasma and SSHC, 4) individual, stock and temporal variability in SSHC, including changes associated with smoltification, and 5) effects of unpredictable chronic stress on plasma and SSHC.

This project was in collaboration with the Bernier and Laberge labs at the University of Guelph. Gill homogenate NKA activity was measured by the BC Centre for Aquatic Health Sciences (Campbell River, BC, Canada).

Methods and Findings

Laboratory Studies

Scale preparation and extraction of corticosteroids followed the methods described by Laberge et al., (2019) with a few small modifications. Preliminary studies were done to determine the number of scales required for analysis, as well as to examine whether scale cortisol concentrations varied across body regions.

Using hatchery-reared juvenile Chinook salmon, three experiments were performed to assess the temporal profiles of cortisol accumulation and clearance in plasma and scales in response to stressors of varying intensity and duration: an acute stressor, three weeks of unpredictable chronic stress, and the transition from freshwater (FW) to seawater (SW) under elevated temperatures. Cortisone, the breakdown product of cortisol, was also quantified to determine whether whole animal and local cortisol metabolism contribute to scale cortisol levels and whether scale cortisol-cortisone ratios can be used for long-term stress monitoring.

Effects of Acute Stress on SSHC in Juvenile Chinook Salmon

Methods

Groups of juvenile Chinook Salmon were acclimated and held in 12.5 ºC SW. Following acclimation, undisturbed control fish were sampled to obtain baseline plasma and scale corticosteroid values. Experimental groups were subjected to a 1 minute air exposure. Control groups were not handled. Plasma and scale samples collected from both groups at 1, 24, or 72 h post-stress were analyzed to determine levels of cortisol and cortisone.

Major Findings

As expected the acute handling stress (air exposure) resulted in the rapid increases in plasma cortisol and cortisone levels and the ratio of cortisol-cortisone (Fig. 1) These increases returned to baseline levels within 24 hours.

Interestingly, a similar pattern of increases in scale cortisol and cortisone levels was observed, with levels returning to baseline within 72 hours. Scale corticosteroid clearance lags behind clearance from plasma. The ratio of cortisol-cortisone followed a similar pattern returning to baseline within 24 hours.

Interpretation

Our results contradict the finding of Laberge et al. (2019) in goldfish, where the scales did not show an increase in cortisol content following the same acute air exposure stressor. However, during our study McKinley et al. (2025) reported that scale cortisol content can increase within 30 min following an acute stressor in both goldfish and green sunfish. The difference in scale cortisol accumulation in goldfish observed between studies led McKinley et al. (2025) to suggests that underlying factors such as stressor exposure history and the cortisol concentration gradient between scale and blood may influence scale cortisol accumulation under acute stress. This is an area where additional work appears to be warranted.

Scale cortisol concentrations are now commonly used as a biomarker of chronic stress, especially in populations of wild fish. The majority of these studies have assumed that stress associated with capture has no effect on levels of scale cortisol. Our work and the recent study by McKinley et al. (2025) provides evidence that this assumption is not necessarily true. Future studies need to consider how acute stress during capture and the timing of their scale sampling relative to capture might inflate scale cortisol values.

Effects of Unpredictable Chronic Stress (UGS) in Juvenile Chinook Salmon

Methods

Juvenile Chinook Salmon were transferred into twelve experimental tanks and assigned into two treatments, control (6 tanks) or UCS (6 tanks). Fish held in 12.0 ºC SW and acclimated for 3 weeks. Following acclimation, all tanks assigned to the UCS treatment group were exposed to one of the following randomly assigned stressors once a day for 3 weeks: holding out of water in a net for 1 min; chasing with a dip net for 10 min; holding in shallow water for 5 min. These stressors were applied at randomly assigned times (9 am, 12 pm, or 3 pm) to prevent anticipation of the stressor. Fish in the control groups were not handled. Scale and plasma samples were obtained from half of the fish from each tank (7-8 fish/tank) and treatment at 1, 2, and 3 weeks following the onset of UCS. Sampling was conducted ~18 h after the last stressor exposure to avoid the influence of the last acute stress response on the measurements.

Major Findings

We found novel evidence that scale cortisol can decrease while plasma cortisol remains elevated under conditions of chronic stress (Fig. 2). Cortisol and cortisone levels in the plasma and scales of controls remained low throughout the experiment. Sustained elevation in plasma cortisol, along with the absence of growth in body size, during the UCS period, indicates that fish in the UCS group were chronically stressed. Despite this, scale cortisol levels in the UCS fish returned to baseline by week 3, indicating that a mechanism for cortisol clearance from the scales was engaged late in the UCS period. Interestingly, plasma and scale cortisone levels showed only a temporary elevation at week 1, suggesting high cortisone clearance rates earlier in the UCS period, potentially both in plasma and scales.

Interpretation

Our results differ from those reported for UCS studies in other species of fish (Laberge et al. 2019; Aerts et al. 2015; Samaras et al. 2021; Kennedy and Janz, 2023). These studies reported that levels of scale corticosteroids remain elevated, or continually increase while under UCS, regardless of plasma levels. More recently, McKinley et al. (2025) and Opinion et al. (2023) demonstrated that green sunfish and Atlantic salmon can acclimate to UCS by decreasing plasma and scale cortisol over time.

This suggests that the dynamics of the corticosteroid responses to chronic stress in both plasma and scales varies among species of fish. Scale cortisol levels may be only a suitable biomarker for some species of fish.

Our results also indicate that clearance of corticosteroids increased with time under stress, however, it is unknown the mechanism behind this.

Effects of Smoltification at Different Temperatures on Plasma and Scale Stress Hormone Content (SSHC) in Chinook Salmon Smolts

Methods

In anadromous salmonids, the parr-to-smolt transition, which prepares juvenile fish to survive the migration from freshwater (FW) into seawater (SW), is more sensitive to environmental stressors than other life stages. As such, this study hypothesized that combined thermal stress and the transfer from FW to SW would induce chronic stress and increase scale cortisol content in Chinook salmon smolts. Control fish were kept in FW at 10oC, while experimental fish were acclimated (0.5oC/day) to 10, 12.5, or 15oC and then transferred to SW over 48h. Plasma, scale and gill samples were obtained from all groups at 1, 14 and 28 days post-transfer.

Major Findings

Following transfer to SW, especially at higher temperatures, plasma cortisol generally increased within treatments with time, especially in the highest temperature (12.5 and 15.0oC) treatments . Within treatments scale cortisol remained relatively constant over time, with the 15oC saltwater group having the highest levels at 1 and 14 days (Fig. 3).

When compared to controls and other experimental groups plasma cortisone values were elevated in the 15oC seawater group, at 1 and 28 days (Fig 4A). Scale cortisone was measured at higher levels than cortisol at all time periods. Scale cortisone was highest in the 12.5 and SW15oC seawater treatments, with some evidence that levels declined with time.

Neither gill NKA activity, nor plasma osmolality explain the differences observed in corticosteroid content.

Interpretation

In contrast to what we found in our unpredictable chronic stress study, scale cortisol levels remained relatively constant over time in this study. This suggests that scale corticosteroid dynamics may differ depending on the type, and temporal application of chronic stress.

Insights

Overall, this project has vastly elevated our understanding of scale corticosteroid dynamics and usability for Chinook (and coho, to a lesser degree) salmon.

While scale cortisol content has been proposed as a reliable, retrospective look into the stress history of fishes, similar to hair (Koren et al. 2011) or feathers (Macbeth et al. 2010), our data shows that levels of corticosteroids in fish scales are far more dynamic than previously thought.

In juvenile Chinook salmon, the measurement of scale corticosteroids has limited use as biomarkers of chronic stress, due to their susceptibility to acute stress, rapid clearance after acute stress, and the onset of a corticosteroid clearance response under prolonged chronic stress. Furthermore, both scale cortisone and the scale cortisol-cortisone ratio were found to be less consistent, more variable, and cleared faster than scale cortisol, and thus are unlikely to be better biomarkers of chronic stress than scale cortisol alone. Whether this is true for other species of salmon is unclear.

Our results identify a number of factors necessary to consider when planning studies and/or evaluating/interpreting the results of previously published studies, to ensure that measured differences in scale corticosteroids are due to differences in how the fish are responding to their environment rather than being an artefact of study design.

Next Steps

There remains a poor understanding of: 1) mechanisms/pathways by which corticosteroids are deposited too and cleared from scales, 2) environmental and other factors which control rates of deposition and clearance of scale corticosteroids, 3) the extent to which there are species or sex-specific differences in these processes and 4) the physiological reasons for, and the importance of these processes, in maintaining fish homeostasis.

Future research in all of these areas would make important contributions to our understanding the dynamics and role/s of corticosteroids in scales.

Based on this projects results we do not currently recommend using scale cortisol, or cortisone, as biomarkers of chronic stress in the management off and/or conservation efforts for Chinook salmon.

Tables and Figures

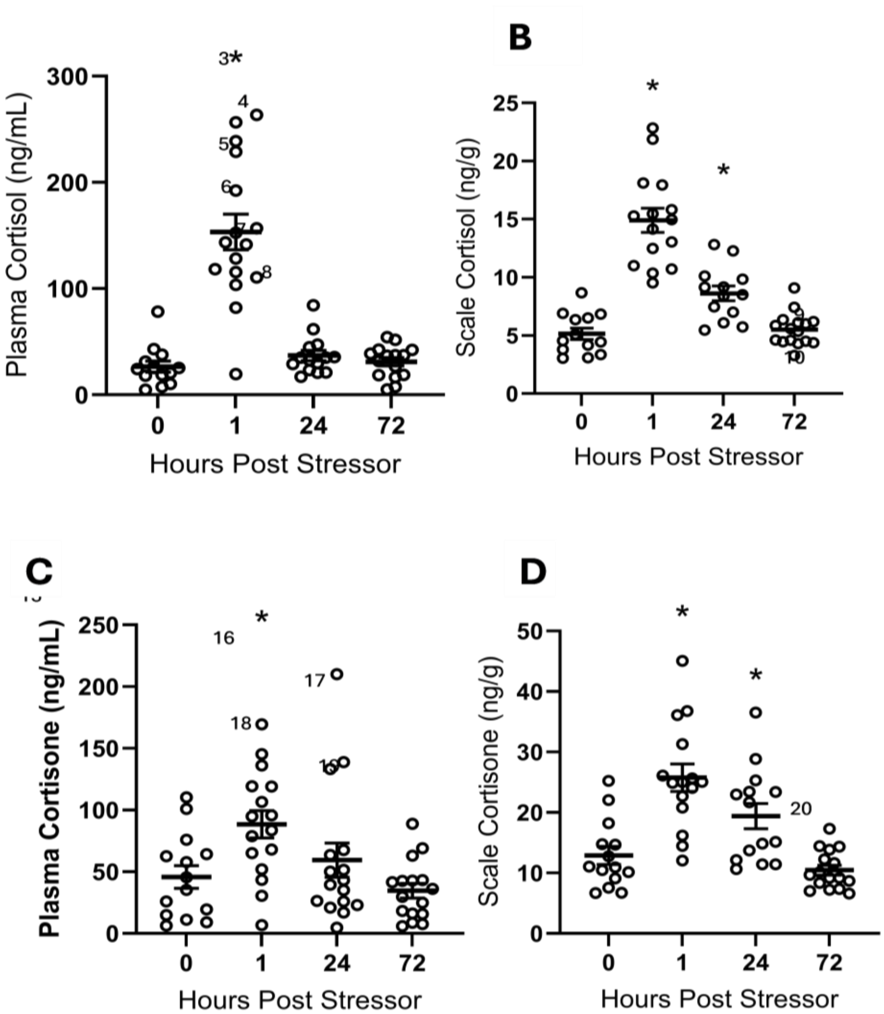


Figure 1. Effect of an acute stressor on (A) plasma cortisol, (B) scale cortisol, (C) plasma cortisone, and (D) scale cortisone in Chinook salmon smolts. Fish were stressed by being held out of water for one min. Time 0 non-handled fish served as controls. Plasma cortisol levels were compared with a Kruskal-Wallis test followed by a post hoc Dunn's test. Plasma cortisone and scale corticosteroid values were compared with one-way ANOVAs followed by

post hoc Dunnet's post hoc tests. Differences from time 0 values for a given variable are indicated by an asterisk. Data are means ± SEM, along with individual data points (plasma cortisol, n = 13-16; scale cortisol, n = 13-16; plasma cortisone, n = 14-16; scale cortisone, n = 14-16).

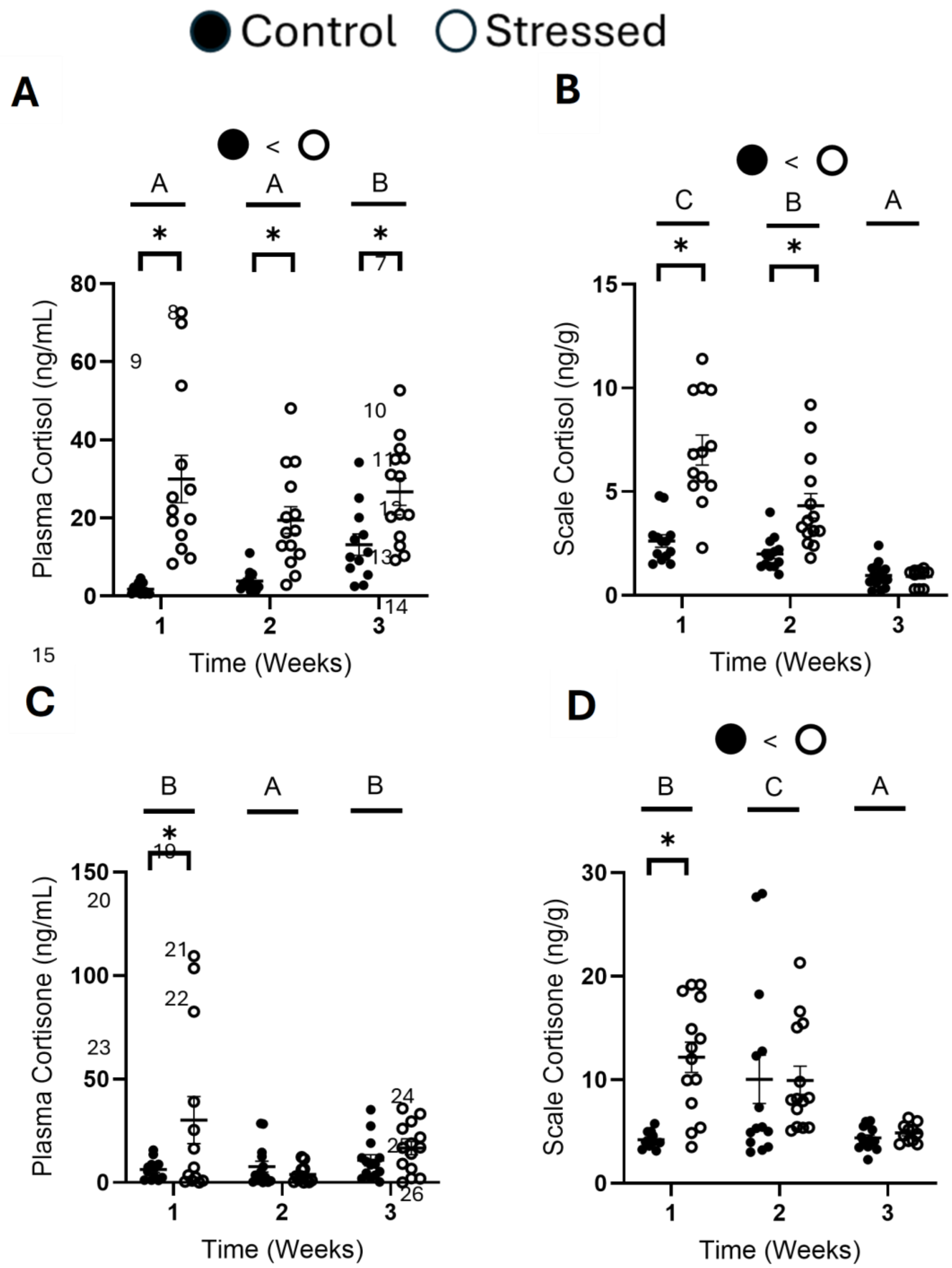


Figure 2. Effects of an unpredictable chronic stressor on (A) plasma cortisol, (B) scale cortisol, (C) plasma cortisone, and (D) scale cortisone in Chinook salmon smolts. Fish were either exposed to one of three acute stressors daily in a pseudorandomized sequence for up to 21 days (Stressed) or left undisturbed (Control). Plasma and scale corticosteroid levels were compared with two-way ANOVAs (A, B) or Generalized Linear Models (C, D) followed by post hoc Tukey's HSD tests or LSD pairwise contrasts. Differences are depicted using either underlined letters (overall time effect), oversized circles (overall treatment effect), or asterisks (between treatments within a timepoint).

Data are means ± SEM, along with individual data points (plasma cortisol, n = 12-14; scale cortisol, n = 11-14; plasma cortisone, n = 13-15; scale cortisone, n = 11-15).

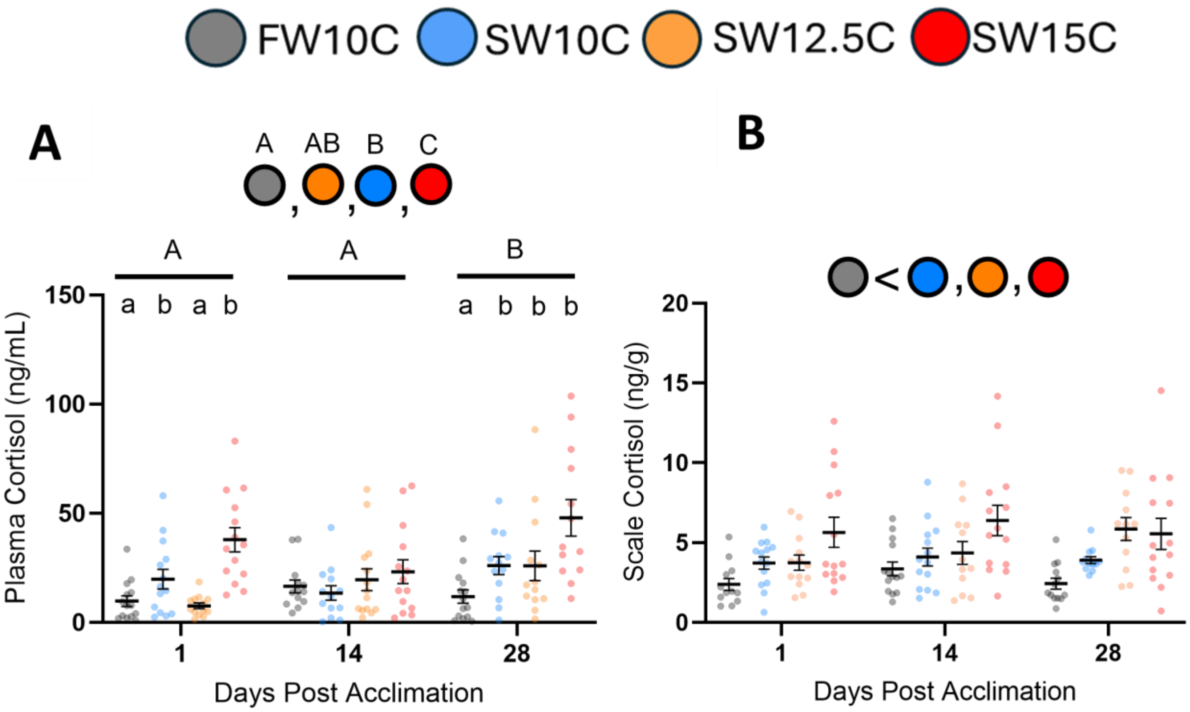


Figure 3. Effects of a combined osmotic and thermal (OsmoThermal) stressor on (A) plasma cortisol and (B) scale cortisol content of Chinook salmon smolt. Fish were either left at control conditions (FW10C), or maintained under one of three OsmoThermal stressors (SW10C, SW12.5C, or SW15C) for up to 28 days. Plasma cortisol values were compared with a two-way ANOVA (A), followed by a post hoc Tukey's HSD test. Scale cortisol values were compared with a Generalized Linear Model (B), followed by an LSD pairwise contrast. Differences are depicted using either underlined letters (overall time effect), oversized circles with capital letters above (overall treatment effect), or lowercase letters (between treatments within a timepoint). Data are means ± SEM, along with individual data points (plasma cortisol, n = 13-14; scale cortisol, n = 12-14).

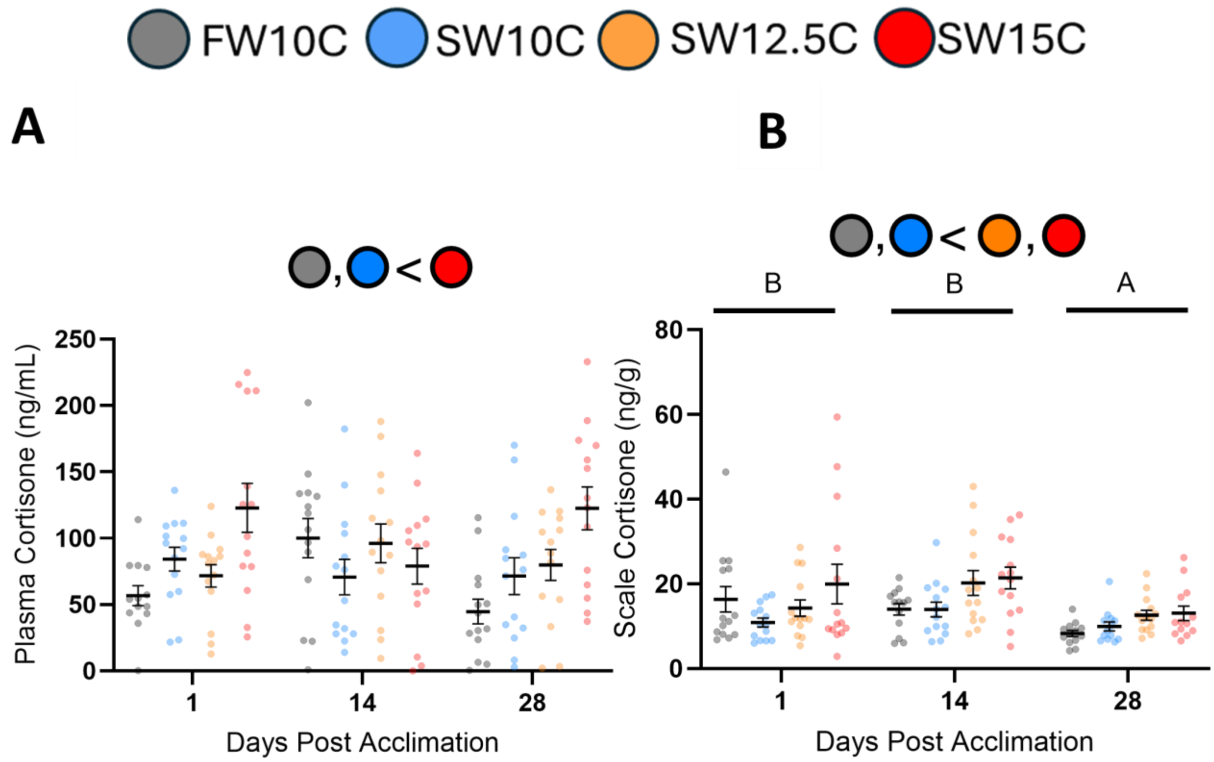


Figure 4. Effects of a combined osmotic and thermal (OsmoThermal) stressor on (a) plasma cortisone and (B) scale cortisone content of Chinook salmon smolt. Fish were either left at control conditions (FW10C), or maintained under one of three OsmoThermal stressors (SW10C, SW12.5C, or SW15C) for up to 28 days. Plasma and scale (A, B) cortisone values were compared with Generalized Linear Models, followed by LSD pairwise contrasts. Differences are depicted using either underlined letters (overall time effect), oversized circles (overall treatment effect), or lowercase letters (between treatments within a timepoint). Data are means ± SEM, along with individual data points (plasma cortisol, n = 13-14; scale cortisol, n = 12-14).

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2448 – Proactive, Holistic Salmon Health Management

Holistic assessment of health and condition of Chinook during hatchery rearing at two hatcheries, Nitinat River and Robertson Creek (in progress)

Collaborations: SEP Hatcheries: Nitinat River Hatchery, Robertson Creek Hatchery, Chehalis River Hatchery, Tenderfoot Hatchery, and Puntledge Creek Hatchery.

Region: Southern BC

Waterbodies: Nitinat, Sarita, Robertson, Maria Slough (Chehalis), Puntledge, and Tenderfoot

Species: Chinook

Populations: Nitinat, Sarita, Robertson, Maria Slough (Chehalis), Puntledge, and Tenderfoot

Highlights

Idea of the project

Current fish health monitoring at SEP hatcheries is primarily reactive, responding to disease outbreaks. Molecular tools allow the detection of pathogens, disease, stress, and smoltification from minimally invasive gill biopsies via salmon Fit-Chips. Further, non-invasive e(nvironmental)RNA is able to detect infectious agents and stress on population level from water samples. Together, these tools may allow for proactive and adaptive fish health management to improve hatchery operations.

Key findings

- A two-year proof of concept study in collaboration with SEP enhancement hatcheries (Robertson Creek and Nitinat) was followed by a third year with Conservation Hatcheries. Consistent proactive health monitoring of live and moribund sampled fish (gill) was able to identify shifts in stressors and pathogens in cultured cohorts as well as provide insights on smolt readiness for saltwater that showed interannual variation.
- In the final year, conservation hatchery staff was trained in sterile tissue and water sampling protocols.

- Simultaneous sampling of eRNA from different water sources utilized in the hatchery identified potential sources of fish infections.
- Stress assessment via eRNA on a cohort level without the need to assess individual fish deliverd mixed results with some stressors more readily detected than others.
- Pathogen screening of eRNA samples showed that source water profiles shifted over the rearing season and differed between hatcheries.
- Through the use of Salmon Fit-Chips, a novel virus (Influenza B-like virus) was discovered after it triggered a molecular signal indicative of a host response to a virus in the absence of any viruses already in the MGL assay panel. *Implications of these findings*
- Molecular tools provide a means of proactive health monitoring at hatcheries. Specifically, eRNA can provide critical non-invasive insights into cohort health and development, making it particularly useful in the conservation hatchery context. Identifying pathogen presence within cohorts using eRNA and nonlethal or post-mortem gill samples provides important context to hatchery managers and creates opportunities to get ahead of pathogen outbreaks or adaptively manage husbandry.
- Despite these successes, current sampling and analysis pipelines are labor intensive and could benefit from future research into automatization (e.g. automated eRNA sampling systems).
- The potential for cohort/population level measures of stress was explored by running eRNA samples on Fit-Chips. This was a partial success, for example the thermal stress signature at Robertson Creek (Figure 6). More refining and baseline work is required to fully implement the tool.

Background

The DFO salmon enhancement program (SEP) is undergoing a modernization process to improve hatchery effectiveness. Specifically, an increased focus is being placed on conservation-based hatcheries. Modernized practices aim to produce high quality rather than quantity of smolts and try to minimize husbandry practices associated with elevated stress or pathogen exposure. One intention is to minimize pathogen infections to reduce transmission risks to wild stocks, fostering better conservation outcomes. Smolt readiness is often critical to survival of hatchery releases, but conventional assessment is invasive, expensive, and slow. Novel molecular tools offer attractive avenues to assess the effectiveness of many of the SEP modernization goals and inform scientifically defensible hatchery operations. To achieve proactive and adaptive management, molecular data can monitor the effects of husbandry, mortality, and treatment in near real-time. In this project we aim to provide near real-time health monitoring based on gill tissue biopsies as well as eRNA through deploying salmon Fit-Chips in collaboration with the following SEP hatcheries: Nitinat River, Robertson Creek, Chehalis River, Tenderfoot creek, Puntledge River, Rosewall Creek.

