BOTTLENECKS TO SURVIVAL

TAGGING-RELATED MORTALITIES & REJECTIONS FOR HATCHERY REARED CHINOOK & COHO SALMON

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EXECUTIVE SUMMARY

The *Bottlenecks to Marine Survival Program* (hereafter the *Bottlenecks Program*) aimed to understand tagging-related mortality and tag rejection rates for Chinook and coho salmon across multiple hatcheries, providing insights to inform field tagging activities and improve salmon survival. The study found mean overall tagging mortality rates of 1.74% for Chinook and 0.62% for coho, within the accepted 0-5% limits determined by Volsett et al. (2020). Kaplan-Meier survival curves indicated significant variation in survival rates among hatcheries, with most Chinook tagging events showing over 99.0% survival. Coho salmon also exhibited high survival rates, with 100% tagging-related survival at two hatcheries in 2023.

Individual taggers significantly impacted mortality rates, with high mortality rates associated with, new taggers, underscoring the need for consistent training and monitoring. Temporal trends showed that the first two days post-tagging were critical, with 50% of both mortalities and rejections occurring by day 3, and 95% by day 10. This highlights the importance of early post-tagging handling and protocol improvements to reduce adverse impacts.

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

In summary, the *Bottlenecks Program's* findings emphasize the importance of early post-tagging handling, consistent tagger training, and improved tagging protocols to enhance salmon survival rates. These survival rates will be utilized to inform tagging-related survival estimates for the field tagging activities in the *Bottlenecks Program*. Moreover, continued data collection and analysis will further optimize tagging practices and contribute to a better understanding of tagging impacts on salmon survival.

Citation:

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INTRODUCTION

The application of tags in salmonid research provides valuable information on fish movements, survival rates, behaviour, and population dynamics (Drenner et al. 2012). However, when designing a tagging program, it is important to consider the type of tag required, size of the tag, tag retention, and impact of tagging on fish behaviour and survival.

Coded wire tags (CWT) have historically been a fundamental tool in Pacific salmon stock assessment, offering cohort or stock-level insights. While CWTs originated in the 1960s and significantly advanced knowledge about Pacific salmon, they present limitations when compared to modern tag technologies (Drenner et al. 2012; Beacham et al. 2019). Passive Integrated Transponder (PIT) tags have become prevalent in salmonid research over the past three decades and provide information down to the individual level that CWTs do not (Prentice et al. 1990b; Hale & Gray, 1998). Using PIT tags in research has several advantages over other electronic tags. PIT tags are cost-effective compared to acoustic and satellite tags (Zentner et al., 2021).

Additionally, PIT tags have an infinite life span as they do not require batteries, making them ideal for long-term studies (Larsen et al. 2013; Allan et al., 2018). The small size of PIT tags enables researchers to tag juvenile salmon during critical life stages, such as outmigration to the ocean, without causing significant interference (Tiffan et al. 2015) . The ability of PIT tags to be detected in rivers and even after being consumed by predators allows for data collection across various locations and after predation or harvest events (Buchanan and Skalski 2007; Babey et al. 2020; Sherker et al. 2021). Passive detections of PIT tags facilitate the development of mark-recapture models, providing valuable survival information for salmonid research, including freshwater outmigration timing and smolt-to-adult return rates (Skalski 2007; Knudsen et al., 2009).

When implementing a PIT tag program, tag retention, fish length, and anatomical placement are important considerations (Dieterman & Hoxmeier, 2009). Research has also shown that accurately determining tag location is critical to reduce negative impacts on the fish (Hale & Gray, 1998). Additionally, investigations on the effects of PIT tags on salmonids have emphasized the need to understand the impacts on survival, growth, and behaviour, especially when extrapolating results to untagged populations (Knudsen et al., 2009).

The effects of tagging on a fish's health and survival are primary concerns for researchers and managers alike, and understanding the potential impacts of PIT-tagging juvenile salmon is essential to inform salmonid survival rates derived from tagging studies. A number of factors including species, location, tagger, and fish handling, can determine the effects of PIT tagging. Therefore, it is important that any tagging program carefully review its tagging methodology to ensure that the tagging procedure is not negatively impacting the health or behaviour of the fish. Concerns regarding the stress associated with handling and tagging and potential long-term impacts like reduced growth and infections leading to mortality highlight the importance of assessing the effects of tagging on individual fish within any tagging program.

Vollset et al. (2020) conducted a systemic review of PIT tagging effects on the mortality and growth of juvenile salmon. They found that tagging-related mortality could be minimized by only applying tags that were no larger than 17.5% of the fish body weight. For 12-mm PIT tags, this translates to a minimum fork length of 69 mm at which expected mortality is approximately 5% with a lower bound of 0% (Vollset et al. 2020); they also made note of areas which lack knowledge on the influence of tagging mortalities such as water temperature, tank flow, and fish density.

The *Bottlenecks Program* is a multi-year, multi-stock PIT tagging study investigating the survival bottlenecks of Chinook, coho, and steelhead salmon across 10 watersheds on Vancouver Island. Thousands of fish are tagged at hatcheries, rivers, estuaries, and at sea yearly. The program's success relies on the successful tagging and release of fish without negatively impacting their chances of survival.

This study aimed to understand what the primary drivers are for tagging-related mortality. This will assist *Bottlenecks Program* researchers to understand better what these values may be in the river and ocean environments. This study also aimed to understand which variables are the primary drivers of tagging-related mortality and rejection (i.e. species, tagging facility, methods of handling of post-tagged fish, size, water temperature, tagger, holding tank flows, tank dimensions and rearing density) to help inform the more extensive program of tagging related mortality and rejection rates.

MATERIALS AND METHODS

Study Area

The Salish Sea is an inland sea encompassing Puget Sound, Juan de Fuca Strait, and the Strait of Georgia (Figure 1). The area spans from Campbell River on Vancouver Island to the Olympic Peninsula. Multiple threatened ecologically significant Pacific salmon units, such as the Nanaimo River spring and summer-run Chinook, utilize the Salish Sea.

Our study area is concentrated along the west coast of the Strait of Georgia, the northeastern portion of the Salish Sea and includes 10 watersheds. Systems within the area were chosen based on their salmon run contributions within the region and where Salmon Enhancement Program facilities were located. These facilities release millions of Chinook and hundreds of thousands of coho annually to support a mixed-stock fishery within the Salish Sea.

For the study of tagging related impacts on Chinook and coho salmon, we conducted detailed post-tagging monitoring at four of the hatcheries where PIT tagging occurs for the *Bottlenecks Program*: Quinsam River, Puntledge River, and Nanaimo River for Chinook tagging and coho tagging and Goldstream River Hatchery for only coho tagging (Table 1).

