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| **Canadian Technical Report of Fisheries and Aquatic Sciences**  Technical reports contain scientific and technical information that contributes to existing knowledge but which is not normally appropriate for primary literature. Technical reports are directed primarily toward a worldwide audience and have an international distribution. No restriction is placed on subject matter and the series reflects the broad interests and policies of Fisheries and Oceans Canada, namely, fisheries and aquatic sciences.  Technical reports may be cited as full publications. The correct citation appears above the abstract of each report. Each report is abstracted in the data base *Aquatic Sciences and Fisheries Abstracts*.  Technical reports are produced regionally but are numbered nationally. Requests for individual reports will be filled by the issuing establishment listed on the front cover and title page.  Numbers 1-456 in this series were issued as Technical Reports of the Fisheries Research Board of Canada. Numbers 457-714 were issued as Department of the Environment, Fisheries and Marine Service, Research and Development Directorate Technical Reports. Numbers 715-924 were issued as Department of Fisheries and Environment, Fisheries and Marine Service Technical Reports. The current series name was changed with report number 925.  **Rapport technique canadien des sciences halieutiques et aquatiques**  Les rapports techniques contiennent des renseignements scientifiques et techniques qui constituent une contribution aux connaissances actuelles, mais qui ne sont pas normalement appropriés pour la publication dans un journal scientifique. Les rapports techniques sont destinés essentiellement à un public international et ils sont distribués à cet échelon. II n'y a aucune restriction quant au sujet; de fait, la série reflète la vaste gamme des intérêts et des politiques de Pêches et Océans Canada, c'est-à-dire les sciences halieutiques et aquatiques.  Les rapports techniques peuvent être cités comme des publications à part entière. Le titre exact figure au-dessus du résumé de chaque rapport. Les rapports techniques sont résumés dans la base de données *Résumés des sciences aquatiques et halieutiques.*  Les rapports techniques sont produits à l'échelon régional, mais numérotés à l'échelon national. Les demandes de rapports seront satisfaites par l'établissement auteur dont le nom figure sur la couverture et la page du titre.  Les numéros 1 à 456 de cette série ont été publiés à titre de Rapports techniques de l'Office des recherches sur les pêcheries du Canada. Les numéros 457 à 714 sont parus à titre de Rapports techniques de la Direction générale de la recherche et du développe­ment, Service des pêches et de la mer, ministère de l'Environnement. Les numéros 715 à 924 ont été publiés à titre de Rapports techniques du Service des pêches et de la mer, ministère des Pêches et de l'Environnement. Le nom actuel de la série a été établi lors de la parution du numéro 925. |

Canadian Technical Report of Fisheries and Aquatic Sciences ####

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Comparing the ecology of hatchery- and natural-origin San Juan Chinook from freshwater outmigration to marine entry

by

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# ABSTRACT

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# RÉSUMÉ

Finnis, S., Guyondet, McKindsey, C.W., T., Arseneau, J., Barrell, J., Duhaime, J., Filgueira, R., Gallardi, D., Gaspard, D., Gibb, O., Goodwin, C., Hua, K., Macdonald, T., Milne, R., Lacoursière-Roussel, A. 2023. Guidance on sampling effort to monitor mesozooplankton communities at Canadian bivalve aquaculture sites using an optical imaging system. Can. Tech. Rep. Fish. Aquat. Sci. ####: vii + 101 p.

[texte]

# PREFACE

[text]

# INTRODUCTION

[text]

# METHODS

## Ethics statements

### First Nations traditional territory

The field components of this project occurred in the traditional territory of the Pacheedaht First Nation. The initial conception and planning for the project was done in partnership with the Pacheedaht Fisheries Department and was guided by their priority to restore the San Juan watershed, rejuvenate the San Juan Chinook population and conserve the resource for future generations. Their Fisheries Team was involved in all aspects of this project and in particular lead the field work component with support from DFO Stock Assessment as needed.

### Animal care

Fish were handled following Standard Operating Procedures set out by DFO Stock Assessment in accordance with the Canadian Council on Animal Care Guidelines for fish handling (CCAC 2005). All fish were dip-netted out of the RST live box and transferred to buckets with aeration stones. Non-salmonid bycatch (e.g., amphibians, lamprey) were enumerated and released immediately downstream.

Salmonids retained for biological sampling were transferred to larger totes kept under shade with more aeration stones and tree branches for cover to reduce stress. Bucket water temperature was monitored throughout the sampling period and kept within ± 2°C of the river temperature. Fish only receiving fork length and weight measurements were not subjected to anesthetic; instead, fish were transferred to a viewer with water to have fork length estimated, and then quickly strained to obtain a field wet weight. This method was chosen as it was determined the very small fry were too delicate and susceptible to mortality under anesthetic.

Fish being processed for additional sampling (e.g., DNA), including lethal sampling, were exposed to a dose of 15-30 mg/L Tricaine methanesulfonate (‘TMS’ aka ‘MS-222’ aka Syncaine, from Syndel). TMS used in freshwater was buffered with sodium bicarbonate (baking soda) to reduce acidity (2 parts baking soda to 1 part TMS); TMS used in brackish or salt water was not buffered. Exact dose varied slightly based on individual uptake and water temperature. Length of exposure varied depending on water temperature and sampling method. Fish allocated for non-lethal sampling (e.g., DNA) were removed from anesthetic once they lost equilibrium (i.e., flipped on side) but still while maintaining operculum movement. Fish allocated for lethal sampling were left in the TMS solution until equilibrium was completely lost and operculum movement ceased (i.e., anesthetic overdose). Temperature in the TMS bath was also monitored to keep within ± 2°C of the river temperature. Vidalife water conditioner (from Syndel) was also applied to all water and equipment to protect the mucous layer. TMS was disposed of away from any water sources or aquatic habitat to avoid effects on fish or other non-target sensitive animals (e.g., amphibians).

## Study area

The San Juan River empties into Port San Juan (Port Renfrew, BC) on the southwest coast of Vancouver Island (Figure xa). It supports genetically distinct populations of Chinook and Coho (CITE), as well as a moderate abundance of SWVI Chum. The tributaries of the San Juan (Harris and Lens creeks) are particularly productive for Coho and Steelhead. This area falls within the traditional territory of Pacheedaht First Nation, who are committing tremendous effort towards re-establishing the natural Chinook population through habitat restoration, monitoring, and co-management of the 4 Mile Hatchery. The hatchery has enhanced Chinook since 1979 (excluding 1989), and historically enhanced Chum (1983, 1985, 1990-1998, 2001, 2002), Coho (1978-2006, 2008, 2010-2012), Pink (1978, 1980, 1990, 1992) and Sockeye (1983). Historically the 4 Mile Hatchery releases Chinook out of pens in Fairy Lake, which is a tidally-influenced lake downstream of the RST. However, in an effort to increase imprinting and recruitment by seeding the optimal upper river habitat, Chinook were released in the upper San Juan River in 2024 and 2025. All fish released in the upper river were adipose fin clipped making identification of hatchery fish in the RST possible.

