Enhancing the sustainability of capture and release marine recreational Pacific salmon fisheries using new tools and novel technologies

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Preface

This five-year project was funded through the British Columbia Salmon Restoration and Innovation Fund and was conceived and conducted by the Pacific Salmon Ecology and Conservation Laboratory at the University of British Columbia. It was also partially supported through a Discovery Grant from the Natural Sciences and Engineering Council or Canada, and through Canada Foundation for Innovation funds to the Ocean Tracking Network Canada, one of our industry partners who provided key telemetry infrastructure support.

All of the proposed project deliverables and activities were achieved. Specifically, we: 1) generated telemetry-based catch and release mortality estimates for Chinook and coho salmon from marine recreational fisheries in British Columbia, values which we used to estimate Fisheries Related Incidental Mortality (FRIM) values; 2) gained a significant understanding of how specific environmental and fish conditions affected post-release mortality; 3) developed new tools and confirmed approaches for improving survival of released fish; 4) produced a list of science-based Best Practice Recommendations for recreational catch and release salmon fishing, which also included collaborating on 4 informational videos for public consumption; 5) trained four graduate students who are in progress of completing theses and who to date have delivered 41 presentations at conferences and regional management working groups, and who have produced 3 scientific papers on C/R science and its application (with 12 in preparation); also trained was a postdoctoral fellow who led the preparation of a large review paper soon to be submitted to a peer-reviewed journal integrating all known capture and release outcomes from commercial and recreational fishing gear in Pacific salmon fisheries including a best practices section for release of salmon from all gear types, and lastly; 6) created strong science partnerships and collaborations among DFO biologists and managers, academics, technology industries, and partners in the recreational fishing industry all of whom helped us conduct important and applicable research for conserving Pacific salmon and ensuring the long-term sustainability of fishes and fisheries.

Executive Summary

● Catch and release (C/R) is a practice used in recreational fisheries resulting from regulations for conserving particular species, populations, or sizes of fish, or as a practice to meet personal values. C/R enables increased fishing opportunities and is critical for implementing mark-selective fisheries.

● C/R will be a major component of future recreational salmon fisheries, but its broad usage has been limited by two major issues which this research directly addressed: identifying the magnitude of post-release mortality (the main component of Fisheries Related Incidental Mortality, FRIM) which we determined with telemetered freely migrating fish, and, understanding the mechanisms of post-release mortality so that fishing practices can be modified to enhance survival of released fish.

● We worked with sport fishing groups and other partners to capture, tag and release Chinook and coho salmon in different locales of coastal British Columbia, utilizing a broad spatial scale acoustic receiver network that is in place throughout the Salish Sea. We experimentally assessed the effects of air exposure duration, landing time and approach, hook size and other gear, and release approach on fish impairment and injuries, and on subsequent survival at different time scales post-release.

● We conducted C/R studies on: 616 Chinook salmon tagged on East Coast Vancouver Island (ECVI) and tracked through the Discovery Island region, 430 Chinook salmon tagged in Barkley Sound and tracked to spawning areas, and, 549 coho salmon tagged and tracked in Juan de Fuca Strait.

● ECVI Chinook salmon that were released with various (and some times minor) types of injuries to fins, scales, and/or eyes had on average 15-20% poorer survival within the first 10 days of release compared to fish that were in good physical condition when released, with the latter group having very little mortality during this time period.

● ECVI Chinook with any type of eye injuries, caused by hooks piercing the ocular cavity from the mouth, demonstrated an additional 15-20% mortality on average after 40 days post-release compared with fish in good physical condition or with other non-eye injuries.

● We estimate FRIM for adult Chinook (52–99 cm FL) to range up 40% depending on fishing practice, gear type, and subsequent injuries caused by the C/R encounter. Modifying fishing practice and gear as we determined can result in minimal FRIM.

● Experimental manipulations to air exposure duration led to environmentally specific results. ECVI Chinook exposed to air ranging up to 300 seconds exhibited only modest (~10%) post-release mortality compared to non-air exposed fish over 10 days. Yet Barkley Sound Chinook bound for Robertson Creek Hatchery exposed to 300 seconds of air exhibited 50% mortality to the entrance of Alberni Inlet, only a ~ 5-day migration.

● We identified carry-over effects to freshwater environments resulting from marine C/R. Robertson Creek Chinook typically encounter sub-lethal or lethal temperatures (> 20°C) during their freshwater spawning migrations through the Somass River which is a significant additional migratory stressor. No

fish reached the hatchery if they were air exposed in the marine environment > 90 seconds, and of the few that did, all were males which are known to be more resilient to C/R stressors than females.

● There is a strong size effect on survival of C/R fish. In most years, ECVI Chinook that were tracked for at least 10 days and that were smaller than 62 cm FL had ~ 36% mortality while those larger than 80 cm FL had ~4-12% mortality – these two size groups are often ones that regulations require release. Robertson Creek Chinook that we tracked into freshwater and were larger than 70 cm FL had 12% mortality while those smaller than 70 cm FL had 19% mortality. Every decrease of 1 cm FL was associated with 6% increase in the odds of mortality in coho ~3.3 days post-release.

● As with Chinook, post-release mortality levels of coho salmon increased with scale loss, bleeding, and eye damage – eye injuries were associated with 2.8 times greater odds of mortality within the first ~3.3 days after release than coho salmon without an eye injury.

● Coho seemed to be less resilient than Chinook to C/R practices. Unlike Chinook, coho in good condition when released still suffered on average 17% short-term (~3.3 days post-release) mortality. Short-term FRIM (which we defined as the difference between post-release mortality of good condition and poor condition fish) was on average 31% which is nearly twice that observed for ECVI Chinook. Based on coho tracked into Puget Sound, the difference in mortality levels between good and poor condition fish after a median migration time of 9 days continued to be ~ 30% suggesting most of the FRIM for coho occurred in the first few days after release.

● Landing nets are not fish friendly. There was a direct relationship between the use of nets and fin injuries which led to high mortality in our companion holding study. In the tagging studies, 90% of Chinook salmon landed without nets had no visible fin damage.

● We identified the presence of 12 pathogens in ECVI Chinook and 11 in coho, but infection rates for Chinook salmon were half that of coho (average 1.1 vs 2.3 pathogens per fish, respectively). No relationships among pathogen loads and mortality were observed for either species.

● Anglers were surveyed using a phone app (3612 responses, 1503 different anglers) revealing they generally employed fishing behaviours and had capture outcomes similar to what we used and found, thus our field experimental approaches reflected behaviours of typical anglers.

● We also interviewed anglers in person (n = 26) gathering opinions of C/R as a conservation tool. They were generally open to new information on best practices to improve survival of C/R fish. Many were already using some of the practices we recommended. Anglers were supportive of creating more educational resources using our study results.

● We made 15 recommendations that DFO can adopt as regulations, and should adopt as 'best fishing practices' involving: landing, handling and releasing approaches, gear choices, and fishing tactics that will minimize FRIM for marine migrating Chinook and coho.

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Acknowledgements

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Project Background

Pacific salmon face a gauntlet of fishing gear as they migrate from oceanic feeding grounds to natal freshwater spawning sites, and while millions of fish typically are harvested each year in British Columbia, a portion of all species are released. DFO fisheries management has a policy of 'selective fishing' defined as the goal of avoiding non-target animals and releasing them 'alive and unharmed' if encountered (Fisheries and Oceans Canada 2001). The portion of salmon that is being released is increasing dramatically now that regulations are in place to protect several populations and species in decline. This is particularly an issue for Chinook (*Oncorhynchus tshawytscha*) and coho (*O. kisutch*) salmon fisheries, highlighted by the recent COSEWIC assessment where 14 southern British Columbia Chinook salmon designatable units (DUs) have been assessed as Threatened or Endangered, and on-going Threatened status for Interior Fraser River coho salmon. Complete closures to recreational fishing were adopted in 2019 in some coastal areas and have remained in place in some regions where Southern Resident Killer Whales (SRKW; *Orcinus orca*) may feed on them, and where populations of concern are most likely to be encountered. Catch and release (C/R) is a management tool that allows recreational fishing opportunities (for both targeted stocks and those considered by-catch) and creates economic benefits for local communities and the sport fishing industry. Further, mark-selective fisheries aim to provide harvest opportunities directed on hatchery produced, and marked, Chinook and coho salmon, while non-marked and wild fish are released. Directed and by-catch related C/R will continue to be a major component of future recreational salmon fisheries, but its broad usage is limited by two issues which this research directly addresses.

The first issue is that mortality does occur to released fish, but its true magnitude is generally unknown for recreational marine salmon fisheries. Fishing-related incidental mortality (FRIM) is the summed mortality of fish that encounter fishing gear but are not captured and that subsequently die. The largest component of FRIM is believed to be associated with fish that die after capture and release (post-release mortality). DFO now uses FRIM to help manage Pacific salmon fisheries (Patterson et al. 2017a). Our research group are some of the leaders in assessing post-release mortality for Pacific salmon, and for developing potential solutions to mortality issues. Most of the early research done by others on FRIM, and which is currently used to inform harvest management of recreational fisheries by DFO, is insufficient in assessing C/R mortality as it is focused only on short-term post-release time periods (e.g., 24-72 hours) with released fish being kept in artificial enclosures for observation. Recent research, and review of global literature, by our group (Raby et al. 2015a) indicates that longer-term and more realistic assessments for post-release mortality rates are needed, a sentiment shared by DFO Science Branch (DFO 2016). While post-release mortality rates can be low under some circumstances, they can also be dramatically higher than those currently documented in DFO's Integrated Fisheries Management Plans (IFMPs). Some freshwater C/R studies have shown near total mortality of released salmon when assessed over long time periods. The second issue is that to enhance the sustainability of recreational marine C/R fisheries, we need to find ways to minimize post-release mortality which means understanding its causes so that improved fishing approaches can be tested, recommended and implemented.

Project Approaches

Our main approach to study post-release mortality was to assess all aspects of a capture event, assess fish condition and environmental conditions, and track fish after they have been released from a fishery using electronic tracking devices. Our past research has found that the physiological state of a released fish (e.g., stress, injury) and local environment (e.g., water temperature, predator presence) can have large effects on mortality following C/R. There has been no focused research using these rigorous approaches examining post-release mortality for recreational marine C/R fisheries (e.g., for Chinook and coho salmon).

We engaged with knowledge users and the angling community in developing and conducting the research and continued to do so throughout the project working with a Scientific Advisory Committee and conducting numerous outreach presentations and symposia to ensure the work that was done was relevant and that users would be likely to adopt the findings.

<u>Assessing post-release mortality</u>

Our project worked with sport fishing groups and other partners to capture, acoustically tag (using rapid and minimally invasive methods so as to not unduly influence survival), and release Chinook and coho salmon in different locales of coastal British Columbia where recreational fishing commonly occurs. We utilized the broad spatial scale acoustic receiver network that is in place throughout coastal British Columbia (managed by several groups including our partners Ocean Tracking Network Canada, and Kintama Research; Figure 1). C/R fish were tagged and tracked as they passed acoustic receiver lines to obtain both short- and long-term survival estimates - receiver lines were situated along salmon migratory routes and many extended from shore to shore at several locations: Queen Charlotte Strait northern Vancouver Island, Johnstone Strait, Discovery Islands, Northern Strait of Georgia, Haro Strait, Juan de Fuca Strait, lower Fraser River, and Puget Sound. The present submerged receiver networks enabled us to quantify survival at different temporal and spatial scales (e.g., shortly after release, at different mid-points through coastal homeward migration, and for Fraser River bound fish, at river entry). We also deployed receivers in the Somass River (Barkley Sound) to examine survival to spawning grounds. Receiver networks from US collaborators in Puget Sound and west coast of Washington enabled survival to be assessed for US bound salmon migrants if they were tagged. We consulted with our Sport Fishing Institute (SFI) of British Columbia and DFO partners and conducted our tagging in key areas where there are typically large recreational fisheries occurring.

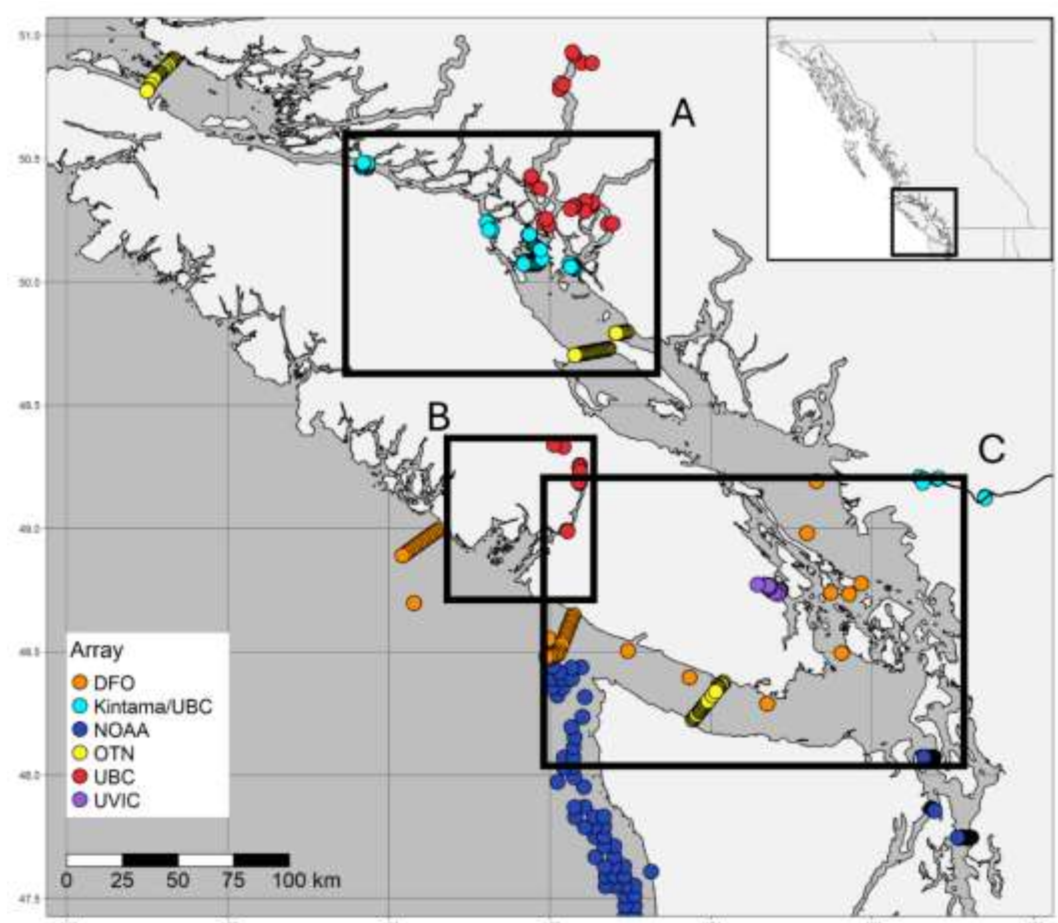

Figure 1. Map depicting the receiver locations (2019 – 2022) available to detect Chinook and coho salmon affixed with acoustic tags. Black rectangles depict the study areas for the: Discovery Islands Chinook salmon study (Study-1, A), Barkley Sound Chinook salmon study (Study-2, B) and Juan de Fuca coho salmon study (Study-3, C).

Causes of post-release mortality

In this project we used similar methods as we have in the past where we assessed post-release mortality for commercial net fisheries (Cook et al. 2015, 2018) which involved using many of the same acoustic receiver arrays that were used in this project, wherein we found that: time in gear, time of air exposure, injury level, stock, species and maturation level all played roles in affecting post-release mortality. In the present project, we measured all aspects of the C/R event in typical angling fisheries including gear and hook type, depth of capture, time on the fishing line, air exposure time, landing net type, and injury assessments (scale loss, eye injuries, wounds, bleeding, etc.). Prior to release, fish were rapidly externally tagged with acoustic transmitters (e.g., Raby et al. 2015b) and small tissue samples were taken for lab-based DNA stock ID, and bioassays of physiological condition for some fish. Based on results in years 1 and 2, we took a more experimental approach in subsequent field years imposing different C/R treatments (e.g., experimentally varying gear/hook type, air exposure time) to directly understand the multivariate components to post-release mortality.

Solutions to post-release mortality

In addition to our biological field studies, we collaborated with social scientists and one of our partner groups to conduct two social science studies wherein we collected data from anglers to learn about their perspectives on C/R fishing and willingness to adopt different fishing approaches, and anglers during their fishing events using a smart phone app on specific details associated with their landing and handling approaches. Based on our biological and social science results, results from a companion holding study we led in partnership with the SFI of British Columbia (BCSRIF Final report 2020-261; see Zinn et al. 2024), and, results from a recent review paper we wrote examining C/R studies on all types of net and hook/line Pacific salmon fisheries (Prystay et al. 2024), our research group developed a list of 'best fishing practices' to help minimize post-release mortality.

Overview of Project Locations and Approaches

We conducted our telemetry studies out of three general locations: the Discovery Islands, Barkley Sound between Bamfield and Port Alberni, and Juan de Fuca Strait near Port Renfrew (Figure 1). A companion C/R laboratory holding study was conducted at the Bamfield Marine Sciences Centre. Research questions for the telemetry studies focused on the factors associated with post-release mortality, and the effects of angler mediated gear types and handling methods that could provide management recommendations to improving post-release survival. Fish were captured using standard recreational angling methods and gear types were varied to mimic angler's behaviours while participating in the fishery. Variation in gear included modification of hook size, the use of inline attractors ('flashers'), and altered terminal tackle (e.g., plugs, hoochies). This allowed us to investigate simple changes that anglers could make while fishing to reduce injury and physiological exertion to the fish. Handling methods were tested with modified landing methods that included the use of different landing nets, water-line release, boat-side tagging, and air exposure (0 to 300 sec) treatments. These methods provided the assessment of a broad range of handling that is likely to occur within the fishery, and pushed the limits of certain practices (e.g., air exposure). We collected information on the capture and handling event, in addition to fin tissue (for genetic stock identification [GSI]) and (in some projects) non-lethal gill biopsy samples (for genomic analyses: physiological condition and infectious agents). Observation of environmental data and the physiological condition at time of capture provided insight into the natural extrinsic and intrinsic drivers of post-release mortality. A minimally invasive acoustic transmitter was attached to the exterior of each salmon, and upon release we tracked the tagged salmon with an extensive network of acoustic receivers located at multiple locations along their return migrations (Figure 1). We used lack of detection at receivers we expected fish to cross, based on DNA stock ID and the location of their natal rivers, as a proxy for mortality. Statistical analyses were used to investigate extrinsic and intrinsic factors assessing the cumulative impacts of the complete angling interaction and how the environment, fish condition, and angler interactions affect post-release outcomes.

In summer 2019, we conducted a pilot study to test and refine our angling, handling, tagging, tracking and analysis approaches. This project 'piggy-backed' on an NSERC-funded study examining SRKW and Chinook salmon interactions (Hendriks 2024). One hundred large bodied adult Chinook (> 80 cm FL) were tagged and released from June 14 to August 9 near Port Renfrew British Columbia (Hendriks 2024). We tested different landing, processing and release techniques. Fish were passively tracked post-release using the broad-scale receiver array stationed through the Salish Sea, west coast Vancouver Island, northeast coast Vancouver Island, Johnstone Strait and Discovery Islands (Figure 1). DNA stock identification was used to inform the survival assessments enabling us to focus just on populations that were expected to migrate eastward across the first large acoustic array (Juan de

Fuca array, ~40 km southeast of the tagging location). Of the 58 Chinook in this assessment, survival was extremely high (93%; 95% CI = 82-98%,) with most fish taking 1 to 3 days to reach the array (Hendriks 2024). Further examination just of Fraser River bound fish (n=29) found high survival to the lower Fraser River from release (79.3%; 95% CI = 58-93%) with most fish taking 8 to 20 days to enter the river after release (Hendriks 2024). This pilot study confirmed that we could angle, handle, bio-sample, and release externally tagged adult Chinook, and have very high survival (i.e., acoustic array detections) to numerous natal rivers if fish were landed quickly with minimal air exposure, kept fish submerged in an on-board processing sling, had small biological samples taken (e.g., tissues for stock ID), tagged externally with an acoustic transmitter, and then promptly released (Hendriks 2024). Therefore, our study approaches were ideally suited to explore how changes in capture, handling and release techniques affected post-release mortality.