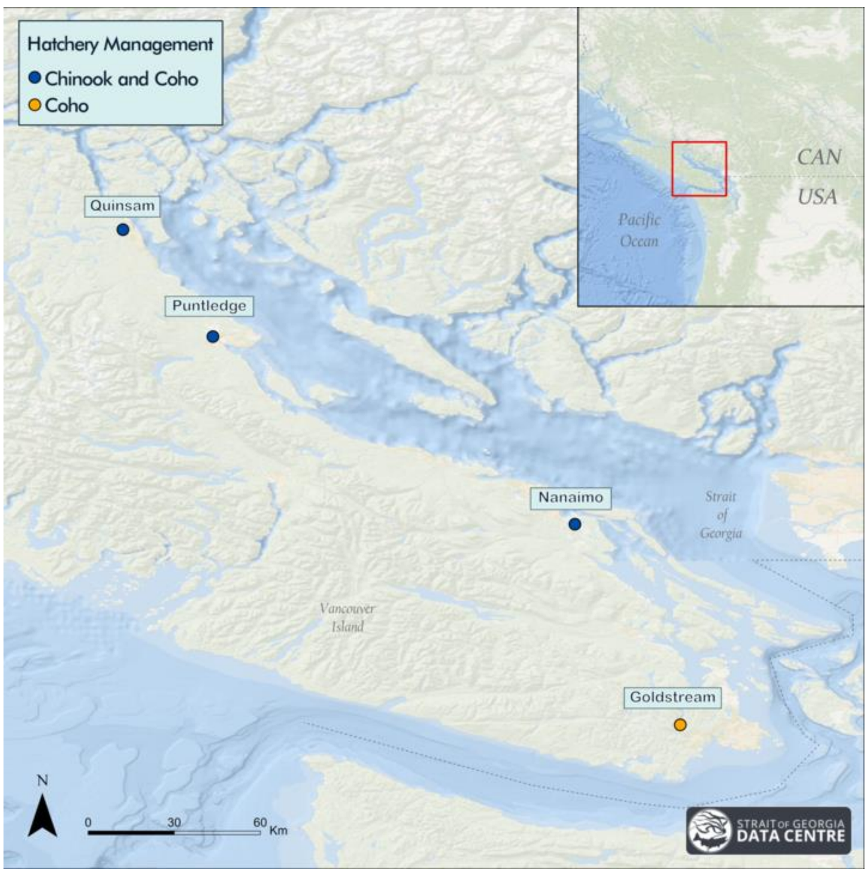

Figure 1. Map of the study area showing the different types of hatchery facilities where Chinook and coho were tagged.

Table 1. Summary of hatchery tagging as of 2023.

WATERSHED	HATCHERY	SEP/CH	SPECIES	HOLDING TANK (CIRC, RW, OTHER)	YEARS
Nanaimo	Nanaimo River	CH	ck/co	circ	21_22_23
Puntledge	Puntledge River	SEP	ck/co	circ	21_22_23
Quinsam	Quinsam River	SEP	ck/co	circ	21_22_23
Goldstream	Goldstream River	CH	co	circ	22_23

Fish Handling, Tagging and Post-Tag Monitoring

Hatchery fish were typically removed from the main population a day (or more) before tagging. Fish were typically held off food for 24 hours before a tagging event. Fish were transferred into a freshwater bath prepared with 50 mg/L of Tricaine methanesulphonate (TMS), buffering with sodium bicarbonate ($NaHCO_3$) to prevent acidification, following the Canadian Council on Animal Care's standardized methodology (Ackerman et al., 2005). All anesthetic baths included Vidalife (Syndel Canada, Nanaimo, BC), a water conditioner that preserves the fish's natural mucous layer, preventing abrasions (Syndel 2019).

Once fish were adequately anesthetized (i.e., slowed breathing, subdued response to touch, movements slowed), after approximately four minutes in the anesthetic bath, they are handled carefully and quickly to reduce the time they are exposed to TMS and the air (Ian Keith, DFO-SEP Vet, Pers. Comm. 2021). All Chinook and coho were tagged with 12 mm FDX-B PIT tags (Biomark, Boise, ID). PIT tags were administered in salmonids with a fork length equal to or greater than 69 mm, in hatchery environments as the 12 mm PIT tags should equate to ~17.5% of a salmonid's body weight to minimize risk of mortality from tagging (Vollset et al. 2020). Once anesthetized, PIT tags are injected into the body cavity, anterior to each fish's pelvic girdle (Figure 2) with a sterilized, one-time-use, preloaded needle.

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

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

Tagged fish were immediately released into either static recovery baths or flow-through tagging tables directly into the holding tank (either circular (circ) or runway (rw) tanks) or were transported from flow-through tagging tables into static recovery tubs and then moved into their long-term monitoring holding tank. Tagged fish were typically monitored for at least 14 days before release, where and when possible (Vollset et al. 2020).

