HATCHERY RELEASE STRATEGIES REVIEW: DATA SUMMARY REPORT

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The following is a summary of the data used for the Pacific Salmon Foundation's Hatchery Release Strategies Review. The review of hatchery release strategies was part of a larger Hatchery Effectiveness Review funded by the British Columbia Salmon Restoration and Innovation Fund (BCSRIF-2019-136). The objectives of the release strategies review were to evaluate the outcomes of different strategies used by salmon hatcheries throughout British Columbia (BC) and inform how they could be adapted to improve survivals and meet production objectives moving forward.

We conducted three separate analyses to this end:

1. a systematic review of the literature on release strategies from BC and the western United States,
2. an evaluation of hatchery experimental releases of coded wire tagged (CWT) Chinook and Coho salmon throughout the province since 2000, and
3. a comprehensive analysis of release strategy effects on survival and return ages of CWT Chinook and Coho in BC from 1972 to present.

The data used for these analyses are described below with the datasets themselves publicly available on the Strait of Georgia Data Centre.

PART 1: SYSTEMATIC LITERATURE REVIEW

A keyword search was conducted using two commercial academic search engines, Web of Science Core Collection (WoS) and Aquatic Sciences and Fisheries Abstracts (ASFA) to capture peer-reviewed literature. The Fisheries and Oceans Canada (DFO) Library, and the Google Scholar search engine were used to find additional grey literature. The relevant data (Table 1) were extracted and collated in a spreadsheet which is publicly available on the Strait of Georgia Data Centre.

Table 1: Description of the data extracted from each reference in the systematic literature review process.

DATA CATEGORY	DATA EXTRACTED
Publication	Publication date, publication type, authors, first author affiliation, title, journal, year of publication, volume, page numbers, abstract, ISSN/ISBN, DOI
Study details	Country, region, system (area or watershed of the study), river salmon released into, hatchery name and coordinates, brood years used, total number of years of the study, mark type used (e.g. CWT, AD clip, etc), species, life stage, which release strategy was being investigated, how many release strategies were investigated, the nature of the treatment and whether it was categorical or continuous, numbers of fish released per treatment and overall numbers released for the entire study, stats type used in analyses
Study results	Response variable being measured, number of response variables evaluated, directional response (e.g. higher or lower for categorical treatments, positive or negative for continuous treatments), management recommendations made by authors, brief summary of main findings and any biases

Cover photos by: top: Eiko Jones, left, centre and right: Sam James

PART 2: HATCHERY EXPERIMENTS

Experimental releases of enhanced Chinook and Coho salmon from DFO facilities were evaluated to determine the effects on marine survival rates, exploitation rates, and return ages. Hatchery practices and environmental conditions have changed considerably since enhancement began in the 1970s, therefore we chose to focus on experiments conducted in the past 20 years to better understand the effects of release strategies on production outcomes *today*. We focused on the species and stocks for which there were sufficient (minimum of 3 years) releases and recoveries of coded wire tagged (CWT) fish. This is because there is a standardized recovery program for CWTs that allows for better accounting of enhanced production. There is no such recovery program for thermal marks, therefore they were not included in our analyses.

The information required for this analysis was: which facilities had conducted experiments, what the treatment groups were (with details on release weights, dates, and life stages), how many fish were released per treatment per year, and how many fish were recovered from each treatment group each year (either in fisheries, hatchery removals, or escapement). Most of this information was available in the Salmonid Enhancement Program's (SEP) Recovery by Tagcode Report (provided by Cheryl Lynch, SEP, December 2019). This report provides release and escapement data from the Enhancement Planning and Assessment Database (EPAD) and catch data from the MRP (Mark Recovery Program of CWT data) database. Note that the EPAD is constantly being updated as changes are made to the MRP data and quality control and assurance is an ongoing process. Therefore, there may be some minor differences in the data we are sharing (from 2019) and the current version of the data in EPAD.

These data provide information on each release event, such as the release location, the average weight at release, the start and end dates of release, and the numbers released. They also include information on the ages and numbers of returns in commercial and recreational fisheries, in escapement surveys, and to the hatchery, which SEP uses to calculate survival and exploitation rates by age class of each brood year using estimated tag numbers. Estimated numbers account for tags in the sampled and *unsampled* part of the catch or escapement and are calculated as:

$$Estimate = \frac{\#\ observed\ tags}{sample\ rate} \quad (1)$$

where the sample rate is the portion of a catch strata directly sampled for CWT recoveries (target sample rate is typically 20%). Survival rates (S_i) are calculated for each release group i as:

$$S_i = \frac{1}{r_i} \sum_a^A C_{ai} + E_{ai} \quad (2)$$

where r_i is the total number of tagged releases for group i, a and A are the minimum and maximum return ages, respectively, C_{ai} is the estimated catch-at-age (in number of fish) of group i in both US and Canadian fisheries, and E_{ai} is the estimated escapement-at-age of group i to their natal hatchery or stream.