Study 1 – East Coast Vancouver Island Chinook salmon

<u>Methods / Results</u>

In 2020, the project commenced with capture and tagging of Chinook salmon in the Discovery Islands region (Figure 2) and continued until 2022. Dates ranged from June 2 to 14 in 2020, June 4 to 15 in 2021, and May 14 to 25 in 2022 with an additional period from July 25 to August 2 in 2022. A total of 616 Chinook salmon were tagged and released across the three years of study with 179, 200, and 237 being tagged in each respective year. Survival, or proportion detected, was defined as either reaching the Northern Strait of Georgia array (central OTN array, Figure 1), or being detected beyond a 10-day period at any of the other receiver arrays. This 10-day benchmark aligns with the observation period used in holding studies completed for BCSRIF Project 261 (Zinn et al. 2024) , where majority of mortality, if it occurred, did so after day 3 but before day 10. Survival was determined using Kaplan-Meier analyses which are 'time-to-event' approaches using the last known detection (or fishery recovery) as the 'event'.

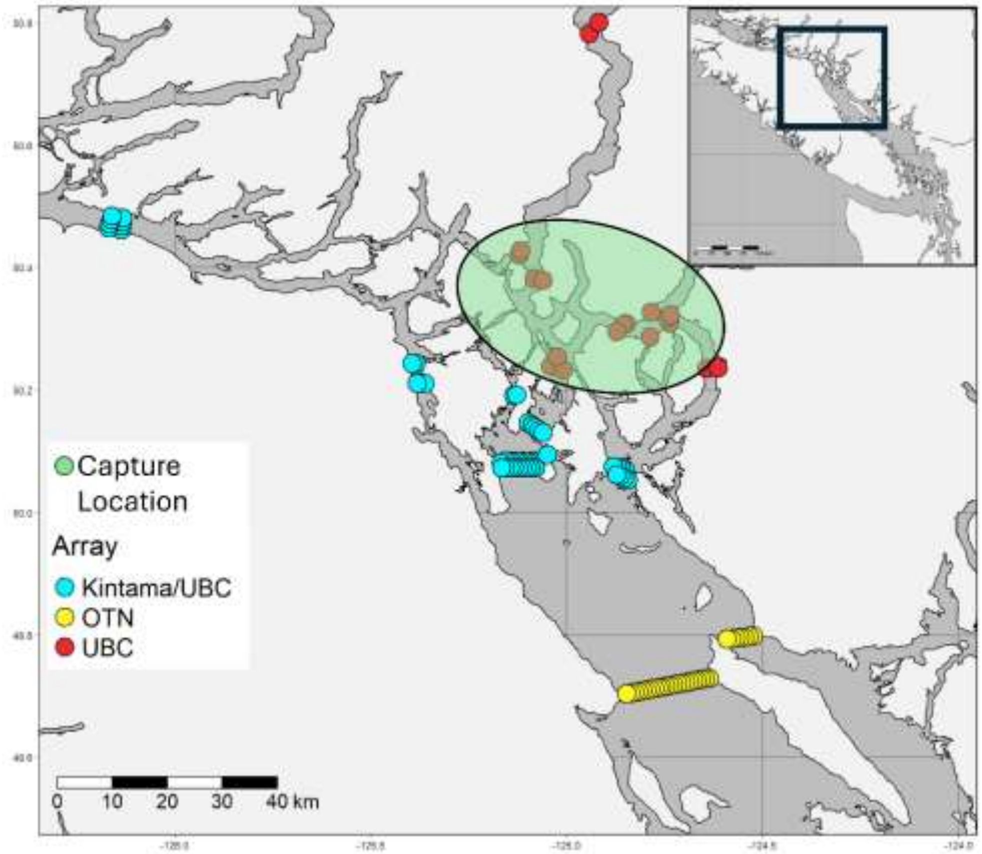

Figure 2. Map depicting the East Coast Vancouver Island Chinook salmon study area. Yellow dots indicate the Northern Strait of Georgia Array managed by OTN, blue dots indicate receivers in Johnstone Strait and various other locations on the west side of the Discovery Islands managed by Kintama Research and UBC, red dots indicate receivers located through the Discovery Island area managed by UBC. Fish were tagged and released in the green area.

In 2020, 179 Chinook were landed with 50 being directly placed into the sampling sling for physical assessment and tagging. With the remaining 129 individuals placed into an air exposure treatment group that ranged from 30 to 120 seconds and were comprised of 13 individuals in each. The Qualicum / Puntledge reporting group fish were the dominant stock complex making up ~ ⅔ of the stock composition for the entire sample, and 53-83% within each air exposure treatment group. The remaining stocks included, Cowichan, Squamish, South Puget Sound, Lower Fraser Fall; all of which must migrate in the same direction across receiver arrays towards their natal rivers. Average survival ranged from 62 to 100% among air exposure treatments. There was no clear relationship between length of air exposure and survival levels (Figure 3). With the exception of the two longest air exposure periods, all other shorter treatments had average survival ranging from 60 to 85%. This result suggests that other factors, aside from the air exposure levels that we implemented, are responsible for latent mortality we observed and in subsequence years we experimentally modified other factors associated with the capture and release approach, including longer air exposure periods.

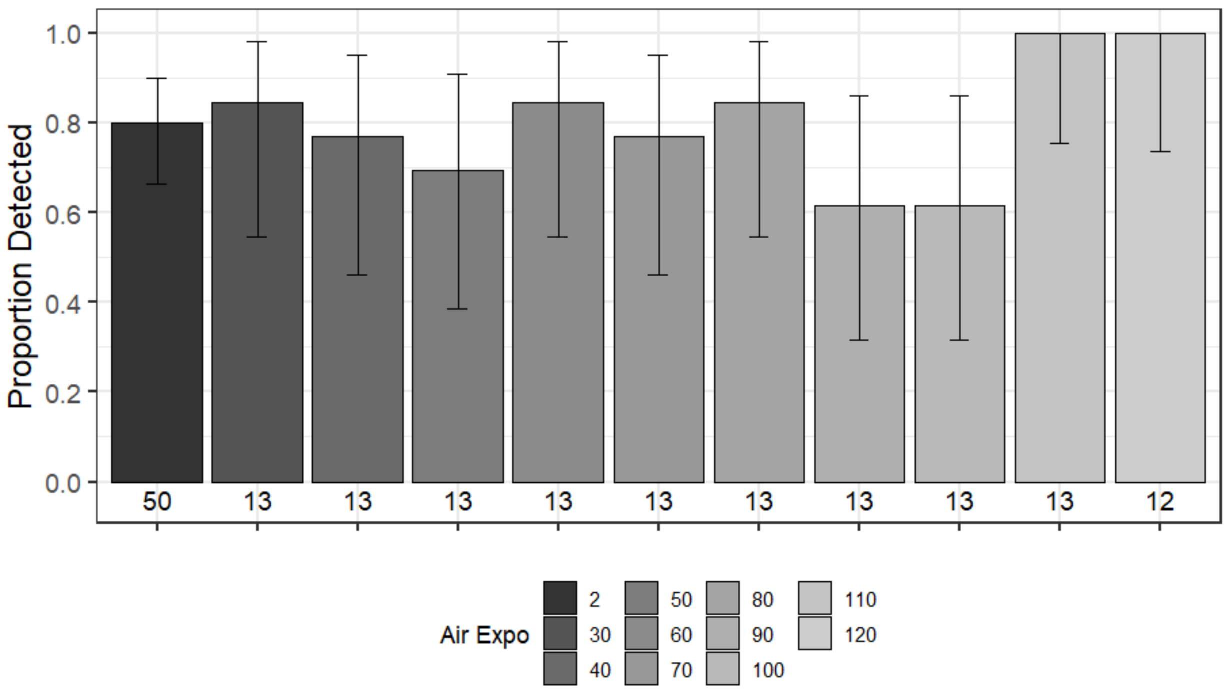

Figure 3. Post-release survival (95% confidence intervals) of Chinook salmon to the Northern Strait of Georgia Array or to any other array beyond a 10-day post-release period in 2020 after landing with a net, then either being placed directly into the sampling sling (2 seconds) or placed on the vessel deck for a prescribed air exposure treatment ranging from 30 to 120 seconds (varying shades of gray). Sample sizes are provided along the X-axis.

Across all years, we sampled and tagged 464 Chinook that were expected to migrate through our receiver network. These fish had variable levels of handling and air exposure, with 246 receiving no air exposure, and 218 receiving an air exposure treatment (Figure 4A). We expanded the air exposure treatment in 2021 to range from 30 to 300 seconds (Figure 4B). Further, we completed boat-side tagging (aka tagging at the water line) allowing us to sample and tag some fish which were not be removed from the water eliminated both air exposure and reducing other handling aspects (e.g., net use and time on the deck). In sum, we had a total of 102 Chinook that were never removed from the water (69 were never netted, 33 were netted), 144 that were netted and placed directly into our on-board sampling sling, and 218 that were air exposed to different degrees (Figure 4C). Fish exposed to air had somewhat poorer survival (Figure 4A) but there was no clear relationship between survival and air exposure time (Figure 4B). However, a relationship existed between survival and other 'handling' aspects associated with fish being exposed to air in that survival was poorest when fish were air exposed to some level and were brought on board for processing (Figure 4C). Air exposure may not have a direct relationship with survival, however, the effect of related factors associated with handling and air exposure (e.g., netting, scale loss, mucus removal, and fin damage) highlight the importance of how cumulative impacts can affect survival outcomes. A factor that may have buffered against strong effects of air exposure is the fact that water temperatures were generally very cool during tagging across all years of study with a range from (n = 665, mean ± SD: 13.9°C ± 2.3°C; range: 8.1°C to 18°C) which reduces potential effects of anaerobiosis and tissue anoxia.

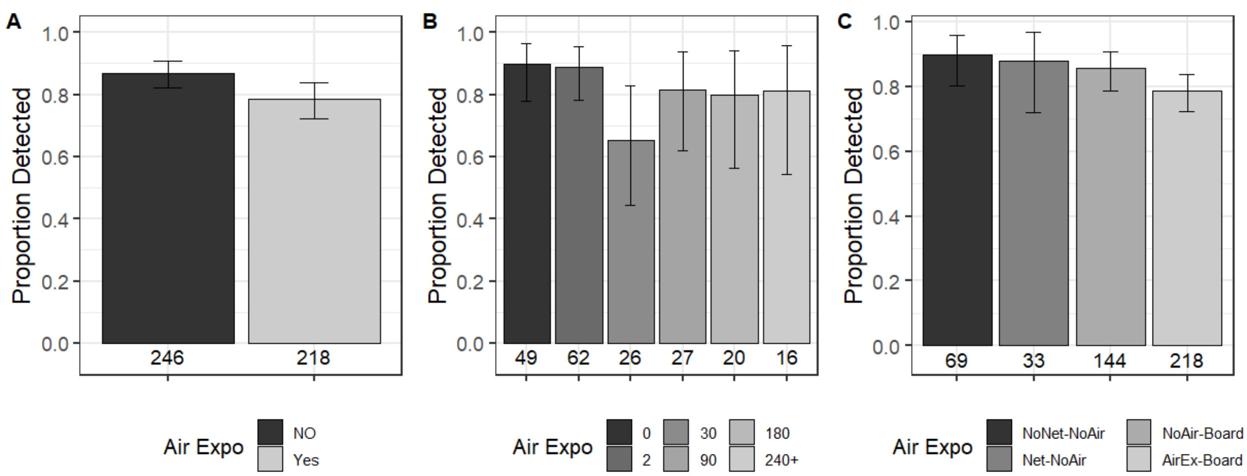

Figure 4. (A) Post-release survival (95% confidence intervals) to the NSOG array or beyond 10-days for Chinook salmon that experienced any air exposure treatment (Yes), or those that were never removed from water and tagged boat-side (No), for Chinook in all years combined (2020-2022). (B) In 2021 Chinook were either tagged boat-side and never removed from the water (0), were netted and placed directly into the sampling sling then tagged (2), or they were air exposed from 30 to 300 seconds prior to placement into sampling sling. (C) All years were combined and grouped into those tagged boat-side without any net interaction and never leaving the water (NoNet-NoAir), those tagged boat-side, never leaving the water, and were netted (Net-NoAir), those that were netted, boarded, and placed directly into the sampling sling (NoAir-Board), and those that were netted, boarded, placed on the vessel deck, and air exposed for 30 to 300 seconds (AirEx-Board).

In 2021, variation in terminal tackle, specifically hook size and hook category were assessed. Within marine recreational fisheries both relatively smaller ‘recreational’ hooks and large ‘commercial’ hooks are used depending on gear type, location, and angler choice. We contrasted the hook size and most notably the ‘recreational’ and ‘commercial’ styles of hooks. These two hook types vary in the general proportion of various hook characteristics and the gauge (wire thickness) of the hooks. Two different hooks may be classified as a ‘3/0’ hook size, however, the shank, gap, and throat (distance from base of hook curve to point of hook) lengths, may differ by up to 10mm. Across all years of study we used a range hooks from ‘3/0 recreational’ with a gap width and throat length of 14 mm (angle gap = 19.8 mm), to a larger ‘7/0 commercial’ hook with a gap width of 29mm and throat length of 33mm (angle gap = 43.9 mm). These lengths were used to calculate a single value, the angle gap, using a 90-degree triangle and using the simple $AG = \sqrt{a^2 + b^2}$ equation, where a = gap width and b = throat length.

A total of 429 fish were caught using the relatively smaller ‘recreational’ hooks and 187 were caught using the larger ‘commercial’ hooks. Once fish were boated, we assessed a variety of injuries and categorized as described in Table 1 which ranged from non-existent (‘0’) to extremely severe (‘3’). Photographic examples of fish exhibiting a range of injury scores are in Figure 5 to 7.

Table 1. Injury scoring for eye injuries, bleeding, scale loss, fin damage, and natural wounds

Injury Type	Injury Score			
	0	1	2	3
Eye Puncture	None	Minor puncture; single puncture and/or minor ocular hemorrhage; blood minor but apparent; globe intact	Full puncture through complete eye; significant intraocular hemorrhage and pooling blood; globe and structural integrity maintained	Complete enucleation and/or ocular rupture; no structural integrity; significant blood loss
Bleeding	Pinpoint puncture and ooze	Tissue damage; torn flesh, less than 1cm; moderate ooze; rate of loss decreases while sampling	Significant tissue damage; >1cm torn flesh; apparent vasculature damage; no observed rate change	Apparent arterial damage at or near gill structures; pulsing blood
Scale Loss	None	<5%	5-15%	>15%
Fin Damage	None	Minor fraying	Multiple torn rays; 50% or greater length of fin	Torn ray extending to tissue at base of fin; blood loss; snapped fin rays
Wounds	None	Torn dermal tissue	Exposed tissues; dermal, muscular, cartilaginous hanging or fully exposed	Severe tissue damage; greater than 5% of the whole organism

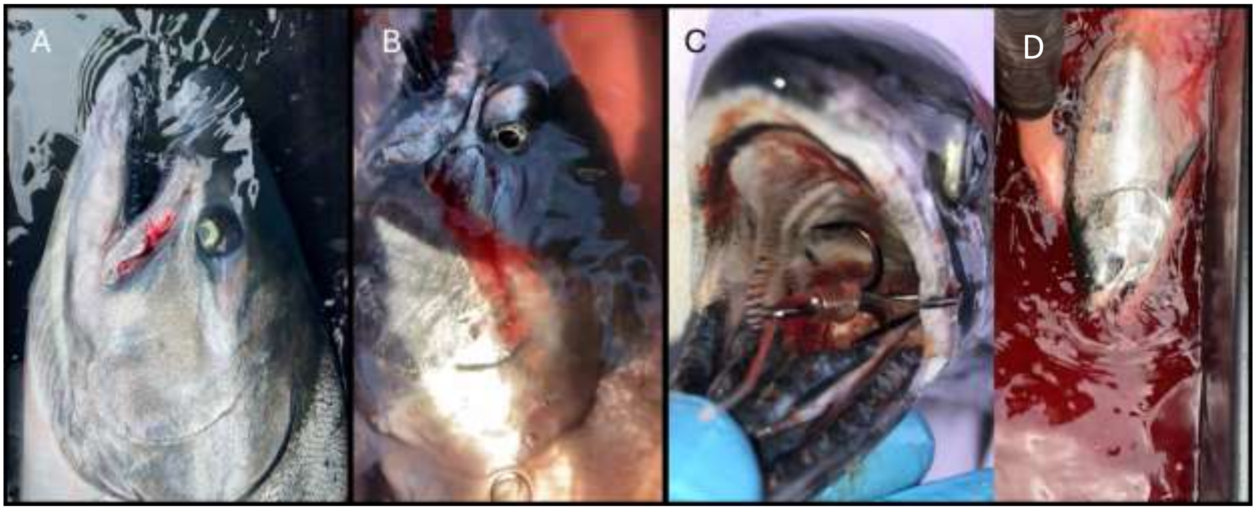

Figure 5. Examples of: A) a bleeding score of 1 with minor tear and oozing wounds , B) bleeding score of 2 with more significant tissue tear and persistent ooze, C) hooking location associated with bleeding score of a 3, and D) sampling sling water as a result of a bleeding score of a 3 – this image does not capture the pulsing nature of this most severe level of bleeding.

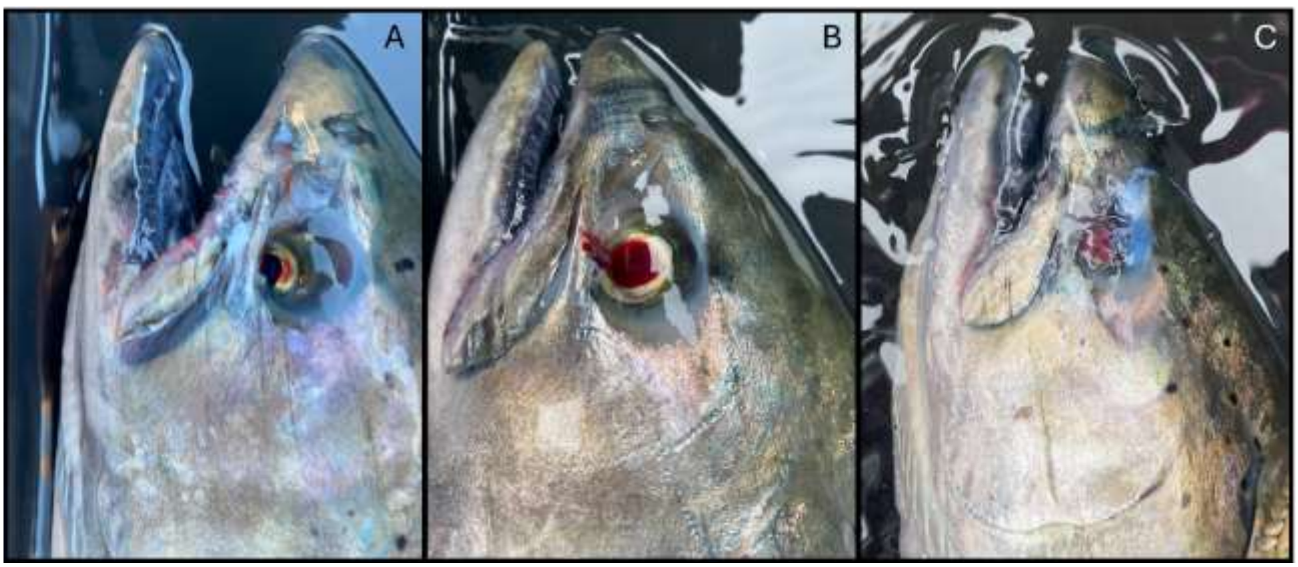

Figure 6. Examples of eye injuries: score of 1 with minor intraocular hemorrhage (A), score of 2 with full puncture and significant hemorrhage (B), and score of 3 with severe loss of structural integrity (C).

Figure 7. Examples of scale loss: A) < 5% score of 1. B) 5 to 15% score of 2, and C) ≥ 15% score of 3.