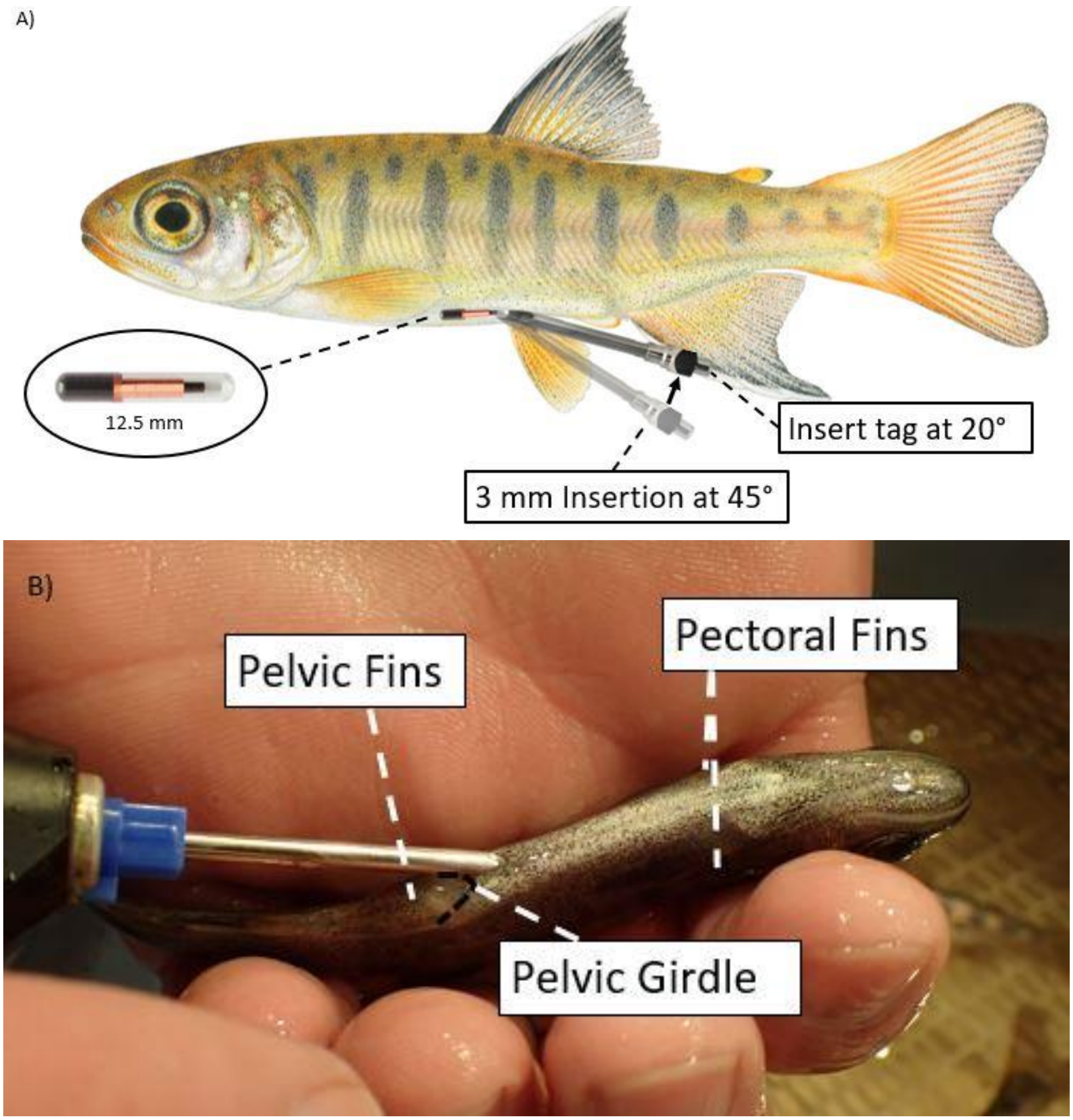

Figure 2. PIT tags are inserted into each fish's body cavity, anterior to the pelvic girdle, using a sterile, one-time-use hypodermic needle.

Data Wrangling and Analysis

All data wrangling, analysis and graphics were completed using R statistical software and tidyverse (R Core Team 2023; version 2023.09.01 "Desert Sunflower"; Wickham et al. 2019). Kaplan-Meier survival curves were constructed using the "survival" package, and the log-rank test was conducted using the "surv" function (Therneau 2023).

Tagging Related Mortality Analysis

Our study utilized survival times inferred from tag date with mortality, tag rejection, and squib (a tag which did not deploy correctly and remained in the needle post-tagging) events. Time to survival was bookended by release date, either into the river or an earthen pond (Atkinson et al. 2024). For this study, tagged fish were held for various durations from 10 to >200 days; as such, we used a 30-day cut-off value, assuming mortalities and rejections post 30 days were the result of additional factors such as disease.

To analyze these data, we first employed Kaplan-Meier survival curves to provide empirical visualizations of survival probabilities over time, separated by hatchery. This method allowed us to estimate and plot survival functions for Chinook and coho salmon from Quinsam, Puntledge, and Nanaimo hatcheries. This non-parametric method allowed for the survival function estimation from lifetime data, where the probability of surviving past a certain time point is calculated for each group. The survival time was calculated from the date of tag implantation until the date of death or the end of the study period, whichever came first. Fish whose tags were expelled (rejected) or who had an unknown tag status were treated as censored observations. The Kaplan-Meier curves were plotted to visually compare the survival distributions across the different hatcheries, clearly depicting the survival probability over time for each group. Statistical differences between the survival curves were assessed using the log-rank test to determine significant variations among the hatcheries.

RESULTS

During the first three years of the *Bottlenecks Program*, overall tagging-related mortality for Chinook and coho smolts was estimated to be 1.74 and 0.62% (Table 2). These results align with the 0 – 5% tagging-related mortality determined by Vollset et al. (2020).

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

Table 2. Summary of all species (Chinook and coho) and facilities from study years 2021 – 2023 of non-viable tags from the *Bottlenecks Program* hatchery tagging during the 30-day post-tagging monitoring period. Data are from the Nanaimo, Puntledge, Quinsam, and Goldstream hatcheries.

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

In the first three years of the *Bottlenecks Program*, the survival rate of hatchery Chinook related to tagging was 1.74% on average (Table 3). Across the three years, tag rejections and unknowns (either mortality or tag rejection) comprised 0.89% and 0.11%, respectively.

Table 3. Summary of non-viable tags from Chinook for study years 2021 – 2023 from the *Bottlenecks Program* hatchery tagging during the 30-day post-tagging monitoring period. Data are from the Nanaimo, Puntledge and Quinsam hatcheries.

TAG STATUS	OUTMIGRATION YEAR					
	2021		2022		2023	
	N	%	N	%	N	%
mortality	281	1.41	131	0.66	628	3.16
reject	230	1.15	271	1.35	34	0.17
squib	0	0.00	2	0.01	0	0.00
unknown	65	0.32	0	0.00	0	0.00
euthanized	0	0.00	0	0.00	76	0.17

Coho salmon had an average tagging-related mortality rate of 0.62% and a tag rejection rate of 0.54% across the three years (Table 4). Additionally, 0.06% of non-viable tags could not be confidently allocated to either a mort or a tag rejection (Table 4).

Table 4. Summary of non-viable coho for all years (2021 – 2023) from the *Bottlenecks Program* hatchery tagging during the 30-day post-tagging monitoring period. Data are from the Nanaimo, Puntledge, Quinsam, and Goldstream hatcheries.

TAG STATUS	OUTMIGRATION YEAR					
	2021		2022		2023	
	N	%	N	%	N	%
mortality	290	1.93	55	0.24	24	0.08
reject	118	0.78	228	1.01	12	0.04
squib	11	0.07	8	0.03	0	0.00
unknown	41	0.27	0	0.00	0	0.00
euthanized	0	0.00	0	0.00	76	0.26

Temporal Tag Mortality and Rejection Trends

The analysis of tag mortalities and rejections over 30 days post-tagging revealed distinct patterns in the timing and frequency of these events. The data indicates that most mortalities and rejections occur within the first few days following tagging, highlighting the critical impact of initial post-tagging stress and handling.

The percentage of daily tag mortalities from the total mortality count was calculated, revealing a rapid increase in mortalities during the initial days. On the tagging day (i.e., day 1), 23.1% of all mortalities occur. The mortality rate increases significantly on day 2 (i.e., 24 hours post-tagging) to 31.5%. By day 3, the cumulative percentage of mortalities reaches approximately 59.6%, with the daily mortality rate at 4.5%. By the end of the first week, the cumulative percentage of mortalities typically reaches ~90.0%, with daily mortality rates tapering off to around 2.3%. This indicates that most mortalities occur within the first week post-tagging. Beyond this point, mortalities gradually decline, suggesting that the acute effects of tagging largely subside by the end of the first week.

Similarly, tag rejections predominantly occur early in the post-tagging period, with 24.2% on day 1. By day 2, the percentage of rejections reaches 47.5%, and by day 3, it reaches 49.0%. Within the first seven days, the cumulative percentage of rejections reaches about 82.2%, with daily rejection rates around 2.1%. These trends underscore the importance of the initial post-tagging period and the need for improved tagging protocols and handling practices during this critical time to reduce adverse impacts on fish survival and tag retention.

