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West Coast of Vancouver Island Natural-Origin Chinook Salmon (*Oncorhynchus tshawytscha*) Stock Assessment in 2024

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Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

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ACRONYMS

AABM—Aggregate Abundance Based Management

AUC—Area Under the Curve

BC—British Columbia

COSEWIC—Committee on the Status of Endangered Wildlife in Canada

CPUE—Catch Per Unit Effort

CTC—[Joint] Chinook Technical Committee [of the Pacific Salmon Commission]

CTD—Conductivity, Temperature, and Depth

CU—Conservation Unit

CWT—Coded-Wire Tag

CYER—Catch Year Exploitation Rate

DFO—[Department of] Fisheries and Oceans Canada

DIDSON—Dual-frequency Identification Sonar

ER—Exploitation Rate

FSC—Food, Social, and Ceremonial [fisheries]

IFMP—Integrated Fishery Management Plan

ISBM—Individual Stock Based Management

LRP—Limit Reference Point

MSE—Management Strategy Evaluation [or Management Procedure Framework] as in DFO (2021a).

MSY—Maximum Sustainable Yield

NBC—Northern British Columbia

NCBC—Northern and Central British Columbia

NGO—Non-Governmental Organization

NWVI—Northwest Vancouver Island

PBT—Parentage-Based Tagging

pHOS—proportion Hatchery-Origin Spawners

pHOS-stray – proportion stray Hatchery-Origin Spawners

PNI—Proportionate Natural Influence

pNOB—proportion of Natural-Origin fish in Broodstock

pNOS—proportion Natural-Origin Spawners

POH—Post-orbital to hypural [fish length]

PST—Pacific Salmon Treaty

RAMS—Risk Assessment Methodology for Salmon

RPA—Recovery Potential Assessment

RR—Removal Reference
SARA—Species at Risk Act
SBS—Southern British Columbia
SEAK—Southeast Alaska
SEP—Salmonid Enhancement Program
SMU—Stock Management Unit
SNP—Single Nucleotide Polymorphism
SWVI—Southwest Vancouver Island
TRP—Target Reference Point
USA—United States of America
USR—Upper Stock Reference
WCVI—West Coast of Vancouver Island
WSP—Wild Salmon Policy

GLOSSARY

Abundance—Number(s) of fish.

Age—Salmon ages are typically comprised of a freshwater age and a marine age. However, since the vast majority of WCVI Chinook enter the ocean after <1 year, we broadly refer to *total age* (years) throughout the report, except where otherwise stated.

Broodstock—Adult Chinook and their eggs or milt that are collected for use in a hatchery production program.

Coded-wire tag (CWT)—A length of stainless-steel wire that is about 1.1mm long and 0.25mm in diameter and engraved with a numeric code. CWTs are applied to Chinook juveniles and are used to trace Chinook recovered in sampling programs back to a natal hatchery, release location, release strategy, and brood year.

Conservation Unit (CU)—a group of wild Pacific salmon sufficiently isolated from other groups that, if extirpated, is very unlikely to recolonize naturally within an acceptable timeframe, such as a human lifetime or a specified number of salmon generations (Holtby and Ciruna 2007).

Hatchery enhancement—The practice of rearing fish in hatcheries and releasing them as juveniles into waterbodies to bolster local population abundance.

[Chinook] Enumeration—Counting fish.

Freshet—High discharge event in a river driven by heavy rains or snowmelt.

Hatchery-origin Chinook—Chinook salmon that hatched from eggs collected and used for broodstock in a hatchery program.

Hatchery production—Number(s) of fish released annually by a hatchery.

Incidental mortality—Mortality arising from injuries or other afflictions that result from the capture and subsequent release of fish.

[Chinook] Jack—Precocious males that attain early sexual maturity and return to spawn after only 1 winter at sea, or less.

$ln(\alpha)$—Productivity parameter from a Ricker stock-recruit relationship (Ricker 1975).

Maximum sustainable yield—The largest catch that can be continuously taken from a stock under existing environmental conditions (Ricker 1975).

Natural-origin Chinook—Chinook salmon that hatched from eggs deposited in a natural freshwater environment and whose parents may have been either hatchery- or natural-origin themselves.

Otolith thermal mark—A marking method that involves subjecting developing eggs or recently hatched alevins to changes in water temperature to produce a specific banding pattern on the developing otoliths of the fish. Otoliths extracted from recaptured fish can then be examined under a microscope to determine the original hatchery and production program based on the banding pattern.