Methods and Findings

Main methods used

Nucleic acids were extracted from salmon gill biopsies collected from hatchery cohorts and were run on the Fluidigm Biomark nanofluidic qPCR platform. Within a single analytical run, this platform allows for assays of 20 infectious agents and 58 salmon genes to be run against 80 gill samples. The salmon gene expression can be statistically analyzed to provide probabilities (0-1) for certain salmon "stressor states" including: food deprivation, imminent mortality, viral disease, smoltification, hypoxia, inflammation, and immune stimulation. Detailed methods for the Fit-Chip laboratory and statistical analysis can be found in Akbarzadeh et al. (2024). Salmon Fit-Chips were also used to analyze the nucleic acids extracted from water filtered at the hatcheries known as e(nvironmental)RNA. Crucially this approach allows for the detection of live pathogens present in the water around the fish or in the hatchery water source, acting as an early warning signal for pathogen exposure and infection. Similar to the stress assessment gill biopsies with Fit-Chips, using the relative ratios of salmon RNAs in the water can inform the stress status of a hatchery cohort on the group level, for instance detecting if fish are mounting an antiviral response indicative of viral infection, suffering from stress such as high temperatures or hypoxia, or if fish are getting ready for the transition to saltwater (smoltification), which dictates the optimal release date from the hatchery. Exploring the use of eRNA by comparing the results of cohort eRNA Fit-Chips results with the stress and pathogen signature of individuals within the cohort was a key objective of the initial phase of the project as it holds great promise for stocks of conservation concern due to the ability to monitor cohort health non-invasively.

Advancements in methodology, technology, and application/Products and tools produced

eRNA salmon Fit-Chips were refined for the non-invasive monitoring of hatchery cohorts. Specifically, pathogens could be assessed effectively while cohort level hypoxia and temperature stress measurements showed promising results in the eRNA Fit-Chips. Other parts of the eRNA Fit-Chips require additional research and development to streamline procedures and reduce variability.

Advancements in communication and knowledge transfer

An automated reporting pipeline was developed to classify Fit-Chip data and produce figures which streamlined data analysis and reporting, providing managers with expedited fish health metrics. While the reporting was not in real-time, this project did provide in season reporting and future iterations of the project would need to address the obstacles to real-time reporting identified throughout the project.

Key results and information generated

Fit-Chip data from eRNA and tissues provide useful information for hatchery managers, making them a promising tool for the future. Specifically, we demonstrate that Fit-Chips can:

- efficiently track pathogen prevalence and load in fish tissues and eRNA water samples (Figure 1 and 2);

- document pathogen exposure from source waters and cohort tanks across the entire rearing period (Figure 1-3);
- document smoltification progression from gill biopsies which could be used to optimize release timing (Figure 4);
- detect viral disease development signals in gill biopsies associated with known viruses and led to the discovery of a novel virus where no known viruses were detected (Figure 5); and
- detect specific stressors simultaneously from eRNA and gill biopsies (Figure 6).

Insights

With this project we demonstrate the utility of salmon Fit-Chips for proactive hatchery management through individual level gill biopsies as well as on cohort level through eRNA from water samples. Our data:

- identifies source water the occasional origin of pathogen exposure and infections (Figure 3);
- documents several instances of pathogen detections in water prior to detections in tissues (Figure 2);
- identifies changes in water properties as the likely source of stress (Figure 6);
- demonstrates that 30% of the mortalities at Chehalis (Maria Slough Chinook) displayed a food deprivation signature as well as low weight to length ratio, suggesting that the fish had ceased feeding weeks prior to their death;
- documents that smoltification status at release varied substantially between years (Figure 4);
- documents the association of viral disease development (VDD) signature with known viruses (Figure 5); and
- identified a novel Influenza B-like virus associated with VDD positive fish of unknown impact (Figure 5).

This project informs salmon management by providing an early warning tool for pathogen and stress monitoring from non-invasive eDNA/eRNA samples of specific interest for stocks of conservation concern. This has generated substantial discussion with managers at Tenderfoot Creek hatchery. This project has also documented the effects of water source on pathogen levels and highlighting pathogen vs imprinting tradeoffs:

- River water → higher pathogen loads early
- Well water → lower early infections but spikes when switched to mixed water
- Continuous mixed water → lowest stable pathogen levels.

We monitored smoltification progress over the rearing season, demonstrating that this approach could be used to inform release timing decisions. This project also monitored pathogen abundance in source water too, demonstrating that this approach could be used to inform decisions to shift to new water sources. This work provided single tool to assess multiple stressors cumulatively impacting hatchery reared fish, as well as, providing a baseline of cohort health against which to evaluate future return success to identify key factors impacting post release survival.

Areas of uncertainty

- Addressing the sampling artifact(s) and/or the causes of mismatch in the smoltification, VDD, and imminent mortality panels assessed by eRNA and gill biopsy Fit-Chips
- The impact of the two observed high prevalence viruses PsNV and InfB for which no formal pathogenicity data is available.

Next Steps

Future optimization for Fit-Chip monitoring of hatchery cohorts will focus on the following:

- automated eRNA sampling systems installed on rearing tubs to alleviate the burden of sampling and permit more frequent sampling events;
- improved sample handling and laboratory processing; and
- tailored reporting to operational needs of specific hatcheries.

The data from this pilot project could be integrated into salmon conservation management by:

- integrating molecular data as a standard in hatchery management practices;
- integrating the hatchery database with the molecular reporting pipeline to improve results turnaround; and
- considering the impacts of microbes and pathogens, both positive and negative, within the natal systems for salmon conservation hatcheries (e.g., rearing in surface waters may result in increased survival despite; Harstad et al., 2018).

Tables and Figures

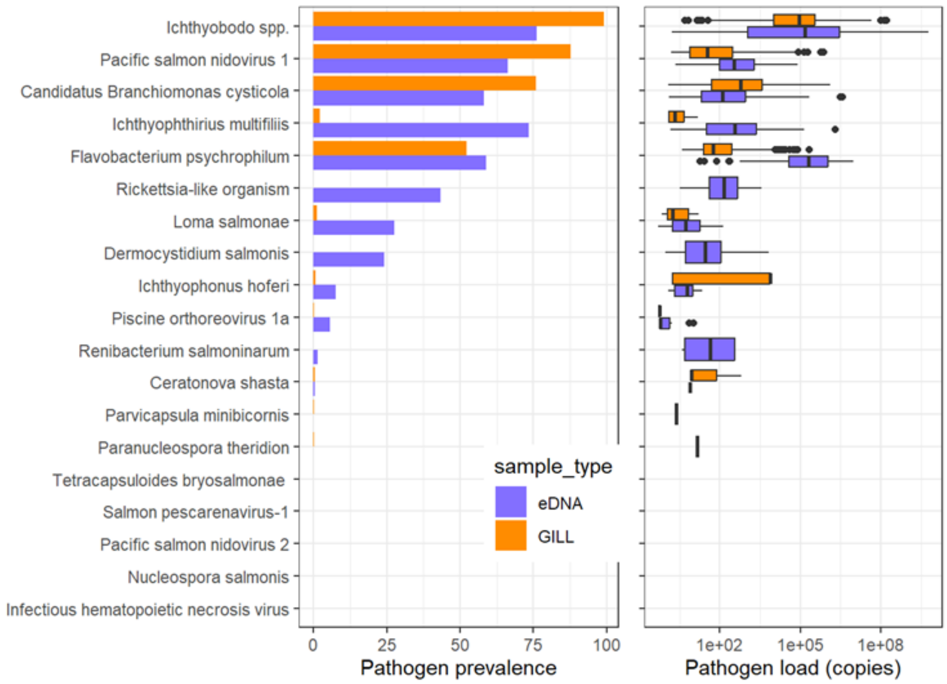

Figure 1. Fit-Chip eRNA validation: Strong correlation in detection of pathogens in hatchery fish and eDNA/eRNA water (Nitinat 2024). Pathogen prevalence and load within gill tissue (orange) or tank water (purple).

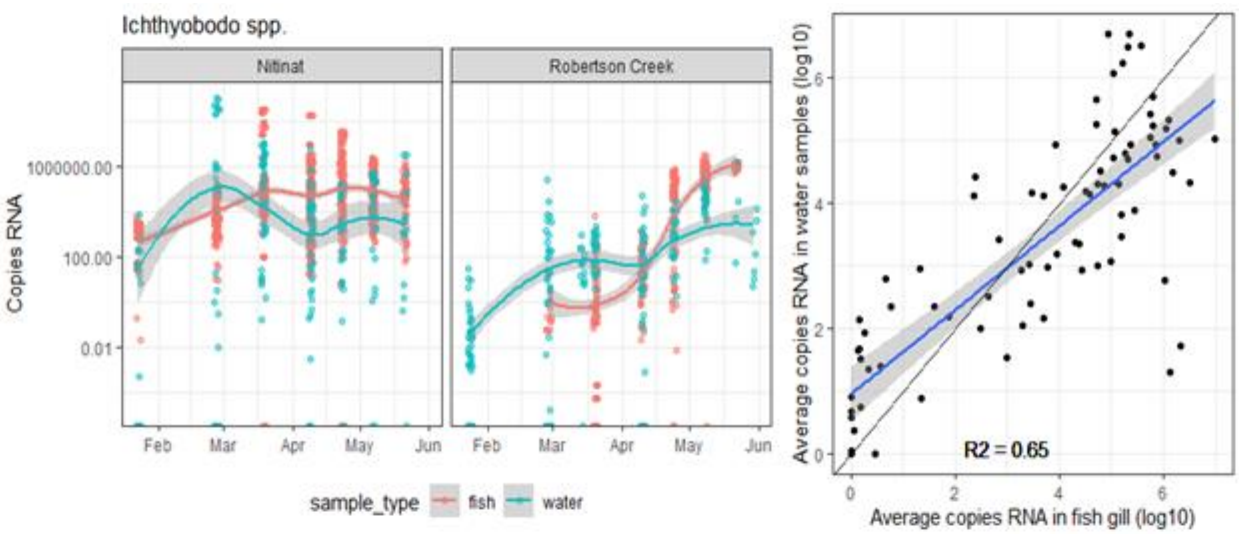

Figure 2. Fit-Chips can track pathogen load in both fish tissues (red) and water samples (blue, eRNA). Ichthyobodo spp loads in water (eRNA) peak before detections in fish gill tissues at two hatcheries (left panels).Ichthyobodo load in gill and water were strongly correlated with each other (right panel).

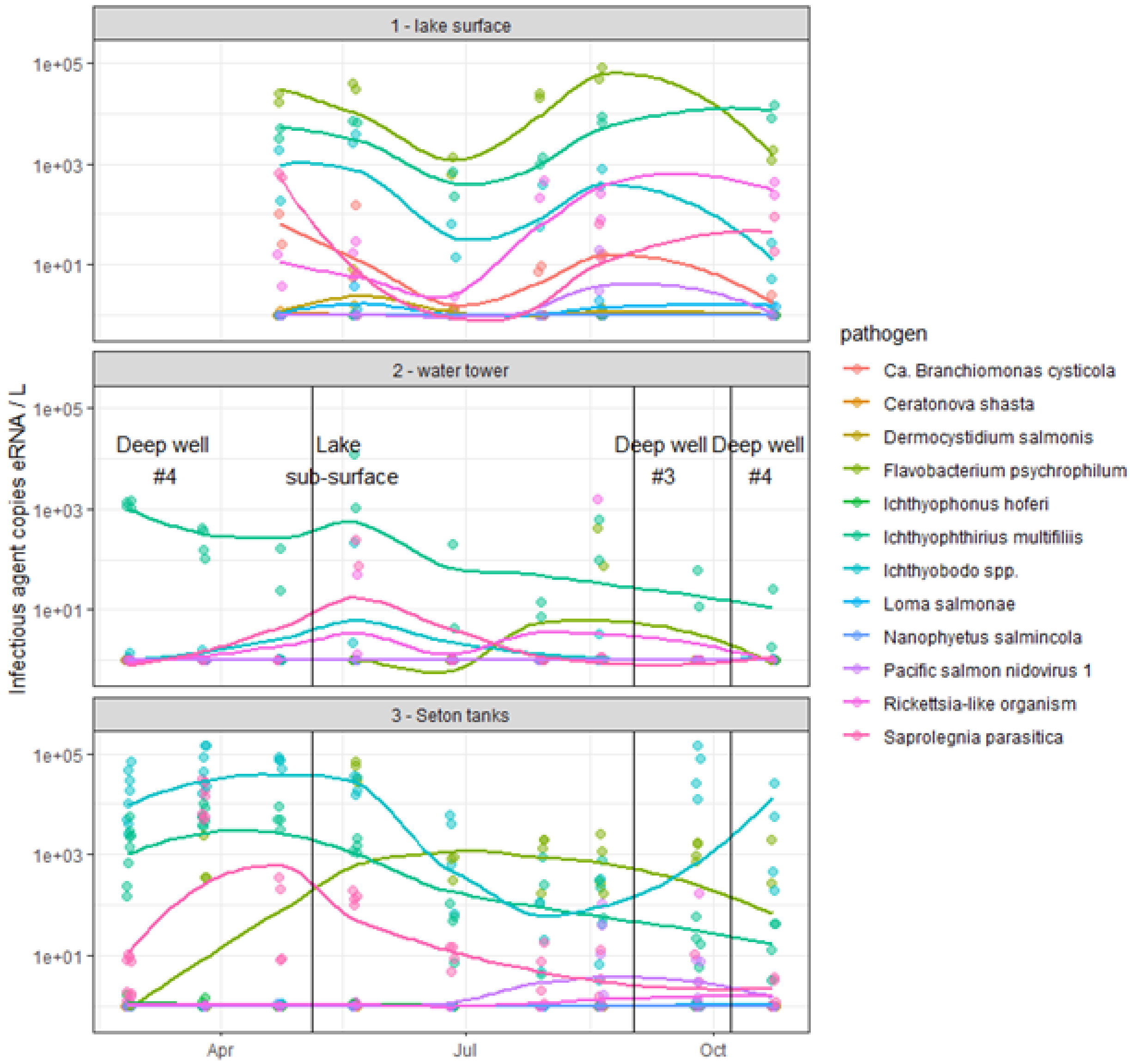

Figure 3. Fit-Chips provide pathogen tracking in source water and rearing tanks over the rearing season (Tenderfoot 2025). Pathogens in lake surface samples showed synchronous seasonal shifts (top). Pathogen concentrations in the water tower fluctuated between the different water sources used (middle panel, vertical lines and text). Pathogen concentrations in the rearing tanks for the study population presumably reflected a combination of influences from source water and the population itself (bottom).

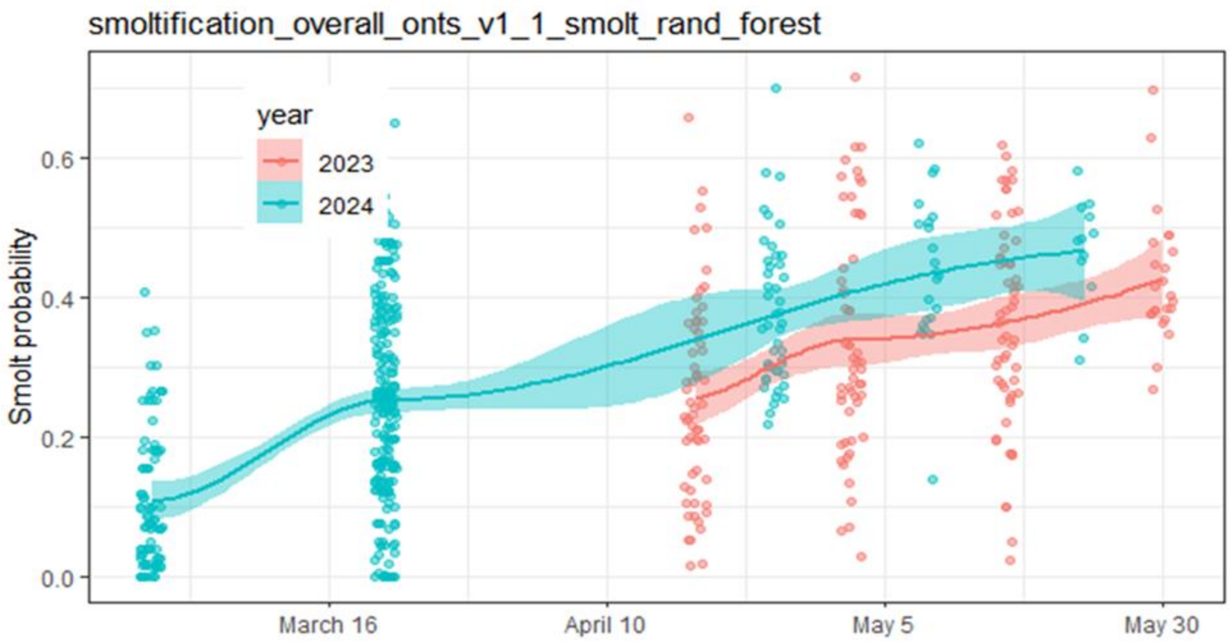

Figure 4. Fit-Chips can monitor smoltification status in fish tissues during hatchery rearing and provide smolt readiness information to managers. Smoltification status at Robertson Creek showed significant variation between years.

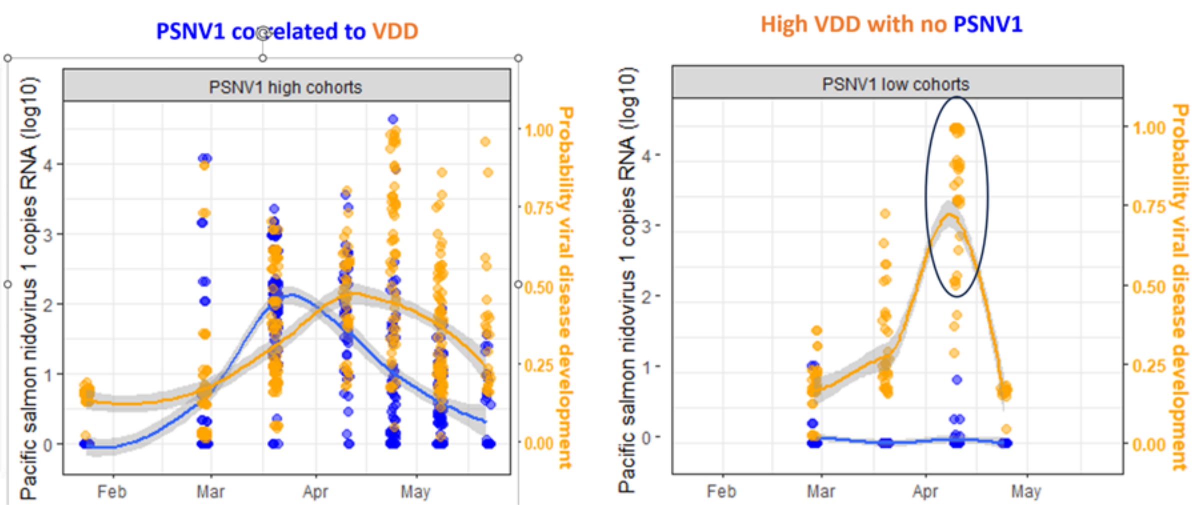

Figure 5. FitChips provide proactive health monitoring through the early detection of viral disease and novel viral agents. High loads of PsNV (Pacific salmon nidovirus) were associated with high probability of a viral disease development gene expression signature (left). A novel Influenza B like (IfnB) virus was discovered in collaboration with Dr. Gideon Mordecai in a VDD high cohort with low PsNV detections (right) and no other known viruses present. Targeted IfnB assays demonstrated a correlation between IfnB and the probability of viral disease development.

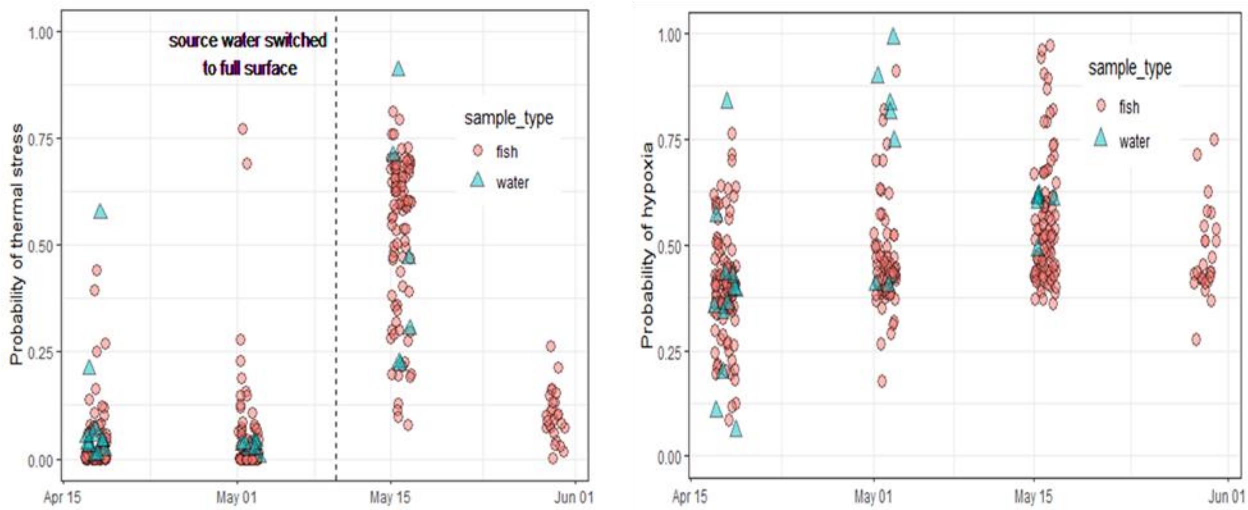

Figure 6. Fit-Chips provide promising results by resolving selected stressor states from eRNA water samples. The thermal stress signature (left) and hypoxia signature (right) were resolved in both the fish gill tissue (red circles) and eRNA samples (blue triangles). The correlation between fish and water for thermal stress was stronger than that between fish and water for hypoxia.

References

Akbarzadeh A, Ming TJ, Schulze AD, Kaukinen KH, Li S, Gunther OP, Houde ALS, Miller KM (2024) “Developing molecular classifiers to detect environmental stressors, smolt stages and morbidity in coho salmon *Oncorhynchus kisutch.” Science of the Total Environment,* 951(15). https://doi.org/10.1016/j.scitotenv.2024.175626

Harstad DL, Larsen DA, Miller J, Adams I, Spangenberg DK, Nance S, Rhobach L, Murauskas JG, Beckman BR. 2018. Winter-rearing temperature affects growth profiles, age of maturation, and smolt-to-adult returns for yearling summer Chinook salmon in the Upper Columbia River Basin. North American Journal of Fisheries Management, 38:867-885.

FISHERY MONITORING AND HARVEST TECHNIQUES

9000 - Enhanced MSF Monitoring and Chinook Reference Fishery

[Enhanced monitoring of recreational chinook salmon mark-selective fisheries in south coast BC tidal waters : reference fishery, 2023]

[Enhanced Monitoring of Recreational Chinook Salmon Mark-Selective Fisheries in South Coast BC Tidal Waters: Reference Fishery, 2024]

[South Coast Area BC Chinook Reference Fishery Biological Data - Open Government Portal]

Collaborations: Sport Fishing Institute of British Columbia (SFI)

Region: Southern BC

Waterbodies: Bute Inlet, Toba Inlet, Sechelt Inlet, Gulf Islands/Saanich Inlet, Victoria & Haro Straight, Howe Sound

Species: Chinook

Highlights

- The Chinook reference fishery was a fishery-independent study to assess estimates produced by DFO's fishery-dependent recreational fishery catch monitoring (creel) program particularly for mark-selective fisheries (MSFs). This included catch by size class, hatchery mark rate, and stock composition of unmarked Chinook that would otherwise be released at sea in a pure MSF.

- The reference fishery provided an unbiased baseline of the Chinook composition vulnerable to the recreational fishery, something that creel data alone cannot fully provide, and is therefore a valuable tool for evaluating active MSFs and supporting future MSF design.

- Results indicate that core assumptions underlying creel estimates in MSFs need to be explicitly considered in fishery planning, as reliance on creel data alone can misrepresent impacts on stocks of concern and affect management decisions.

Background

Mark-selective fisheries (MSFs) have been implemented as a management tool to shift exploitation away from natural-origin Chinook salmon toward hatchery-origin fish; the latter often have their adipose fin removed at the hatchery and are referred to as "marked". In pure MSFs, unmarked stocks are legally required to be released at sea and thus are unavailable to dockside sampling. Following widespread recreational Chinook closures in 2019, a series of mixed-bag and pure MSFs were progressively introduced across southern British Columbia between 2020 and 2024, increasing the need for robust monitoring to evaluate their impacts.

During consultations, First Nations and stakeholders raised concerns about potential encounters with Chinook stocks of concern in MSFs. In response, the Pacific Salmon Strategy Initiative (PSSI) supported enhanced monitoring under the Harvest Transformation pillar, including expanded creel surveys and the development of a Chinook reference fishery. The reference fishery was designed to address key data gaps by independently assessing mark rates, legal rates (i.e., proportion of legal size Chinook encountered), and stock composition–particularly for unmarked fish in pure MSFs–aligning with recommendations from the Pacific Salmon Commission to improve monitoring of MSFs. This work was made possible through collaboration between DFO and the Sport Fishing Institute of BC, with support from a BC Salmon Restoration and Innovation Fund grant that enabled the use of charter vessels and local guide expertise.

Methods and Findings

Sampling operations were designed to closely mirror typical recreational Chinook salmon fisheries to ensure that sampled fish were representative of those vulnerable to capture by recreational anglers. Reference fishing trips were conducted by experienced local guides operating as standard charter excursions. A trained DFO sampler was assigned to each vessel to document and sample all Chinook salmon encountered. Activities were restricted to MSF open areas or predefined sampling boundaries (Figure 1). While guided fishing typically results in higher catch rates than unguided effort, the objective of the reference fishery was not to estimate fishing effort but maximize catch in order to characterize catch composition, mark rates, and stock composition of Chinook encountered by the recreational fishery. In total, 780 boat days of Chinook sampling were completed over the 3-year study.

Chinook salmon were identified at the boat's side, briefly brought aboard for sampling, and released immediately following best-practice handling procedures consistent with DFO guidelines. All non-Chinook species were released immediately and recorded. For each Chinook sampled, data collected included catch location, time to landing, fork length, adipose fin clip status, and a tissue sample for stock ID (genetic stock identification (GSI) and parentage-based tagging (PBT; Beacham et al., 2022)). Results are presented at the stock region level, where assignment confidence is highest and alignment with Canadian stock management units is strongest (Beacham et al., 2018).

This project generated a novel, fishery-independent dataset and provided unbiased baseline information on the stock composition (Figure 3), mark rate (Figure 2), and legal-size rate of Chinook salmon vulnerable to the recreational fishery, regardless of size or mark status. The dataset also includes detailed spatial and operational metadata linked to each encounter, enabling improved interpretation of results and supporting future analyses. Products from this work include publicly released biological datasets, technical reports, and dashboards that enhance transparency, support management evaluation of MSFs, and improve communication of results to partners and stakeholders.

Insights

The Chinook reference fishery has substantially advanced understanding of Chinook salmon populations encountered by recreational fisheries by providing a baseline of biological data. By sampling Chinook regardless of size or mark status, this project has generated unbiased estimates of stock composition, mark rates, and legal-size rates that are not otherwise observable during mark-selective fishery (MSF) monitoring. These data improve understanding of which stocks are exposed to recreational fishing activity, including stocks of concern that are can be poorly represented by dockside sampling programs in MSFs (Figure 3).