The San Juan estuary is extensive and spans two major arms, the southernmost one emptying near the town of Port Renfrew, while the northernmost one connects to the Gordon River near the Pacheedaht reserve and community of Elliotsville. The tidal influence extends through both of these areas, and at the highest tides into Fairy Lake. Both arms empty into Port San Juan, a relatively small, shallow sound varying from approximately 10-40 m depth (depending on the tide) with fairy consistent bathymetry throughout (Fig xx).

## Field sampling

### Freshwater outmigration: Rotary screw trap (RST)

RST site selection was limited based on river accessibility and adequate depth for the trap at all water levels. The site selected for this study (48.577800°N, -124.304148°W) is located on private property which also ensured added security for equipment. The trap was placed on an outside bend to increase flows and ensure a deep enough location for the duration of the project (Figure xb). An RST was operated previously in 2006 and 2007 and located in the lower river, upstream of Fairy Lake (approximately 48.581795°N, -124.339615°W). This site was not selected for the current study due to the extremely low flows that occurred at that site later in the Spring; historical trap efficiency declined to <1 rotation per minute in May and required the trap to be moved upstream to maintain drum rotations (Hop Wo et al, unpubl. data).

With DFO support, Pacheedaht First Nation Fisheries Program operated a 6’ diameter RST during the spring outmigration of 2023, 2024 and 2025. Program lengths each year varied: in 2023 we conducted a pilot program to test equipment, site selection, and build capacity. In 2024 and 2025 the programs ran longer and were more intensive. In 2024 we installed an Inclined Plane Trap (IPT) in the early season while the RST was unavailable. Table xx summarizes the program durations and fishing frequency for each year.

Table xx. Program length and fishing frequency for each year of juvenile sampling in the San Juan River.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Year** | **Gear** | **Program start** | **Program end** | **Fishing frequency** | **Notes** |
| 2023 | 6’ RST | March 23 | June 15 | 1-2 nights/week | Trap not fished from May 10 to June 1 due to crew limitations |
| 2024 | IPT | March 12 | March 20 | 4 nights/week |  |
| 6’ RST | March 25 | May 30 | 4 nights/week |  |
| 2025 | 6’ RST | February 26 | May 29 | 4 nights/week |  |

Each year, traps were generally set in the late afternoon/evening (between 1:00-5:00 pm) and checked the next morning (approximately 8:30-9:00 am). Daytime fishing trials were conducted in 2023, but it was determined little-to-no smolt migration occurred during the daytime. In 2024 and 2025, fishing was essentially continuous as the trap was re-set immediately after all fish were removed and environmental parameters were collected. The trap was not set when a significant flood was expected due to concerns for crew safety and fish health. During unexpected high water events the trap was also not efficient (did not rotate) as the channel flow was directed away from the bend; see Appendix 2 Figure xx for example photos of the RST at different water levels. The RST oscillated around 4 RPMs each year, averaging 4.26 ± 2.23, 3.00 ± 1.00, and 4.60 ± 1.39 RPMs in 2023, 2024 and 2024, respectively.

Water quality parameters were collected either using a YSI DSS probe or a HOBO temperature and dissolved oxygen data logger (U26-001 with required Optic USB Base Station Base-U-4 and HOBOware Pro software, [www.onsetcomp.com](http://www.onsetcomp.com)). Debris caught in the RST were categorized by broad type (logs, sticks, leaves/organic debris, algae) and relative amount (low, medium, high). Rotations-per-minute were also measured each evening and morning to ensure appropriate flow. Ideal RPMs for this site and trap were deemed to be 3-5; if RPMs were outside of this range, the trap was re-positioned.

### Estuary and nearshore marine: Beach and purse seine

We collected Chinook samples from an existing beach seine program established by Pacheedaht in (year), the methods for which will not be given in detail here. Information described below pertains solely to the samples collected specific to this study. Biological samples were collected from a sub-set of beach seined fish primarily for stomach contents, otolith micro chemistry, and DNA analyses. Surface water quality was measured at each site using a YSI DSS Probe (model).

Nearshore marine surveys were conducted with a small hand-operated purse seine during the late spring and summer of 2023, 2024 and 2025 in Port San Juan. Six core sites were selected for repeated surveys in order to track the outmigration timing, relative abundance, and diets of hatchery and natural Chinook. Site selection was based The purse seine used was approximately 30 ft deep, xx ft long and made out of xx mesh (Pacific Net and Twine). Purse seining was conducted approximately every two weeks at the core sites, with additional sites surveyed as able based on weather and tides (Figure xx). At each purse seine site we measured water quality at the surface (0 m), 5 and 10 m depths using a YSI DSS Probe (model).

### Fish enumeration and biological sampling

All fish were identified to species, enumerated, and noted adipose fin presence (for Chinook only). In the RST, Coho were classified as either fry (sub-yearlings) or smolts (yearlings) primarily based on size. The exception was alevin, which were only assigned to this life history stage if a yolk sack was present, or the fish was not completely “buttoned up”. Appendix Figure A1 illustrates size cut-offs observed for each Coho life history type.

For the RST and beach seine non-lethal samples, fork length (nearest mm) and wet weight (to nearest 0.1 g) were collected from up to 30 individuals of each species and life stage each day. To avoid excessive stress to young, small fry caught in the RST, fork length was measured in a viewer with water rather than exposure to anaesthetic (Figure xb). For all other handling (e.g., beach seining) fish were anaesthetized prior to length and weight measurements. For lethal samples (every 3rd Chinook), fish were euthanized, and weight, height and fork length were collected using a scale and measuring board (respectively). Height was measured at the widest part of the body, just posterior to the operculum and anterior to the dorsal fin (see Figure xa). Lethal samples were collected for DNA (species ID confirmation and/or stock identification, as needed), otolith microchemistry, and stomach content analyses.