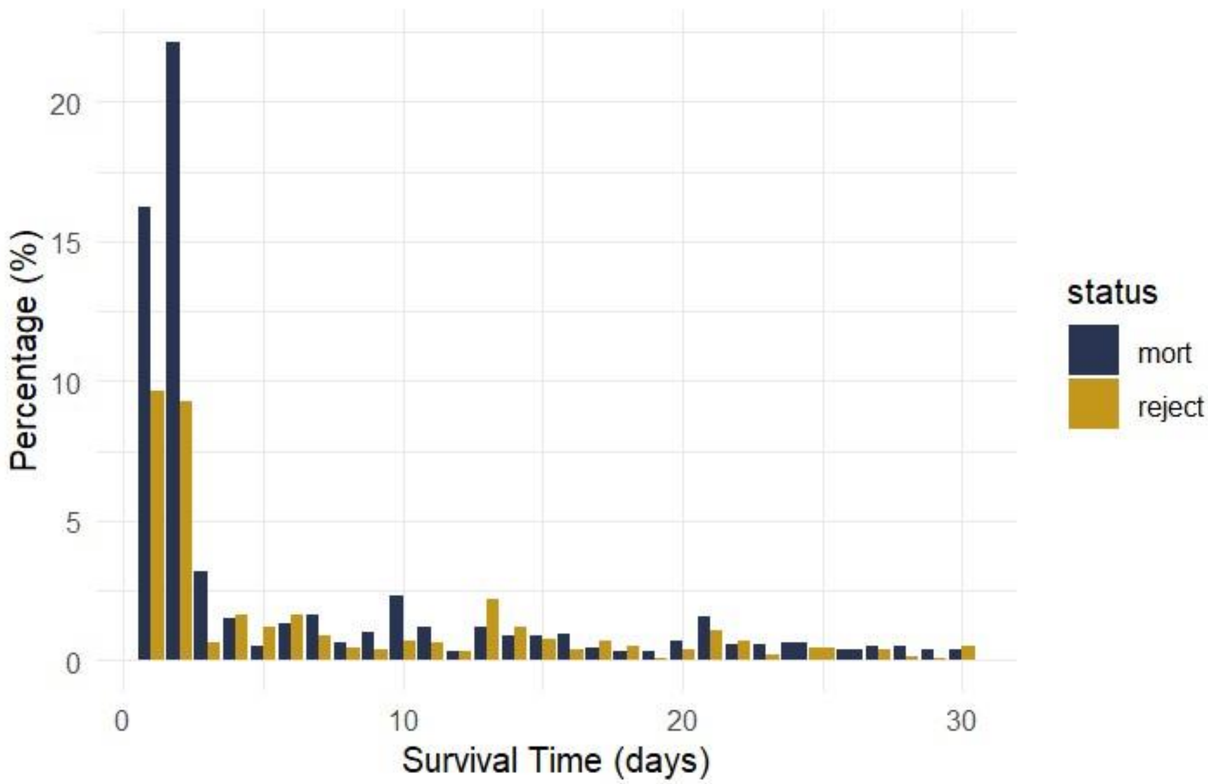

Figure 3. This bar shows the percentage of tag mortalities and rejections over the 30 days post-tagging. The y-axis represents the percentage of total occurrences, while the x-axis denotes the survival time in days.

Kaplan-Meier Survival Curves

Overall survival probabilities post-tagging were high, however there were notable differences between facilities and years (Figure 3). In 2021, Quinsam Chinook exhibited the lowest survival rates, with 96.8% survival to the end of the 30-day period. Puntledge Chinook showed 98.3% survival to the end of the holding period, and Nanaimo Chinook maintained the highest survival rate, 99.5%, 30 days post-tagging. In 2022, Nanaimo and Quinsam maintained > 99.5% survival post-tagging, while Puntledge Chinook had 98.1% survival, indicating an overall improvement from the previous year. Although the post-tagging holding period was shorter in 2022 (> 20 days), losses had stabilized by day 5 post-tagging. In 2023, Quinsam had over 99.4% survival by the end of the 23 days, while Puntledge had reduced survival compared to the previous year, but it was still above 98.6%. Nanaimo Chinook exhibited a lower survival rate of 94.7% over a shorter 12-day holding period.

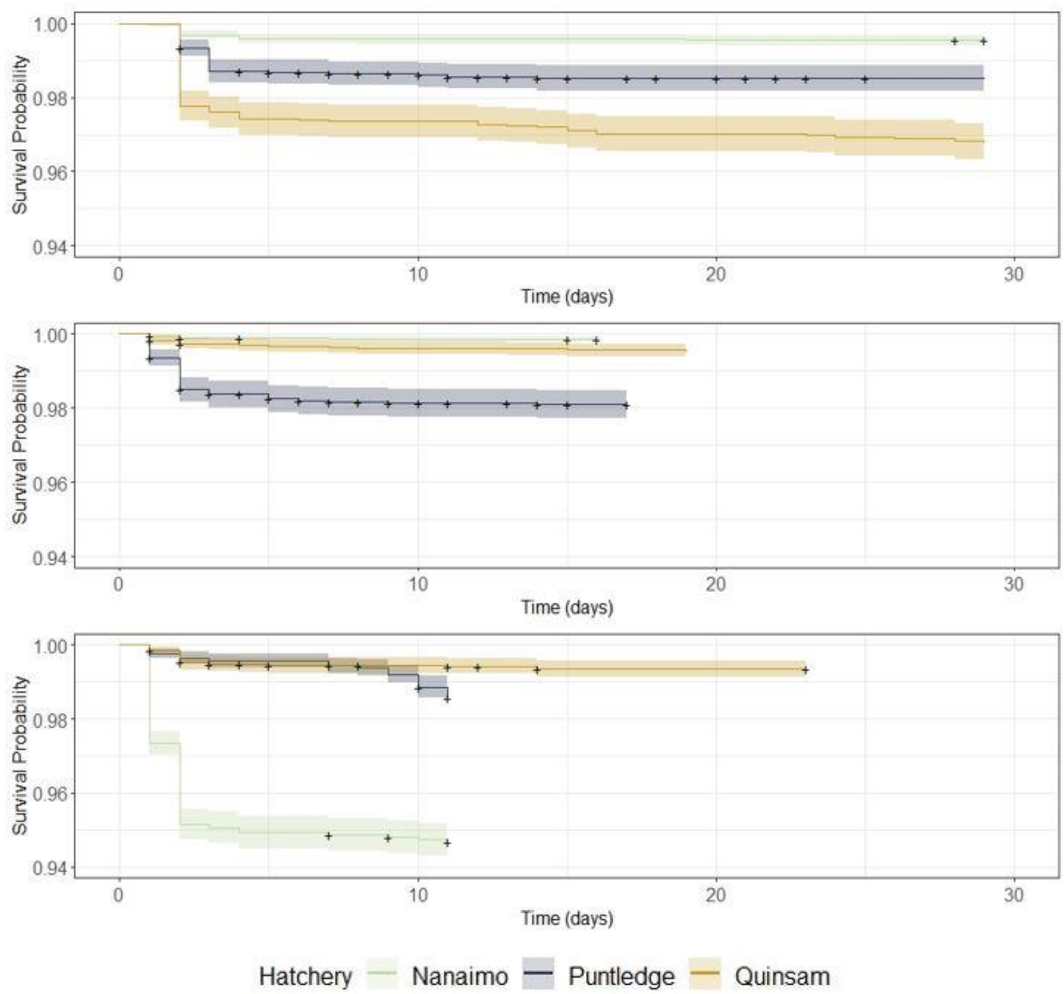

Figure 4. Kaplan-Meier survival curves for Chinook salmon smolts tagged in 2021 (top), 2022 (middle), and 2023 (bottom) across three hatcheries: Nanaimo, Puntledge, and Quinsam.