The results directly inform decision-making, planning, and policy guidance related to MSFs. The data reduce uncertainty around the impacts of MSFs on vulnerable Chinook stocks and allow managers to critically evaluate assumptions underlying current catch monitoring methods, particularly creel-based estimates (see Figure 2). This improved evidence base supports more informed trade-offs between fishing opportunity and conservation objectives, helps align MSF design with realistic monitoring capacity, and contributes directly to Integrated Fisheries Management Plan (IFMP) development and briefings to the Minister on key management decisions.

The project also advances understanding of cumulative impacts and pathways of effect by providing detailed encounter data that can be linked to regulations, fishing dynamics and compared to standard catch monitoring methods. In doing so, it highlights key limitations of existing monitoring tools and identifies where biologically meaningful thresholds and risks may be underestimated due to data gaps. Importantly, MSFs inherently constrain the ability to observe impacts on all stocks encountered in the fishery; the reference fishery partially overcomes this limitation and clarifies where residual uncertainty remains.

Overall, the primary outcome of the Chinook reference fishery is a meaningful reduction in uncertainty in fisheries management. In the absence of robust data, management must rely heavily on the precautionary approach; this project provides the empirical evidence needed to move from precaution driven by uncertainty to precaution informed by data. The insights gained will continue to guide future MSF planning, help determine reference fishery requirements through collaborative processes, and support ongoing improvements to monitoring frameworks based on lessons learned from this unique and valuable dataset.

Despite the substantial reduction in uncertainty achieved through the reference fishery, some limitations remain. Analytical power can be constrained in certain spatial and temporal strata where sample sizes are low, particularly for stocks that occur at very low prevalence. Even with robust sampling effort, rare Chinook stocks may not be detected, and absence of detection should not be interpreted as absence of exposure. The reference fishery is not a census, but rather a robust, fishery independent sampling program designed to complement existing creel monitoring. As such, it cannot fully resolve all sources of uncertainty inherent in recreational catch monitoring, but it provides critical context for interpreting estimates and understanding the limitations and assumptions of current monitoring tools.

Next Steps

Key remaining knowledge gaps relate to understanding when and where a reference fishery is necessary versus when existing creel and complementary monitoring tools are sufficient to evaluate MSFs. Future work should focus on using the reference fishery baseline to formally test assumptions underlying creel-based catch and encounter estimates, identify strata where monitoring power is limited, and define thresholds for acceptable uncertainty in MSF evaluations. This will help determine the conditions under which a reference fishery provides the greatest value and where alternative monitoring approaches may be appropriate.

Project findings should be operationalized by integrating reference fishery outputs directly into MSF planning and assessment processes. The reference fishery is an effective tool for evaluating active MSFs and should be considered strategically in future MSF design, particularly for fisheries with high conservation risk or limited observability. Moving forward, closer collaboration between Stock Assessment and Fisheries Management is recommended to align MSF design with monitoring capacity, and to jointly determine reference fishery requirements based on management objectives, data needs, and evaluation metrics. This approach will support efficient use of resources while ensuring MSFs are implemented and assessed using the best available data.

Tables and Figures

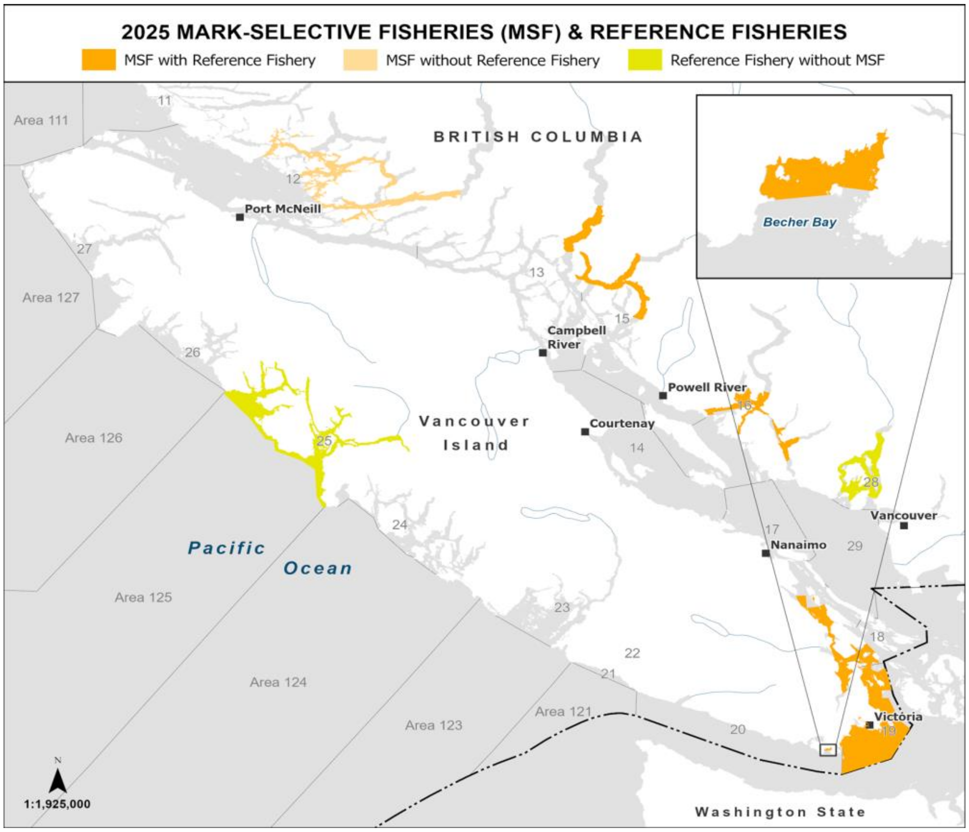

Figure 1. Map of MSFs with Chinook reference fisheries, MSFs without Chinook reference fisheries and areas without MSFs but with Chinook reference fisheries in the DFO South Coast Area in 2025. Note the reference fishery in Area 25 was not funded by PSSI.

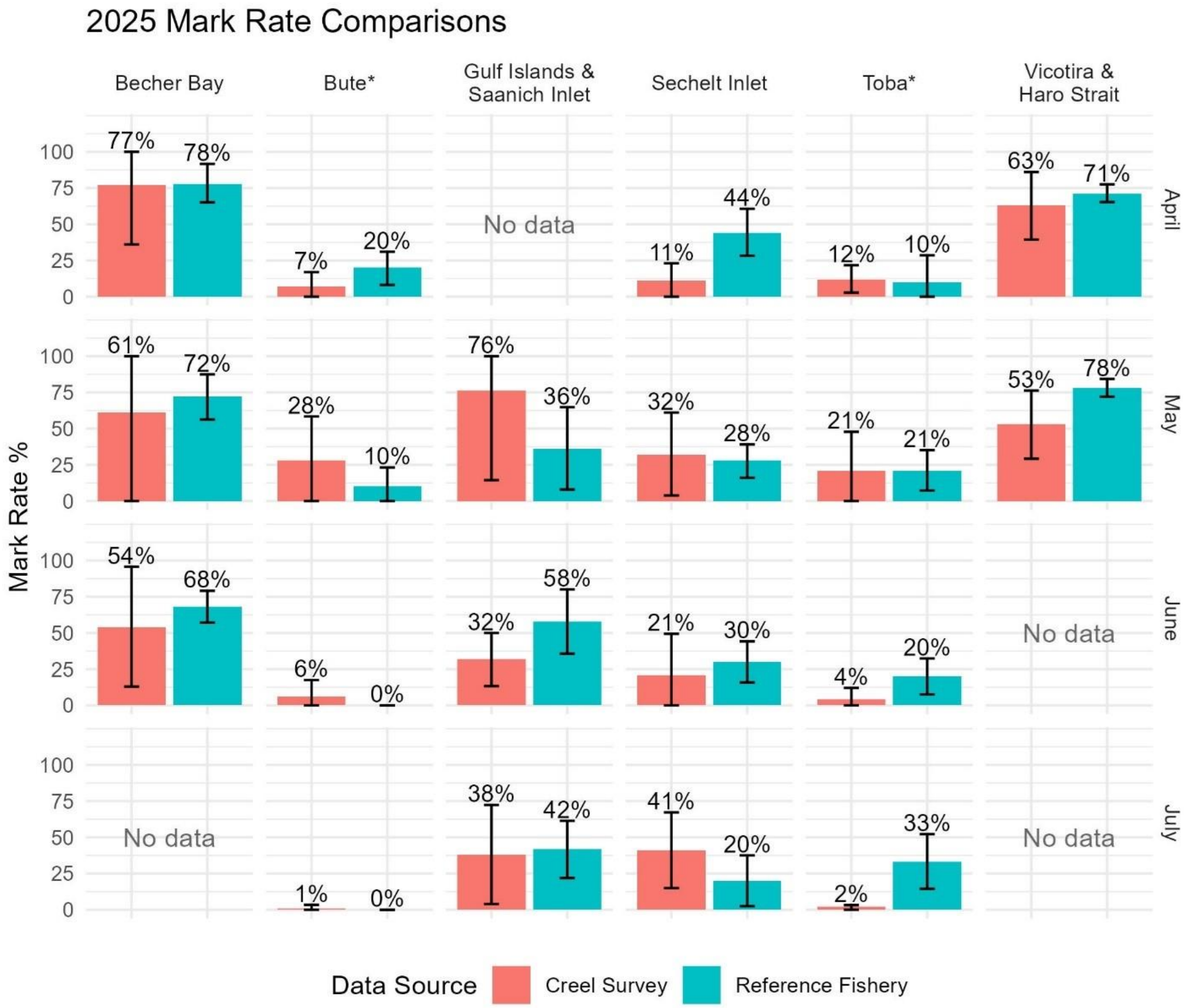

Figure 2. Comparison of creel-estimated mark rates (red) and reference fishery-observed mark rates (blue) by month and MSF in 2024. Error bars represent 95% confidence intervals. “NA” indicates the fishery was not open, while “No data” means the fishery was open but the reference fishery was not operating. Asterisks (*) indicate mixed-bag MSFs (Bute and Toba Inlets); all others are pure mark-selective fisheries.

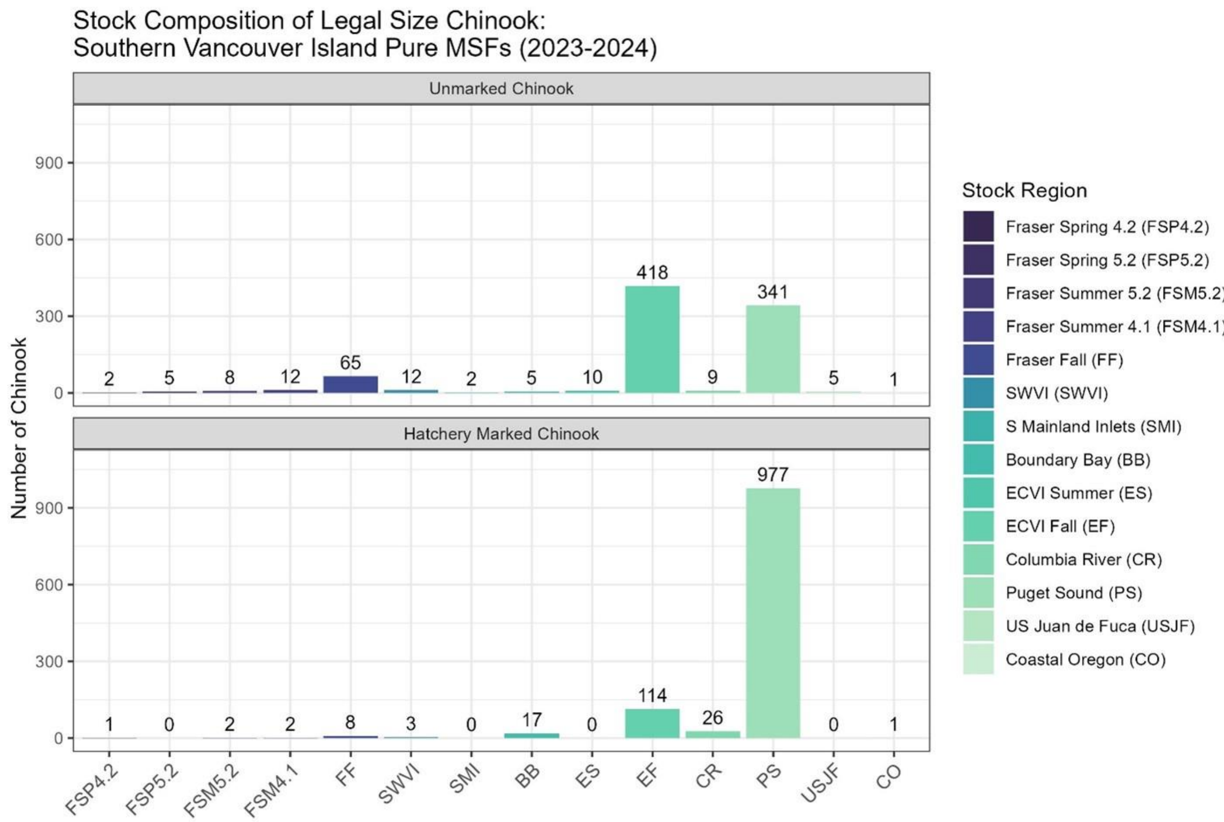

Figure 3. Stock composition of legal sized Chinook salmon by month and mark status in all reference fisheries conducted within Southern Vancouver Island. Numbers at the top of each bar are the sample size of Chinook caught in the reference fishery in each category.

References

Beacham, T.D., Wallace, C., MacConnachie, C., Jonsen, K., McIntosh, B., Candy, J.R., and Withler, R.E. 2018. Population and individual identification of Chinook salmon in British Columbia through parentage-based tagging and genetic stock identification with single nucleotide polymorphisms. Canadian Journal of Fisheries and Aquatic Sciences 75(7): 1096-1105. https://doi.org/10.1139/cjfas-2017-0168

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2394 - Trawl Fishery Enhanced Salmon Bycatch Monitoring

Review of Salmon Bycatch in the Pacific Region 2022/23 Groundfish Trawl Fishery and Preliminary Results of an Enhanced Monitoring Program

Salmon Bycatch Monitoring and Sampling Results for the Pacific Region 2023/24 Groundfish Trawl Fishery

Salmon Bycatch Monitoring and Sampling Results for the Pacific Region 2024/25 Groundfish Trawl Fishery

Collaborations: Canadian Groundfish Research and Conservation Society, David Suzuki Foundation, Archipelago Marine Research Ltd., and JO Thomas and Associates Inc.

Region: BC Coast

Species: All *Oncorhynchus* spp

Highlights

Bycatch of Pacific salmon in the groundfish trawl fishery has emerged as an important management issue due to the potential impacts on stocks of conservation concern, particularly for Chinook salmon, which constitute the majority of salmon bycatch. Beginning fall 2022, an enhanced monitoring program for salmon bycatch was implemented to provide accurate estimates of catch by species and to characterize the stock composition of Chinook salmon.

The monitoring program captured large fluctuations in Chinook salmon bycatch with total catches peaking at 26,273 individuals during the 2022/23 trawl fishery followed by a steep decrease to 7,040 individuals for the 2024/25 trawl fishery. This marked reduction coincided with the implementation of a salmon bycatch management plan in 2024, which included the introduction of a fleet-wide Chinook salmon bycatch cap of 9,500.

Representative sampling across three and a half years of fishing improved our understanding of the stock composition of Chinook salmon bycatch, including stock-specific catches and catch of Chinook salmon coded-wire tag (CWT) indicator stocks. Across all years examined, the majority of Chinook salmon bycatch originated from stocks in the continental United States, whereas Canadian-origin bycatch was dominated by the Fraser River Fall 4(1) stock.

Background

The Pacific Region groundfish trawl fishery is one of the largest commercial fisheries in British Columbia by catch volume and value. Management of the fishery is informed by a comprehensive monitoring program that includes mandatory electronic monitoring and dockside validation of all catch. In recent years bycatch of Pacific salmon, particularly Chinook salmon, has emerged as a management issue due to the potential for impacts on stocks of conservation concern. In trawl fisheries, salmon are a prohibited species that cannot be targeted or sold, but until recently monitoring requirements for salmon bycatch were no different than those applicable to all catch species and representative information on catch by stock were not available.

In collaboration with the Groundfish Trawl Research and Conservation Society, the groundfish trawl industry, non-profit organizations, and monitoring service providers, DFO developed an enhanced monitoring and sampling program for salmon bycatch to address knowledge gaps and inform management of the fishery. The program was designed to provide accurate estimates of salmon bycatch by species and determine impacts on Chinook salmon stocks of concern by estimating stock composition and coded wire tag catches. Enhanced monitoring was initiated in September 2022 and has continued until February 2026, covering multiple fishery years and informing the development a salmon bycatch management plan for the trawl fishery.

Methods and Findings

Commercial groundfish trawl catch is monitored and reported using a combination of fisher logs, audits of independent at-sea electronic monitoring, and dockside observer validation of landed catch. Prior to enhanced monitoring, Pacific salmon were required to be released and catch estimates were based primarily on fisher logs and at-sea observer data, with limited, opportunistic biological sampling of catch. Retention and sampling requirements for Pacific salmon were revised to enable accurate estimation of the number of salmon caught by species, and accurate estimation of stock composition for Chinook salmon catch. The key changes implemented as part of the enhanced monitoring program were to: 1) require mandatory retention of salmon bycatch from all option A trawl vessels (covering all vessels that fish using mid-water trawl nets); 2) independently validate all salmon bycatch, either during trip offloads or examination of all retained salmon heads by independent designated observers; and 3) sample CWT and DNA tissue samples representatively from a subset of Chinook salmon bycatch.

The enhanced monitoring program provided independently validated estimates of salmon bycatch over three years of the groundfish fishery, with data collection currently ongoing for a fourth year. Monitoring procedures, analysis methods, and annual results were published in technical reports (Lagasse et al 2024, Lagasse et al 2025, Lagasse et al 2026), providing the first comprehensive, publicly available reporting on salmon bycatch in the trawl fishery. The new monitoring requirements were successfully implemented for all Option A trawl vessels (over 35 active vessels each year) and nearly 12,000 Chinook salmon were identified to stock-of-origin using genetic stock identification (GSI), parentage-based tagging (PBT), and CWT methods. These samples were used to determine Chinook salmon stock composition and catch of CWT indicator stocks in a statistically representative manner.

Monitoring results revealed large fluctuations in salmon bycatch across years, while stock composition of Chinook salmon remained relatively stable. Chinook salmon bycatch increased drastically in 2022 coinciding with the first year of the enhanced monitoring program, peaking at a historic high of 26,237 Chinook salmon (out of 28,183 Pacific salmon) that was more than double any previous years since 2008. Bycatch remained relatively high during the following year with 21,696 Chinook salmon caught during the 2023/24 trawl fishery. Following implementation of a salmon bycatch management plan, Chinook salmon bycatch plummeted to 7,040 Chinook salmon for the 2024/25 trawl fishery. Stock composition across the three years of monitoring data showed that the majority of these Chinook salmon originated from the continental United States. Among Canadian stocks, most bycatch originated from the Fraser Fall 4(1) stock, which includes the Harrison River and Chilliwack River CWT indicator stocks.

Insights

Results from the enhanced monitoring program provide foundational information for fisheries management, and can contribute to our knowledge on the spatio-temporal distribution of Chinook salmon stocks. Accurate estimates of salmon catch by species is critical to track and manage the fishery, while stock composition data allows the evaluation of catch of Chinook salmon by stock. Many salmon-directed fisheries are managed to minimize impacts on stocks of concern, such as Fraser spring and summer Chinook salmon, and representative estimates of stock composition in the trawl fishery allow these impacts to be accounted for in run reconstructions and considered in risk assessments, Species at Risk Act listing advice, and other management decisions. The groundfish trawl fishery operates year-round and fishes in areas and times that are not typically represented by other fisheries, therefore the samples and stock identification information collected help to fill gaps in our understanding of when and where Chinook stocks are present within the Pacific Region.

Information generated from the enhanced monitoring program has already been operationalized to develop a salmon bycatch management plan for the trawl fishery. The management plan includes a fleet-wide Chinook salmon bycatch cap of 9,500 fish along with individual vessel bycatch caps. In response to these new restrictions, the groundfish trawl industry has been investigating the use of exclusion devices - escape hatches that allow salmon to swim out of nets prior to hauling in - among other methods for reducing salmon bycatch. These regulations and changes in fishing practices have already mitigated impacts on Chinook salmon, decreasing catches by over two thirds from 2023/24 to 2024/25.

Next Steps

The groundfish trawl fishery is a year-round, multi-species fishery that may vary in the distribution of effort and catch over time in response to regulations, market incentives, fish stock abundances, and other factors. Therefore, stock composition and catch patterns observed during the enhanced monitoring program should not be considered representative of future years. The enhanced monitoring program represented three and a half years of salmon bycatch in the groundfish trawl fishery, however, ongoing monitoring is needed to evaluate impacts on Chinook salmon stocks of concern. There is currently uncertainty in future funding and capacity for representative sampling of DNA tissue and CWTs to estimate stock composition, which may lead to information gaps in the future. Continued monitoring, along with communication and collaboration among the trawl industry, advisory groups, First Nations, and DFO, is important for the adaptive management of salmon bycatch in the trawl fishery moving forward.

Tables and Figures

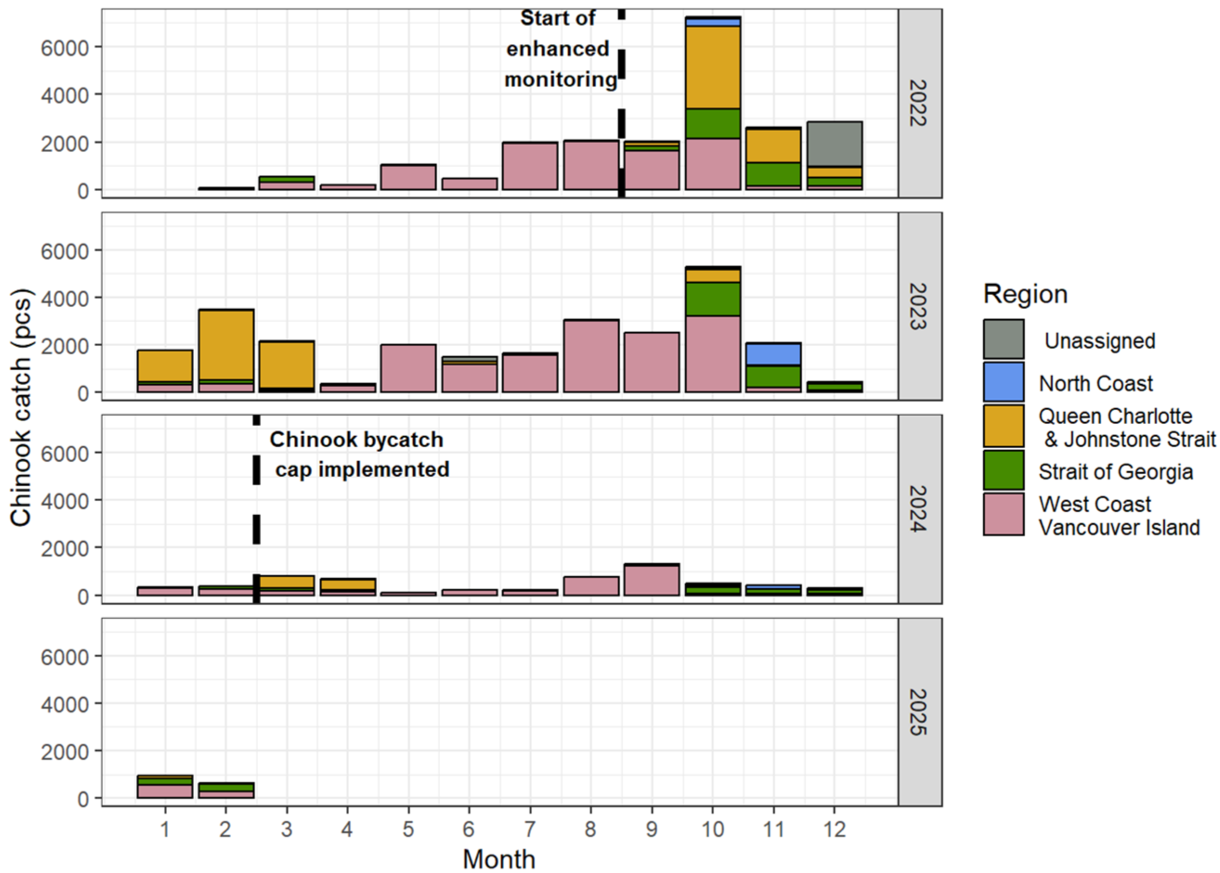

Figure 1. Chinook salmon bycatch by month and region in the groundfish trawl fishery from 2022 to the end of the 2024/25 fishery on February 21, 2025. The enhanced monitoring program and changes to retention requirements began on September 22, 2022. Chinook salmon bycatch since February 21, 2025 is not yet available or shown.

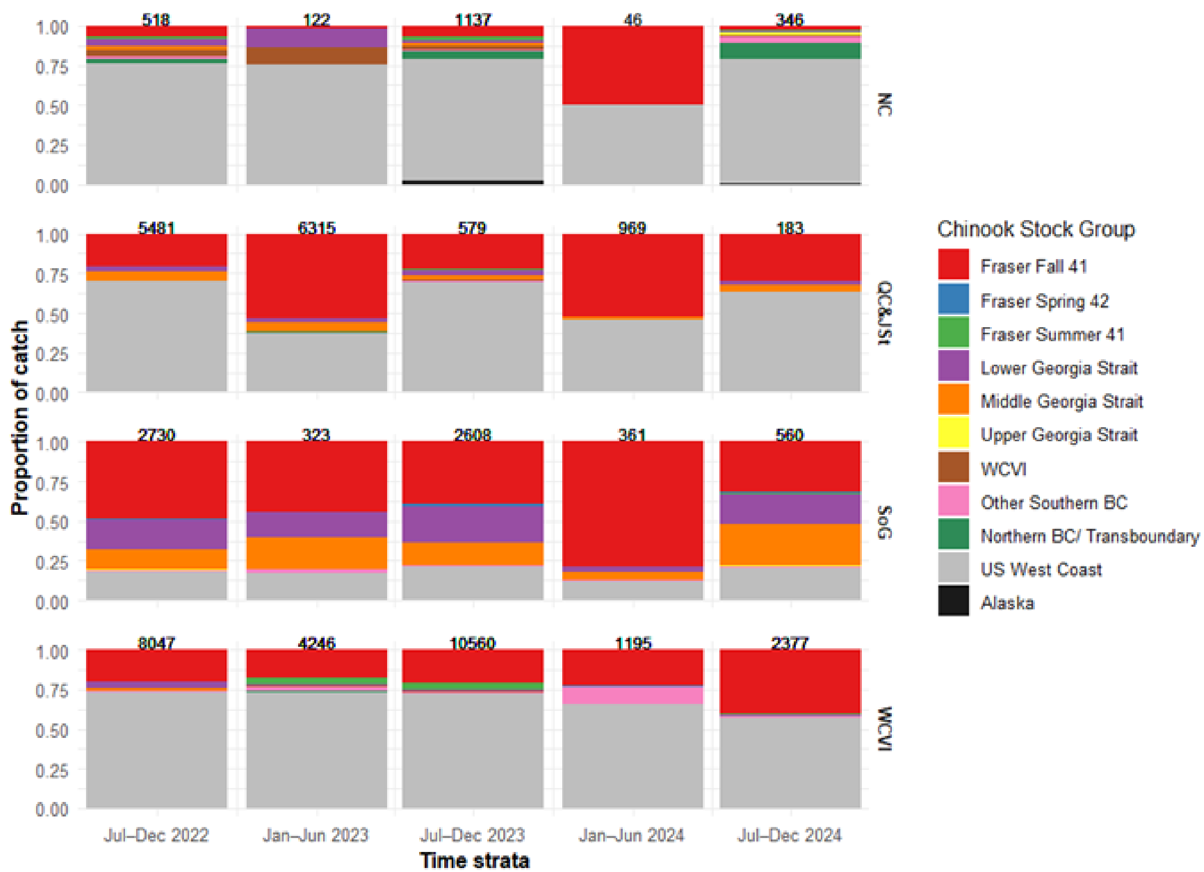

Figure 2. Chinook salmon stock composition by half-year time strata and catch region using CWT and GSI-PBT stock identification methods for bycatch occurring between September 2022 to December 2024. The numbers above each bar represent the catch of Chinook salmon within each time and region combination. The regions shown are as follows: NC = North Coast, QC&JSt = Queen Charlotte and Johnstone Strait, SoG = Strait of Georgia, and WCVI = West Coast Vancouver Island. The Other Southern BC stock group includes Fraser Spring 5(2), Fraser Summer 5(2), Boundary Bay Fall 4(1), Mainland Inlet Chinook stocks.