A similar process was used to sample purse seine fish, with the exception that a weigh scale was not used to collect wet weights while in the field due to boat movements interfering with measurements. Instead, only height and fork length were collected, and a predictive model was developed to model weight from fish height in order to calculate condition factor (see section xx and Appendix section xx).

All lethal Chinook samples were frozen on ice immediately in the field. When DNA samples were required a section of the anal fin (approximately the size of a grain of rice) was clipped and stored in 95% non-denatured ethanol vials at room temperature for later analysis. Unique sample IDs were assigned to each sample for tracking results.

A fish in a plastic container

AI-generated content may be incorrect.A fish swimming in a tank

AI-generated content may be incorrect.

Figure x. a) Height measurement location for juvenile Chinook. B) Juvenile Chinook from the RST measured non-invasively in a viewer.

## Lab processing

Only juvenile Chinook were collected for lethal sampling as they were the focus of the study. Therefore, section 2.4 only applies to juvenile Chinook.

### Dissection protocol

Fish were stored in -20oC until dissection could occur. All tools were sterilized at the beginning and end of dissections with bleach, sodium thiosulfate, and 95% ethanol (distilled water rinse between each step). Between fish, tools were cleaned thoroughly and sanitized with 95% ethanol.

We collected lab fork length, height, and weight from lethal samples, as well as confirmed adipose fin presence. We checked clipped fish for coded wire tags (CWTs) using a metal detector; detected CWTs were dissected out and codes were recorded using a microscope. Back-up DNA samples were also collected by taking a segment of anal fin and storing at room temperature in 95% non-denatured ethanol. Brain tissue was removed in order to collect otoliths which were stored at room temperature in separate left and right vials for subsequent microchemistry analysis. Stomachs were removed from the esophagus to anus and stored separately (frozen) for subsequent diet analysis.

### Otolith microchemistry

[Nicole/Micah to write?]

### DNA analyses

DNA samples were collected primarily to assess stock identification (including hatchery/natural origin using Parental-Based Tagging or “PBT”), and in some cases confirm species identification (primarily between Chinook and Coho). Samples were submitted to the Molecular Genetics Lab (MGL) at the Pacific Biological Station. A full outline of their lab procedures and equipment can be found at <https://www.pac.dfo-mpo.gc.ca/science/facilities-installations/pbs-sbp/mgl-lgm/index-eng.html>.

Based on the advice of the MGL, natural-origin Chinook populations were grouped together to ensure reliable genetic population assignments. These groups are outlined below in Table/figure xx. Fish required a ≥ 80% assignment probability to a given group in order to be assigned; those with < 80% assignment probability were assigned to an “Unknown” stock ID.

[FtF map]?

### Diet analyses

Stomachs were stored at -20oC until analyses. Prior to dissection, stomachs (including contents) were weighed to the nearest 0.1 g. Stomach contents were then dissected out into a petri dish, and where possible components were identified under a dissecting microscope. Most of the RST stomachs were either empty or contained microscopic fragments that did not register on a scale; for these stomachs, contents were identified to the lowest possible level (often to Class) and fragments were counted. For the beach and purse seine stomachs, contents were identified to the lowest taxonomic level possible and weighed to the nearest 0.01 mg (wet weight).

## Data analyses

### RST Abundance estimates

Daily, unadjusted catch data is provided for all years of the RST program. In addition, estimates of absolute outmigration abundance were calculated for species/life history stages of interest in 2024 and 2025: natural-origin Chinook, Coho fry (sub-yearlings) and Coho smolts (yearlings). In order to calculate an annual total abundance for Chinook and Coho we first infilled for unfished periods (section 2.5.1.1) and then used the mark-recapture data to calculate total abundance estimates (2.5.1.2). We did not adjust counts for effort in these two years as fishing was essentially continuous within each day (i.e., the trap was fished through the day and night) and between years. Abundance estimates were made only for Chinook and Coho as the RST program was not designed to cover the early Chum outmigration, nor was it intended for trout and other non-salmonids.

#### Infilling unfished days

We infilled missed or unfished days for all of the key juvenile salmonid species/life history types of interest: Chinook (natural), and Coho (fry/sub-yearlings and smolts/yearlings). Infilling was done using models provided in the *imputeTS* package in R (Moritz and Bartz-Beielstein 2017) (see Table x).

We assessed the performance of imputation models against a sub-set of our dataset held back for validation purposes (20%) in both 2024 and 2025 separately. These years were analyzed separately owing to the very different patterns of capture (including zeroes) which can influence infilling model success. For each model we calculated mean absolute error (MAE) and mean absolute scaled error (MASE), and also evaluated their ability to predict true zeroes in the dataset. Any model that predicted negative catch was immediately excluded as a candidate. Following this, we picked the species- and year-specific model with the best metrics and most biologically plausible patterns overall. We also calculated mean average percentage error (MAPE) as it is a common model evaluation metric, but we did not use it consistently as a metric in this study as it is unable to be calculated when zeroes are observed/predicted.

Table x. Interpolation models explored in this study to infill missed/unfished days. Adapted from Table 3 in Moritz and Bartz-Beielstein (2017).

|  |  |  |  |
| --- | --- | --- | --- |
| **Model type** | **Model option** | **Description** | **Variations for this report** |
| na\_interpolation | linear | Imputation by linear Interpolation |  |
| stine | Imputation by stine Interpolation |  |
| na\_kalman | StructTS | Imputation by structural model & Kalman smoothing |  |
| auto.arima | Imputation by ARIMA state space representation & Kalman smoothing |  |
| na\_ma | simple | Missing value imputation by simple moving average | 2- and 3- day moving averages |
| linear | Missing value imputation by linear weighted moving average | 2- and 3- day moving averages |
| exponential | Missing value imputation by exponential weighted moving average | 2- and 3- day moving averages |

#### Mark-recapture procedure and total abundance estimates

*- Mark recapture (in some years)*

*+ Marking frequency, assumptions*

*+ Marking method, length of time in BB*

*+ Release location and timing*

*+ Equations/method for estimating abundance*

We marked all salmonids caught between Tuesday-Thursday each week with Bismarck Brown and released them upstream of the RST to assess trap efficiency and obtain abundance estimates for focal species (Chinook, Coho). After all enumeration, sample and data collection were complete, all salmonids were transferred to a bucket with aeration stones and dyed with a concentration of 25 mg/L of Bismarck Brown dye. Fish were removed from dye after one hour and transferred to fresh water for a brief recovery period. Any mortalities were noted and removed from the release totals.

