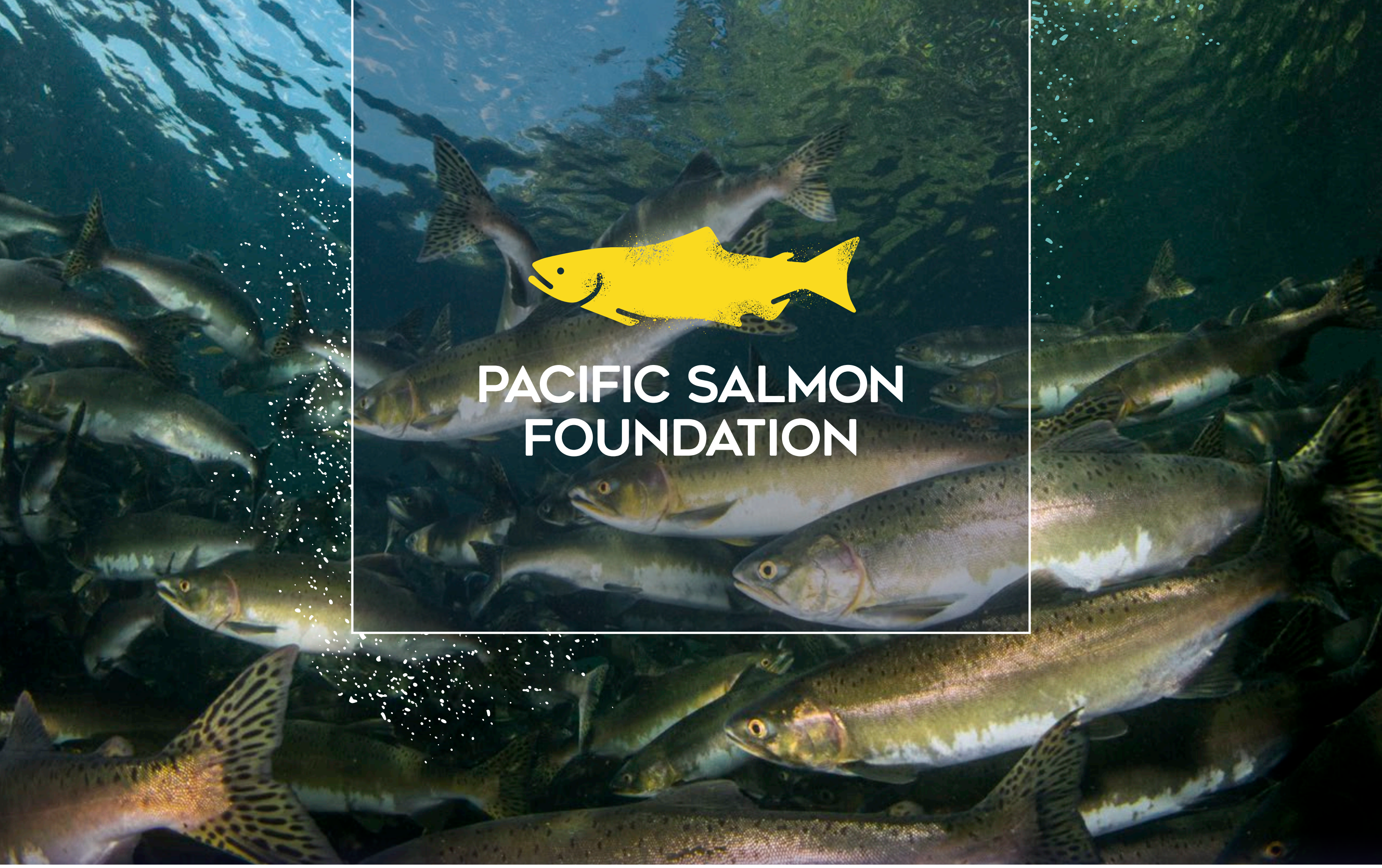

PACIFIC SALMON FOUNDATION



REVIEW AND ASSESSMENT OF ENHANCEMENT FOR HARVEST AND REBUILDING

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

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Photo by: Eiko Jones

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2. EXECUTIVE SUMMARY

Hatchery production in BC is intended to provide salmon for at least one of the following: harvest, rebuilding, assessment (for Pacific Salmon Treaty requirements), conservation, stewardship, or education objectives. The Pacific Salmon Foundation received BCSRIF funding to conduct a comprehensive review of Hatchery Effectiveness. As part of the review, we evaluated the effectiveness of production for harvest and rebuilding objectives.

In this report, we explore methods to assess the effectiveness of enhancement for both harvest and rebuilding purposes. We did not explore the effectiveness for other objectives (e.g., assessment, conservation, or stewardship). For harvest, we focused on Chinook and coho where coded-wire tag (CWT) information is available, with some additional analyses on chum. For rebuilding systems, we used recent production plans (2014-2021) to identify lines of production labelled as "rebuilding" objective in at least one year of the 2014-2021 plans. In both cases, we develop methods that could be applied broadly. However, in doing so we discovered that there are many nuances to enhancement objectives (e.g. rebuilding may mean many different things, each with different objectives potentially), and in specific locations and times broader methods may not fully capture the level of detail or all relevant information required.

In many cases, metrics for measuring the effectiveness of production were lacking; therefore, we also provide a framework for future monitoring and assessment programs.

Harvest

In order to assess production for harvest, we asked three questions:

1. What is the enhanced contribution of Chinook, coho, and chum salmon to total catch and escapement in BC?
2. Where are enhanced salmon showing up in fisheries catch? Which fisheries are harvesting enhanced salmon?
3. What is the efficiency of each hatchery at producing fish for harvest?

We compiled all available catch records to develop a single estimate of total catch of hatchery-produced Pacific salmon in BC, however recreational catch data are absent in many areas and we were unable to obtain recreational catch records for the central (CCST) and north coasts (NCST) prior to 2012. We also developed a method for extending coded-wire tag (CWT) expansions to account for non-CWT-associated hatchery releases.

We found that Chinook, coho, and chum fisheries in the inner south coast region (ISC) have the highest enhanced contributions. Since the late 1970s/early 1980s, estimates of the average enhanced contribution were 37% (ranging from about 7% to 90%) for Chinook; for coho, 41% (ranging from 5% to 100%); and for chum (net fisheries, specifically), 43% (ranging from near zero to 100%). On the west coast of Vancouver Island (WCVI), estimates of the enhanced contribution to fisheries were 26% (ranging from about 2% to 75%), 34% (ranging from about 2% to 100%), and 25% (ranging from near zero to 75%) for Chinook, coho, and chum (net) fisheries, respectively. Given a lack of data for the NCST and CCST, enhanced contributions to catch were not estimated for these regions, although Lynch et al. (2020) report 16% and 19% enhanced contributions of chum salmon to net fisheries in the NCST and CCST, respectively (based on our analysis of data from Lynch et al. 2020).

Both total salmon catches and enhanced salmon catches have decreased over time. As catches have decreased, we have seen a shift in the distribution of Chinook and coho catch from predominantly commercial to predominantly recreational fisheries, likely due to changes in regulations and fishery openings. Most of BC's enhanced production is harvested in BC, however Alaskan fisheries take a significant proportion of the total enhanced production. WCVI sport fisheries and northern troll fisheries are the next largest fisheries categories after Alaskan fisheries. There are also shifts over time in the catch distributions. Hatchery coho (likely from South Coast and US hatcheries) have been largely caught in the northern Strait of Georgia sport fisheries, as well as troll fisheries off of southwest Vancouver Island.

Rebuilding

In order to assess the effectiveness of production under the rebuilding objective, we asked two main questions:

1. Does enhancement for rebuilding increase total, natural-origin, and/or wild spawner abundance?
2. What happens when enhancement stops?

Several additional questions were also explored:

3. Are results different between regions?
4. How many systems have sufficient assessment information to be assessed?

We used annual SEP production plans from 2014-2021 to identify those systems that had hatchery releases of Chinook salmon with the production objective of rebuilding. Spawner abundance, number of releases and release stage, enhanced contribution, and hatchery-origin spawner proportion data since 1950 (although many years are missing data) were extracted from various DFO databases and compiled. Dashboards[1] and data summaries were used to identify which systems had enough information to be analysed. Ultimately, of 45 rebuilding systems, 26 had sufficient information to assess changes in total spawner abundance after enhancement began, and 17 had limited information available to assess changes in natural-origin and wild spawner abundance. Only 10 systems were identified as 'high-quality' systems with long, consistent time-series of overlapping spawner abundance and enhanced contribution information.

Photo by: Nicole Christiansen

1. Dashboards refer to a compilation of information. In this case, our dashboards for Chinook salmon contain information on spawners (wild, natural-origin, and hatchery origin) hatchery releases, enhanced contributions and pHOS and/or PNI data in a series of figures for each rebuilding system. These are essential sources of compiled information for this report.

By using a 'generational' analysis across Chinook rebuilding systems, we identified general increases to total spawner abundance with enhancement, however, the response of natural-origin and wild spawners was mixed. Wild spawner abundance in rebuilding systems showed mixed results in the 3rd generation following enhancement, relative to pre-enhancement levels, but in most cases (13 of 17, or 75%), wild spawner abundance was lower than pre-enhancement abundance following the 3rd generation post-enhancement. This was the case even with continued enhancement. These analyses were constrained by a lack of spawner abundance and enhanced contribution information in many systems. Qualitative examination of trends in hatchery releases and spawner abundance for systems with discontinuous releases indicate that total spawner abundance is highly sensitive to hatchery supplementation; when enhancement is stopped, spawner abundance immediately (the next generation) declines and there is no 'natural spawner' demographic lasting effect; there does not appear to be a self propagating naturally spawning boosted population. However, we identified only 4 systems with discontinuous releases, while most systems labelled rebuilding have had relatively consistent releases since enhancement began, suggesting the need for development of enhancement management targets to guide release numbers and timeframes. More robust analyses using additional metrics such as relative reproductive success are severely constrained by the lack of system level age structure, exploitation rates, and long-time series of enhanced contributions for the majority of Chinook rebuilding systems. Since Chinook enhancement in BC is largely in the form of integrated populations (mixing between hatchery and wild Chinook is allowed), it is difficult to provide an assessment of the trade-offs between enhancement and potential deleterious or beneficial effects of enhancement to wild Chinook in these systems. We provide recommendations for data collection and assessment in enhanced systems, however it may be logistically difficult and expensive to implement these recommendations in all enhanced systems.

This report serves as an initial inventory of the status of catch and enhanced contributions from BC's hatchery production, and presents a method of assessing effectiveness of rebuilding enhancement.

Photo by: Nicole Christiansen

3. INTRODUCTION

The Salmonid Enhancement Program (SEP) began in 1977 with the goal of doubling catch of Pacific salmon in BC (Hilborn & Winton 1993). Although releases increased steadily until the early 1990s (Figures 1-5), this goal was never achieved. Overall, numbers of hatchery releases have decreased since the late 1990s and the objectives behind enhancement efforts have shifted over time in response to changing priorities. Today, all enhanced releases are assigned to at least one management objective: production of salmon for harvest, rebuilding, conservation, assessment, stewardship, or education purposes (SEP 2018).[2] Enhancement may be designed to meet more than one of these objectives. The production objectives are important for establishing the necessary evaluation and fish health management requirements.

Based on the objectives outlined in the Integrated Fisheries Management Plans[3] each year, about 21% of enhancement projects in BC release salmon with the objective of producing fish for harvest. However, including spawning channels, by sheer numbers, those projects make up the vast majority of hatchery releases or 65-88% by species (including harvest and assessment/harvest objectives Table 1). After harvest and assessment/harvest, releases identified for rebuilding purposes are the second largest contributor at between 1% and 18% of total releases by species. When we reviewed the production plans for 2014-2021, we identified 120 'lines-of-production' under the harvest objective, and 115 lines of production under the rebuilding objective (Figure 6). For our purposes, a 'line of production' is considered to be all releases into one system with the same production objective. As such, large facilities may produce many lines of production whereas smaller Community Involvement Program facilities may only produce one line of production. BC's South Coast has the largest number of harvest and rebuilding systems (104), followed by the Lower Fraser River area (79). Most of these systems are enhanced with coho, chum, and Chinook, with only a small number of systems that are enhanced with pink and sockeye. Much of the pink and sockeye production occurs in spawning channels, with some spawning channel production of chum (Little Qualicum for example). Spawning channels are not considered in this report (however they are assessed in a different report as part of the comprehensive Hatchery Effectiveness review). We did not assess any pink or sockeye salmon lines of production.

Table 1. Mean percent of target releases in BC that fall under each management objective for each salmon species (standard deviation in parentheses) from 2014-2021. Numbers capture all target enhancement from both hatcheries and spawning channels from these Integrated Fisheries Management Plans.

Objective	Chinook	chum	coho	pink	sockeye
Assessment	4 (1)	–	2 (2)	<1 (<1)	<1
Assessment/Conservation	3 (2)	–	2 (1)	–	–
Assessment/Harvest	35 (3)	–	11 (1)	–	<1 (<1)
Assessment/Rebuilding	1 (<1)	1 (<1)	1 (<1)	–	<1 (<1)
Conservation	1 (1)	<1 (<1)	1 (<1)	–	<1 (<1)
Education	<1	<1	1	–	–
Harvest	42 (3)	88 (3)	54 (5)	79 (6)	99 (<1)
Harvest/Rebuilding	–	–	–	1	–
Rebuilding	12 (1)	10 (2)	18 (4)	17 (5)	<1 (<1)
Stewardship	1 (<1)	1 (1)	9 (4)	3 (4)	<1 (<1)
Stewardship/Education	<1	<1	<1	–	–

2. The earliest SEP Production Planning Framework was produced in 2012.
3. Integrated Fisheries Management Plans only began in 2014 and information on production objectives prior to that are not available.

Harvest Effectiveness

Monitoring hatchery production requires the ability to identify hatchery fish in fisheries, brood collections, and on spawning grounds. For Chinook and coho, current and historical assessment has largely been based on the use of coded-wire tags (CWTs) inserted into the snouts of a subset of the juveniles prior to release from the hatchery. Typically, tagged fish also have their adipose fin clipped (AD-clipped) to allow for visual identification of hatchery-origin fish. Subsequent recovery of these tags in the heads of adult salmon provides data on the hatchery of origin, age, and ultimately the survival of a given cohort released from a hatchery and year. To reduce exploitation of wild stocks and facilitate identification of hatchery fish in real-time, many hatcheries in the United States and those in southern BC producing coho have switched to mass-marking their releases, and have initiated mark-selective fisheries. A subset of clipped fish still receive CWTs to provide the necessary data for assessment. There is much debate around the efficacy of both the CWT and mass-marking assessment programs, as well as alternative approaches such as those using genetics (for example Parentage Based Tagging and Genetic Stock Identification methods; PSC SFEC 2016, Beacham et al. 2021). However, since CWTs are still the primary and preferred method of salmon fishery assessment in BC, our review is based on CWT data for Chinook, coho, and chum where available. Pink, chum, and sockeye salmon released from spawning channels are typically not tagged and therefore do not use the same methods of assessment. However, some tagging of chum salmon has been conducted in the past and we have incorporated those data where possible.

Production of salmon for harvest is defined by the SEP Production Planning Framework (2018) as follows:

> “Enhancement for fisheries that are reliant on enhanced production, and would disappear or become severely constrained in the absence of enhancement. This includes harvest opportunities for First Nations, recreational, or commercial fisheries. When the objective is to provide a targeted-fishery opportunity, production targets may be set to consider both natural spawning and harvest requirements.”

To guide production, SEP has historically used a Logic Model which outlines activities, their inputs, outputs, and desired outcomes. The immediate outcome of producing fish for harvest is that “enhanced salmon support harvest”, while the intermediate outcome is that “enhanced salmon and improved habitat contribute to sustainable economic, social and cultural harvest opportunities” (SEP 2018). The overarching outcome is that “enhanced salmon and habitat contribute to ecosystem health and economic productivity” (SEP 2018).

These outcomes are broad and lack specific metrics to adequately assess the effectiveness of producing fish for harvest as defined in the Production Planning Framework. Enhanced salmon *are* being caught, but to what degree, and what is the impact on both fisheries and ecosystems? Which fisheries are most reliant on hatchery production? In theory, *effective* production for harvest should result in the salmon being caught. If they are not being caught and are contributing disproportionately to escapement, for instance, then the mechanisms and rationale for this enhancement needs to be re-evaluated. As part of the Pacific Salmon Strategic Initiative (PSSI), work is currently underway within the Salmonid Enhancement Program to update enhancement planning processes and develop project-specific goals for each line of production. To better understand production for harvest and help guide future production goals, we considered three overarching questions in our review:

1. What is the contribution of all enhanced Chinook, coho, and chum salmon to catch and escapement in BC?
2. Where are enhanced salmon produced for harvest being caught? (i.e., Which fisheries are harvesting enhanced salmon?)
3. What is the efficiency of each hatchery at producing fish for harvest?

Below, we provide a summary of our findings addressing these three questions and highlight the data needs and limitations in answering them. In addition, we identify areas for improvement that could be incorporated into future initiatives.

Rebuilding Effectiveness

Enhancement for rebuilding purposes is a method that is employed to assist populations that have been identified as 'below apparent carrying capacity', and is one of the core enhancement objectives of SEP. Recently, there has been considerable attention given to rebuilding since many populations are in decline or have been severely affected by human development, land use, challenges in both freshwater and marine environments and possibly overfishing. Rebuilding/recovery is also a central tenant of the PSSI,[4] and will be required under the Fish Stock Provisions of the updated *Fisheries Act* where SMUs[5] below their Limit Reference Points will require rebuilding plans. As such, the assessment of the effectiveness of rebuilding production is critical to future planning and implementation of recovery planning.

Production of salmon for rebuilding is defined by the SEP Production Planning Framework (SEP 2018) as follows:

> “Enhancement of a stock that is below apparent carrying capacity. This includes rebuilding depleted populations and mitigating for habitat loss.”

Photo by: Mitch Miller

4. PSSI is the Pacific Salmon Strategy Initiative. General information can be found online at: https://www.dfo-mpo.gc.ca/campaign-campagne/pss-ssp/index-eng.html

5. Stock Management Units, or Major Fish Stocks, are large groups of salmon (or other types of fish) that are specifically prescribed under the Fisheries Act. Examples include Interior Fraser Coho and WCVI Chinook.

However, through numerous discussions with SEP over the course of this review, it became clear that "rebuilding" as a production objective may mean many different things. For example, a local First Nation may identify that a population in their territory is depressed, and ask for enhancement to rebuild the population, concomitant with a request to provide some of those fish for food or economic harvest. In other cases, the need for rebuilding or conservation enhancement is apparent as in the case of the Big Bar landslide and upper Fraser Chinook populations, or in the case of Cultus sockeye. It is clear that there is some nuance to the objective, however, even after extensive discussion with SEP biologists, we are not aware of any document or list that summarises and describes these specific issues and how systems from the production plans are prioritised. Only 2 systems have rebuilding as their objective in one year, and then harvest in a subsequent year, or vice versa (e.g., Sarita River, Sooke River). In the absence of a complete list of "rebuilding systems" from SEP, or production plans with objectives outside of the 2014-2021 timeframe, we simply used any system that has been identified as having the enhancement objective of "rebuilding" in any production plan from 2014-2021 (from here on, a 'rebuilding system').

When we began this project, we believed assessment of the effectiveness of rebuilding would be a relatively simple exercise utilizing escapement and enhanced composition to measure the effectiveness of enhancement in rebuilding systems against objectives or targets across BC with a standardised approach. Unfortunately, we were not able to identify specific targets or goals in the vast majority of rebuilding systems. Based on extensive discussion with SEP, this appears to be a major focus of their enhancement planning both currently and in the future. We also identified major data gaps in the information available to assess rebuilding systems. For example, some enhanced systems lack long time-series of escapement enumeration. In many systems, there are only a few years, if any, of enhanced contribution information. This makes it difficult to apply standardised methods across regions and species in BC, and problematic to examine trends in natural-origin[6] or wild[7] spawner abundance over long timeframes, except in a few systems. While we appreciate that there are logistical and cost constraints that may preclude access to some systems, appropriate information should be collected to provide rationale for enhancement and the ability to assess effectiveness and impacts.

Photo by: Danny Swainson

6 Natural-origin spawners refers to salmon whose parents spawned in the natural environment (parents could be hatchery-origin or natural-origin, or one of each).

7 Wild spawners are progeny of natural-origin salmon that also spawn naturally (e.g., 2nd generation natural-origin salmon).

In order to assess the effectiveness of enhancement for rebuilding, we developed a suite of questions that can be applied across all systems. However, while we realise that these questions may relate to not only rebuilding streams, but to any streams that have had enhancement, in this report we constrained the analysis to rebuilding systems. Specific questions addressed in this portion of the report pertain directly to enhancement at the stream/line of production/release site level.

In the absence of standardized assessable goals, triggers or management objectives across regions and species in terms of rebuilding, these questions were meant to inform whether enhancement at the stream level was effective.

Questions included:

1. Does enhancement for rebuilding increase total, natural-origin, and/or wild spawner abundance?
2. What happens when enhancement stops?

Several additional questions were also explored:

3. Are results different between regions?
4. How many systems have sufficient assessment information to be assessed?

Additional Supplementary information can be found in 3 Appendices:

- Appendix A (summary of rebuilding systems)
- Harvest Supplemental Information (Appendices A-C)
- Rebuilding Supplemental Information

Photo by: Nicole Christiansen

4. METHODS

4.1 DATA SOURCES

4.1.1 SEP PRODUCTION OBJECTIVES AND STREAM SELECTION

Objectives for each line of production are provided in the annual IFMPs from 2014-2021 (SEP 2021a, Personal Communication). To apply objectives to production prior to 2014, the production plans were merged and then filtered to include releases (excluding transfers) and primary production only (excluding alternative production). We sought to match an objective to every unique combination of project, stock, and run timing. Where multiple objectives had been listed, we selected the one with the greatest number of average target releases between 2014-2021.

For the Chinook rebuilding analysis, streams were selected from the combined 2014-2021 IFMP Production Plans filters (Objective = Rebuilding or Assessment/Rebuilding, Production Activity Type=Release, Production Strategy Level=Primary). We then used the Production Plan information on release stages, mark types, and release site to complete a list of Rebuilding Systems. For each system, a dashboard was completed using information as described in the following data source sections. These dashboards are included in the Rebuilding Supplemental Information (SI).

4.1.2 ESCAPEMENT DATA

Escapement is the number of fish that 'escape' harvest and return to the spawning grounds. These numbers are obtained through visual stream walking surveys, snorkel surveys, aerial stream surveys, mark and recapture and dead pitch, and fish fences and provide an estimate of spawner abundance. But the methods applied in a system may change over time.

For the rebuilding analyses, escapement (or total spawner abundance) was sourced from the Pacific Salmon Foundation Pacific Salmon Explorer (PSE) team (Hertz 2022, Personal Communication). In most cases it is up to date to 2020. The PSE escapement database draws from DFO's NuSEDs database.[8]

Individual rebuilding systems were extracted using the unique POP_ID field. In some cases, a number of systems were combined into one analysis system due to the manner in which spawner estimates were recorded in NuSEDs and hence the PSE database (e.g., the Bedwell River system includes entries for Bedwell River, Ursus Creek and Bedwell System which includes counts from both the Bedwell River and Ursus Creek). These systems were manually extracted from the PSE database, combined in an appropriate manner and then added back into the analysis worksheets.

Photo by: Benjamin Fortini

8. Available online at: https://open.canada.ca/data/en/dataset/c48669a3-045b-400d-b730-48aafe8c5ee6

4.1.3 ENHANCED CONTRIBUTIONS

Enhanced contributions to broodstock and river returns can be extracted from two sources. For Chinook, the SEP Proportionate Natural Influence (PNI) Database, provides estimates of PNI, proportion of natural-origin brood (pNOB) , and proportion of hatchery-origin fish on the spawning grounds (pHOS)[9] for a number of systems across BC (SEP 2021b). These estimates are based on thermal and/or CWT recoveries in broodstock and river returns. For other species, we used enhanced contributions estimated in the Enhancement Planning and Assessment Database System (EPADS). These files were provided by SEP (Lynch 2021a, Personal Communication).

For the Chinook rebuilding analysis, we preferentially used the pHOS, PNOB, and PNI estimates from SEP since they have been quality checked and analysed by SEP up to the last version provided, versus the estimates from EPADS. If estimates based on thermal marks were available, we used those in favour of CWT-based estimates for enhanced contributions, as thermal mark rates (typically 100%) exceed CWT mark rates.

In the harvest effectiveness analyses, we used the enhanced contributions to escapement from EPADS to compare among production objectives for each species in each region.

4.1.4 RELEASE INFORMATION

Information on hatchery releases was provided by SEP via the Release Report from EPADS (Lynch 2021b, Personal Communication). Unique combinations of release stock and release site were used to compile releases by life stage and at each release site for each of the rebuilding systems. The same dataset was used for the hatchery and rebuilding analyses.

4.1.5 ANALYSES

All statistical analyses were completed in the R Programming Language (R Core Team, 2021).

Photo by: Benjamin Fortini

9. See Withler et al. 2018 for more information.

4.2 HARVEST EFFECTIVENESS

Our analyses focus on the species for which we have CWT data to facilitate assessment: Chinook and coho. Select analyses are also included for chum, for which a combination of CWT and fin-clip data have been extracted and further compiled or analysed by us from Lynch et al. 2020.

The analyses can be divided into three parts, although the data and figures from one often inform the others. The first part assesses the contribution of enhanced fish to total catch and escapement (although this is constrained by the available data). The second examines where the production goes, using a variety of visual techniques to highlight which fisheries are harvesting the most enhanced production, the spatial distribution of the catch, and how that has changed over time. And the third examines catch efficiency, estimated from the number of fish caught per thousand released from each facility. Given data limitations, we focus our results on what we believe can be assessed, but include a summary text box in each section that lists assumptions and details on what we were unable to assess.

4.2.1 ENHANCED CONTRIBUTION TO CATCH AND ESCAPEMENT

Catch

In order to determine the contribution of enhancement to total catch in BC, we must first know total catch.[10] This information was surprisingly difficult to come by and no single record of total annual salmon catches in BC currently exists. A request was sent to DFO's Statistical Catch Unit for total annual catches of salmon by region back to at least to 1972. Initially, we were only able to obtain recreational catch data back to 2012 and commercial catch data (by gear type and region) back to 1996 with comments that data from earlier years were not available (see Table 2 for data summary). Upon further inquiry we were able to obtain archived commercial catch records going back to 1982 and southern BC creel survey data back to 1981. Recreational catch data for the central and north coasts are patchy with a mix of creel and logbook data, or no data at all for some management areas. Therefore, the only recreational catch data we were able to obtain for these regions is from the Internet Recreational Effort and Catch program (iREC) which has complete records dating back to 2013. This program collects monthly fishing effort and catch data by randomly selecting fishers to report their catch. We were advised that First Nations FSC catches are protected and that catch numbers are only made public when enough Nations report their catch to create 'roll up' catch estimates, making data inconsistent and incomplete both spatially and temporally (Evans 2021, Personal Communication). Total annual catch was then estimated by summing total annual commercial and recreational catches by area. Therefore, we were unable to assess the contributions of enhancement to First Nations FSC catch.[11]

The next piece of information required for estimating enhanced contribution to total catch is the total catch of hatchery-reared salmon.These data also do not currently exist. The only information available comes from CWT recoveries, which are only a proportion of total hatchery releases (Figure 1 – Figure 2; see Harvest SI Appendix A for annual catch summaries). DFO uses expansion factors to account for potential CWTs in the unsampled catch (i.e. the 'estimated' catch) as well as untagged individuals released as part of a CWT cohort (i.e. the 'expanded' catch). However, some hatcheries release salmon that are neither tagged nor associated with a CWT cohort and are therefore not included by either expansion factor.

10. This analysis includes catch of enhanced salmon under all SEP objectives, even those which are not specifically producing fish for harvest (e.g., rebuilding, stewardship etc.).

11. Since we were not able to include First Nations FSC catch we only looked at marked recoveries and expansions to the commercial and recreational catches to estimate enhanced contributions to those fisheries.

Table 2. Summary of datasets required to estimate enhanced contribution to total annual salmon catches in BC, the timeframes covered, who they were provided by, and whether or not they were available for each region (NCST = north coast, CCST = central coast, WCVI = west coast Vancouver Island, ISC = inner south coast).

Data	Species	Source	Years	Provider	NCST	CCST	WCVI	ISC
Commercial catch	All	Commercial Salmon Logbook Program	1996-2021	Statistical Catch Unit (Jason Parsley)	✓	✓	✓	✓
	All	Archived Commercial Catch Statistics System (fish slips)	1981-1999	Statistical Catch Unit (Jason Parsley)	✓	✓	✓	✓
Recreational catch	All	iREC	2013-2021	Statistical Catch Unit (Rob Houtman)	✓	✓	✓	✓
		Creel surveys	1981-2021	Statistical Catch Unit (John Davidson)	✗	✗	✓	✓
First Nations catch	All	None	NA	NA	✗	✗	✗	✗
Hatchery catch	Chinook and coho	EPADS CWT recoveries by statistical area	1972-2021	Salmonid Enhancement Program (Brock Ramshaw)	✓	✓	✓	✓
	chum	Lynch et al. 2020	1980-2018	Salmonid Enhancement Program (Cheryl Lynch)	✓	✓	✓	✓
	All	Total hatchery catch	NA	NA	✗	✗	✗	✗
Enhanced contribution to catch	Chinook and coho	None	NA	NA	✗	✗	✗	✗
	chum	Lynch et al. 2020	1980-2018	Salmonid Enhancement Program (Cheryl Lynch)	✓	✓	✓	✓
Enhanced contribution to escapement	All	EPADS	1973-2019	Salmonid Enhancement Program (Joan Bateman)	✓	✓	✓	✓

The CWT recoveries from the EPADS were not available to the same spatial resolution as the recreational and commercial catch data. Due to the nature of the commercial fisheries in particular, CWT recoveries are often reported from vessels fishing across multiple statistical areas. Therefore, total annual catch data and CWT recoveries were grouped into four catch regions to facilitate assessment: north coast (NCST), central coast (CCST), west coast Vancouver Island (WCVI), and inner south coast (ISC) (including the Fraser River; Table 3, Figure 7). These regions are used throughout the analyses, rather than statistical areas.

Table 3. Grouping of Pacific Management Areas (PFMAs) into fishing areas.

Area	PFMAs
North Coast	1, 101, 2, 102, 142, 3, 103, 4, 104, 5, 105
Central Coast	6, 106, 7, 107, 8, 108, 9, 109, 10, 110, 130
Inner South Coast	11, 111, 12, 13, 14, 15, 16, 17, 18, 19, 28, 29
West Coast Vancouver Island	20, 21, 121, 22, 23, 123, 24, 124, 25, 125, 26, 126, 27, 127

We then estimate the total annual hatchery catch, which we will call the extended or total hatchery catch. We used the expanded CWT recoveries by gear type and region and applied an additional expansion factor to account for all hatchery releases that were unassociated with a specific CWT cohort in a given region in a given year. For this, the proportion of releases associated with a CWT was calculated as follows:

$$\textit{Proportion CWT associated releases} = \frac{\textit{Total CWTs released} + \textit{Total associated CWT releases in cohort}}{\textit{Total releases}}$$

where each value is a total for a given species, region, and year. For species, regions or years in which no CWTs were applied, the top term would then be equal to 0, and the proportion of CWT associated releases would be 0, with unassociated releases accounting for 100% of releases. This proportion was then offset by 3 years for Chinook and 2 years for coho to translate to the adult return year (assuming the majority of Chinook return as 4-year-olds and the majority of coho return as 3-year-olds).