Coho post-tagging survival probabilities were generally high, with an overall increase in survival from 2021 to 2023. In 2021, the Nanaimo hatchery had the lowest survival rates for coho, with a sharp decline to about 95.5%, and survival continued to decline throughout the 30 days. Puntledge and Quinsam maintained higher survival rates of 99.2 and 99.7%, which stabilized for Quinsam after day 2, but Puntledge saw a slight decrease in survival starting on day 10. In 2022, coho survival rates showed some variation among hatcheries, but overall, they were higher. Goldstream survival rates dropped to around 99.3% immediately and then held over 30 days, whereas Quinsam maintained higher survival rates above 99.6%. Nanaimo saw a slight decrease in survival starting on day 20, but it stayed high at 99.6%. In 2023, survival rates for coho across most hatcheries were high. Goldstream and Puntledge survival probabilities each of 99.7%. Meanwhile, Nanaimo and Quinsam had 100% survival rates.

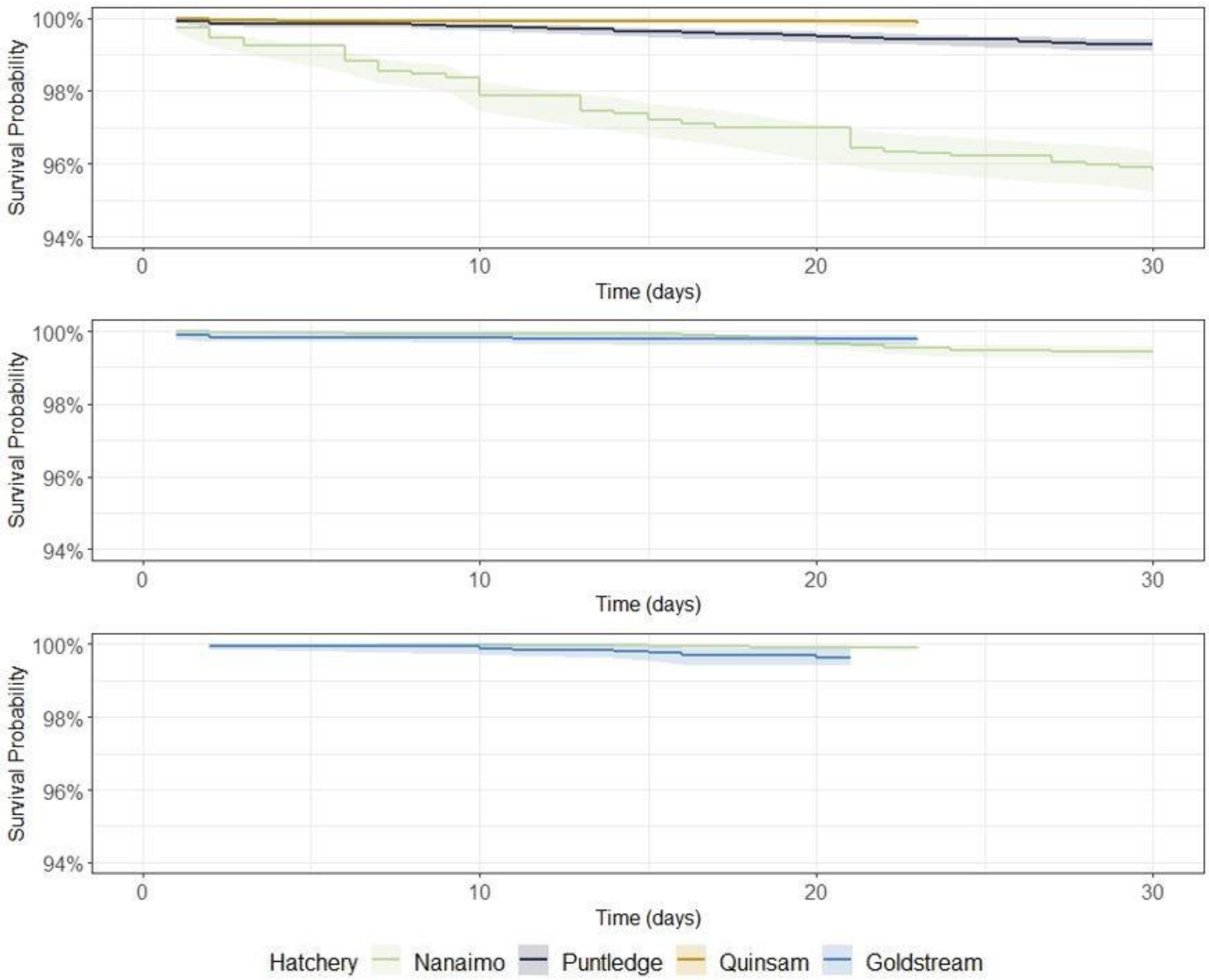

Figure 5. Kaplan-Meier survival curves for coho salmon smolts tagged in 2021 (top), 2022 (middle), and 2023 (bottom) across four hatcheries: Nanaimo, Puntledge, Quinsam and Goldstream.

Tagger Effects

Tagging events with higher-than-normal mortalities or tag rejections were driven by an individual tagger. The average tagging-related mortality rate was 1.74 and 0.62% for Chinook and coho, respectively. Only two tagging dates had mortality rates noticeably above these averages.

The highest mortality rates for an individual tagger occurred on Fall and Summer-run Chinook smolts in 2023 at the Nanaimo hatchery facility. On this date, one tagger (ID = 18) had a tagging-related mortality rate of 34.8% and 22.7% for the Summer and Fall-run cohorts, respectively (Figure 4). Further, a new tagger (ID = 34) had a comparatively low mortality rate (6.6%), higher than the acceptable target of 5%. All other taggers (N = 15) had an overall tagging-related mortality of 0.67%.