The difference in the combination of gap and throat length can significantly influence the number of fish experiencing eye damage, and also influences the severity of the eye injuries that occur (Figure 8). For individuals caught with 'recreational' hooks, 9% were observed with a minor eye injury and only 2% expressed a more severe eye injury receiving a score of 2 (or greater). While those caught with 'commercial' style hooks, 32% had a minor level of eye injury, 8% had a moderate eye injury or score of 2, and 5% had severe eye injuries or complete rupture and loss of the eye. Overall, only 11% of fish caught with 'recreational' hooks were exhibiting any eye injury and these injuries were less severe, while comparatively, 45% of fish caught with 'commercial' hooks had eye injuries and they were more severe.

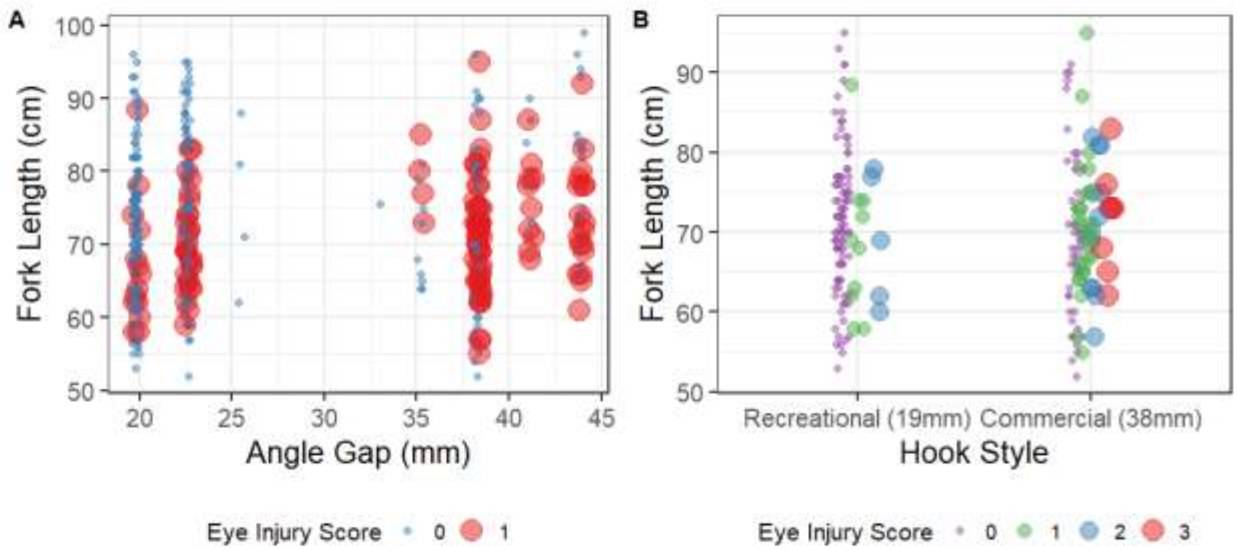

Figure 8. Scatter plot showing the relationship between hook size (mm) and fork length (cm). Hook size is described as the 'angle gap', or the distance from the right angle made from the base of the gap and the shank of the hook to the hook point. (A) Contrasts the presence (red dot) or absence (blue dot) of an eye injury across the various hook sizes used across all years of sampling, while (B) contrasts the eye injury score ranging from no injury (0; purple dot) and to minor (1; green dot), to severe (3; red dot) for Chinook captured in 2021, when hook size was a specified treatment that compared 3/0 (19mm angle gap) and 6/0 (38mm angle gap) sized hooks in the recreational and commercial styles, respectively.

For all years of study, we created 'fishery effects' groups categorizing released fish as: 'good condition' (n = 140; no air exposure, minor bleeding (score 0-1), no eye injuries, no scale loss, minor fin fraying (score 0-1)), 'limited injury' (n = 216; air exposure (30-300s), no eye injuries, moderate scale loss (score 1-2), moderate bleeding (score 2), moderate fin fraying (score 2)), 'severe injury' (n = 129; air exposure (30-300s), severe bleeding (score 3), severe scale loss(score 3), severe fin fraying (score3)), and, 'eye injuries' (n = 131; eye injury (any eye injury, score = 1 or greater) as a separate group given the apparent latent effects on survival (Figure 10). In holding studies (Zinn et al. 2024), injuries like bleeding, scale loss, or fin damage often resulted in immediate mortality or were related to increased probability of mortality through the 10-day holding period. Yet, there was no relationship observed between eye injuries and either immediate or latent mortality during those holding studies (Zinn et al. 2024). In our telemetry studies, we observed variable levels of immediate and latent mortality of tagged fish within these 'fishery effect' groups (Figure 6A). We completed time-to-event analyses where the event is the last known detection or recovery post-release, comparing a 'control' group (e.g., good condition fish), to different injury groups (Figure 6). Using a final detection is not a perfect definition for mortality as we do not know the true fate of the fish at this time and some of the fish would have certainly survived beyond their last known detection.

However, the relative difference among the contrasted groups is the important result to highlight. Note the large immediate mortality levels of up to 20% (e.g., within 10 days of release) for all groups except those released in ‘good condition’, our closest proxy to a ‘control’ fish possible in tagging and tracking studies, which had limited mortality during that time period (Figure 6A and B). Further, after the first 10 days post-release, all groups showed declining detection proportions and a similar declining rate of time to last detection, including those in good condition, implying other non-fishery related factors were responsible for that apparent mortality. However, at approximately 40 days post-release, eye injured fish exhibited a divergent pattern and increased rate of time to last detection relative to all other fishery effect groups suggesting a further potential latent impact of this injury type on survival (Figure 9A and C). Figure 9B demonstrates a consistent pattern of roughly 15-20% difference in detections (aka survival) between our ‘baseline’ group (aka ‘good condition’ fish) and all injury type groups combined with most of the differential mortality occurring in the first 10 days post-release. Further, it appears that eye injuries are a unique injury type that increases mortality disproportionately after 40 days post-release responsible for a further 15-20% mortality (Figure 9C). Thus, fish with eye injuries had both short-term (0-10 days, Figure 9A) and long-term (40-70 days; Figure 9C) consequences.

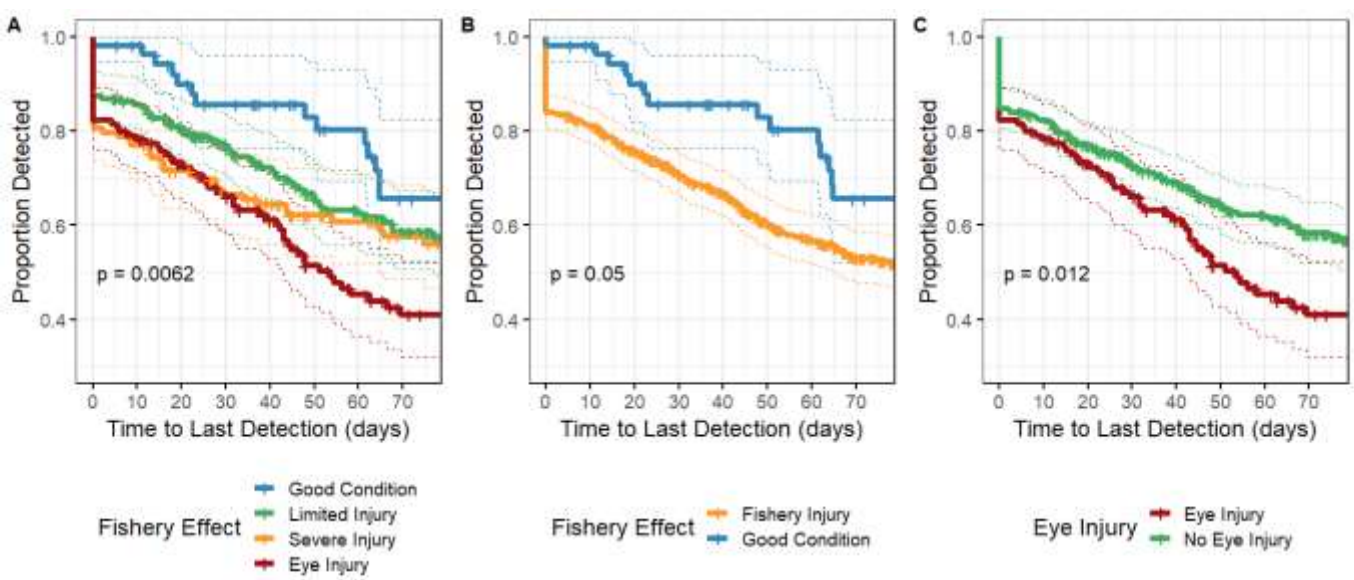

Figure 9. Kaplan-Meier curves (and 95% confidence limits) for time to last detection post-release or recovery by anglers or hatchery staff among (A) different fishery effect groups, categorized as ‘good condition’, ‘limited injury’, ‘severe injury’, and ‘eye injury’, and (B) ‘good condition’ fish and all other fishery effect groups combined, and lastly (C) fish that sustain and eye injury or not. Definitions for each group are found in text.

In 2022, we examined the effect of handling methods that are commonly used within the fishery. We developed a landing technique that allowed tagging and sampling to occur without the fish interacting with a net and without ever removing them from the water (Figure 10). We adapted our sampling sling to float beside the boat and allow for retention of the individual fish, while not causing any interaction with mucous, scales, or fins (Figure 10). This allowed the comparison of handling methods ranging from untouched water-line release to a fish that was netted, boarded, and air exposed.

Figure 10. (A) On-boat sampling sling made from vinyl coated polyester developed for tagging and sampling live salmon with limited physical contact and impacts for the individual. (B) Modification of the sling with flotation that allowed fish to never be removed from the water but contained next to the vessel for tagging and sampling.

Injuries included eye injuries, non-eye injuries causing bleeding, fin fraying or tearing, scale loss, tissue damage, and the observation of gill distress due to a pathogenic state (see descriptions in Table 1). Injuries causing bleeding were observed in 21% of interactions, with 13% displaying minor bleeding (score = 1, puncture or dermal tearing with oozing blood), 5% displaying moderate and bleeding (score = 2, streaming blood, apparent vasculature damage) and 2% severe bleeding (score = 3, pulsing blood, apparent arterial damage near vital organs, i.e., gills) (Table 2).

Table 2. Summary of scored eye injury and bleeding observed for all Chinook captured and tagged from 2019 to 2022, where injury severity increases with numeric score. Details for each score can be found in the text.

	Bleeding Score				
Eye Injury Score	0	1	2	3	Total
0	526 (68.76%)	70 (9.15%)	22 (2.88%)	16 (2.09%)	634 (82.88%)
1	67 (8.76%)	16 (2.09%)	13 (1.70%)	2 (0.26%)	98 (12.81%)
2	11 (1.44%)	10, 1.31%	3 (0.39%)	0 (0.00%)	24 (3.14%)
3	5 (0.65%)	3, 0.39%	1 (0.13%)	0 (0.00%)	9 (1.18%)
Total	609 (79.61%)	99 (12.94%)	39 (5.10%)	18 (2.35%)	765 (100.0%)

Similarly, scale loss was observed in 27% of interactions, with 18% being minor (score = 1, <5%), 6% being moderate (score = 2, 5 - 15%) and 3% severe (score = 3, >15%), however, this was highly related to the air exposure treatment that was imposed on the individual with longer air exposure times increasing the severity of scale loss (Table 3).

Table 3. Summary of scored scale loss observed in Chinook among four treatment groups related to air exposure and associated handling, across all years of study from 2019 to 2022. Details for each score can be found in the text.

	Scale Loss				
Air Exposure Treatment	0	1	2	3	Total
No Air + Water Release	197 (25.75%)	8 (1.05%)	0 (0.00%)	0 (0.00%)	205 (26.80%)
Net + Boarded + No Air	235 (30.72%)	54 (7.06%)	12 (1.57%)	6 (0.78%)	307 (40.13%)
<60s Air Exposure	55 (7.19%)	38 (4.97%)	20 (2.61%)	0 (0.00%)	113 (14.77%)
>60s Air Exposure	72 (9.41%)	39 (5.10%)	13 (1.70%)	16 (2.09%)	140 (18.30%)
Total	559 (73.07%)	139 (18.17%)	45 (5.88%)	22 (2.88%)	765 (100.00%)

Survival probability was ~ 85% for fish that were not bleeding and which had no scale loss, whereas fish that were bleeding or had scale loss generally had somewhat lower survival probabilities, with the exception of fish with high levels of scale loss (Figure 11). This finding speaks to the need to conduct future multivariate analyses to better understand the relationships specifically between bleeding, scale loss and survival.

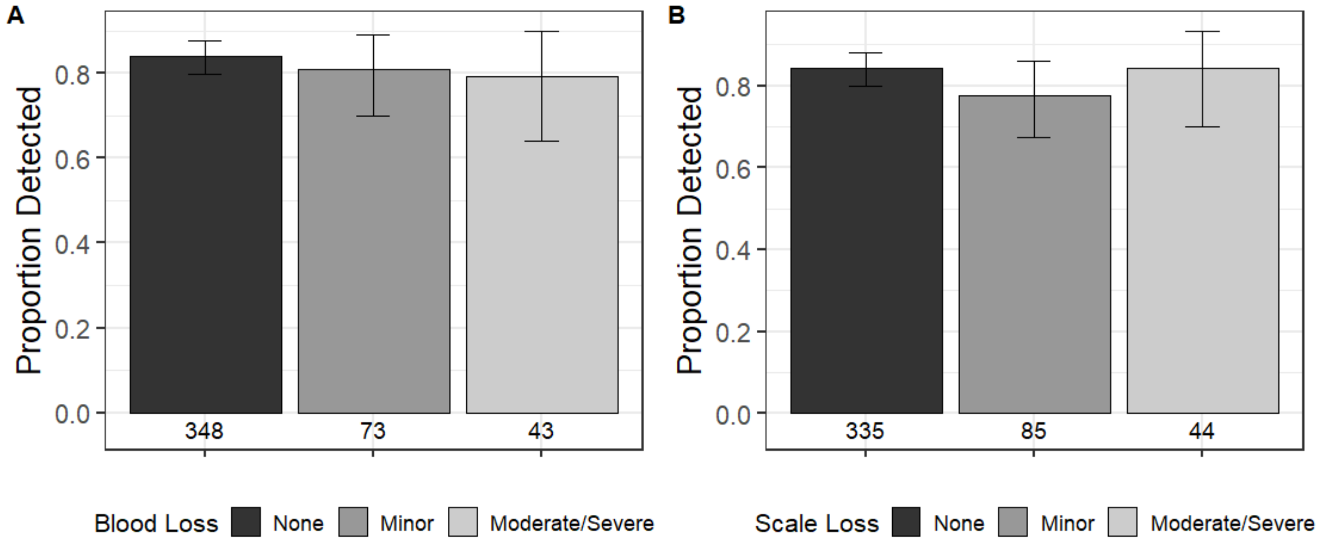

Figure 11. Post-release survival (with 95% confidence intervals) to the NSOG array or beyond 10-days for Chinook salmon with variable scored levels of observed bleeding (A) and scale loss (B).

All years data were examined using the condition categories described above (see Figure 6). 'Complete sample' are all fish combined within a given year regardless of their release condition. Fish in 'good condition' at release generally had excellent survival, in 2021 it was 100%, the other years were 92% (62-99%, 95% CI) and 96% (76 – 99%, 95% CI; Figure 12). Depending on the year, the poorest survival was either the eye injury or severe injury groups. Complete sample survival ranged from 80% (72 – 85%, 95% CI) to 88% (79 – 94%, 95% CI) across three years of study within the Discovery Islands.

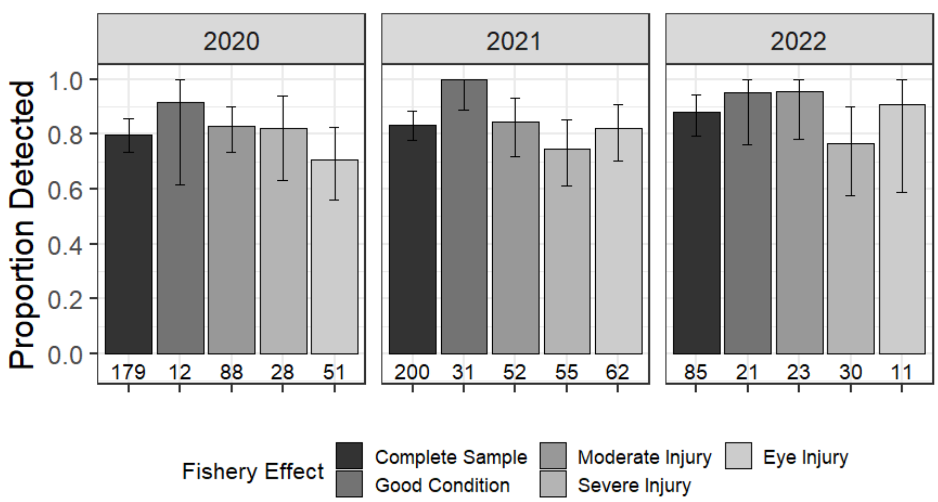

Figure 12. Post-release survival (with 95% confidence intervals) to the NSOG array or beyond 10-days for the complete sample of Chinook salmon for each year of study, along with each fishery effect group.

Another pattern that we uncovered was that in most years, survival probability increased with increasing body-size (Figure 13). This finding likely derived from a number of factors including: larger fish are likely more sexually mature and this reduces injuries caused by physical handling, the larger relative body size to the size of hook which limits the severity of injuries that occur, and, a greater ability to cope with the physiological stress response associated with a fishery interaction.

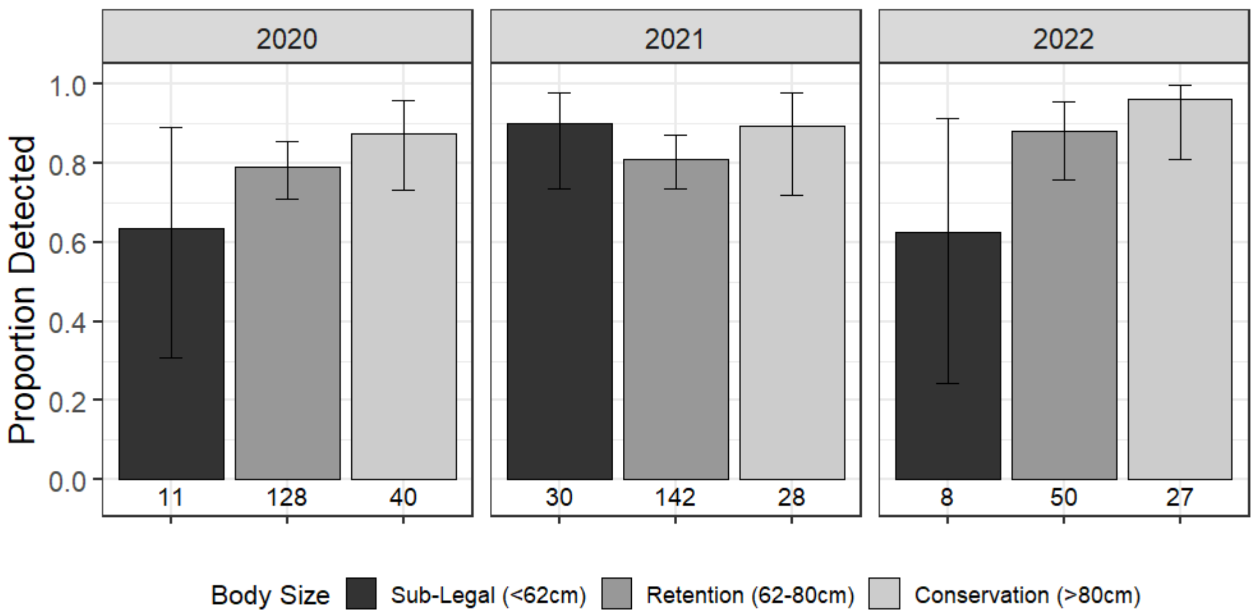

Figure 13. Post-release survival (and 95% confidence intervals) to the NSOG array or beyond 10-days for Chinook salmon across all years of study in the Discovery Islands region, among three fork length based regulated size classes in the Strait of Georgia. During fishery retention openings on the east coast of Vancouver Island (portions of Pacific Fishery Management Area (PFMA) 12 and 20, PFMA 13 – 19, PFMA 28 – 29), all Chinook salmon less than 62 cm fork length (Sub-Legal) must be released. During portions of the year, in an effort to conserve larger bodied yearling (stream-type) Fraser River Chinook stocks, Chinook salmon greater than 80 cm fork length (Conservation) must be released.