Exploitation rates (U_i) are calculated for each release group i as:

$$U_i = \frac{1}{\sum_a^A C_{ai} + E_{ai}} \sum_a^A C_{ai} \quad (3)$$

wherein the sum of the catch-at-age is divided by the sum of the catch-at-age plus escapement-at-age.

Note that the estimates for S_i and U_i are not equivalent to other estimation methods applied annually for the Chinook and Coho technical committees within the Pacific Salmon Commission.

Photo by: Mitch Miller

Often, larger release groups will have multiple unique tagcodes within the group. This is generally because there are a limited number of coded wire tags on each spool for each tagcode, resulting in more than one being used per release group. In these cases, we aggregated all releases of salmon of the same weight, on the same date, of the same stock at the same location and assigned them the same tagcode (aggRelCode). Survival rates, exploitation rates, and ages were also calculated by aggregated release group, rather than by unique tagcode.

The Recovery by Tagcode reports contain data usability flags, and were therefore used to filter the data to meet the following criteria prior to conducting any analyses:

- SURVIVAL_CODE = Y
- EXPLOITATION_CODE = Y
- MARK_TYPE_CODE = CWT
- Age, ExplRate, TotCatch+Esc, SurvRate, AVE_WEIGHT ≠ NA
- STOCK_NAME ≠ Yukon R

Problematic releases are also flagged in the database and a list of release events that were unsuitable for analyses were also provided by SEP. Many of these were removed through our SURVIVAL_CODE = Y filter, however those that weren't are listed in the 'unsuitable_releases.csv' file. Many of the issues appeared to stem from concerns around the health of the juveniles released or major mortality events. We therefore scanned the comments of the recovery reports for any other unsuitable releases that may have still had a SURVIVAL_CODE = Y, adding 19 additional unsuitable releases to create a full record to be excluded from our analyses (see FLAG_SOURCE' in 'flagged_releases.xlsx' on the Strait of Georgia Data Centre metadata page to distinguish between PSF's added flags and SEP's original flags). These releases were removed from our final hatchery data file (see 'Chinook_release_recovery_data.xlsx' and 'Coho_release_recovery_data.xlsx').

It was also brought to our attention after analyses were complete that some Coho tagcodes should be excluded when measuring survival or harvest rates. This is because of the nature of the mass marking program and mark selective fisheries. By 2005, all hatchery coho yearling production in SBC was adipose clipped (AD-clipped) to indicate hatchery origin. CWTs continue to be used, but CWT recoveries have become less effective due to the low proportion of AD-clipped fish with CWTs. Double index tagging was used in some cases to provide a means to estimate fishery impacts on unmarked natural-origin fish without relying on assumption-based model projections. For this, two related CWT groups were released: one AD-clipped and one unclipped. Recoveries were then used to inform differences in exploitation rates on the two groups. However, because many Coho fisheries are mark selective, fewer CWTs from the unclipped release groups were likely recovered, biasing survival rates. We were unable to revise our analyses given our project timelines, however for other users of these data, **note that unclipped but CWT'd Coho releases should not be used for estimating survival rates**. Unclipped CWT Coho releases make up 3% of the releases in the dataset, therefore we do not anticipate a significant change in model outcomes, however the data should still be removed prior to analyses.

Photo by: Sam James

The list of experimental releases was compiled through conversations with SEP staff, as well as by systematically searching the releases in EPAD for those with more than one release strategy in a given release year (e.g. more than one release weight or date). We also searched the release comments for anything that might suggest an experimental release. Any potential experiments were then confirmed and details obtained from hatchery staff.

The following is a summary of the data acquired, their source, and any data manipulations that were required:

Table 2: Summary of the data collated for assessing hatchery experiments on CWT Chinook and Coho in BC.