The total hatchery catch of each species in each region each year was calculated as:

$$\textit{Extended (total) hatchery catch} = \frac{\textit{Expanded CWT recoveries}}{\textit{Proportion CWT associated releases}}$$

from which we calculate annual enhanced contributions to total catch by species and region by dividing our extended hatchery catch by the total catch:

$$\textit{Enhanced contribution} = \frac{\textit{Extended hatchery catch}}{\textit{Total catch}}$$

Annual enhanced contributions were also calculated for each fishery (i.e. net, troll, or recreational) for each species in each catch region. These calculations were only possible for regions and years with total commercial and recreational catch records, and therefore are only possible for 2013 onwards for the NCST and CCST regions. For estimating the mean enhanced contributions of each species to fisheries in each region, we removed years in which the enhanced catch exceeded total catch as this is unrealistic and must arise from errors in accounting.

For total hatchery catches and enhanced contributions of enhanced chum, recoveries of fin clipped and CWT'd chum from 1980-2018 were extracted from Lynch et al. 2020. Note that only certain statistical areas and fisheries (primarily net) were consistently sampled for chum. Therefore, our regional chum summaries reported below are only representative of data-reporting areas and show enhanced contributions to net fisheries only. It has been recommended by Lynch et al. that catch and enhanced contributions be calculated on an individual statistical area basis. As this was not possible for Chinook and coho, we present chum data in the same format as the other species (regionally).

4.2.2 CATCH DISTRIBUTION

The EPADS provides data on the fisheries and statistical areas in which CWTs are recovered. In general, we assumed that unassociated releases from facilities/years with other CWT groups are likely to have similar catch distributions as their tagged counterparts. However, releases from facilities without tagging programs are difficult to accurately track to their location of recovery, and stocks with different run-timing components may not be accurately represented either. Given this uncertainty, we present catch distribution data for the SEP's expanded CWT catch data from the EPADS only (i.e. without our CWT extension). Chum catch distributions were only available for net fisheries.

We first created maps of the distribution of hatchery Chinook and coho salmon catch by their region of origin (NCST, CCST, WCVI, and ISC) over three discrete time periods: 1975-1989, 1990-2004, and 2005-2020 (Harvest SI Appendix B). The first time period (1975-1989) captures earliest available catch records and a period of relatively abundant catch. The middle time period (1990-2004) captures the dramatic decline in salmon survival rates through the 1990s with the corresponding decrease in harvest rates. The third period (2005-2020) captures distributions based on current production and fishery practices. For each region, the total expanded enhanced catch was summed for each time period and separated into Commercial, Sport, or 'Other' (i.e. data on fishery type not provided) fisheries and presented as a circle to illustrate the proportion of total catch per region. This allowed us to observe changes to the distribution of hatchery produced fish, both spatially and between fisheries, over time. Note that fishery locations may change over time due to specific openings and closures and thus distributions likely reflect changes in fisheries management as well as actual fish distributions.

To gain a better understanding of which fisheries are harvesting hatchery salmon, we then created area-density plots which show the proportion of annual total catch by sector in each catch region (NCST, CCST, WCVI, ISC) over time.

4.2.3 EFFICIENCY OF PRODUCTION FOR HARVEST

Efficiency was calculated as the number of tagged (or clipped for chum) fish caught per thousand tagged releases from a given hatchery and species. This metric allows for comparison between facilities with different scales of production. Annual data were rolled-up by region and presented by production objective as they are outlined in the IFMPs. For chum, we used expanded catch of fin-clipped or CWT'd chum releases adjusted for mark mortality rates (Lynch et al. 2020) and used the catch age composition to determine the corresponding brood year. Catch was then related back to hatchery releases by brood year to determine catch per 1,000 releases.

While we have undertaken this evaluation, these results should not be interpreted without consideration of several factors including environmental variation/trends, status of natural populations coincident with hatchery production, fishing effort and management actions, allocation policy, and even international agreements. Catch of hatchery production is determined by access to the fish (migration routes, timing, and fishing opportunities), limitations imposed by conservation or allocation needs, and varying management objectives that have varied over time. The interpretation of these efficiency results requires much greater understanding of the environment and fishery management than this simple calculation portrays.

4.3 REBUILDING

To address our questions, we look at the effects of enhancement by evaluating changes in total, natural-origin, and wild spawner abundance where available using a fairly simple generational approach.

We separated spawner time-series into a number of time-periods to capture changes in spawners over time. An example is shown below for the Sarita River (near Bamfield in Barkley Sound). In Sarita River, the first year of enhancement was 1985 (1984 brood year). As these fish primarily return as 4 year-olds, significant hatchery returns would have first been observed in 1988. We separated the spawner time-series into 6 periods (Table 4).

Table 4. Example breakdown of spawner abundance into time-periods for analysis for Sarita River Chinook (WCVI).

Time-Period	Year Range
Historical	All years up to and including 1976
2-generations pre-enhancement	1977-1985
First year of releases/enhancement	**1985**
First generation post-enhancement	1986-1989
Second generation post-enhancement	1990-1993
Third generation post-enhancement	1994-1997
All years after the 3rd generation post-enhancement	1998 and >

We then applied the enhanced contributions (where data exists) to total spawner abundance to estimate natural-origin and wild spawners. For summary figures, we used geometric means since spawner abundance is typically log-normal distributed as below where $spawners_{i,period}$ are the annual ($_i$) spawner estimates in that time period ($_{iperiod}$):

$$geomean_{period} = \exp(mean(\log(spawner_{i,period})))$$

Total spawners refers to the total number of spawners on the spawning grounds. Total spawner estimates are comprised of both hatchery origin fish (e.g. spawned from captured broodstock and released as juveniles, which may or may not be marked with either a CWT, an adipose fin clip, or a thermal mark), and natural-origin fish that are unmarked are juvenile progeny from adult spawners that spawned in the wild (parent fish may or may not be of hatchery origin). We then used enhanced contribution information (either from EPADS or from the Proportionate Natural Influence Database) to estimate natural-origin spawners in each year and each system where information is available. This is a simple calculation and is based on the estimates provided for hatchery origin fish that have been marked, and identified as hatchery origin in either broodstock collections, or in sampling the escapement in river systems.[12] For Chinook, we used the pHOS estimates to derive pNOS (1-pHOS) using thermal mark information if available, and then CWT information secondarily.

12. Additional details on the nuances to these estimates can likely be provided by SEP, however there is no report or reference to refer to that contains all the information for all species.

Wild fish, as defined by the wild salmon policy, are fish that:

> "have spent their entire life cycle in the wild and originate from parents that were also produced by natural spawning and continuously lived in the wild." (DFO 2005)[13]

For the purposes of this report, we used the metric $pNOS^2$ as a proxy for wild fish, as it is difficult to identify 2nd generation wild salmon. Emerging genetic methods (e.g., Parentage Based Tagging; Beacham et al. 2022) may provide the opportunity to identify these fish and should be included in enhancement planning in the future. $pNOS^2$ reflects the probability that 2 natural-origin parents mated in the previous generation (Holt 2021, Personal Communication). For more details on the Proportionate Natural Influence (PNI) see Withler et al. (2018).

For rebuilding systems, analyses conducted were dependent on the information available. Some systems were either not found in NuSEDs, or lacked sufficient spawner information for any analysis. Some systems had spawner information, but no enhanced contribution data. Many systems had sufficient spawner information and some enhanced contribution information to proceed with limited analyses. A few systems had long enough time series of spawner abundance and enhanced contribution estimates to complete analyses for total, natural-origin, and wild spawners over all time periods. We also qualitatively examined rebuilding systems to identify those where enhancement stopped or was reduced to very low levels, as well as systems where enhancement was discontinuous. These systems are important contributions to our explorations since they provide insight into what happens when enhancement is stopped and how sensitive spawner abundance is to enhancement. A description of rebuilding systems for Chinook, along with what data are available, and what analyses were completed for each system, is provided in the Rebuilding Appendix A and in the Rebuilding SI.

Photo by: Benjamin Fortini

13. Available online at: https://www.pac.dfo-mpo.gc.ca/fm-gp/salmon-saumon/wsp-pss/policy-politique-eng.html

5. RESULTS

5.1 HARVEST

5.1.1 ENHANCED CONTRIBUTION TO CATCH AND ESCAPEMENT

Total Annual Catch

The total annual catches of Chinook, coho, and chum salmon have decreased significantly since the early 1990s across the coast of BC. In many cases, present day catches are only a fraction of what they were prior to the dramatic declines (Figure 8 to Figure 10); also see Tables A.1.-A.3. in Harvest SI Appendix A. However, it is important to note that in most areas hatchery releases have also decreased since the 1990s (Figure 1, Figure 2, Figure 3).

In the NCST and CCST regions, net fisheries made up the majority of the salmon catch in the 1980s, although Areas 4, 8, 9, and 10 also had large troll fisheries (Figure 8 to Figure 10). Recreational catch information is limited in these regions prior to 2013, and therefore not all recreational catch is included historically. Over the same time period, terminal net fisheries accounted for most of the salmon catch in WCVI, while recreational fisheries were the main source of salmon catch in the ISC. However, in recent years, recreational fisheries have replaced commercial fisheries as the main source of Chinook and coho salmon catch across the province. Chum continue to be caught mainly in commercial net fisheries (Figure 8 to Figure 10). In this compilation of catch data, we did not endeavor to capture uncertainty.

Total Enhanced Catch

In most regions, total enhanced catches of Chinook, coho, and chum have decreased since the mid-1990s (Figure 11 to Figure 13); see Harvest SI Appendix A for annual hatchery catch records by species and region). Based on our estimates, total enhanced catches of Chinook in the last 10 years were 26% of the pre-1996 enhanced catch in CCST fisheries and 46% of the pre-1996 catch in ISC fisheries, but were roughly the same for NCST and WCVI fisheries.

In the NCST, our extended enhanced catches of Chinook and coho were considerably higher than those obtained from the expanded CWT catch alone, which showed a 76% decrease in enhanced catch (Figure 11, Figure 12). This large discrepancy between the two enhanced catch estimates also aligns with years in which the mark rate dramatically decreased in these regions (Figure 1, Figure 2). For Chinook and coho on the NCST, the proportion of releases associated with a CWT went from approximately 80% to approximately 10%, and approximately 40% to only 4%, respectively. Given the similarity in trends between the two enhanced catch values in other years and regions, it is likely that catch calculations using limited CWT data leads to an overestimation of catch (as seen for the extended catch using unassociated releases). For coho, the total extended enhanced catch in the last 10 years was 11% of the pre-1996 enhanced catch in CCST fisheries, 8% in WCVI fisheries, only 3% in ISC fisheries, but was about the same for NCST fisheries. In contrast, the expanded CWT recoveries on their own show that recoveries in NCST fisheries were only 7% what they were prior to 1996. Reduced marine survival in both Chinook and coho as well as deliberate reductions in coho production by SEP due to cost reductions or realignment of production targets are likely the main contributors to the reduced enhanced catch.

We saw a decline in hatchery chum catches in southern BC fisheries, with little change in the NCST and CCST fisheries (although NCST data are only available up until 2003; Figure 13). The average annual enhanced catch since 2005 is 89% of the pre-1996 catch in WCVI fisheries and 87% in ISC fisheries.

Enhanced Contribution to Catch

Enhanced contribution estimations were only available from 2013 onwards for the NCST and CCST regions, where hatchery Chinook from BC have constituted an average (mean) of 23% (sd ± 17%) and 26% (sd ± 12%), respectively (Figure 14). Fisheries in the ISC region have seen the greatest enhanced contribution across all 3 species. Since 1980, hatchery Chinook in BC have constituted a mean of 37% (sd ± 18%) of the catch in ISC fisheries (excluding the two years in which the enhanced contribution was > 1) and 26% (sd ± 19%) of the catch in WCVI fisheries (Figure 15; see Harvest SI Appendix A for annual data tables of enhanced contribution by region).

For coho, enhanced contribution estimations were only available from 2013 onwards for the NCST and CCST regions, where hatchery coho from BC have constituted a mean of 7% (sd ± 3%) and 3% (sd ± 3%), respectively (Figure 16). Meanwhile in southern BC, the mean enhanced contribution has been 34% (sd ± 22%) to catch in WCVI fisheries and 41% (sd ± 19%) to catch in ISC fisheries (excluding the years for which enhanced contributions were > 1 [WCVI: N = 4; ISC: N = 9]; Figure 17). However, the enhanced contributions to coho fisheries have also varied over time. This is likely due to reductions in harvest opportunities for conservation purposes, and the relocation of fisheries to terminal areas near to facilities that produce coho.

Based on the data provided by Lynch et al. (2020) and our compilation, the mean enhanced contribution of chum has been 16% (sd ± 15%) to catch in NCST net fisheries, 19% (sd ± 10%) to catch in CCST net fisheries, 25% (sd ± 21%) to catch in WCVI net fisheries, and 43% (sd ± 29%) to catch in ISC net fisheries (Figure 18, Figure 19). Enhanced contribution data for chum salmon were not provided for troll or recreational fisheries, however catch of chum salmon in troll and recreational fisheries is much less.

When broken down by fishery type for Chinook, coho, and chum (i.e. net, troll, or recreational), we found that hatchery salmon constitute a large proportion of the net and recreational fisheries and a relatively small proportion of the troll fisheries (Figure 20 - Figure 27). In these figures, there are some years with very small catch numbers (not visible on figures given the scale adjusted to larger years), however we were still able to estimate an enhanced proportion. In NCST net, troll, and recreational fisheries, they have made up 9% (sd ± 12%), 10% (sd ± 5%), and 34% (sd ± 16%) of the catch since 2013, respectively (Figure 20). In CCST net and recreational fisheries, they have made up 46% (sd ± 14%) and 23% (sd ± 19%) of the catch since 2013, respectively (Figure 21). If we exclude years in which the enhanced contribution to catch was greater than 1, the average enhanced contribution of Chinook to net, troll, and recreational fisheries on the WCVI has been 35% (sd ± 33%), 10% (sd ± 9%), and 35% (sd ± 22%), respectively since 1981 (Figure 22). In ISC net, troll, and recreational fisheries, enhanced Chinook have made up 28% (sd ± 13), 12% (sd ± 11%), and 37% (sd ± 16%) of the catch, respectively (Figure 23).

For coho, the average enhanced contribution to net, troll, and recreational fisheries on the NCST has been 5% (sd ± 6%), 6% (sd ± 2%), and 18% (sd ± 18%), respectively, since 2013 (Figure 24). On the CCST, average contributions to net, troll, and recreational fisheries have been close to zero, 3% (sd ± 2%), and 5% (sd ± 4%), respectively, since 2013 (Figure 25). WCVI has been 22% (sd ± 23%), 17% (sd ± 17%), and 38% (sd ± 21%), respectively, since 1981 (Figure 26). And in the ISC, contributions to net, troll, and recreational fisheries have been 27% (sd ± 21%), 17% (sd ± 14%), and 46% (sd ± 21%), respectively, since 1981 (Figure 27).

For coho in particular, there were several years in which the total estimated hatchery catch exceeded the total estimated catch, resulting in an enhanced contribution > 1 (Figure 12). There are a number of factors that may contribute to this. First, numbers of coho released may be overestimated due to inaccurate accounting of mortalities in earthen channels or of shed tags. There may be locations or fisheries where catch is under-reported, or methods of expansion and extension may not be accurate. Another potential confounding factor is the reduction of coho targeted fisheries starting in 1998. Fishing that has been available is typically restricted to times/areas near facilities that produce coho salmon, with limited assessment. These areas may have very high proportions of enhanced catch and inflate catch expansions.

Enhanced Contribution to Escapement

Overall, the enhanced contributions to escapement of salmon produced for harvest objectives have been similar to those produced for other objectives (Figure 28 - Figure 30). The exception is in WCVI, where enhanced Chinook contributions to systems associated with harvest production objectives were lower than to systems for other production objectives. For coho, ISC production for harvest actually had significantly higher contributions to escapement than production for conservation and stewardship. For chum, many lines of production do not have known production objectives, however, contributions to escapement from production for harvest were similar or slightly higher than production for other objectives.

ASSUMPTIONS

- Archived and commercial catch data can be merged into a continuous record of commercial catch (i.e. datasets are comparable)
- SBC creel surveys capture all recreational catch
- DFO's CWT expansion factors are accurate
- Our method of CWT *extension* accurately accounts for releases that are unassociated with CWTs to provide total enhanced catch
  - Assumes age compositions and survival rates of non-tagged, unassociated releases is similar to CWT'd releases for a given species in a given region in a given year
- Efforts to recover CWTs in fisheries are consistent over time
- Omitting years where enhanced contribution >1 allows for realistic estimation of enhanced contribution
- CWT sampling in escapement is comparable between systems and accurately portrays enhanced contribution
- Changes to production objectives as a result of fisheries management decisions are comparable
  - Realistically, shifts in fisheries management more likely to affect harvest objectives than other lines of production
- Since we have years with enhanced contributions > 100%, and there may be other statistics associated with catch estimation or enhanced contributions with positive bias, we assume other statistics have minimal bias and error

CANNOT ASSESS

- Total annual catch in NCST or CCST (missing recreational catch)
- Enhanced contribution to catch for NCST and CCST
- Total annual catch by First Nations fisheries
- Total enhanced catch of coho post-1996 due to reduction in CWT application and recovery during the post-1998 SBC Coho Conservation Plan

5.1.2 CATCH DISTRIBUTION

For species that have been marked with CWTs, CWT recovery information can be used to show distribution of catch spatially (in different fisheries) and by different sectors (Alaska, commercial Canadian, recreational, etc.). The following catch distributions are based on expanded CWT recoveries only.

Chinook

While Alaskan fisheries harvest less BC origin enhanced Chinook overall than British Columbia fisheries, they still harvest a significant portion of BC origin enhanced Chinook (Figure 31). Within BC, the largest harvests of enhanced Chinook have been by the WCVI sport fishery, the northern Strait of Georgia sport fishery, and the northern troll fishery, although contributions to each fishery has varied over time (Figure 31; see Harvest SI Appendix B for catch distributions by fishery type for each region). The majority of hatchery Chinook produced by:

- NCST hatcheries were caught in Alaskan, CCST, and NCST fisheries (in that order);
- those from CCST hatcheries, in CCST, Alaskan, and NCST fisheries;
- those from WCVI hatcheries, in WCVI, Alaskan, and N/CCST fisheries; and
- those from ISC hatcheries, in northeast Vancouver Island, Strait of Georgia, and N/CCST fisheries (see Harvest SI Appendix B for maps of catch by region).

Across fisheries along the coast, we have also observed a shift in the distribution from commercial to recreational fisheries, and between regions (e.g., ISC Sport to WCVI Sport). While catch numbers have decreased in most regions, the proportion of that catch going to recreational fisheries has increased (see maps of catch distributions in Harvest SI Appendix B). This is likely due to changes in overall abundance and the allocation policies within DFO. For example, as abundance decreases, commercial catch is the first to be reduced, followed by recreational, and then priority First Nations fisheries.

Coho

Overall, the northern ISC sport fishery has been the largest harvester of enhanced coho from BC hatcheries, followed by the WCVI troll fishery, although contributions to each fishery have varied over time (Figure 32). For example, there was a major shift in CWT catch from the ISC sport fishery to the WCVI sport fishery that occurred in the late 90s. Across all regions, total catch and catch distribution shifted dramatically after 1998, which is reflective of management decisions to protect coho throughout SBC (e.g. implementation of mass-marking, reductions in hatchery production; see Harvest SI Appendix B for catch distributions by fishery type for each region).

The majority of coho produced by NCST hatcheries were caught in Alaskan and NCST fisheries; those from CCST hatcheries, by CCST and NCST fisheries; those from WCVI hatcheries, by WCVI fisheries; those from ISC hatcheries, by Strait of Georgia, northeast Vancouver Island, and WCVI fisheries (see maps of catch distributions in Harvest SI Appendix B).

Chum

Data on hatchery recoveries of chum salmon were only available for net fisheries and were typically reported across multiple statistical areas. Therefore, we have summarized enhanced chum catch by region, as shown in Figure 13.

ASSUMPTIONS

- Distribution of CWT recoveries are representative of all other hatchery production within each production area

5.1.3 EFFICIENCY OF PRODUCTION FOR HARVEST

Ideally, effective production for harvest would result in a greater proportion of salmon intercepted by fisheries (marine or terminal) than returning to spawning grounds. Catch efficiency (presented as catch per thousand releases) is another way of looking at this assumption, and we would expect to see a higher catch efficiency for production for harvest than for other objectives, such as conservation. Detailed catch efficiency plots for each stock in each region can be found in the Harvest SI Appendix C.

The efficiency of production for harvest has been highly variable over space and time. Production objectives have changed, along with fishing regulations and marine conditions. As a result, production for harvest has not yielded consistently higher catch efficiency than production for other objectives over the entire time period assessed (Figure 33 – Figure 34). For Chinook production from the NCST and ISC, as well as coho production from the WCVI and ISC, catch efficiency started relatively high and then rapidly decreased in the early 1980s and 1990s, respectively. If we just consider catch efficiency since 2000, hatchery salmon produced for harvest purposes have generally had higher median catch efficiencies than production for other objectives (not including 'Unknown' production objectives; Table 5).

Table 5. Median and range of catch efficiency (catch per thousand releases) since 2000 of hatchery production of Chinook (CN) and coho (CO) salmon from hatcheries in the north coast (NCST), central coast (CCST), west coast Vancouver Island (WCVI), and inner south coast (ISC) by production objective.

Objective	NCST		CCST		WCVI		ISC	
	CN	CO	CN	CO	CN	CO	CN	CO
Assessment	0.5 (0.0–18.7)	16.6 (0.0–50.3)	–	–	1.9 (0.0–4.3)	–	1.6 (0.0–11.0)	–
Conservation	–	–	–	–	3.2 (0.0–15.4)	–	0.9 (0.0–5.8)	1.2 (0.0–6.7)
Harvest	1.2 (0.0–7.5)	5.5 (2.6–19.4)	1.8 (0.0–11.8)	8.4 (1.5–35.1)	3.3 (0.0–28.7)	8.4 (0.0–67.2)	1.0 (0.0–32.8)	1.5 (0.0–68.1)
Rebuilding	1.2 (0.0–9.2)	–	0.1 (0.0–11.6)	–	2.9 (0.0–23.1)	–	0.7 (0.0–9.8)	0.5 (0.0–15.1)
Stewardship & Education	–	7.7 (0.0–27.9)	–	–	–	2.1 (0.0–6.1)	–	1.1 (0.0–4.3)
Unknown	–	5.5 (0.0–23.4)	4.3 (3.0–12.8)	12.2 (3.2–23.6)	6.6 (0.0–10.6)	–	1.9 (0.0–14.6)	0.7 (0.0–16.0)

The catch efficiencies for coho were much higher than for Chinook overall, sometimes by an order of magnitude (Figure 33 – Figure 34; Table 5). This could be partially explained by implementation of Mark-Selective coho directed fisheries. Similar to Chinook, the median catch efficiencies since 2000 have been higher for salmon produced for harvest and assessment purposes than those produced for other objectives (not including 'Unknown' production objectives).

ASSUMPTIONS

- Survival rates are similar across stocks and lines of production with similar life histories and geographical timing and distribution
- Production with differing years of data can be compared
- Other factors influencing catch efficiency (e.g. fisheries management, marine conditions) have the same effects across stocks/regions

5.2 REBUILDING

5.2.1 CHINOOK

We identified 45 'rebuilding systems' for Chinook in our review of the 2014-2021 SEP production plans. Some of these have had the objective of providing harvest as well during that time period (Sarita River, Sooke River). Of these, two were either not in NuSEDs or could not be located in the releases database (Elaho River and Portage Creek). Only 36 systems had any pHOS data and only 10 systems had long time-series of spawner abundance and pHOS data. Table 6 provides a high-level summary of data availability for Chinook rebuilding systems. Appendix A provides a detailed description of Chinook rebuilding systems with data availability, analyses included, and notes on why or why not they were included.

Table 6. Summary table of Chinook rebuilding systems with data availability.

Metric	Number of Systems
Included in rebuilding plans 2014-2021	45
Number of systems in NuSEDs	44
Number of systems with releases in SEP release database	44
Number of systems with any pHOS data	36
Number of systems with relatively long timeseries of pHOS information (e.g. approximately 50% of enhanced years, or more than 10 years)	10
Number of systems included in total spawner analysis*	29
Number of systems included in natural-origin spawners/wild spawners analysis*	26
Number of systems with truncated or reduced enhancement analysis	6
Number of systems with on-again/off-again enhancement	4
Number of "robust" systems (e.g., those systems with consistent spawner and pHOS information that overlaps)	~10

*due to missing information in some systems, not all metrics were able to be completed for each of the 26 systems.

We plotted all the spawner time-series (Figure 35), release time-series by release site and release stage (Figure 36a-d), and all the pHOS information (Figure 37) for the 45 included Chinook rebuilding systems to show the level of data availability. Notably, when arranged by region some patterns are evident, with most of the Fraser River pHOS information derived from CWT estimates, with relatively good coverage; some coverage in the North and Central Coasts (NCC) (mostly CWT) and Strait of Georgia (SoG) regions (mixed between CWT and thermal in recent years) and mostly thermal derived pHOS in the WCVI region. This also shows that there are only a handful of rebuilding systems with long time-series of pHOS information for Chinook, and highlights one of the key issues in our analysis. When the same data are plotted by year and system against the integrated-wild (> 0.72), integrated-transition (> 0.5 and < 0.72), and integrated-hatchery (< 0.5) thresholds provided in Table 3 of Withler et al. (2018), we can see that many of the rebuilding systems have multiple years below the 0.72 threshold (Cheakamus River, Gold River, Leiner River, Nanaimo River-fall, Nicola River, Sarita River, Shuswap River — middle, Sooke River, Sucwoa River, Tahsis River) (Figure 38). Through examination of these figures, we can easily see the range of data availability between systems. Many systems have little or no escapement or enhanced contribution data.

5.2.1.1 GENERATIONAL ANALYSIS

To address the first question for rebuilding, that is to see how total spawners, natural-origin spawners, and wild spawners responded to enhancement, we conducted a 'generational analysis' as described in Section 4.3. Figures of the generational time period for each rebuilding system can be found in the Rebuilding SI. To summarise the information in Rebuilding SI, summary figures of the generational analysis were completed using 2 metrics: **(1)** the ratio of the geometric mean of the 3rd generation after enhancement begins (3rd gen) to the geometric mean of the 2 generations immediately preceding enhancement (Pre2gens), and **(2)** the ratio of the geometric mean of all years after the 3rd generation after enhancement began (Post3rdgen) to the geometric mean of the 2 generations immediately preceding enhancement.

Comparing Pre2gens and the 3rdgen (Figure 39) indicates that most of the systems had increased total spawner abundance in the 3rd generation after enhancement began (23 of 26), and of the 8 systems which had sufficient spawner and pHOS information in the 3rdgen, most systems showed similar or increased natural-origin spawners (7 of 8), but there were mixed responses by wild spawners (4 increased, 4 decreased). Comparing Pre2gens and the Post3rdgen (Figure 40) indicates that many of the systems still had increased total spawner abundance after the 3rd generation after enhancement started (16 of 26), however natural-origin spawner response was mixed (7 decreased, 9 increased) and wild spawners tended to decrease (11 of 16). Taken together, these results indicate that total spawner abundance tended to be higher after enhancement, however initial increases (in the 3rd generation) may not last beyond 3 generations. Given the confounding aspect of changes in productivity (e.g. marine survival rates) this varying response between systems and over time was not unexpected. Although some of these systems may have additional assessment information and estimates of marine survival for some years, these were not included in our analysis, and it is quite likely that many of the rebuilding systems do not have long time series of marine survival rates.

To assess our second question, does spawner abundance respond differently in different regions, we compared the above metrics between regions (NCC=North and Central Coast, SOG=Strait of Georgia, WCVI=West Coast Vancouver Island). The 3rdgen versus Pre2gens boxplot (Figure 41) shows that there are some differences between regions, with all regions showing a median increase in total spawners, and NCC, SOG and WCVI with increased median natural-origin and wild spawner response (however there is considerable variation in the SOG region). The Post3rdgen versus Pre2gens boxplot (Figure 42) is slightly different, with most NCC, SOG and WCVI systems showing an increase in total spawners, Fraser and SOG showing decreased natural-origin and wild spawners, NCC showing increased natural-origin and wild spawners, and WCVI showing increased natural-origin spawners but decreased wild spawners. It should be noted that only 1 system in the NCC region has enough information to assess these metrics for natural-origin and wild spawners (Bulkley River Chinook).

What happens when enhancement is stopped, turned on and off, or severely restricted? We qualitatively explored this question using the dashboards found in the Rebuilding SI for Chinook rebuilding systems. Profiles of spawner abundance and releases clearly show that in populations where on-off production has been implemented that total spawner abundance one generation length after releases is highly sensitive to the number of hatchery releases, with patterns of spawner abundance following patterns in releases. This is most apparent in spawner and release profiles for Salmon River (JNST), Tahsis River, and Tranquil Creek. While a little unclear due to gaps in spawner data, Tlupana River may also follow this pattern where enhancement between 2001 and 2014 increased spawner abundance with subsequent return to pre-enhancement abundance. Interestingly, spawner abundance appeared to increase dramatically in 2001 and 2002, before hatchery releases returned to the system.

Our exploration of what happens when enhancement stops was hampered by data limitations. Of the rebuilding systems with enough spawner data to assess trends, only four had enhancement that stopped completely (Maria Slough, Chuckwalla River, Kilbella River, and Cypre River), and only two systems had significant reductions in enhancement (Chemainus River and Toquart Creek). With the exception of Maria Slough, enhancement did not have a lasting effect, with spawners decreasing quickly after enhancement ceased. Spawners in Maria Slough remained high between 2007 (the last year of enhancement) until around 2016 when spawner abundance decreased to very low levels. In all these cases, although spawner data is limited, spawners declined to near pre-enhancement levels.

Additional system specific information can be found in the Rebuilding SI, which contains detailed dashboards for each system including spawner abundance, release information, EPADS enhanced contributions, pHOS and PNI data, and the generational analysis for those systems that we included.


Photo by: Sam James

6. DISCUSSION

The following sections discuss our findings and recommendations associated with our assessment of harvest and rebuilding effectiveness. For both objectives, we aimed to establish common analytical techniques that could be applied across species, regions, and/or enhanced systems to provide a standardized suite of results which would inform hatchery production initiatives. In the context of this review, we were somewhat successful, but through extensive discussions with stakeholders and DFO (both SEP and Stock Assessment) during the course of this 2+ year project, we came to understand that our analyses would be limited by data limitations and availability (e.g., annual enhanced contributions to spawners for each system and system specific age data), and that standardised approaches may not capture the nuance of specific programs in specific areas. A good example of this includes WCVI Chinook enhanced contributions where there has been extensive GSI sampling in terminal areas that may present different results (e.g., in Barkley Sound enhanced contributions are likely much higher than over the entire WCVI region) from our analysis on enhanced contributions to total catch using CWT information (DFO and SFAB, personal communication, 2022).

We also determined that there were few, if any, specific production plans or enhancement plans for systems considered under the rebuilding objective that included measurable and assessable thresholds, management goals, and targets for rebuilding enhancement. When conceptualising this component of our comprehensive review, we assumed that these types of plans would exist for each system, and that the development of standardised metrics/analyses to compare system specific performance versus these thresholds/targets would be useful.

6.1 HARVEST

The majority of hatchery production (releases) in BC is intended to support harvest, however the effectiveness of that production remains highly uncertain. From our analysis, it would appear that data on the total annual catch of Pacific Salmon is incomplete, and that enhanced contributions to catch are not regularly monitored in many cases (although some data are available on a stock-specific and fishery specific basis). We used the data available through the CWT assessment framework to try to measure contributions of BC enhancement to salmon fisheries, the distribution of enhanced catch, as well as the efficiency of production for harvest relative to other production objectives. Below is a summary of key findings as they pertain to our 3 research questions, as well as key limitations.