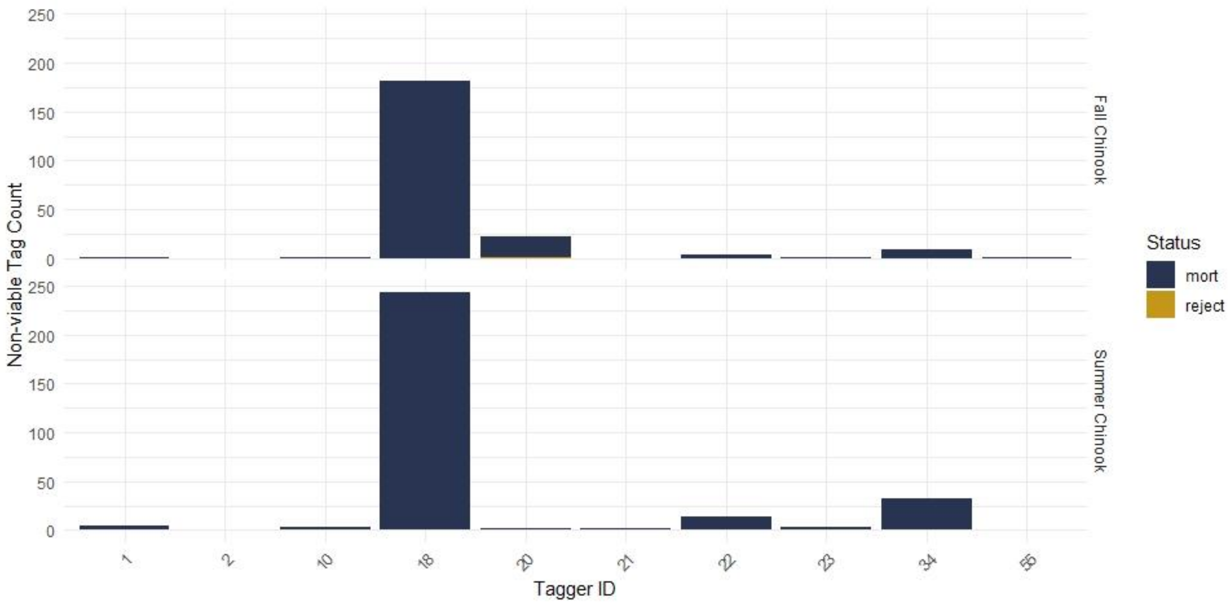

Figure 6. Non-viable tag (mort or reject) summary for Nanaimo 2023 hatchery Chinook tagging of Fall- (top) and Summer-run (bottom) Chinook cohorts. The x-axis shows individual tagger IDs. Both cohorts were tagged on the same date by the same taggers.

Additionally, in two different years during the Puntledge Chinook tagging, individual and new taggers had high tagging mortality and rejection rates. In 2021, two new taggers had mortality rates of 4.3% and 4.2% each while also having large tag rejection rates of 8.9% and 10.4% (Figure 5). In 2022, a single new tagger had mortality and rejection rates of 10.4% and 30.0% (Figure 6). In both instances, the average tagger mortality rates were 0.34% and 0.69%; the mean tagger rejection rates were as low as 0.79% and 0.75%.

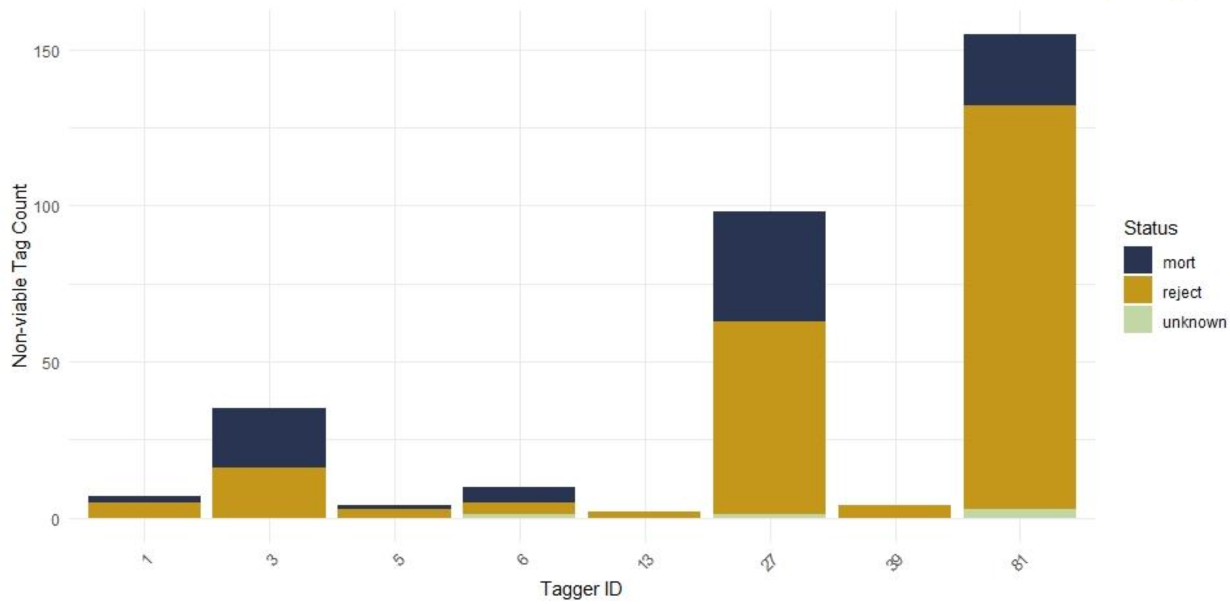

Figure 7. Non-viable tag (mort or reject) summary for Puntledge hatchery Chinook tagging on April 21, 2021. The x-axis shows individual tagger IDs.

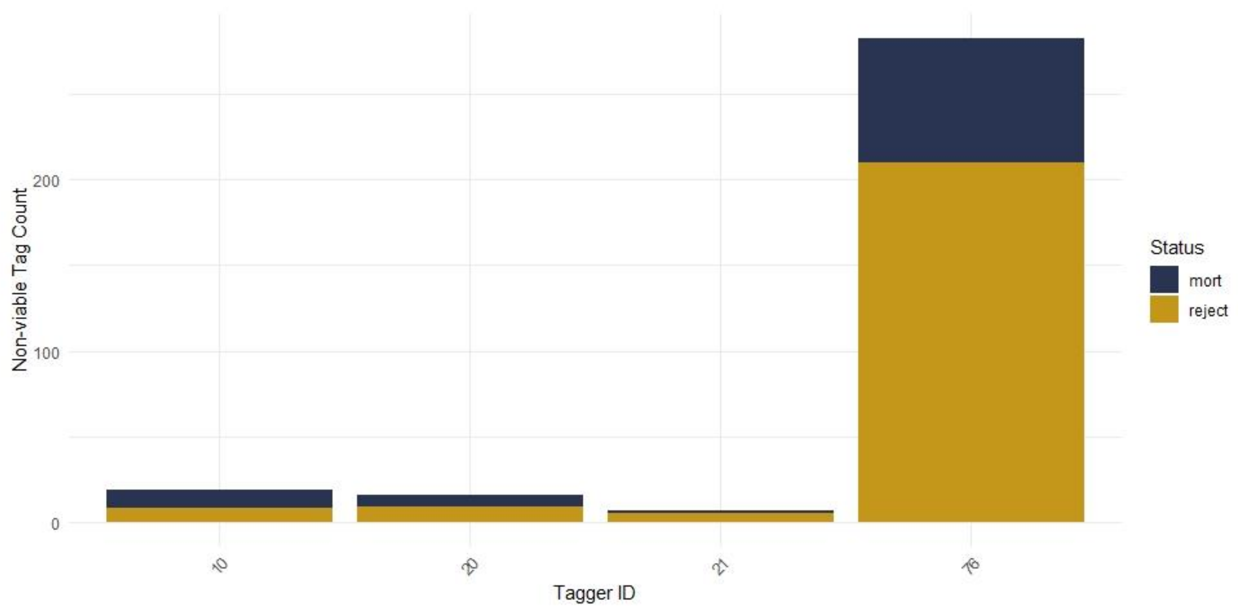

Figure 8. Non-viable tag (mort or reject) summary for Puntledge hatchery Chinook tagging on May 24, 2022. The x-axis shows individual tagger IDs.