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Lagasse, C.R., Fraser, K.A., Houtman, R., Grundmann, E., Komick, N., Brien, M.O., Braithwaite, E., and Cornthwaite, A.M. 2024. Review of Salmon Bycatch in the Pacific Region 2022/23 Groundfish Trawl Fishery and Preliminary Results of an Enhanced Monitoring Program. Can. Manuscr. Rep. Fish. Aquat. Sci. 3273: v + 35 p.

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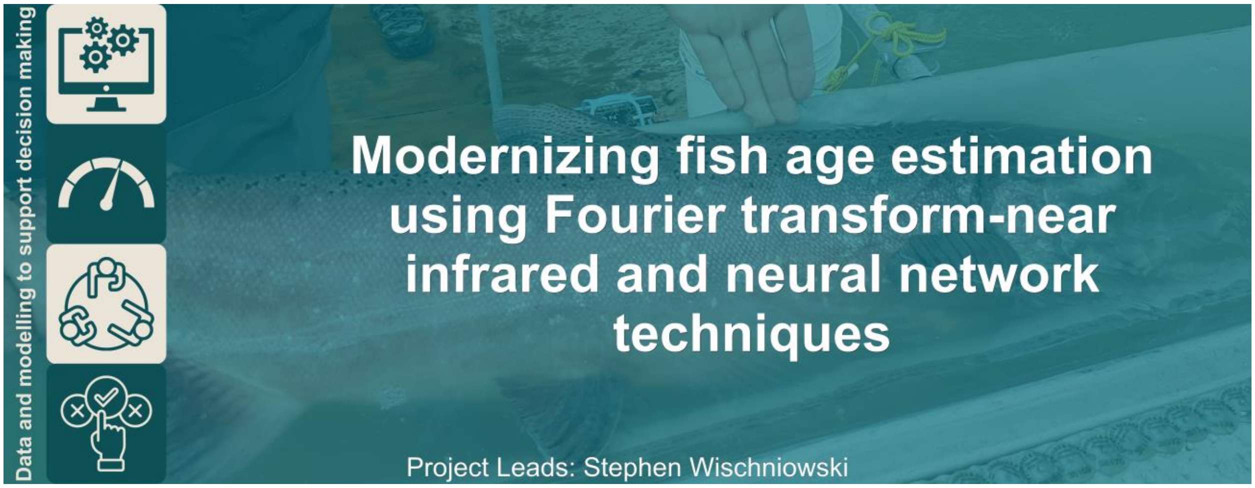
NEW TOOLS AND MODELS TO SUPPORT DECISION-MAKING

2439 - Modernizing Fish Age Estimation with FT-NIR and AI



Employing deep learning for chum salmon (Oncorhynchus keta) age estimation through scale image analysis (submitted to CJFAS)

Collaborations: Pacific States Marine Fisheries Commission: Robert T. Ames, Matt W. Callahan, and Niels Leuthold; Alaska Fisheries Information Network: Robert T. Ames, Matt W. Callahan, and Niels Leuthold; Alaska Fisheries Science Center, Juneau, AK, USA: Patrick D. Barry; Alaska Department of fish and Game. Mark, Tag, and Age laboratory, Juneau, AK, USA: Jodi C. Neil; Northern Southeast Regional Aquaculture Association. Sitka, AK, USA: Taylor Scott and Benjamin H. Adams; Canadian Integrated Ocean Observing System Pacific Region, ocean Networks Canada, Victoria, B.C., Canada: Jordan T. Watson

Species: Chum, Chinook

Highlights

- The Alternative Age Estimation program (AAE) in the Sclerochronology lab (SCL) is conducting research in Convolutional Neural Network (CNN) and Deep Machine Learning (DML) predictive age modeling with a goal to deploy an AI-driven pipeline that augments traditional ageing techniques and transforms fish age estimation.
- Chum salmon CNN predictive age models for the most common age classes have been very successful, attaining precision rates up to 94% (Ames et al. submitted CJFAS 2026). Fourier Transform-Near Infrared (FT-NIR) spectroscopy and Otolith Shape Analysis (OSA) have provided acceptable age predictions for Rougheye/Blackspotted (REBS complex), Yelloweye and Pacific Ocean Perch rockfish and have demonstrated excellent results for the REBS complex speciation and Yelloweye stock ID.
- The steadily increasing demand for age data regularly exceeds program capacity, and with the SCL experiencing reductions in funding and skilled personnel, traditional age estimation has become a bottleneck in providing age data.. Automation of the age assignment process for salmon and rockfish species will facilitate increased capacity

and supplement existing personnel providing key model age data to ensure fisheries are sustainably managed.

Background

The SCL program provides approximately 120,000 quality controlled age-estimates for salmon and groundfish species annually. Age data are inputs in calculating rates of reproductivity, growth and mortality, critical components in stock productivity and are key parameters in stock assessment analyses. Provision of timely age data estimates enables downstream modelling of stocks performance and allow for these information to be available for consultation processes which are pivotal for sustainable fisheries management, conservation strategies and ecological research. The steadily increasing demand for age data regularly exceeds program capacity forcing requests to be aged on a prioritized basis, with the SCL experiencing reductions in funding and skilled personnel, traditional age estimation has become a bottleneck in providing age data for the management of Pacific salmon and groundfish (Malde et al. 2020).

Traditional techniques, such as scale and otolith age assignment are labour intensive, time consuming, and prone to inter-reader variability. Improved and accelerated age estimates through the deployment of an AI-driven pipeline of CNN and DML predictive age modeling will augment traditional ageing techniques and transform fish age estimation (Moen et al. 2023; Vabø et al. 2021).

A multiple agency effort (DFO, Pacific States Marine Fisheries Commission (PSMFC), National Oceanic and Atmospheric Administration (NOAA), Alaska Department of Fish and Game (ADF&G) and the Northern Southeast Regional Aquaculture Association (NSRAA)) have developed working models to successfully predict chum ages with an AI algorithm trained on 15,000 scale images. Although the existing models are coastwide (Alaska, BC and Washington), our research team is currently supplementing BC images to increase the robustness of the coastwide models while developing new models specific to chum salmon captured in waters local to BC.

This is the first step in providing a multi-species Alternative Age Estimation pipeline designed to augment age assignment output capacity within the SCL.

Methods and Findings

For any AI predictive age model to function it requires input data or attributes, these are typically species and structure dependent. The SCL has focused on the attributes extracted from scales and otoliths for its investigations into predictive age assignment (Figure 1).

In the case of salmon, specifically chum the scale growth pattern is the attribute and a scale image is the means of interpretation (LaLanne and Safsten 1969; McNicol and MacLellan 2010). Chum salmon scales were collected by four agencies: NOAA, ADF&G, NSRAA and DFO. All groups prepare scales similarly for age estimation; scales are mounted to a gum card and acetate impressions are made. An automated high-speed Leica Emspira 3 mobile base camera system was used to selectively and rapidly image impressions of DFO chum scales. CNN models were developed using 15,754 scale images; 24% of the total collection. Data were split into training (70%, n=11,012), validation (15%, n=2,365), and testing (15%, n=2,377) and randomly but stratified by age classes to ensure consistent age class distributions across each set. We deployed an ensemble of three CNN models architectures with a proven track record in their application for image classification and regression problems. The ensemble model of EfficientNetV2L, NASNetLarge, and ConvNeXtLarge provided excellent age predictions for the most common age classes of chum recruiting to the fishery (Figure2) (Ames et al., In press).

In the case of groundfish, the otolith is the structure employed and its weight, shape morphometrics and Infrared spectral scan are the attributes. Together, the otolith morphometric attributes (weight, dimensional measurements, and shape outlines) and FT-NIR spectroscopic data (Benson et al. 2023) were used in machine learning algorithms in R to create predictive statistical models for species classification, stock delineation, and the automated age estimation of select rockfish species. Specifically, age estimation models of Rougheye, Yelloweye and Pacific Ocean perch provided estimates that met the lower acceptable precision rates set by quality control parameters for human generated precisions (Figure 2). Previously aged samples from the SCL Structure Library will be sourced, attribute data will be collected and incorporated into current models to increase the robustness of age predictions of these rockfish species.

The Alternative Age Estimation program has made great advancements in predictive age modeling based on key attributes of otoliths and scales with plans to apply these models to the most commonly aged species at the SCL.

Insights

Traditional age estimation methods rely on highly specialized skills developed through long-term mentorship, these methods are time-intensive and resource-heavy, limiting scalability and throughput. The steadily increasing demand for age data regularly exceeds program capacity forcing requests to be aged on a prioritized basis. While a significant amount of expertise is required to produce fish age estimates this is something AI can be trained to do. This modernization and the work to date establishes the groundwork for an AI-driven pipeline that augments traditional age estimation techniques, dramatically increasing efficiency while maintaining scientific rigor. Accurate and precise age estimation is pivotal for sustainable fisheries management, conservation strategies and ecological research.

Increased capacity benefits age-structured stock assessments that facilitate judicious fisheries resource management decisions commonly via science advice generated in CSAS processes which depend on high quality and consistent age-data. Commercial Fisheries programs are managed in partnership with stakeholders relying on scientific assessments and are dependent on consultative processes to develop and review policies, procedures and regulation.

The implementation of AI pipelines are designed to augment age output and not meant to replace age readers. SCL institutional ageing knowledge acquired over 40 years of ageing experience must be maintained to ensure predictive age assignments remain precise and do not drift as a result of environmental pressures such as climate change.

Next Steps

Model training, testing and validation will continue with previously aged samples in order to increase samples robustness of the three aforementioned rockfish species and chum. New species (Chinook, Quillback Redbandded and Widow rockfish) are currently in the process of scale imaging, and otolith weighing, imaging and IR scanning. The overall goal is to create a image, weight and IR libraries of all species aged within the SCL age catalog. Model training, testing and validation will proceed on all species when enough structure attributes have been attained. This is the metadata foundation that will support age predictive AI age modeling.

Climate change, in the form of increasing water temperatures will diversely affect salmonid species causing variations in the physiological traits of growth and metabolic condition. Consequentially, driving a divergence from historical growth patterns causing interpretational difficulties that can result in the “smearing” of age classes. The creation of image based libraries has a two fold advantage; (1) it allows for automated predictive age assignments, and (2) it provides the ability to monitor changing growth rates by the direct measure of scale annuli. Measures of growth can provide information encompassing external environmental conditions as indicators of habitat quality, and internal physiological status of health, stress and reproductive state. The development of automated measures of annular growth are currently under investigation. As climate change becomes more prevalent the SCL expects that age requests will increase to compensate for the dynamic shifts in the ecosystem.

Current plans for operationalization of real-time age prediction of chum salmon are underway. This will rely on a Frame Work computer that is specifically design to run the chum age predictive models and the SCL’s high speed automated scale imaging camera. The series of events are as such;

- scale images will be auto captured from the high speed camera,
- an R-script will create image file names of species and specimen ID,
- all other attribute metadata such as measure of scale growth will be extracted,
- scale age will be predicted, recorded, and exported to the Mark and Recovery database.

Tables and Figures

Sclerochronology Lab Research Branch
Alternative Age Estimation Species and Attribute Numbers

Species	Structure	Attribute	Number
Pacific Ocean perch	otolith	FT-NIR/image/wt.	3244
REBS	otolith	FT-NIR/image/wt.	5410
Yelloweye	otolith	FT-NIR/image/wt.	3546
Quillback	otolith	FT-NIR/image/wt.	3409
Bocaccio	otolith	image/wt.	264
Canary	otolith	image/wt.	394
Lingcod	otolith	FT-NIR/image/wt.	169
Arrowtooth flounder	otolith	FT-NIR/image/wt.	382
Hake	otolith	image/wt.	1627
Chum	scale	Image	10700
Chinook	scale	Image	~8000
Atlantic Cod	otolith	FT-NIR	721
Eulachon	otolith	image/wt.	1169

Figure 1. Represents the total number of structure attributes collected by species.

Sclerochronology Lab Research Branch
Alternative Age Estimation Chum Results

An Ensemble model was used to combined all three models. The final ensemble predictions, the weighted average of the three models, were rounded to the nearest integer and compared to the age readers' age estimates.

Age Class 1 - Samples: 31, Precision: 100.00%
Age Class 2 - Samples: 16, Precision: 44.00%
Age Class 3 - Samples: 555, Precision: 94.31%
Age Class 4 - Samples: 721, Precision: 94.09%
Age Class 5 - Samples: 492, Precision: 91.17%
Age Class 6 - Samples: 12, Precision: 60.00%
Age Class 7 - Samples: 2, Precision: 0.00%

Combining age 3 to 6-year-old samples, accuracy across agencies was high: NOAA (89.2%), ADFG (96.2%), NSRAA (85.0%), and DFO (94.1%).

Figure 2. Predictive age results for chum age classes one to seven.

Sclerochronology Lab Research Branch
Alternative Age Estimation Groundfish Results

Precision Targets for Species

Agreement Target	% +/-0	% +/-1 yr	% +/-2 yrs	% +/-3 yrs	% +/-5 yrs
Rockfish					
S. alascanus					80
S. aleutianus					60-80
S. altivelas					80
S. alutus	50	80			
S. babcocki			70		
S. brevispinis		50	70		
S. caurinus	50	80			
S. entomelas	50	80			
S. flavidus	50	80			
S. maliger		70			
S pinniger		50	80		
S. proriger		80			
S. reedi			80		
S. ruberrimus			70-80		
S wilsoni		90			


76% +/-5


78% +/- 1


71% +/- 2

Figure 3. Predictive age results for Sebastes aleutianus, alutus and ruberrimus compared to the age agreement target values set for each species.

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2449 - SalmonMSE Decision-Support Tool

Website and documentation: https://salmonmse.com/

SalmonMSE technical report (in progress)

Collaborations: Blue Matter Science; Huu-ay-aht First Nation; LGL

Region: BC

Species: All *Oncorhynchus* spp

Populations: Sarita River case study

Highlights

- Understanding the performance of management actions prior to implementation is increasingly critical for Pacific salmon given accountabilities under the modernized *Fisheries Act* and growing risks associated with environmental and biological variability and change, yet tools to evaluate harvest, hatchery and habitat levers have not been available.
- We developed an open-source, decision-support tool, **salmonMSE**, to prioritize management actions related to harvest regulation, hatchery enhancement and habitat restoration to achieve objectives across sectors.
- This tool expands on those previously used by explicitly accounting for dynamics of hatchery-origin and natural-origin fish, modelling mark-selective fisheries, considering risk and uncertainty, and including biological realism with the ability to model a diversity of life-history strategies.

Background

Pacific salmon are exposed to numerous interacting stressors, including climate change, fishing, and land-use changes related to e.g., urban development, forestry, mining, and agriculture (Tulloch et al. 2022). Management of salmon is multifaceted to address these stressors: including harvest regulation, hatchery enhancement and habitat restoration.

Management decisions increasingly require transparency and risk-based approaches to respond to uncertainties. For example, the *Fisheries Act* requires the development of rebuilding plans for stocks that fall below limit reference points (considered in a ‘critical’ status zone). There is an emerging need to evaluate performance of candidate management actions for rebuilding plans prior to implementation, and the DFO’s precautionary approach framework requires uncertainty and risk to be taken into account when developing and implementing decision rules.

Similarly, under the *Species at Risk Act*, there is a need to evaluate recovery potential of populations at risk of extinction under various management scenarios. However, we lack accessible, broadly applicable quantitative tools to evaluate management options across management levers.

Through this project we developed an open-source, decision-support tool for Pacific salmon, salmonMSE, to inform science advice for Integrated Management Plans, Rebuilding Plans under *the Fisheries Act*, Salmon Enhancement Plans, and the SARA listing process.

This tool can address questions like:

- What level of hatchery enhancement and harvest regulation are required to achieve rebuilding targets?
- What is the maximum hatchery production possible while maintaining ‘wild’ population status, as defined by proportionate natural influence, PNI goals by Wither et al. (2018)?
- How should mass-marking strategies and mark-selective fisheries be designed in order to achieve harvest and PNI goals while allowing for conservation of wild populations?
- Within hatcheries, which harvest release strategies and broodtake rules best meet conservation and PNI objectives?
- Where relationships between environmental drivers or limiting factors and survival rates have been identified, what are the benefits of habitat restoration to mitigate impacts of those factors on conservation and harvest objectives, relative to other management levers?

In partnership with Huu-ay-aht First Nation, DFO Salmon Enhancement Program and DFO Science, we applied salmonMSE to Sarita River Chinook, on the west coast of Vancouver Island as a case study, to evaluate the impacts of mark-selective fisheries and hatchery scenarios on the ability to achieve a range of conservation, harvest and hatchery objectives, and to inform rebuilding plans.

Methods and Findings

SalmonMSE is a decision-support tool developed for Pacific salmon founded on ‘management strategy evaluation’, MSE, which is an approach for evaluating the relative effectiveness of management actions using computer simulations that represent various possible realities of the fishery and the biological systems (Punt et al. 2016; openMSE 2023). To account for uncertainties, these simulations are repeated over numerous possible realities to produce a distribution of outcomes for each management action.

We developed a stage-based life-cycle model, capturing population processes relevant to Pacific salmon acting in freshwater and marine environments, and the impacts of harvest and environmental conditions on juvenile and adult stages. The underlying model structure is modular and flexible allowing for reduced complexity to simpler model forms when data are limited and increased complexity to address emerging threats when data are available. We included the ability to model an integrated hatchery population, whereby the hatchery and natural spawning components of a population are modelled separately but interact on the spawning grounds.

SalmonMSE provides advances relative to previously available tools that either did not consider risk and uncertainty or did not consider hatchery dynamics explicitly and therefore could not evaluate performance on hatchery objectives related to maintaining wildness of integrated hatchery populations, i.e., high PNI values (Withler et al. 2018). By explicitly modelling hatchery impacts on populations, salmonMSE can evaluate performance on conservation, production and 'wildness' objectives. Our application to a case study on Sarita River Chinook salmon highlights the potential for trade-offs among objectives, suggesting that in some cases it may not be possible to achieve both wildness and high abundances simultaneously. Our case study further highlights that habitat restoration may be needed to support production objectives when survival in freshwater is limiting. An illustrative example is provided in Box 1. This tool fills a critical cap in DFO's ability to strategically evaluate decisions on all three management levers.

The salmonMSE tool is generic and can be applied across Pacific salmon species and populations. salmonMSE can be adapted to data availability, relying on coarse resolution survival rates (e.g., freshwater vs. marine) and meta-analyses, neighbouring populations, and expert opinion for parameterization when data are limited, and providing population-specific finer life-stage resolution and evaluating management actions targeting specific life stages where data are available.

An open-source R package salmonMSE was developed to facilitate access of the tool, with three underlying repositories providing code for the R package and an application to one case study on the west coast Vancouver Island, Sarita River Chinook, and second on-going application to Upper Strait of Georgia Chinook to support the development of a Fisheries Science Advisory Report.

Insights

This tool can inform management decisions and address trade-offs between conservation, harvest, and 'wildness' objectives within rebuilding plans under *Fisheries Act*, Fisheries Science Advisory Reports, SEP production plans, and SARA listing decisions. Furthermore, the modernized *Fisheries Act* requires that management consider the biology of the fish and environmental conditions affecting the stock, and this tool is designed to account for biological characteristics like life-history diversity (e.g., accounting for differences in survival rates among life-history groups within a population) and environmental drivers of survival at various life stages, where data are available.

In answering these questions, this tool can inform both strategic decisions about choices among management lever(s), and operational decisions about harvest control rules, hatchery release strategies and habitat restoration.

Uncertainties are explicitly considered in salmonMSE in two ways. First, distributions are included in parameterization and projections are run over a large number of random Monte Carlo trials to account for parameter uncertainties and to provide probabilistic outcomes (e.g., the probability of achieving management objectives). In this way, the outcomes of management evaluations are less certain and probabilities of achieving objectives more diffuse when underlying parameters are more uncertain. In addition, uncertainties in model structure and parameters can be explicitly considered by running sensitivity analyses over a range of plausible hypotheses. These analyses can help to identify those parameters with the highest impact on the relative performance of management strategies, requiring further monitoring or research to reduce uncertainties.

Next Steps

A training session for technical analysts within DFO, First Nations and partner organizations will be hosted April 2026 to support implementation of salmonMSE. The intended outcomes for the workshop are for participants to understand the scope and capabilities of salmonMSE, have working knowledge of how to apply salmonMSE to simple examples that include integrated hatcheries, and understand how these can be expanded to include complexities in life-history diversity, environmental drivers, and harvest and hatchery management strategies.

SalmonMSE is currently being applied to Upper Strait of Georgia Chinook salmon to inform the evaluation of harvest and hatchery management options for an upcoming FSAR process (planned for Nov 2026). We recommend the application of salmonMSE to inform fisheries stock advice for Pacific salmon more broadly, especially when harvest and hatchery levers are considered and conservation, harvest, and PNI objectives are identified. We further recommend exploring salmonMSE for SEP production planning, e.g., for evaluating alternative release strategies and broodtake rules.

Gaps remain in our ability to include environmental drivers and impacts of habitat restoration into salmonMSE. There are opportunities to combine salmonMSE with inferences from other habitat models or limiting factors frameworks, such as CEMPRA (Cumulative Effects Model for Prioritizing Research Activities) and RAMS (Risk Assessment Methods for Salmon), and causal modelling (e.g., using DSEM, Dynamic Structural Equation Models). Doing so would allow us to more clearly and transparently identify and document risks created by environmental or ecosystem conditions for achieving management objectives, and the relative benefits of more specific restoration efforts to mitigate those impacts.

Tables and Figures

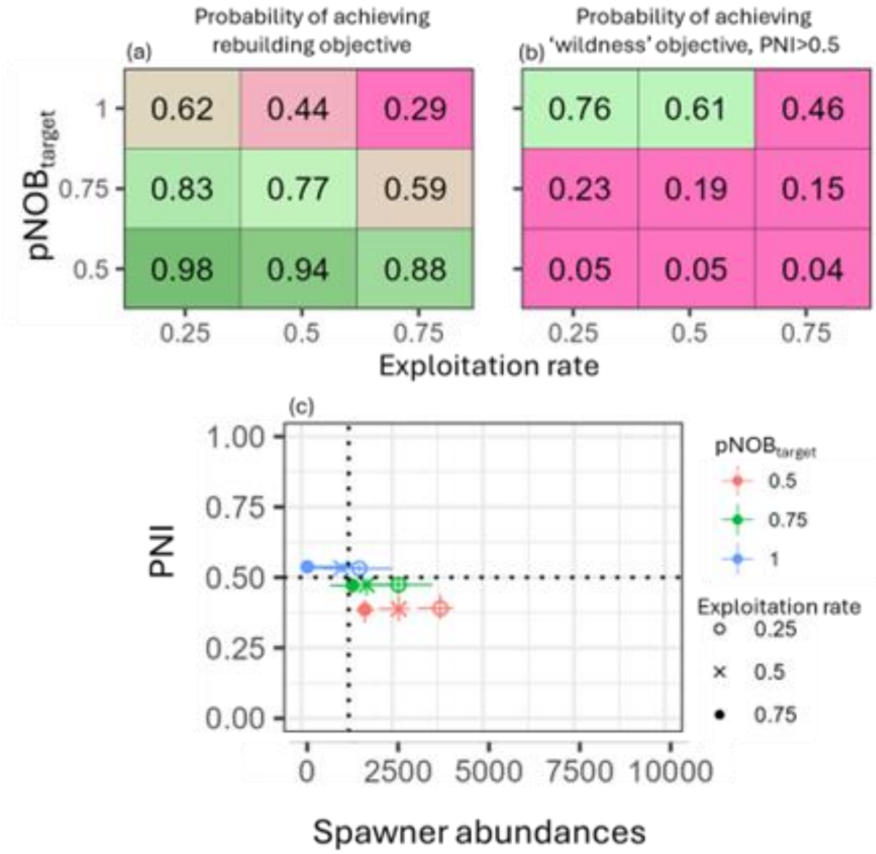

Figure 1. Illustrative example of decision tables from salmonMSE providing performance on (a) ability to achieve abundance-based rebuilding target and (b) 'wildness' objective with proportionate natural influence, PNI>0.5 (top right) under combinations of harvest strategies (exploitation rates: 0.25, 0.5, 0.75) and hatchery broodtake targets (the proportion of natural-origin fish in the broodtake, pNOBtarget: 0.5, 0.75, 1). When pNOBtarget is high, fish tend to be more adapted to the natural environment than the hatchery environment and PNI values are high, though hatchery sizes are often smaller due to challenges in collecting large numbers of natural-origin brood, especially when mark rates are low. Green cells depict relatively high probability of achieving objectives and pink, low. Trade-offs between achieving high abundances and high PNI are shown in panel (c) (x-axis and y-axis, respectively). In this example, none of the proposed management strategies (coloured circles and x's) clearly maximize both abundances and PNI. The vertical dotted line is a candidate rebuilding target, and the horizontal dotted line is the PNI objective.

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3682 - Legislation Applicable to Pacific Salmon and Ecosystems

Legislation Applicable to Pacific Salmon and Ecosystems (LAPSE) dashboard viewer

Enns J., Lagasse C., Gillis D., and Wright M. 2026. An interface between statutes and salmon: the Legislation Applicable to Pacific Salmon and Ecosystems (LAPSE) framework. Primary Publication (**in progress**)

Collaborations: DFO Species at Risk Program, Fish and Fish Habitat Protection Program, Province of British Columbia Ministry of Water Land and Resource Stewardship

Region: BC

Species: All *Oncorhynchus* spp

Highlights

Main Idea

Addressing threats to salmon populations and habitat often requires coordinated, inter-jurisdictional action that can be hindered by the complex governance landscape of resource management within Canada. The LAPSE framework is a systematic process and open-source tool that bridges regulatory language with standardized threat classifications to characterize and help navigate the complex legislative framework relevant to Pacific salmon and their habitats in British Columbia.

Key Findings

A database of 196 federal and provincial statutes was created using a repeatable, structured method to parse, classify, and relate individual clauses. Findings highlight the intricate, inter-jurisdictional way in which threats relevant to salmon are regulated. Consistent with general understanding, most legislation relevant to freshwater habitat fell under provincial jurisdiction while jurisdiction for fisheries was under federal control. However, these divisions were not always clear-cut and many management domains were under both jurisdictions and spread across hundreds of legislative sections, with pollution and spatial designation domains having the highest amount of associated legislation.

Implications
The LAPSE framework demonstrates the ability to identify regulatory pathways relevant to specific human activity threats, making it easier for managers and practitioners to navigate the complex legal landscape for salmon. The tool can support systematic reviews of regulatory strengths and shortcomings with respect to specific salmon threats and inform the develop of recovery strategies or management plans.