Genomic analyses were conducted on gill tissue from all tagged individuals in 2020. Laboratory processing and analyses were completed by the Molecular Genetics Laboratory (Pacific Biological Station, Nanaimo, British Columbia) to assess the physiological condition at time of capture and the presence of particular salmon pathogens. We looked for the presence of 25 pathogens with 12 being detected. The most prevalent was *Tenacibaculum maritimum* (n = 37, 21%; bacterium) followed by *Parvicapsula pseudobrachicola* (n = 31, 17%; myxozoan parasite), *Flavobacterium psychrophilum* (n = 25, 14%; bacterium) and *Candidatus Syngnamydia salmonis* (n = 20, 11%; bacterium; Figure 14)). *T. maritimum* is of particular interest given the detrimental impacts it can have on survival of farmed salmon and the potential for tenacibaculosis (the disease state related to *Tenacibaculum* species) affecting survival of wild salmon.

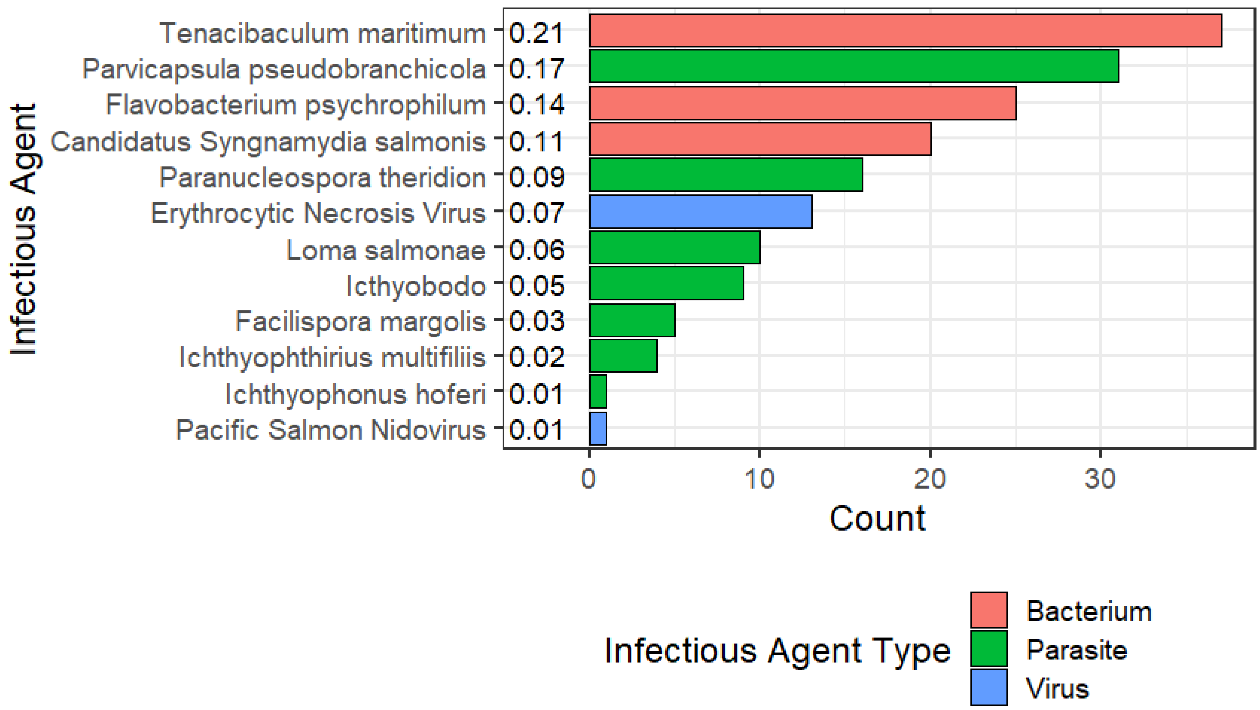

Figure 14. Number of Chinook salmon expressing genetic signatures for 12 infectious agents observed in 2020 in the Discovery Islands on the east coast of Vancouver Island, with the proportion of the complete sample along the y-axis.

Genomic biomarkers were examined to determine the physiological state of tagged fish at time of capture. Biomarkers related to 'imminent mortality', 'mortality related signatures', osmotic stress, thermal stress, inflammation, immune response, viral disease development, and general stress were assessed (Miller et al. 2011, Miller et al. 2017, Akbarzadeh et al. 2018, Houde et al. 2019,). Biomarker panels for 'imminent mortality', viral disease development (VDD), and thermal stress related to 18°C, were classified by the Molecular Genetics Laboratory using a random forest model framework to determine the relationship of specific gene groupings and loads to samples with known stressed or moribund states, determined through laboratory testing and experiments. Individuals with a classified score above 0.5 have genomic profiles related to individuals that were known to be in an associated stressed state or moribund (A. Bass, DFO; pers comm). Our data suggest that these Chinook were not thermally stressed, and only two individuals were possibly experiencing viral effects of an infection (Figure 15). However, neither of the two individuals with VDD classified genomic signatures above the 0.5 threshold were also positive for any of the 25 pathogens that were tested for. Yet, infection with other viral pathogens remains a possibility and the relationship to survival was non-significant. The classification for 'imminent mortality' related genomic signatures was positive, or greater than 0.5, for 24 of 179 (13.4%) of the individuals tagged and biopsy sampled in 2020. The proportion of fish that were detected post-release for individuals with a positive classification score was 0.71 (n = 17 /24), while the proportion for those detected with a negative score was 0.84 (n = 129 / 154). This suggests that post-release mortality for a segment of our tagged fish might have been additionally influenced by the fish's initial pathogen state. The mean time of detection post release for Chinook with positive classification scores was 37.8 days (range excluding no detection; 12.5 – 90.0 days) and for negative classification scores was 53.3 days (range excluding no detection; 5.7 – 146.0 days). These analyses are ongoing.

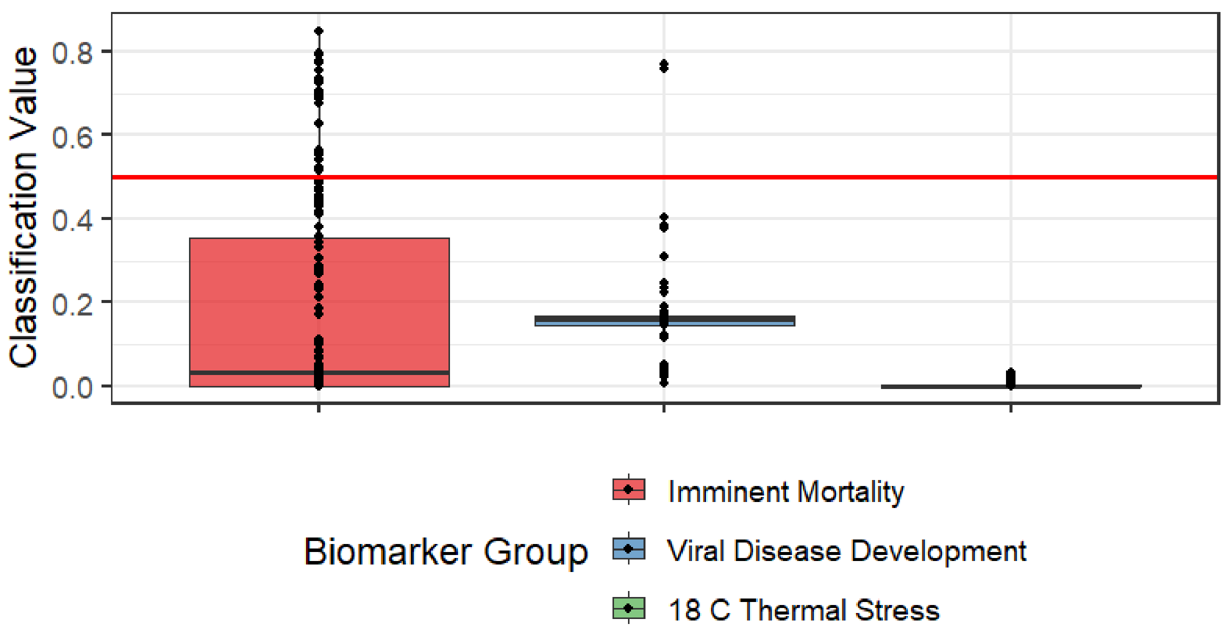

Figure 15. Random forest classified data for Chinook salmon captured in the Discovery Islands in 2020 for 'imminent mortality', viral disease development, and thermal stress related to 18 °C water biomarker panels, where values greater than 0.5 (red horizontal line) are indicative of a stressed state or morbidity.

Study 2 - Barkley Sound Chinook salmon

<u>Methods / Results</u>

In 2021, the Chinook catch-and-release study expanded to Bamfield, British Columbia. This study was designed to tag maturing fish in Barkley Sound and track them from the ocean to their freshwater spawning locations with the aim of better understanding how fisheries interactions effect released fish during this habitat transition. The Stamp/Somass River is a severely anthropogenically modified system with 3 dams (Elsie Lake, Great Central Lake, and Sprout Lake), a hatchery to artificially supplement salmon stocks (Robertson Creek Hatchery), and a pulp mill that was built on the estuary in 1956 (Catalyst Paper Corporation). This watershed has a history of low discharge rates and paper effluent combining in the estuary and resulting in hypoxic water quality lethal to fish and other aquatic life. Although flow controls have been implemented to lessen these hypoxic events, this watershed remains challenging for migration. Previous research has focused only on migration within marine or freshwater environments and has failed to assess migration across the two. This is especially important to consider through the lens of carryover effects, where the experience of a fish in one stage of life impacts the next.

We targeted Robertson Creek Hatchery (RCH) Chinook, which were headed for the Stamp River near Port Alberni. Before tagging the fish, we deployed an acoustic array from the entrance of Barkley Sound to RCH in the Upper Stamp River (fish will rarely migrate past this point; Figure 16). A passive integrated transponder (PIT) array is already in place along their migration at a fish ladder in the Stamp River, so we utilized the existing infrastructure maintained by DFO. In August 2021 we tagged 282 Chinook salmon in Barkley Sound, with a variety of tag types including passive integrated transponder PIT tags, ibutton temperature loggers, and acoustic tags. In 2022 we tagged 148 fish with all three tag types on each fish. Dates ranged from August 9 to September 6 in 2021, and August 4 to September 6 in 2022. The average temperature of surface water during tagging was 15.6°C (± 2.3°C). Fishing effort in 2022 was reduced to accommodate another BCSRIF funded study (see Zinn et al. 2024). Research questions were shaped in a similar way to the ECVI research, wherein we tested handling methods that anglers could implement in a capture event. Fish were captured using standard recreational methods as described above. Handling methods tested in 2021 included air exposure (0 to 300 seconds) and net use (net vs. no net). In 2022, this evolved to a boat-side no net treatment where the fish experiences no air exposure, no net use, and was tagged at the waterline over the side of the boat. The second treatment included net use, where the fish was landed with the net and then tagged boat-side without any air exposure, and the third treatment brought the fish aboard with a landing net and air exposed it until the hooks were taken out on the deck of the boat.

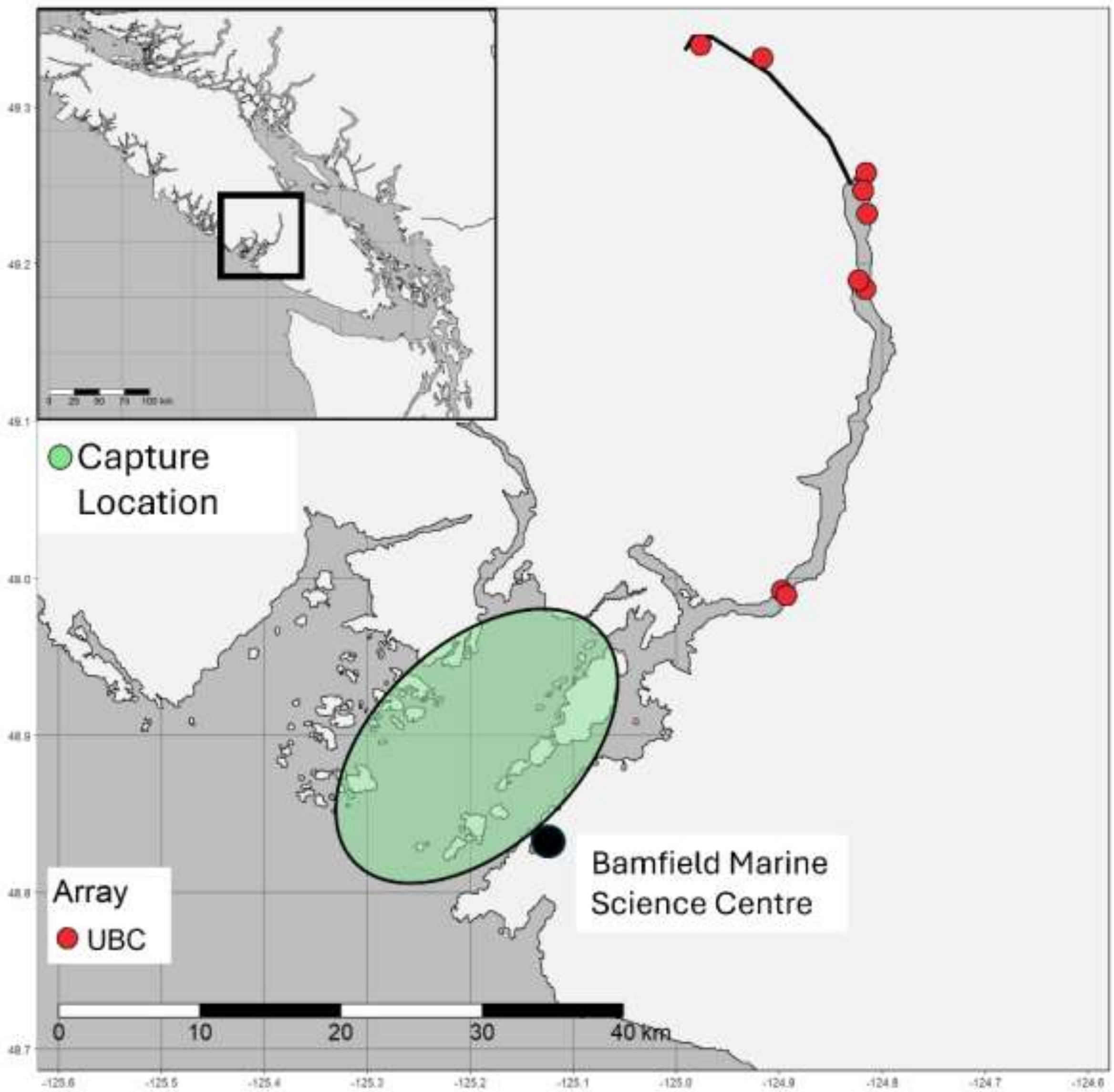

Figure 16. Map depicting the Barkley Sound Chinook salmon study region.

After tagging the fish in August, the study re-located to Port Alberni on the Stamp River from September through October and pivoted to tracking tagged fish in freshwater. Any tags received from the public (57 in 2021 and 21 in 2022) enabled the download of ibutton temperature data and provided the opportunity to learn about the re-capture (where, when, how, etc.) of the harvested fish. In addition, we collaborated with RCH to recapture any tagged fish for sampling through dead pitch, live sorting, or dip netting them in the raceways. In 2021 we were able to resample 12 fish at the hatchery, and in 2022 no tagged fish were recovered. When recaptured at the hatchery, these fish were euthanized and resampled. Resampling included the same process as on-board the tagging vessel, but also included weight (g) of their heart, spleen, and liver. For every fish recovered, a separate baseline fish was sampled within the hour that was similar size and maturation state to the tagged fish, but did not have any indication of previous fisheries encounter (no hook wound, gillnet scars, etc.) The difference in successful resampling was possibly due to the warm Fall experienced in 2022 where drought conditions with warm temperatures and low flows persisted throughout their freshwater migration and may have prevented them from reaching the upper river. To our knowledge is the first instance of physiological resampling individual Chinook salmon that were released in the marine recreational fishery and recovered in freshwater.

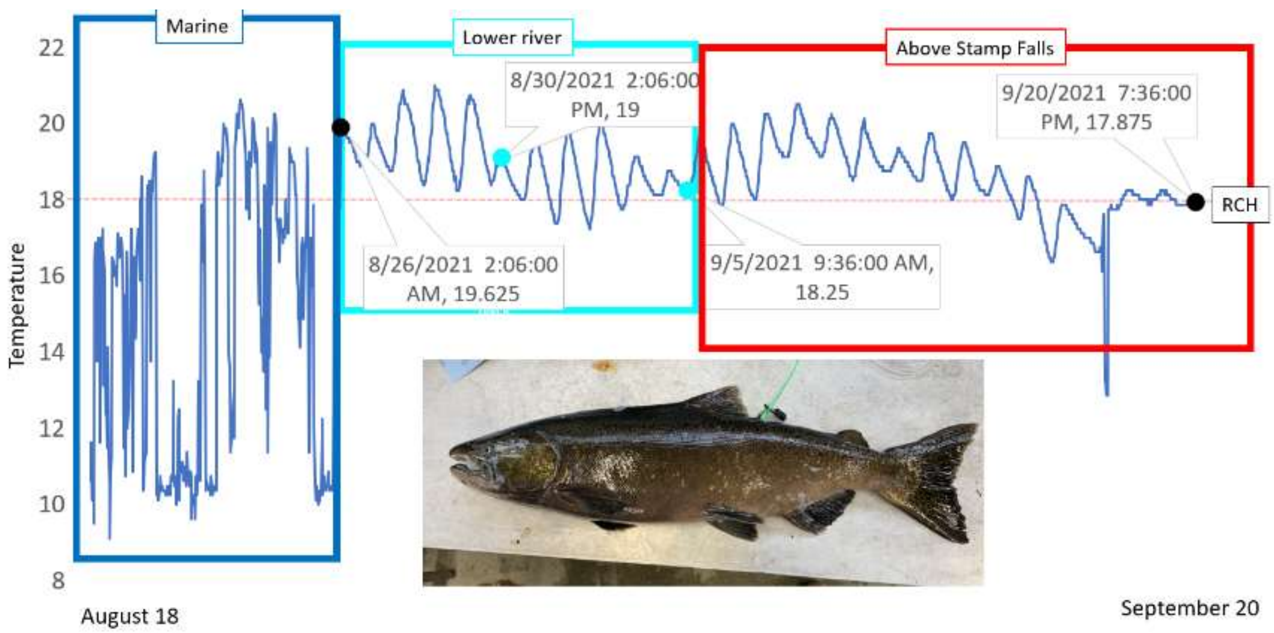

Figure 17. Example of ibutton temperature (˚C) data from a fish recaptured at the hatchery showing marine, lower river, and upper river water temperature exposure/selection. The first black dot represents river entry (Aug 26th 2021), and last one represents arrival at the hatchery (Sept 20th 2021). The blue dots in the middle show PIT detections, with the fish attempting to go past the PIT array on Aug 30th, and likely falling back then re-attempting Sept 5th. Red horizontal line at 18°C represents a temperature associated with heat stress in Pacific salmon.

A total of 322 Chinook salmon from the RCH stock (206 in 2021 and 116 in 2022) were tagged and released across the two years of study. Other stocks encountered throughout the two years were mostly comprised of Nitinat (n = 49), Sarita (n = 22), other West coast Vancouver Island (n = 7), East coast Vancouver Island (n = 4), and Puget Sound (n = 6). Fork length for tagged Chinook across the two years ranged from 53-94 cm (mean = 76.5 cm). Survival to 5-days or successful river entry for the RCH stock was 93% in 2021 (n = 45; RCH stock with acoustic tags), and 85% in 2022 (n = 97) for a total of 88% survival (or 12% mortality) across the two years (n = 142). Capture mortality, which occurred during the tagging process (up to 5 minutes) in this study was 1% for all captured fish (n = 4). Survival for fish larger than 70cm fork length was 88%, and those smaller than 70 cm fork length had 81% survival to freshwater or 5-days. Fish experienced potentially lethal temperatures (> 20°C) along their spawning migrations when they entered the lower Somass River (Figure 17), and this was more common in 2022. At the hatchery, 100% of the fish that were recaptured in 2021 (n = 12) were males, and none of the recaptured fish were air exposed over 90 seconds. Air exposure dictated the likelihood of subsequent harvest, with fish that were not air exposed composing the majority of the harvested fish. The fish that were not air exposed may have recovered from the angling stress sooner than those that were air exposed because a subset of these fish was caught by anglers, which suggests fish were displaying normal feeding behaviours. High levels of air exposure also impacted probability of survival to the entrance of the inlet, with only 50% of acoustic tagged fish that were air exposed for 300 seconds surviving to the entrance of Alberni Inlet. Differences in survival between sexes was observed in 2021, where males had significantly higher survival to freshwater entry than females (98% vs. 87%).