DATA	SOURCE	MODIFICATIONS
facility	Recovery by Tagcode Report (SEP)	none
species	Recovery by Tagcode Report (SEP)	none
stock	Recovery by Tagcode Report (SEP)	none
run	Recovery by Tagcode Report (SEP)	none
# of fish released	Recovery by Tagcode Report (SEP)	Aggregated so that release groups with same weight and date from the same facility were treated as one release group
release weight	Recovery by Tagcode Report (SEP)	none
release date	Recovery by Tagcode Report (SEP)	Releases with a difference between the start and end dates of more than 15 days were excluded. The midpoint of the release interval was used for any remaining multi-day releases. Where only the release year and month were given we used the 15th day of the month (n = 7 release events).
life stage release	Recovery by Tagcode Report (SEP)	"Fall Fry" were an experimental fall release at select facilities that were neither fry nor subyearling CN - removed from analyses. 'Smolt 0+' = subyearling, 'Smolt 1+' = yearling
# of fish recovered	Recovery by Tagcode Report (SEP)	Recoveries and returns are given by age class in the recovery report therefore we calculated estimated survival and exploitation rate by tagcode and calculated a weighted return age per tagcode, and then by ocean entry year.
experimental objectives	comments in EPAD, hatchery interviews	none

Photos by: Sam James

PART 3: MODELLING OF RELEASE STRATEGY EFFECTS ON SURVIVAL AND RETURN AGES

This analysis utilized all release and recovery data available for CWT'd Chinook and Coho since modern day enhancement in BC began in 1972. The objective was to go beyond the handful of short-term experiments and maximize the full extent of the available data to estimate release strategy effects on survival and return age outcomes and develop hatchery-specific recommendations for improving the effectiveness of hatchery strategies.

The hatchery data inputs for part three were the same as in part two with release and recovery information coming from the Recovery by Tagcode Reports from SEP (see 'Chinook_release_recovery_data.xlsx' and 'Coho_release_recovery_data.xlsx').

To assess the impacts on return age, we used mean age of return for Chinook and mean proportion of Jacks (Age-2 males) for Coho. This was because while 99.5% of Chinook returns were 2-5 year olds, 99.6% of Coho returns were 2-3 year olds, making it easy to separate Coho ages into 'Jacks' and Age-3's. For Chinook, mean age of return $\bar{a}_i$ for each release group i was calculated as:

$$\bar{a}_\imath = \frac{1}{R_{.i}} \sum_{a}^{A} R_{ai} \alpha$$

where R_{ai} is the total number of returns at age calculated by summing escapement and catch, and a dot "." In place of the subscript a represents summation over that index.

For Coho, the proportion of Jacks J_i for each release group i was calculated as:

$$J_i = \frac{R_{2i}(1 - f_{2i})}{R_{.i}^{M}}$$

Where the superscript M identifies male returns, thus R_{2i} is the total number of Age-2 returns while $R_{.i}^{M}$ is the estimate total male returns (catch + escapement) summed across all ages for release group i. Proportion of Jacks was then transformed to the log-odds (logit) scale for model fitting.

We also needed to consider the proportion of females in the returns, as females tend to return at older ages. Biological sampling for sex composition of escapement was available for approximately 30% and 47% of Chinook and Coho CWT releases, respectively and was obtained from escapement records. There is no biological sampling for sex composition of catch and so the sex proportions only reflect escapement. The proportion of females in total returns was determined by multiplying the proportion of females of each age class in the biological sampling of escapement by the total returns of each age class and then dividing by total returns. These data were added to those from the Recovery by Tagcode report in our final hatchery data files. Note that the age data used throughout our analyses were the CWT ages from the EPAD Recovery by Tagcode reports, not the ages from the biological sampling of escapement.

Photos by: Sam James

An additional step in this analysis was to examine whether the inclusion of specific environmental indices could provide better model fits compared to using random year effects and a fixed decreasing temporal trend covariate. We considered both large-scale and local environmental conditions, as well as predation. The Pacific Decadal Oscillation is a long term recurring pattern of ocean climate variability in the Pacific that has been linked to salmon demography (Mantua *et al*. 1997) and was used as our large-scale climate indicator. Coastal sea surface temperatures were used to capture local environmental dynamics at the time of ocean entry.

In order to pair the environmental data to hatchery releases both spatially and temporally, we needed to know when and where the fish were released, as well as when and where they entered the ocean. Neither release coordinates nor ocean entry points are currently reported by SEP and were therefore compiled through both conversations with watershed enhancement managers (WEMs) and pulling coordinates from maps. Some saltwater entry points occurred in coastal inlets or estuaries, for which we also identified the nearest ocean entry point along the expected migration route that was outside the inlet or estuary.