DISCUSSION

This study investigated the tagging-related effects of PIT tagging juvenile enhanced Chinook and coho across multiple hatcheries as part of the *Bottlenecks Program*. The objective was to provide an understanding of tagging effects to inform our overall survival estimates derived from PIT tags and provide broader insights into potential causes of tagging-related mortality and tag rejections from which improvements can be made.

Mean overall tagging-related mortality rates across the three years were 1.74% and 0.62% for Chinook and coho, respectively. These values lie within the accepted limits determined by Volsett et al. (2020) of 0 – 5% within the confidence intervals.

The Kaplan-Meier survival curves indicated significant variation in survival rates among hatcheries and years. For Chinook, only two tagging events had relatively high mortality, and only one had significant mortality above the 5% threshold (5.3%). For coho, 2021, Nanaimo had the lowest survival rates, with 95.5% surviving the 30-day post-tagging period. All other coho tagging events had > 99.0% tagging-related survival rates. In 2023, two hatcheries, Nanaimo and Quinsam, had 100% tagging-related survival rates, reflecting highly effective tagging and handling protocols.

Temporal trends in post-tag mortalities and rejections underscore the importance of the initial post-tagging period. The first two days post-tagging are particularly crucial, with the highest percentages of both mortalities and rejections observed during this period and 50% of tag rejections and mortalities occurring by day 3. This early peak suggests that the initial days post-tagging are critical, and inferences around total mortality cannot be made prior to this post-tag monitoring period. In the initial week, the frequencies of these events drop considerably, indicating that the acute phase of tagging-related stress has passed; with 90% of all mortalities and tag rejections occurring by day 7. Improvements in tagging protocols and handling practices during this critical period can significantly reduce the adverse impacts on fish survival and tag retention.

Individual taggers had notable impacts on mortality rates. For instance, in 2023, one tagger had extraordinarily high mortality rates at the Nanaimo hatchery. This suggests that further training and standardized procedures are required to mitigate such high mortality rates. Additionally, new taggers had comparatively higher mortality rates, indicating the importance of experience and possibly highlighting a learning curve associated with tagging. In 2021 and 2022, the Puntledge hatchery also experienced high mortality and rejection rates associated with specific taggers. These figures underscore the importance of consistently training and monitoring new taggers to ensure they adhere to best practices. Overall, tagging-related mortality and tag rejections decreased throughout the three years of this study. Therefore, training and experience can minimize tagging effects.

In 2021, the facilities that did not have tagging rooms or flow-through tables showed increased mortality across all taggers. This was likely associated with the static anesthetic baths and the multiple handling events, post tagging, to transport fish to their final holding tank. Due to a mortality rate increase, the DFO-SEP veterinarian monitored and provided guidance at the next tagging event, and recommendations were made and actioned. The recommendations were to use only flow-through tagging tables, reduce post-tag handling, and follow the tagging guidelines provided by Vollset et al. (2020). A 17.5% tag weight to body weight limit was applied, resulting in only tagging salmon smolts larger than 70 mm (~4 grams).

Water temperature was monitored during the 2022 and 2023 study years, at the time of tagging, and during the 30-day post-tag recovery and monitoring periods. This was done to understand better if water temperature impacted tagging-related mortalities and rejection rates. Additionally, mean water velocity measurements were made to understand if flow or water velocity during the post-tag monitoring period influenced tag rejection rates. However, due to the overall high survival rate (98.0%), there were not enough mortalities from any given tagging event to detect meaningful effects of these factors. Nonetheless, the continued collection of these data may allow for a meta-analysis utilizing what will eventually be six years of hatchery tagging data as part of the larger *Bottlenecks Program*.

The recommendations provided by the DFO veterinarian were good additions to the program and were effective at reducing overall handling and tagging-related survival. Based on these recommendations a standard operating procedure was developed by the Bottlenecks Program for the PIT tagging of enhanced salmon (Negrin et al. 2024). However, the inherent nature of these mortalities appears to be driven by individual taggers and is usually the result of a first-time tagger or an over-confident tagger unnecessarily increasing their tagging speed. While monitoring of tagging staff during tagging events occurs and new taggers are now directed to only tag 1 tray on their first tagging event, increased mortalities can still occur. Further, these mortalities do not necessarily occur instantaneously but over hours and days, resulting in an inability to correct the mistake at the time. Therefore, all taggers must receive an overview of the tagging method before all tagging events, new taggers are carefully supervised, and the tagger ID be recorded so that tagger effects pot-tagging can be reviewed with each individual.

Study Limitations

Despite the valuable insights provided by this study, several limitations must be acknowledged. The generalizability of the findings may be limited to the specific fish species, tagging methods, and environmental conditions studied. Variations in environmental conditions and handling practices across different tagging locations could have introduced inconsistencies in the data. The lack of information on individual fish condition and potential confounding variables, such as fish health and stress levels, limits the ability to isolate the specific factors contributing to tag mortalities and rejections.

Recommendations

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

- The cohort of fish to be tagged be held off food for 24 hours before tagging.
- Tag length should not exceed 17.5% of the fish length (~70 mm fork length when using FDX-B 12 mm tags) (Vollsett et al. 2020).
- Utilize flow through tagging tables where possible to reduce physical handling of fish post-tagging.
- When training, limit new taggers to 1-tray (100 tags) during their first tagging event
- New taggers should train on larger fish (coho smolts).
- Tagger ID should be recorded so that tagger-related effects can be addressed prior to future tagging events.

The *Bottlenecks Program* recommends that all PIT tagged fish be held in separate tanks for a minimum of 14 days post-tagging and monitored daily for tagging-related mortalities and rejections. However, longer monitoring periods of up to and > 30 days should be achieved where possible. In addition, precautions should be taken regarding overfeeding during the final few weeks prior to release.

Continue Development of Cox Mixed Model

Multiple models were tested against the data during data analyses to determine what variables were drivers of tagging-related mortalities. However, some of these comparisons could not be completed due to the high survival rates and the study's multiple systems. A preliminary model was only utilized on the 2021 dataset from the three main hatchery facilities (Puntledge, Nanaimo, and Quinsam). While the model was not run against the three years of data for this report, we anticipate utilizing the model after additional years of tagging (n = 6) to explore the specific effects of facility, tank flow, water temperature, and tagger.