The average of number of fins damaged for the tagged Chinook at capture was 5.7, and upon resampling at the hatchery it decreased to 3.6 fins damaged (n = 10; Figure 18). Although their score reduced, it is significantly higher than that of the baseline fish, that had an average of 0.72 fins damaged (n = 10). This shows that fin damage does not heal in ~50 days, while it may become less apparent during spawning migrations as fish reabsorb their scales and mature. The average gill health of the tagged fish (number of necrotic tips) also differed, increasing from 0.2 at capture to 0.4 during freshwater resampling. The average gill health score was 0.08 for baseline fish. From marine capture to freshwater resampling, the tagged fish gained an average of 2.89cm fork length and lost 2.67 cm in girth. Calculated weight for the tagged fish (length (cm) x girth (cm) x girth (cm) /12,300) decreased by an average of 0.36 kg. Average fat density readings at were 6.69 (behind gill plate) and 4.97 (below dorsal fin) at capture and 0.96 and 0.84 during freshwater resampling. Baseline fish had average fat density readings of 0.92 and 0.84.

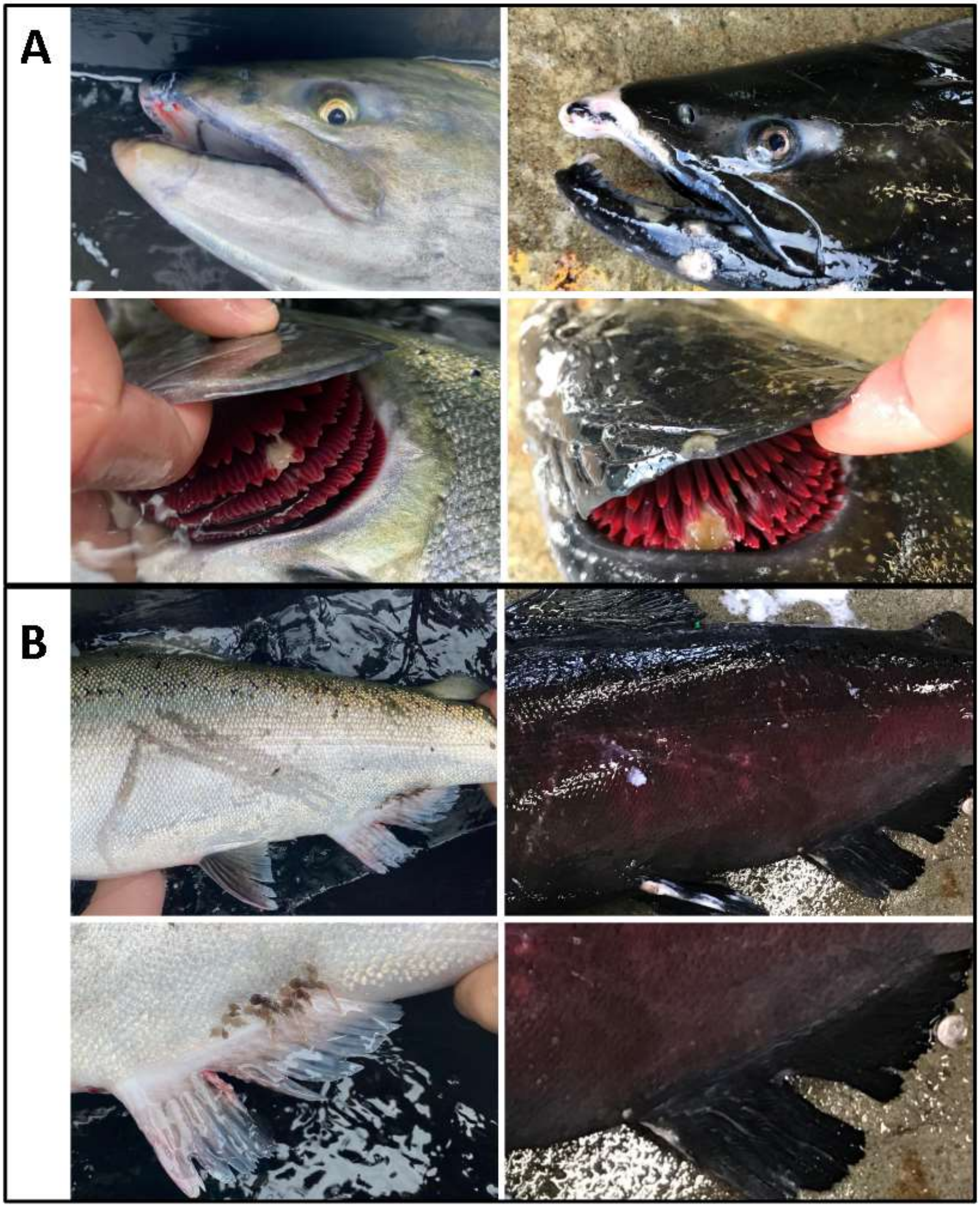

Figure 18. A) Progression of hook wound and gill infection in a single fish 49-days post-release (left side at capture, right side at recovery at Robertson Creek Hatchery); B) Progression of fin damage in a single fish 46-days post-release (left side at capture, right side at recovery at Robertson Creek Hatchery).

Study 3 – Juan de Fuca coho salmon

Methods / Results

This three-year study (2020 – 2022) investigated factors associated with post-release mortality and travel rate (km/day) of coho salmon in a marine recreational fishery in British Columbia, Canada. Adult coho salmon were recreationally angled in the marine environment, affixed with acoustic tags, and tracked during their return migration to three main receiver lines (Figure 19): Juan de Fuca Strait (JDF), lower Fraser River, and Puget Sound. Capture, sampling, and tagging methods followed those outlined in "Overview of Project Locations and Methods". From September 1-18, 2020, and August 23 – September 3, 2021 we tagged 323 coho salmon and a subset of fish were subject to an air exposure treatment (30 – 300 sec) upon capture. Sea surface temperature was 11.8˚C (median; range = 11.1˚C – 14.5˚C; measured every 30 minutes) in 2020 and 13.2˚C (median; range = 12.7˚C – 13.7˚C; measured daily at the start of tagging) in 2021. Injuries were recorded as outlined in Table 1.

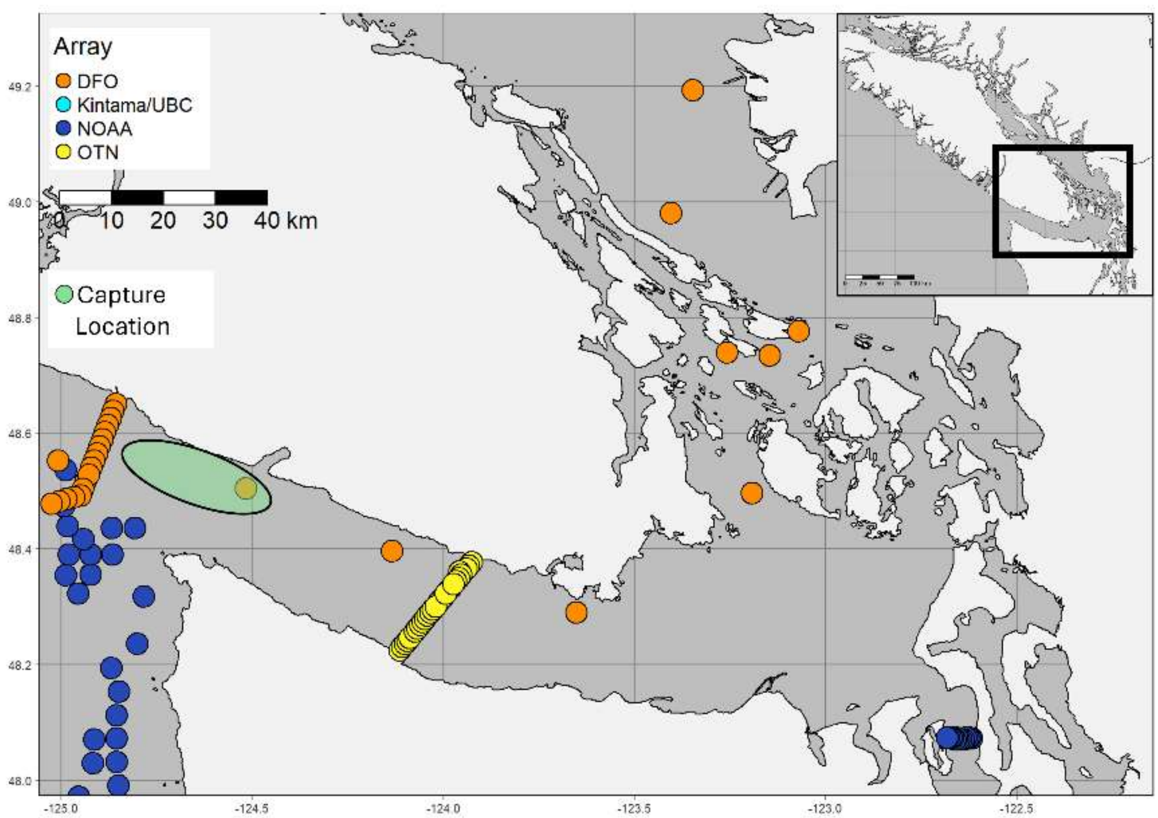

Figure 19. Map depicting the Juan de Fuca coho salmon study region. Fish were tracked across the Juan de Fuca (JDF) line (yellow dots) and the Puget Sound Admiralty Inlet line (blue dots, lower right corner). Fraser River lines not on map.

In 2020 and 2021, post-release mortality to the first point of detection (i.e., JDF receiver array, ~50 km from release, median = 3.3 days) was 31.5% (95% CI: 26.1 – 37.4%; n = 279). Post-release mortality to the Fraser River (near Maple Ridge) was 77.4% (95% CI: 63.8 – 87.7%; n = 53) and survivors took a median 13.4 days to reach this point of detection. In 2020, post-release mortality to the entrance of Puget Sound (Admiralty Inlet) was 56.0 % (95% CI: 34.9 – 75.6%; n = 25), and in 2021 post-release mortality was 55.1% (95% CI: 43.4 – 66.4%; n = 78), with survivors over both years taking a median 9 days to reach these receivers. We investigated the association of 10 variables with post-release mortality and travel rate to the JDF receiver line: year, sex, eye injury, scale loss, hook location, bleeding, air exposure, number of fins damaged, fork length, and population. We found scale loss, eye damage, bleeding, and smaller body size of coho salmon were associated with increased odds of mortality. Coho salmon with an eye injury had 2.77 times (95% CI = 1.37 – 5.59, p = 0.0044) greater odds of post-release mortality than coho salmon without an eye injury. Every decrease of 1 cm FL is associated with 1.06 times (95% CI = 1.11 – 1.01, p = 0.0126) increase in the odds of post-release mortality. Going up each level of scale loss (i.e., 0-5% → 5-10% → 10-35% → >35%) was associated with 1.94 times (95% CI = 1.36 – 2.77, p = 0.0003) greater odds of post-release mortality. Going up each level of bleeding (i.e., none → minor → major) was associated with 2.38 times (95% CI = 1.44 – 3.93, p = 0.0008) greater odds of post-release mortality. Increased scale loss and smaller body size were also associated with slower migration rates post-release (Lunzmann-Cooke et al. 2024).

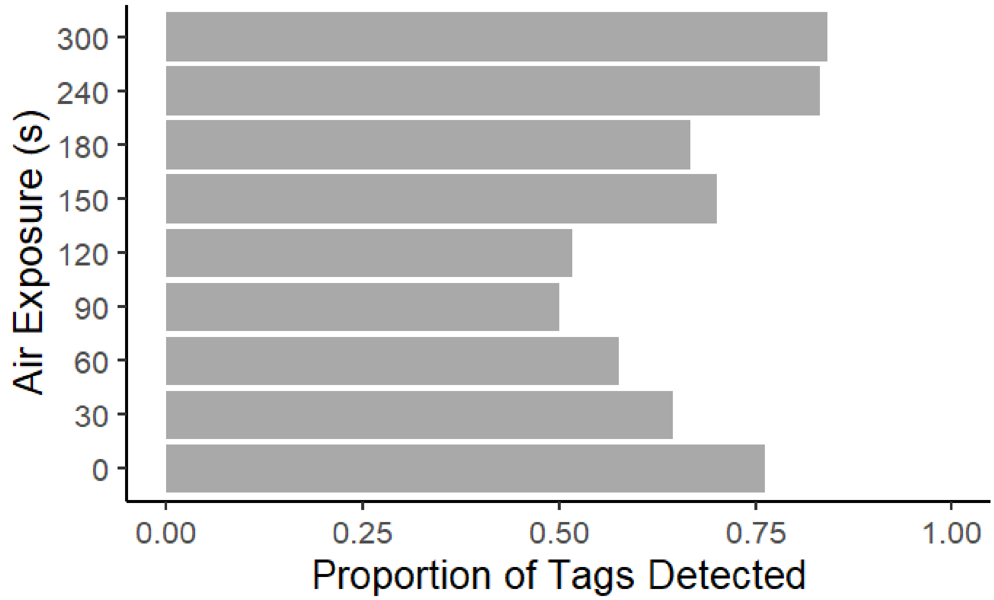

Figure 20. Proportion of air-exposed (0 – 300 s) tagged and released coho salmon detected on the Juan de Fuca receiver array post-release.

In similar approach to Study 1 with Chinook, we compared mortality estimates to the JDF receiver line for coho salmon across three broad 'fishery effects' groups: A) 'good condition' (no air exposure, no bleeding, no eye injuries, no scale loss), B) 'moderate condition' (air exposure [30-300s], no eye injuries, and one or more of the following injuries: moderate scale loss [score 1-2], minor bleeding [score 1]), and C) 'poor condition' (air exposure [30-300s], and one or more of the following injuries: eye injury, major bleeding [score 2], severe scale loss [score 3]). We found that mortality to the JDF receiver line increased with fish condition: A) good condition fish: 17.0% (95% CI: 8.1 – 29.8%; n = 53), B) moderate condition: 33.9% (95% CI: 22.1 – 47.4%; n = 59), and C) poor condition: 48.1% (95% CI: 36.5 – 59.7%; n = 77). Fish size did not influence fish condition, and when coho salmon were grouped based on the largest population groupings (i.e., Puget Sound and Fraser River stocks), there was virtually no difference in mortality for coho in good condition. Longer-term, Puget Sound coho in good condition continued to have much lower mortality 40.0% (95% CI: 19.1 – 64.0%; n = 20) than those in moderate 83.3% (95% CI: 62.6 – 95.3%; n = 24) or poor condition 70.8% (95% CI: 48.9 – 87.4%; n = 24) when tracked to the first receiver line in Puget Sound (Admiralty Inlet).

Gill clips from 200 coho salmon were collected in 2020 to conduct genomic analysis to assess physiological condition and presence of infectious agents. We found the presence of 11 infectious agents, with *Paranucleospora theridion*, Loma salmonae, Salmovirus WFRC1 virus, *Erythrocytic Necrosis Virus*, and *Tenacibaculum maritimum* as the most prevalent (Figure 21). As outlined in Study

1, biomarkers associated with imminent mortality, thermal stress, viral disease development, mortality related signatures, osmotic stress, inflammation, and immune response were analyzed by the Molecular Genetic Laboratory at DFO. Statistical analyses of biomarkers and infectious agents are ongoing but do not appear to be associated with short- and long-term mortality.

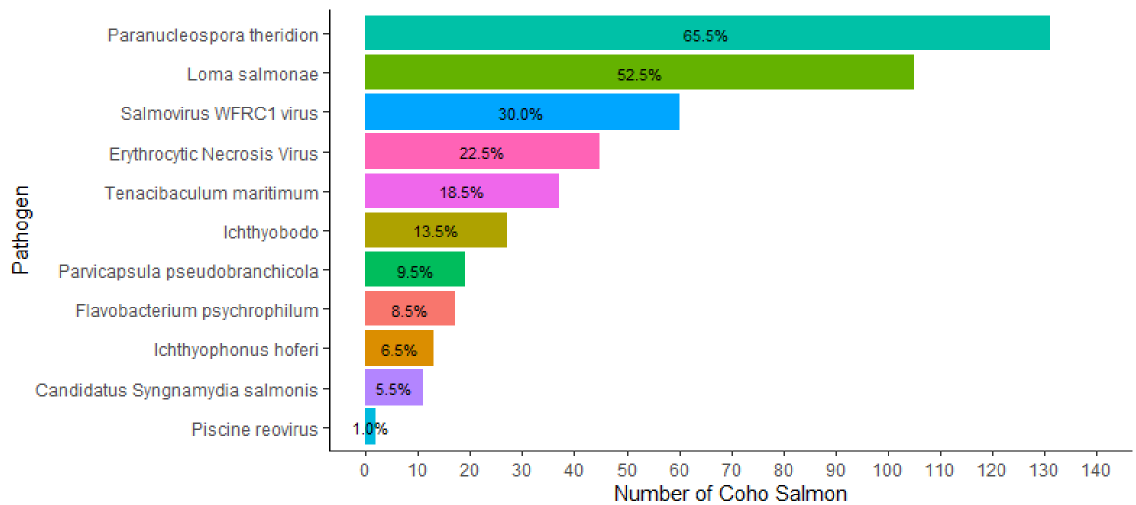

Figure 21. Number of coho salmon expressing the presence of 11 infectious agents in the Strait of Juan de Fuca in 2020

From September 1-10, 2022, we tagged 226 coho salmon. Sea surface temperature was 10.8˚C (median; range = 10.4˚C – 11.1˚C; measured daily at the start of tagging) in 2022. Given we found fisheries injuries were associated with post-release mortality and travel rate in previous years, and not air exposure, we did not test air exposure further and instead tested different gear types (hook size and net type) to help determine how to reduce fisheries injuries. To test for the effect of hook size on the frequency of eye injuries and bleeding, we used either a barbless, 3/0 (Gape = 16mm, Throat = 16 mm, Gap = 22.6 mm) or a 5/0 (Gape = 18, Throat = 18, Gap = 25.5 mm) Mustad Siwash fishing hook, a commonly used hook type in this fishery. To test the effect of net types typically used in this fishery, anglers either used a knotless, vinyl-coated landing net, or a knotted, polypropylene landing net.

In 2022, post-release mortality to the first point of detection (i.e., JDF receiver array, ~50 km from release, median = 3.4 days) was 25.9% (95% CI: 20.3 – 32.3%; n = 218). Post-release mortality to the Fraser River was 64.3% (95% CI: 50.4 – 76.7 %; n = 56). Post-release mortality to the Puget Sound line was 62.9 % (95% CI: 53.1 – 71.9%; n = 110). We investigated the association of seven variables with post-release mortality and travel rate to the first point of detection (i.e., JDF receiver line): sex, eye injury, scale loss, bleeding, number of fins damaged, fork length, and population. We found results consistent with 2020 and 2021 where scale loss and smaller body size of coho salmon were associated with increased odds of mortality, and smaller body size was associated with slower travel rate post-release. We found no difference in the frequency of eye injuries nor bleeding between these two hook sizes. However, we did find a difference in fisheries injuries between net types with the probability of scale loss being lower when using the knotless net compared to the knotted net (Figure 22A). Net type did not influence the severity of fin damage (Figure 22B), but fish caught with the knotless net did have a significantly higher number of fins damaged than those caught with the knotted net (Figure 22C). Interestingly, there was a positive association between fork length and both fin damage severity and number of fins damaged.