1. **What is the enhanced contribution of Chinook, coho, and chum salmon to total catch and escapement in BC?**

Currently, there are no known targets for enhanced contributions to harvest against which to measure success or effectiveness of production. Based on hatchery release numbers and extended CWT recoveries in BC fisheries we found that, on average, hatchery Chinook salmon constituted 23%-26% of the catch and hatchery coho constituted 3%-7% of the catch in northern BC fisheries since 2013. In southern BC, hatchery Chinook constituted 26%-37% of the catch and hatchery coho constituted 34%-41% of the catch since 1981. Hatchery chum constituted 16%-19% of the net catch in northern BC and 25%-43% of the net catch in southern BC on average between 1980 and 2019 (based on our compilation and analysis of data from Lynch et al. 2020). Whether or not these are the desired levels of enhanced contribution to harvest is unknown, therefore we cannot say whether these numbers illustrate effective production for harvest.

Given that most southern BC coho have been mass-marked since the late 1990s and mark-selective coho fisheries have increased, we were surprised that the enhanced contribution of coho to fisheries was not higher. This may be due to the decrease in CWT recoveries and erosion of the CWT method of assessment as a result of the mass-marking program. So few AD-clipped fish are tagged with a CWT that recoveries are low, despite the increased submission of heads or snouts from marked fish (Beacham et al. 2019). Therefore, basing our extension on only CWT recoveries may be biasing our estimates of enhanced contribution downward. Other marking methods, such as parentage-based tagging paired with genetic stock identification could be used to determine whether or not our estimates are in fact underestimates. Furthermore, mark rate information in recreational fisheries is typically fisher-dependent, and data sources such as iREC are likely highly uncertain in terms of marked recoveries.

It is also uncertain whether or not our extension of CWT catch accurately accounts for non-CWT-associated releases. It is thought that CWTs typically underestimate enhanced contributions compared to thermal marks, which require fewer expansions due to 100% mark rates. Our extension was intended to account for all releases, including those thermally marked and non-CWT'd. However, a direct comparison of our estimates to thermal mark-based estimates would be required to determine whether or not our method also underestimates enhanced contributions. To our knowledge, this has not been completed.

In addition, given the mixed-stock nature of salmon fisheries, it is unknown to what degree this level of enhanced contribution affects harvest rates on wild populations and whether or not it has led to their overharvest. Data for enhanced contributions to escapements suggest that a disproportionate number of hatchery fish produced for harvest are actually ending up on the spawning grounds for some species in some regions. This could either be because there is surplus production that is not captured by fisheries due to conservation or other management decisions, or that fisheries are ineffective at harvesting hatchery production.

2. **Where are enhanced salmon showing up in fisheries catch? Which fisheries are harvesting enhanced salmon?**

Overall, the enhanced contribution to troll fisheries was much lower than that to net or recreational fisheries. Net and recreational fisheries tend to be relatively close to shore and can be terminal in nature facilitating targeted fishing of hatchery returns, whereas troll fisheries are further offshore and are more likely to encounter salmon from other origins (e.g. salmon from the US). About a third of the catch of Chinook from NCST, CCST, and WCVI hatcheries has been harvested by Alaskan fisheries. Similarly, about 36% of the catch of coho from NCST and CCST hatcheries has been harvested by Alaskan fisheries.

In BC fisheries, the distribution of hatchery catch has changed over time. Prior to 2000, when CWT recoveries were more abundant, most enhanced catch occurred in commercial fisheries. However, since annual harvest rates have decreased, recreational fisheries now account for the majority of enhanced catch, particularly for coho. This shift towards sport fisheries has also been reported by the Pacific Salmon Commission (PSC 2005).

Some work has been done by members of DFO's Stock Assessment to reconstruct WCVI terminal runs for the past few years. In 2015, it was estimated that 82% of the terminal area catch was of hatchery-origin (Dobson et al. 2015). This is based on the best available CWT, thermal, and genetics data. While our assessment did not examine terminal harvest specifically, our estimates of the total hatchery contributions to net fisheries on WCVI often exceeded 100%, and have been about 30% to recreational fisheries since 2015. Thus, while our estimates of total hatchery contributions to net fisheries may be over-estimates, it is likely that the percent contribution is high and in agreement with the findings of Stock Assessment's run reconstructions. However, further investigations could be made to compare our estimates to those for the WCVI terminal fisheries.

3. What is the efficiency of each hatchery at producing fish for harvest?

We observed a higher catch efficiency from most facilities in the first few years of enhancement, followed by a rapid decrease in catch efficiency. This is consistent with decreases in ocean harvest rates under the Pacific Salmon Treaty and in many places restrictions on harvest due to conservation concerns. Overall, the highest catch efficiencies were observed for production from WCVI hatcheries. Over time, there has been little difference in the catch efficiency between production objectives, with production for rebuilding just as likely to be caught as production for harvest. Ultimately, once in the ocean, there is no objective associated with a salmon and a fish released for harvest has an equal probability of being caught as a fish released for conservation. Fisheries cannot distinguish between production types unless information is known on migration timing and routes, stock composition, and fisheries susceptibility for example. Comparison of harvest efficiency between production objectives is informative since production for harvest should be harvested at higher rates than production for conservation or rebuilding.

However, as mentioned previously, this measure of 'efficiency' is misleading and we recommend a more comprehensive assessment be undertaken. This simple comparison of catch per thousand releases fails to account for changes to hatchery production methods, fisheries regulations, fishing behaviour, and marine survival, all which vary over space and time.

Limitations and Considerations

Currently, the main challenges in assessing enhanced contributions to catch are data availability and accessibility. Here, we bring together disparate datasets to produce estimates of total catch in the province, however a formal record of total salmon catches over time should be created and be publicly available. In addition, the central and north coast lack consistent reporting of recreational catch in some areas. A system for regular reporting of recreational catch data needs to be established in order to report on total salmon catches in BC, as well as enhanced contribution to those catches.

There is also no established method for accounting for non-CWT-associated hatchery production. Given the considerable investment in production for harvest, a method of assessment is required to be able to report on outputs from that investment. Significant numbers of non-CWT-associated hatchery fish are released along our coast each year, some of which go unaccounted for in catch and escapement recoveries (although there is some monitoring of thermal marks and genetics to determine hatchery-origin). One way of addressing this is to manually review all releases each year and assign the non-CWT-associated releases to the most similar CWT release group (e.g. Cross et al. 1991). Another proposed method has been to apply indicator stock survival and exploitation rates to all non-indicator releases to estimate total enhanced catch numbers. However, indicators may not always accurately represent the survival or exploitation of nearby stocks (Beacham et al. 2022). Furthermore, certain Conservation Units[14] (CUs) lack consistent indicator data, while others have multiple indicators per CU. However, there are tools now available to provide a robust and accurate method for measuring and reporting on enhanced contribution to catch needs to be established in order to ascertain the actual returns on investment in hatchery production for harvest.

Finally, as we understand, planning of production for harvest in general lacks measurable targets in relation to fisheries objectives, preventing monitoring and evaluation. As described by the framework, the purpose of producing fish for harvest is to provide opportunities for harvest and support fisheries that are reliant on enhancement and would disappear or become severely constrained in the absence of enhancement. How do we know which fisheries these are? Is it desirable to create fisheries that are reliant on enhancement? These are issues that must be considered when planning for harvest production. Therefore, as the SEP moves forward with stock-specific enhancement plans with measurable performance metrics, it will be important to consider the broader implications of large-scale hatchery production for harvest on the health and sustainability of salmon populations, including wild salmon and salmon in rebuilding and conservation enhancement programs.

14. A Conservation Unit of salmon is "a group of wild salmon sufficiently isolated from other groups that, if lost, is very unlikely to recolonize naturally within an acceptable timeframe (e.g., a human lifetime or a specified number of salmon generations)." DFO Wild Salmon Policy 2005.

6.2 REBUILDING

Rebuilding of depleted salmon populations is required under the new Fish Stock Provisions of Canada's revised Fisheries Act (2019), and under DFO's Sustainable Fisheries Framework (2009). The 2018 Production Planning Framework (SEP 2018) indicates that the rebuilding enhancement objective is for enhancement of a stock that is below apparent carrying capacity including rebuilding depleted populations and mitigating for habitat loss. It was beyond the scope of this review to document the reasons why rebuilding enhancement has occurred in the systems where it is occurring, however, presumably there was some process to determine and prioritise which systems required enhancement.

Our primary question was to address the effectiveness of enhancement for rebuilding purposes; that is, once a system has been identified as depleted, or below carrying capacity, and enhancement has begun for rebuilding purposes, has enhancement been effective in rebuilding the population?

There were a number of key challenges that made our question more difficult to answer, the foremost being data quality/quantity and availability, and a lack of performance measures to assess against (e.g., measurable goals or outcomes with thresholds and timeframes). For example, in general, we were unable to find SEP advice or recommendations on the following:

- Once enhancement has started, when will it be turned off?
- How many generations will be enhanced?
- What is the level to which the depleted stock should be rebuilt?
- Are there assessment programs in place that will allow for measurement of success or failure?
- Are there management targets and tools that would trigger scaling up/down the enhancement?
- Are the effects of enhancement being monitored (e.g., domestication, introgression, fitness in wild and hatchery progeny, reproductive success, marine survival)?

We were unable to find these types of comprehensive plans for any rebuilding systems that we examined, even after extensive discussions with SEP staff. However, with implementation of the Pacific Salmon Strategy Initiative, we hope that in the future enhancement planning for the purposes of rebuilding will be more thoughtfully executed.

In the absence of plans that detailed measurable goals and thresholds, and after 2+ year of exploratory analyses and data development, we chose to address our questions using fairly straightforward methods, appreciating the uncertainty in applying more complex analyses in the absence of information. To this end we attempted to create a scalable and consistent assessment method that could be applied across species and regions so that results could be compared. For this approach, we chose a 'generational' analysis that looked at changes in spawner abundance after enhancement started. Many rebuilding systems had insufficient information to even assess changes in total spawners in generations subsequent, let alone changes in natural-origin or wild spawners. Only **8 out of the 45** rebuilding systems in this study had enough information to assess spawner response in the 3rd generation post enhancement to pre-enhancement levels. Our data compilation flags the paucity of data available from historical assessment programs to support the assessment of effectiveness of enhancement for rebuilding programs.

One potential solution would be that enhancement should not occur in places without appropriate assessment programs that would provide quantifiable information that can be used hand in hand with enhancement plans that include performance measures that provide goals and thresholds. It is possible that enhancement, without assessment will have benefits in some places where assessment is impossible, however, without assessment the impacts (either positive or negative) can not be evaluated. It could be that the systems with sufficient information (e.g. long time-series of overlapping spawner enumerations and enhanced contributions) could be used as proxies for nearby systems, although differences in production strategies and nuances in stock/system specific conditions would need to be considered.

While there has been a vast amount of work to explore the relationship between fisheries management and rebuilding of depleted stocks (see for example NRC 2014, Benson et al. 2016, Holt et al. 2020), there appears to be less literature available on the assessment of successes or failures of enhancement to effectively rebuild salmon populations. While beyond the scope of this report to provide a thorough review of the effects of enhancement in salmon, especially those associated with genetic or other loss of fitness consequences, it is worthwhile to provide some context to our analyses. There is a preponderance of literature documenting loss of fitness and/or productivity in hatchery origin individuals, or natural populations in relation to hatchery contributions (see Chilcote 2003, Araki et al. 2007a, 2007b, 2009, Chilcote et al. 2011, Christie et al. 2012a, 2012b, Christie et al. 2014, Scheurell et al. 2021). Many of these studies investigated effects in steelhead populations and/or segregated hatchery environments, neither of which are under review in this report, however others explored these relationships in coho and Chinook and found similar effects (e.g. Nickelson 2003, Buhle et al. 2009, Venditti et al. 2018, Koch et al. 2022). In BC, earlier studies showing these results prompted a CSAS review on genetic considerations under Chinook enhancement following work done in Washington, with the ultimate conclusion that rebuilding programs must be planned in combination with the advice provided in Withler et al. (2018) and include genetic management plans.

Further studies on Chinook (e.g., Koch et al. 2022) showed that supplementation of Upper Yakima River Chinook increased overall abundance of fish spawning naturally on the spawning grounds, however hatchery origin Chinook had reduced reproductive success. Venditti et al. (2018) showed a number of key results based on a comparison between supplemented and reference streams in Idaho for Chinook. They found that supplementation increased abundance at some life stages, but that it did not persist into post-supplementation phases; after supplementation ceased, abundance and productivity returned to pre-supplementation relationships, highlighting the importance of addressing limiting factors. Buhle et al. (2009) explored the relationships between hatchery and wild coho along the coast of Washington and found that not only did hatchery origin coho spawners exhibit stronger density dependence than wild spawners, but productivity of wild salmon decreased as releases of hatchery juveniles increased.

There are also studies documenting demographic boosts to spawner abundance and no loss of reproductive success in enhanced populations (Hess et al. 2012, Janowitz-Koch et al. 2019, Courter et al. 2022). These authors found trends towards lower survival of hatchery origin fish but no reduction in fitness for hatchery-natural-origin crosses, even after 2 generations, with some evidence of a second-generation boost (e.g., hatchery origin individuals spawning naturally and providing further offspring or grand-offspring to the population). These programs used 100% natural-origin broodstock, highlighting the importance of natural-origin broodstock in integrated programs, but they did not assess the results after enhancement ceased, or beyond relatively short time-frames.

In general, we found very few studies that looked at the effectiveness of enhancement programs to rebuild populations after enhancement had ceased other than the results presented in Venditti et al. (2018). Taken together, the evidence from systems with 'on-and-off' enhancement and systems where enhancement has stopped or been dramatically reduced over time suggest that enhancement for rebuilding is not effective once stopped, and that short-term supplementation does not lead to increased spawners long-term. Investigations into the cause for failure of rebuilding efforts in these systems are certainly warranted, as there may be habitat or other limiting factors involved.

Our results for Chinook salmon do provide evidence of a 'demographic boost' in total spawners in the 3rd generation following enhancement, as was found in many of the studies reviewed above, however the response of natural-origin and wild spawners is much more mixed. In **11 out of 16 systems** (69%) examined in this study there was actually a decrease in wild spawners in the period following the 3rd generation after enhancement (Figure 40). This could be from a number of factors including more broad declines in productivity regionally, long-term fitness/ negative genetic consequences, or numerical considerations such as swamping of natural populations with hatchery origin spawners resulting in reduced chance of natural-origin fish mating with other natural-origin fish.

We plotted pHOS and PNI data for the Chinook rebuilding systems (Figure 37 and Figure 38). Firstly, these data show that there are only long-time series of pHOS for approximately **10 out of the 35** systems shown, and that many systems are often below the integrated-wild threshold of 0.72 given in Withler et al. (2018: Table 3). The data also show that there can be significant differences in PNI estimates using thermal and CWT information (e.g., Sarita River Chinook). It is understood from discussions with SEP staff that rebuilding systems may start out with low PNI (high hatchery influence), but then should trend towards higher PNI over time (Michael Thom, SEP, personal communication, 2022). This appears to only be the case in two systems (upper Bulkley River and middle Shuswap River Chinook). In the few systems that have long-time series of pHOS information, there are many systems where PNI has remained variable around the same level, or declined over time, which would possibly contradict the intention of rebuilding. We suggest that, as above, genetic management thresholds, goals and time frames be incorporated into enhancement plans, given the advice provided in Withler et al. (2018).

There are many factors that confounded our attempts at this assessment. These include a lack of stream specific data in many cases, including estimates of spawner abundance, enhanced contributions and stream specific age data and exploitation rates. There are also shifts in regional and local productivity over time that will influence the relationship between the numerical abundance of hatchery origin returns and possible fitness related effects of enhancement, and inhibit simplified analyses like ours over longer time frames. This also makes it difficult to assess on a stream level what would happen if enhancement was not occurring. More than likely many of these systems would remain depressed until limiting factors (e.g., freshwater habitat issues and in some cases harvest considerations) are addressed. It would appear that while hatchery production increases total spawner abundance in these systems over the short term, and generally while enhancement is ongoing, when stopped, spawner abundance does not remain increased. These findings should be used to inform proposed enhancement for rebuilding purposes and provides cautionary evidence on the effectiveness of long-term rebuilding enhancement. Resources used for long-term enhancement to support depressed populations must be weighed against the benefits of addressing limiting factors within our control and the potential deleterious effects of enhancement to wild populations.

7. RECOMMENDATIONS

Through our work on harvest and rebuilding enhancement effectiveness, we have developed a better understanding of SEP enhancement objectives, data limitations and challenges, and assessment methodologies. The following recommendations are important to consider given our experience in attempting to assess effectiveness of rebuilding for Chinook:

Harvest Effectiveness

1. We do not know of any targets or objectives for enhanced contributions to harvest, which makes it difficult to assess effectiveness, and problematic to scale production for harvest accordingly. We recommend the development of targets for enhanced contributions of harvest either by region or fishery. Targets must consider both socio-economic, ecological, and conservation and rebuilding needs.

2. Consider adoption of alternative marking methods and assessment programs (e.g., PBT and GSI) to estimate enhanced contributions to fisheries for coho salmon.

3. Compare CWT estimated enhanced contributions to estimates based on thermal marks or GSI data to assess uncertainty in expansions and marking methods/sampling, where both sets of data are available and overlap, as has been done for coho.

4. Implement more fisher-independent assessment programs to estimate enhanced contributions in recreational fisheries. These might include reference fisheries for example.

5. Conduct a more thorough analysis of hatchery efficiency that accounts for changes in fishery regulations and management (e.g., long-term closures for conservation), and marine survival.

6. Create a formal, accessible compilation of catch data, including commercial, recreational, and First Nations fisheries, and improve recreational catch reporting. Catch sample data in all fisheries should be designed to estimate enhanced contributions.

7. Improve estimation of non-associated releases in fisheries catches to account for all enhanced contributions to catches.

Rebuilding Effectiveness

1. Enhanced contributions are key to assessing effects (and effectiveness) of enhancement for rebuilding, yet in most systems there is no or very limited information. This is a serious shortcoming of assessment programs and should be considered high priority in systems enhanced for rebuilding.

2. Proposed mass-marking initiatives under PSSI may make it easier to assess enhanced contributions accurately, however given post-enhancement performance, the cost of mass-marking and continued enhancement should be weighed against the benefits of habitat restoration activities and supporting wild spawners.

3. It would be informative to be able to assess rebuilding systems for effects of enhancement on relative reproductive success, however there are very few systems with the data to support this analysis. It would be a worst-case scenario where enhancement was implemented to rebuild a population, and once removed spawner abundance declined to pre-enhancement levels yet the remaining post-enhancement 'wild' population may be disadvantaged with regards to fitness to local habitat.

4. For each line of production for rebuilding, there should be clear targets, timelines, and goals to **(1)** manage PNI and scale hatchery contributions appropriately, and **(2)** provide a framework to assess effectiveness of the rebuilding program. Our understanding is that this is a known issue and efforts are underway in the SEP program to do this currently.

5. We suggest a review (independent or otherwise) of current rebuilding enhancement (and any proposed rebuilding enhancement under PSSI) for all lines of production that provides clear and transparent rationales for enhancement and measurable objectives to assess performance against.

6. With improved monitoring, assessment, data collation and data availability, additional more in-depth analyses could be developed using state-space models or Dynamic Factor Analysis for example to identify trends between enhanced systems and reference sites.

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Photo by: Danny Swainson

9. FIGURES

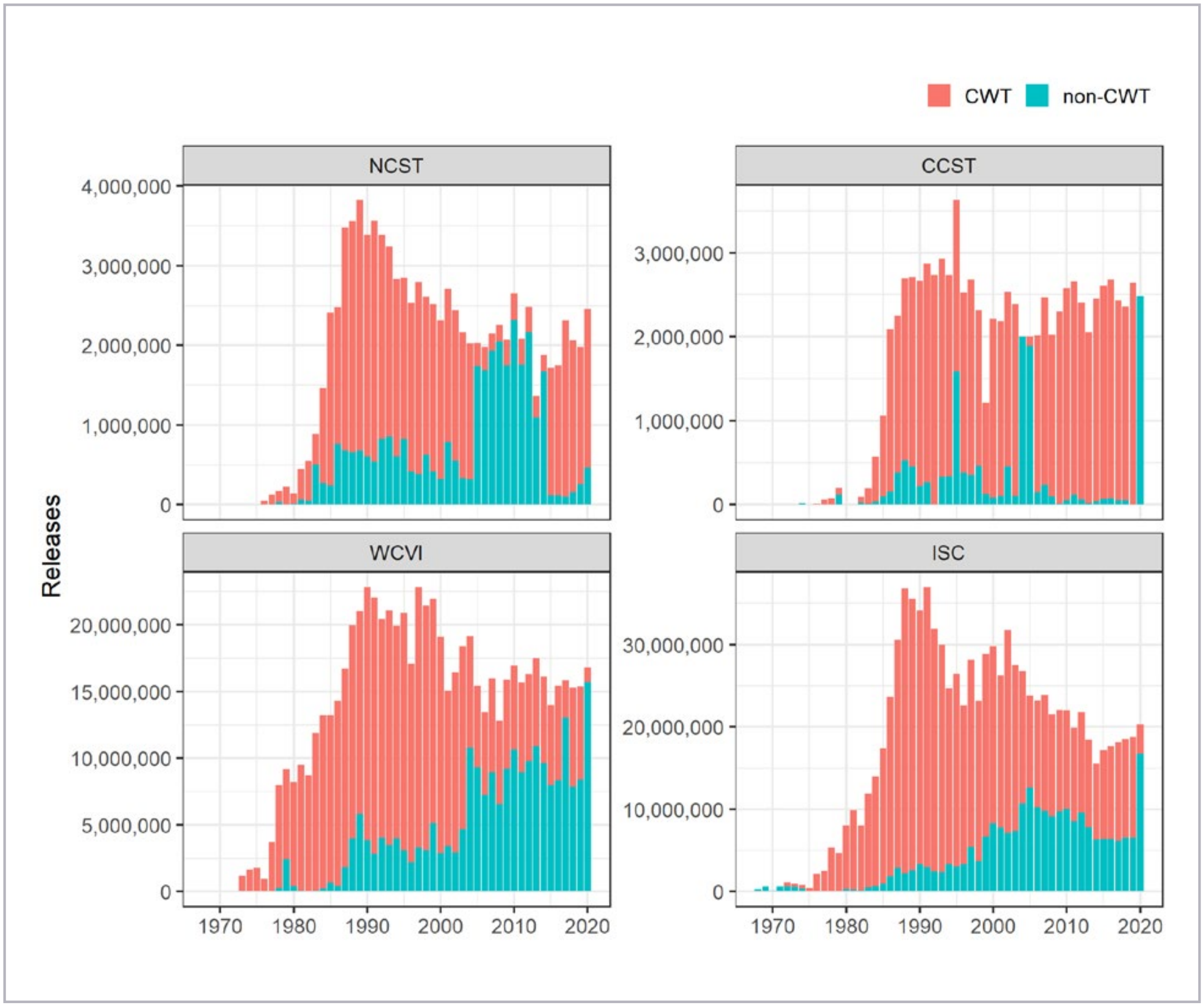

Figure 1: Total annual releases of hatchery **Chinook** for all enhancement objectives along the north coast (NCST), central coast (CCST), west coast of Vancouver Island (WCVI) and inner south coast (ISC) since 1968 by release year. Releases that were tagged with a CWT or untagged but associated with a CWT release group are shown in red, while untagged releases with no associated CWT are shown in blue. Note different y-axis scales.

Figure 2: Total annual releases of hatchery **coho** for all enhancement objectives along the north coast (NCST), central coast (CCST), west coast of Vancouver Island (WCVI) and inner south coast (ISC) since 1968 (by release year). Releases that were tagged with a CWT or untagged but associated with a CWT release group are shown in red, while untagged releases with no associated CWT are shown in blue. Note different y-axis scales.

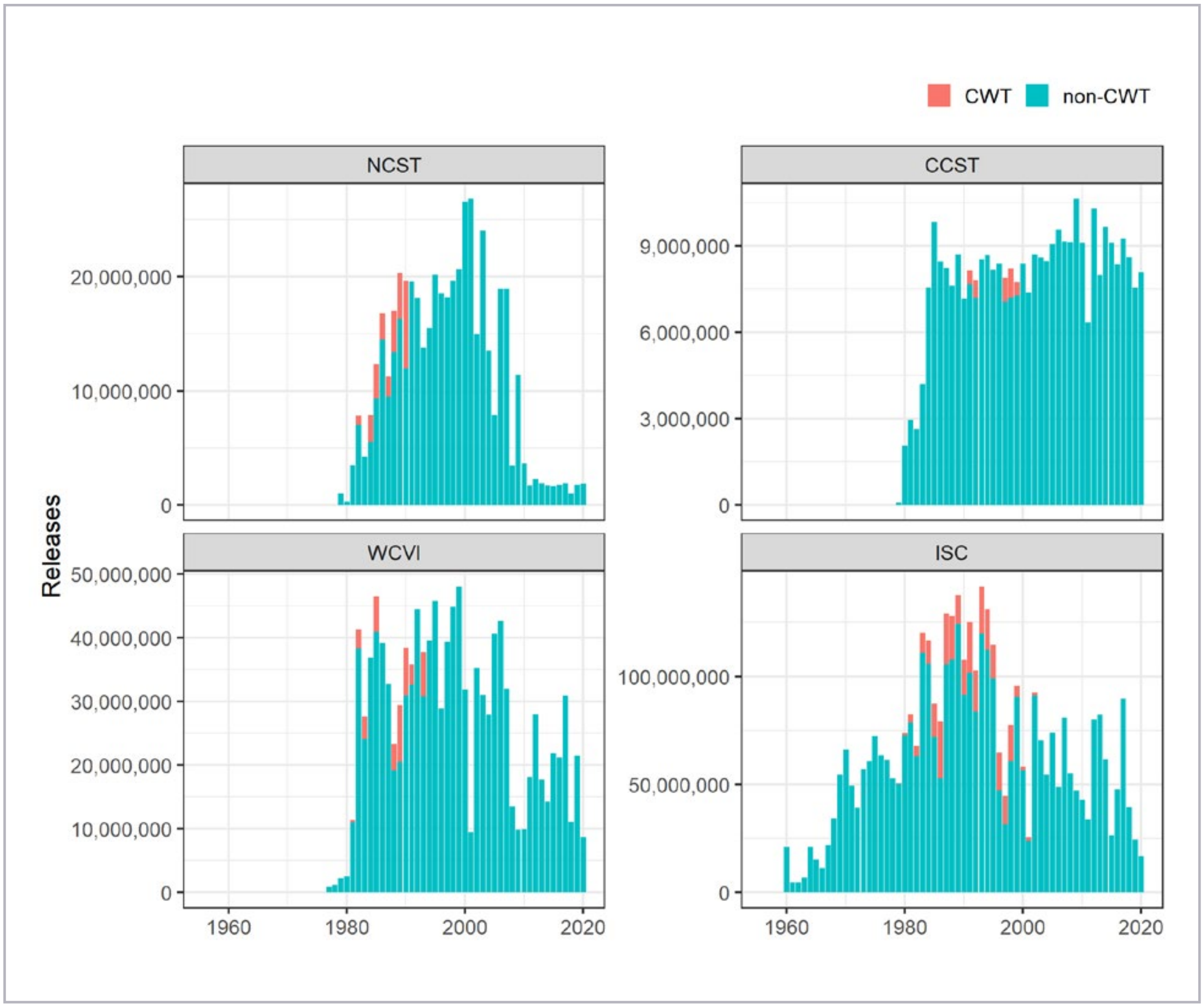

Figure 3: Total annual releases of hatchery **chum** for all enhancement objectives along the north coast (NCST), central coast (CCST), west coast of Vancouver Island (WCVI) and inner south coast (ISC) since 1956. Releases that were tagged with a CWT or untagged but associated with a CWT release group are shown in red, while untagged releases with no associated CWT are shown in blue. Note different y-axis scales. Releases from spawning channels were included as this is a summary figure.

Figure 4: Total annual releases of hatchery **pink** for all enhancement objectives along the north coast (NCST), central coast (CCST), west coast of Vancouver Island (WCVI) and inner south coast (ISC) since 1956. Releases that were tagged with a CWT or untagged but associated with a CWT release group are shown in red, while untagged releases with no associated CWT are shown in blue (>99% releases are non-CWT). Note different y-axis scales. Releases from spawning channels were included as this is a summary figure.

Figure 5: Total annual releases of hatchery **sockeye** for all enhancement objectives along the north coast (NCST), central coast (CCST), west coast of Vancouver Island (WCVI) and inner south coast (ISC) since 1964. Releases that were tagged with a CWT or untagged but associated with a CWT release group are shown in red, while untagged releases with no associated CWT are shown in blue (>99% releases are non-CWT). Note different y-axis scales. Releases from spawning channels were included as this is a summary figure.

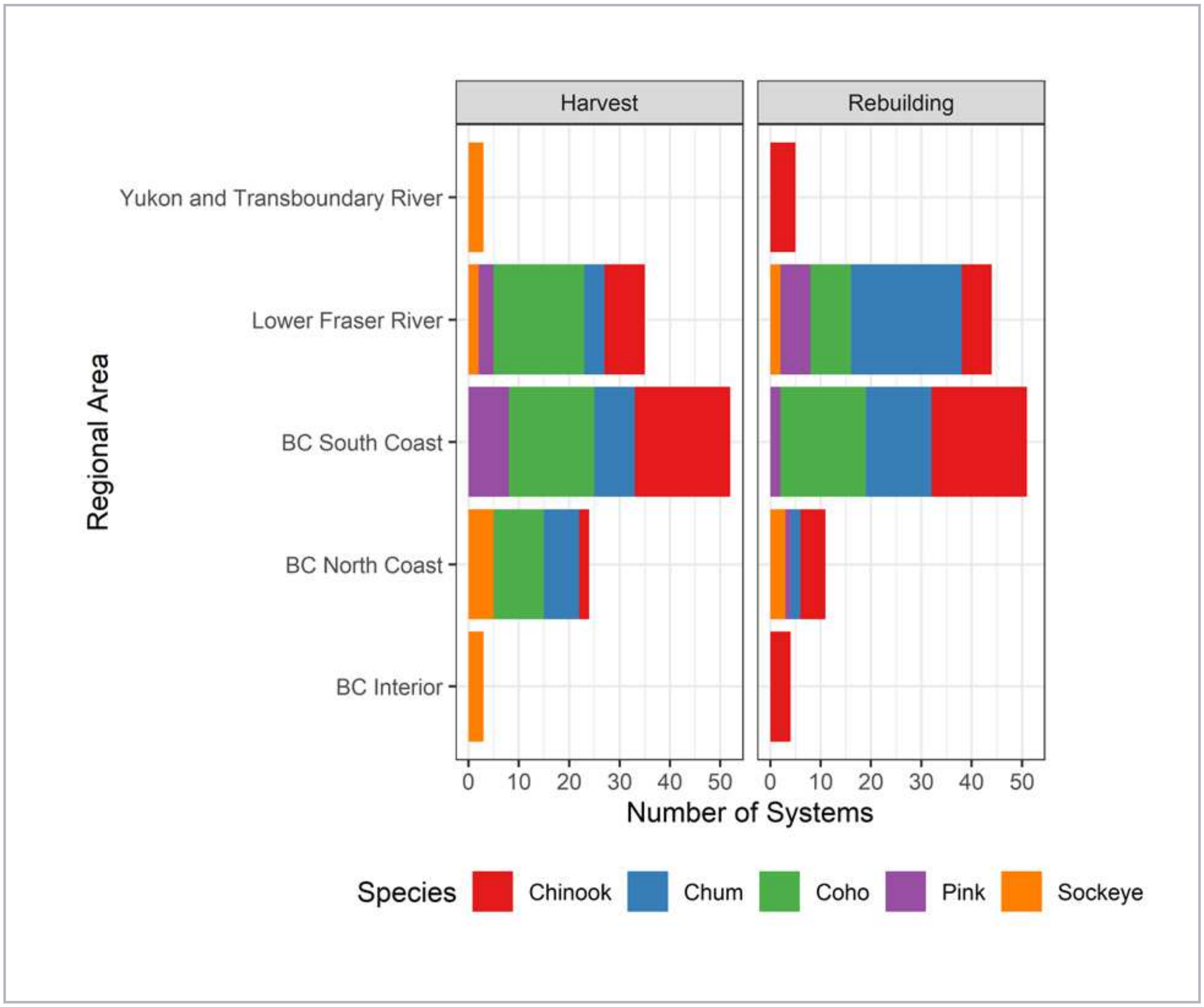

Figure 6: Number of unique production lines by objective, species, and production area from the 2014-2021 SEP production plans.