Productivity—Refers to the relative reproductive success of a population.

Redd—An area of streambed excavated by a female Chinook where eggs are deposited, fertilized, and buried throughout incubation (Healey, 1991).

Sound—A coastal waterbody that is characterized as an inlet of seawater that diverts from the main ocean and may take one of two forms. In the first form, the sound is formed by seawater that moves inland by way of a river valley, creating a type of harbor that is surrounded by tall hills and mountains. In the second form, the seawater may completely separate an area of land from a larger land mass, forming an island near the shore. In many cases, a sound is filled with several islands.

Stakeholder(s)—Individual(s) or organization(s) with a vested interest in decision-making pertinent to WCVI Chinook salmon.

Stock—A group of salmon used as the focal unit for management.

Stock Management Unit (SMU)—A group of one or more Conservation Units that are managed together with the objective of achieving a joint status.

Stock status—The Wild Salmon Policy status of a salmon Conservation Unit, either “Red”, “Amber”, or “Green” (DFO 2005).

Surfline—The point offshore where waves and swells are affected by the underwater surface and become breakers.

Survey life—length of time in days that spawning salmon are available to be seen and counted in a survey area.

S_{gen}—Spawner abundance that would result in recovery to S_{MSY} in one generation in the absence of fishing (Holt et al. 2009).

S_{MSY}—Spawner abundance at maximum sustainable yield (Holt et al. 2009).

S_{REP}—Spawner abundance at replacement; equivalent to spawning capacity or historic equilibrium abundance of spawners with no fishing (Parken et al. 2006; Holt et al. 2023a).

U_{MSY}—Harvest or exploitation rate at maximum sustainable yield (Holt et al. 2009).

Terminal [area, fishery, harvest, etc.]—For WCVI Chinook salmon, referring to all marine waters within one nautical mile of the WCVI surfline. More generally describes the marine area where a certain stock is concentrated just before entering its natal watershed.

Thalweg—The path or line of lowest elevation in a riverbed.

ABSTRACT

Natural-origin Chinook salmon returning to West Coast of Vancouver Island rivers are of significant conservation concern. Two candidate limit reference points identified for the Stock Management Unit do not adequately capture the variability in productivity among natural-origin populations, which is important for long-term sustainability of the stock. We therefore considered additional information on the distribution of fish within the Stock Management Unit, their genetic diversity, and population demographics, which led to the conclusion that these fish are at 'critical' status. Of particular concern are small, struggling populations within Clayoquot Sound. Multiple factors, many of which interact with our changing climate, are responsible for ongoing poor status and include: reduced fish sizes and proportions of female spawners resulting from size-selective mortalities from fisheries, predators, and environmental changes; reduced genetic diversity caused by interbreeding with hatchery-origin salmon and straying; habitat losses in rivers and the nearshore marine environment resulting from habitat perturbations; and overall changes in prey quality and availability. In contrast, returns of hatchery-origin Chinook are relatively high, generating significant cultural, social, and economic benefits. Balancing conservation of natural-origin Chinook with the benefits conferred from hatchery production requires improved collaborative governance and planning, as well as a better understanding of factors limiting natural productivity to be obtained through continued research, monitoring, and assessment. Mitigation opportunities include continuing to adapt hatchery practices to reduce negative impacts on natural-origin salmon, reducing size-selectivity in fisheries, development of fisheries targeting marked hatchery-origin fish, monitoring and protecting habitat and water quality, and restoring degraded freshwater and estuarine ecosystems. Going forward, we recommend further research on:

1. the validity of using hatchery stocks as indicators of natural-origin salmon survival and distribution,
2. additional quantitative reference points and approaches to integrate these into single status assessments,
3. causal mechanisms, survival bottlenecks and additional potential mitigation options,
4. hatchery science including experimentation, and
5. ecosystem models to better understand cumulative and synergistic interactions among limiting factors including climate.

Periodic status updates are encouraged including the continued application of multi-stakeholder information gathering and assessment approaches involving local knowledge-holders, particularly First Nations.