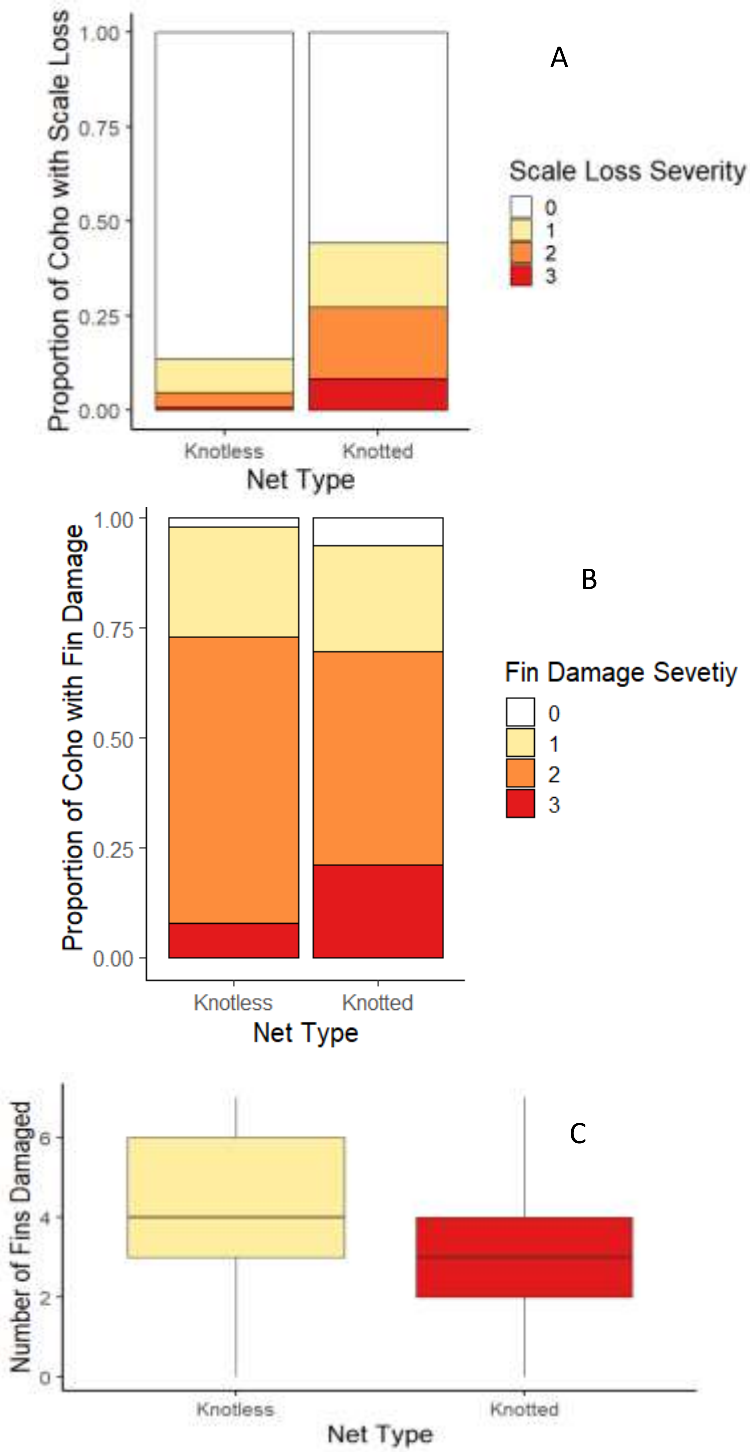

Figure 22. Proportion of coho salmon landed with knotless or knotted net in 2021 showing: A) scale loss severity, B) fin damage severity, and C) number of fins damaged.

Study 4 – Angler Opinions on Marine Recreational Pacific Salmon Fisheries in British Columbia

Methods / Results

The purpose of this interview study was to explore the opinions of recreational Pacific salmon fishers on catch-and-release and understand how angler behaviours are influenced by their perception of catch-and-release as a conservation measure. We also wanted to provide a voice for recreational anglers regarding current management of recreational fisheries and assist with the development of a 'best practices fishing guide'. The study focused on: 1) opinions on fishing best practices and how to improve survival of released fish, and 2) perspectives on salmon hatcheries and the development of mark-selective fisheries. We recruited participants opportunistically at fishing docks, through online advertisements, and via chain-referral. A pre-determined list of questions was used to guide discussions, but we allowed participants to discuss topics of interest at will.

We conducted semi-structured interviews between August 2021 – January 2022 with 26 recreational Pacific salmon anglers. Interviews were conducted face-to-face or virtually and took between 0.5 – 2.5 hours. We interviewed 4 women and 22 men (mean age = 50 years old), and 7 participants were current recreational salmon fishing guides. Analysis of interview data is ongoing, but preliminary examination shows that most of the anglers we interviewed believed air exposure and bleeding to be top factors influencing survival of a released fish. When asked the percentage of released fish that likely survive, the responses varied, as did their support for catch-and-release as a conservation tool. The opinions on hatchery fish were mixed: some anglers were only supportive of hatchery fish as a last hope for a wild population, while others were supportive of hatchery fish for increased fishing opportunities. In general, anglers were open to new information on best practices, and many already implemented the best practices we recommend in the present report. All anglers were supportive of creating more educational resources for anglers with our study results.

Study 5 – Angler Gear Choice and Handling Behaviour Survey Collected Through a Smartphone Application

Methods / Results

In partnership with the SFI we developed a simple online survey for anglers to describe their interaction with individual Chinook and coho salmon during their angling experience. Participation was voluntary and the survey commenced on May 15, 2020, garnering 3612 survey responses, from 1503 different anglers over the nearly 3 years it ran. The survey of angler practices was conducted through the FishingBC smartphone application (aka 'app') while filling out their 'Catch Log' and 'Catch Entry' sections of the app. Anglers could access the survey while actively participating in the fishery in an effort to limit any recall related biases. Anglers were asked six questions related to their individual interaction with Chinook and coho while participating in marine recreational fisheries.

Anglers reported factors related to angling choices, including the gear type (bait or artificial) and hook size. Additionally, they were asked about the fishery interaction, specifically, the time of fight, the hook location that was observed and the presence of an injury resulting in bleeding. And lastly, they were asked about the fishery handling methods or the level of air exposure the fish was subjected to during their catch and release interaction. These results have helped inform our research questions as well as provided validation to our survival estimates through developing an accurate description of the fishery, which closely resembles the gear and methods used during our research.

Anglers reported interactions from all Pacific Fisheries Management Areas (PFMAs) with those in PFMA 20 providing the greatest number of reports (n = 543). Participation has increased in every year of study with 493 participants in 2020 and 890 in 2023, and reports peak in July and August for both Chinook and coho salmon fisheries (Figure 23).

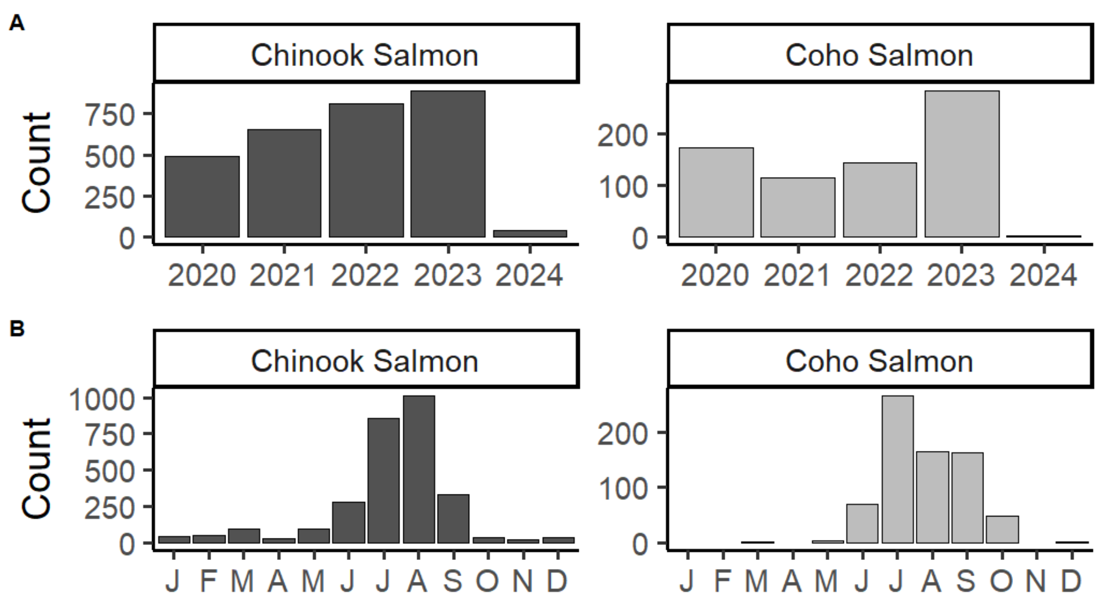

Figure 23. Smartphone app participation for each species across all (A) years of study and across all (B) months.

Results from the app also included size information on captured fish and helps identify seasonal patterns in species capture (Figures 23 and 24). With digital licensing recently becoming a legal option for anglers to record their catch, we can expect an increasing amount of data provided by anglers. Demographic data may provide fisheries managers with temporal and spatial information required for more precise and fishery specific FRIM modeling for characteristics known to influence survival. Specifically, body size is known to influence survival outcomes and these app reports can provide an accurate description of each Pacific fisheries management area (PFMA) at different times of year. With only 3612 reports across three years of collection we can observe trends of increasing mean body size for coho salmon as the summer season progresses and an increasing and decreasing trend of body size for Chinook salmon across the entire year (Figure 24A). Similarly, we can observe variation among PFMAs and weak trend of decreasing body size as PFMA number increases, or as the fishery moves south (Figure 24B).

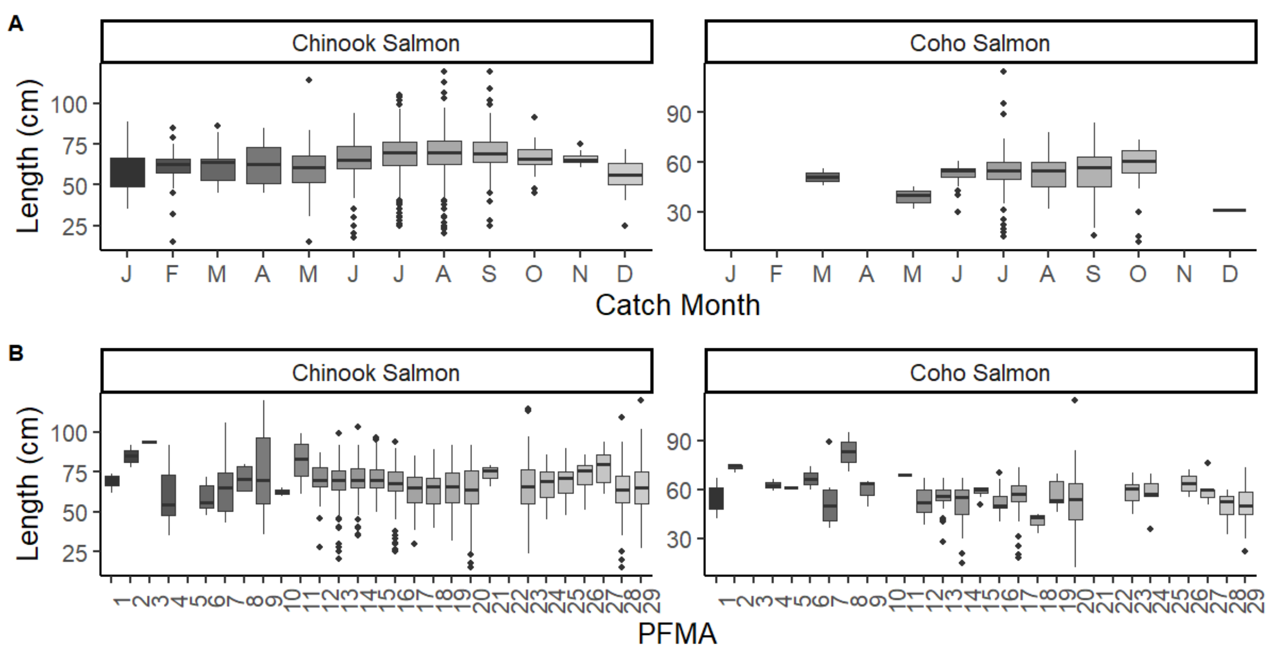

Figure 24. Reported fork length for Chinook and coho salmon compared among months (A) and each Pacific Fisheries Management Area (PFMA).

Chi-squared test of independence and Mann-Whitney *U*-tests were used to assess the relationship between app reported results to the data we collected during our capture and tagging procedures (Figure 25A). A Chi-squared test of independence indicated that there were no statistically significant differences between the app reported observation of bleeding and our observations while tagging, which suggests that app users are providing objective reporting for this injury type (Figure 22A). However, one pattern that clearly differed between the app responses and our field observations from tagging and release was that many members of the public stated their fight times were much longer than our experiences (Figure 25B). This could simply reflect the inability of the public to accurately gauge time when fighting a fish (we meticulously recorded it), or, it could reflect behaviours of some anglers playing fish longer before landing. If this latter notion is true, it means that fish captured by some fishers may express more negative survival outcomes, especially if surface temperatures are relatively warm. However, we expect the majority of the increased mean reported fight time is more likely related to reporting biases than to actual observed fight times as anglers often over estimate fishery related times (McCormick et al. 2013) and fight times with salmonids are often relatively short in duration (Roth et al. 2018).

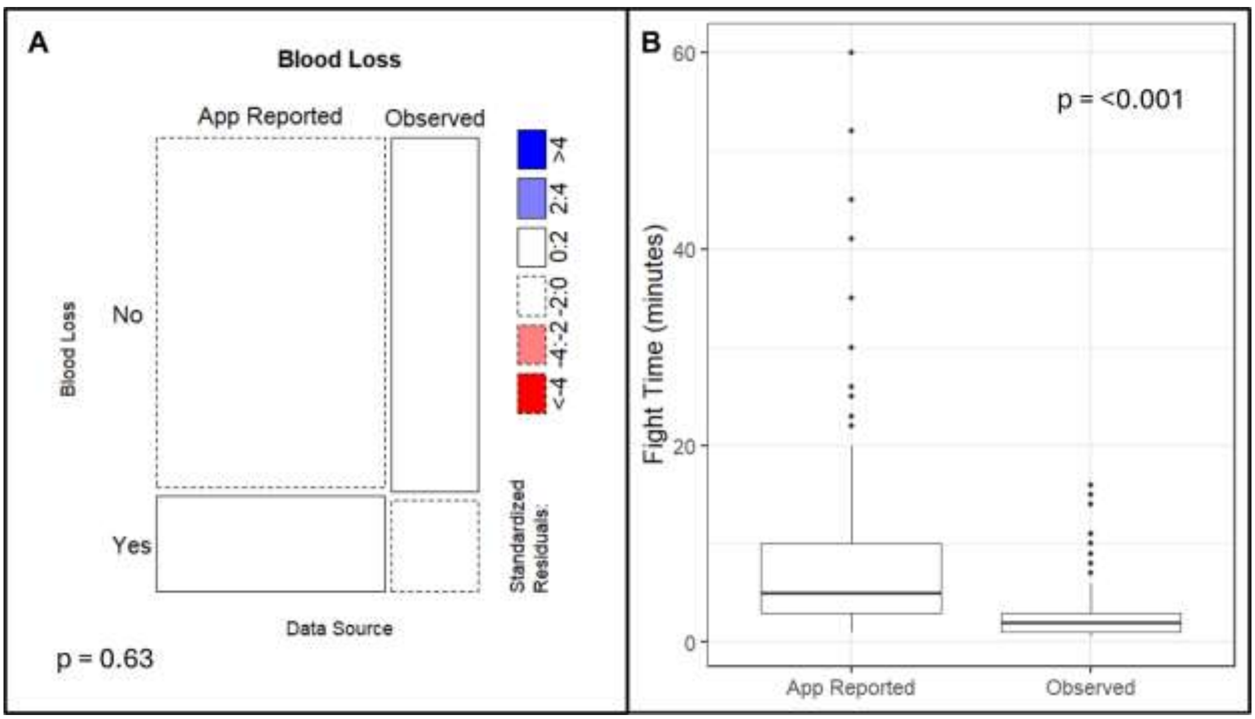

Figure 25. (A) Mosaic plot depicting the Chi-square test of independence result and (B) a box plot and Mann-Whitney *U* test result comparing the app reported results and data observed during capture and tagging procedures for all Chinook and Coho salmon studies for observed blood loss (A) and fight times (B).

Discussion

This research is ground-breaking in its approach and results helping to modernize our understanding of C/R mortality in Pacific salmon recreational fisheries. Our ability to estimate post-release mortality at various time scales means that FRIM models can now be populated with accurate information to facilitate better escapement models, it enables the development of best capture, handling and release practices, it facilitates inferences on the effects of climate change on C/R mortality, and thus in its totality helps make British Columbia and Canada a leader in conducting more sustainable recreational salmon fisheries. Below we discuss the main issues that were uncovered in our research which sets the stage for the articulation of best C/R practices which follows below.

Air exposure issues

Air exposure can be considered acute hypoxia for fish, and when a fish is removed from water, a cascade of physical and physiological disturbances take place (Cook et al. 2015). Hypoxia can also occur when fish have been burst swimming (e.g., fisheries capture) and tissues become oxygen depleted requiring anaerobiosis to fuel basic metabolic needs and swimming until tissues can be re-oxygenated. When burst swimming occurs immediately followed by air exposure, such as in typical C/R events, oxygen recovery is impaired and can lead to dramatic physiological consequences which can lead to post-release mortality. In recreational fisheries, fish are often air exposed to take photographs, remove hooks, measure, and/or identify species. Most fisheries lack explicit recommendations regarding exactly how much air exposure is tolerable, yet it has long been recognized that removing fish from water is not beneficial to their survival (Cook et al. 2015). Pelletier et al. (2007) reviewed best handling guidelines for anglers and found that although most incorporated recommendations regarding air exposure, they were inconsistent and vague. External variables such as environmental conditions, species, or life stage can all factor into air exposure tolerance.

Although there did appear to be a general negative impact of air exposure, air exposure alone did not appear to drive post-release mortality outcomes for Chinook or coho salmon along their marine return-migrations. However, for Chinook tracked into freshwater, high air exposure durations not only increased probability of mortality but seemed to influence post-release behavior where RCH Chinook that were not air-exposed were more likely to be recaptured. Although air exposure alone did not explain post-release mortality outcomes, across all studies we found that injuries associated with air exposure and handling events (e.g., scale loss, fin damage) increased probability of mortality for both Chinook and coho salmon. The impact of air exposure may differ between salmon tracked in the marine environment and those entering freshwater because of the relatively cooler marine water temperature compared to the Chinook entering freshwater which experienced warmer water temperatures. Cooler water can allow a greater aerobic scope compared to fish released in warmer freshwater which may limit the ability to recover physiologically (Eliason et al. 2011). Given air exposure can be inherently harmful to most fish, and probability of injury increases with air exposure because more time is spent handling the fish, we recommend avoiding air exposure completely (or under 10 seconds if possible; e.g.; Cook et al. 2015). Ideally, a captured fish should be kept submerged in water over the side of the boat while identification, measurements, photography, and de-hooking is taking place, and then should be released at the water line.

Injury issues

Physical injury associated with C/R events arises from the fish body contacting hooks, nets, boats, and anglers. Skin damage can be an entry way or site for infections, and along with gill damage can lead to bleeding. Hooking wounds are also a large contributor to bleeding. The loss of scales and mucus reduces the skin's barrier function which can lead to osmoregulatory challenges, which if large could be a proximate cause of mortality for fish (Svendson and Bogwald 1997, Mateus et al., 2017, Olsen et al., 2012). Bass et al. (2018) collected moribund adult sockeye salmon immediately below the tailrace of the Seton Dam Fishway and found that over 50% had physical wounds (variously resulting from escapement from a downstream gill-net fishery, marine sea louse scars, and powerhouse screen encounters). Moreover, wounds and scars occurred in a greater percentage of females than males, possibly because their small bodies made them more able to escape from gill-nets. Compared to those with no wounds, PIT-tagged sockeye salmon with wounds had 62% lower odds of successfully reaching the spawning area 40 km upstream of the release site. Clearly, the association between visible injuries and migration failure indicates that damage to the integument can have significant consequences. Determining the impact of injury for salmon prior to starting their freshwater migration is key to understanding migration success overall.