The release site was approximately 500 m upstream of the RST. Fish were released as late in the day as possible and under large woody debris/roots for maximum cover to reduce stress and predation. Release numbers were recorded by species and life stage for subsequent analyses. Fish with obvious wounds or those subjected to TMS anesthetic were excluded from the mark-recapture procedure, as were those captured on Friday mornings (as it was unlikely they would still be in the system the following week). Any recaptures were enumerated by species and life stage and released immediately downstream. We did not mark any fish with Bismarck Brown that had been exposed to TMS anaesthetic in order to avoid cumulative stressors and risk biasing the mark-recapture process (e.g., that marked fish have the same survival as unmarked fish).

[m-r equation]

### Catch-per-unit-effort (CPUE)

Beach and purse seine count data were expressed as relative CPUE, specifically as the number of a given species divided by the number of sets each day and/or each site (depending on the specific analysis). At most sites we only conducted one set each day so as to avoid the chance of double counting or repeat-sampling individuals.

### Condition factor

We used Fulton’s condition factor ‘K’ as a metric to assess overall health and energy reserves of juvenile salmonids. Condition factor was calculated for all species/life stages encountered in the RST which had both a measured length and weight available (equation 1):

K = 100 (1)

where W is the wet weight (g) and L is the fork length (mm). We used general guidelines provided by Barnham and Baxter (1998) and Gao (2024) to interpret condition factor results broadly, from ‘extremely poor’ to ‘excellent’ condition. The following table is a combination of these two sources used to interpret our results (Table x), although note that most condition factor guidelines are based on adult salmonids and not juvenile life stages.

Table x. Condition factors adapted from Barnham and Baxter (1998) and Gao (2024) used to interpret K values in the present study.

|  |  |
| --- | --- |
| **K value** | **Condition interpretation** |
| > 1.60 | Excellent condition |
| 1.2-1.6 | Good, well-proportioned |
| 1.0-1.2 | Fair condition |
| 0.9-1.0 | Poor condition, long and thin |
| < 0.90 | Extremely poor condition, emaciated; large head and narrow, thin body |

As mentioned in section 2.3.3, using lethally-sampled Chinook weighed in the lab we were able to develop a model that explained the relationship between Chinook height and weight. This model was used to predict missing Chinook weights primarily for the fish non-lethally sampled in the purse seine catches, allowing us to estimate condition factor. The height-weight relationship for San Juan Chinook is detailed in Appendix xx.

### Size-specific survival (Chinook otolith microchemistry)

[Nicole/Micah to write?]

### Diet analysis

For RST stomachs, diet data were expressed as the proportion of stomachs empty, or with trace amounts of dietary contents (i.e., enumerated and identified as dietary items, but not able to be weighed). We chose not to assess stomachs as “full” or “partial” owing to the subjectivity around such measurements.

For beach and purse seine stomachs, individual contents were grouped into higher level taxonomic groupings based on source (marine/terrestrial/freshwater). We calculated the percentage of each dietary group per individual (by weight) and averaged across all samples to compare diets between sites within comparable time periods and by capture method (e.g., beach seine). To compare dietary preferences and feeding “intensity” across time and space more broadly, we calculated a Partial Fullness Index (PFI) for each dietary group in each individual fish (equation 2):

PFI = (2)

where is the wet weight (g) of each individual prey group, and is the wet weight (g) of the fish including the stomach and contents (e.g., pre-dissected field weight)

PFI is ideal for comparing juvenile diets over various life stages as it accounts for body size of larger individuals, thus reducing bias. For example, it reduces bias that might occur between larger hatchery-origin Chinook in the purse seine compared to smaller, natural-origin fish in the beach seine. We excluded contents from analyses that were not clear prey items, for example plant material/wood fragments, rocks, and feathers.

### Statistical analyses

#### Assumptions

Prior to any statistical analyses we checked assumptions of normality using quantile-quantile plots and Shapiro-Wilk tests. Depending on the outcome of these tests, we then checked the assumption of homogeneity of variance using either Flinger-Killeen tests (if non-normally distributed) or F-tests (if normally distributed), along with assessing the pattern of residuals from a simple linear model. All test are available in the *stats* package in R (CITE). If these assumptions were violated we used non-parametric tests, for example Mann-Whitney U-tests in place of Student’s T-Tests.

#### Predicting fish weight from height

We explored whether height could be used as a proxy for wet weight. To examine this relationship, we fit an exponential model to the full Chinook dataset which included fish sampled from the RST, beach and purse seine sampling.

Although the relationship between height and weight in the full dataset was significant (Table xx, Figure xxa), it appeared that at small body size (RST) the model tended to over-estimate weight, while at larger body size (purse seine) it would be more likely to under-estimate weight (Figure xxa). Log-transformation did not improve the relationship when all fish were considered. Therefore we separated the data into two datasets to model the relationship between height and weight: freshwater (RST) and early marine (beach and purse seine), and fit separate models to each of these life stages (Figure xx).