Background
Many Pacific salmon populations in British Columbia are experiencing declines driven by multiple anthropogenic stressors including habitat degradation, climate change, and fisheries harvest (Ulaski et al. 2025). Addressing threats to salmon habitat often requires coordinated, inter-jurisdictional action that can be hindered by the complex governance landscape for resource management within Canada (Becklumb 2013). Pacific salmon management is particularly complex due to their anadromous life cycles spanning international boundaries, as well as freshwater and marine ecosystems. For example, while salmon populations and fisheries are regulated federally, water use and watercourse alterations affecting aquatic habitat are managed provincially, with both governments having authority to designate protected areas.

Assessment frameworks like the IUCN-CMP Direct Threats Classification (Salafsky et al. 2008) have been developed to evaluate anthropogenic activities and limiting factors as a means of understanding drivers of population declines and mitigation priorities. However, a key challenge is identifying actions that are both impactful and feasible across the wide geographic range and diverse life history of Pacific salmon. The LAPSE process and framework was developed to decode the complexity between threats to salmon and corresponding environmental legislation by creating an interface between regulatory language and anthropogenic threat categories.

Methods and Findings
We accumulated 196 Canadian federal and British Columbian provincial statutes (including acts, regulations, codes, and orders) relevant to Pacific salmon stewardship through a systematic keyword search process using the Canadian Legal Information Institute (CanLII) website. Indigenous legislation, Yukon Territorial legislation, municipal bylaws, and international conventions were not included due to scope limitations, though these may overlap with federal or provincial legislation and be important for the governance of Pacific salmon.

The methodology involved parsing legislation by individual clauses (paragraphs) using automated HTML extraction, then developing a keyword-matching process that assigns clauses to “management domains,” defined as discrete areas of administrative concern (aligned with the IUCN-CMP Direct Threats Classification). The parsed legislation was stored in a SQLite database with datatables including jurisdiction, act name, legislation type, paragraph content, section, heading, management domain, IUCN-CMP threat category, scope, and matched keywords. Keyword lists were derived from IUCN-CMP threat definitions, word frequency analyses of collected legislation, and iterative researcher input and revision to ensure specificity and relevance.

Clauses were categorized by salmon-specific scope ranging from direct salmon references to general governance: “1 - Salmon” (Pacific salmon specifically); “2 - Fish” (fish including salmon);

“3 - Habitat” (habitat including salmon habitat); and “4 - Governance” (administrative processes and structure). Additionally, clauses were categorized by type (prohibition, authorization, designation, etc.) to understand the nature and intent of legislative provisions. The management domain categories were aligned with IUCN-CMP Level 2 threat categories, though some lumping and splitting was required to better match with sector-by-sector Canadian and British Columbian legislation.

Key findings revealed that pollution was the management domain with the highest section count, split almost evenly between federal and provincial jurisdictions. Fisheries was among the top three section counts with a majority under federal jurisdiction, while Water Use and Watercourse Modifications was in the top four with a majority under provincial jurisdiction– indicating an underlying disconnect where salmon harvest is controlled federally while habitat aspects are governed provincially. The IUCN-CMP Level 2 threat category “9.1 Water-Borne & Other Effluent Pollution” matched with the highest number of sections, followed by “5.4 Fishing, Harvesting & Controlling Aquatic Species.” Pacific salmon-specific language was found in far fewer sections than indirect, less specific language, with more federal legislation sections matching salmon harvest categories than provincial.

Insights

The LAPSE framework characterizes the legislative architecture governing Pacific salmon and their ecosystems. The framework could inform salmon management decisions, policy guidance, and planning by providing a structured method to identify which statutes, regulations, and specific clauses are relevant to particular threats affecting salmon populations. Our case studies demonstrated the tool’s application for two threats: For “Geological Events” (landslides), the framework identified eight pieces of legislation largely related to forestry, revealing that clauses were mostly “Instruction” and “Designation” types. For “Dams & Water Management / Use” (identified as Extreme-High threat for Fraser Interior Chinook), the framework revealed extensive legislation with more evenly distributed clause types, with “Interpretation & Purpose” and definition sections being most common.

The co-occurrence analysis of management domains within individual clauses reveals the complexities of legal language, for example, aquaculture regulations that simultaneously address pollution, demonstrating that regulatory provisions often span multiple threat categories. This insight is important to help understand cumulative impacts and developing comprehensive mitigation strategies.

Sources of uncertainty in the framework include researcher subjectivity in legislation inclusion and keyword list development, though the use of documented keyword lists allows for transparency and repeatability. The framework does not verify implementation or enforcement of statutes by responsible officials, presenting legislation as written rather than as practiced. Additionally, context and meaning of keywords can cause mis-categorization, requiring iterative revision to ensure accuracy. The study also notes that the number of statutes, sections, or clauses is not a measure of the quality or effectiveness of legislation, but rather provides visibility into what exists in the regulatory landscape.

Next Steps

Remaining knowledge gaps include the lack of representation of Indigenous law, Yukon Territorial legislation, municipal bylaws, and international conventions that were outside the scope of this initial study but are pivotal in Pacific salmon governance. Further development could assess how policies, departmental frameworks, and actual implementation practices align with legislative requirements, as gaps between written legislation and its application or enforcement can significantly affect the effectiveness and utility of laws and regulations (Bankes et al 2014; Bogetti et al 2025). The framework would benefit from ongoing maintenance to account for legislative changes and updates to IUCN-CMP threat classifications, as well as user feedback to refine keyword matching algorithms and reduce mis-categorization.

The project outputs could be operationalized for Pacific salmon management in a few ways. As a publicly-accessible, open-source tool, it can assist practitioners, First Nations groups, and policy makers in understanding and analyzing legislation and regulations relevant to Pacific salmon and anthropogenic activities. The framework can support systematic reviews of the regulatory strengths and shortcomings with respect to specific salmon threats, informing policy reforms to address gaps and improve coordination across jurisdictions. Finally, integration with existing processes such as Recovery Potential Assessments, rebuilding plans under the *Fisheries Act's* Fish Stock Provisions, and Wild Salmon Policy implementation could strengthen the development of recovery plans and management strategies.

Tables and Figures

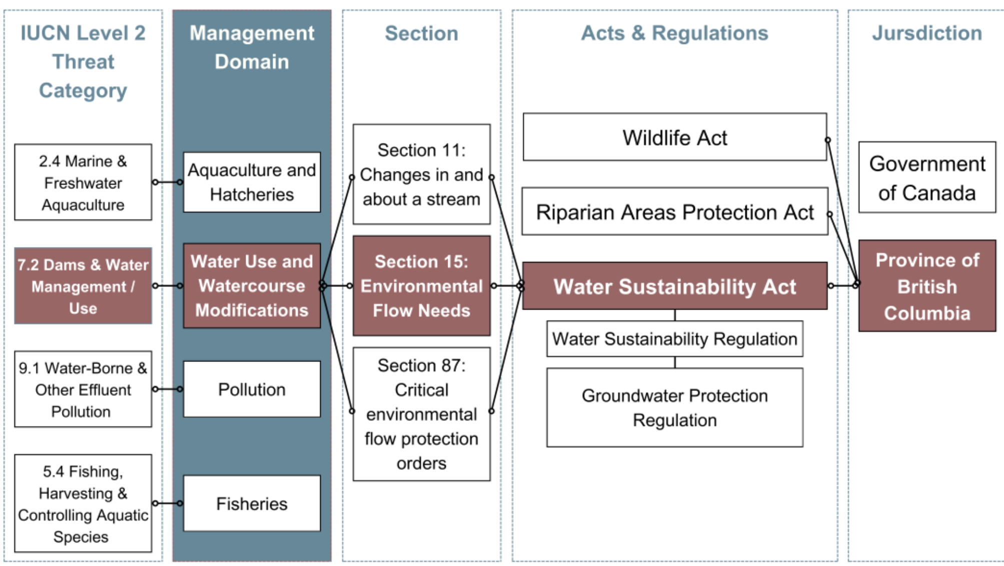

Figure 1. Flowchart showing example values, categories, and relationships among legislative statues, clauses and IUCN – CMP Level 2 threat categories and management domains. Sections contain multiple clauses that are linked to specific acts or regulations that are assigned to a management domain and threat category using keyword classification.

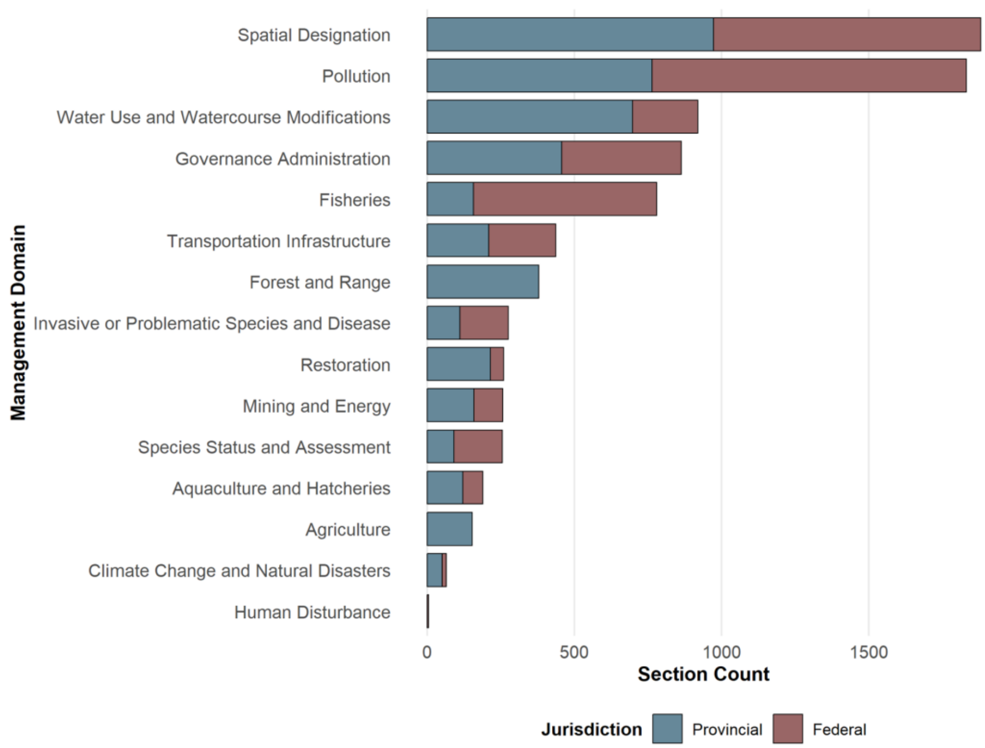

Figure 2. Counts of sections assigned to management domain, stacked by jurisdiction. Each section from 196 federal and provincial statutes was matched to management domains using keyword associations. Multiple assignments were possible if keywords from more than one management domains were present in a section. Management domains were aligned with IUCN – CMP level 2 threat categories, except in some cases such as spatial designation and governance administration which do not have associated threat categories.

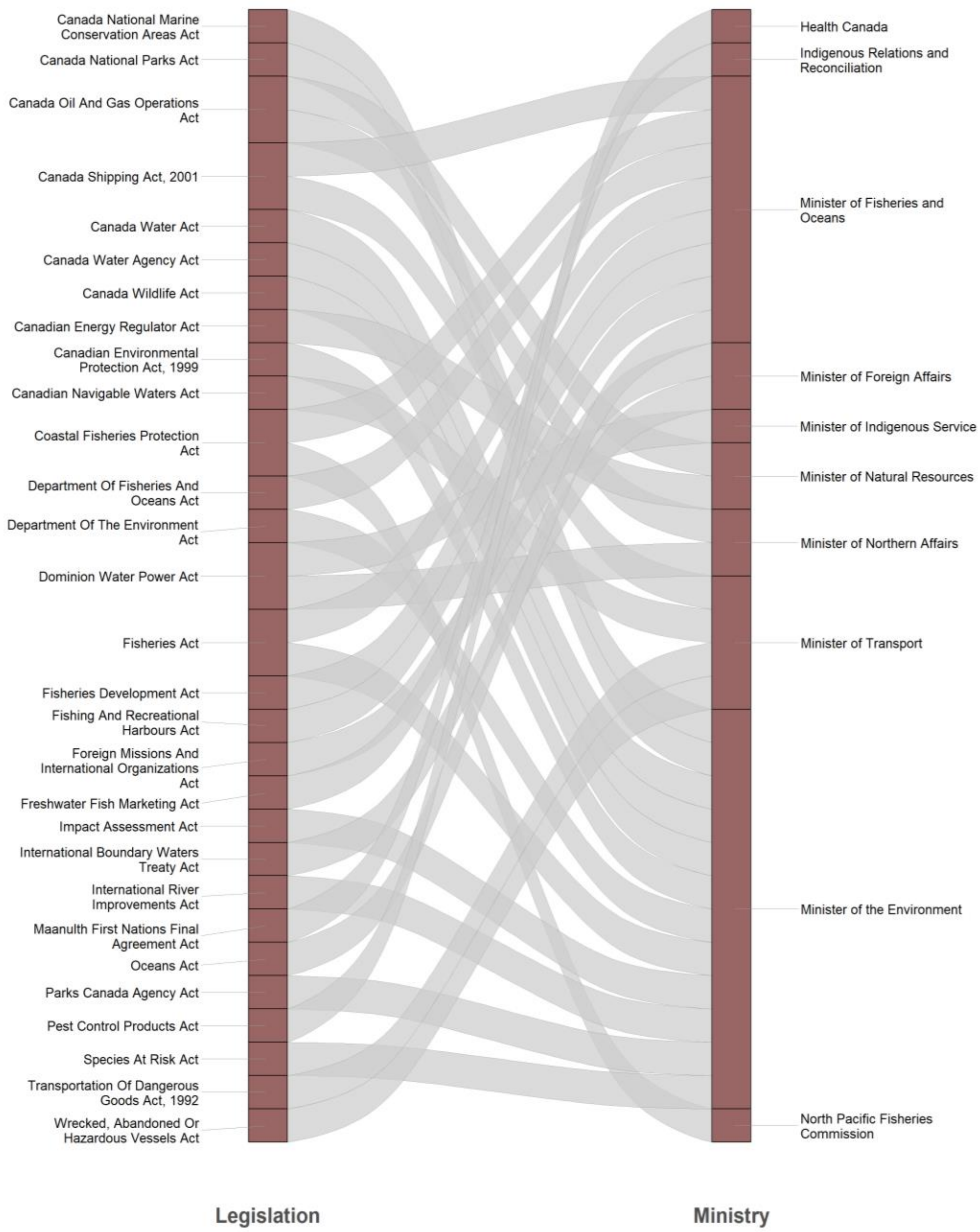

Figure 3. List of Canadian federal acts relevant to Pacific salmon and habitat governance with assigned ministries referenced from the federal Table of Public Statutes and Responsible Ministers (Department of Justice Canada 2026).

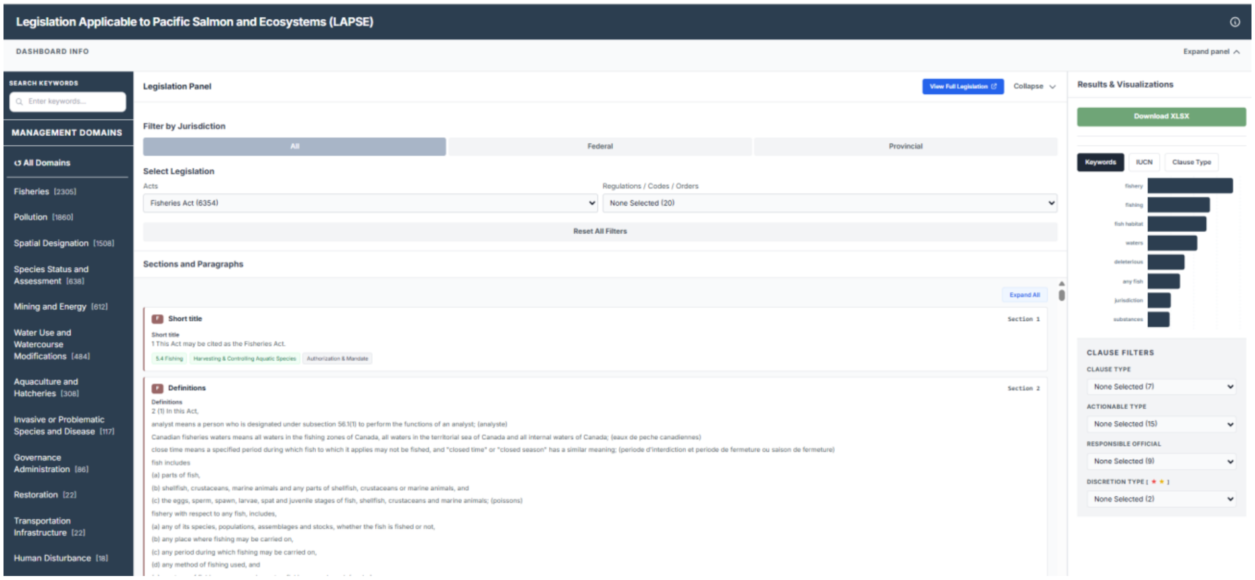

Figure 4. Screenshot of the LAPSE tool online app.

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APPENDIX A. OVERVIEW OF PHASE TWO BCSRIF PROJECTS

Table A-1: *List of BCSRIF projects with descriptions of proposed work from original project proposals. All phase two BCSRIF projects are included, along with a subset of phase one projects related to thematic areas.*

Project	Description
BCSRIF_2019_040 **Title:** Determination of Bottlenecks Limiting Wild and Enhanced Juvenile Salmon and Steelhead Production in BC using PIT tags and Spatially Comprehensive Arrays **Recipient:** Pacific Salmon Foundation	Together with partners the Pacific Salmon Foundation will develop the monitoring and evaluation framework to determine survival bottlenecks in freshwater and marine environments for hatchery and wild chinook coho and steelhead. Research monitoring and evaluation activities will seek to maximize the performance of hatchery and wild stocks; and the installation of new infrastructure will support adaptive management of hatchery programs to meet harvest conservation and sustainability objectives. **Collaborators:** BC Conservation Foundation, UVIC, Freshwater Fisheries Society of BC, K'ómoks First Nation, A-Tlegay Fisheries Society, Cowichan Tribes, Snʊˈneɪməxʷ First Nation, shíshálh Nation, Nanoose First Nation, Nanaimo River Stewardship Society, UNBC, SFU, UBC, Redd Fish Restoration, Toquaht Nation, Nature Trust BC, Peninsula Streams Society, VIU, and several enhancement societies
BCSRIF_2019_045 **Title:** Empowering Indigenous community fisheries with deep learning - computer vision for adaptive management of terminal salmon fisheries **Recipient:** Pacific Salmon Foundation	This project will integrate traditional and modern technologies through the development of new computer vision deep-learning programs to automate salmon counting and species identification from video and sonar data. Connecting these tools with community-run escapement monitoring programs around the North and Central Coast will support the transition towards real-time data integration and in-season monitoring to inform the adaptive management of salmon fisheries. **Collaborators:** Tula Foundation Haida Fisheries Simon Fraser University Fisheries and Oceans Canada Pacific Salmon Foundation Salmon Watersheds Program Pacific Salmon Foundation Salmon Watersheds Program Heiltsuk Integrated Resource Management Department Kitasoo Xai'xais Stewardship Authority
BCSRIF_2019_058 **Title:** Enhancing Sustainability of capture & release marine recreational Pacific salmon fisheries using new tools/technology **Recipient:** University of British Columbia (Vancouver), Department of Forest and Conservation Sciences	The University of British Columbia will lead a science partnership project to conduct research on improving the sustainability of capture and release marine recreational Pacific salmon fisheries using new tools and technology. **Collaborators:** Moss Rock Foundation Dr. Steve Cooke (Carleton University) Ocean Tracking Network Canada ... 24 in total from year-end report
BCSRIF_2020_217 **Title:** Developing a cumulative effects modelling framework for the recovery of aquatic salmonid populations **Recipient:** University of British Columbia (Vancouver), Institute for the Oceans and Fisheries	University of BC researchers and partners will develop a framework for modeling cumulative impacts on salmonid populations to guide recovery planning and adaptive management based on stressor-response functions related to multiple threats. **Collaborators:** Alberta Environment and Parks Fisheries and Oceans Canada (Freshwater Institute) BC Ministry of Environment Simon Fraser University
BCSRIF_2020_292 **Title:** First Nations-led catch monitoring to inform sustainable mixed-stock fisheries management on the Central Coast	This project will focus on designing and implementing a coordinated strategy to fill data gaps related to Central Coast salmon populations which will inform management measures to promote sustainable opportunities for marine and Food Social Ceremonial fisheries.

Project	Description
Recipient: Central Coast Indigenous Resource Alliance Society	
BCSRIF_2020_311 **Title:** The application of nanopore technology for the rapid detection and characterization of pathogenic organisms in enhancement hatcheries **Recipient:** BC Centre for Aquatic Health Sciences Society	The recipient aims to validate Nanopore technology as a rapid and broad-range tool for detecting salmon pathogens from biological and environmental samples from hatcheries. The technology will be applied to screen broodstock examine pathogen sources and their distribution in hatchery systems and identify/characterize the agent(s) associated with disease occurrences.
BCSRIF_2022_319 **Title:** Fishing BC App: Tidal Waters Licence Integration and Recreational Catch Monitoring and Data Collection Enhancements Project **Recipient:** Sport Fishing Institute of BC	The Sport Fishing Institute will build on ongoing work to improve the Fishing BC app. Recent improvements funded through BCSRIF included addition of recreational fisheries regulations, catch and possession limits, safety notes, and species identification, and the next phase will enhance the information display and access, as well as tools for improved catch and compliance monitoring, including the option for recreational anglers to submit catch data directly into the DFO National Recreational License System (NRLS). **Collaborators:** DFO Rec Fisheries, Fisheries Management, IMIT, CDOS, & others Simon Fraser University University of British Columbia - Dept Forest and Conservation Sciences
BCSRIF_2022_321 **Title:** Squamish Estuary Chinook Salmon Habitat Restoration Project **Recipient:** Squamish River Watershed Society	In partnership with DFO and Squamish Nation, SRWS has developed and will implement a restoration plan to restore connectivity and access for juvenile out-migrating Chinook between the Squamish River and the central nutrient rich estuary. The project includes the modification of a training berm/spit to allow for an 850m opening. The training berm/spit has been a barrier for the past 50 years preventing fish access and freshwater exchange from the river to the estuary. In January 2022, a 300m opening was created and this project will add an additional 550m to the opening. Outcomes include improvements to; water quality, flood mitigation, and coastal resilience as well as improvements to sediment deposition in the estuary, marsh accretion, increase in carbon storage and sequestration and support to species at risk within the area. **Collaborators:** DFO Squamish Nation
BCSRIF_2022_322 **Title:** San Juan and Gordon Rivers – Salmon Estuarine Habitat Restoration **Recipient:** Pacheedaht First Nation	Pacheedaht First Nation is intending to implement 3 restoration projects in the San Juan and Gordon River estuaries with support from the San Juan Roundtable and its technical sub-committee which includes DFO. Habitat issues in these watersheds are linked to excess sediment delivery resulting from forest harvesting activities and associated road-building. This has resulted in the infilling of holding pools and estuarine tidal channels and in some cases cutting off upstream connections to freshwater. This issue was particularly devasting in the fall of 2022 when stage 5 drought occurred during the month of October indicating an urgent need to restore this habitat. The project aims to address the issues of channel connectivity, availability of low salt marsh habitats and loss of holding pools by: improving salmon access to existing spawning and nursery habitats, rehabilitating damaged estuarine nursery habitats and restoring cool water holding pools for migrating salmon. **Collaborators:** DFO SEP, Resource Restoration Unit DFO Stock Assessment BC Environmental and Climate Monitoring – Hydrology and Hydrometrics BC MFLNRORD Ministry of Transport and Infrastructure
BCSRIF_2022_326 **Title:** Aeromonas salmonicida	KPU Applied Genomics Center will work with Abbotsford Animal Health Center to perform whole genome sequencing for several Aeromonas species, including

Project	Description
Genome Sequencing and qPCR Test Development **Recipient:** Kwantlen Polytechnic University, Applied Genomics Centre	Aeromonas salmonicida (A. salmonicida) which is a pathogenic bacterium that severely impacts salmonid populations, and other fish species. A. salmonicida is a non-motile, gram-negative bacterial pathogen that causes disease and mortality in wild and cultured fish from freshwater, brackish, and salt water. This pathogen is transmitted by direct contact and all life stages are susceptible. In order to effectively monitor A. salmonicida and support fish health, it is crucial to be able to accurately identify A. Salmonicida. However, current methods cannot distinguish between A. salmonicida and other closely related species and there is currently no molecular test specific to A. salmonicida available in Canada. A key deliverable of this project will be high quality genome sequences for Aeromonas salmonicida, Aeromonas bestiarum, and ~5 additional closely related Aeromonas species. The sequences will be made publicly available to DFO and others. **Collaborators:** BC Ministry of Agriculture Animal Health Centre
BCSRIF_2022_328 **Title:** Salmon Recovery – advancing planning and action **Recipient:** Pacific Salmon Foundation	This project will undertake activities to explore the current situation and context for Pacific salmon, present challenges and potential solutions. The Pacific Salmon Foundation (PSF) will undertake 4 activities including a rapid assessment to identify top priorities for salmon at conservation unit or stock management unit scales, development of a Conservation Strategy for the Heart of the Fraser area, development of a Salmon Recovery Plan in the upper Fraser area and an application of an existing successful method to provide salmon seasonal access to floodplain habitat in the Lower Fraser R. **Collaborators:** The Upper Fraser Fisheries Conservation Alliance First Nations Fisheries Council Sumas First Nation
BCSRIF_2022_329 **Title:** Meziadin River Up-looking Hydroacoustic Sockeye Smolt Enumeration Project **Recipient:** Gitanyow Fisheries Authority	The Gitanyow Huwlip Society will estimate Meziadin Lake sockeye smolt production for a period of 3 years. Gitanyow Fisheries Authority, partnered with Skeena Fisheries Commission, will use an upward-looking hydroacoustic technique and implement a biological sampling program. Following a successful pilot of the hydroacoustic technology in the first season, this project will build two IPT (inclined plane traps) for the collection of bio samples over the study period. Information collected through the study, such as out migrating smolt abundance, size, age composition and origin, will be used to better understand Meziadin Lake sockeye productivity. This information will help inform future studies, restoration priorities, and management approaches for Meziadin Lake sockeye. **Collaborators:** DFO StAD
BCSRIF_2022_331 **Title:** Bute Inlet Salmon Viability Strategy **Recipient:** Xwemalhkwu (Homalco) First Nation	In response to the massive habitat destruction triggered by glacial melting in the Elliot Creek Watershed and severe storm destruction of the Orford Bay hatchery in 2020, Homalco First Nation will lead a project to reconstruct the Homalco-Taggares Hatchery in Orford Bay as a Multi-Species Hatchery and Stewardship Center. The project will undertake stock assessment and genetic analysis, and hatchery production activities to bolster the Southgate River chinook population, and collect oceanographic & climate related data in order to understand the effects of changing river & ocean conditions on salmon stock survival. Further funding has been added to this proposal request to cover the activities of a Geohazard assessment for land stability before any construction activites occur. **Collaborators:** Bute Inlet Roundtable Members Gillard Pass Fisheries Association Hakai Institute Ecosystem Research Homalco First Nation DFO Stock Assessment & Community Advisor Bute Inlet Roundtable
BCSRIF_2022_332 **Title:** Research in support of Sarita Chinook as an Ecological	Huu-ay-aht First Nations will undertake work over a 3-year study period, to consider the applicability for the Sarita Chinook population as an ecological indicator for the COSEWIC listed West Vancouver Island, Ocean, Fall (South)

Project	Description
Indicator and WCVI Chinook Salmon Rebuilding **Recipient:** Huu-ay-aht First Nations	population and the Westcoast Vancouver Island (WCVI) Management Unit. The proposed project will enumerate migration of Chinook smolts, monitor and evaluate salmon distribution, habitat use and spawning areas in the Sarita estuary and river system, consider predation impacts and study the nearshore marine habitat use and biological characteristics of Chinook Salmon in Numukamis Bay (which the Sarita River empties into) and Barkley Sound. **Collaborators:** Nitinat hatchery DFO Southcoast - StAD (?) WCVI Indigenous Nations LGL Limited
BCSRIF_2022_334 **Title:** First Nations led salmon habitat and population monitoring, research and cumulative effects assessment in the Lower Fraser River and Boundary Bay **Recipient:** Salish Sea Indigenous Guardians Association	The Salish Sea Indigenous Guardians Association will build an Indigenous led salmon population and habitat monitoring program which will include the monitoring of both juvenile and adult salmon and their habitats in priority areas in the Lower Fraser River and Boundary Bay. This work will lead to the creation and implementation of an Indigenous lead cumulative effects assessment framework and the creation of a long-term restoration action plan which will utilize Indigenous knowledge from within the communities to set long term priorities and short-term actions. The project will also incorporate watershed scale assessments and specific research projects to understand the impacts of both floods and flood infrastructure on wild salmon populations and incorporate considerations for flood mitigation into salmon recovery plans. **Collaborators:** Fisheries and Oceans Canada's Community Stream Monitoring network DFO Community Advisors Rivershed Society of BC A Rocha Semiahmoo Fish and Game Club Langley Environmental Partners Society Streamkeepers groups Clear Seas UBC - Indigenous Fisheries Center
BCSRIF_2022_337 **Title:** Chinook Salmon Assessments and WCVI Chinook Salmon Rebuilding in the Kaouk and Artlish Watersheds **Recipient:** Ka:'yu:'k't'h'/Che:k'tles7et'h' First Nation	Ka:'yu:'k't'h'/Che:k:tles7et'h' First Nations (KCFN) will undertake work over a 3-year study period in the Kaouk and Artlish Rivers to fill in information gaps regarding the life history of two of three Chinook indicators for the West Vancouver Island, Ocean, Fall (North) population Conservation Unit. The project will build on stock assessment data collected over the past 10 years in the Kaouk and Artlish watersheds and will cover the life history from egg deposition by spawning Chinook to nearshore marine, in support of the WCVI Chinook rebuilding initiative. **Collaborators:** DFO Southcoast StAD WCVI Indigenous Nations LGL Limited
BCSRIF_2022_339 **Title:** NEWSS-Salmon Habitat Recovery Projects **Recipient:** NEWSS	The Nechako Environment and Water Stewardship Society will complete fish habitat restoration projects in the Nechako watershed to continue to enhance recovery opportunities for Chinook and Coho salmon as well as conduct a complementary eDNA study to assist in determining distribution of salmonids in the Stuart/Nechako watershed to further inform future restoration efforts in the area. **Collaborators:** UNBC School District #91
BCSRIF_2022_341 **Title:** ʔaayaaqa (Herring) Herring Spawn Dynamics **Recipient:** Nuu-chah-nulth Tribal Council	
BCSRIF_2022_345 **Title:** Digital Imaging of Wild Coho Returns to the Lillooet River Conservation Unit **Recipient:** Lil'wat First Nation	The primary goal of this project is to generate an escapement estimate of wild Coho to the Lillooet CU for each return year of 2023, 2024, 2025. Key activities include; operating an ARIS from mid-Sept to mid-Nov and review data files and generating an escapement estimate. This project will provide an estimate for escapement which will enable a data-driven approach to Coho fisheries improving the likelihood of sustainably managed salmon.