Our research found that the greater the levels of injury, the more likely a fish's functioning becomes impaired and subsequent survival impacted. For marine-migrating Chinook and coho salmon, we observed that common recreational fisheries injuries (e.g., scale loss, eye injury, bleeding, fin damage, other tissue damage) increased probability of post-release mortality, but the impact varied with species and time. Coho salmon showed impacts of scale loss, eye injury, and bleeding on short-term post-release mortality, and a negative relationship between scale loss and travel rate. For Chinook salmon, there appeared to be a collective impact of all injuries on short-term post-release mortality, but eye injuries increase probability of latent mortality as well. Eye injuries can result in blindness which may impact a fish's ability to evade a predator, forage for food, and navigate, which appears to negatively impact the fish long after the C/R event. Fin damage alone was not a driving factor for post-release mortality in Chinook and coho salmon tracked through the marine environment. However, fin damage severity has been associated with short-term mortality in our companion holding study research (Zinn et al. 2024) and unsuccessful upstream migration (Bass, unpublished). In our findings, the latent effects of fin damage were visible for Chinook salmon tracked into freshwater where fins did not heal in ~50 days. Fin damage has obvious implications for swimming efficiency (and potentially predator avoidance), which could be exacerbated during freshwater migrations as salmon must frequently overcome physical barriers. To reduce the likelihood of eye injury and bleeding, we recommend anglers not use treble hooks, and only use small single barbless hooks.

Netting / landing issues

Landing methods, including net interactions, vary during C/R events depending on the target species, angler experience, the fishery anglers are participating within, and the regulations placed on that fishery (Arlinghaus et al. 2007). The methods used by anglers are largely dependent on the intent of their fishing activity, whether harvest or pure recreation is the goal, as the intended outcome will affect who chooses to participate in these fisheries and how these anglers handle their catch (Brownscombe et al. 2017). Net interactions are well studied in marine commercial fisheries, where we know detrimental effects occur through damage to the dermal layer, scale loss, and mucous removal, which all play a part in immune defense and osmoregulation (Zydlewski et al, 2010, Teffer et al. 2017, Cook et al. 2019; Prystay et al. 2024). Landing nets are commonly used in many recreational fisheries and are believed to limit handling time and allow anglers to reduce air exposure while various forms of handling and hook removal occurs (Brownscombe et al. 2017). However, the use of a landing net (Barthel et al. 2003, Johnston et al. 2023, Zinn et al. 2024) and net type (Lizée et al. 2018, Lunzmann-Cooke et al. 2023) can influence the number of fins damaged and the severity of fin damage that occurs, which as we demonstrated in our holding studies, affects short-term survival (Zinn et al. 2024). Rubber-coated nets were just as likely to cause fin damage in marine captured Chinook salmon, as non-coated nylon meshed nets (Zinn et al. 2024).

Generally, when anglers limit fish handling during C/R interactions, post-release survival is improved due to reductions in the physiological disturbance of the fish (Cooke et al. 2001, Arlinghaus et al. 2007, Cook et al. 2015). Reduced handling also limits the likelihood of detrimental interactions with foreign environments, like the deck of a boat, shoreline, landing nets, and angler's hands, which can all lead to various injuries. Practices that reduce the overall handling like the use of dehooking devices (Cooke et al. 2022, Zinn et al. 2024), or cutting lines of deeply hooked fish (Cooke and Danylchuk 2020), or using barbless hooks (DuBois and Dubielzig 2004, Arlinghaus et al. 2007) will reduce handling times and physical handling, and thus reduce chance of post-release mortality. Reducing physical handling of fish will also reduce the removal of the protective mucous layer which is important for reducing pathogen infection and eventual disease (Svendson and Bogwald 1997, Baker and Schindler 2009; Teffer et al. 2017; Di Cicco et al. 2023). Maturation can reduce some of the physiological effects of physical handling. As salmon physiologically prepare for upstream migrations, and in particular as scales become tighter attached to the body, they are better able to cope with some aspects of physical interactions with fishers or gear (Donaldson et al. 2012, Raby et al. 2013, Bass et al. 2018a). Nevertheless, maturing Pacific salmon are still prone to skin lesions and abrasions caused by release from net fisheries in freshwater (Bass et al. 2018, Kanigan et al. 2019) and these types of injuries can lead to premature mortality (Bass et al. 2018a, 2018b). Immature and younger salmon in marine environments are particularly susceptible to scale loss and injury associated with landing net interactions and handling in recreational fisheries and are generally more likely to suffer handling-related mortality than older more mature salmon (Zinn et al. 2024; Hendriks 2024). We recommend releasing fish at the waterline (i.e., using various tools like pliers or a 'gaff-release' method) and to avoid landing nets whenever possible thereby reducing scale loss and fin damage.

<u>Size-effects</u>

Body-size can play a key role in fisheries interactions as gear types are often selected to target specific fish and specific age classes. Larger bodied individuals are less prone to severe injuries sustained during recreational fishing interactions with hooks, as they are relatively large compared to the hook than their smaller bodied conspecifics (Johnston et al. 2021). Hook type has also been shown to influence injury and survival outcomes, as smaller Chinook salmon captured with treble hooks were more detrimentally impacted by injuries and the resulting increased probability of mortality observed in the holding studies (Zinn et al. 2024). However, longer landing times are often associated with larger fish, meaning a longer recovery time is required to achieve ionic homeostasis (Meka and McCormick 2005). While physiological recovery may take longer for larger individuals, a consistent pattern of increased survival probability relative to body-size has been observed among studies (Bendock and Alexandersdottir 1993, Johnston et al. 2023, Zinn et al. 2024). Body-size can also influence post-capture behaviour as Havn et al. (2015) showed larger individuals were less likely to drop back during upstream migrations after capture. Nevertheless, small fish have an increased likelihood and severity of injuries. Thus, overall, larger bodied salmon have an increased probability of surviving C/R events. Fisheries should therefore modify management practices or gear types in order to limit the number of fishery interactions with smaller bodied fish, similar to what some commercial fisheries have done (Orsi et al. 1993).

Disease issues

When a fish is responding to a stressor (i.e., a C/R encounter), the release of cortisol is associated with an increase in susceptibility to disease and infections (Pickering and Pottinger 1989). In addition, on-board handling may exacerbate exposure to infectious agents (Davis and Schreck 1997). Acute injuries to the dermal layer or the removal of mucous may create additional opportunities for pathogens to enter the body (Svendson and Bogwald 1997). We detected 25 potential infectious agents in marine-migrating Chinook and coho salmon, several of which have been associated with disease and mortality in Pacific salmon (Miller et al. 2014, Bass et al. 2022, Bateman et al. 2022). The prevalence and impact of infectious agents is relatively unknown for marine-migrating Pacific salmon adults, and this research is essential to disentangle the causes of post-release mortality. Infection rates of Chinook captured in the Discovery Islands was 59% (n = 106 / 179) with an average of 1.1 pathogens per individual, with 4 pathogens being the greatest number observed within a single individual. Of the 200 coho salmon 97% had at least one pathogen present with an average of 2.3 pathogens per fish, and a maximum of 6 pathogens on a single fish The most prevalent pathogen observed in Chinook salmon was *Tenacibaculum maritimum* a bacteria known to cause tenacibaculosis, a diseased state associated with ‘mouth-rot’ in farmed Atlantic salmon which can cause upwards of 40% mortality during infection outbreaks at farms and has been recently identified in wild caught Chinook salmon for the first time (Di Cicco et al. 2023). No pathogen infections appear to be related to survival outcomes, nor the imminent mortality or viral disease development classified data. Given a small sample of fish expressed positive signs of a viral diseased state we may have failed to select the correct suite of pathogens that were affecting these individuals. However, given the variation in survival probabilities among the groups of positive and negative 'imminent mortality' classified individuals, we see evidence to suggest that not all observed mortality is directly related to the fisheries interaction. Rather, a portion of this observed mortality is expected due to a naturally occurring declining physiological state, nevertheless, analyses are on-going.

Temperature issues

Water temperature plays a large role in regulating physiological processes for fish (Brett 1971). Increased temperatures lead to elevated metabolic demands (Brett 1995), which results in less scope for immune function, growth, and reproduction, unless food consumption also increases accordingly (Fry 1971; Brett 1971). Pacific salmon generally prefer colder water when compared to other freshwater fish, and this is especially important in the riverine environment where young salmon hatch and maturing salmon migrate upstream to spawn. There are multiple lines of evidence that show that elevated water temperatures may exacerbate other negative effects, especially those associated with fisheries interactions (Gale et al. 2013). When water temperature is high enough for metabolic performance to reach the limit within the scope for activity, anaerobic metabolism is required for burst swimming to escape danger or migrate through obstacles to spawning grounds (Burnett et al. 2014). Burst swimming can only occur for brief periods of time before tissue oxygen debt must be repaid which means that predator avoidance or barrier surmounting may only briefly be able to take place. Further, if water temperatures remain high following strenuous exercise, and cool water refugia cannot be found where tissue oxygen debt can be repaid, mortality can be rapid. High temperatures have been shown to reduce the ability of salmonids to recover from exercise (Farrell et al. 2008) and lower the likelihood of survival following a stressor such as an angling event (Gingerich et al. 2007; Gale et al. 2013). Frequent levels of burst swimming have been shown in physiological telemetry studies to cause migration mortality (Hinch and Bratty 2000). The combination of warm water temperatures, fisheries encounters, and infectious agents have potential in combination to have serious impacts on C/R outcomes and fitness of Pacific salmon. In addition to these stressors affecting Pacific salmon individually, they may have synergistic, rather than simply additive effects. Given that warming temperatures are predicted to change host-pathogen relationships in the future (Miller et al. 2014), it is increasingly important to evaluate these stressors collectively (Breitburg et al. 1998; Crain et al. 2008).

In marine environments, salmon can seek thermal refugia by swimming deeper and experiencing cooler conditions. Cooler water temperatures allow salmon to recover from stressors like air exposure as well as decrease their recovery time from a fishery interaction (Gale et al. 2011, Nguyen et al. 2014, Cook et al. 2015). However, as migrations progress into shallower coastal waters and eventually into riverine environments these thermal refugia become less common and relatively warmer (Elmer et al. 2023). While these refugia provide a benefit, especially to marine C/R salmon, water temperature at time of capture has been related to decreased survival probability, even when time of thermal exposure remains limited (Zinn et al. 2024, Van Leeuwen et al. 2024). Longer landing and handling times in warm waters are associated with increased plasma cortisol and lactate, and thus increases physiological recovery time (Meka and McCormick, 2005), and decreases survival probability. Further, salmon must alter their behaviour post-release to seek these thermal refugia which may impart a competitive disadvantage and limit their feeding or delay their migration (Elmer et al. 2023). Given the synergistic effects of thermal stress and all other fishery related stressors, avoiding C/R during times of high-water temperatures should be a key recommendation for all anglers participating in both marine and especially freshwater fisheries.

Sex-effects issues

It is becoming increasingly clear that differences in physiology can result in much higher levels of female post-release mortality in freshwater fisheries (e.g., Teffer et al. 2017). There are several potential explanations for this phenomenon. Females appear to respond more strongly to stress than males (reviewed in Hinch et al. 2021). With their elevated baseline cortisol levels, females may have an impaired response to additional stressors such that they cannot effectively mobilize additional energy stores or clear waste products. A prolonged post-capture cortisol recovery period could contribute to immunosuppression and increased susceptibility to infectious disease (Pickering and Pottinger 1989) which could lead to post-release mortality.

Another potential explanation is reduced cardiac performance. Mature female salmon have a routine heart rate that is 21% higher than in males (Sandblom et al., 2009), which will lead to a reduced scope to increase heart rate during strenuous activity and therefore decrease ability to mobilize cardiac capacity. Females also divert more blood to develop their relatively larger gonads than males during maturation. Since the fish heart does not have the capacity to fully perfuse all organs at the same time (Farrell 2016; Farrell and Jones 2023), it may not be possible to partition blood flow according to the needs of all organs. A prioritization of blood flow to gonads rather than swimming muscles could force females to disproportionately utilize burst swimming, with negative latent effects. If females exert a greater anaerobic effort, they could incur a greater tissue oxygen debt and take longer to fully recover. Delayed recovery of C/R fish could thus result in an inability of females to avoid predators.

Sexes did not seem to differ in their post-release survival patterns in Chinook salmon or coho salmon when tracked through marine waters. The exception was when C/R Chinook salmon were tracked into freshwater areas (e.g., Robertson Creek Hatchery) wherein we observed no females, only males, reaching spawning areas. These fish must transit through several fisheries, anoxic and warm freshwater routes, and traverse a fishway – all of these factors are known to elevate female mortality relative to males (Hinch et al. 2021). This issue highlights the cumulative and/or synergistic effects that need to be considered when managing for escapement targets in C/R fisheries.

<u>Release issues and facilitated (assisted) recovery</u>

Facilitated recovery is an approach commonly practiced in recreational fisheries, especially where C/R is a likely outcome, in order to 'recover' captured fish that are physiologically impaired exhibiting disequilibrium (Robinson et al. 2013). Recovery methods have had some success in commercial fisheries which often involve on board troughs (e.g., Fraser Box) which utilize high speed water to 'ram ventilate' exhausted fish (Buchanan et al. 2002; Farrell et al. 2001). In recreational fisheries, flow through, soft mesh recovery bags are sometimes used to place fish into, with anglers orienting bags or fish held by hand, into an upstream flow position, or often fish are moved in a 'back-and-forth rocking' technique by hand in an attempt to increase water flow over the gills (Brownscombe et all 2013, Donaldson et al. 2011, Donaldson et al. 2013, Robinson et al. 2015).

Past research has demonstrated that these commonly used practices within recreational fisheries provide limited to no benefit promoting fish survival post-release and can in some cases reduce post-release survival (Donaldson et al. 2013, Robinson et al. 2013, 2015). These approaches will only enhance post-release survival if the main physiological issue associated with capture/handing event is anoxia and disequilibrium brought on by excessive anaerobiosis and in particular associated with warm water capture and prolonged air exposure. Most recreationally captured fish get injured which cannot be helped by facilitated recovery approaches and few angled fish exhibit high levels of disequilibrium particularly in cool marine waters. The confinement of bags or the physical constraint of holding fish during any recovery attempt increases the fish stress response (Robinson et al. 2013) and could further injure the fish by removing scales and mucous, damaging fins, and increasing air exposure. Given the limited evidence for increases in survival with device-based, or hand-facilitated, recovery approaches in Pacific salmon recreational marine fisheries (Donaldson et al. 2013), and the ability for released salmon to immediately reach cool water at depth, the likely result of any recovery attempt would be to increase the stress response, prolong exposure to warmer water, and have a detrimental effect on survival. Anglers should consider the relative level of exhaustion of the captured fish in so far that captured fish whose swimming ability is impaired, has reduced equilibrium (e.g., floats upside down on the water surface) and is not ventilating well should be provided with some protection from predators prior to release by using a bag or holding at the water line (Lawrence et al. 2023). However, fish should be released as soon as equilibrium is re-established (Donaldson et al. 2013, Robinson et al. 2015). In most situations, the loss of equilibrium associated with C/R is caused by asphyxiation or anoxia which is not typically encountered if fish are captured in cool water, and are not exposed to air.

Importance of, and potential compliance with, best C/R practices

Our app study results revealed that anglers generally reflected the fishing behaviours and capture outcomes we found as part of our studies. This reinforces the strength and realism of our field experimental approaches as we were indeed reflecting the behaviours of typical anglers. Our surveys and interviews of anglers revealed they felt that air exposure and bleeding were the top factors influencing survival of a released fish, and that gear type, hook size and hooking location were important factors affecting bleeding and injury, and subsequent post-release survival. To a degree, angler opinions were supported by our results particularly in terms of the importance of injury and hook size. However, it may be surprising to anglers that ‘fish friendly’ landing nets can be large contributors to post-release mortality. As anglers had recognized, factors that increase scale loss, damage fins, eye injuries and cause bleeding, like we found with nets, time on boat (which correlates with air exposure), are the mechanisms underlying the largest amounts of post-release mortality.

However, one pattern that clearly differed between the public responses from the app study and our observations conducting field tagging and release was that many members of the public stated that their fight times were much longer than our experiences. This could simply reflect the inability of the public to accurately gauge time when fighting a fish (we meticulously recorded it), or, it could reflect behaviours of some anglers spending far too long playing a fish before landing. If this latter notion is true, it means that fish captured by some fishers will express much more negative survival outcomes than we observed, highlighting the importance of developing scientifically-based best C/R practices.

In conclusion, interviewed anglers ranged in their opinions of their support for C/R as a conservation tool and many were not sure if released fish survived or not, but anglers were generally open to new information on best practices to improve the survival of C/R fish. In fact, many already implement the best practices we recommend below. All anglers were supportive of creating more educational resources for anglers with our study results. Therefore, it will be critically important to publicize our best practice recommendations (below) widely and across numerous types of media (e.g., DFO fisheries management web sites, ENGO web sites e.g., Pacific Salmon Foundation, SFI, environmental/fisheries blogs and informational videos, and press releases to the general media). Lastly, we urge DFO to convert these recommendations into regulations to further ensure the sustainability of fishes and fisheries.

Best Practices Recommendations for Releasing Marine Recreationally Captured Chinook or Coho

Gear Choice Recommendations

Use smaller hook sizes – larger hooks are related to more severe injuries and larger gap widths increase probability of eye injury and decrease survival probability (Johnston et al. 2021). Gap width of 15 mm (e.g., 3/0 'Octopus' hook) or smaller is recommended.

Avoid treble hooks – although treble hooks were less likely to cause eye injuries, their use increased hook wound severity and decreased survival probability (Zinn et al. 2024; Clarke et al. 2021). This was especially pronounced in smaller fish that are non-retainable in the fishery (e.g., Chinook salmon <62 cm).

Avoid tandem hook point setups – (e.g., when using bait or artificial lures) – multi-hook setups are prone to multiple hooking locations on the fish's body which increases the likelihood of a lethal hooking location.

Avoid flashers – In-line flashers cause higher metabolic rates during landing and prolong the metabolic recovery of the 'fight' after release which means fish are less likely able to swim rapidly post-release and would be at higher predation risk; this phenomenon is greater for female salmon relative to males (Van Wert et al. 2024).

Landing Recommendations

Land fish as quickly as possible – prolonged anaerobic exercise (aka burst swimming) increases the metabolic oxygen debt which if it gets too large, can lead to cardiac arrest. This is particularly a problem if flashers are used when water temperatures are warm and fish are exposed to air prior to release. Decreasing fight time reduces the time needed for fish to re-oxygenate their organs (Birnie-Gauvin et al. 2023).

Avoid air exposure – air exposure increases anaerobic metabolic costs and thus increases recovery time and the probability of mortality (Raby et al. 2012). If it's not possible to avoid air exposure, limit this to less than 10 seconds (Cook et al. 2015).

Avoid using landing nets – the use of landing nets including 'fish-friendly' ones made of rubber-coated or nylon are associated with fin splitting and scale loss (Johnston et al. 2023; Lunzmann-Cooke et al. 2022; Zinn et al. 2022; Barthel et al. 2003). If a net must be used so that fish can be measured, ensure fish remain in the water, and the net remains loose to help avoid contact with fins, dermal tissue, and the mucous layer.

Handling Recommendations

Limit touching of fish – reduce physical handling as much as possible, do not use gloves to handle fish.

Handle with wet hands – when required to handle fish, only do so with bare wet hands. Only touch areas like the caudal peduncle and under the pectoral fins where the fish can be evenly supported, and never hold fish vertically by the tail or touch the gills.

Release Recommendations

Release fish at the water line – bringing the fish aboard with a net and handling the fish with hands will cause injuries and can lead to delayed mortality. Use a gaff, or other purpose-built tools, to release fish at the water line.

Release immediately – release the fish immediately rather than trying to 'revive' them next to the boat. Revival techniques increase stress and can cause more harm than good (Robinson et al. 2013). Attempts at reviving when surface waters are warm will further stress fish and can cause post-release mortality (Robinson et al. 2015). Only delay the release of fish if they appear moribund or have lost full equilibrium. Use a submerged recovery bag to protect the fish from predators while it recovers which should only take a few minutes.

Fishing recommendations

Avoid small fish – move fishing locations or increase size of lures to limit interactions with smaller (e.g., sub-legal) fish as these individuals are more susceptible to injuries and mortality associated with catch and release interactions.

Avoid fishing locations if predators are present – marine mammal predators may remove fish from your lines, injure fish during the fight, or capture fish post-release before they have had time to recover from the fight.