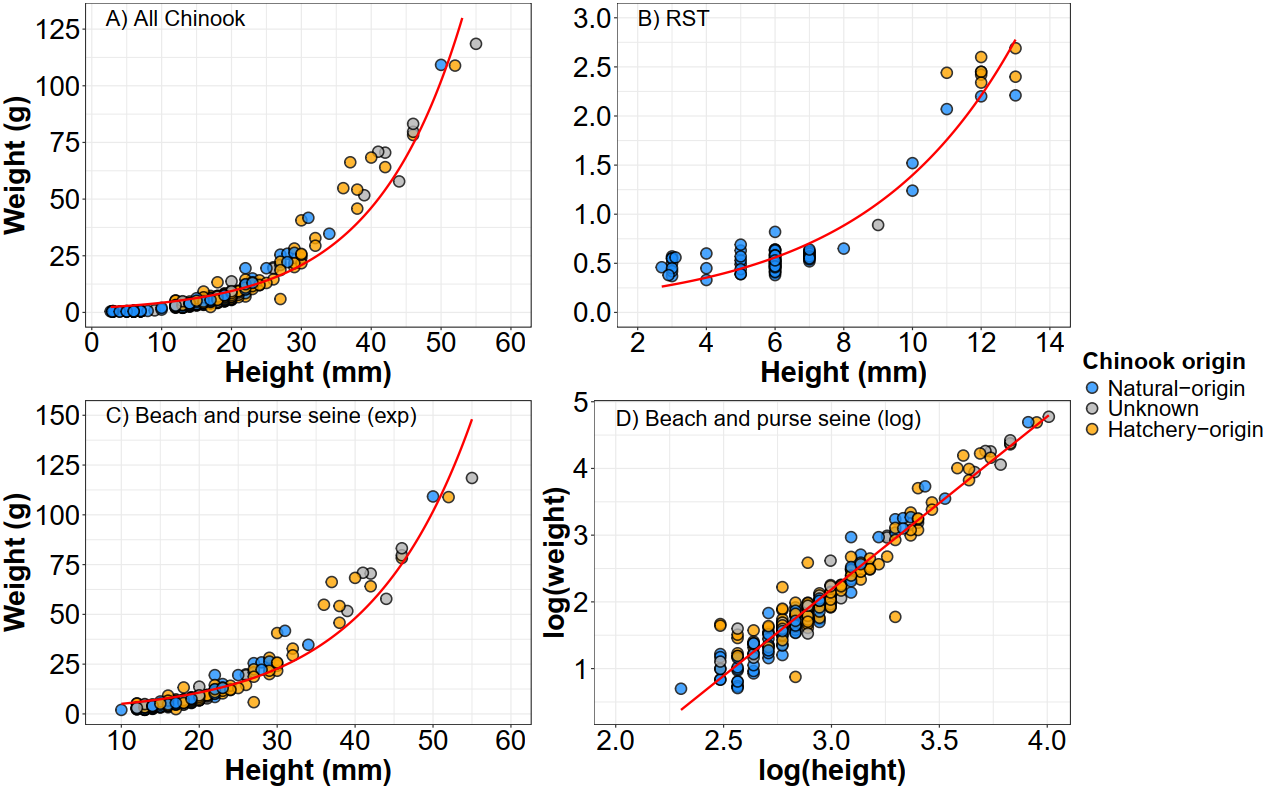


Figure xx. a) Exponential model fit to all fish sampled from all methods including the RST, beach seine, and purse seine, exponential models fit to fish from the b) RST and c) beach and purse seine only, and d) linear model fit to log-transformed height and weight from the beach and purse seine only. Exponential models were fit using the *nls* function in R (unweighted) and linear models were fit using the *lm* function in R.

The RST-only model still retained a clear significant relationship between height and weight (*p* < 0.01, *R2* = 0.92; Table 1), with the model appearing to better represent the height-weight relationship. We also explored the use of a Gompertz model to fit to the RST-only Chinook relationship as well, but the model did not provide an improved fit and would have been challenging to implement in future scenarios. However, caution should be exercised when trying to use the exponential model in Figure xxb above to predict weights outside of the observed data ranges. Exponential models assume infinite exponential growth which is not biologically plausible above a certain height and weight threshold.

A linear model fit log-transformed height and weight data from the beach and purse seine samples (*p* < 0.01, *R2* = 0.93) slightly better than compared to an exponential model (*p* < 0.01, *R2* = 0.92, Table 1), and is easier to implement for future predictive modelling. Therefore we used the linear model to predict missing fish weights from the purse and beach seine.

Table x. Parameter estimates and statistics for exponential models fit to the full dataset and RST-only dataset (corresponds to Figure xx).

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Model** | **Parameter** | **Estimate ± SE** | **t-value** | **p-value** | **R2** | **RMSE** |
| Full dataset | *A* | 1.929874 ± 0.091215 | 21.16 | <0.01 | 0.912 | 4.61 |
| *b* | 0.079375 ± 0.001075 | 73.82 | <0.01 |
| RST-only | *A* | 0.14181 ± 0.01057 | 13.41 | <0.01 | 0.923 | 0.174 |
| *b* | 0.22884 ± 0.00684 | 33.46 | <0.01 |
| Beach and purse seine only (exp) | *A* | 2.397387 ± 0.142407 | 16.84 | <0.01 | 0.921 | 5.41 |
| *b* | 0.074964 ± 0.001347 | 55.66 | <0.01 |
| Beach and purse seine only (lm) | *Intercept* | -5.58447 ± 0.14094 | -39.62 | <0.01 | 0.933 | 0.228 |
| *slope* | 2.59059 ± 0.04728 | 54.80 | <0.01 |

# RESULTS

## Freshwater outmigration (RST)

### Migration timing

Coho fry (sub-yearlings) were the most abundant species/life stage encountered. While their peak migration was variable across years, catches were usually consistently high through April. As expected, Chum were the earliest migrants and it is likely we only caught the very tail-end of the freshwater portion of Chum outmigration. Chinook followed Chum outmigration, with most Chinook leaving anywhere from late February to mid-April. A second, smaller Chinook outmigration was noted around May, although in much lower abundance (Figure xx and Figure xx).

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Figure xx. Observed RST catches of key juvenile salmonids in the San Juan River from 2023-2025. Black triangles along the x-axis indicate hatchery Chinook release dates in the upper San Juan River. Release group sizes are given in Table xx. Catches have not been adjusted for effort or missed days. Note differing x and y axes between panels.

Hatchery-origin Chinook were released into the upper San Juan River in 2024 and 2025. In 2024 we observed an immediate, large pulse of hatchery Chinook within 24-hours of release, indicating these fish were able to travel approximately 10 km in < 24 hours. In 2025 we did not see the same degree of hatchery abundance in the RST following release dates for two potential reasons. First, the RST capture efficiency in 2025 was much lower than in 2024 likely due to prolonged high water. Second, while some fish released in 2025 were larger body size (closer to 5 g), the overall goal in 2025 was to release smaller fish in pulses to help improve imprinting in the upper San Juan River, as noted by significantly smaller hatchery Chinook seen in 2025 compared to 2024 (Mann-Whitney U-test, *W* = 6416.5, *p* < 0.01).

Table x. Hatchery Chinook releases in the upper San Juan River in 2024 and 2025. All fish released in-river were adipose clipped. Note this does not represent the full extent of hatchery enhancement for San Juan Chinook. Release dates correspond to Figure xx.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Release year  (parental brood year)** | **Release date** | **Release group size** | **Average weight at release (g)** | **Average weight recorded in RST (g)\*** |
| 2024 (2023) | April 29 | 42,560 | 3.5 | 3.14 |
| 2025 (2024) | April 27 | 80,000 | 2.5-5 | 2.58 |
| April 28 | 120,000 |
| April 30 | 40,000 |
| May 9 | 60,000 |
| May 10 | 120,000 |
| May 11 | 35,000 |

*\* Average hatchery Chinook weight pooled across all sampling days*

### Abundance estimates

#### Infilling missed/unfished days

We infilled abundances for three key juvenile salmon life history types that we could obtain reliable abundance estimates from: natural-origin Chinook, yearling Coho and sub-yearling Coho. We only infilled abundances from 2024 and 2025; we did not infill from 2023 as there were not enough data points to make meaningful infilling assumptions. Table xx outlines the model chosen for each life history type, and a brief rationale. Infilled catch figures and full details on metric results are available in Appendix x.