1. INTRODUCTION

This report summarizes information and advice pertinent to the management and rebuilding of natural-origin Chinook salmon (*Oncorhynchus tshawytscha*) within the West Coast Vancouver Island (WCVI) Chinook stock management unit (SMU). Natural-origin salmon are the offspring of fish that spawned in the wild. Natural-origin salmon are not the same as wild salmon, which are defined in the Wild Salmon Policy as: "salmon that spend their entire lives in the wild and originate from parents that were also produced by natural spawning and continuously lived in the wild" (DFO 2005). Information provided in this report is relevant to the implementation of Fisheries and Oceans Canada's (DFO) mandate to balance conservation and sustainable benefits while respecting ongoing reconciliation with First Nations. In addition, this work supports implementation of the Fish Stock provisions within the *Fisheries Act*, as well as the development of a Fishery Science Advisory Report and a Recovery Potential Assessment under the *Species at Risk Act* (SARA).

WCVI Chinook are important to the economic and social wellbeing of WCVI First Nations and communities. As a result, First Nations and communities along the WCVI endeavour to strike a balance between maintaining overall Chinook salmon abundance while protecting the genetic and demographic diversity of the species within the SMU. The challenge is to rebuild natural-origin (including wild) Chinook abundance and diversity while maintaining and improving the food, cultural, social, and economic benefits conferred by hatchery-origin Chinook.

As we shall see in this report, the preponderance of hatchery-origin Chinook, which have until recently largely been visually indistinguishable from natural-origin Chinook, complicates our assessment of stock status. The exception has been a small proportion of hatchery-origin Chinook whose adipose fins were removed prior to their release to indicate the presence of an internal Coded-Wire Tag (CWT). The ability to visually differentiate hatchery- from natural-origin Chinook is improving along the WCVI, with several hatcheries now mass marking (adipose fin removal with or without a CWT) their releases. Advancements in genetic identification of hatchery-origin Chinook, using Parentage Based Tagging (PBT), further improves our ability to differentiate the influence of specific hatcheries on natural-origin Chinook.

The geographic area occupied by WCVI Chinook is huge, extending from their spawning and rearing areas within major watersheds along the WCVI northward in the ocean throughout the Gulf of Alaska and sometimes north of the Aleutian Islands. Also important are large Sounds, key geographical features of the WCVI coastline that include Barkley Sound/Alberni Inlet, Clayoquot Sound, Nootka Sound/Esperanza Inlet, Kyuquot Sound, and Quatsino Sound. The terrain surrounding the complex coastline of these inlets and their watersheds is generally steep and mountainous.

There are many third-order rivers entering the inlets, but most are relatively short, generally much less than 100 km, with limited flood plains and side channels. Suitable spawning habitat, including appropriate gradient, gravel substrate, percolation, and water depth and velocity, is generally limited to mainstems of the larger WCVI rivers. The total length of accessible Chinook spawning habit for surveyed WCVI rivers ranges from about 2–97 km.

River discharge during the fall and winter is primarily driven by rainfall. Precipitation on the WCVI is among the highest in North America, with most falling from October to March. Rivers supporting Chinook tend to be 'flashy' (rapid and frequent fluctuations in discharge) during these months due to the steep topography of most watersheds and the high levels of precipitation; some rivers can increase by 2–3 m in height within 12 hours during major rainfalls. In contrast, discharge during spring and summer is primarily driven by snow melt. Only a handful of WCVI rivers are fed by glaciers or large lakes with dams that moderate flows; the rest are vulnerable to drought following depletion of the annual snowpack until the return of fall rains. Water levels can be very low during extreme droughts (typically mid-July to September), with some sections receiving only subsurface water input. Deforestation caused by widespread logging contributes to increased variability in river discharge by reducing capacity for water retention relative to intact watersheds buffered by old growth forests.

1.1. OBJECTIVES

While stock rebuilding is a complex multi-sectoral/governmental process, DFO has three foundational objectives, each with activities for which DFO Science has some responsibility:

- Balancing conservation needs with maintenance of sustainable benefits
  - Assess stock status, including the roles of natural and human factors (i.e., harvest, hatchery, and habitat), to inform management frameworks.
- Improved collaborative governance and planning
  - Engage with resource managers, First Nations, and stakeholders to provide decision support through Risk Assessments and Management Strategy Evaluation
  - Collaboratively work-plan with other branches and governments, First Nations, and stakeholders to ensure science is relevant to management and regulatory decisions
- Improved understanding through research, monitoring and assessment
  - Apply a life cycle, climate informed, and ecosystem approach to salmon monitoring and research to inform Risk Assessments and Management Strategy Evaluation

With respect to this report, our primary objectives are to provide advice or to document knowledge gaps on:

1. Stock status and trends, including stock structure, distribution, and sources of mortality
2. Ecosystem and climate change considerations relevant to the stock