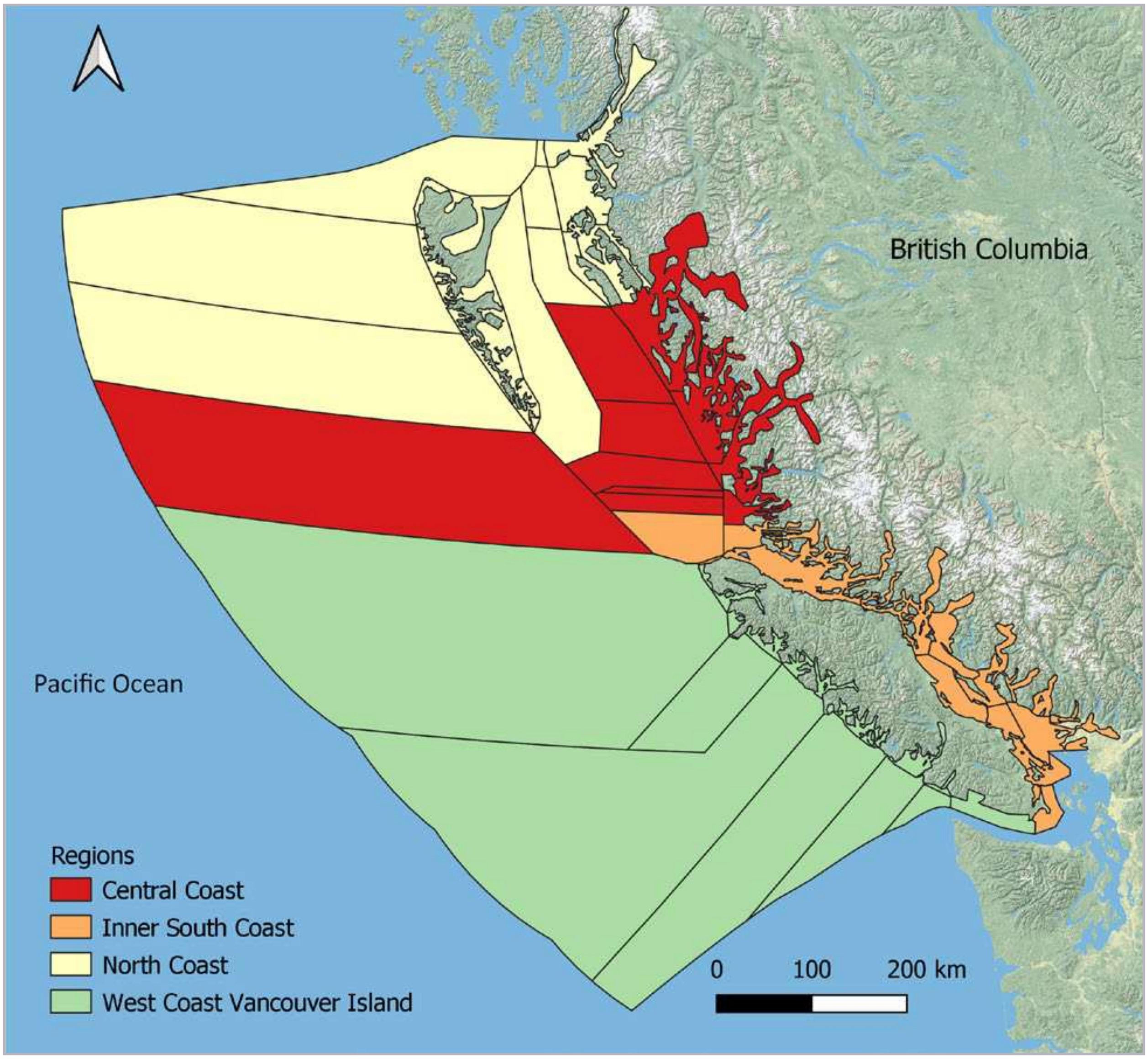

Figure 7: Map of DFO Statistical Area combinations for regional designation in harvest analysis.

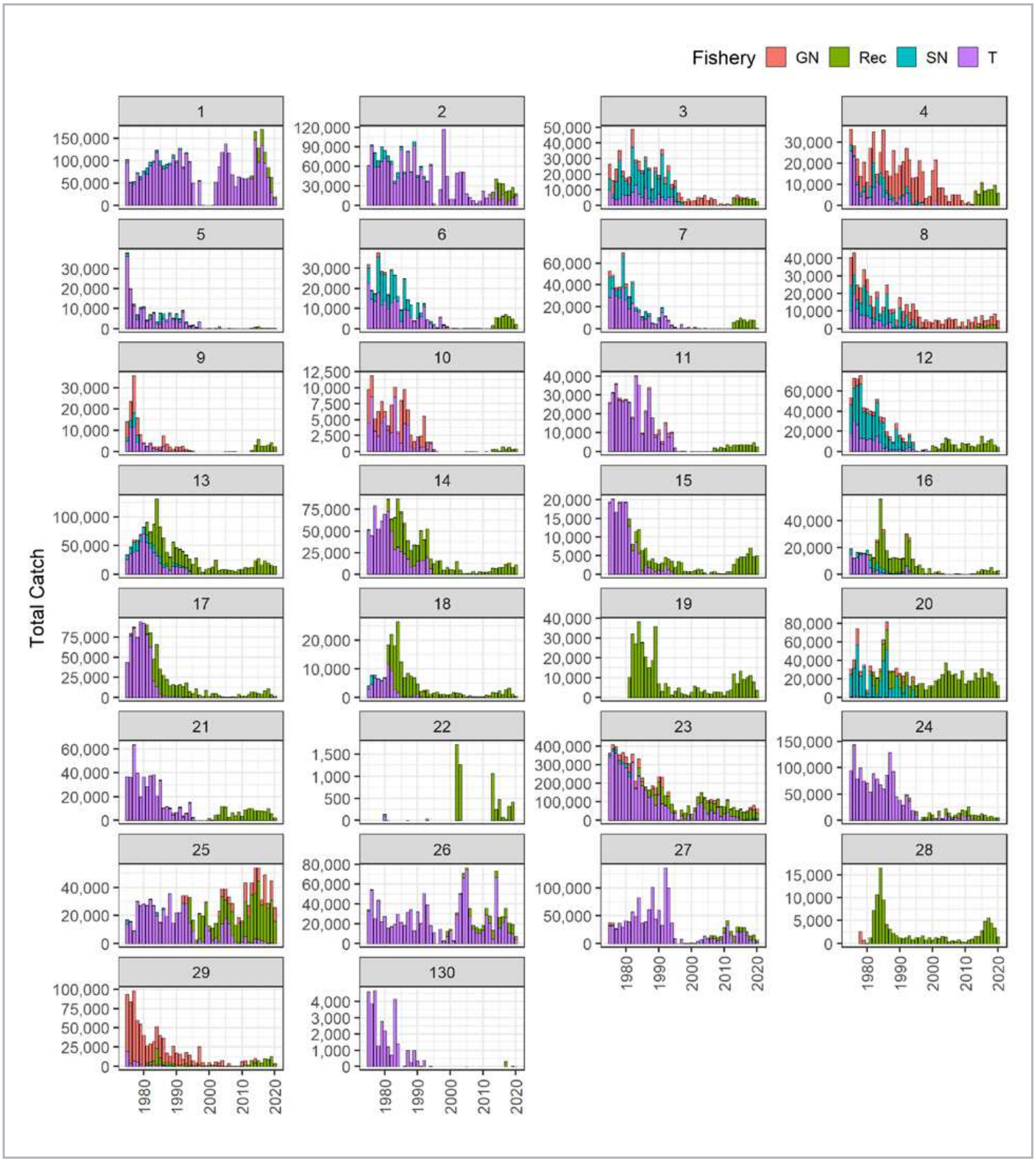

Figure 8: Total annual **Chinook** catch by statistical area and fishery from 1975-2020: gill net (GN, red), seine net (SN, green), troll (T, blue), and recreational (rec, purple).

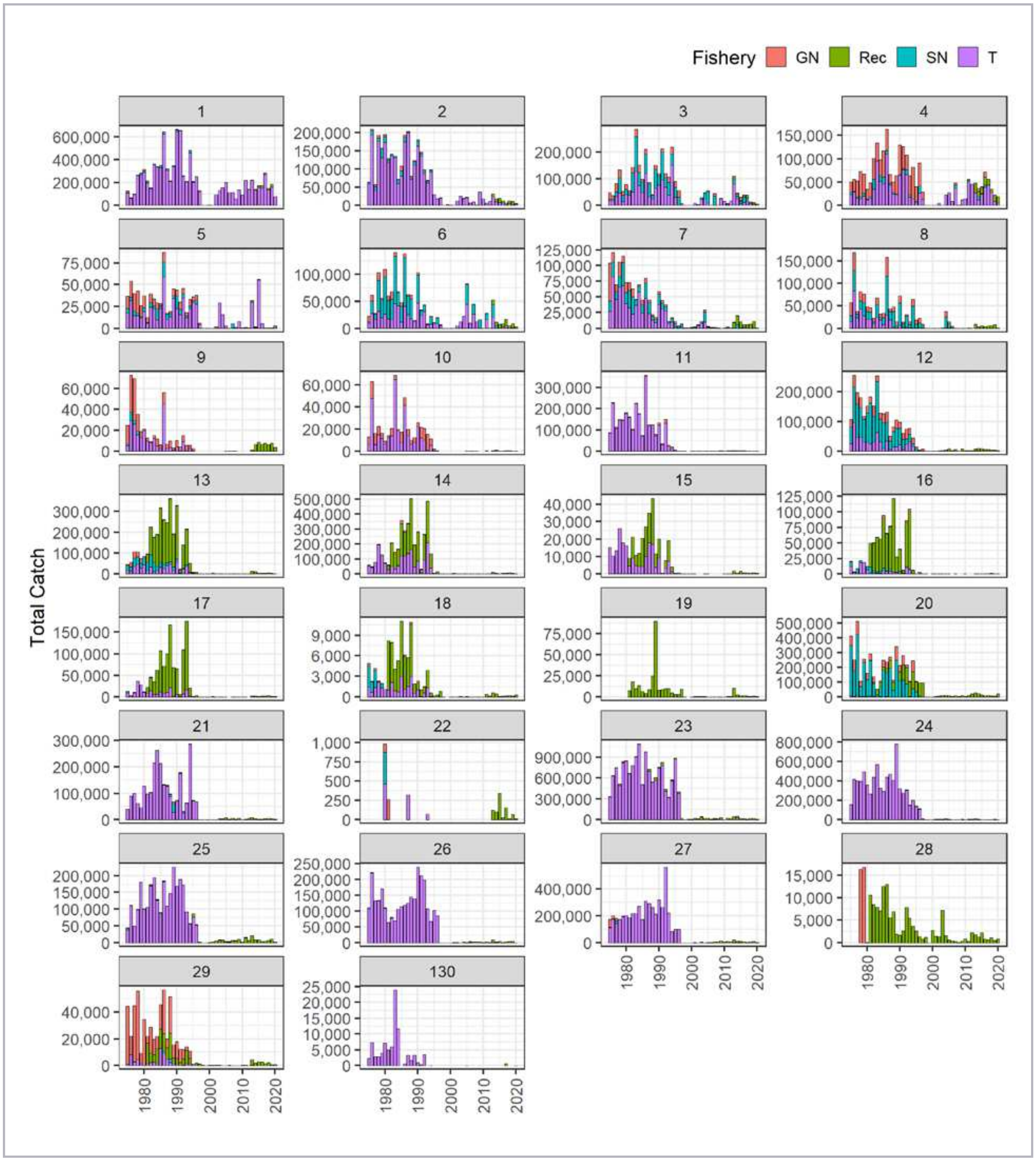

Figure 9: Total annual **coho** catch by statistical area and fishery from 1975-2020: gill net (GN, red), seine net (SN, green), troll (T, blue), and recreational (rec, purple).

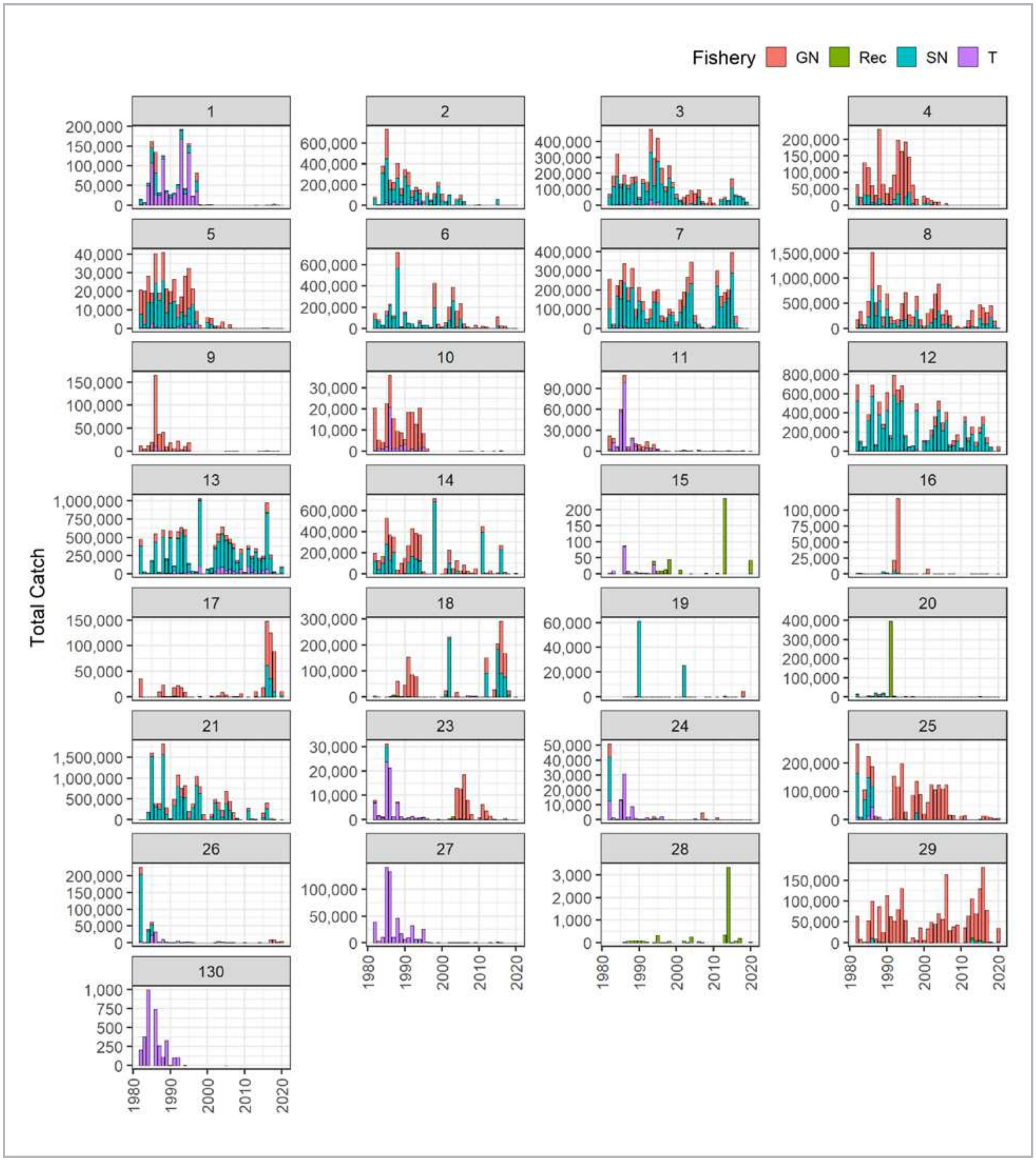

Figure 10: Total annual **chum** catch by statistical area and fishery from 1981-2020: gill net (GN, red), seine net (SN, green), troll (T, blue), and recreational (rec, purple).

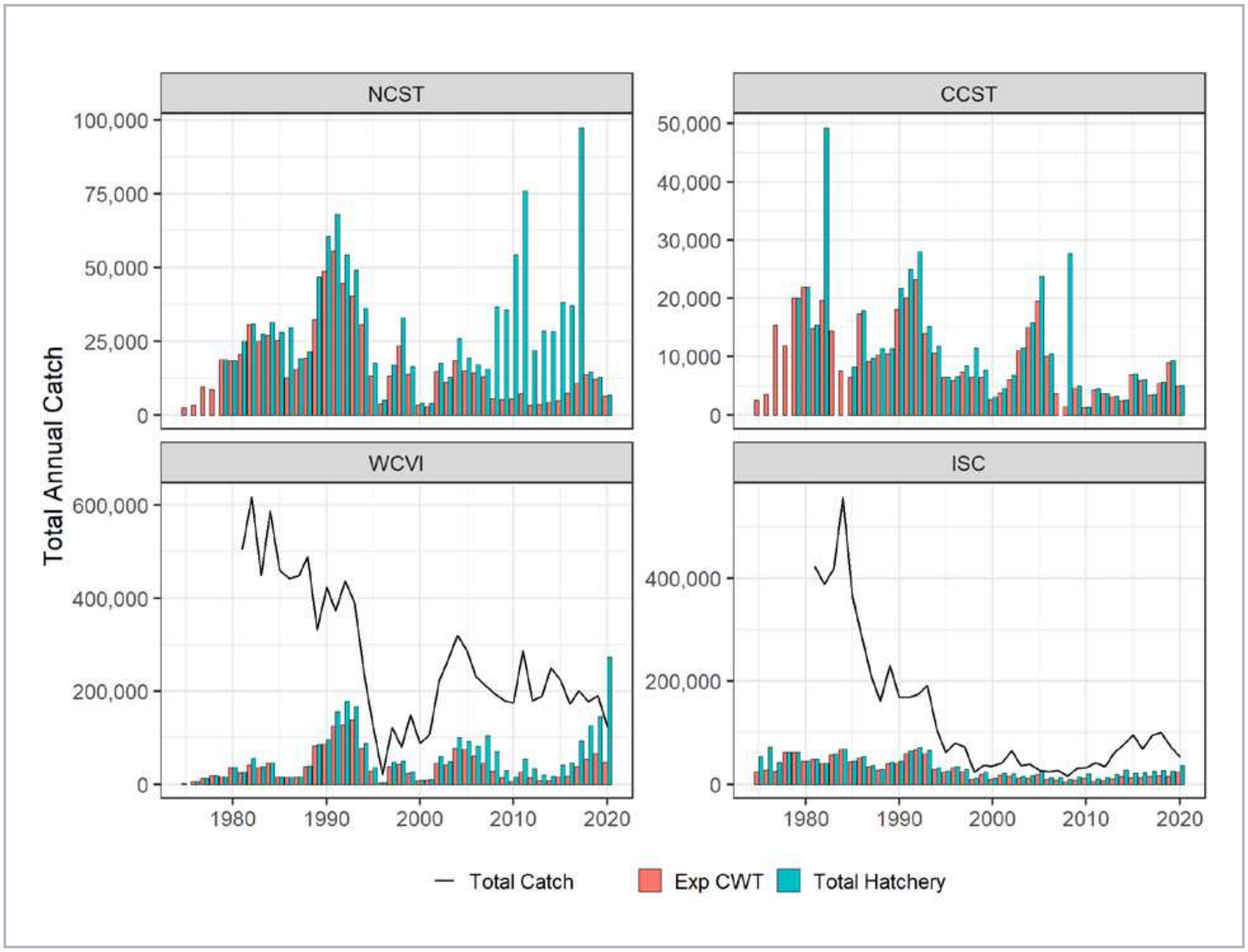

Figure 11: Total annual expanded CWT **Chinook** catch (red), total hatchery catch (accounting for non-CWT-associated releases; blue), and overall total **Chinook** catch (black line) in fisheries in each region (NCST = north coast, CCST = central coast, WCVI = west coast of Vancouver Island, ISC = inner south coast). Total catch is only provided for WCVI and ISC regions.

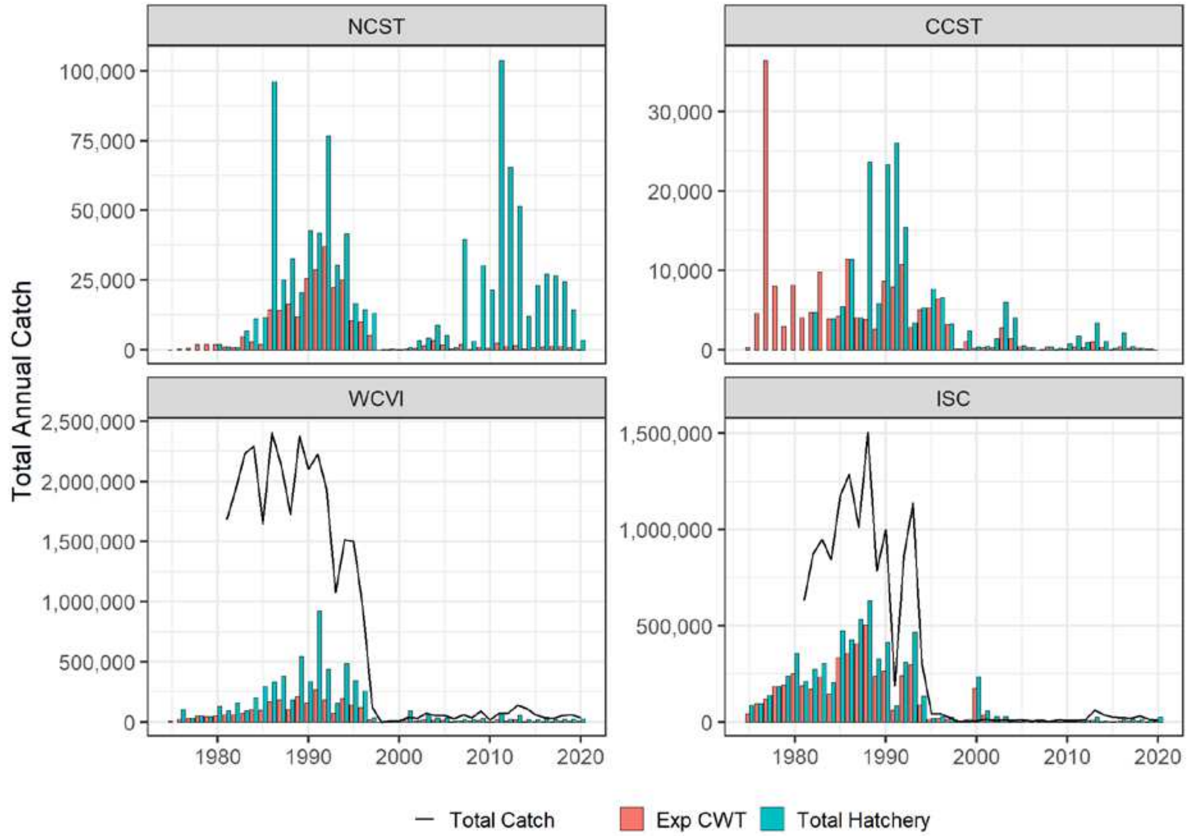

Figure 12: Total annual expanded CWT **coho** catch (red), extended total hatchery catch (accounting for non-CWT-associated releases; blue), and estimated overall total **coho** catch (black line) in fisheries in each region (NCST = north coast, CCST = central coast, WCVI = west coast of Vancouver Island, ISC = inner south coast).

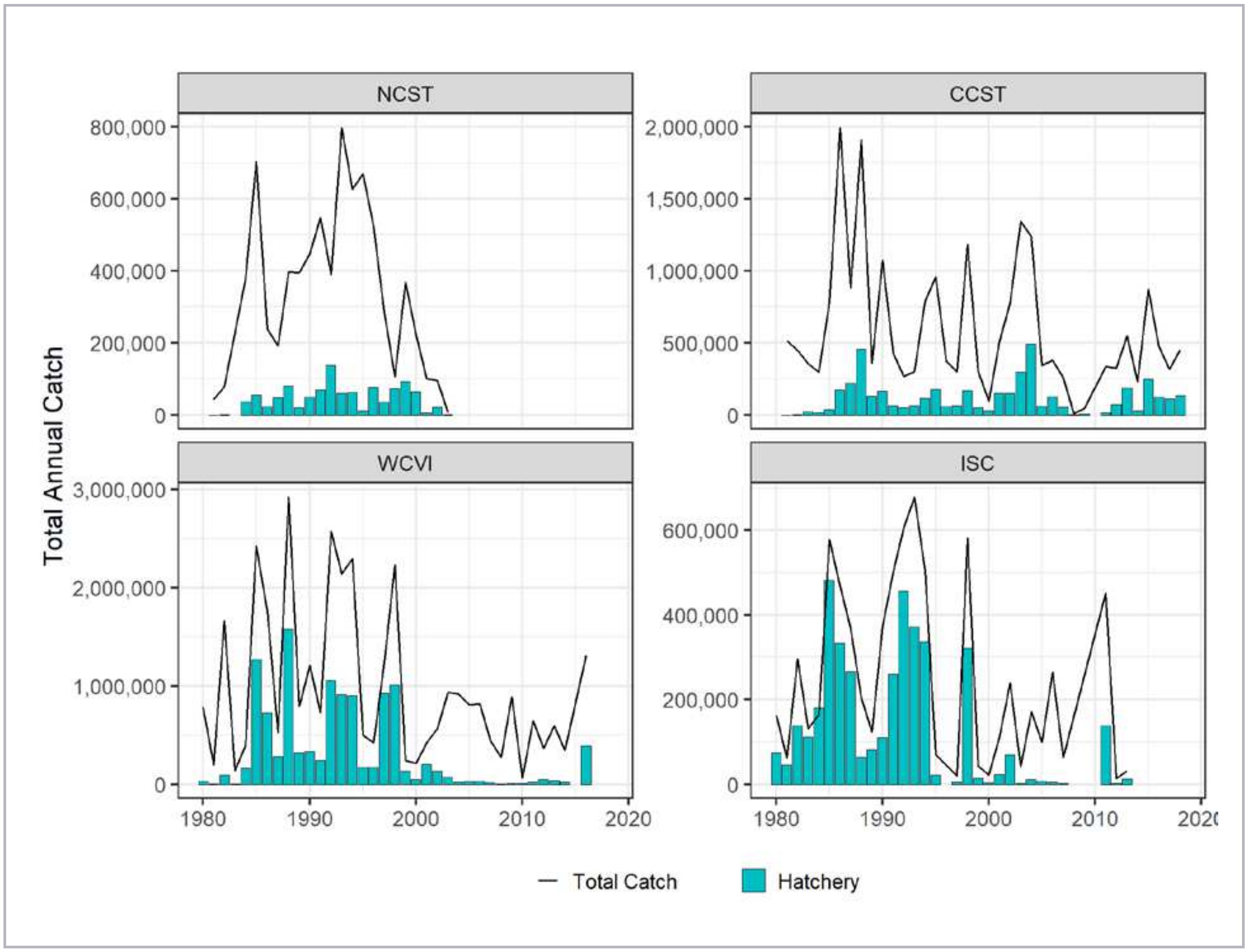

Figure 13: Total annual catches of hatchery **chum** in net fisheries (blue) and overall total **chum** catch (black line) in fisheries in each region (NCST = north coast, CCST = central coast, WCVI = west coast of Vancouver Island, ISC = inner south coast). Hatchery catch data from Lynch et al. 2020.

Figure 14: Top: Total catch (commercial and recreational) of **Chinook** in north coast (NCST) central coast (CCST) fisheries. Bottom: The proportion of total catch coming from BC hatchery production (red) or other sources (blue) in NCST and CCST fisheries.

Figure 15: Top: Total catch (commercial and recreational) of **Chinook** in west coast Vancouver Island (WCVI) and inner south coast (ISC) fisheries. Bottom: The proportion of total catch coming from BC hatchery production (red) or other sources (blue) in WCVI and ISC fisheries.

Figure 16: Top: Total catch (commercial and recreational) of **coho** in north coast (NCST) central coast (CCST) fisheries. Bottom: The proportion of total catch coming from BC hatchery production (red) or other sources (blue) in NCST and CCST fisheries.

Figure 17: Top: Total catch (commercial and recreational) of **coho** in west coast Vancouver Island (WCVI) and inner south coast (ISC) fisheries. Bottom: The proportion of total catch coming from BC hatchery production (red) or other sources (blue) in WCVI and ISC fisheries.

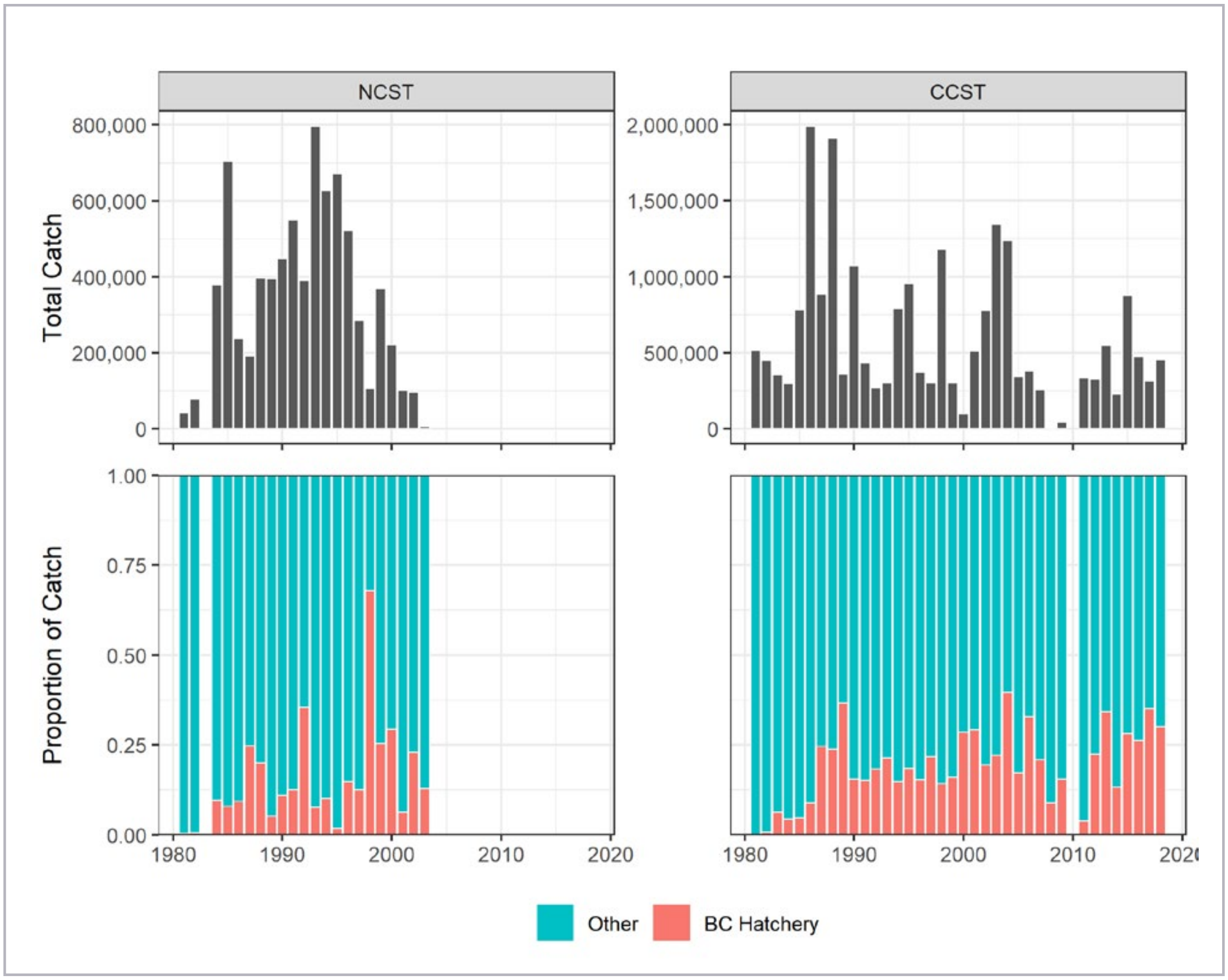

Figure 18: Top: Total catch of **chum** in northern (NCST) and central (CCST) BC net fisheries. Bottom: The proportion of total catch coming from BC hatchery production (red) or other sources (blue) in NCST and CCST net fisheries. Data from Lynch et al. 2020.