Table xx. Species/life history- and year-specific infilling models selected along with the rationale for selection (NO = natural-origin, HO = hatchery-origin). See Appendix xx for details.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Year** | **Life history type** | **Days fished  (days infilled)** | **Infilling model** | **Rationale/notes** |
| 2024 | Chinook (NO) | 79 (37) | na\_kalman, (StructTs) | Lowest values in all metrics |
| Coho (sub-yearling) | 79 (37) | na\_kalman (ARIMA) | Lowest values in all metrics |
| Coho (yearling) | 79 (37) | na\_interpolation (stine) | Lowest values in all metrics |
| 2025 | Chinook (NO) | 93 (47) | na\_interpolation (linear) | Na\_interpolation (linear), na\_kalman (ARIMA and StructTS) all had same metric values, but linear was chosen because xx |
| Coho (sub-yearling) | 93 (47) | na\_ma (simple, 2-day winow) | Lowest values in all metrics; 2- and 3-day moving average window performed the same, so went with smaller window. |
| Coho (yearling) | 93 (47) | na\_kalman (ARIMA) | Lowest values in all metrics |

#### Chinook and Coho abundance estimates

## Biological sampling

### Size, weight and condition

We collected length and weight data from a total of 3,532 juvenile salmonids, and height from 929 juvenile Chinook between 2023-2025 (Table x).

Table x. Mean fork length, height, wet weight and condition factor for key juvenile salmonids encountered in the RST from 2023-2025. Averages are given with standard error in brackets.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Year** | **Species/life history** | **n** | **Mean fork length (mm)** | **Mean height (mm)** | **Mean wet weight (g)** | **Mean condition factor** |
| 2023 | Chum | 103 | 39.10 (0.21) | - | 0.43 (0.01) | 0.73 (0.01) |
| Coho alevin | 7 | 33.14 (0.34) | - | 0.47 (0.06) | 1.28 (0.13) |
| Coho fry (sub-yearling) | 554 | 39.13 (0.23) | - | 0.59 (0.02) | 0.93 (0.01) |
| Coho smolt (yearling) | 135 | 83.04 (1.52) | - | 7.33 (0.49) | 1.1 (0.02) |
| Chinook (natural) | 125 | 40.9 (0.2) | 10.62 (1.24) | 0.56 (0.01) | 0.83 (0.01) |
| 2024 | Chum | 83 | 38.95 (0.24) | - | 0.40 (0.01) | 0.68 (0.01) |
| Coho fry (sub-yearling) | 868 | 36.3 (0.19) | - | 0.46 (0.03) | 0.85 (0) |
| Coho smolt (yearling) | 131 | 93.37 (1.29) | - | 8.96 (0.33) | 1.04 (0.01) |
| Chinook (natural) | 315 | 41.4 (0.39) | 5.28 (0.09) | 0.66 (0.04) | 0.84 (0.01) |
| Chinook (hatchery) | 38 | 64.79 (1.03) | - | 3.14 (0.14) | 1.16 (0.06) |
| 2025 | Chum | 55 | 37.4 (0.4) | - | 0.38 (0.01) | 0.74 (0.02) |
| Coho fry (sub-yearling) | 561 | 36.12 (0.18) | - | 0.46 (0.01) | 0.93 (0.01) |
| Coho smolt (yearling) | 68 | 95.66 (1.83) | - | 9.7 (0.52) | 1.06 (0.01) |
| Chinook (natural) | 239 | 42.95 (0.47) | 7.59 (0.2) | 0.81 (0.04) | 0.91 (0.01) |
| Chinook (hatchery) | 250 | 61.96 (0.3) | 12.14 (0.04) | 2.58 (0.04) | 1.07 (0.01) |

We observed a significant difference in Chinook fork length over stat weeks (STATS), with size increasing from around 40 mm in March and early April to over 60 mm by late May. Change in condition factor was less pronounced and did not change significantly over stat weeks (STATS).

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Figure x. Weekly mean (± standard error) fork length and condition factor for juvenile San Juan Chinook encountered in the RST each year by stat week (given as the month and week number, e.g., 03-2 indicates the second week of March).

### Size-specific survival (otolith microchemistry)

FROM MICAH:

*Ok, we have the outlines of the dataset for the San Juan otoliths, just a few clarifying points:*

*1) We are not really sure what the reality of some of the growth conditions of the fish rearing in a brackish lake, but the fork length regression is potentially unreliable for a good number of samples. This is especially problematic due to some fish that are larger than anticipated by the original FL regression. It may be more accurate to use the otoliths to identify length achieved before entering any brackish environment, which we can switch to, but this system is just a lot different than ones we have looked at here so I am not sure how to best overcome this challenge.*

*2) There were a number of discrepancies between the scales and otoliths, 19/77 adults had age disagreements, and these were concentrated in the 2024 adults (12/40). If we looked at the biodata for these fish we could probably indicate which age is more likely to be accurate. This is not much different than standard disagreements between otolith and scale ages as seen in other subyearling Chinook. One of these fish is a clear yearling which we have indicated.*

*3) We have included basic data only at the moment but plan to conduct several analyses. We will have diagnostic plots showing the estuary entry size by origin by year, estuary residence by origin by year, age at return by origin, estuary entry size by age at return, estuary residence by age at return, relative size at end of first marine winter by age at return, and what we assume to be fairy lake usage by natural origin fish and age at return. If we have access to the biodata we can also compare how length at return is a factor in some of these variables.*

*..*

*Well, it is just more that otolith to FL relationships can change drastically between pure FW growth and estuarine growth, so we don't really know what the fairy lake growth will do to these fish, but the regression can change completely, let me grab an example*

*A diagram of a river

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*Here for example is the fork length to otolith radius relationship for Cowichan split between samples collected in the estuary vs those collected in the RST*

*we just want to make sure that we could give you some sort of reliable metric of size, we may have to just count fairy lake as the start of the estuary for fish that chose to hang out there*

*Looking at the regression sizes predicted, some of these natural origin fish are clearly too big*

*Here is the segmented regression for San Juan (including some hatchery individuals)*

*A graph with a line and dots

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*These individuals follow a standard relationship we expect for the fork length to otolith radius relationship*

*My concern is that fish that enter Fairy Lake might start to grow differently and thus we might not be able to confidently say how larger they are when they leave the lake and use the estuary below the lake*

*Ok, for interest, we found that roughly 31 natural origin fish did not appear to use the lake while 27 did of the successfully returning natural origin adults*

*The yearling was 297560 in otomanager*

*For instance, all but one of the EU 0.2 fish used the lake*

*And only 3 of the 13 age 0.4 fish used the lake*

### Stomach contents

We collected a total of n=96 juvenile Chinook stomachs from the RST, primarily in 2024 and 2025. Each year approximately 40% of stomachs were empty, while the rest had either trace amounts of material and/or identifiable, weighable prey items (Figure x).