Project	Description
	Collaborators: LGL Limited JohnsonFishSci
BCSRIF_2022_346 **Title:** Genetic monitoring of Kokanee-sockeye salmon (*Oncorhynchus nerka*) hybrid fitness and long term outcomes associated with an experimental re-introduction program **Recipient:** University of British Columbia (Okanagan), Department of Biology	This project builds on the the experimental sockeye salmon (*Oncorhynchus nerka*) reintroduction project in Skaha Lake (British Columbia) to investigate hybridization between anadromous sockeye and resident kokanee . This collaboration between Indigenous (Okanagan Nation Alliance), Provincial (BC Ministry of Forests) and Academic (University of British Columbia Okanagan) partners will combine genetic, morphological and microchemistry analyses to investigate behavior and fitness within the Skaha Lake system over a 15-year period. The results from this work could inform government-to-government efforts to monitor sockeye reintroduction efforts, address critical uncertainties, and inform future management decisions. **Collaborators:** Okanagan Nation Alliance BC Ministry of Forests UBC Okanagan
BCSRIF_2022_347 **Title:** Selective Fishing Using a Salmon Trap in the Campbell River Estuary **Recipient:** A-Tlegay Fisheries Society	A-Tlegay Fisheries Society proposed project involves the assessment, design, construction, and operatation of a tidal waters selective fishery salmon trap close to their traditional fishing sites in the Campbell/Quinsam rivers estuary on Vancouver Island. Historically, heart and chevron shaped traps were used extensively by First Nation communities along the estuary to capture adult salmon prior to the development of commercial fisheries. Recent revitalization of fish traps as a terminal fishery in other areas along the coast has been shown to be successfully at catching and selectively harvest hatchery marked salmon species while releasing wild (unmarked) salmon and steelhead of conservation concern. Partnering with We Wai Kai First Nation, Wei Wai Kum First Nation, LGL Limited, and the Wild Fish Conservancy; the initiative will develop First Nations' capacity for sustainable salmon stewardship through the development of the best selective harvest fishing methods possible in traditional fishing areas while preserving wild stocks of conservation concern. **Collaborators:** LGL Limited Wild Fish Conservancy
BCSRIF_2022_348 **Title:** Chemainus-Koksilah Twinned Watershed Salmon Sustainability Project- Phase 2 **Recipient:** Halalt First Nation	Cowichan Tribes, in collaboration with Halalt First Nation, will expand the successful Chemainus-Koksilah Twinned Watershed Salmon Sustainability Project through enhanced stock assessment studies including the addition of a Passive Integrated Transponder (PIT) tagging component, and the continuation of process-based restoration work in high-valued tributaries of the Chemainus and Koksilah watersheds. The continuation and expansion of the current monitoring program would provide data on the abundance, productivity, and diversity of salmon and steelhead in the previously data-deficient Koksilah and Chemainus rivers over a 4 or 5-year life cycle for chum, coho, and COSEWIC-listed summer and fall-run Chinook salmon. **Collaborators:** Halalt First Nation Q'ul-lhanumutsun Aquatic Resources Society (QARS) DFO – StAD Nanaimo River Stewardship Society – support for PIT tag of hatchery raised Chemainus Chinook Pacific Salmon Foundation Evans Redi-Mix
BCSRIF_2022_349 **Title:** Clayoquot Pacific Salmon Recovery Initiative **Recipient:** Redd Fish Restoration Society	Redd Fish Restoration Society, in collaboration with with Ahousaht, Hesquiaht and Tla-o-qui-aht Nations, will build on the successess of the Clayoquot Wild Chinook Salmon Initiative Project to address habitat loss at a watershed scale in priority watersheds in Clayoquot Sound. The project will implement process-based restoration strategies starting with addressing slope stabilization issues resulting from forestry activities in the upper watersheds, and including but not limited to implementing instream habitat restoration in the mainstem and floodplain in each watershed to help create more productive rearing habitat to increase rearing potential to produce larger, healthier smolts capable of thriving in a changing marine environment.

Project	Description
	Collaborators: Ahousaht Nation as represented by Maaqtusiis Hahoulthee Stewardship Society Inter-Fluve Tla-o-qui-aht First Nation Hesquiaht First Nation
BCSRIF_2022_351 **Title:** Estimating aggregate Coho salmon escapement to the Lower Fraser Management Unit **Recipient:** Lower Fraser Fisheries Alliance Society	The Lower Fraser Fisheries Alliance will continue the successful Chilliwack coho PIT tag escapement project to estimate the total escapement of coho to the Lower Fraser and Chilliwack River through the implementation of an assessment fishery and coho passive integrated transponder (PIT) program. The program will address knowledge gaps for the stock status of the Lower Fraser Coho Management Unit and results will be used to inform fisheries management decisions and support the long term prosperity of BC salmon stocks. **Collaborators:** DFO Fraser StAD LGL Consultants Lil'Wat Nation
BCSRIF_2022_356 **Title:** Campbell River Estuary Salt Marsh and Eelgrass Restoration **Recipient:** Greenways Land Trust	This project will restore approximately two hectares of the Campbell River Estuary towards pre-development conditions, led by Discovery Coast Greenways Land Trust in partnership with the Wei Wai Kum First Nation. Using process-based restoration techniques, the project will re-create salt marsh and eelgrass habitat that has been lost due to historic logging practices in the estuary and improve connectivity to the river by adding new tidal channels. Increasing estuarine habitat for out-migrating juvenile chum and Chinook salmon in the system is expected to increase the amount of time they spend feeding and growing in the estuary, thereby increasing their survivability at sea. **Collaborators:** Wei Wai Kum First Nation City of Campbell River A-tlegay Fisheries Society
BCSRIF_2022_357 **Title:** TFN Fish Trap – Capacity Building, Communications and Operations 2023-26 **Recipient:** Tsawwassen First Nation	This project will build on the successful Fraser River Tsawwassen First Nation pound net project near Steveston, B.C.. This project includes training for TFN members to operate the pound net, required safety equipment and operational improvements for the pound net as well as engagement with the TFN community, local governments and the general public on the sustainable selective fishing opportunity a pound net provides. This also includes a continued robust salmon mortality study, ongoing data collection and reporting activities for the length of this project. **Collaborators:** LGL Limited Wild Fish Conservancy
BCSRIF_2022_358 **Title:** Determining the mechanisms of impacts of a changing climate on zooplankton in the Salish Sea using models and observations **Recipient:** University of British Columbia (Vancouver), Department of Earth, Ocean and Atmospheric Sciences	University of British Columbia (UBC), in partnership with Ocean Sciences (DFO) and University of Washington, will use a combined approach to examine the impacts of climate change on the food available to out-migrating juvenile salmon and resident adult species in the Salish Sea. Using both computer models and observational data, the team will focus on zooplankton responses to stressors such as ocean warming and increased atmospheric CO2. This information will be critical to identifying potential benefits or threats posed to wild Pacific Salmon populations in response to climate change. **Collaborators:** Fisheries and Oceans Canada - Science University of Washington, Oceanography Institute of Ocean Sciences
BCSRIF_2022_360 **Title:** Basin-scale Events to Coastal Impacts (BECI) **Recipient:** North Pacific Marine Science Organization	The overall objective of BECI (to 2030) is to implement an integrated international ocean intelligence system of modelling, monitoring, and forecasting that provides timely (near real-time) advice allowing for improved knowledge and the ability to sustainably manage coastal fisheries. A significant component is to develop a better understanding of the impact of current and future climate conditions for the North Pacific socio-ecological system. Two-year funding is requested from BCSRIF to ensure the effective development of the project and commence work on early deliverables related to the necessary downscaled basin-wide models, data governance and engineering for the modelling and visualization, indigenous participation in the design of the project,

Project	Description
	and ensure that there is effective and efficient coordination of the project. Salmon will be an exemplar species while a modular approach will allow for the work to include / be applied to other species of interest. BCSRIF funding will be used to advance Canadian interests and develop an innovative approach to ocean forecasting that allows for enhanced down-scaled modelling of the boundary conditions (open ocean) for use in higher resolution coastal models that are in use or being developed. The goal is to inform fisheries production predictions that more fully account for the ongoing and increasing implications of climate change. Partners in Canada that have expressed an interest in BECI include the government agencies DFO and ECCC, Canadian fishing industry (CanFisCO and BC Seafood Alliance), First Nations (e.g., FNFC) and academic scientists. The BCSRIF investment would leverage comparable (if not more significant investments) from the Unites States and Japan. **Collaborators:** Environment and Climate Change Canada (ECCC) DFO Hakai institute and Tula Foundation NPAFC – International Year of the Salmon PICES NOAA UBC BECI North Pacific Research Board (NPRB) Columbia River Inter-Tribal Fisheries Commission (CRITFC)
BCSRIF_2022_361 **Title:** Identifying and mitigating hot spots of salmon exposure to toxic road runoff **Recipient:** University of British Columbia (Vancouver), Department of Civil Engineering	The UBC team is proposing to document and mitigate the adverse impacts of toxic road runoff on BC salmon in the Lower Mainland, with a focus on the emerging tire-related chemical 6PPD-quinone. Salmon populations in the Fraser River Basin are threatened by numerous stressors, including the impacts of growing urban populations. This science partnership group will assess the prevalence of stormwater contaminants, particularly 6PPD-quinone, in salmon-bearing streams in BC and will identify opportunities for green infrastructure interventions to protect salmon populations from toxic road runoff contaminants. **Collaborators:** Fisheries and Oceans Canada - Science Simon Fraser University City of Vancouver City of Surrey A Rocha and Shared Waters Alliance Fraser Basin Council- Salmon Safe BC Salish Sea Indigenous Guardians Association (SSIGA)
BCSRIF_2022_362 **Title:** Watershed Futures Initiative: Towards climate resilience of salmon watersheds **Recipient:** Simon Fraser University, Department of Biological Sciences	The overarching goal of the Watershed Futures project is to inform and catalyze the effective stewardship of cumulative effects to increase resilience of salmon watersheds to climate change. The project aims to understand climate change thresholds, sensitivities and cumulative effects on salmon ecosystems which will help inform stakeholders, rightsholders, and managers in watershed management to increase climate-resilience of BC's salmon watersheds. Activities will address critical knowledge gaps, and will deliver scientific projects to inform benchmarks and management targets, identify paths forward and catalyze a connected network to improve the climate resilience of BC's salmon watersheds. **Collaborators:** UBC's Department of Forest and Conservation Sciences UBC's Centre of Indigenous Fisheries5. SFU Salmon Watersheds Lab Pacific Salmon Foundation's Salmon Watershed Program Thompson-Okanagan Region Resource Management West Coast Environmental Law First Nations Wild Salmon Alliance
BCSRIF_2022_366 **Title:** Restoration of salmon habitat at Cultus Lake, BC: a Green Shores® demonstration project **Recipient:** SCBC Stewardship Centre for BC	SCBC is proposing to implement a collaborative, highly visible Green Shores project to demonstrate and educate the public on the use of nature-based restoration strategies, improve riparian and aquatic habitat and mitigate erosion at Cultus Lake, to benefit endangered Cultus Lake Sockeye, lake ecosystems and community values. Green Shores is a platform for incentivizing actions that provides practical strategies for foreshore design and shoreline and riparian management that can help restore areas of erosion and flooding while promoting healthy shoreline and freshwater environments. This project will restore ~150m of shoreline, decrease anthropogenic nutrient loadings to the lake, create awareness, develop capacity with partners and property owners

Project	Description
	and conduct monitoring and evaluations. **Collaborators:** Cultus Lake Park Board Cultus Lake Stewardship Society (CLASS) Green Shores Technical Advisory Committee (GSTAC) University of Victoria SCBC Conservation and Stewardship Practices Committee Cultus Lake Parks Board and Environmental and Area Planning Committee
BCSRIF_2022_368 **Title:** Thompson-Shuswap Salmon Habitat Assessment, Monitoring & Restoration Program (2023-26) **Recipient:** Secwepemc Fisheries Commission	This project, being led by the Secwepemc Fisheries Commission (on behalf of the Thompson-Shuswap Salmon Collaborative), seeks to conduct a suite of inter-related activities focused on assessing, monitoring, and responding to freshwater habitat threats facing wild salmon and steelhead in the Thompson-Shuswap sub-region. Project activities will include assessing and mapping sensitive stream habitats; identifying areas of cold-water refugia critical for fish survival during climate change; salmon habitat restoration including improving fish passage; and expanding hydrometric monitoring in drought-sensitive streams. Project outcomes will inform the Thompson-Shuswap Salmon Collaborative’s integrated planning process that aims to provide strategic recommendations and identify the work needed to implement priorities and actions that will benefit salmon ecosystems while considering impacts from climate change and human uses. **Collaborators:** Thompson-Shuswap Salmon Collaborative (TSSC): Fisheries and Oceans Canada BC Ministry of Land, Water and Resource Stewardship Secwepemc Fisheries Commission
BCSRIF_2022_370 **Title:** 10,000 Wetlands Project **Recipient:** The B.C. Wildlife Federation	BCWF is proposing to install beaver dam analogues (BDA) throughout BC in collaboration with partners to advance process-based restoration and measure BDA efficacy for addressing watershed threats, particularly climate change and extreme weather, and support fish and wildlife habitat. BDA methodology has gained momentum and support recently to address drought and low-flow stream habitat, riparian degradation and improvements to fish habitat. This project will install BDA's, initiate training, monitor installations to generate BDA research and determine effectiveness, and refine BDA installation and monitoring protocols. The project goal is to establish BDA technology as a method for stream restoration in BC as this method is a low-cost approach to wetland restoration and fish habitat enhancement designed to mimic natural wetlands and ecological processes. **Collaborators:** British Columbia Institute of Technology (BCIT) Nature Trust of BC (NTBC) Nicola Valley Institute of Technology (NVIT) Ministry of Land, Water and Resource Stewardship, South Coast Ministry of Land, Water and Resource Stewardship, Thompson-Okanagan Nechako Environment and Water Stewardship Society Pacific Salmon Foundation (PSF)
BCSRIF_2022_371 **Title:** Skeena River Fish Trap Project **Recipient:** Lax Kw’alaams Business Development LP.	This project is being conducted by Lax Kw'alaams Fisheries in collaboration with Skeena Fisheries Commission and the Wild Fish Conservancy to assess the viability of an impoundment net fish trap in the lower Skeena River. Net fish traps are one of the oldest methods of fishing technology, and have been used for millennia by First Nations to harvest salmon and other species. This technology supports selective fishing practices and reduces bycatch mortality, as well as having utility as a stock assessment and research platform to monitor Skeena River salmon and other species such as Steelhead. **Collaborators:** Wild Salmon Conservancy Skeena Fisheries Commission
BCSRIF_2022_373 **Title:** Resilient Waters Phase 3: Restoration and Research for Salmon and Flood Resilience in the Lower Fraser Watershed	Resilient Waters Phase 3 builds off the successes of the first two phases of this large-scale effort to restore connections to wild salmon habitat in the Lower Fraser River while advancing best practices in fish-friendly flood-control infrastructure. Activities included in this phase include the implementation of one large scale restoration project to provide up to 3 linear km of high quality juvenile Coho and Chinook rearing habitat within an existing Wildlife

Project	Description
Recipient: MakeWay Charitable Society	Management Area, one research project to better understand impacts of pumps on salmon, and a post-restoration monitoring program to assess the success of sites where flood infrastructure has been restored for fish passage compared to baseline assessments conducted in prior phases of Resilient Waters. Finally, results from all project activities will help to inform MakeWay's ongoing efforts to advance and communicate best practices for fish-friendly flood infrastructure. **Collaborators:** Nature Trust of BC Ducks Unlimited Canada BC South Coast Conservation Land Management Program, BC Land, Water, Resources Stewardship Kwikwetlem and Katzie First Nations SFU Ecological Restoration Program DFO Lower Fraser Restoration Unit Specialist Kerr Wood Leidal Consulting Engineers Pearson Ecological University of British Columbia Pacific Salmon Lab, UBC Coastal Adaptation Lab City of Surrey Salish Sea Indigenous Guardians Association DFO Lower Fraser Restoration Unit Specialist First Nations – Cheam, Seabird Island Leqamel, Tswawwassen Watershed Watch Salmon Society
BCSRIF_2022_374 **Title:** Scaling the Implementation of Riparian Restoration **Recipient:** Investment Agriculture Foundation British Columbia	This multi-year initiative addresses the threat of riparian habitat degradation through improved agricultural practices that benefit salmon ecosystems and multiple Species at Risk. Farmland Advantage (FLA) operates with Indigenous partners on a watershed-to-watershed basis, identifying climate change adaptation and mitigation goals and assessing restoration opportunities within riparian areas adjacent to salmon bearing streams and rivers. This project works directly with farmers and ranchers to support them taking a stewardship role of riparian and salmon habitats on private lands. Starting April 1, 2025, FLA will be renamed “BCSRIF SIRR (Scaling the Implementation of Riparian Restoration)” to recognize the sole BCSRIF focus of this funding program. **Collaborators:** Federal Ministry of Environment and Climate Change Canada BC Ministry of Agriculture and Food BC Ministry of Water Land and Resource Stewardship
BCSRIF_2022_377 **Title:** Lower Adams Habitat Restoration Initiative (LAHRI) **Recipient:** Skw’lax te Secwépemcuclew	The overall objective of the project is to focus on re-establishing connectivity and habitat conditions to support and sustain recovery of Adams River sockeye, other salmon, and resident fish species. The key project elements will be the assessment of current geomorphic conditions to inform restoration planning, design, feasibility, monitoring, and implementation. The project will rely on evidence based decision-making metrics, employ a precautionary approach, and will be committed to implementing processed-based restoration solutions. The project will be conducted in the approximately 3.5 km length reach downstream of Squilax-Anglemont Road bridge to the confluence of Shuswap Lake on the lower Adams River as this area supports the majority of sockeye spawning habitat for the Adams River. **Collaborators:** Pacific Salmon Foundation Secwépemc Communities DFO Province of BC, Ministry of the Environment, BC Parks Province of BC, Ministry of Forests, Resource Management, Fish and Wildlife Branch
BCSRIF_2022_379 **Title:** Strait of Georgia Herring: Restoring the Salmon Food Web **Recipient:** Pacific Salmon Foundation	
BCSRIF_2022_383 **Title:** Restoring Fraser River Estuary Salmon Habitat (ReFRESH)	Ducks Unlimited Canada (DUC) will build on the successes of their ongoing work by expanding the Fraser River Estuary Salmon Habitat (FRESH) Restoration project to include new research and monitoring activities to improve the ability of future salmon habitat restoration efforts, with results to be shared with government and NGO restoration practitioners. A research project will be undertaken to better understand natural tidal marsh habitat forming processes

Project	Description
Recipient: Ducks Unlimited Canada	including the implementation of new marsh habitat restoration pilot projects using the results of these studies. Another new project will evaluate the success of created (i.e., compensation, offsetting sites) tidal marshes through fish usage studies, and results will be used to restore/enhance a number of sites within the Fraser River Estuary. Finally, the project include the continuation of long-term effectiveness monitoring for the FRESH Restoration Project and extension of the Sturgeon Bank Sediment Enhancement Pilot Project for an additional two years. **Collaborators:** Ducks Unlimited Canada Raincoast Conservation Foundation Lower Fraser Fisheries Alliance Asarum Ecological Consulting Tsawwassen First Nation BC Ministry of Land, Water and Resource Stewardship BC Ministry of Forests Environment and Climate Change Canada - Science & Technology Branch Fisheries and Oceans Canada - Resource Restoration Unit Vancouver Fraser Port Authority City of Richmond Metro Vancouver National Research Council of Canada Pacific Institute for Climate Solutions UBC Pacific Salmon Ecology and Conservation Lab UBC Conservation Decisions Lab Simon Fraser University - Faculty of Environment Simon Fraser University - Remote Sensing of Environmental Change (ReSEC) Lab British Columbia Institute of Technology - Ecological Restoration Program Northwest Hydraulic Consultants West Coast Environmental Law Roundtable and Technical Working Group. Envirowest Consultants Inc. World Wildlife Fund - Canada MakeWay's Resilient Waters Katzie First Nation Rivershed Society of BC Salish Sea Indigenous Guardians Association Farmland Advantage Stó:lo Research and Resource Management Centre
BCSRIF_2022_384 **Title:** Development of High-resolution Climate Change Freshwater Hazard Data for BC **Recipient:** Pacific Climate Impacts Consortium	The Pacific Climate Impacts Consortium (University of Victoria) aims to expand upon their current work (BCSRIF_2019_074_2) by providing results on the impact of climate change on the freshwater environment at a resolution sufficient to represent individual stream reaches and lakes. This project will deliver highly detailed streamflow and water quality data and associated exposure indicators to support site-specific (e.g., spawning grounds, and stream or lake rearing habitat) climate change vulnerability, habitat, and stock assessments, using exposure indicators that quantify the magnitude of expected changes in the freshwater environment. Changes could include increasingly extreme flow levels (low and high), high water temperatures, and hypoxia (low dissolved oxygen), which all pose as potential hazards to salmon survival across various life stages. The study is to be conducted primarily in areas with the majority of priority wild salmon stocks in BC. This project will involve two main activities: Hydrologic Modelling and Data Portal deployment. **Collaborators:** Fisheries and Oceans Canada
BCSRIF_2022_385 **Title:** Tsecmenúl̓ecwem-kt (We Repair the Land) - Deadman Recovery & Resiliency Initiative **Recipient:** Skeetchestn Indian Band	The Deadman River Watershed Restoration Program (the Program) by the Skeetchestn Natural Resources Corporation aims to restore the post-wildfire valley-bottom to a climate-resilient riverscape by establishing a comprehensive monitoring and research program as well as implementing land and riparian restoration treatments in the watershed using process based restoration through nature-base solutions. The watershed is heavily impacted by resource development and climate change including high road density; high equivalent clear cut area; riparian disturbance; and approximately 55% has been burned during wildfires. The Program will develop a comprehensive monitoring program to measure the recovery of the watershed at biotic and abiotic levels for factors that impact the habitat quality of Chinook, Coho, and Steelhead; form a research group to advise on development, prioritization, placement, and delivery of the treatment options; and develop and test watershed restoration treatments that will also be tested for effectiveness including land treatments, channel treatments and road/trail rehabilitation.