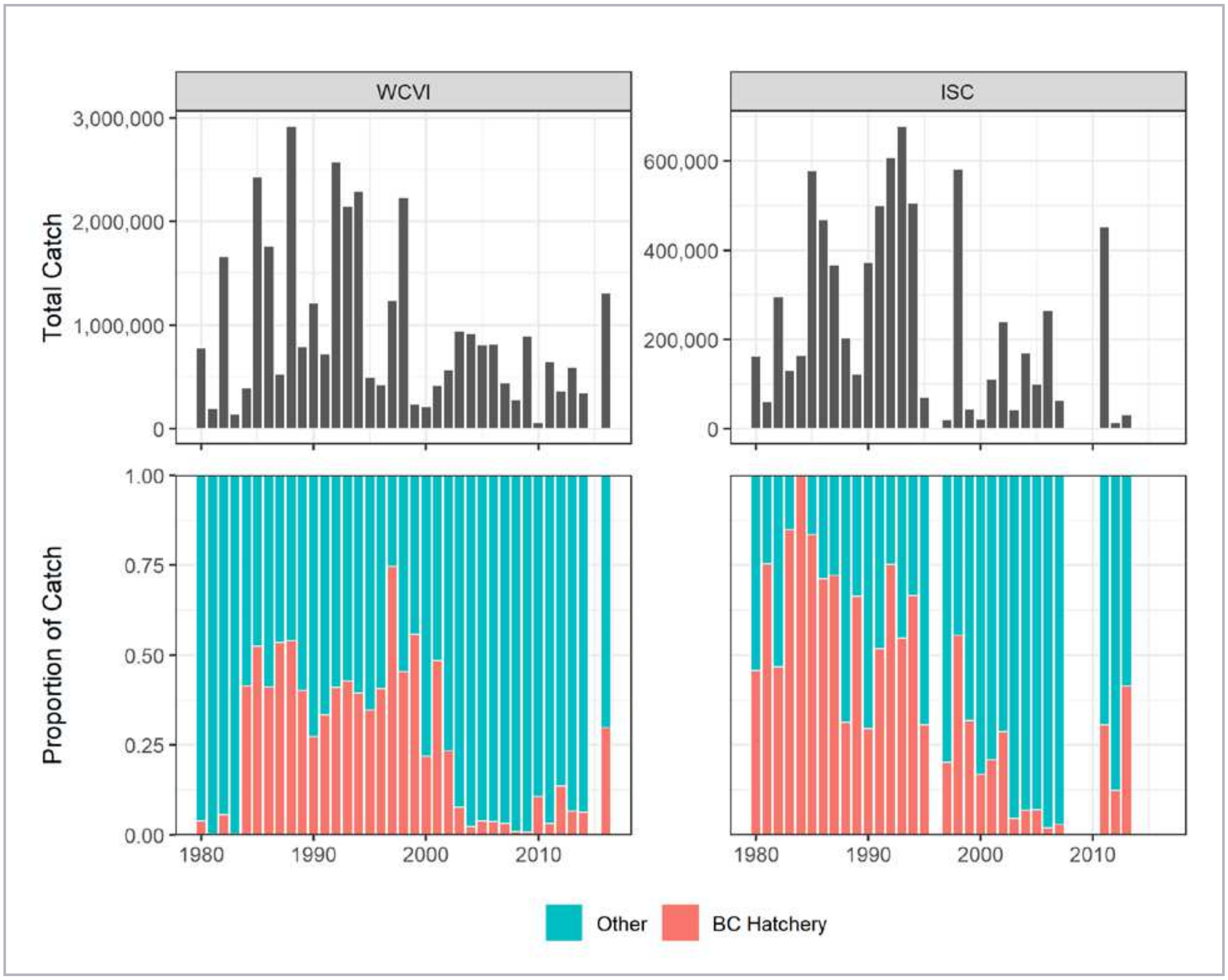

Figure 19: Top: Total catch of **chum** in west coast Vancouver Island (WCVI) and inner south coast (ISC) net fisheries. Bottom: The proportion of total catch coming from BC hatchery production (red) or other sources (blue) in WCVI and ISC net fisheries. Data from Lynch et al. 2020.

Figure 20: Total catch of **Chinook** in net, troll and recreational fisheries on the NCST (top) with the proportions of total catch coming from BC hatchery production (red) and other sources (blue) for each recovery year (bottom).

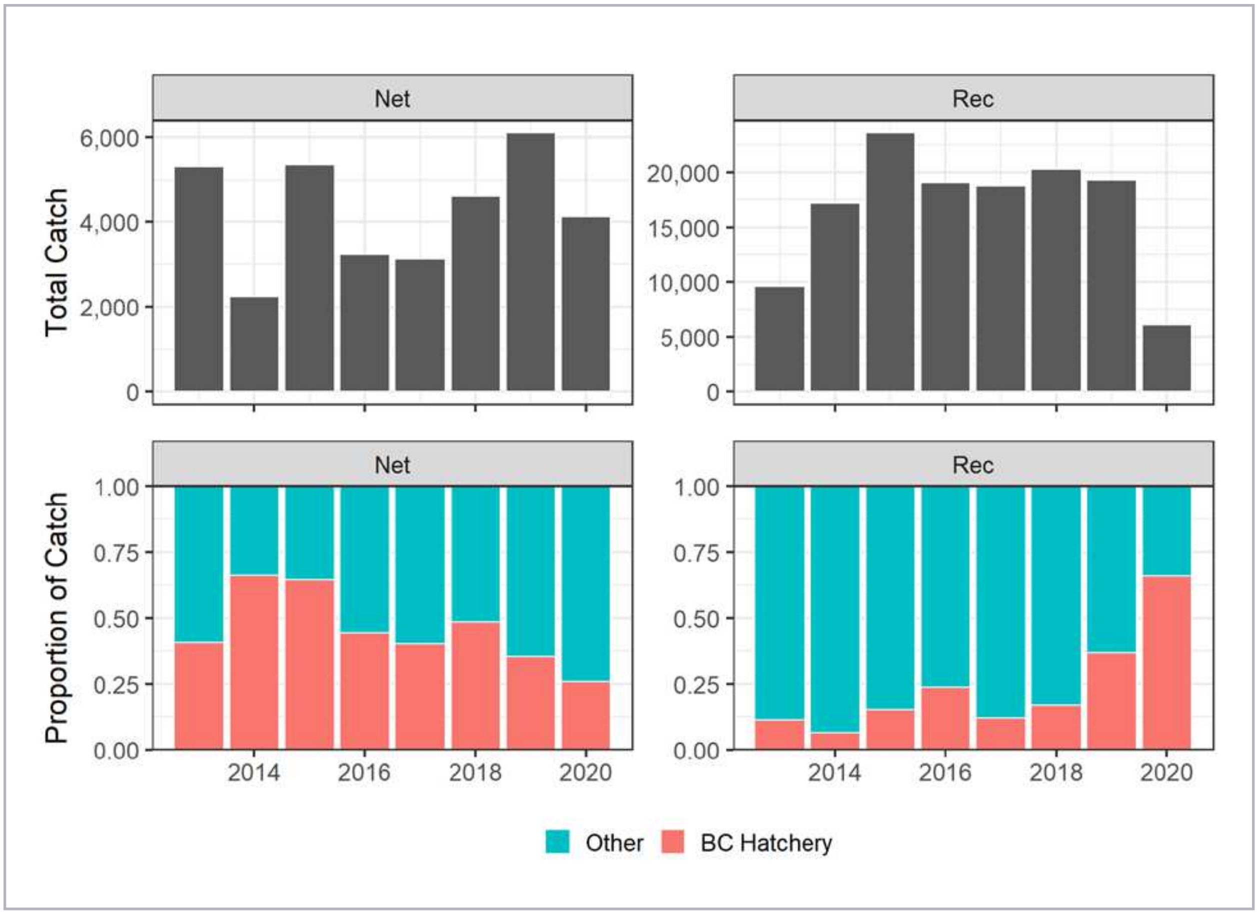

Figure 21: Total catch of **Chinook** in net, troll and recreational fisheries on the CCST (top) with the proportions of total catch coming from BC hatchery production (red) and other sources (blue) for each recovery year (bottom).

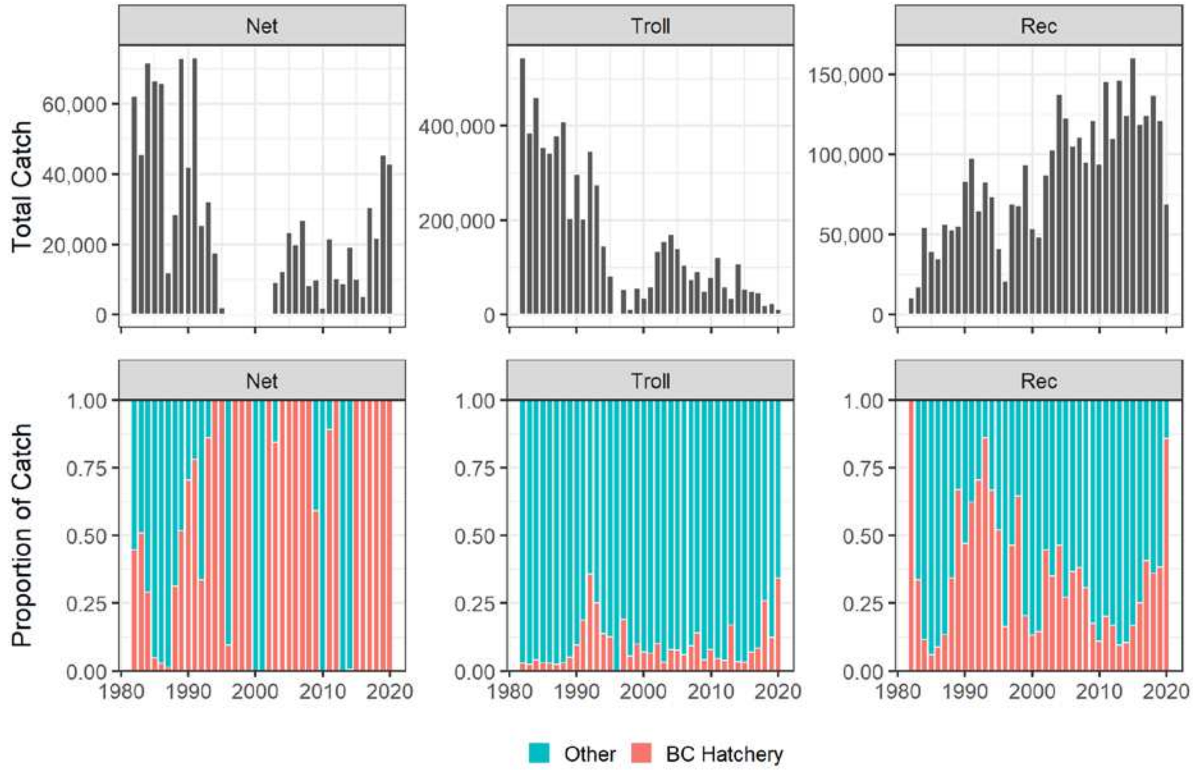

Figure 22: Total catch of **Chinook** in net, troll and recreational fisheries on the WCVI (top) with the proportions of total catch coming from BC hatchery production (red) and other sources (blue) for each recovery year (bottom).

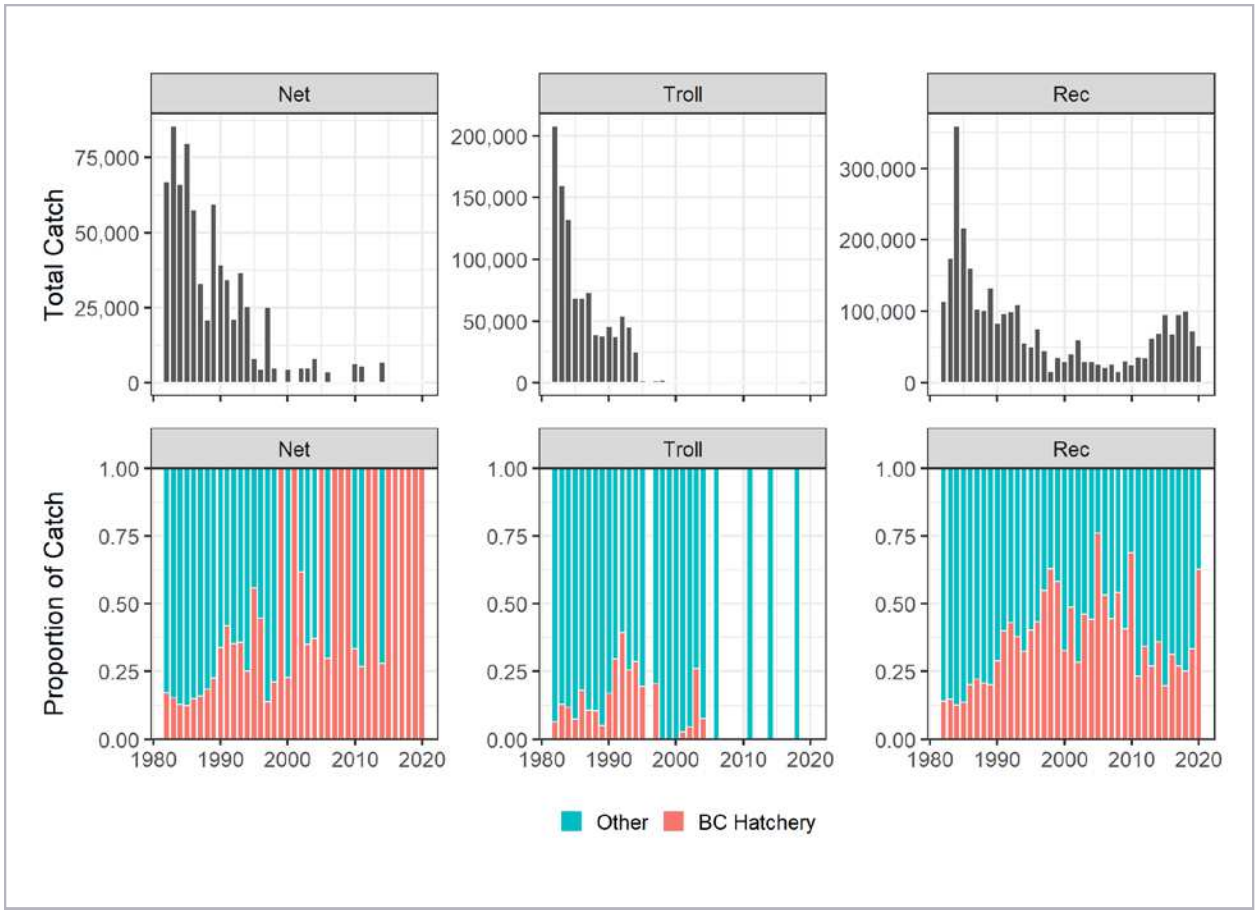

Figure 23: Total catch of **Chinook** in net, troll and recreational fisheries on the ISC (top) with the proportions of total catch coming from BC hatchery production (red) and other sources (blue) for each recovery year (bottom).

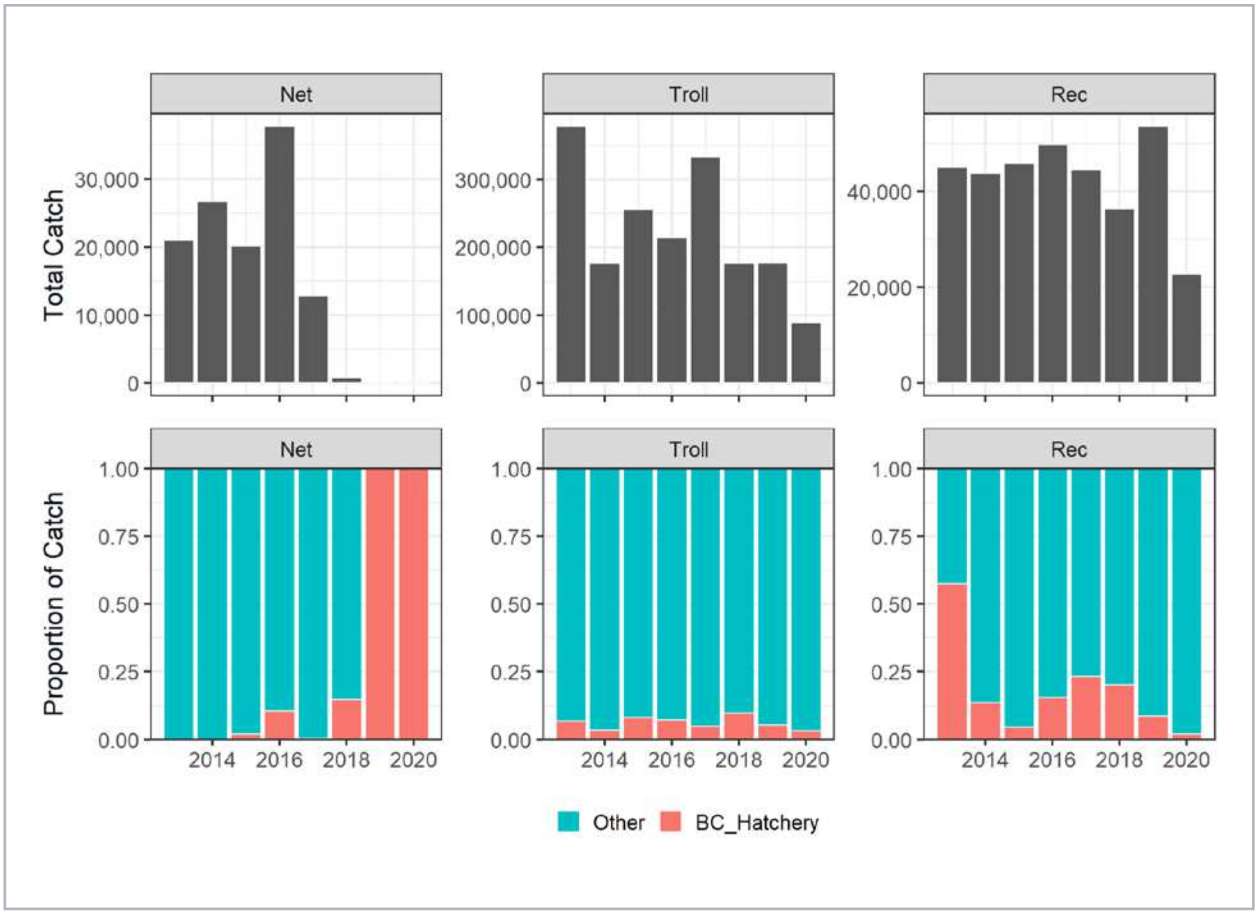

Figure 24: Total catch of **coho** in net, troll and recreational fisheries on the NCST (top) with the proportions of total catch coming from BC hatchery production (red) and other sources (blue) for each recovery year (bottom).

Figure 25: Total catch of **coho** in net, troll and recreational fisheries on the CCST (top) with the proportions of total catch coming from BC hatchery production (red) and other sources (blue) for each recovery year (bottom).

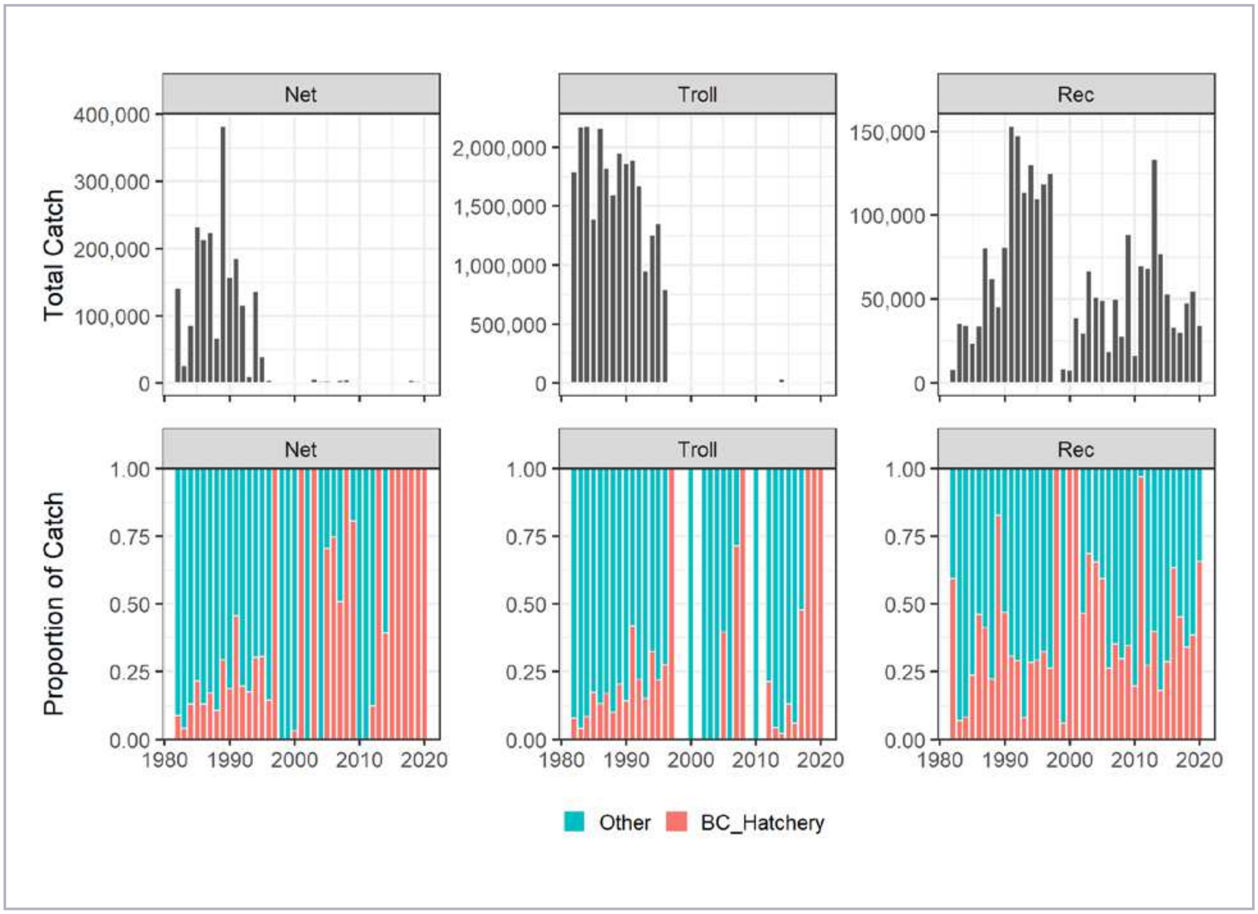

Figure 26: Total catch of **coho** in net, troll and recreational fisheries on the WCVI (top) with proportions of hatchery (red) and non-hatchery (blue) catch shown for each recovery year (bottom).

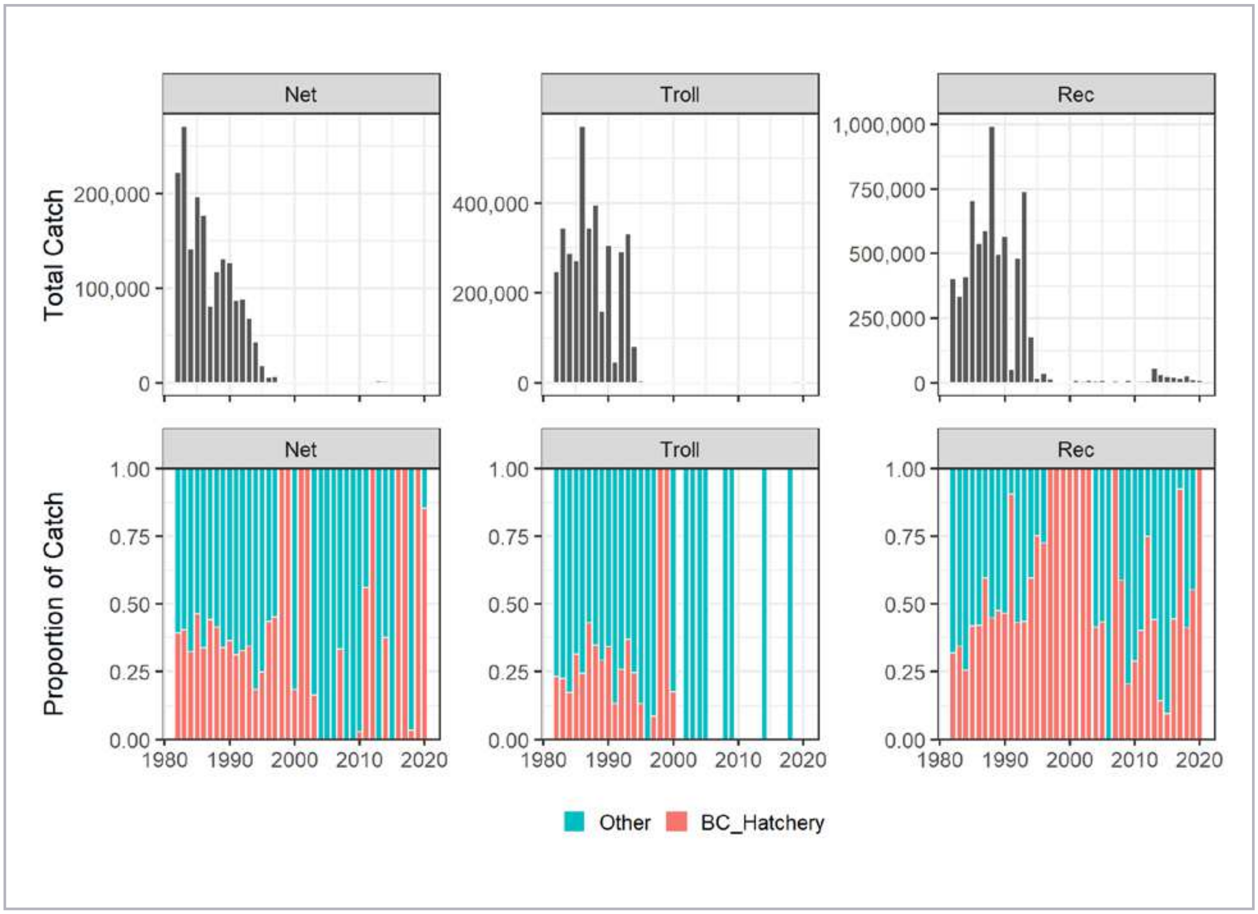

Figure 27: Total catch of **coho** in net, troll and recreational fisheries on the ISC (top) with proportions of hatchery (red) and non-hatchery (blue) catch shown for each recovery year (bottom).

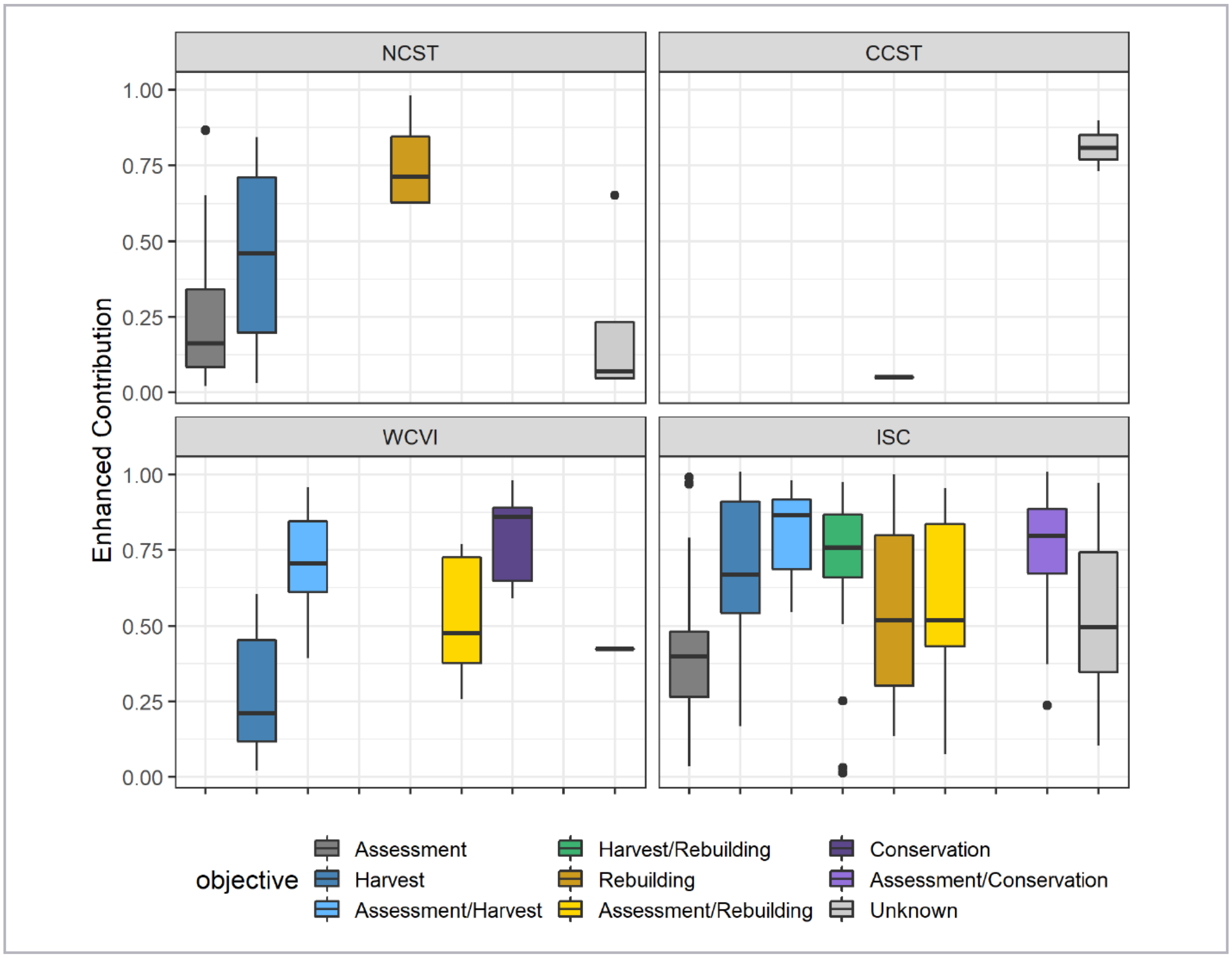

Figure 28: Enhanced contribution of **Chinook** to escapement on the north coast (NCST), central coast (CCST), west coast of Vancouver Island (WCVI), and inner south coast (ISC) by production objective over all years of enhancement.