With both release locations and points of ocean entry, we were able to measure migration distances as well as migration timing. Distance was measured by tracing the route down the centre of the waterways using QGIS. The river and coastal migration distances were used to estimate the number of days it took for salmon to migrate from the release site to ocean entry points based on mean travel speeds for Chinook (CN) and Coho (CO) from Melnychuk *et al*. 2010 (their Figure 4). Estimates for the Fraser River (CN: 47 km/day, CO: 36 km/day), were much higher than speeds for other rivers (CN: 8 km/day, CO: 8 km/day) and coastal areas (CO: 4 km/day). There were no estimates of Chinook travel speeds for coastal areas, so we used the Coho estimates (4 km/day) to estimate the duration of coastal migration distances (i.e., travel time between saltwater and ocean entry points) for both species.

Ocean entry points were then used to define the centre of a rectangular area of early ocean residence for juvenile salmon that was +/- 40 km in directions perpendicular to the shoreline and +/- 125 km in directions parallel to the shoreline. A maximum distance of 40 km off the coast was based on findings that the highest catches of juvenile salmon occurred within 40 km of the shore in Southeast Alaska (Orsi *et al*. 2003). Average SST data for each release event was calculated based on the weighted proportion of ERSST grid cells that overlapped with the ocean residence polygons for the 30 days before and after the estimated date of ocean entry.

Harbour seals and killer whales are two of the dominant marine mammals consuming salmon. Therefore, we used harbour seal numbers in the year of ocean entry and killer whale numbers for the mean return year of each release event. Harbour seal abundance estimates for the Strait of Georgia and the rest of the BC coast for 1970-2020 were estimated from logistic models using parameter estimates from Olesiuk 2010. Strait of Georgia numbers were used for hatcheries in that region, while numbers for the outer coast were used for all other facilities. Both Northern Resident (Chasco *et al*. 2017, Towers *et al*. 2020) and Southern Resident (Centre for Whale Research Data) killer whale numbers were used for hatcheries in Strait of Georgia and Vancouver Island hatcheries, while Northern Resident numbers only were used for North and Central Coast hatcheries.


Photo by: Sam James

The following is a summary of the environmental datasets used. The corresponding data are available on the Strait of Georgia Data Centre under 'Associated Resources'.

Table 3: Summary of environmental data collated for hierarchical multi-hatchery modelling.

DATA	DESCRIPTION	SOURCE
Freshwater migration distance	The distance between where the salmon were released by the hatchery and where they entered saltwater. We identified saltwater entry points as those where the river migration route met the ocean boundary of the coastal watershed polygon.	Canadian Geographic Watersheds
Total biomass released	Biomass was calculated as the number of releases of all species per year at a given release location times the average weight at release (g). Note that where release weights were not available, biomass was recorded as 0 kg, meaning total biomass released per release site may be underestimated in some locations/years.	Recovery by Tagcode Reports (EPAD)
Pacific Decadal Oscillation (PDO)	Index of ocean climate variability (pressure and temperature) for the North Pacific area spanning 1000s of kilometers	Mantua *et al*. 1997
Sea Surface Temperature (SST)	Monthly values for 2° x 2° grid cells from NOAA's extended reconstruction of SST. For each release site, we identified ocean entry points and a region of early ocean residence for juvenile salmon that was +/- 40 km in directions perpendicular to the shoreline and +/- 125 km in directions parallel to the shoreline. Average monthly SST for each release event was calculated based on weighted proportion of ERSST grid cells that overlap with the ocean residence polygons. We used 60-day weighted averages for SST corresponding to estimated dates of ocean arrival for each release event. This 60-day average was centered around the ocean arrival date to estimate an average SST for the period 30 days before and after ocean entry.	NOAA's National Centre of Environmental Information, Huang *et al*. 2017
Harbour seal abundance	Harbour seal numbers in the year of ocean entry to account for predation on juveniles. Abundance estimates for Strait of Georgia and the rest of the BC coast (i.e., Haida Gwaii, North Coast, Central Coast, Queen Charlotte Strait, Discovery Passage, West Coast Vancouver Island) for 1970-2020 were estimated from logistic models using parameter estimates from Olesiuk *et al*. 2010. We used Strait of Georgia seal numbers for hatcheries in Strait of Georgia, while the time series for the BC outer coast was used for hatcheries in Northeast Vancouver Island, Central Coast, Northern BC and West Coast Vancouver Island.	Olesiuk 2010
Killer whale abundance	Both Northern and Southern Resident numbers in the mean return year of each hatchery release were used for analyses. Only Northern Resident numbers were used for hatchery releases on the central and north coast of BC.	Chasco *et al*. 2017, Towers *et al*. 2020, Centre for Whale Research Data

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