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Figure x. Juvenile Chinook stomach fullness in the San Juan RST from 2023-2025. Labels at the bottom of bars indicate number of stomachs collected each year. Identifiable prey items included those which could be weighed, while ‘trace’ refers to presumed prey fragments too light to be weighed.

# DISCUSSION

# CONCLUSION

# ACKNOWLEDGEMENTS

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Pacheedaht's relationship with and stewardship of the land in and around the San Juan watershed has existed for millenia and continues to this day. Their dedication and care for the land, waters and animals inhabiting their territory made this work more successful and meaningful, and DFO staff are grateful for their generosity in sharing knowledge and context for this collaborative study.

Rod, Linda and Thomas Bealing were also instrumental in providing access, machinery, time, and passion to the project. Thank you to the Bealing Family for welcoming us onto your land and supporting us for several years while we tested the boundaries of what excavators and RSTs can achieve.

Thank you as well to Lisa Margetish and Shane Bruinsma from 4 Mile Hatchery, and Heather Wright (DFO Community Advisor) and for their tireless dedication to improving the San Juan Chinook enhancement process, including marking and releasing hatchery Chinook which made our RST program more successful, and for lending safety signage for the project as well.

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# AUTHOR CONTRIBUTIONS

Listed in order appearing in authorship list.

Study conception/funding/coordination: KHD, JB, NL, MQ, WL, HJ

Field data acquisition: KHD, JA, PFN

Lab work: JA, MQ, NL

Data analysis and results interpretation: KHD, JB, DB, NL, MQ, HJ

Report development: KHD, JB, HJ

Report review: KHD, JB, DB, NL, MQ, HJ,

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# APPENDICES

## TECHNICAL OPERATIONS

### RST operations



A)

B)

Stump 2

Stump 1



C)

D)



E)

F)

Figure xx. The RST at different water levels during 2025. Note the position of the two stumps in photos for orientation. A) February 24, water at approx. 4 m or 175 m3/s, B) March 21 water at approx. 3.9 m or 160 m3/s, c) April 14, water at approx. 2.8 m or 36 m3/s, d) May 19 water at appox. 2.4 m or 14 m3/s. In e) February 22-23 and f) March 23-24, levels exceeded the bank height and the RST was deposited on the ground on top of the bank; these events corresponded to 5.7 m or 450 m3/s and 5.75 m or 500 m3/s, respectively. At high flows above approx. 150 m3/s the site becomes a back-eddy and the trap spins slowly (or hardly at all). This is ideal for avoiding logs and reducing damage to the trap, but not for fish capture.

## ABUNDANCE ESTIMATES

### Infilling for missed/unfished days

Model evaluation metrics are provided below for each species/life history type, followed by figures showing infilling results.

Table xx. All infilling models considered by year and species/life history type with associated metrics. Mean absolute error (MAE) was calculated with and without zero points (MAE\_w0 or MAE\_no0, respectively) to evaluate the ability to predict zero catch when observed. Mean absolute scaled error (MASE) and mean absolute percentage error (MAPE) are also given, although MAPE was not considered a strong metric as it cannot be calculated for observed zeroes.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Year** | **Infilling model name** | **MAPE** | **MAE\_w0** | **MAE\_no0** | **MASE** | **Notes** |
| 2024 | chinook\_natural\_kal.structs | 1.213 | 6.007 | 6.820 | 0.443 | Model selected |
| chinook\_natural\_interp.linear | 1.245 | 6.446 | 7.396 | 0.475 |  |
| ~~chinook\_natural\_interp.stine~~ | ~~1.219~~ | ~~6.501~~ | ~~7.227~~ | ~~0.479~~ | Excluded – predicted negative catch |
| ~~chinook\_natural\_kal.arima~~ | ~~1.712~~ | ~~7.456~~ | ~~8.159~~ | ~~0.549~~ | Excluded – predicted negative catch |
| chinook\_natural\_MA.exp3 | 1.285 | 7.727 | 8.811 | 0.569 |  |
| chinook\_natural\_MA.exp2 | 1.333 | 7.769 | 8.852 | 0.572 |  |
| chinook\_natural\_MA.linear3 | 1.116 | 7.828 | 8.650 | 0.577 |  |
| chinook\_natural\_MA.linear2 | 1.195 | 7.898 | 8.719 | 0.582 |  |
| chinook\_natural\_MA.simp3 | 0.874 | 7.958 | 8.458 | 0.586 |  |
| chinook\_natural\_MA.simp2 | 0.993 | 8.063 | 8.563 | 0.594 |  |
| 2025 | chinook\_natural\_interp.linear | 0.948 | 4.930 | 12.856 | 0.555 | Model selected |
| chinook\_natural\_kal.arima | 0.948 | 4.930 | 12.856 | 0.555 |  |
| chinook\_natural\_kal.structs | 0.948 | 4.930 | 12.856 | 0.555 |  |
| ~~chinook\_natural\_interp.stine~~ | ~~1.071~~ | ~~5.251~~ | ~~13.230~~ | ~~0.592~~ | Excluded – predicted negative catch |
| chinook\_natural\_MA.simp2 | 0.649 | 5.278 | 13.130 | 0.595 |  |
| chinook\_natural\_MA.simp3 | 0.649 | 5.278 | 13.130 | 0.595 |  |
| chinook\_natural\_MA.linear2 | 0.800 | 5.351 | 13.155 | 0.603 |  |
| chinook\_natural\_MA.linear3 | 0.800 | 5.351 | 13.155 | 0.603 |  |
| chinook\_natural\_MA.exp2 | 0.921 | 5.433 | 13.196 | 0.612 |  |
| chinook\_natural\_MA.exp3 | 0.921 | 5.433 | 13.196 | 0.612 |  |
| 2024 | coho\_subyearling\_kal.arima | 0.935 | 67.175 | 67.175 | 0.252 | Model selected |
| ~~coho\_subyearling\_interp.stine~~ | ~~1.609~~ | ~~91.931~~ | ~~91.931~~ | ~~0.344~~ | Excluded – predicted negative catch |
| coho\_subyearling\_kal.structs | 2.343 | 93.723 | 93.723 | 0.351 |  |
| coho\_subyearling\_interp.linear | 1.293 | 95.357 | 95.357 | 0.357 |  |
| coho\_subyearling\_MA.exp3 | 1.313 | 138.347 | 138.347 | 0.518 |  |
| coho\_subyearling\_MA.exp2 | 1.318 | 138.460 | 138.460 | 0.519 |  |
| coho\_subyearling\_MA.linear3 | 1.147 | 145.179 | 145.179 | 0.544 |  |
| coho\_subyearling\_MA.linear2 | 1.164 | 145.569 | 145.569 | 0.545 |  |
| coho\_subyearling\_MA.simp3 | 0.911 | 155.292 | 155.292 | 0.582 |  |
| coho\_subyearling\_MA.simp2 | 0.940 | 156.000 | 156.000 | 0.584 |  |
| 2025 | coho\_subyearling\_MA.simp2 | 3.070 | 43.815 | 43.815 | 1.172 | Model selected |
| coho\_subyearling\_MA.simp3 | 3.070 | 43.815 | 43.815 | 1.172 |  |
| coho\_subyearling\_MA.linear2 | 3.866 | 52.174 | 52.174 | 1.396 |  |
| coho\_subyearling\_MA.linear3 | 3.866 | 52.174 | 52.174 | 1.396 |  |
| coho\_subyearling\_interp.linear | 4.413 | 56.831 | 56.831 | 1.521 |  |
| coho\_subyearling\_kal.structs | 4.413 | 56.831 | 56.831 | 1.521 |  |
| coho\_subyearling\_MA.exp2 | 4.509 | 58.944 | 58.944 | 1.577 |  |
| coho\_subyearling\_MA.exp3 | 4.509 | 58.944 | 58.944 | 1.577 |  |
| ~~coho\_subyearling\_kal.arima~~ | ~~4.893~~ | ~~60.562~~ | ~~60.562~~ | ~~1.620~~ | Excluded – predicted negative catch |
| ~~coho\_subyearling\_interp.stine~~ | ~~5.282~~ | ~~63.144~~ | ~~63.144~~ | ~~1.689~~ | Excluded – predicted negative catch |