Project	Description
	Collaborators: Secwepemc Fisheries Commisssion Skeetchestn Indian Band
BCSRIF_2022_387 **Title:** Charting a Path for Coastal First Nations' Community Salmon Enhancement Initiatives **Recipient:** Great Bear Initiative Society	This project is the second phase of "Coastal First Nations Salmon Enhancement and Restoration Initiative", which implemented upgrade to 6 remote community hatcheries throughout the North and Central coasts. Building on that work, this new phase will focus on providing on-site technical support, developing site-specific operating manuals, and sharing best practices for operating and managing the newly upgraded hatcheries, with opportunities for participating First Nations to refresh and build fish health technical skills. Successful implementation of salmon enhancement programs is essential and is important to integrate into Nation-led efforts to protect and rebuild salmon in the territories. **Collaborators:** Kitasoo Xai'xais (CEDP and AFS hatcheries) Kitasoo Xai'xais Stewardship Authority Old Massett Village Council (CEDP hatchery) Gitga'at Hartley Bay (CEDP hatchery) Heiltsuk Integrated Resource Management Department Heiltsuk Mcloughlin Bay (CEDP hatchery) Nuxalk Stewardship Office (Snootli Creek hatchery, Atnarko sockeye recovery program) Wuikinuxv Nation (Percy Walkus hatchery) Central Coast Indigenous Resource Alliance DFO North Coast Restoration Unit (engineering and biological staff) and DFO Community Advisors in Haida Gwaii, Terrace and Bella Coola
BCSRIF_2022_389 **Title:** Mitigating Inputs of Tire Wear Toxins to Protect Salmonid Habitat on Vancouver Island **Recipient:** British Columbia Conservation Foundation	This project aims to identify where the major sources of tire wear toxin (TWT) inputs are along eastern Vancouver Island, investigate the spatiotemporal concentration changes of the TWTs from point sources and evaluate the efficacy of engineered solutions to remove and/or prevent TWTs from entering salmon-bearing streams. This project leverages the power of an innovative technology development that enables high throughput chemical analysis, at a significantly reduced cost relative to current standardized analysis methods for TWTs, and provides real-time data for on-site measurements including treatment efficacy. In partnership with Vancouver Island University's Applied Environmental Research Laboratory, the University of Victoria's Community Water Innovation Laboratory, local First Nations, stewardship groups and local government representatives, the BC Conservation Foundation will determine TWT 'hotspots' and identify the most effective means at protecting freshwater salmonid habitat from these harmful toxins. **Collaborators:** Snuneymuxw First Nation Cowichan Tribes Gorge Waterway Action Society Fanny Bay Salmonid Enhancement Society Vancouver Island University University of Saskatchewan Quadrocore University of Victoria Fisheries and Oceans Canada Stewardship Groups (various) University of British Columbia Pacific Salmon Foundation
BCSRIF_2022_397 **Title:** Mapping, monitoring and restoring important forage fish habitats in Coastal British Columbia to support salmon conservation efforts. **Recipient:** Comox Valley Project Watershed Society	Comox Valley Project Watershed Society will build off the successes of their completed BCSRIF-funded project to apply and refine recently developed research tools and models to identify forage fish spawning, rearing, burying and foraging habitats in the Salish Sea and off the west coast of Vancouver Island. Active restoration of at least two potential forage fish spawning beaches will also take place. This work will continue to contribute to the conservation of important food sources for Pacific salmon, including chinook and coho. **Collaborators:** North Island College K'ómoks First Nation Ditidaht First Nation Redd Fish Restoration Society Parks Canada Environment and Climate Change Canada BC Forage Fish Monitoring Network University of Victoria Geography Department University of Victoria – Jaunes Lab Hakai Institute Province of BC Coastal and Ocean Resources Pacific Salmon Foundation
BCSRIF_2022_399 **Title:** Evaluating climate change scenarios for the Quesnel	This project will focus on understanding the effects of climate change on salmon ecosystems and the direct effects of increasing water temperatures and wildfire-contaminated spawning habitat on interior Pacific salmon early life

Project	Description
Watershed to determine flood, fire and temperature risks posed to Upper Fraser salmon stocks. **Recipient:** University of Northern British Columbia, Department of Geography, Earth and Environmental Sciences	stages. Improvements to hatchery infrastructure will aid Chinook enhancement and conservation efforts with collaborators at DFO and Upper Fraser Fisheries Conservation Alliance. Construction of a center of excellence will provide classroom/outreach space to provide First Nations training and community outreach, while specialized laboratory facilities will increase collaboration and salmon ecosystem research. This project will build educational and research capacity, improve Chinook salmon culture and deliver to the adjustment of management protocols for existing Pacific salmon stocks in these areas and to the development of mitigations to address climate change. **Collaborators:** Upper Fraser Fisheries Conservation Association Horsefly River Roundtable Cariboo Envirotech Fisheries and Oceans Canada - SEP & Science
BCSRIF_2022_401 **Title:** Supporting and connecting community-based monitoring for climate-resilient salmon ecosystems **Recipient:** Pacific Salmon Foundation	This PSF project will assist communities strive to adjust fisheries management to deal with climate change uncertainties by monitoring climate change in salmon freshwater habitats. This project will enable both local and broad scale planning for climate resilient salmon ecosystems. This will include the PSF leads working with 26 different organizations across BC including 14 First Nations' organizations to: 1) Scale-up the application of computer-vision tools to empower communities with real-time information on salmon returns that can inform proactive in-season fisheries management; 2) Harmonize community-led monitoring of salmon ecosystems by providing guidance on best practices, working with partners to implement new stream temperature and flow monitoring where there are gaps, and synthesizing and sharing data across organizations; and 3) Create opportunities for integration and collaboration among communities and projects through workshops and working groups. Systems and communities listed for scaled-up computer vision tools for real-time enumeration: 1. Kitwanga R. (Gitanyow FN) 2. Bear R. (Skeena Fisheries Commission) 3. Kwaka Creek (Kitasoo Xais Xais FN) 4. Yakoun River (Council of Haida Nations) 5. Taku R. (Taku R. Tlingit FN) 6. Koeye River (Heiltsuk Integrated Resource Management Department) 7. Wannock River (Wuilinuxv FN) 8. Atnarko River (Nuxalk Fish & Wildlife) 9. Alsek R. - Klukshu weir 10. Thompson Watershed - Shuswap Lake **Collaborators:** Taku River Tlingit Haida Fishery Program Gitanyow Fisheries Gitga'at Fisheries Kitasoo Xai'xais Stewardship Authority Heiltsuk Integrated Resource Management Department Nuxalk Stewardship Wuikinuxv Fishery Program Secwepmec Fisheries Commission Skeena Fisheries Commission Central Coast Indigenous Resource Alliance North Coast Skeena First Nations Stewardship Society Nanwakolas Council (Jordan Benner) Broughton Area Wild Salmon Initiative Fisheries and Oceans Canada British Columbia Institute of Technology University of Toronto Simon Fraser University Pacific Data Stream Living Lakes/Columbia Basin Hub Hakai institute Morice Watershed Monitoring Trust Skeena Knowledge Trust Wild Salmon Centre Ecofish Research Ltd.
BCSRIF_2022_404 **Title:** Oolichan From Estuary to Offshore: Assessment of Early Marine Populations and Limiting Factors of Central Coast Oolichan (Eulachon: Thaleichthys pacificus) in Douglas Channel and Gardner Canal **Recipient:** Ecofish Research Ltd.	
BCSRIF_2022_407 **Title:** Watershed Restoration	The Watershed Restoration Prioritization Tool/ Solutions for Gold River Steelhead Project is a collaborative project led by NSWS and partners to

Project	Description
Prioritization Tool/Solutions for Gold River Steelhead **Recipient:** Nootka Sound Watershed Society	support long-term management and recovery of priority salmon stocks in the Nootka Sound region of West Coast Vancouver Island, with a particular focus on threatened Chinook Salmon and Steelhead stocks in the Gold River watershed. This project is a continuation of a previously supported BC SRIF project (BC SRIF 2020_301) and includes three main project components (or activities): 1) stream temperature and hydrometric monitoring network in Nootka Sound; 2) riparian silviculture restoration project implementation and monitoring; and 3) community engagement and expansion of the Nootka Sound Salmon and Watershed Assessment Tool. These activities will provide crucial physical, technical, and decision-support infrastructure to support the NSWS and partners in ongoing work to support salmon conservation and recovery actions in Nootka Sound. **Collaborators:** Solutions for Steelhead (S4S) Gold River Task Force (including: BC MFLNRORD, DFO, NSWS, Western Forest Products, BCIT, Mowachaht/Muchalaht First Nation, and Steelhead Society), and Ecofish Research Ltd.
BCSRIF_2022_410 **Title:** Portage Creek Chinook Salmon Recovery Program **Recipient:** St'át'imc Government Services (SGS)	This project will provide key information to preserving and managing the endangered Portage Creek Chinook population. Through innovative and robust methods, the project will provide a high-precision estimate of juvenile and spawner abundance within Portage Creek to quantify enhancement success. Important information on migration timing and proportionate natural influence (PNI) will be collected to inform future management and enhancement activities. The program will bring together local Indigenous communities from St'át'imc Nation, DFO, BC Hydro, and InStream Fisheries Research. **Collaborators:** InStream Fisheries Research DFO – Salmon Enhancement Program, StAD BC Hydro
BCSRIF_2022_412 **Title:** Post Flood Support for Fish and Fish Habitat Recovery in the Nicola Watershed **Recipient:** Scw'exmx Tribal Council	The Scw'exmx Tribal Council's Fisheries Department, the Nicola Watershed Stewardship and Fisheries Authority (NWSFA), is requesting funds to support strategic post 2021 flood recovery actions in the Nicola Watershed. These include the remediation of several site specific areas where critical habitat has been degraded by extreme flood event; support for a watershed assessment and rapid deployment team to address fish stranding and passage issues as they occur and support watershed rehabilitation planning work; and the continuation of a juvenile standing stock project to track Chinook and Steelhead juvenile recruitment in response to flood. Each of these projects has been identified as high priority by the Fish Emergency Technical Team consisting of representatives from NWSFA, DFO and BC. There are 18 sites and issues that have been identified as requiring immediate attention and/or presenting opportunities to offset the impacts of flooding on fish and fish habitat and it is expected that through the support of the BCSRIF the NWSFA will be capable of addressing at least 10 of the sites and at least two of the major projects identified. **Collaborators:** Scw'exmx Tribal Council's member Bands/local FN governments. Landowners Provincial and Federal governments
BCSRIF_2022_414 **Title:** Columbia River Salmon Reintroduction Initiative (CRSRI): Bringing the Salmon Home **Recipient:** Okanagan Nation Alliance	The Bringing the Salmon Home Initiative is founded upon a historic Agreement and guided by Indigenous-led governance involving five governments. It is supported by commitments from leadership, but it has not received sufficient funding to meet these obligations. This project proposes 16 activities across 3 workstreams including salmon ecosystem rebuilding, salmon habitats and connectivity, and knowledge synthesis and integration. The project will explore feasibility and reintroduction options with the intent to improve knowledge to support decision-making, enhance salmon ecosystem resilience, support principles in UNDRIP and DRIPA, interweave Indigenous Knowledge and western science, build transboundary support and coordination.

Project	Description
	Collaborators: Syilx Okanagan Nation Secwépemc Nation Ktunaxa Nation DFO Province of British Columbia
BCSRIF_2022_415 **Title:** Restoring freshwater connectivity for Pacific salmon **Recipient:** Canadian Wildlife Federation	The Restoring freshwater connectivity for Pacific salmon project by the Canadian Wildlife Federation is a continuation and expansion of their current BCSRIF project (BCSRIF_2019_137). The goals of the 2023-2026 project are to develop up to seven indigenous led watershed connectivity remediation plans in Pacific salmon habitat; update three existing watershed connectivity remediation plans; improve the habitat suitability modelling and assessment techniques for BC salmon to allow for better prediction of important spawning and rearing habitat areas disconnected by both longitudinal and lateral barriers in conjunction with UNBC; identify and rank the most important barriers to fish passage caused by rail infrastructure and initiate development of an action plan to restore access to spawning and rearing habitat that is currently cut off by rail stream crossings; and improve the knowledge and application of best practices for stream crossings among practitioners in government and the private sector to prevent future unintended fragmentation of habitat through the development of a short course and supporting resources relating to stream crossings. Target areas for watershed plans include the Bowron River and Quesnel River watersheds as well as other yet to be determined. **Collaborators:** Lower Fraser Fisheries Alliance (LFFA) Central Coast Indigenous Resource Alliance (CCIRA) Upper Fraser Fisheries Conservation Alliance (UFFCA) Skeena Sustainability Assessment Forum Project Team (SSAF PT) Office of the Wet'suwet'en, Gitxsan Gitanyow, and Witset First Nation Lhtako Dené Nation (LDN) Scw'exmx Tribal Council (STC) T'exelc, Williams Lake First Nation (WLFN) The Horsefly River Roundtable (HRR) The Pacific Salmon Foundation (PSF) BC Ministry of Land, Water and Resource Stewardship (MLWRS) BC Ministry of Forests (MOF) BC Ministry of Transportation and Infrastructure (MOTI) DFO Salmonid Enhancement Program (SEP) University of British Columbia (UBC)
BCSRIF_2022_425 **Title:** Empirically resolving interspecific competition experienced by North Pacific salmon in the open ocean **Recipient:** University of British Columbia (Vancouver), Institute for the Oceans and Fisheries	This project uses samples collected through trawl surveys conducted under the International Year of the Salmon to combine Compound-Specific Isotope analysis with diet analysis to resolve competitor interactions among salmon and other species in the East North Pacific. Bulk-isotope analyses indicate that there is a high degree of trophic overlap between other taxa that co-occur with salmon, such as myctophids, squid, and jellyfish indicating a significant source of competition. This information will support the development of a food-web model to determine how competitor interactions impact grown and survival of salmon on the high seas. **Collaborators:** The North Pacific Anadromous Fish Commission (NPAFC) Pacific Salmon Foundation Mitacs
BCSRIF_2022_426 **Title:** Investigation of water acidification and habitat on imprinting and homing in Pacific salmon **Recipient:** University of British Columbia (Vancouver), Department of Zoology	Led by the University of British Columbia Department of Zoology, this project will aim to identify how changes in the environment can impact a salmons olfactory response during different life history phases. This will improve understanding of how rearing conditions can affect physiology during key periods when salmon undergo olfactory imprinting on natal habitats, and how captive rearing conditions can be managed to limit impacts on imprinting. **Collaborators:** BC Ministry of Land and Water Resource Stewardship
BCSRIF_2022_427 **Title:** Fish Passage Restoration in Gitksan Territory	The Skeena Fisheries Commission, in partnership with Gitksan Watershed Authorities will undertake activities to restore fish passage and utility of upstream habitats by replacing fish barriers in Gitksan Territory on the Skeena River watershed. This project provides opportunities for training of fisheries technicians and youth, and will support continued restoration efforts in the area.

Project	Description
Recipient: Skeena Fisheries Commission	**Collaborators:** North Coast Skeena First Nations Stewardship Society (NCSFNSS) Gitksan Watershed Authorities (GWA) North Coast DFO Salmonid Enhancement Program and Resource Restoration Unit
BCSRIF_2022_430 **Title:** Resilient Estuaries in the Salish Sea: Phase Two (Baseline Assessments and Ground-truthing) **Recipient:** SeaChange	The Resilient Estuaries in the Salish Sea: Phase Two (Baseline Assessments and Ground-truthing) project will build upon research completed in partnership with the Pacific Salmon Foundation and will provide baseline assessments of critical salmonid habitats in the highly resilient estuaries identified during that work. In light of current and forecasted climate impacts, the project will focus on smaller estuaries with attributes that make them more resilient to the impacts of climate change. These estuarine systems provide critical nearshore habitats for salmonids in the Salish Sea bioregion and needed habitat connectivity between the large estuaries of the Salish Sea.This will allow us to refine the recommendations in the DRAFT Restoration and Conservation Action Strategy Plan also formulated as part of Phase One and will set up community and First Nations-led restoration and conservation efforts anticipated to be undertaken in Phase Three. **Collaborators:** Pacific Salmon Foundation (PSF) Jacklyn Barrs, World Wildlife Fund (WWF) Peninsula Streams and Shorelines (PSS) Coastal Restoration Society Dept. of Fisheries and Oceans BC Parks Parks Canada Islands Trust Local Land Conservancies
BCSRIF_2022_433 **Title:** Towards food security: restoring salmon and their habitat **Recipient:** Office of the Wet’suwet’en	Our project aims to assess, monitor, and rebuild salmon populations and their habitat throughout Wet’suwet’en ancestral territory. While abundant salmon populations once provided annual sustenance to the Wet’suwet’en people, such abundance and diversity has largely eroded over the last several decades to the point of no longer fulfilling our community’s needs. There is an urgent need to restore our lands and waters that have been degraded due to logging, road building, agriculture, highway, railway, and urban development, and to rebuild our salmon populations to a level of abundance that can sustain our annual food needs and provide for the surrounding biological community. We will accomplish this through a multi-pronged approach that partners with academics, local environmental organizations, First Nation, government, and watershed groups to undertake activities recently deemed of high priority. Broadly, these include: engaging with local land users to stabilize streambanks and rebuild riparian structure in the most degraded habitats, develop robust rebuilding plans for culturally important and highly diminished species and populations, and improve monitoring data for such populations to assess effectiveness of ongoing habitat restoration and rebuilding efforts. **Collaborators:** A Rocha Morice Water Monitoring Trust DFO Gixsan Watershed Authority
BCSRIF_2022_435 **Title:** Colquitz River Salmonid Restoration and Monitoring Project **Recipient:** Peninsula Streams Society	PSS is proposing to undertake projects to support Greater Victoria's urban salmon ecosystems. Through assessments and restoration they will work to develop the key priorities for sustainable salmon habitats within the contexts of Indigenous knowledge, science, urbanization, and climate change. Working collaboratively with partners, PSS will create a shared vision of active and effective salmon stewardship in select culturally and significant watersheds. **Collaborators:** Pacific Salmon Foundation District of Saanich BC Community Gaming Grants BC Province - Dept of Forest, Fish and Wildlife BC Conservation Foundation
BCSRIF_2022_436 **Title:** Establishing baselines, risks, and mechanisms of thiamine deficiency in British Columbia Chinook salmon	Thiamine (vitamin B1) deficiency complex (TDC) is a rapidly emerging issue impacting Chinook salmon in California and Alaska, but has received extremely limited evaluation in British Columbia. TDC may already be a factor in BC Chinook declines, and is expected to be a burgeoning issue under climate change. Thiamine is derived from prey in the marine environment and levels in predators vary in response to changing ocean conditions and diet. This project

Project	Description
Recipient: University of British Columbia (Vancouver), Institute for the Oceans and Fisheries	will provide baseline knowledge of the status of thiamine in BC Chinook salmon by: 1) determining thiamine levels in eggs and river entry fish from populations representative of life history types; 2) establishing the thiamine attributes of Chinook prey species; and 3) evaluating links between thiamine status of Chinook and mechanisms of TDC. This project will identify populations experiencing or at risk of TDC, guide realistic mitigation strategies in hatcheries, and inform prediction of future change. **Collaborators:** Bon Chovy Fishing Charters University of Washington Pacific Salmon Foundation Fisheries and Oceans Canada Salmonid Enhancement Program
BCSRIF_2022_438 **Title:** Highway 16 and CN Corridor Stranding Remediation/Willow Creek Arch Culvert/Mid-Scully Creek Spawning Gravel Addition. **Recipient:** Kitsumkalum Indian Band	Building on feasibility studies funded through a previous BCSRIF intake, this project will implement designs to improve identified fish stranding sites along the Highway 16 corridor between Prince Rupert and Terrace along the lower Skeena River. This work will be led by Kitsumkalum Band Fish and Wildlife Department, in collaboration with BC Parks, CN Rail, Ministry of Transportation (MoTI), and DFO with the goal to provide 2-way fish passage and additional spawning and rearing habitat, as well as reducing fish stranding mortality. **Collaborators:** DFO MoTI FLNRORD Regional District of Kitimat-Stikine Lakelse Watershed Stewards Society Kitsumkalum Band Westland Resources
BCSRIF_2022_439 **Title:** Nanwakolas 50 Watersheds Project **Recipient:** Nanwakolas Council Society	The Nanwakolas 50 Watersheds Project is an Indigenous-led science partnership and research project to understand, and develop tools to address, the threats posed by climate change and forest management on salmon populations and their habitat. The project will comprise of three collaborative science research areas: climate-salmon research, forestry-salmon research, and environmental DNA-salmon research. The study is based on a nested design across the territories of the Nanwakolas-member First Nations and include a broader territorial scale collection of stream temperature data to validate, build and improve predictive models as well as a smaller scale focused study on select watersheds with a more intensive assessment of stream temperature and ecosystems including eDNA collection. This research will also integrate LiDAR-derived characterizations of the focal watersheds to quantify the effect of forestry and watershed variability on water temperature and salmon ecosystems. Partners on this project include five member First Nations of the Nanwakolas Council, including the leadership and Guardians of the Wei Wai Kai, Wei Wai Kum, Tlowitsis, Mamalilikulla and the K’omoks First Nations, all of whom were engaged in the development of this project, as well as the Hakai Institute, Department of Fisheries and Oceans, Coast Area Research Section of BC Ministry of Forests, as well as scientists from Ecosfish Research, the University of British Columbia, University of Ottawa, and Simon Fraser University. **Collaborators:** Hakai Institute Ecofish Research Ltd. BC Ministry of Forests - Coast Area Research Section University of British Columbia University of Ottawa Simon Fraser University Nanwakolas member-Nations’ territories: Heydon Creek, Apple River, Fulmore River, Tuna Creek, Read Creek, Lull Creek, Salmon River, Puntledge River, Quinsam River, Eve River, Mamalilikulla First Nation, Musgamagw Dzawada’enuxw, Mamalilkulla First Nation, K’omoks, Tlowtisis, and Da’naxda’xw Awaetlala First Nations Pacific Salmon Foundation Salmon Watersheds Program Broughton Archipelago Transition Initiative Wei Wai Kum and We Wai Kai Nature Trust BC Salmon Coast Field Station Society
BCSRIF_2022_442 **Title:** Identifying factors that influence early marine survival of WCVI Chinook salmon	Our project brings together a broad group of Indigenous and non-Indigenous collaborators to evaluate timing and causes of mortality in west coast Vancouver Island (WCVI) Chinook salmon during early marine residence. We will use PIT-tagging to estimate survival, and combine these estimates with individual-based measures of environmental stress using cutting-edge gene-expression tools (“Fit-Chips”). Additionally, we will monitor environmental DNA

Project	Description
Recipient: Pacific Salmon Foundation	(eDNA) to determine key rearing habitats, availability of prey, and presence of predators and pathogens across spatial and temporal scales. Our project will fill key information gaps pertaining to at-risk Chinook populations, prescribed for rebuilding under the Fisheries Act. Ultimately, the findings will help to inform targeted habitat restoration, protection, and enhancement efforts for WCVI Chinook salmon. Adding to ongoing collaborations with WCVI First Nations, DFO, local NGOs, and PSF's Salmon Bottlenecks project, we will leverage extensive experience, expertise, and infrastructure already in place to deliver the most comprehensive investigation to date of early marine survival in WCVI Chinook salmon. **Collaborators:** Pacific Salmon Foundation DFO Science Branch Mitacs
BCSRIF_2022_444 **Title:** Enhancing Estuary Resilience: A Collaborative Approach to the Monitoring and Restoration of Estuaries with Coastal First Nations **Recipient:** Nature Trust of British Columbia (NTBC)	Through our 'Enhancing Estuary Resilience: A Collaborative Approach to the Monitoring and Restoration of Estuaries with Coastal First Nations' initiative, The Nature Trust of British Columbia (NTBC) will continue and expand monitoring and research to assess estuary resilience to sea-level rise and other climate impacts across the coast of BC using the Marsh Resilience to Sea Level Rise (MARS) tool and will work with our existing and expanded First Nations partnerships to identify additional estuary restoration opportunities. Funding provided through this project will also be used to augment restoration activities proposed for the Cowichan River estuary to restore core natural estuarine processes and will allow NTBC and First Nations partners to continue to monitor and adaptively manage previously completed restoration projects at the Salmon and Nanaimo River estuaries. The NTBC partners with 15 First Nations and Tribal Councils, environmental organizations, and academic institutions to implement collaborative monitoring and research across the coast of BC. **Collaborators:** Federal and Provincial governments ENGO partner organizations WCCLMP (Management Committee) DFO Resource Restoration Unit 15 coastal First Nations and Tribal Councils Broughton Aquaculture Transition Initiative (BATI) Mamalilikulla First Nation (Hoyeha River estuary) Simon Fraser University Salmon Watersheds Lab (SWL) US National Oceanic and Atmospheric Administration (NOAA) Office for Coastal Management US National Estuarine Research Reserve System (NERRS) Hakai Institute
BCSRIF_2022_447 **Title:** Xá:y Syí:ts'emílep: Gill Bar Restoration and Management Plan **Recipient:** Stó:lo Service Agency	The project aims to implement an Indigenous-led approach to researching, restoring, and conserving the Gill Bar area of the Fraser River. The project team along with technical professionals of the S'ólh Téméxw Stewardship Alliance, aim to assess the Gill Bar for habitat destruction related to the impacts of long term heavy recreational use and to conduct an inventory of the habitats and species use. These findings will then feed into an in-river island management plan and associated restoration works. The project will be conducted in collaboration with academic partners at the River's Institute at BC Institute of Technology. The City of Chilliwack is also partnering on the project as they work on a complementary plan to co-manage the land use of the area with the Pelólhxw Tribe. **Collaborators:** DFO - Salmonid Enhancement Program, DFO - Resource Restoration Unit, BC Ministry of Forests and Ministry of Land, Waters and Natural Resource Stewardship
BCSRIF_2022_448 **Title:** Chilako River and Tributary Stream Corridor Restoration Demonstration **Recipient:** Lheidli T'enneh First Nation	The Chilako River and Tributary Restoration is a Lheidli T'enneh led initiative that takes a strategic, process based approach to recovering impacted spawning and rearing habitat. The key activities include the use of low-tech, process based techniques to restore riparian vegetation on riverbanks and tributary floodplains. The objectives are to rehabilitate stream and river corridors such that stability exists during valley wide floods and the floodplain remains connected to the river during the extreme summer low flows. The project team includes 4 levels of government, local NGO's, academia, industry and an

Project	Description
	extensive list of private landowners who all work together in the interest of River Corridor restoration.
BCSRIF_2022_449 **Title:** Analysis of forestry effects on Pacific salmon in Musgamagw Dzawada'enuxw territory and across coastal BC. **Recipient:** Salmon Coast Field Station Society	The project will be four components (i) provide a quantitative and qualitative history of forestry and salmon in Musgamagw Dzawada'enuxw territory, (ii) quantify the effects of forest harvesting histories on salmon abundance for all Pacific salmon species in coastal BC, (iii) establish a temperature, sedimentation, and dissolved oxygen monitoring system in salmon watersheds of Musgamagw Dzawada'enuxw territory to quantify stream temperatures and water quality in relation to forestry activity and support a centralized database of stream temperatures coast-wide initiated by the PSF, and (iv) develop a new non-invasive method for studying salmon stress responses using environmental DNA technology and applies it to salmon in relation to temperature and environmental variation across watersheds in Musgamagw Dzawada'enuxw territory. The project components will thus provide proximate empirical data on the environmental conditions of salmon habitats, salmon stress, growth, and immune responses to their stream environments, as well as population level relationships from salmon and forestry timeseries. The outcomes of the project will provide detailed histories of forestry and salmon in the watersheds of Musgamagw Dzawada'enuxw territory, new fieldwork with which to analyze how forestry practices and history interact with climate change to affect salmon, and a quantitative analysis of salmon population responses to forestry histories across the full British Columbia coast.
BCSRIF_2022_450 **Title:** Gwa'sala 'Nakwaxda-xw Fully-Integrated Salmon Habitat Restoration Project (GNN-FISHR) **Recipient:** Gwa'sala 'Nakwaxda'xw Nations	The Gwa'sala 'Nakwaxda-xw project will focus on salmon habitat restoration and enhancement in Smith Inlet and Seymour Inlet on the Central Coast. This will include upgrades to the Warner Bay Hatchery, Seymour Inlet stock monitoring, and restoration activities along the Nekite River, in partnership with experts in habitat restoration and informed by Traditional Knowledge holders. This multi-phased approached will employ a strategy of integrated ecosystem repair and monitoring to support healthy stock levels and rebuilding initiatives. **Collaborators:** Gwanak Resources DFO Great Bear Rainforest Tours BC FLNRO
BCSRIF_2022_451 **Title:** Boundary Bay Chinook salmon restoration in the TA'TALU watershed **Recipient:** A Rocha Canada	A Rocha Canada will assess the status of the Boundary Bay Chinook salmon conservation unit (CU) and its habitat in the TA'TALU (Little Campbell River) watershed, with the overarching goal of improving the sustainability of the CU in this system. The Boundary Bay Chinook salmon population is currently data deficient and was recently listed as Threatened under COSEWIC. A Rocha will implement a coded wire tag (CWT) study to assess the status of the Boundary Bay Chinook salmon CU, in addition to conducting a bio-cultural (ecological and Indigenous knowledge) assessment of the watershed with a focus on Chinook habitat, implementation of instream and riparian restoration to repair degraded Chinook habitat, and support Semiahmoo FN efforts to reinstate a First Salmon Ceremony. **Collaborators:** Little Campbell Hatchery DFO FIA StAD Salish Sea Indigenous Guardians Association
BCSRIF_2022_453 **Title:** Establishing a Test Fishery for Chinook Salmon in key areas of the BC Coast **Recipient:** Sport Fishing Institute of BC	This project will operate a Pilot program to develop a Test Fishery for Chinook Salmon to be used to supplement and verify stock composition data used in the development and management of Marked Selective Fisheries (MSF) for Chinook Salmon. Key areas have been identified, PFMA areas 18 to 21 where there is a lack of sufficient data or existing data is out of date. Professional Charter Vessels will be hired to conduct Test Fishing in these areas to obtain detailed catch data and biological samples of each Chinook encountered. These detailed samples will be used to better understand Stock Composition and timing in these areas.