Avoid catch-and-release when surfaces waters are at or above 18°C – these temperatures are known to increase mortality post-release (Teffer et al. 2019). Fish may appear healthy when released, however the added thermal stress interacts with all other capture and handling factors leading to a much higher probability of mortality.

Lessen your interactions – if you catch a fish that is legal to keep, do so, and do not continue fishing for salmon once you have your legal limit thereby reducing the number of fish that must be released.

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Van Wert J.C., Hendriks B., Johnston S., Zinn K., Hinch S.G, and Eliason EJ. 2024. Metabolic recovery of marine Chinook salmon from catch-and-release fishing. International Congress on the Biology of Fish. Ann Arbor, Michigan. June 2024.

Zinn, K.R., S.D. Johnston, and Hinch, S.G. 2024. Influence of gear type and landing methods on short-term survival of Chinook salmon released in the marine recreational fishery: updating previous research and developing best practices. Summary report 2020-261. British Columbia Salmon Restoration and Innovation Fund.

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Publications based on project results (n = 3)

Freshwater, C., S.C. Anderson, D.D. Huff, J. Smith, D. Jackson, B. Hendriks, S.G. Hinch, S.D. Johnston and J. King. Individual depth distributions of ocean dwelling Chinook salmon on the continental shelf are shaped by interactions between location, season, and ecological conditions. 2024. Movement Ecology. 12, 21. https://doi.org/10.1186/s40462-024-00464-y

Lunzmann-Cooke, E.L. S.G. Hinch, A.L. Bass, S.D. Johnston, B.J. Hendriks, A.D. Porter, S.J. Cooke, and D.W. Welch. 2024. Recreational fisheries-related injuries and body size affect travel rate and post-release mortality in marine migrating coho salmon (*Oncorhynchus kisutch*). Fisheries Research, 276: 107062.

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Informational videos for public consumption (n = 4)

2021 - Fishing with Rod – UBC Symposium Presentation
https://www.youtube.com/watch?v=8nThmHxQkaE

2022 - Reel West Coast – Bamfield and Barkley Sound studies
https://www.youtube.com/watch?v=GBpPFeu1Rl8&t=36s

2023 - Reel West Coast - Bamfield and Barkley Sound studies
https://www.youtube.com/watch?v=V_-nGLWNPQw&t=44s

2023 - Fishing with Rod - Bamfield and Barkley Sound studies
https://www.youtube.com/watch?v=TRds3uMLAns&t=70s

In preparation thesis chapters and future publications (n = 12)

Johnston, S.D., B.J.L. Hendriks, E.L. Lunzmann-Cooke, K.R., Zinn, S.G. Hinch, A.D. Porter, E.L. Rechisky, and D.W. Welch. Gear type and related injuries influence post-release survival probability of marine captured and released Chinook salmon. In prep.

Johnston, S.D., B.J.L. Hendriks, E.L. Lunzmann-Cooke, K.R., Zinn, S.G. Hinch, A.D. Porter, E.L. Rechisky, and D.W. Welch. Risk of fishery exposure varies among populations with variable marine residence and migration patterns. In prep.

Johnston, S.D., E.L. Lunzmann-Cooke, K.R., Zinn, A.L. Bass, S.G. Hinch, B.J.L. Hendriks, A.D. Porter, E.L. Rechisky, and D.W. Welch. Post-release survival of Chinook salmon related to the condition at time of capture assessed through genomic analyses. In prep.

Johnston, S.D., S.G. Hinch, B.J.L. Hendriks, B.P.V. Hunt, and S.J. Cooke. Smartphone app survey results compared with observed recreational salmon fishery handling and gear selection in marine recreational salmon fisheries in British Columbia. In prep.

Johnston, S.D., E.L. Lunzmann-Cooke, K.R., Zinn, A.L. Bass, C.F. Freshwater, S.G. Hinch, and B.J.L. Hendriks. Infectious agents observed in wild caught adult Chinook and coho salmon among three geographically distinct regions. In prep.

Lunzmann-Cooke, E.L., S.G. Hinch, A.L. Bass, S.D. Johnston, K.R. Zinn, A.D. Porter, S.J. Cooke, and D.W. Welch. The influence of net type and hook size on recreational fisheries-related injuries of adult coho salmon (*Oncorhynchus kisutch*). In prep.

Lunzmann-Cooke, E.L., A.L. Bass, S.G. Hinch, S.D. Johnston, K.R. Zinn. Infectious agents and physiological condition of marine migrating adult coho salmon. In prep.

Lunzmann-Cooke, E.L., B.J. Hendriks, S.G. Hinch, A.D. Porter, S.J. Cooke, and D.W. Welch. Behaviour and movement of return migrating adult coho salmon (*Oncorhynchus kisutch*) in the marine environment using acoustic telemetry. In prep.

Lunzmann-Cooke, E.L., S.G. Hinch, N. Young, S.J. Cooke, and A. Reid. Angler opinions on conservation measures in Canadian recreational Pacific salmon fisheries. In prep.

Zinn, K.R., S.D. Johnston, A.L. Bass, B.J.L. Hendriks, E.L. Lunzmann-Cooke, and Hinch, S.G. Investigating how multiple stressors from marine recreational catch-and-release, warm water temperatures, and infectious agents impact the spawning migrations of Chinook salmon. In prep.

Zinn, K.R., S.D. Johnston, A.L. Bass, B.J.L. Hendriks, E.L. Lunzmann-Cooke, and Hinch, S.G. Short-term thermal selection and impacts of temperature on the migratory patterns of Chinook salmon released in the recreational fishery from the marine environment to freshwater spawning grounds. In prep.

Zinn, K.R., S.D. Johnston, A.L. Bass, B.J.L. Hendriks, E.L. Lunzmann-Cooke, and Hinch, S.G. Assessing the injury progression and physiological state of individual Chinook salmon caught in the marine recreational fishery from release to spawning grounds: carryover effects. In prep.

Conference presentations based on project results (n = 26)

Hendriks, B.J., S.D. Johnston, J. Watson, A.W. Trites, B.P.V. Hunt, D.W. Welch, E. L. Rechisky, A.D. Porter, S.G. Hinch. 2022. Behaviours and movement patterns of return migrating adult Chinook salmon throughout the Salish Sea. Synthesis of the International Year of the Salmon and Roadmap to 2030; Salmon a Rapidly Changing World. Vancouver, BC. October 5, 2022.

Hendriks, B.J., S.D. Johnston, J. Watson, A.W. Trites, B.P.V. Hunt, D.W. Welch, E. L. Rechisky, A.D. Porter, S.G. Hinch. 2022. Depth and rates of movements of marine captured and released adult Chinook salmon. Canadian Conference of Fish and Fisheries Research. Vancouver, BC. February 25, 2022.

Hinch, S.G., S.J. Cooke, D.A. Patterson. 2022. Survival and Fitness of Pacific Salmon Released from Fisheries Capture: a Growing Concern as Stocks Decline and Climate Changes. International Year of the Salmon Symposium, Vancouver, BC, Oct. 4, 2022.

Hinch, S.G., S. Johnston and B. Hendriks. 2019. Overview of marine adult salmon science conducted in 2019 by UBC. Sport Fishing Policy Conference, Vancouver, BC. Nov 15, 2019.

Hinch, S.G., S.J. Cooke, D.A. Patterson. 2019. Survival and Fitness of Pacific Salmon Released or Escaped from Fisheries Capture: a Growing Concern as Stocks Decline and Climate Changes. Annual General Meeting of the American Fisheries Society. Reno, Nevada. Sept. 30, 2019.

Johnston, S.D., B.J.L. Hendriks, E.L. Lunzmann-Cooke, K.R., Zinn, S.G. Hinch, A.D. Porter, E.L. Rechisky, and D.W. Welch. 2024. Infectious agent and genetic biomarker expression among recreationally caught and released Chinook salmon. 18th Annual Symposium on Salmon Migrations, Ecology and Management. University of British Columbia, Vancouver, BC. February 1st, 2024.

Johnston, S.D., B.J.L. Hendriks, E.L. Lunzmann-Cooke, K.R., Zinn, S.G. Hinch, A.D. Porter, E.L. Rechisky, and D.W. Welch. 2023. Multi-year survival patterns of Chinook salmon released form recreational fisheries capture. 17th Annual Symposium on Salmon Migrations, Ecology and Management. University of British Columbia, Vancouver, BC. February 2nd, 2023.

Johnston, S.D., B.J.L. Hendriks, E.L. Lunzmann-Cooke, K.R., Zinn, S.G. Hinch, A.D. Porter, E.L. Rechisky, and D.W. Welch. 2022. Reel Impacts: Post-release mortality of capture and released Chinook salmon in marine recreational fisheries. Salmon in a Rapidly Changing World; Synthesis of the International Year of the Salmon and a Roadmap to 2030. Vancouver, British Columbia, October 5, 2022.

Johnston, S.D., B.J.L. Hendriks, E.L. Lunzmann-Cooke, K.R., Zinn, S.G. Hinch, A.D. Porter, E.L. Rechisky, and D.W. Welch. 2022. Angler reported capture and handling data collected from smartphone application surveys and how that relates to telemetry assessed survival results. 16th Annual Symposium on Salmon Migrations, Ecology and Management. University of British Columbia, Vancouver, BC. February 3, 2022.

Johnston, S.D., B.J.L. Hendriks, E.L. Lunzmann-Cooke, K.R., Zinn, S.G. Hinch, A.D. Porter, E.L. Rechisky, and D.W. Welch. 2022. Reel Impacts: Post-release mortality of capture and released Chinook salmon in marine recreational fisheries. The Canadian Conference for Fisheries Research. Vancouver, British Columbia, February 25-26, 2022

Johnston, S.D., B.J.L. Hendriks, E.L. Lunzmann-Cooke, K.R., Zinn, S.G. Hinch, A.D. Porter, E.L. Rechisky, and D.W. Welch. 2021. Reel Survival: Using acoustic telemetry to investigate recreational fisheries post-release survival of Chinook and coho salmon. 15th Annual Symposium on Salmon Migrations, Ecology and Management. University of British Columbia, Vancouver, BC. February 4, 2021.

Johnston, S.D., B.J.L. Hendriks, S.G. Hinch, D.W. Welch, E.L. Rechisky, and A.D. Porter. Effects of recreational catch and release on migrations of marine Chinook salmon. 2020. 14th annual Symposium on Salmon migrations, ecology and management. University of British Columbia, Vancouver, BC. February 6th, 2020.

Lunzmann-Cooke, E.L., B.J. Hendriks, S.D. Johnston, A.D. Porter, D.W. Welch, E.L. Rechisky, and S.G. Hinch 2023. Investigating post-release mortality of coho salmon in a Canadian marine recreational fishery. International Conf. on Fish Telemetry. Sete, France. June 11-16, 2023.

Lunzmann-Cooke, E.L., B.J. Hendriks, S.D. Johnston, A.D. Porter, D.W. Welch, E.L. Rechisky, and S.G. Hinch 2023. Investigating post-release mortality of coho salmon in a marine recreational fishery. Pacific Ecology and Evolution Conference. Vancouver, BC. April 1-2, 2023.

Lunzmann-Cooke, E.L., B.J. Hendriks, S.D. Johnston, A.D. Porter, D.W. Welch, E.L. Rechisky, and S.G. Hinch 2023. Investigating post-release mortality of coho salmon in a marine recreational fishery. American Fisheries Society Washington-British Columbia Chapter Conference. Bellingham, WA. March 20-23, 2023.

Lunzmann-Cooke, E.L., B.J. Hendriks, S.D. Johnston, A.D. Porter, D.W. Welch, E.L. Rechisky, and S.G. Hinch Investigating post-release mortality of coho salmon in a marine recreational fishery. 17th Annual Symposium on Salmon Migrations, Ecology and Management. University of British Columbia, Vancouver, BC. February 2nd, 2023.

Lunzmann-Cooke, E.L., B.J. Hendriks, S.D. Johnston, A.D. Porter, D.W. Welch, E.L. Rechisky, and S.G. Hinch 2022. Investigating post-release mortality of coho salmon in a marine recreational fishery. International Year of the Salmon Symposium. Vancouver, BC. October 5, 2022.

Lunzmann-Cooke, E.L., B.J. Hendriks, S.D. Johnston, A.D. Porter, D.W. Welch, E.L. Rechisky, and S.G. Hinch 2022. Investigating post-release mortality of coho salmon in a marine recreational fishery. 16th Annual Symposium on Salmon Migrations, Ecology and Management. University of British Columbia, Vancouver, BC. February 3, 2022.

Lunzmann-Cooke, E.L., B.J. Hendriks, S.D. Johnston, A.D. Porter, D.W. Welch, E.L. Rechisky, and S.G. Hinch 2022. Investigating post-release mortality of coho salmon in a marine recreational fishery. Canadian Conference for Fisheries Research. Vancouver, BC. February 25-26, 2022.

Lunzmann-Cooke, E.L., B.J. Hendriks, S.D. Johnston, A.D. Porter, D.W. Welch, E.L. Rechisky, and S.G. Hinch Investigating post-release mortality of coho salmon in a marine recreational fishery. 9th annual Ocean Tracking Network Symposium. Ocean Tracking Network. Online. November 15-16, 2021.

Lunzmann-Cooke, E.L., B.J. Hendriks, S.D. Johnston, A.D. Porter, D.W. Welch, E.L. Rechisky, and S.G. Hinch 2021. Investigating post-release mortality of coho salmon in a marine recreational fishery. 15th Annual Symposium on Salmon Migrations, Ecology and Management. University of British Columbia, Vancouver, BC. February 4, 2021.

Van Wert, J.C., B.J. Hendriks, S. Johnston, K. Zinn, S.G. Hinch, and E.J. Eliason. 2024. Metabolic recovery of marine Chinook salmon from catch-and-release fishing. International Congress on the Biology of Fish. Ann Arbor, Michigan. June 2024.

Zinn, K.R., S.D. Johnston, A.L. Bass, B.J.L. Hendriks., E.L. Lunzmann-Cooke and Hinch, S.G. 2023. Effects of angling approaches and riverine water temperature on survival to spawning grounds of marine captured and released Chinook salmon. World Recreational Fishing Conference, Melbourne, Australia.

Zinn, K.R., S.D. Johnston, A.L. Bass, B.J.L. Hendriks, E.L. Lunzmann-Cooke, and Hinch, S.G. 2022. Cumulative effects of angling approaches and riverine water temperature on survival to spawning grounds of marine captured-and-released Chinook salmon. The Canadian Conference for Fisheries Research. Vancouver, British Columbia, February 25-26, 2022.

Zinn, K.R., S.D. Johnston, A.L. Bass, B.J.L. Hendriks, E.L. Lunzmann-Cooke, and Hinch, S.G. 2022. Effects of angling approaches and riverine water temperature on Chinook salmon survival to spawning grounds. 16th Annual Symposium on Salmon Migrations, Ecology and Management. University of British Columbia, Vancouver, BC. February 3, 2022.

Community and management group presentations based on project results (n = 15)

Hinch, S.G. 2021. Survival of Pacific salmon released from fisheries capture. British Columbia Wildlife Federation Annual Meeting Keynote Presentation, On-line, Vancouver BC. May 27, 2021

Johnston, S.D., B.J.L. Hendriks, E.L. Lunzmann-Cooke, K.R., Zinn, S.G. Hinch, A.D. Porter, E.L. Rechisky, and D.W. Welch. 2024. Post-release survival observed in recreationally caught and released Chinook salmon. IMAT Working Group Post Season Salmon Review. Nanaimo, BC. March 19, 2024

Johnston, S.D., B.J.L. Hendriks, E.L. Lunzmann-Cooke, K.R., Zinn, S.G. Hinch, A.D. Porter, E.L. Rechisky, and D.W. Welch. 2023. Capture and handling effects of recreational catch-and-release practices on Chinook salmon and the relationship to pathogen expression. Avid Angler Annual General Meeting. Nanaimo, BC. June 5, 2023

Johnston, S.D., B.J.L. Hendriks, E.L. Lunzmann-Cooke, K.R., Zinn, S.G. Hinch, A.D. Porter, E.L. Rechisky, and D.W. Welch. 2023. Importance of proper handling and gear selection for catch-and-release in recreational fisheries. Port Boathouse Annual Company Meeting. May 27, 2023

Johnston, S.D., B.J.L. Hendriks, E.L. Lunzmann-Cooke, K.R., Zinn, S.G. Hinch, A.D. Porter, E.L. Rechisky, and D.W. Welch. 2022. IMAT Working Group Post-Season Salmon Review: Marine Recreational Chinook and coho Fisheries Incidental Mortality. Island Marine Aquatic Working Group Post-Season Salmon Review. Virtual Meeting. February 9, 2022

Johnston, S.D., B.J.L. Hendriks, E.L. Lunzmann-Cooke, K.R., Zinn, S.G. Hinch, A.D. Porter, E.L. Rechisky, and D.W. Welch. 2021. Reel Survival: Using acoustic telemetry to investigate recreational fisheries post-release survival of Chinook and coho salmon. Campbell River Fishing Guide's Association – Virtual Presentation. November 9, 2021

Johnston, S.D., B.J.L. Hendriks, E.L. Lunzmann-Cooke, K.R., Zinn, S.G. Hinch, A.D. Porter, E.L. Rechisky, and D.W. Welch. 2021. Reel Survival: Using acoustic telemetry to investigate recreational fisheries post-release survival of Chinook salmon. Gillard Pass Fisheries Society Meeting. Stuart Island, British Columbia, June 18, 2021.

Johnston, S.D., B.J.L. Hendriks, E.L. Lunzmann-Cooke, K.R., Zinn, S.G. Hinch, A.D. Porter, E.L. Rechisky, and D.W. Welch. 2021. Reel Survival: Using acoustic telemetry to investigate recreational fisheries post-release survival of Chinook and coho salmon. Vancouver International Boat Show – Virtual Presentation. April 4, 2021.

Lunzmann-Cooke, E.L., B.J. Hendriks, S.D. Johnston, A.D. Porter, D.W. Welch, E.L. Rechisky, and S.G. Hinch 2024. Investigating post-release mortality of coho salmon in a marine recreational fishery. IMAT Working Group Post Season Salmon Review. Nanaimo, BC. March 19, 2024

Lunzmann-Cooke, E.L., B.J. Hendriks, S.D. Johnston, A.D. Porter, D.W. Welch, E.L. Rechisky, and S.G. Hinch 2024. Investigating post-release mortality of coho salmon in a marine recreational fishery. Island Marine Aquatic Working Group Post-Season Salmon Review. Virtual Meeting. February 9, 2022

Zinn, K.R. and Hinch, S.G. 2023. Impacts of catch-and-release fishing on Chinook salmon in Barkley Sound: short-term holding and long-term tagging studies. WCVI Pacific Salmon Barkley Sound Roundtable Technical Meeting. Parksville, British Columbia

Zinn, K.R., Johnston, S.D., Bass, A.L., Hendriks, B.J.L., and Hinch, S.G. 2022. Effects of angling approaches and riverine water temperature on Chinook salmon survival to spawning grounds. Island Marine Aquatic Working Group Post-Season Salmon Review. Virtual Meeting. February 9, 2022

Zinn, K.R., S.D. Johnston, and Hinch, S.G. 2022. Angling approaches and riverine water temperature: Chinook salmon survival to spawning grounds. WCVI Pacific Salmon Barkley Sound Roundtable Technical Meeting. Port Alberni, British Columbia

Zinn, K.R., S.D. Johnston, and Hinch, S.G. 2021. Investigating the cumulative effects of recreational catch-and release and climate change on Chinook salmon in Barkley Sound. WCVI Pacific Salmon Barkley Sound Roundtable Technical Meeting. Port Alberni, British Columbia.

Zinn, K.R. S.D. Johnston, and Hinch, S.G. 2021.The effects of recreational catch and release on Chinook salmon: Barkley Sound. Port Alberni Sport Fishing Advisory Committee. Port Alberni, British Columbia.

Appendix: Powerpoint presentations of in-progress thesis chapters and manuscripts

The following section are powerpoint presentations made by report co-authors Stephen Johnston, Emma Lunzmann-Cooke and Katie Zinn made at the Annual Symposium on Salmon Migrations, Ecology and Management which is held each year at the University of British Columbia. These presentations reflect the thesis chapters and manuscripts that are in progress.