*(cont’d on next page)*

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|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 2024 | coho\_yearling\_interp.stine | 1.599 | 3.099 | 3.610 | 0.542 | Model selected |
| coho\_yearling\_interp.linear | 1.700 | 3.232 | 3.668 | 0.566 |  |
| coho\_yearling\_MA.simp3 | 1.758 | 3.438 | 3.563 | 0.602 |  |
| coho\_yearling\_MA.linear3 | 1.823 | 3.449 | 3.491 | 0.604 |  |
| coho\_yearling\_MA.exp3 | 1.877 | 3.458 | 3.437 | 0.605 |  |
| coho\_yearling\_MA.exp2 | 1.909 | 3.481 | 3.413 | 0.609 |  |
| coho\_yearling\_MA.linear2 | 1.877 | 3.490 | 3.451 | 0.611 |  |
| coho\_yearling\_MA.simp2 | 1.841 | 3.500 | 3.500 | 0.613 |  |
| coho\_yearling\_kal.structs | 1.353 | 3.545 | 3.983 | 0.620 |  |
| coho\_yearling\_kal.arima | 1.000 | 4.125 | 5.125 | 0.722 |  |
| 2025 | coho\_yearling\_kal.arima | 0.768 | 0.542 | 0.816 | 1.083 | Model selected |
| coho\_yearling\_interp.linear | 1.014 | 0.750 | 0.935 | 1.500 |  |
| ~~coho\_yearling\_interp.stine~~ | ~~1.075~~ | ~~0.781~~ | ~~0.996~~ | ~~1.562~~ | Excluded – predicted negative catch |
| coho\_yearling\_MA.simp2 | 1.083 | 0.833 | 0.944 | 1.667 |  |
| coho\_yearling\_MA.simp3 | 1.083 | 0.833 | 0.944 | 1.667 |  |
| coho\_yearling\_MA.linear2 | 1.138 | 0.851 | 0.999 | 1.703 |  |
| coho\_yearling\_MA.linear3 | 1.138 | 0.851 | 0.999 | 1.703 |  |
| coho\_yearling\_MA.exp2 | 1.178 | 0.863 | 1.041 | 1.726 |  |
| coho\_yearling\_MA.exp3 | 1.178 | 0.863 | 1.041 | 1.726 |  |
| coho\_yearling\_kal.structs | 0.974 | 1.110 | 0.777 | 2.220 |  |

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Figure xx. Observed (black) and infilled (coloured) natural Chinook counts for 2024 and 2025. All models evaluated are shown here for visual comparison. Black circles represent observed counts. Black crosses indicate observed counts removed from the dataset for infilling model validation.

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Figure xx. Observed (black) and infilled (coloured) sub-yearling Coho counts for 2024 and 2025. All models evaluated are shown here for visual comparison. Black circles represent observed counts. Black crosses indicate observed counts removed from the dataset for infilling model validation.

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Figure xx. Observed (black) and infilled (coloured) yearling Coho counts for 2024 and 2025. All models evaluated are shown here for visual comparison. Black circles represent observed counts. Black crosses indicate observed counts removed from the dataset for infilling model validation.

## Coho life history identification

We primarily used size as an indication as to whether Coho were classified as fry (sub-yearlings) or smolts (yearlings). Alevin were the exception, where Coho were only classified as alevin if there was still evidence of a yolk sack (i.e., the fish was not “buttoned-up”). Figure A1 indicates size is a reasonable indicator to separate these life history types.

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Figure A1. Fork length of Coho visually grouped into one of three life history stages: alevin, fry (sub-yearling), or smolts (yearling). Dashed lines represent group means.

## Otolith microchemistry

### Fork length-radius relationship

A linear relationship between juvenile Chinook field fork length (mm) and otolith radius (um) was established by collecting xx lethal samples and ablating otoliths to measure radius.

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Figure xx.