Project	Description
	Collaborators: DFO Science and Fishery Management BC Sports Fishing Institute
BCSRIF_2022_454 **Title:** FRIM – Short term mortality holding and respirometry studies **Recipient:** Sport Fishing Institute of BC	This project will build on a previously funded Fisheries Related Incidental Mortality (FRIM) study led by the Sport Fishing Institute to expand the work to include Coho salmon, in addition to Chinook. This study will utilize best practices developed in the previous study to better understand FRIM in the recreational Coho fishery on West Coast Vancouver Island, and will be further advanced by a new component to study affects of fisheries interactions on fish metabolism. This information will be used to expand the Best Practices Handbook developed in 2020. **Collaborators:** UBC Salmon Ecology Lab Bamfield Marine Sciences Huuayaht First Nation
BCSRIF_2022_456 **Title:** Informed Approaches to Determine Bottlenecks to Survival for Chinook and Coho Salmon and Steelhead **Recipient:** Pacific Salmon Foundation	This work will utilize and refine Passive Integrated Transponder (PIT) tag architecture (data collection application, tagging methods, capture methods, and PIT antennas and arrays) developed through the ongoing BCSRIF-funded “Bottlenecks Program” to track individual fish and provide new insights into survival in the South Coast. The survival of wild and enhanced Chinook and coho salmon will be compared within and between river systems and enhancement strategies (e.g. standard versus late release, smolt versus fed-fry), with tags applied and detected across multiple life history stages to identify periods of higher mortality (“bottlenecks”). Tag detections will also produce run-timing curves, straying rates, and terminal mortality rates. Focused activities will investigate size at ocean entry and migration patterns in the marine environment, information necessary to refine PIT-tag based survival models and understand life-history diversity. PIT tag-based stage-specific survival estimates will compliment studies of potential mediators of survival bottlenecks; environmental and anthropogenic influences on freshwater emigration, starvation in the first winter at sea, fishing-related incidental mortality (FRIM), and in-river pinniped predation. Collectively this work will greatly expand the understanding of factors limiting Chinook and coho salmon survival, suggest strategies to increase productivity, and leave a legacy of refined assessment approaches."This project will build on a previously funded Fisheries Related Incidental Mortality (FRIM) study led by the Sport Fishing Institute to expand the work to include Coho salmon, in addition to Chinook. This study will utilize best practices developed in the previous study to better understand FRIM in the recreational Coho fishery on West Coast Vancouver Island, and will be further advanced by a new component to study affects of fisheries interactions on fish metabolism. This information will be used to expand the Best Prac **Collaborators:** British Columbia Conservation Foundations (BCCF) Cowichan Tribes Snuneymuxw First Nation A-Tlegay Fisheries Society K'ómoks First Nation Kintama Research Services Salmon Coast Field Station UC Davis - Sustainable Aquaculture and Coastal Systems University of Victoria - Department of Biology

APPENDIX B. SUMMARY OF FISHERIES AND ASSESSMENTS DATA SECTION PROJECTS

1. Salmon Tracking, Escapement, Assessment and Management Platform

STREAM Platform Production - Login (DFO access only)

The Salmon Tracking, Escapement, Assessment and Management (STREAM) Platform is a new online resource for DFO staff that helps improve how salmon escapement information is collected, shared, and understood. STREAM brings together data, tools, and easy-to-use applications to support the conservation and management of Pacific salmon.

Fisheries and Oceans staff require timely, consistent access to salmon data across sectors. The STREAM platform enhances the timeliness of salmon escapement data, standardizes the spatial organization of salmon information, and improves reporting on salmon status. This foundational information supports stock assessment biologists, fisheries managers, species at risk biologists, and other decision-makers in delivering informed, data-driven management.

The platform has three main areas: entering and uploading data, learning about salmon populations, and exploring status reports (Figure 1). Through these features, users can view information about salmon populations across different regions and access data that support science, monitoring, and decision-making. As STREAM continues to grow, additional funding would allow us to respond to user feedback, develop more tools that improve data quality, and make more information available to the public.

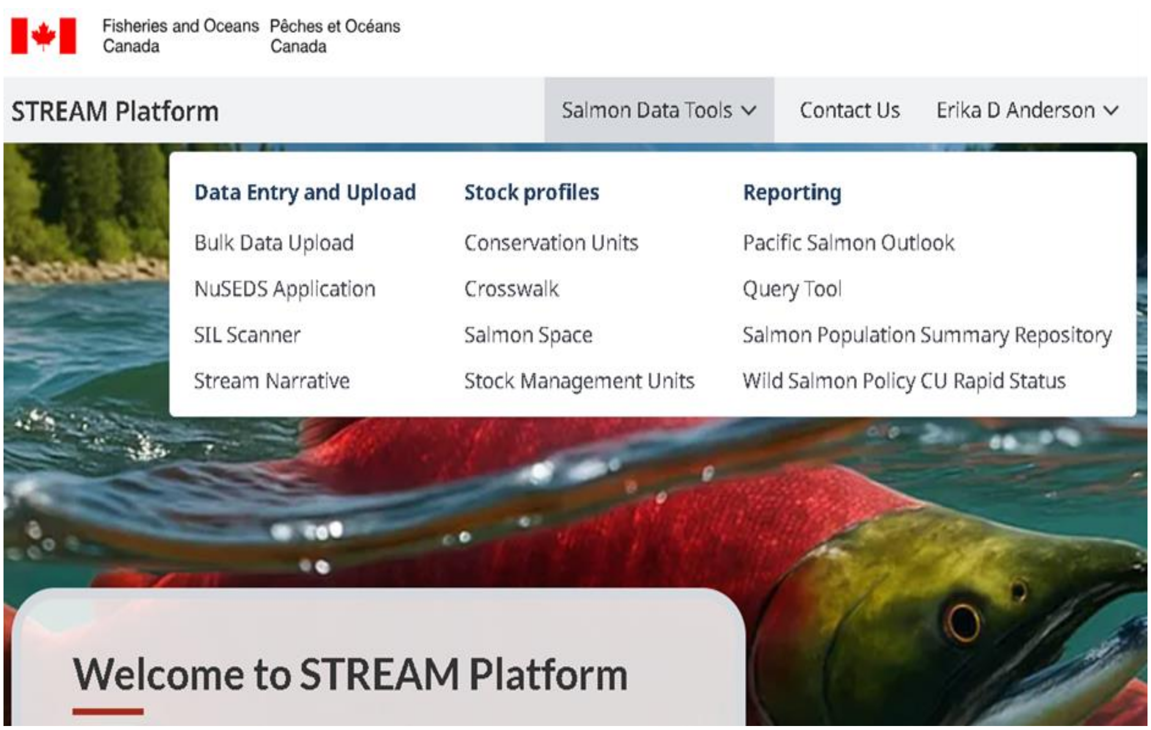

Figure B-1: Screen capture of the Salmon Tracking Escapement Assessment and Management (STREAM) Platform with the table of contents visible.

2. Salmon Space

[Salmon Space](#) (publicly accessible)

Salmon Space is an interactive map that lets you explore salmon information across British Columbia and Yukon. You can search by location or by salmon species to find data such as salmon escapement and stock status (Figure 2).

There is strong public demand for access to salmon data to enhance transparency and build trust in departmental decision-making. Salmon Space provides up-to-date salmon counts and status information in an accessible format. By improving data transparency, this application strengthens trust and alignment between internal and external biologists, Indigenous partners, and the broader community of salmon stakeholders and enthusiasts.

The map includes several optional layers, including census sites, conservation units, stock management units, and designatable units, allowing users to view salmon information at different scales. Data is updated weekly from the Fisheries and Oceans regional database, so the public can access recent information with confidence.

Users can download both tabular and spatial data directly from the site, or customize and print map views to support reports, presentations, and research.

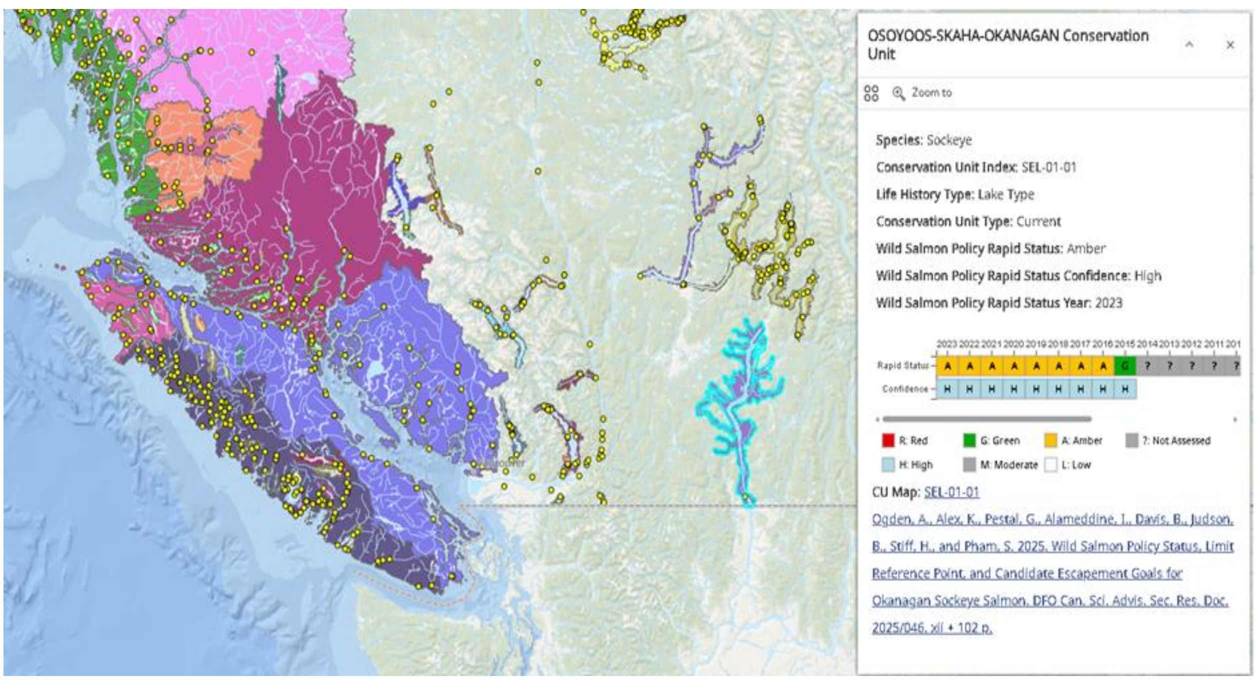

Figure B-2: *Screen capture of Salmon Space showing the Osoyoos-Skaha-Okanagan Sockeye conservation unit (highlighted) with associated information displayed in a pop-up.*

3. Specimen Tracking and Analysis Management Platform (STAMP)

STAMP platform (in development)

The Specimen Tracking and Analysis Management Platform (STAMP) is an integration and tracking system that supports field biologists, laboratories, and analysts by linking information about individual organism specimens across field sampling, tissue handling, and laboratory analysis. STAMP does not collect new data; it connects existing data systems like CREST, KREST and FOS with results data systems like Otomanager and the newly developed Genetics database to ensure that specimen provenance, measurements, and lab results can be reliably tracked and integrated.

Salmon stock assessments and other biological analyses are currently limited by fragmented data systems, inconsistent identifiers, and manual workflows that make it difficult to track tissue samples and link lab results back to individual organisms. STAMP addresses these challenges by providing a standardized unique specimen identifier and shared tracking infrastructure, improving data quality, traceability, and interoperability across projects and systems.

STAMP consists of an integration layer that connects field data systems, laboratory workflows, and results databases, along with tools that support specimen tracking, status reporting, and data linkage. These components enable users to follow specimens from field collection through laboratory processing and to join lab results with organism-level and project-level information.

As STAMP evolves, future development will focus on expanding support to additional lab types, species, and data systems, strengthening data standards and interoperability, and improving tools for querying, reporting, and stewardship. This will enable more efficient operations, reduce manual effort, and support the integrated analyses required by DFO's modern mandate.

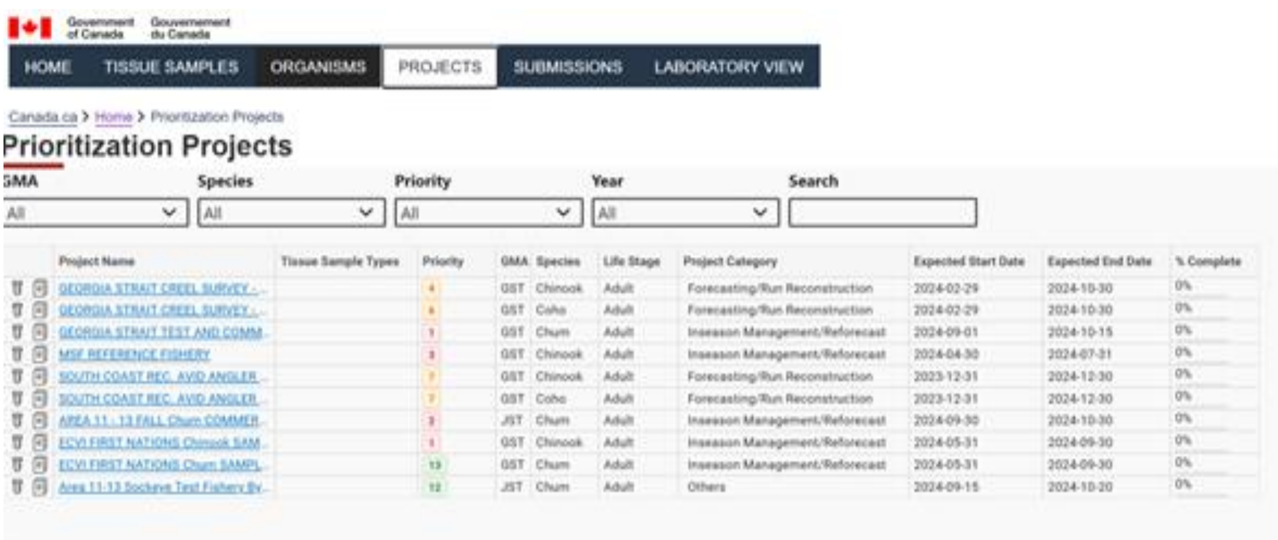

Figure B-3: *Screen capture of STAMP.*

4. SILscanner: Stream Inspection Log Digitization Platform

SILscanner (in development)

SILscanner is a cloud-based digitization and data recovery platform focused on converting paper Stream Inspection Logs (SILs) into machine-readable data. Stream Inspection Logs or SILs are records of how many salmon of each species were observed and counted during a sampling event on a particular day. SILs remain a significant component of salmon monitoring and assessment operations, and SILscanner supports operational programs by transforming these paper records into accessible digital data.

A large volume of salmon monitoring data continues to be captured on paper field forms, which are later keypunched by DFO staff. This creates delays in data availability, limits data quality control, and requires substantial manual transcription effort. SILscanner addresses this challenge by providing a standardized optical character recognition and form-based data extraction pipeline that recovers structured data directly from Stream Inspection Logs, reducing manual data entry and the risk of transcription errors.

The SILscanner platform consists of a cloud-based optical character recognition (OCR) and form-processing pipeline, secure cloud storage for digitized documents, and a database for indexing extracted data. The system is optimized for form-based data capture from SILs, while also supporting the digitization of handwritten and typewritten archival documents and data extraction from text-based PDFs. Digitized records are indexed and made accessible to analytical and text-mining tools, enabling downstream analysis and integration with other salmon data systems.

SILscanner has been rolled out in the Fraser, West Coast Vancouver Island (WCVI), and North Coast (NC) areas and continuing development to scale to additional areas and form types. Future development will focus on expanding regional coverage, improving data extraction accuracy and validation workflows, and strengthening integration with downstream databases. These enhancements will accelerate data availability, improve data quality, and modernize a critical but currently paper-based component of salmon data capture.

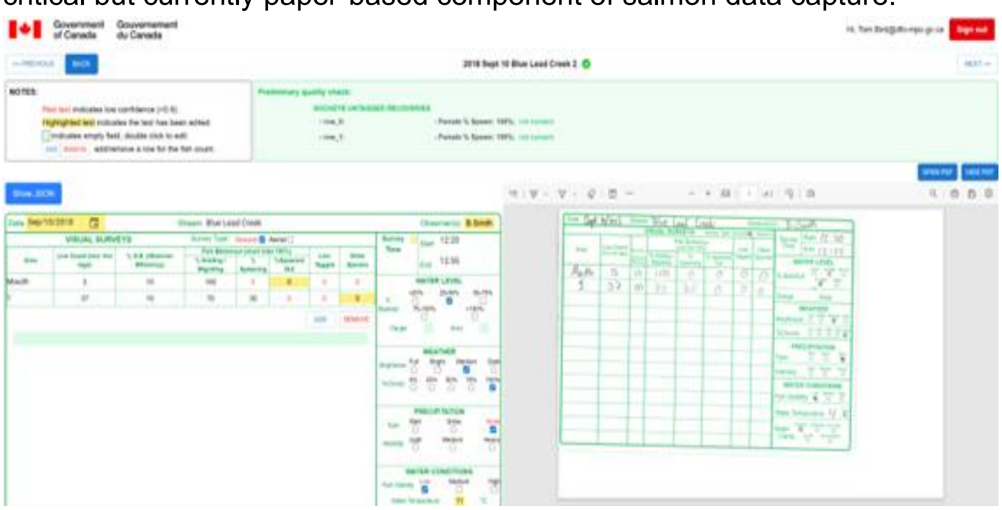

Figure B-4: *Screen capture of SILScanner.*

5. DocFlow: AI-Assisted Document Processing for Regulatory and Program Data

DocFlow (in pilot)

DocFlow is an AI-assisted document processing platform designed to transform large collections of unstructured PDF documents into searchable, analyzable, and decision-ready data. It supports programs such as Fish and Fish Habitat Protection by unlocking information embedded in regulatory, monitoring, and authorization documents that are currently difficult and time-consuming to use.

Many critical program datasets, including those stored in systems like Program Activity Tracking for Habitat (PATH), exist primarily as unstructured PDF files with limited metadata. Retrieving information such as project impacts, habitat footprints, mitigation measures, or species at risk often requires manual review of large numbers of documents, taking weeks and producing inconsistent results. DocFlow addresses this challenge by combining optical character recognition, artificial intelligence, and subject-matter-expert guidance to extract structured data from documents in a transparent and reproducible way.

The DocFlow platform consists of a document ingestion and OCR pipeline, AI-based information extraction tools, and an expert-guided interface that allows users to define, validate, and refine how key information is identified within documents. Extracted data are stored in structured formats and linked across related documents using graph-based representations, enabling efficient search, analysis, and structuring across large document collections.

Initially developed as a proof of concept for PATH authorization documents, DocFlow is being scaled to additional document types, programs, and regions, supporting integrative analyses such as cumulative effects assessment, regulatory performance reporting, and long-term data stewardship.

Figure B-5: Screen capture of DocFlow.

6. DFO Salmon Data Standards

DFO Salmon Ontology (publicly accessible)

The Government of Canada (GC) Fisheries and Oceans Canada (DFO) Salmon Ontology is a W3C-published semantic schema that provides a common, machine-readable framework for describing Pacific salmon data across DFO. It defines core concepts—such as stocks, surveys, samples, measurements, methods, and results—and their relationships using a hybrid Web Ontology Language (OWL) and Simple Knowledge Organization System (SKOS) approach. The ontology is schema-only by design, meaning it contains no data values, which supports clean versioning, reuse across systems, and interoperability with external platforms.

The ontology's purpose is to reduce friction in data integration, discovery, and reuse by providing scientists, data stewards, and managers with a shared, well-defined vocabulary. It aligns with international standards including Darwin Core, Basic Formal Ontology (BFO), Information Artifact Ontology (IAO), Sensor, Observation, Sample, and Actuator (SOSA), Provenance Ontology (PROV), and the InteroperAble Descriptions of Observable Property (I-ADOPT) framework. This alignment supports FAIR (Findable, Accessible, Interoperable, Reusable) and CARE principles while enabling future automation such as validation, provenance tracking, and semantic querying without locking DFO into a single system or tool.

7. Salmon Population Summary Repository (SPSR)

Salmon Population Summary Repository - PRODUCTION (DFO access only)

The Salmon Population Summary Database (SPSR) is a regional repository designed to centralize key salmon population index data—such as spawner abundance, catch, recruitment, exploitation rates, age structure, and hatchery contribution—that underpin routine stock assessments and forecasting. It addresses a major program gap where derived index data are currently scattered across local spreadsheets and bespoke systems, limiting transparency, efficiency, and trust. SPSR is intended to support Fisheries Science Advisory Reports (FSARs) and related assessment work by providing a consistent, FAIR-aligned source of core indices and associated metadata.

The database compiles standardized population indices and reference points at Conservation Unit (CU) and Stock Management Unit (SMU) scales, without replacing authoritative source systems such as NuSEDS, Fishery Operations System (FOS), or coded-wire tag (CWT) databases. It documents methods, assumptions, infilling approaches, and data quality to support reproducibility, succession, and training. SPSR is modeled on established repositories used by the National Oceanic and Atmospheric Administration (NOAA) and is intended for DFO science and assessment staff, with future development focused on expanding coverage, improving interoperability, and supporting strategic reviews of monitoring and assessment frameworks.

8. Open Science Documentation Hub

Open Science Hub (publicly accessible)

The Data Stewardship Unit (DSU) is part of the Fishery and Assessment Data Section (FADS) within the Pacific Region Science Branch of Fisheries and Oceans Canada (DFO). The Open Science Documentation Hub provides a public, authoritative reference for data stewardship practices that support salmon science and assessment. It addresses common challenges related to inconsistent data management, limited documentation, and barriers to reproducible analysis across programs.

The hub supports biologists, analysts, and data stewards by documenting practical guidance, standards, and workflows across the full data lifecycle—from planning and collection to analysis and publication. Content is grounded in real biological and management contexts, including stock assessment and monitoring, and is aligned with FAIR data principles and Indigenous data governance considerations such as OCAP®. The site complements internal FADS resources by making core guidance openly accessible.

9. FADS Salmon Data Wiki

🔗 Salmon Data Wiki (DFO access only)

The FADS Salmon Data Wiki is an internal, community-maintained reference for DFO Pacific Region Science staff that documents the salmon data landscape across programs, databases, and systems. Its purpose is to support orientation, onboarding, and day-to-day work by providing clear, factual descriptions of datasets, infrastructure, and contacts, without replacing authoritative databases or formal scientific documentation.

The wiki organizes information by major data domains (e.g., fisheries, escapement, genetics, enhancement, habitat) and describes how key systems are accessed and used in biological and management contexts such as stock assessment and fisheries management. It is available to all DFO staff and relies on ongoing contributions to remain current. Future work includes improving consistency across entries, strengthening links to authoritative metadata and open data records, and expanding coverage as systems evolve.

10. Custom Salmon Data GPT

🔗 ChatGPT - DFO Salmon Data Standardizer (publicly available)

This supports salmon biologists and data stewards by converting messy spreadsheets into standardized Salmon Data Packages (SDPs) that follow a common specification and shared ontology. It streamlines biological and management data workflows by generating consistent metadata, controlled vocabularies, and semantically enriched variable definitions aligned with the DFO Salmon Ontology, Darwin Core, and I-ADOPT measurement patterns. This approach modernizes salmon data management by embedding ontology-based methods and reproducible standards directly into day-to-day data preparation, improving comparability across stock assessment, monitoring, genetics, and fisheries management datasets.

The project is accessed as a Custom GPT in ChatGPT and is intended for DFO scientists, data stewards, and collaborators, with outputs that are openly reusable as CSV-based SDPs. Next steps focus on expanding ontology coverage, refining measurement patterns, and further automating validation through companion tools (e.g., metasalmon). Simple visuals—such as

SDP workflow diagrams or ontology relationship graphics—are often included to help users quickly understand how raw data are transformed into standardized, reusable packages.

11. Salmon Data Package (SDP)

🔗 Salmon Data Package Github repository (publicly accessible)

The Salmon Data Package (SDP) is a lightweight, frictionless-data-style specification for exchanging salmon datasets between scientists, assessment biologists, and data stewards. It is designed to work with familiar formats such as Excel and CSV while remaining ontology-aware, linking columns and code lists to the DFO Salmon Ontology and related vocabularies. SDP provides a consistent way to describe datasets, tables, variables, and categorical codes without enforcing a single rigid schema.

SDP enables automated validation, reproducible analysis, and interoperability across projects by standardizing metadata and semantics. It supports AI-assisted workflows, integration with R and Python tools (including the metasalmon package), and alignment with standards such as Frictionless Data and Darwin Core. The specification is openly available, versioned, and intended for use by DFO staff and collaborators preparing data for analysis, sharing, publication, or future knowledge-graph integration.

12. Salmon Escapement Estimates Classification Toolkit

🔗 Salmon Escapement Estimates Classification Toolkit (DFO access only)

The Salmon Escapement Estimates Classification Toolkit is an interactive R Shiny application designed to standardize how salmon escapement estimate types are classified across DFO Stock Assessment groups. It responds to long-standing inconsistencies in how estimate types (Type 1–6) have been applied in NuSEDS, which can affect interpretation of data quality and downstream uses such as Wild Salmon Policy (WSP) rapid status assessments. The toolkit operationalizes updated guidance into a transparent, repeatable decision process.

The application guides users through a three-phase, dichotomous classification key that evaluates enumeration methods, estimation methods, and documentation and accuracy requirements. It provides traceable results, clear downgrade logic, and reference visuals to support consistent application across regions and programs. The tool is publicly accessible via ShinyApps.io for DFO staff and collaborators and is supported by structured YAML logic and reproducible documentation outputs. Future work includes refining guidance based on user feedback, aligning outputs more tightly with NuSEDS tables, and supporting broader integration with assessment workflows and training materials.

13. Salmon Outlook Report Automation

🔗 Salmon outlook report Github repository (publicly available)

The Salmon Outlook Report project modernizes the annual Salmon Outlook process, which produces categorical and numeric forecasts of salmon abundance by Stock Management Unit and Conservation Unit to support harvest planning. It addresses tight timelines and fragmented workflows by streamlining how Outlook data are collected, processed, and transformed into tables, reports, and presentations used by science and management.

The project uses Survey123 for structured data collection and R-based workflows to automate report and presentation generation. It supports semi-automated slide decks tailored to different audiences and produces technical reports using R Markdown and the csasdown format. The tools are intended for DFO science and assessment staff and are actively under development, with next steps focused on refining data inputs, stabilizing scripts, and improving integration with evolving crosswalks and Outlook processes.

14. Genetics Results Database (GRD)

Genetic results database Shiny app (DFO access only)

The Genetics Results Database (GRD) is a governed, centralized data product intended to serve as the authoritative source for Genetic Stock Identification (GSI) and Parentage-Based Tagging (PBT) results across DFO programs. It addresses fragmentation, inconsistent formats, and version conflicts that currently slow reuse and reduce confidence in genetics outputs. The GRD shifts long-term stewardship responsibility away from analytical labs toward a sustainable, FAIR-aligned data product with clear ownership and accountability.

The GRD supports science, assessment, and management by providing traceable, versioned genetics results with standardized metadata, aligned with FAIR and CARE principles and Indigenous data governance. Governance roles are clearly defined across the data lifecycle, with integration planned across regional and enterprise systems such as STAMP, CREST, and FOS. The database is intended for DFO staff, collaborators, and partners, with phased development beginning in 2025 and broader system integration in 2026. Success is measured by adoption, reduced integration effort, and sustained governance.