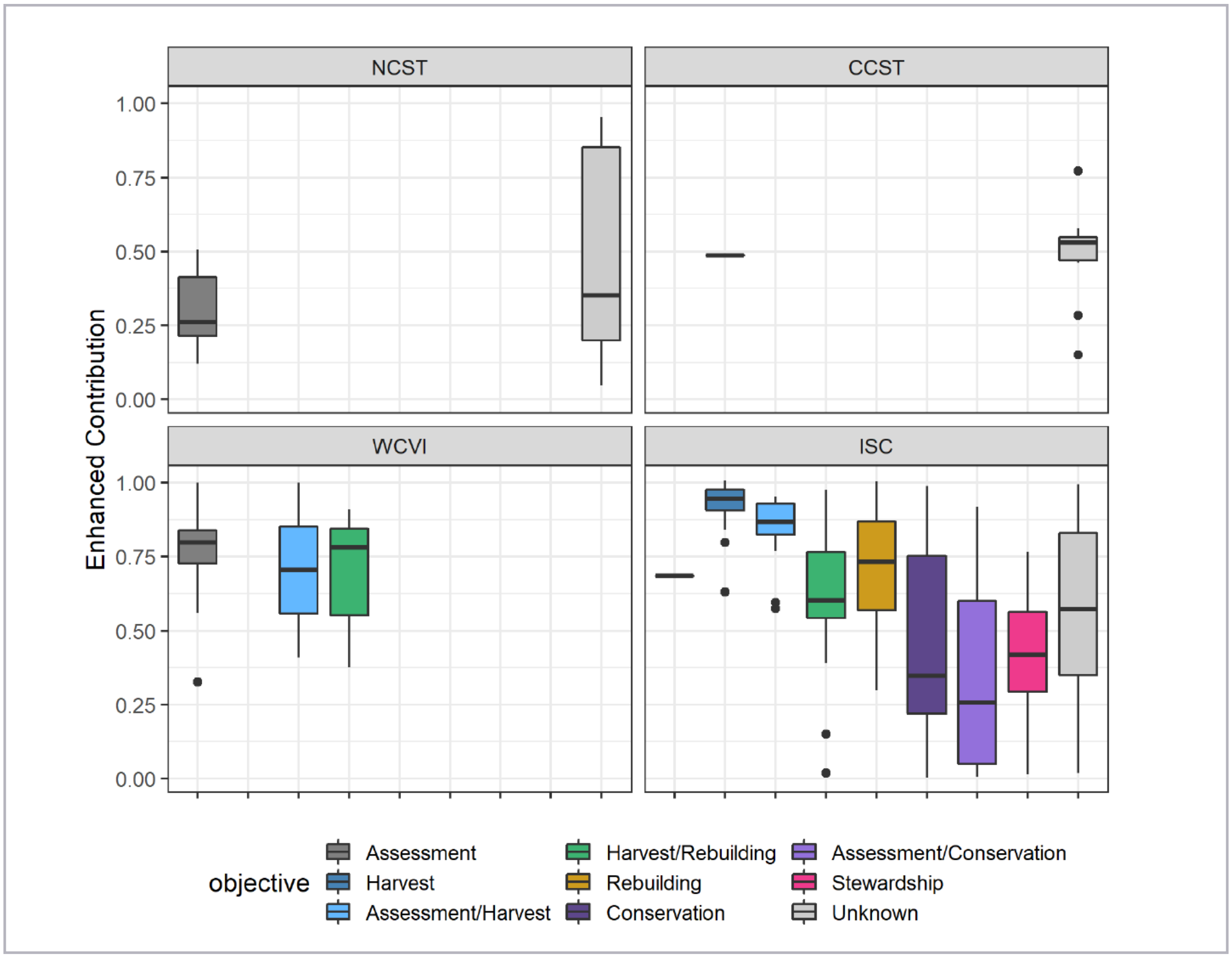

Figure 29: Enhanced contribution of **coho** to escapement on the north coast (NCST), central coast (CCST), west coast of Vancouver Island (WCVI), and inner south coast (ISC) by production objective over all years of enhancement.

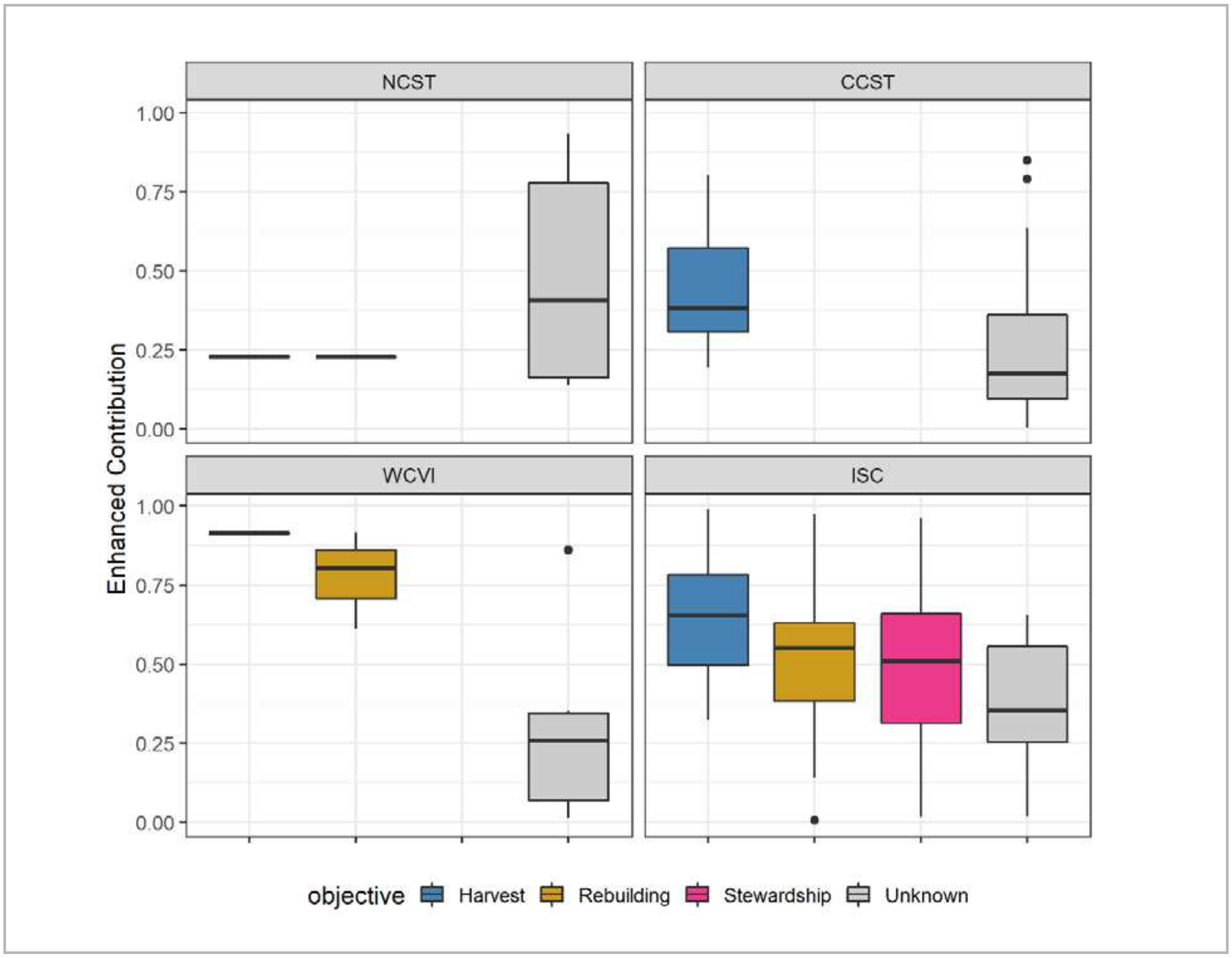

Figure 30: Enhanced contribution of **chum** to escapement on the north coast (NCST), central coast (CCST), west coast of Vancouver Island (WCVI), and inner south coast (ISC) by production objective over all years of enhancement.

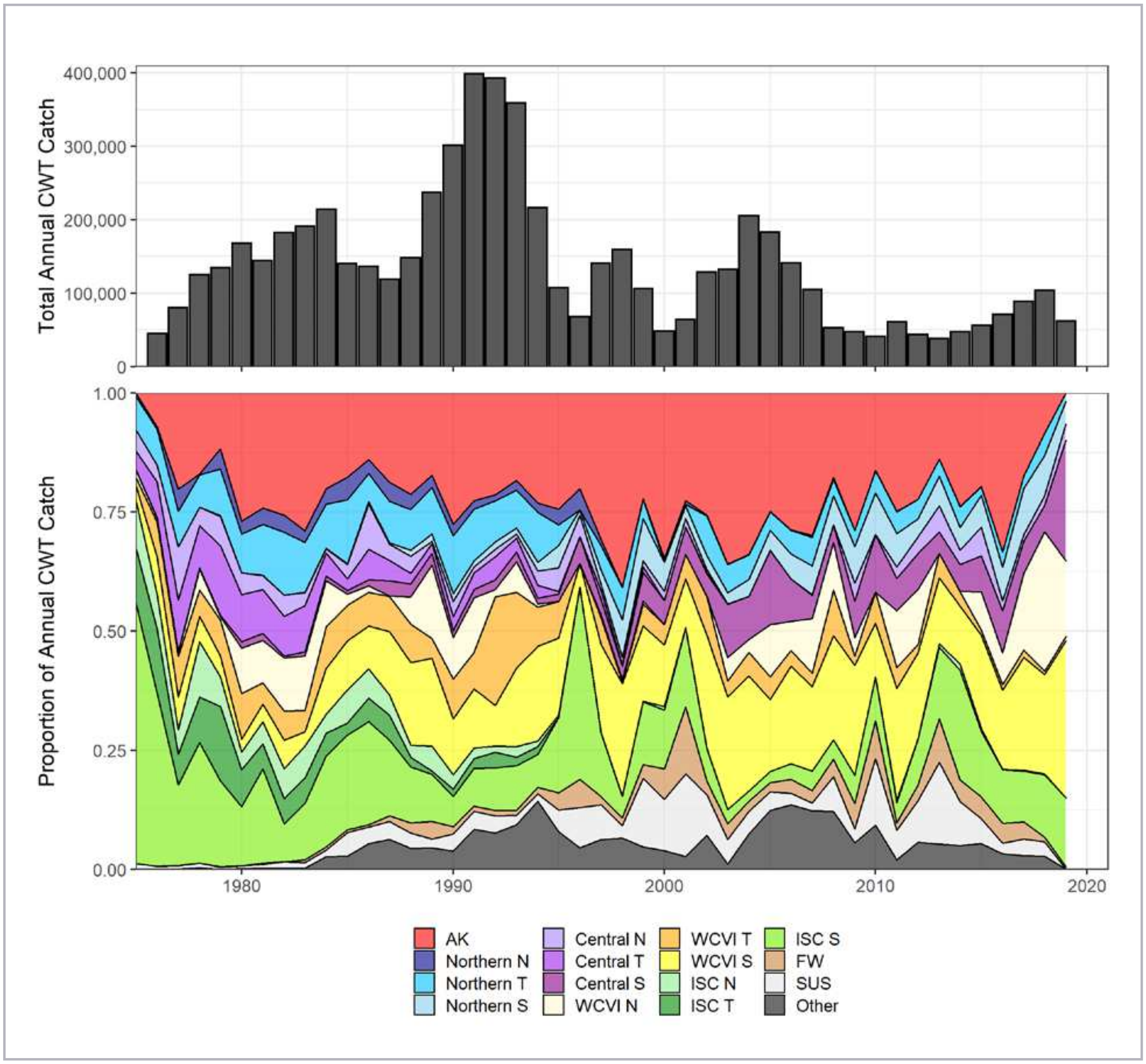

Figure 31: Total annual catch of BC CWT **Chinook** (top) and the distribution of that catch across fisheries over time (bottom). AK=Alaska, N=Net, T=Troll, S=Sport, FW= Freshwater, SUS=Southern US, ISC=Inner South Coast.

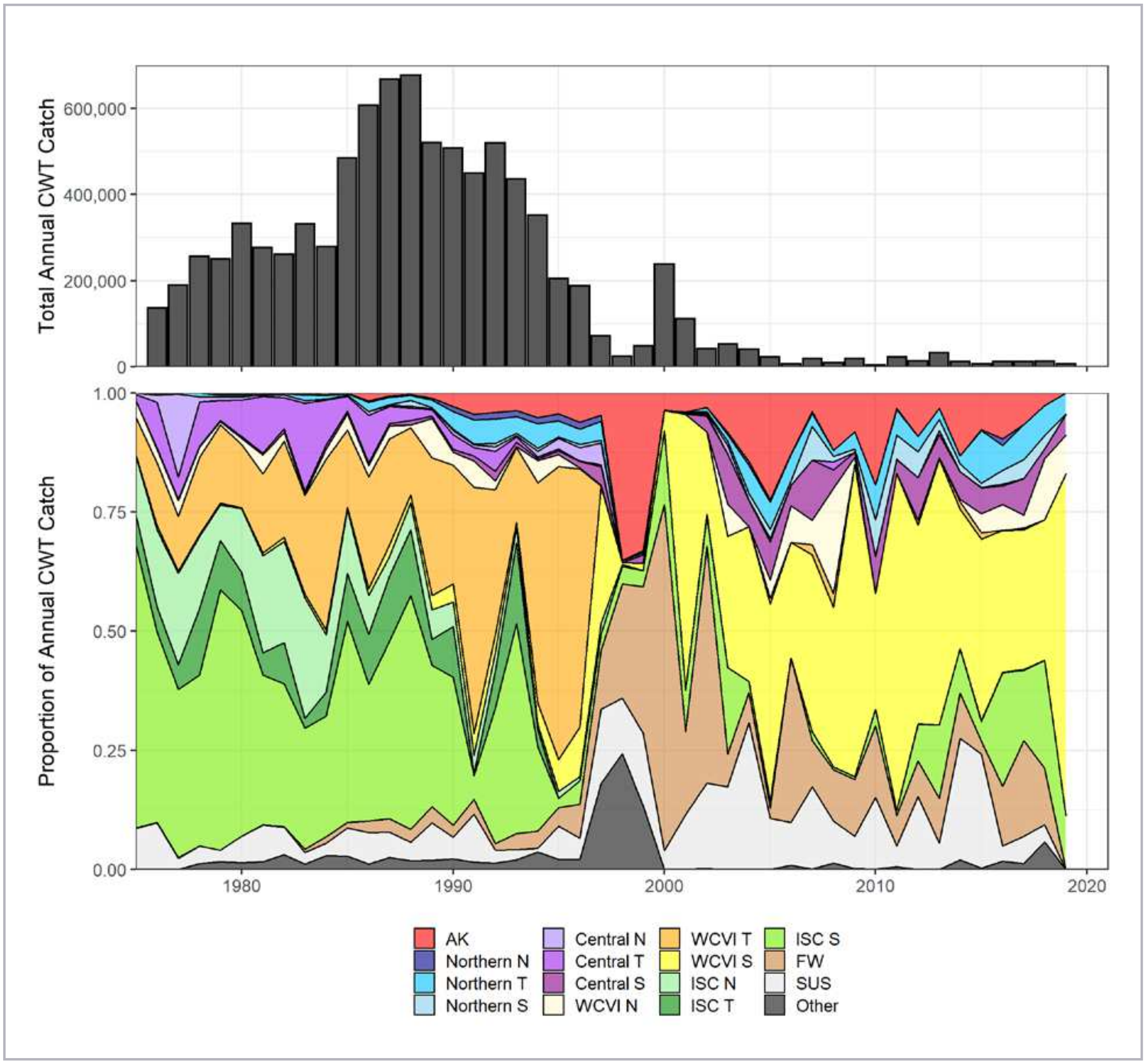

Figure 32: Total annual catch of BC CWT **coho** (top) and the distribution of that catch across fisheries over time (bottom). AK=Alaska, N=Net, T=Troll, S=Sport, FW= Freshwater, SUS=Southern US, ISC=Inner South Coast.

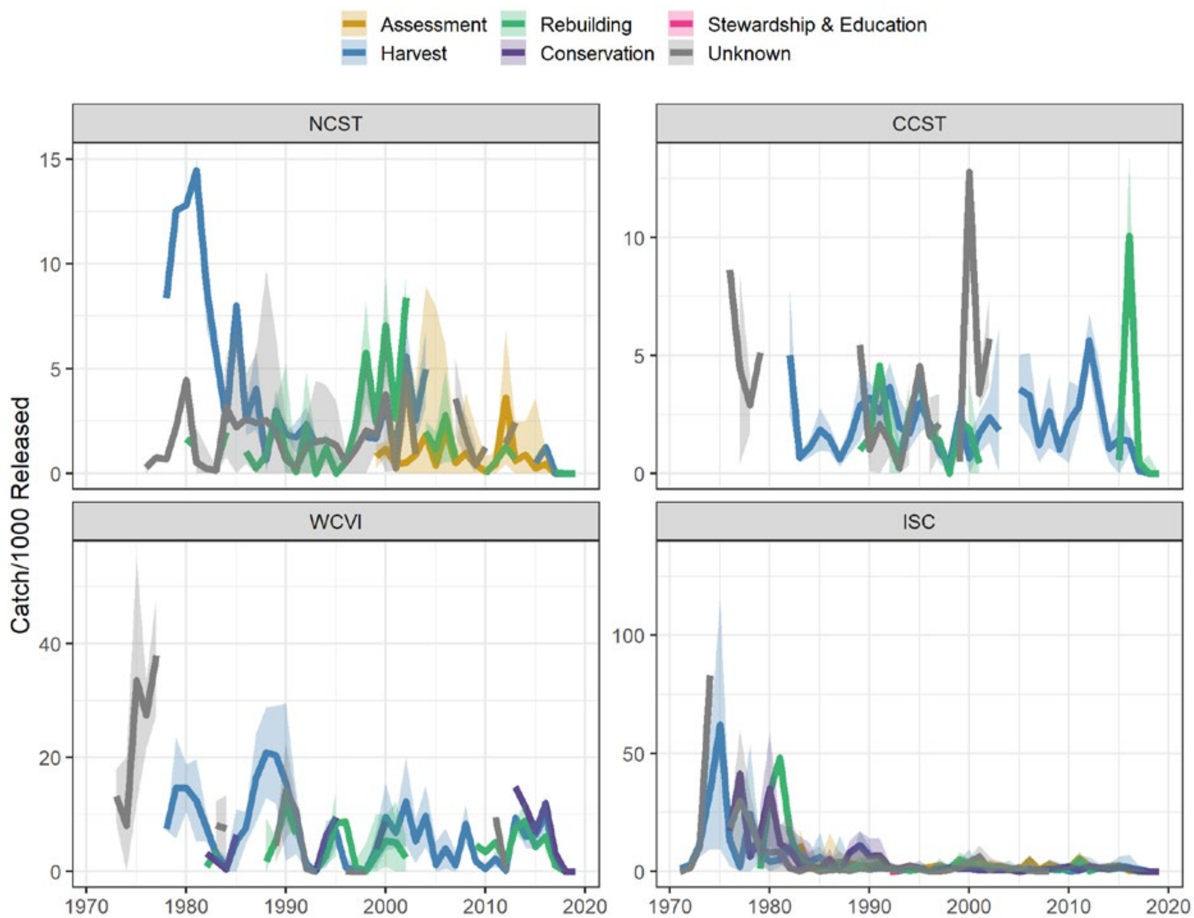

Figure 33: The annual expanded CWT catch per thousand releases of CWT **Chinook** from hatcheries in BC from ocean entry years 1972-2019 by production objective as described in the IFMPs.

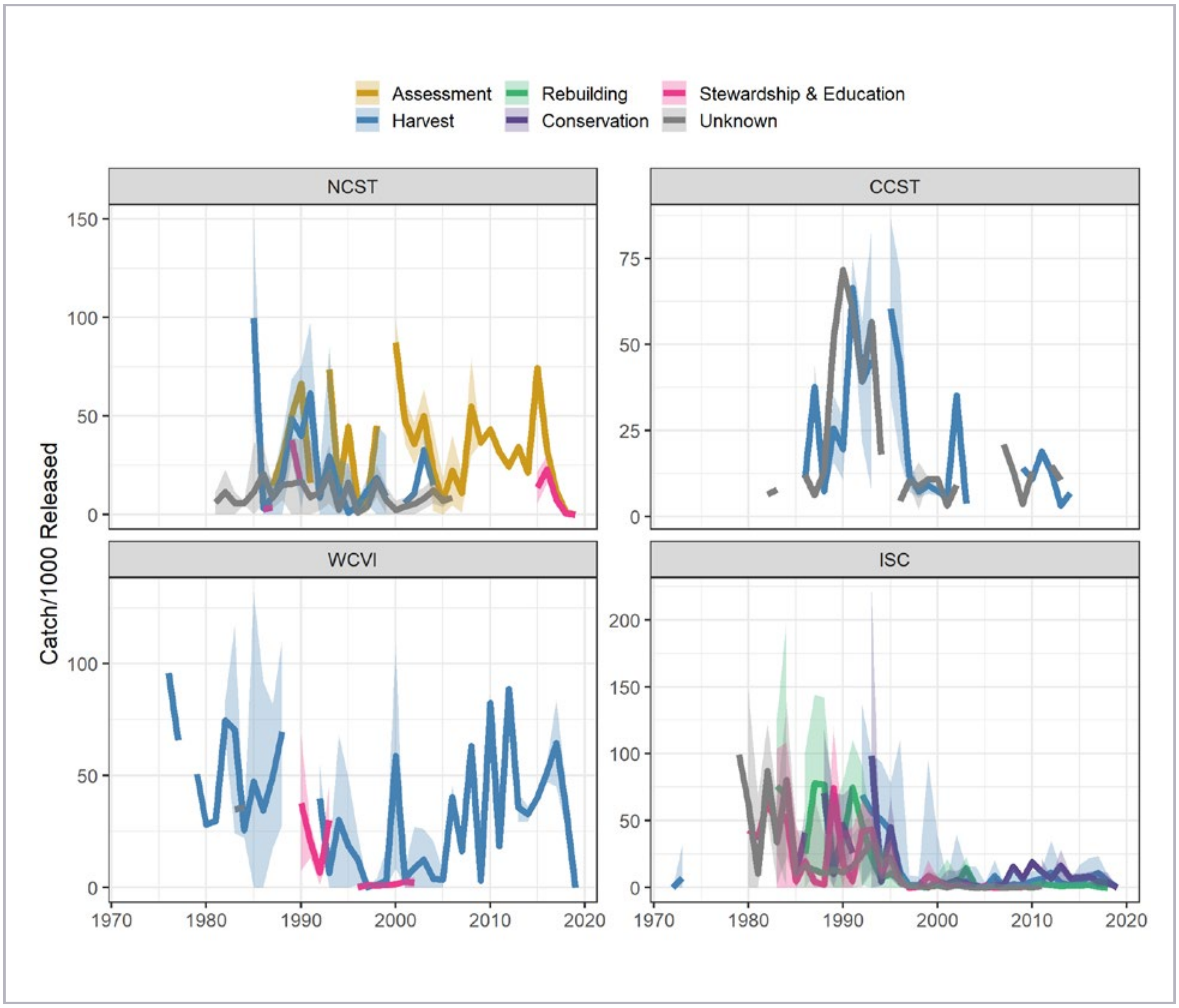

Figure 34: The annual expanded CWT catch per thousand releases of CWT coho from hatcheries in BC from ocean entry years 1972-2019 by production objective as described in the IFMPs.

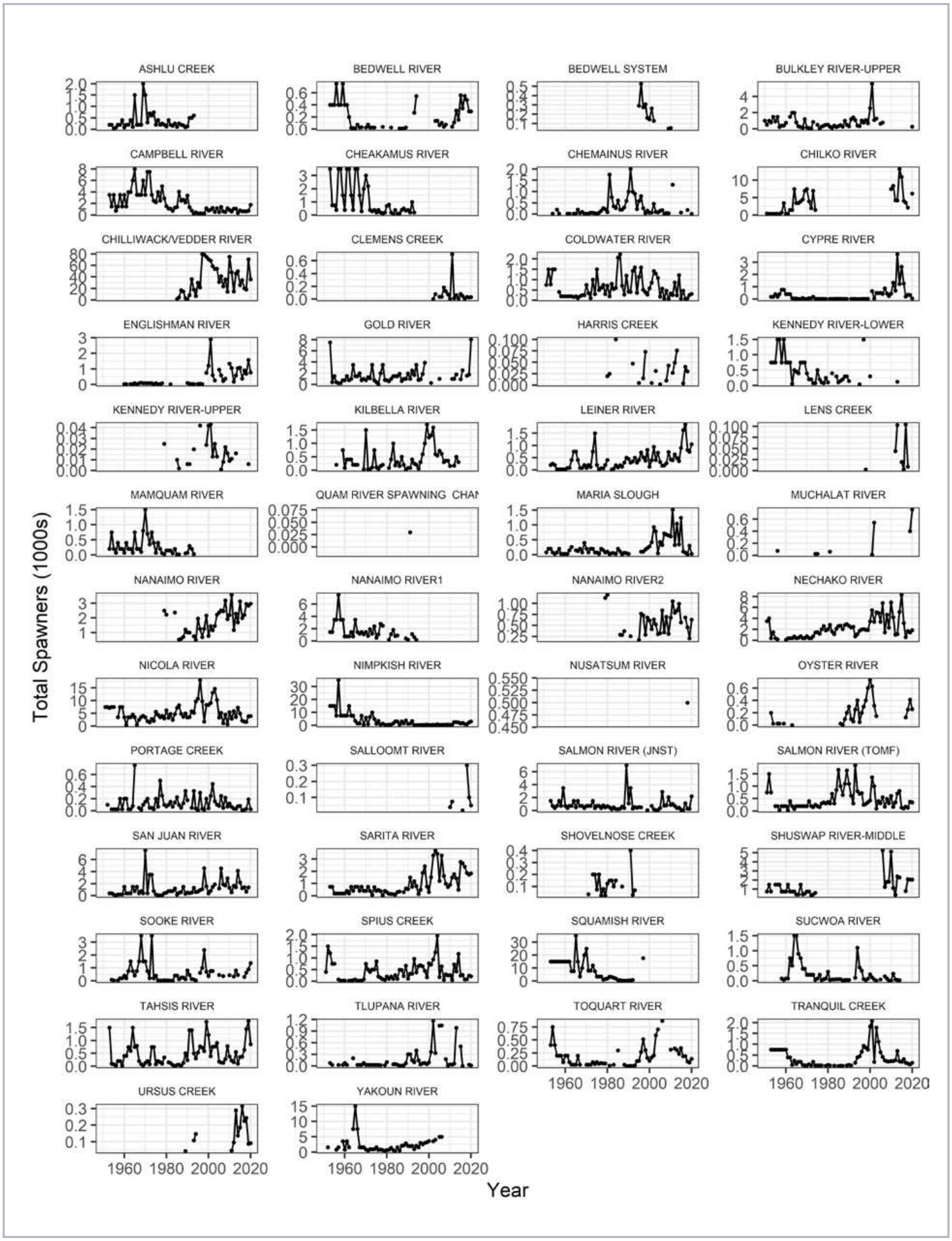

Figure 35: Spawner abundance time-series for **Chinook** rebuilding systems in the 2014-2021 SEP production plans. Note scale is in 1000s and different for each time-series.

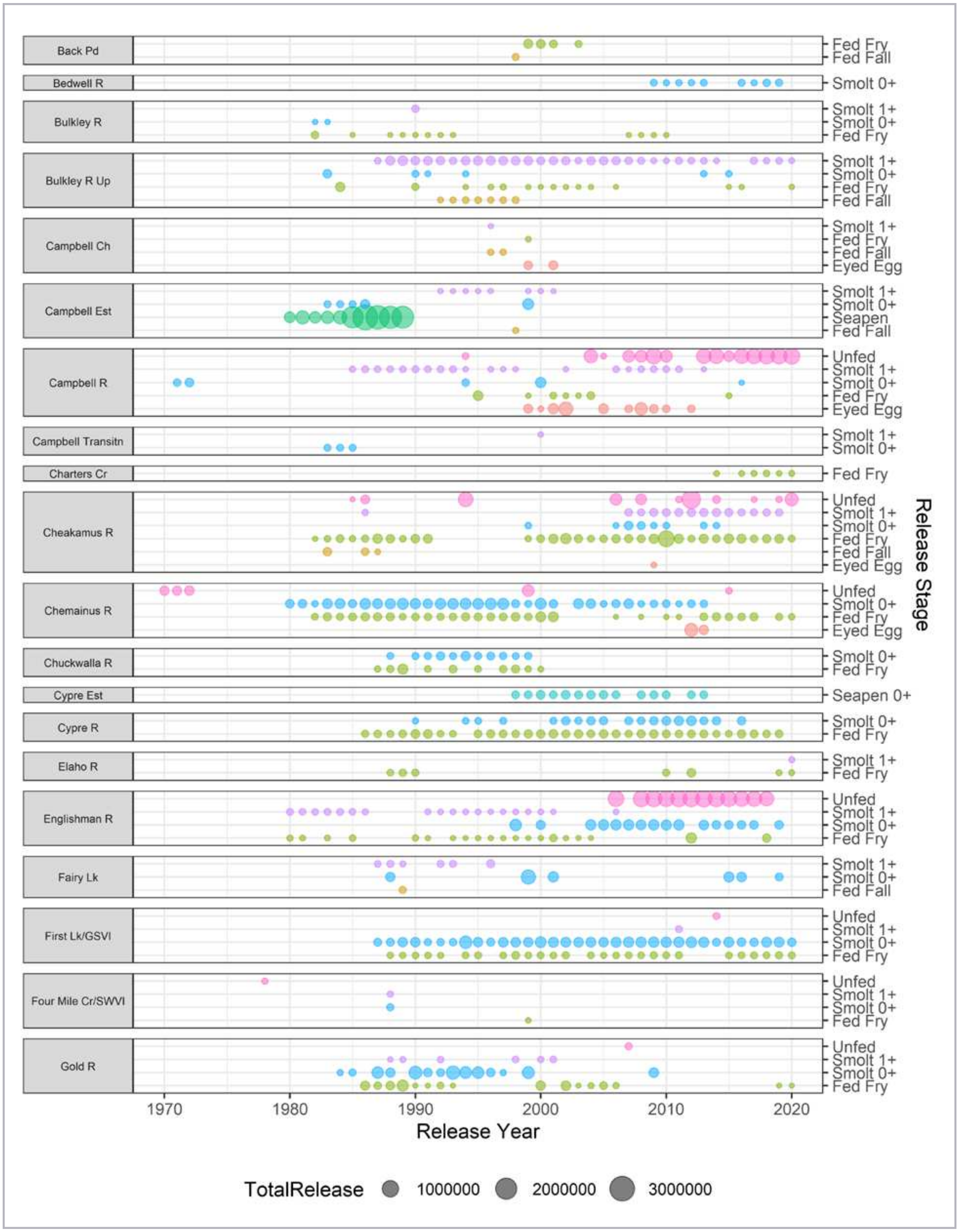

Figure 36a: Releases by release site and release stage for **Chinook** rebuilding systems.