Ethical Considerations

Animal care protocols were developed in conjunction with and approved by the Department of Fisheries and Oceans Salmon Enhancement Programs Veterinarian. All necessary permits and permissions were obtained for tagging and monitoring the fish. Data confidentiality and anonymity were maintained throughout the study.

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APPENDIX A SUMMARY OF TAGGING

OUTMIGRATION YEAR	SYSTEM	TAGGING DATE	SPECIES	COHORT*	STATUS	COUNT	TAG DEPLOYED	PERCENT
2021	quinsam	2020-09-17	co	sm	mort	14	5000	0.28
2021	quinsam	2020-09-17	co	sm	surv	4947	5000	98.94
2021	quinsam	2020-09-17	co	sm	unknown	39	5000	0.78
2021	nanaimo	2021-03-17	co	sm	mort	225	5000	4.50
2021	nanaimo	2021-03-17	co	sm	reject	58	5000	1.16
2021	nanaimo	2021-03-17	co	sm	surv	4717	5000	94.34
2021	quinsam	2021-04-01	ck	f	mort	200	5000	4.00
2021	quinsam	2021-04-01	ck	f	reject	1	5000	0.02
2021	quinsam	2021-04-01	ck	f	surv	4744	5000	94.88
2021	quinsam	2021-04-01	ck	f	unknown	55	5000	1.10
2021	puntledge	2021-04-12	co	sm	mort	38	5000	0.76
2021	puntledge	2021-04-12	co	sm	reject	2	5000	0.04
2021	puntledge	2021-04-12	co	sm	surv	4958	5000	99.16
2021	puntledge	2021-04-12	co	sm	unknown	2	5000	0.04
2021	puntledge	2021-04-21	ck	f	mort	85	5000	1.70
2021	puntledge	2021-04-21	ck	f	reject	225	5000	4.50
2021	puntledge	2021-04-21	ck	f	surv	4685	5000	93.70
2021	puntledge	2021-04-21	ck	f	unknown	5	5000	0.10
2021	nanaimo	2021-04-22	ck	f	mort	33	5000	0.66
2021	nanaimo	2021-04-22	ck	f	reject	4	5000	0.08
2021	nanaimo	2021-04-22	ck	f	surv	4960	5000	99.20
2021	nanaimo	2021-04-22	ck	f	unknown	3	5000	0.06
2021	nanaimo	2021-04-23	ck	s	mort	13	5000	0.26
2021	nanaimo	2021-04-23	ck	s	surv	4985	5000	99.70
2021	nanaimo	2021-04-23	ck	s	unknown	2	5000	0.04
2021	quinsam	2021-11-08	co	sm	mort	19	5000	0.38
2021	quinsam	2021-11-08	co	sm	reject	38	5000	0.76
2021	quinsam	2021-11-08	co	sm	squib	11	5000	0.22
2021	quinsam	2021-11-08	co	sm	surv	4932	5000	98.64

2021	puntledge	2021-12-02	co	sm	mort	63	5000	1.26
2021	puntledge	2021-12-02	co	sm	reject	20	5000	0.40
2021	puntledge	2021-12-02	co	sm	surv	4917	5000	98.34
2022	nanaimo	2022-01-25	co	sm	mort	12	5000	0.24
2022	nanaimo	2022-01-25	co	sm	reject	9	5000	0.18
2022	nanaimo	2022-01-25	co	sm	surv	4979	5000	99.58
2022	goldstream	2022-03-02	co	sm	mort	51	7500	0.68
2022	goldstream	2022-03-02	co	sm	reject	219	7500	2.92
2022	goldstream	2022-03-02	co	sm	squib	8	7500	0.11
2022	goldstream	2022-03-02	co	sm	surv	7222	7500	96.29
2022	quinsam	2022-04-14	ck	f	mort	25	5000	0.50
2022	quinsam	2022-04-14	ck	f	reject	32	5000	0.64
2022	quinsam	2022-04-14	ck	f	surv	4943	5000	98.86
2022	nanaimo	2022-05-10	ck	f	mort	14	5000	0.28
2022	nanaimo	2022-05-10	ck	f	reject	7	5000	0.14
2022	nanaimo	2022-05-10	ck	f	squib	2	5000	0.04
2022	nanaimo	2022-05-10	ck	f	surv	4977	5000	99.54
2022	nanaimo	2022-05-10	ck	s	surv	5000	5000	100.00
2022	puntledge	2022-05-24	ck	f	mort	93	5000	1.86
2022	puntledge	2022-05-24	ck	f	reject	232	5000	4.64
2022	puntledge	2022-05-24	ck	f	surv	4675	5000	93.50
2022	quinsam	2022-11-30	co	smlun	mort	7	2000	0.35
2022	quinsam	2022-11-30	co	smlun	surv	1993	2000	99.65
2022	quinsam	2022-11-30	co	smpun	mort	6	2000	0.30
2022	quinsam	2022-11-30	co	smpun	surv	1994	2000	99.70
2022	quinsam	2022-12-20	co	smlma	mort	5	2000	0.25
2022	quinsam	2022-12-20	co	smlma	surv	1995	2000	99.75
2022	quinsam	2022-12-20	co	smpma	mort	4	2000	0.20
2022	quinsam	2022-12-20	co	smpma	surv	1996	2000	99.80
2023	nanaimo	2023-03-07	co	sm	surv	5000	5000	100.00
2023	goldstream	2023-03-14	co	sm	euthanized	76	10400	0.73
2023	goldstream	2023-03-14	co	sm	mort	27	10400	0.26
2023	goldstream	2023-03-14	co	sm	mort	1	10400	0.01

2023	goldstream	2023-03-14	co	sm	rejected	12	10400	0.12
2023	goldstream	2023-03-14	co	sm	surv	10284	10400	98.88
2023	quinsam	2023-04-18	ck	f	mort	32	5000	0.64
2023	quinsam	2023-04-18	ck	f	reject	24	5000	0.48
2023	quinsam	2023-04-18	ck	f	surv	4944	5000	98.88
2023	puntledge	2023-04-19	co	sm	mort	10	2500	0.40
2023	puntledge	2023-04-19	co	sm	surv	2490	2500	99.60
2023	puntledge	2023-05-29	ck	f	mort	70	4900	1.43
2023	puntledge	2023-05-29	ck	f	reject	9	4900	0.18
2023	puntledge	2023-05-29	ck	f	surv	4821	4900	98.39
2023	nanaimo	2023-05-30	ck	f	mort	220	5000	4.40
2023	nanaimo	2023-05-30	ck	f	reject	1	5000	0.02
2023	nanaimo	2023-05-30	ck	f	surv	4779	5000	95.58
2023	nanaimo	2023-05-30	ck	s	mort	306	5000	6.12
2023	nanaimo	2023-05-30	ck	s	surv	4694	5000	93.88

*cohort: sm = smolt, f = fall-run, s = summer-run, smlun = unmarked late release smolt, smpun = unmarked primary production smolt, smlma = marked late release smolt, smpma = marked primary production smolt.

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