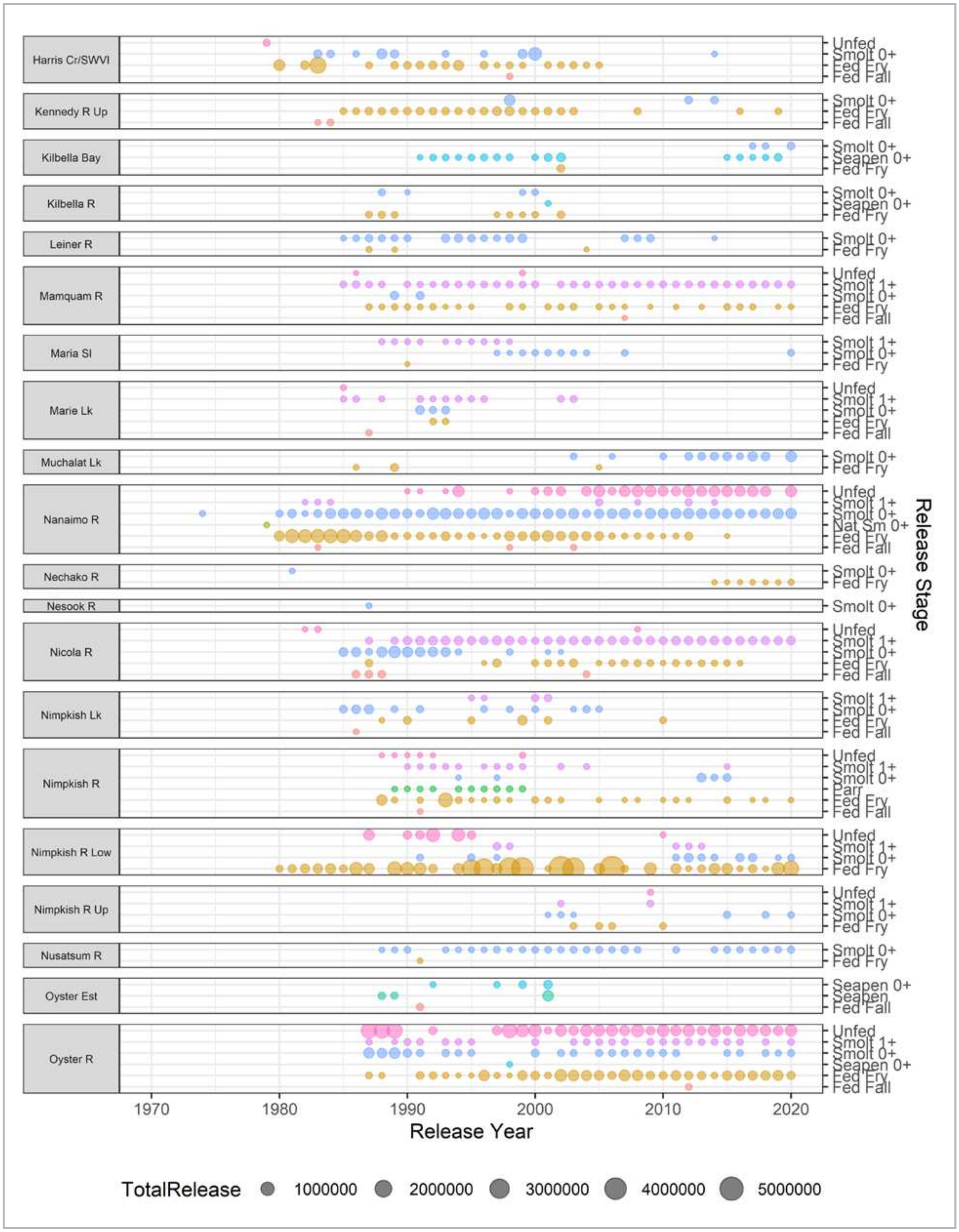

Figure 36b: Releases by release site and release stage for **Chinook** rebuilding systems.

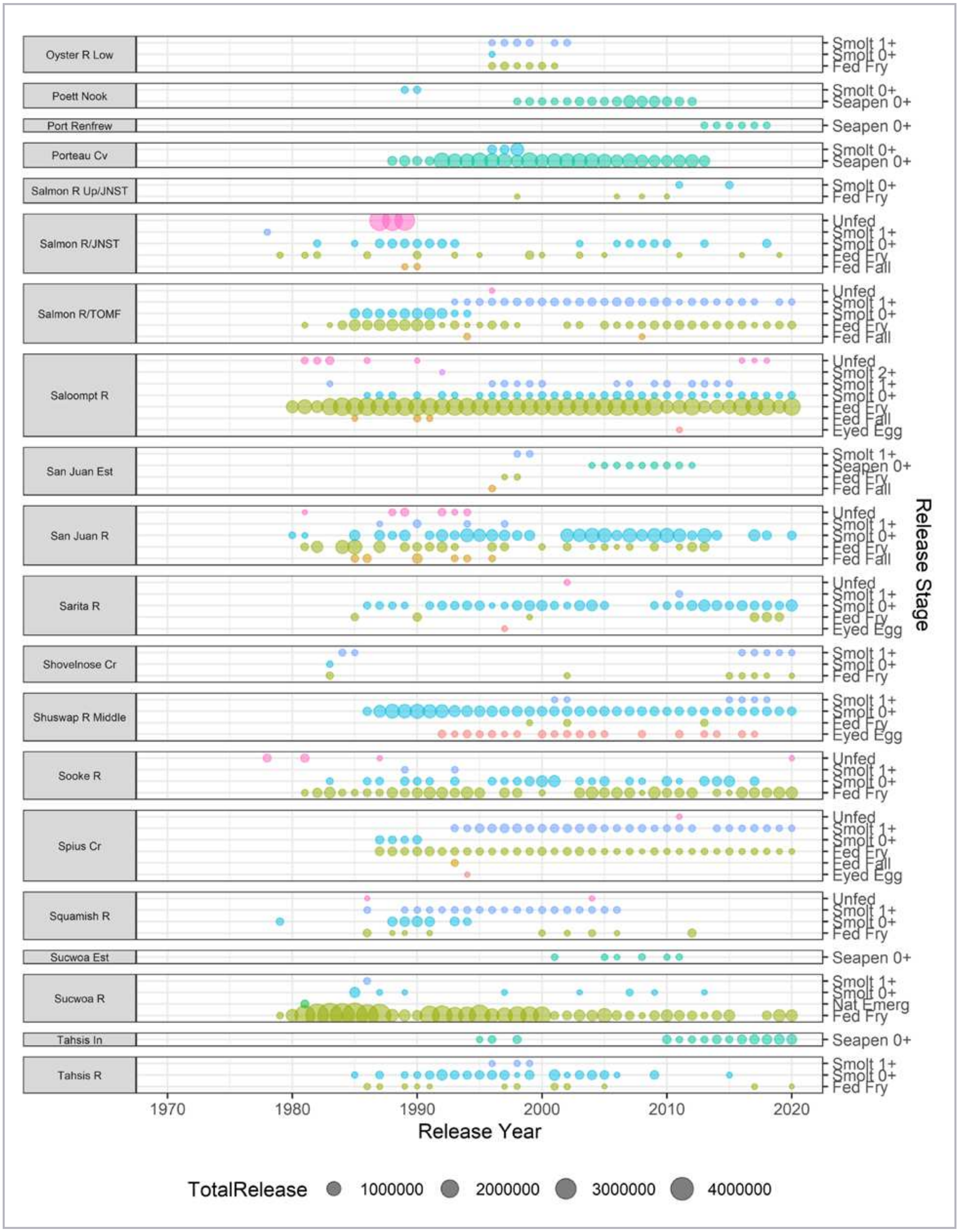

Figure 36c: Releases by release site and release stage for **Chinook** rebuilding systems.

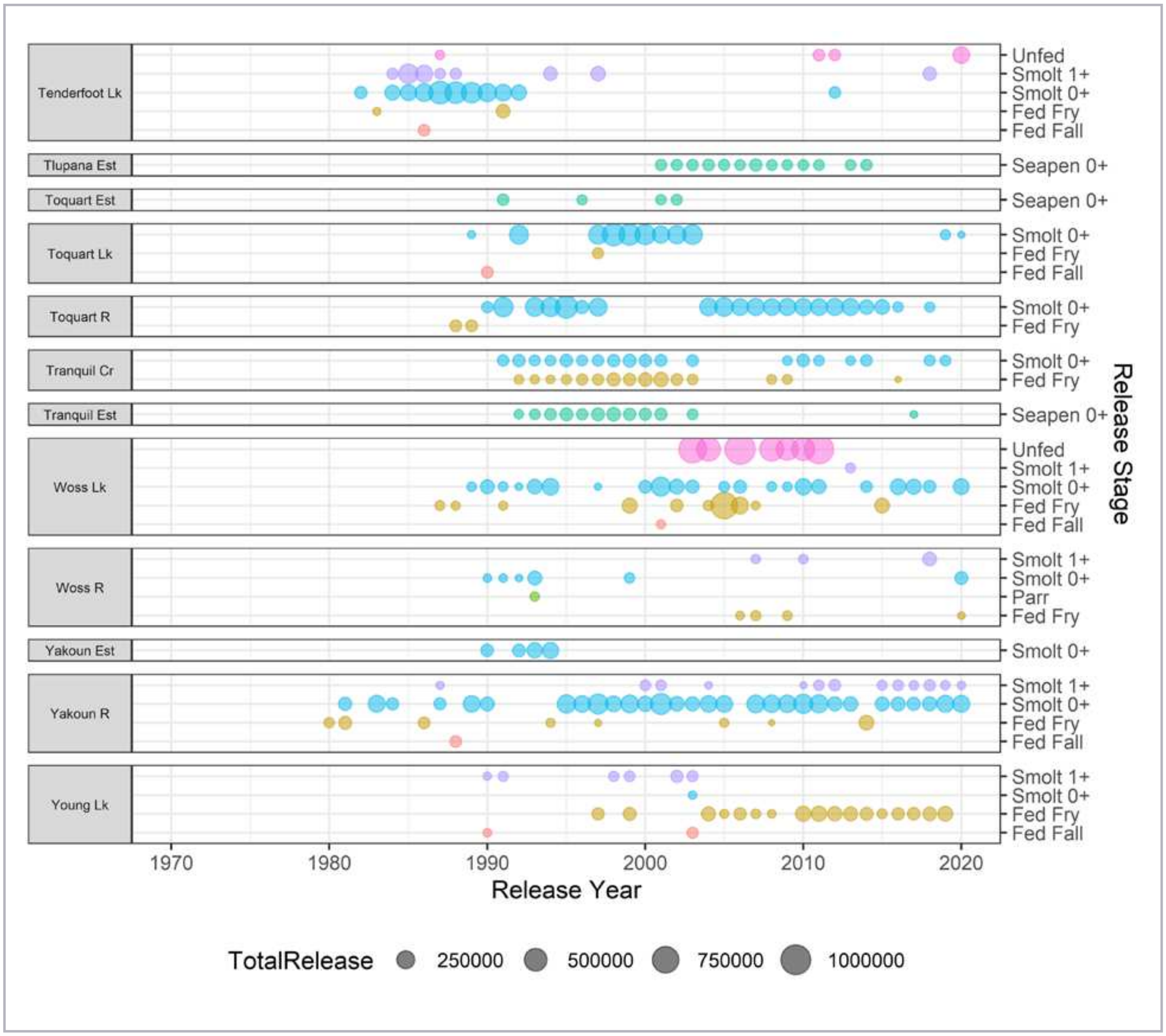

Figure 36d: Releases by release site and release stage for **Chinook** rebuilding systems.

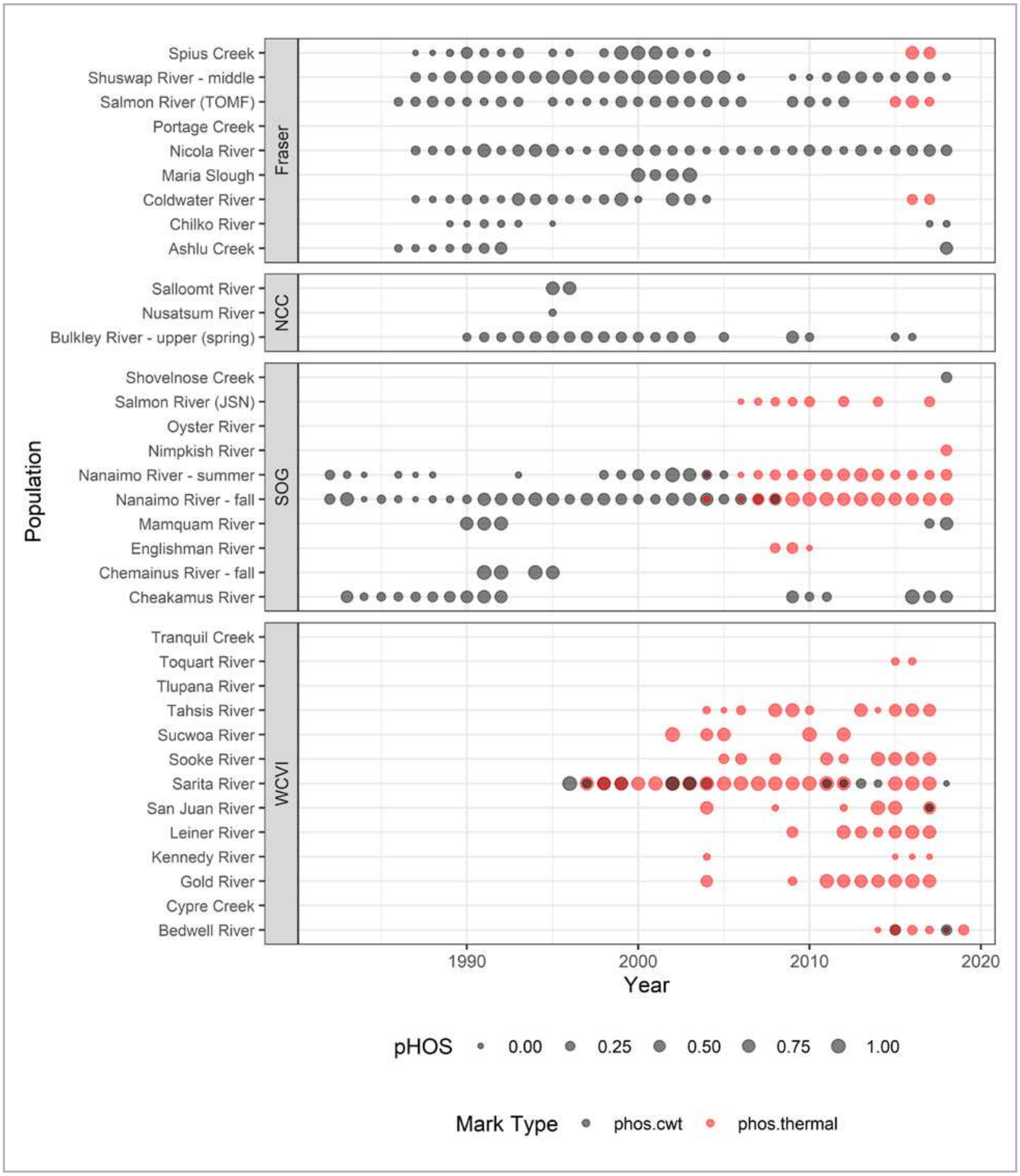

Figure 37: pHOS by region for **Chinook** rebuilding systems. Black points indicate pHOS derived from CWT tags, red points indicate pHOS derived from thermal marks. Larger points indicate higher pHOS.

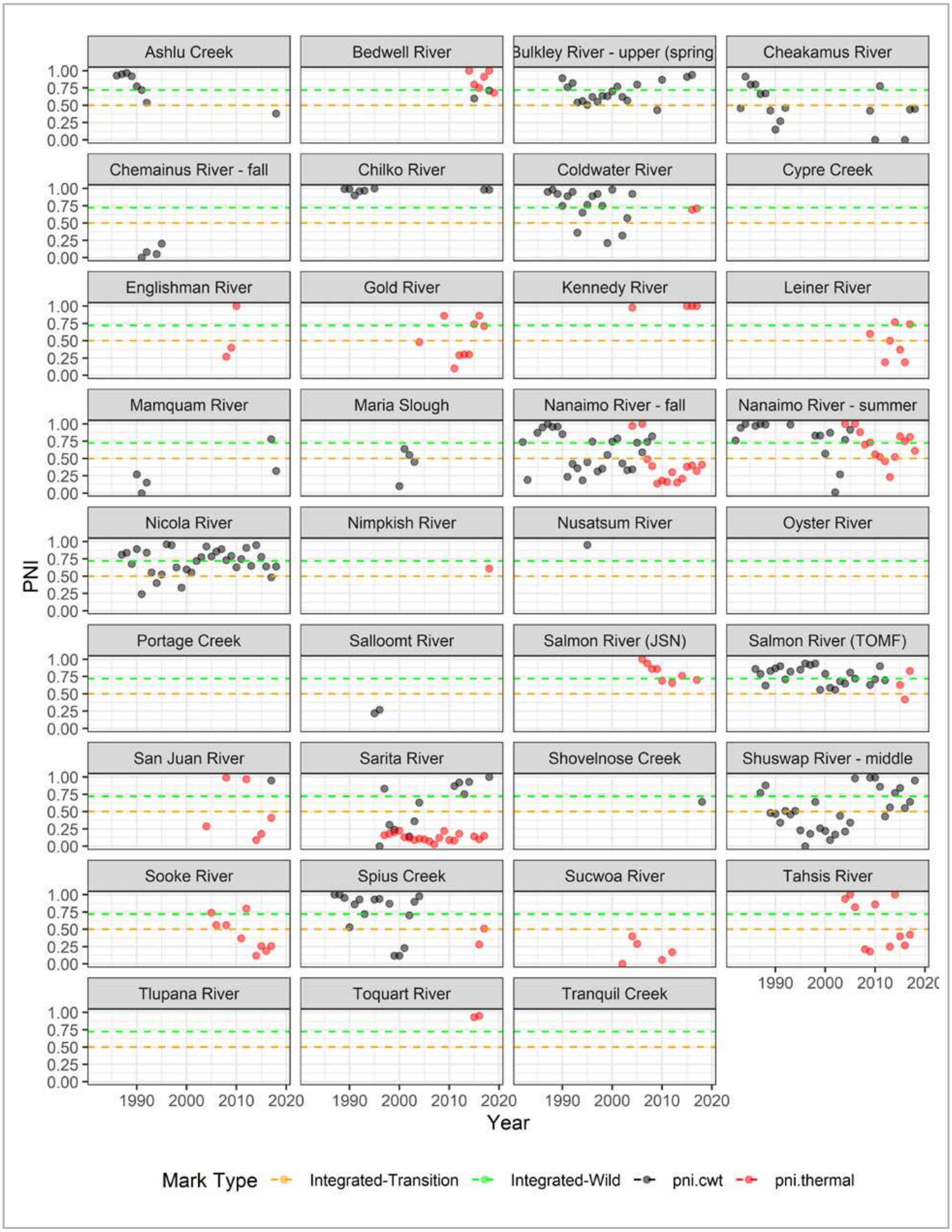

Figure 38: PNI values for **Chinook** rebuilding systems derived from thermal marks (red points) and CWT (black points). The green line indicates the threshold between integrated-wild and integrated-transition categories, and the orange line indicates the threshold between the integrated-transition and integrated-hatchery categories (Wither et al. 2018 Table 3).

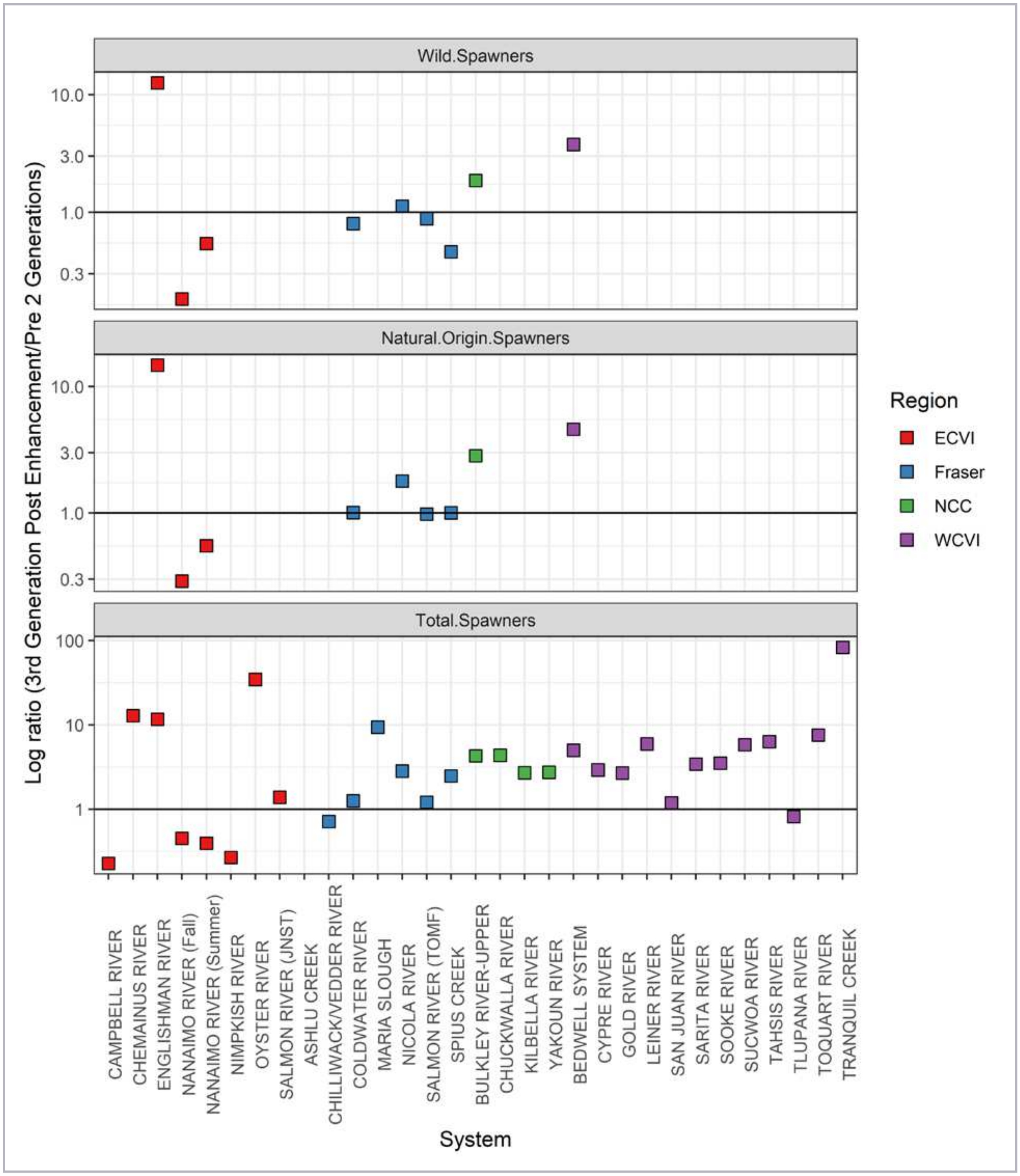

Figure 39: Ratio of the geometric means of 3rd generation post enhancement spawner abundance to the 2 generations immediately prior to enhancement for wild spawners (top), natural-origin spawners (middle) and total spawners (bottom). Point fill colors indicate the region. Note log scale on y-axis.

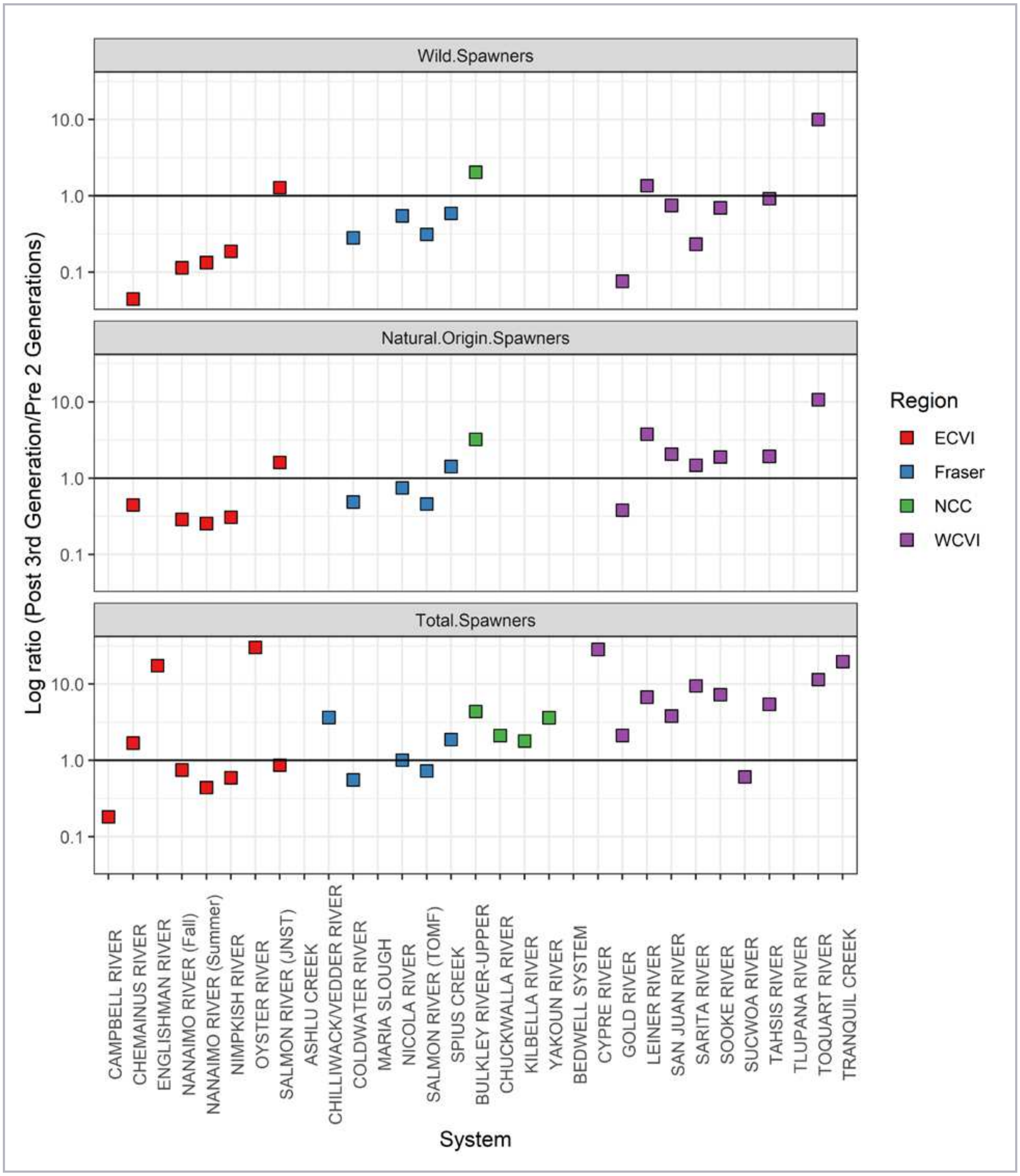

Figure 40: Ratio of the geometric means of post 3rd generation after enhancement (all years more recent than 3 x the generation length after enhancement begins) spawner abundance to the 2 generations immediately prior to enhancement for wild spawners (top), natural-origin spawners (middle) and total spawners (bottom). Point fill colors indicate the region. Note log scale on y-axis.

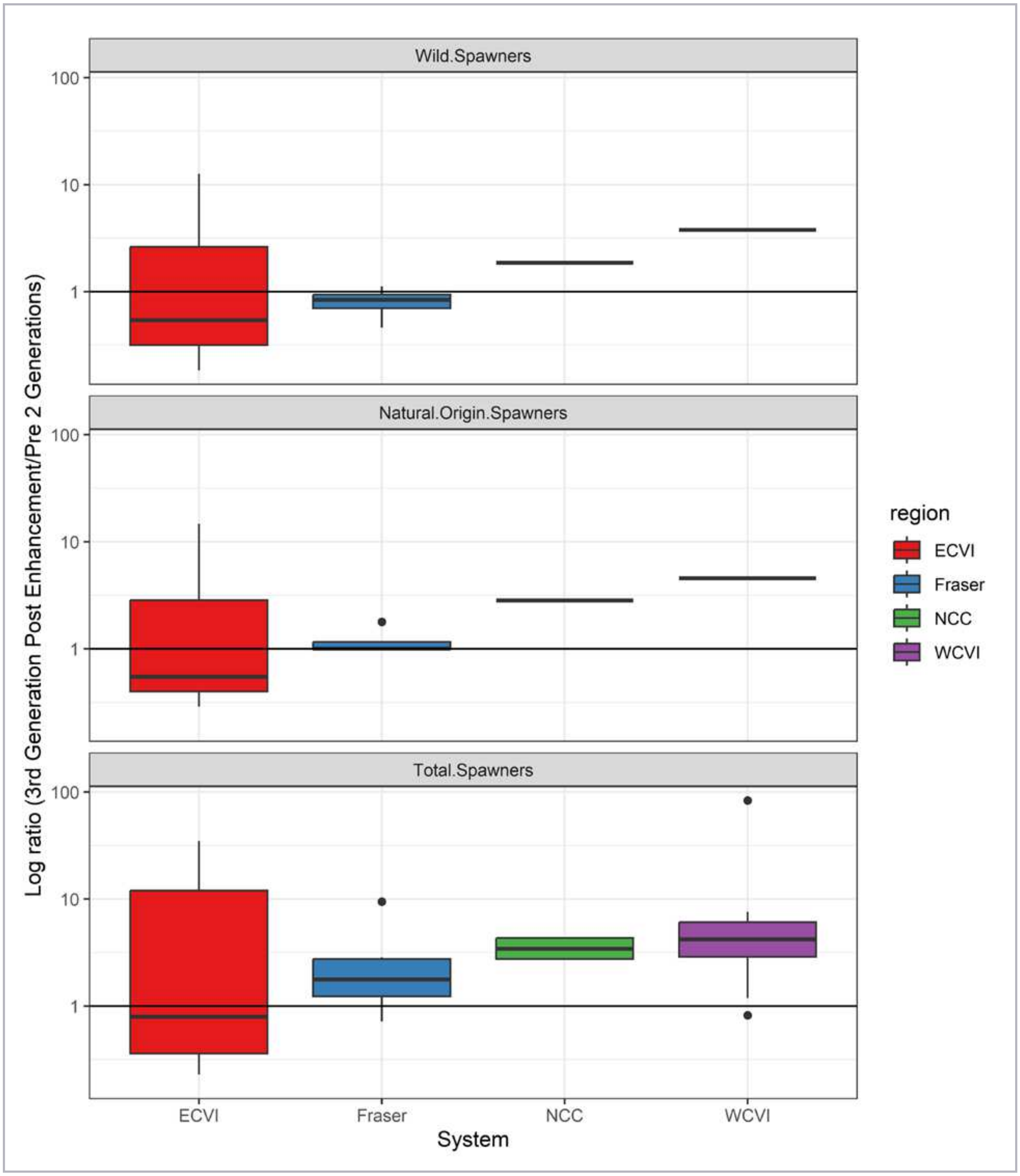

Figure 41: Boxplot of log ratios by region for the geometric means of 3rd generation post enhancement spawner abundance to the 2 generations immediately prior to enhancement.

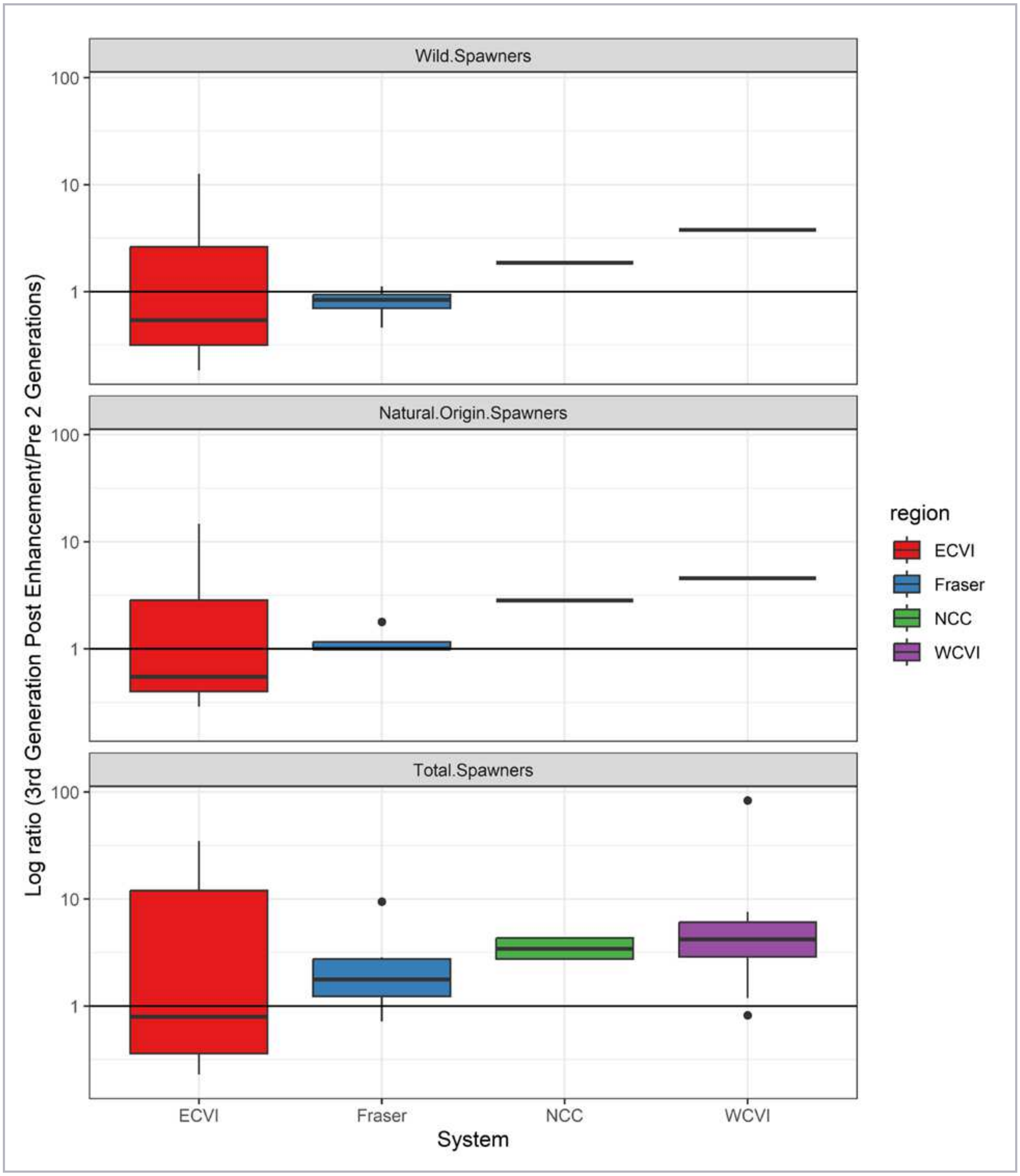

Figure 42: Boxplot of log ratios by region for the geometric means of post 3rd generation after enhancement spawner abundance to the 2 generations immediately prior to enhancement.

REBUILDING APPENDIX A: CHINOOK REBUILDING SYSTEMS DESCRIPTION AND INFORMATION SUMMARY

Table Notes:

Release Stages: Bold release stage indicates either dominant release stage, or in the case where there are historical and more recent releases, the dominant release stage for recent releases.

System	Region	Stat Area	CU Name	Release Sites	Release Stages[15]	Release Strategy	Esc. Data[16]	Enh. Cont Data[17]	PNI/ pHOS Data[18]	Analyses[19]
Campbell River	ECVI	13	East Vancouver Island-North_FA_0.x	Campbell Ch, Campbell Est, Campbell R, Campbell Transitn	**Unfed**, Eyed Egg, Fed Fry, Smolt 0+	Continuous increasing, release stage changes	Yes, c, 1956-2020	Yes, c-, 1978-1983, 2013	No	Ts
	Notes: Continuous spawners, inconsistent releases but recent releases continuous and increasing, mostly unfed fry releases. Only a few years of early enhanced contribution data following first smolt releases in 1971. No pHOS data. Only changes in TS analysed. Some evidence for increased TS following early smolt enhancement but little signal from recent unfed fry releases.									
Chemainus River	ECVI	17	East Vancouver Island-Nanaimo & Chemainus_FA_0.x	Chemainus R	Fed Fry, **Smolt 0+**	Continuous decreasing, release stage changes	Yes, c-, 1954-2009, nc recent	Yes, nc, 1991-95	Yes, nc, cwt 1991-95	Ts
	Notes: Smolts 0+ were released until recently, when releases switched to fed fry ~ 2014. Recent spawners spotty. Only 4 years with enhanced contributions and pHOS data. Only TS analyses. Decline in TS evident with decreasing releases.									
Englishman River	ECVI	17	East Vancouver Island-Qualicum & Puntledge FA 0.x	Englishman River	Unfed, Fed Fry, **Smolt 0+**, Smolt 1+	Continuous decreasing	Yes, c-, 1960-2020	Yes, nc, 1991-95	Yes, nc, cwt 1991-95	Ts
	Notes: Smolts 0+ were released until recently, when releases switched to fed fry ~ 2014. Recent spawners spotty. Only 4 years with enhanced contributions and pHOS data. Only TS analyses. Decline in TS evident with decreasing releases.									
Nanaimo River	ECVI	17	East Vancouver Island-Georgia Strait_SU_0.3	First Lk/GSVI, Nanaimo R	**Smolt 0+**	Continuous decreasing	Yes, c, 1953-2020	No	Yes, c-, cwt and T, 1982-2019	Ts, nos, wild
	Notes: Smolts 0+ were released until recently, when releases switched to fed fry ~ 2014. Recent spawners spotty. Only 4 years with enhanced contributions and pHOS data. Only TS analyses. Decline in TS evident with decreasing releases.									
Nanaimo River	ECVI	17	East Vancouver Island-Nanaimo & Chemainus_FA_0.x	Nanaimo R	Fed Fry, Nat Sm 0+, **Smolt 0+**	Continuous fluctuating	Yes, c 1986-2020	Yes, c, 1982-2008, bs, FSC, river	Yes, c, cwt and T, 1981-2019	Ts, nos, wild
	Notes: Consistent spawner abundance and pHOS data. Increasing escapement with constant releases. However very low PNI (< .5) indicated with more recent thermal pHOS estimates.									

15. Release Stages: Bold release stage indicates either dominant release stage, or in the case where there are historical and more recent releases, the dominant release stage for recent releases.

16. Escapement Data: Yes or No. If yes then either nc (non-continuous) or c (continuous). c- indicates mostly continuous with only a few years missing. If c or c- then year range is indicated.

17. Enhanced Contribution Data: From EPADs database. Yes or No. If yes then either nc (non-continuous) or c (continuous). Strata are identified (bs=broodstock, r=river).

18. PNI/pHOS Data: From SEP Chinook PNI database. Yes or No. If yes then nc (non-continuous) or c (continuous). Number of years given. cwt or T (thermal) source.

19. Analyses: Indicates which analyses the data supports. Total spawners (ts), Natural-origin spawners (nos), Wild spawners (wild), post-release/enhancement (pr), comparison with reference streams (vsref).

System	Region	Stat Area	CU Name	Release Sites	Release Stages[15]	Release Strategy	Esc. Data[16]	Enh. Cont Data[17]	PNI/ pHOS Data[18]	Analyses [19]
Nimpkish River	ECVI	12	East Vancouver Island-North_FA_0.x	Nimpkish R, Nimpkish R Low, Nimpkish R, Up, Woss R	Fed Fry, **Smolt 0+**, Smolt 1+	Semi-continuous increasing	Yes, c, 1953-2020	No	Yes, nc, 2019 only	Ts
	Notes: Consistent spawner data, releases sporadic from 1986 on, no enhanced contribution data and only 1 year of pHOS data. TS analysis supported, but no NOS or wild. TS not increasing with enhancement until possibly last 2 generations since ~ 2010 following more significant consistent enhancement starting in 2011.									
Oyster River	ECVI	12	East Vancouver island-Qualicum & Puntledge_fa_0.x	Oyster Est, Oyster R, Oyster R Low	Fed Fall, Fed Fry, Seapen 0+, **Smolt 0+**, Smolt 1+, Unfed	Continuous stable and low	Yes, nc, 1953-63, 1986-20003, 2017-2020	No	No	Ts
	Notes: Some spawner data (~20 years) following initial enhancement supports TS analysis. No enhanced contribution or pHOS data. TS increased following initial enhancement but most recent generation following 35+ years of enhancement average.									
Salmon River/JNST	ECVI	13	East Vancouver Island-North_FA_0.x	Salmon R Up/ JNST, Salmon R/JNST	Fed Fry, **Smolt 0+**	On-off inconsistent	Yes, c-, 1953-2020	No	Yes, nc, T, 2000-2018	Ts, nos wild
	Notes: Consistent spawner data pre/during enhancement, sporadic releases over 2 periods (~ 1982-1993 and 2006-2018). Only recent years with pHOS data based on thermal marking. Supports TS, and limited NOS and wild analyses, but only many generations after enhancement started. TS appears to increase following enhancement.									
Ashlu Creek	Fraser	29	Southern Mainland-Georgia Strait_FA_0.x	Ashlu Cr, Ashlu Ch	Unfed, Fed Fry, Smolt 0+, **Smolt 1+**	Sporadic, 1983, 1988-1993, 2015 on	Yes, nc	Yes, nc	Yes, nc, cwt, 8	ts-, nos-, wild-
	Notes: Spawner estimates stopped in 1993. Only a few years in 80s to early 90s with releases. Recent releases low levels since ~ 2015. While data supports some analysis, this was based on the spawner data to 1993 only as there are no more recent data.									
Chilko River	Fraser	29	Middle Fraser River_SU_1.3	Chilko R	Fed Fall, Fed Fry, Smolt 0+, **Smolt 1+**	Sporadic, 1987-1991, 2015 on	Yes, nc	Yes, nc	Yes, nc, cwt, 8	None
	Notes: Spawner estimates historically not available when early enhancement occurred. Recent enhancement started 2016 with Smolt 1+, not enough time post-enhancement to see response in spawners and sporadic monitoring.									
Chilliwack River	Fraser	29	Lower Fraser River_SU_1.3 (both spring and summer Chilliwack Chinook are in this CU in SEP release database and in production plans	Chilliwack R	Unfed, Fed Fry, **Smolt 0+**, Smolt 1+	Continuous stable, 1982-present	Yes, nc 1951-2020 with many years missing	No	No	None
	Notes: Significant gap in spawner data in 2 generations prior to enhancement. No enhanced contributions or pHOS data. Large numbers of consistent releases starting 1986 (average ~500k). Given spotty spawner data immediately after enhancement, some evidence that TS increased following enhancement. 2020 spawner abundance highest on record.									

System	Region	Stat Area	CU Name	Release Sites	Release Stages[15]	Release Strategy	Esc. Data[16]	Enh. Cont Data[17]	PNI/ pHOS Data[18]	Analyses [19]
Coldwater River	Fraser	29	Lower Thompson_ SP_1.2	Coldwater R	Unfed, Fed Fry, Fed Fall, Smolt 0+, **Smolt 1+**	Continuous consistent, 1985-present	Yes, c-, 1951-2020	Yes, nc, 1987-2004	Yes, nc, cwt and T, 1987-2004	ts, nos, wild, vsref
	Notes: Releases and spawners continuous since mid-80s, pHOS data from 87-2004, only a couple years of recent pHOS data from thermal marking. Enhancement has been consistent through period.									
Maria Slough	Fraser	29	Maria Slough_ SU_0.3	Maria Sl	Fed Fry, **Smolt 0+**	Sporadic increasing	Yes	Yes,c, 2001-3, bs, river	Yes, c, cwt, 2000-3	ts, nos, wild, pr
	Notes: First release fed fry 1990, consistent releases started 1997 as Smolt 0+. Long time series of spawners with 6-year gap immediately prior to enhancement. 4 years of CWT pHOS/PNI data. TS suggests increased abundance after enhancement started, but high pHOS data indicates significant HOS contributions. Following enhancement TS remains high for about 2 generations but then decreases. High releases in 2020 but no returns yet.									
Nechako River	Fraser	29	Middle Fraser River_SU_1.3	Nechako R	**Fed Fry**, Smolt 0+	Recent continuous, 2014-present	Yes, c	No	No	None
	Notes: Enhancement started 2014, not enough time for a response in spawners, and no pHOS data. Very minimal releases (~2500 fed fry).									
Nicola River	Fraser	29	Lower Thompson_ SP_1.2	Nicola R	Unfed, Fed Fry, Fed Fall, Smolt 0+, **Smolt 1+**	Continuous consistent, 1982-present	Yes, c	Yes, nc, 1987-1994, 2002	Yes, c, cwt, 1987-2019	ts, nos, wild, vsref
	Notes: Enhancement started in ~ 1982, continuous spawners and pHOS (CWT) data.									
Portage River	Fraser	29					Yes, c, 1954-2020	No	No	none
	Notes: Could not find releases in release database, may be a different site name, or 2021 the first planned year of release.									
Salmon River/ TOMF	Fraser	29	South Thompson_ SU_1.3	Salmon R/ TOMF	Fed Fall, **Fed Fry**, Smolt 0+, **Smolt 1+**	Continuous consistent, release stage switched 2010	Y, c, 1951-2020	Yes, c-, 1984-2012, bs and river	Yes, c-, cwt and T, 1986-2018	Ts, nos, wild, vsref
	Notes: Continuous escapement and pHOS data.									
Shuswap River-middle	Fraser	29	Shuswap River_SU_0.3	Shuswap R Middle	Eyed Egg, **Smolt 0+**, Smolt 1+	Continuous decreasing	Yes, nc, 1951-1974, 2006-2020	Yes, c, 1986-2005, bs and river	Yes, c, 1987-2019, cwt	none
	Notes: Spawner data lacking when enhanced contributions are available in mid 80s to ~ 2006. Consistent releases but no spawner information in 2 gens preceding enhancement and during 3 generations after.									

System	Region	Stat Area	CU Name	Release Sites	Release Stages[15]	Release Strategy	Esc. Data[16]	Enh. Cont Data[17]	PNI/ pHOS Data[18]	Analyses [19]
Spius Creek	Fraser	29	Lower Thompson SP 1.2	Spius Creek	Unfed, Eyed Egg, Fed Fry, Smolt 0+, **Smolt 1+**	Continuous consistent, 1987-2020	Yes, c, 1951-2020	Yes, nc, 1987-2004, bs and r	Y, nc, cwt and T, 1987-2004, 2016-2017	Ts, nos, wild
	Notes: There are 2 Spius Creek records in NuSEDs. PopID 46186 was used as there was near complete records and the other one only had 1 estimate. Continuous escapement and pHOS data after enhancement until 2004.									
Cheakamus River	MN-SOG	28	Southern Mainland-Georgia Strait_FA_0.x	Cheakamus River	Unfed, **Fed Fry**, Smolt 0+, **Smolt 1+**	Inconsistent, many release stages	Yes, c, 1953-1993, no recent	Yes, c-, 1983-92, 2009-11, bs, river, FSC	Yes, c-, cwt, 1982-92, 2009-11, 2016-18	None
	Notes: Cheakamus River is part of the Sqaumish River, Mamquam River and Ashlu River complex of enhancement. Many stocks are enhanced in this area and there is likely straying between systems. However, for this analysis they were assessed independently. No spawner data after 1993 so no analyses conducted as consistent releases didn't start until 2006.									
Elaho River	MN-SOG	28	UNK	Elaho River	**Fed Fry, Smolt 1+**		N	N	N	N
	Notes: Elaho River is not in NuSEDs. Only intermittent releases at low numbers (~5-15k fed fry). 1 year of Smolt 1+ releases. Used Squamish River and Shovelnose Creek stocks. Tributary of the Squamish River.									
Shovelnose Creek	MN-SOG	28	Southern Mainland-Georgia Strait_FA_0.x	Shovelnose Cr	Fed Fry, Smolt 0+, Smolt 1+	Continuous decreasing	Yes, nc, 1971-1993	No	Yes, cwt, 2019 only	None
	Notes: Some historical pre-enhancement spawner data, one year of releases (1983), and then recent consistent enhancement starts 2015. No spawner data after 1993 so how is enhancement objective developed? Only 1 year of pHOS. No analyses supported.									
Squamish River	MN-SOG	28	Southern Mainland-Georgia Strait_FA_0.x	Porteau Cv, Squamish R	Fed Fry, Seapen 0+, Smolt 0+	Continuous 1988-2013 stopped	Yes, c, 1953-1992	Yes, nc, 1985-1996	No	None
	Notes: Historical spawner data only goes to just after first generation of enhancement, no pHOS data. Enhanced contribution data suggests high levels of HOS. Releases stopped in 2013 but may have resumed in last 2 years. If recent spawner data was available it would support post-enhancement analysis. No analyses supported.									
Bulkley River – Upper	NCC	4	Upper Bulkley River	Bulkley R, Bulkley R Up	Fed Fall, Fed Fry, Smolt 0+, Smolt 1+	Continuous decreasing	Yes, nc, 1950-2006, 2020	Yes, nc, 1990-2015, bs FSC, river	Y, nc, cwt, 1990-2016,	Ts, nos, wild
	Notes: Spawner data not available in recent years although enhancement has continued, but was available pre-enhancement and during 3 generations after.									
Chuckwalla River	NCC	9	Rivers Inlet	Chuckwalla River	Fed Fry, **Smolt 0+**	Continuous stopped, 1988-2000	Yes, c-, 1956-2011	No	No	Ts, pr
	Notes: Chuckwalla River was enhanced from 1988-2000. There is no enhanced contribution information to assess NOS or wild Chinook. Enhancement appears to have increased TS with possible 2nd generation effect. TS decreased following enhancement to pre-enhancement levels.									

<table>
<tr><th>System</th><th>Region</th><th>Stat Area</th><th>CU Name</th><th>Release Sites</th><th>Release Stages[15]</th><th>Release Strategy</th><th>Esc. Data[16]</th><th>Enh. Cont Data[17]</th><th>PNI/ pHOS Data[18]</th><th>Analyses [19]</th></tr>
<tr><td rowspan="2">Kilbella River</td><td>NCC</td><td>9</td><td>Rivers Inlet</td><td>Kilbella R</td><td>Fed Fry, Smolt 0+, Seapen 0+</td><td>On/off, 1987-2002, 2015-2020</td><td>Yes, c-, 1956-2014</td><td>No</td><td>No</td><td>Ts, pr</td></tr>
<tr><td colspan="10">Notes: Kilbella River chinook enhanced in 2 sites – Kilbella River and Kilbella Bay. There is a long time series for spawners until 2018/19. There is no enhanced contribution or pHOS/PNI data. Apparent increase in TS after enhancement starts, can't assess NOS or wild. Decrease in TS after enhancement stops in 2002. No recent spawner counts after enhancement restarts in 2015 to assess trends in TS.</td></tr>
<tr><td rowspan="2">Nusatsum River</td><td>NCC</td><td>8</td><td>Bella-Coola Bentinck</td><td>Nasatsum R</td><td>Fed Fry, Smolt 0+</td><td>Continuous increasing</td><td>Yes, nc, 2017</td><td>Yes, nc, 1995</td><td>Yes, nc, cwt, 1997</td><td>None</td></tr>
<tr><td colspan="10">Notes: Only one year of spawner counts although releases have been occurring since 1988. Only one year of enhanced contribution or pHOS data.</td></tr>
<tr><td rowspan="2">Salloomt River</td><td>NCC</td><td>8</td><td>Bella-Coola Bentinck</td><td>Salloomt R</td><td>Eyed Egg, Fed Fry, Fed Fall, Smolt 0+</td><td>Continuous fluctuating</td><td>Yes, nc, 2010-2020</td><td>Yes, nc, 1995-6</td><td>Yes, nc, cwt, 1995-6</td><td>None</td></tr>
<tr><td colspan="10">Notes: Very little spawner information although releases occurring since 1983. Only 2 years of enhanced contributions or pHOS data.</td></tr>
<tr><td rowspan="2">Yakoun River</td><td>NCC</td><td>1</td><td>Haida Gwaii-North</td><td>Yakoun Est, Yajoun R</td><td>Fed Fall, Fed Fry, Smolt 0+, Smolt 1+</td><td>Continuous fluctuating</td><td>Yes, c-, 1952-2006</td><td>No</td><td>No</td><td>Ts</td></tr>
<tr><td colspan="10">Notes: Spawner information before and during first 205 years of enhancement, no enhanced contribution or pHOS data to assess NOS or wild spawners.</td></tr>
<tr><td rowspan="2">Mamquam River</td><td>SOG</td><td>28</td><td>Southern Main-land-Georgia Strait_FA_0.x</td><td>Mamuam R</td><td>Fed Fry, Smolt 0+, Smolt 1+</td><td>Sporadic</td><td>Yes, c-, 1950-1993</td><td>Yes, c, 1990-2</td><td>Yes, nc, 1990-2, 2017-18</td><td>No</td></tr>
<tr><td colspan="10">Notes: Mamquam River only has escapement information pre-enhancement. Releases starting in 2015 again. Enhancement started but no spawner data to support rebuilding objective?</td></tr>
<tr><td rowspan="2">Bedwell River</td><td>WCVI</td><td>25</td><td>West Vancouver Island-South_FA_0.x</td><td>Bedwell Est, Bedwell R</td><td>Seapen 0+, Smolt 0+</td><td>Continuous increasing</td><td>Yes, c-, 1953-2020</td><td>Yes, c-, 2015-2019</td><td>Yes, c, cwt, T, 2014-2019</td><td>Ts, nos, wild</td></tr>
<tr><td colspan="10">Notes: Consistent spawner abundance, recent enhancement only since 2009, pHOS data since 2014. Increased spawners apparent after enhancement although TS may have started increased before first HOS returns. Low pHOS and high PNI in recent years. May be 2nd generation effect given increase in TS, NOS and wild and PNI high.</td></tr>
<tr><td rowspan="2">Clemens Creek</td><td>WCVI</td><td>23</td><td>West Vancouver Island-South_FA_0.x</td><td>Clemens Creek</td><td>Smolt 0+</td><td>Very few years of releases</td><td>Yes, c, 2002-2020</td><td>No</td><td>No</td><td>None</td></tr>
<tr><td colspan="10">Notes: Clemens Creek was enhanced for only 3 non-continuous years historically. It is in the 2021 PP for rebuilding. No analysis supported.</td></tr>
</table>

System	Region	Stat Area	CU Name	Release Sites	Release Stages[15]	Release Strategy	Esc. Data[16]	Enh. Cont Data[17]	PNI/ pHOS Data[18]	Analyses[19]
Cypre River	WCVI	24	West Vancouver Island-South_ FA_0.x	Cypre Est, Cypre R	**Smolt 0+, Seapen 0+**	Continuous increasing	Yes, c, 1953-2020	No	No	Ts, pr
	Notes: Consistent spawner data pre/during enhancement. No enhanced contribution or pHOS data. Releases starting 1990, stopped 2016. TS and post-enhancement analysis supported. TS increases after enhancement starts but immediately returns to pre-enhancement levels after releases stopped.									
Gold River	WCVI	25	West Vancouver Island-Nootka & Kyuquot_ FA_0.x	Gold Est, Gold R, Muchalat Lk (releases to Muchalat Lake are listed as rebuilding in PP)	Fed Fry, Seapen 0+, **Smolt 0+,** Unfed	Semi-continuous fluctuating	Yes, nc, 1953-98, 2011-20	No	Yes, nc, T, 2011-17	Ts, nos, wild
	Notes: The Gold River area has been heavily enhanced for harvest. 2014-2018 are listed in the production plans as rebuilding, with releases in Muchalat Lake from the Gold River stock. However, there are also releases in these years for harvest purposes. Limited pHOS data in recent years, however indicates high enhanced contributions. Very little response in TS after initial enhancement in 1984, and a large gap in spawners between 1998 and 2011. TS analysis supported and NOS and wild supported in one recent generation.									
Kennedy River	WCVI	24	West Vancouver Island-South_ FA_0.x	Kennedy R Low, Kennedy R Up	Fed Fry, **Smolt 0+**	Continuous increased then decreased	Yes, nc-, 1953-2019	No	Yes, nc, T, 2003, 2015-17	None
	Notes: Kennedy River has been enhanced since the 1980s, less so recently. Kennedy River upper and lower are both in NuSEDs, however, escapement information is very limited since 1990 for the larger lower systems, and limited in the upper system, with ~ 0-40 spawners in some years. No enhanced contribution data and only a few years of pHOS data suggests very low enhanced contributions. No analysis supported.									
Leiner River	WCVI	25	West Vancouver Island-Nootka & Kyuquot_ FA_0.x	Leiner R	**Smolt 0+**	Sporadic, but associated with Tahsis Estuary releases	Yes, c, 1953-2020	No	Yes, c-, T, 2009-2017	Ts, nos, wild
	Notes: Leiner River first release 1984. Consistent spawners, no enhanced contributions and only a few recetn years of pHOS data which indicate moderate to high enhanced contribution. Response in TS evident with continuing enhancement. Leiner River is likely influenced by releases in the Tahsis Est seapen releases as it is a proximate system and is the stock of origin in some cases.									
Muchalat River	WCVI	25	West Vancouver Island-Nootka & Kyuquot_ FA_0.x	?	?	?	Yes, but very limited	?	?	None
	Notes: Need to investigate this – is it part of the Gold River enhancement area.									
San Juan River	WCVI	20	West Vancouver Island-South_ FA_0.x	Back Pd, Fairy Lk, Port Renfrew, San Juan Est, San Juan R	Fed Fry, Seapen 0+, **Smolt 0+**	Continuous fluctuating, release stage changes	Yes, c, multiple sites, 1953-2019	Yes, 1 year only, river	Yes, nc, cwt and T, 6 data between 2004-2018	Ts, nos, wild
	Notes: San Juan and tributaries has numerous spawner count sites in NuSEDs, numerous release sites and release stages. No enhanced contribution data, only a few years (6) of sporadic pHOS data between ~ 2004-2018 with mixed low and high pHOS suggesting PNI changes. Some evidence of increased TS after enhancement, very limited information on NOS and wild spawners.									

System	Region	Stat Area	CU Name	Release Sites	Release Stages[15]	Release Strategy	Esc. Data[16]	Enh. Cont Data[17]	PNI/ pHOS Data[18]	Analyses[19]
Sarita River	WCVI	23	West Vancouver Island-South_ FA_0.x	Poett Nook, Sarita R	Fed Fry, Seapen 0+, **Smolt 0+,** Smolt 1+	Continuous increasing to stable, 1985-2020	Yes, c, 1953-2020	Yes, nc, 1997-99, 2002-04, 2018-19, bs, FSC, river	Yes, nc, cwt and T, 1997-2018	Ts, nos, wild, vsref
	Notes: Consistent spawners pre/during enhancement. Releases since 1985, limited enhanced contribution data but consistent pHOS data since ~1997. pHOS data suggests very high HOS contributions and very low PNI (< 0.25). All analyses supported. Evidence suggests increased TS, but very low wild spawners during enhancement to present, and very sensitive to enhancement. Little evidence for 2nd generation effects of enhancement. Major discrepancies between CWT and thermal pHOS data.									
Sooke River	WCVI	20	West Vancouver Island-South_ FA_0.x	Charters Cr, Sooke R	**Fed Fry,** Smolt 0+	Continuous relatively stable, release stage changes, 1981-2020	Yes, c-, 1954-2020, some missed years	Yes, on ly 1 year, 2019, river	Yes, nc, T, 2005-2017	Ts, nos, wild
	Notes: Some missing years of spawners during enhancement, consistent releases but some altering between fed fry and smolt 0+ releases. 9 years of pHOS data suggest moderate to high HOS contributions and moderate to low PNI, especially in recent years. Evidence of increased TS with enhancement, but decreases in NOS and wild long-term. No pHOS information for 3rd generation post-enhancement..									
Sucwoa River	WCVI	25	West Vancouver Island-Nootka & Kyuquot_ Fa_0.X	Sucwoa Est, Sucwoa R	Smolt 0+, Seapen 0+	Sporadic on and off, generally low, 1985-2013	Yes, c-, 1956-2014, some missed years	No	Yes, nc, T, 5 years 2002-12	Ts, nos, wild
	Notes: Consistent spawner data pre and during enhancement, sporadic releases, no enhanced contribution data, limited pHOS data (6 years total). Evidence suggests some response in TS following releases, but high pHOS and low PNI in years with data indicate high HOS contributions and low NOS, wild spawners. May be second generation effect from high enhancement in 1985 showing up in 1994.									
Tahsis River	WCVI	23	West Vancouver Island-Nootka & Kyuquot_ Fa_0.X	Tahsis In, Tahsis R	Fed Fry, **Seapen 0+,** Smolt 0+	Continuous increasing	Yes, c, 1953-2020	No	Yes, c-, T, 2004-17	Ts, nos, wild
	Notes: Consistent spawner data, releases starting in 1985 Smolts 0+ then Seapen 0+ more recently. 11 years of pHOS data between 2004-17. Recent pHOS data indicates moderate to high HOS contributions. Low PNI recent years. Evidence that TS increases after enhancement, possible increase in NOS and wild spawners in recent period versus period immediately before enhancement, however may be lower than historical abundance.									
Tlupana River	WCVI	25	West Vancouver Island-Nootka & Kyuquot_ Fa_0.X	Tlupana Est	**Seapen 0+**	Continuous decreasing 2001-14	Yes, c-, 1953-2020 missing some years	No	No	Ts, pr
	Notes: Relatively consistent spawner data pre, during, and post enhancement. No enhanced contribution or pHOS data makes assessing NOS and wild impossible. Some indications that TS increases with enhancement, and immediate decrease following decrease in releases. Most recent spawner data suggests very low spawner abundance ~ 6 years after enhancement ceased. First generation following enhancement saw major increase, however mismatch in timing after releases (too soon).									

System	Region	Stat Area	CU Name	Release Sites	Release Stages[15]	Release Strategy	Esc. Data[16]	Enh. Cont Data[17]	PNI/ pHOS Data[18]	Analyses [19]
Toquart River	WCVI	25	West Vancouver Island-South_ FA_0.x	Toquart Est, Toquart Lk, Toquart R	Fed Fry, Seapen 0+, **Smolt 0+**	Continuous decreasing, 1989-2020	Yes, nc, 1953-2020, some gaps	No	Yes, nc, T, 2015-16 only	Ts, nos, wild
	Notes: Relatively consistent spawner data with one major gap (2004-2012). Releases decreasing in recent years to almost none. 2 years of pHOS data (2015-16) indicate low pHOS and high PNI which makes sense given the low releases. Very low response to enhancement (~ 300k Smolt 0+ releases) for only a 500 TS increase, with no pHOS data. Spawner data in recent years suggests immediate decrease in spawners following decrease in enhancement.									
Tranquil Creek	WCVI	24	West Vancouver Island-South_ FA_0.x	Tranquil Cr, Tranquil Est	Seapen 0+, **Smolt 0+**	Semi-continuous decreasing	Yes, c, 1953-2020	No	No	Ts, pr
	Notes: Consistent spawner data pre- and during enhancement, no enhanced contribution or pHOS data. Increased total spawners following initial enhancement suggests boost from enhancement, after 2003 enhancement ceases and TS immediately decreases, following additional enhancement TS increases and then when enhancement stops.									

Photo by: Danny Swainson


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