Estimate:

3. Candidate reference points
4. The impact of candidate harvest (and/or other management) options on the stock, and

If the SMU is below the limit reference point (LRP), review:

5. CU components contributing to SMU status; factors affecting production and the potential future impact of climate; limiting factors associated with anthropogenic threats and recommendations to prioritize potential mitigation actions; and, if possible, the effect of management actions on probabilities of reaching candidate rebuilding targets

And describe:

6. Exceptional circumstances or assessment triggers for the stock

The final objective, specific to the present report on WCVI Chinook, is to:

7. Develop candidate aggregate abundance LRP, Upper Stock Reference, and Removal Reference for West Coast of Vancouver Island escapement indicators; include Recovery Potential Assessment elements as applicable, and describe hatchery and habitat components.

1.2. FIRST NATIONS RIGHTS AND CONTEXT

The WCVI Chinook SMU spans from T’Sou-ke First Nation’s traditional territory in the south, through the traditional territories of the Nuu-chah-nulth Nations, to the Quatsino First Nation’s traditional territory on the northwestern tip of Vancouver Island. Chinook are of great social, cultural, spiritual, and economic importance to these First Nations. Chinook are known as “suuhaa” in the Nuu-chah-nulth language, as “SȾOḰI¸” in the SENĆOŦEN language of the T’Sou-ke First Nation, and as “sat’sam” in Kwak’wala language of the Quatsino First Nation.

DFO is committed to the recognition and implementation of Indigenous and treaty rights related to fisheries, oceans, aquatic habitat, and marine waterways in a manner consistent with Section 35 of the *Constitution Act*, 1982, the *United Nations Declaration on the Rights of Indigenous Peoples* (UNDRIP), the *United Nations Declaration on the Rights of Indigenous Peoples Act* (UNDA), the UNDA Action Plan 2023–2028, and the federal Principles Respecting the Government of Canada’s Relationship with Indigenous Peoples. DFO-CCG Reconciliation Strategy provides a guidance document to better understand why and how reconciliation informs the work of the Department. Section 35(1) of the *Constitution Act*, 1982 recognizes and affirms the existing Aboriginal and treaty rights of the Indigenous peoples in Canada. The Government of Canada’s legal and policy frameworks identify a special obligation to provide First Nations the opportunity to harvest fish for food, social and ceremonial purposes. Treaty Agreements signed between Nations and the Government of Canada also obligate Canada to provide these opportunities.

The T’Sou-ke First Nation is a Douglas Treaty First Nation. Douglas Treaties are one of the few historical treaties signed in British Columbia between 1850–1854. These treaties surrendered lands near Hudson Bay Company posts and in Victoria in exchange for the continued right to hunt and fish, reserve lands, and a one-time payment. T’Sou-ke is one of the 14 treaty groups on Vancouver Island that signed during this period. Further detail on the Douglas Treaties can be found here.

Five Nuu-chah-nulth Nations (Huu-ay-aht First Nations, Ka:’yu:’k’t’h’/ Che:k’tles7et’h’ First Nations, Toquaht Nation, Ucluelet First Nation, Uchucklesaht Tribe) are signatories on the Maa-nulth Treaty. The Maa-nulth Final Agreement Fisheries Chapter articulates a treaty fishing right for domestic purposes that is protected under Section 35 of the *Constitution Act*, 1982 and includes Chinook salmon and other species. Negotiated through a side agreement, the Maa-nulth Treaty Nations have commercial access through a Harvest Agreement. Further detail on the Maa-nulth Treaty can be found in the applicable IFMP Sections 4 and 10.1 and the full Maa-nulth First Nations Final Agreement can be found here.

Five Nuu-chah-nulth First Nations located on the west coast of Vancouver Island—Ahousaht, Ehattesaht/Chinehkint, Hesquiaht, Mowachaht/Muchalaht, and Tla-o-qui-aht (the ‘Five Nations’)—have an Aboriginal right to fish for any species, with the exception of geoduck, within their fishing territories and to sell that fish. Since 2019, DFO has released an annual Five Nations Multi-Species Fishery Management Plan, which provides for a right-based multi-species sale fishery that DFO considers to accommodate the Five Nations’ Aboriginal commercial fishing rights. The Multi-Species Fishery Management Plan outlines the Five Nations’ fishing opportunities for salmon, groundfish, crab, prawn, sea cucumber, and gooseneck barnacle and the fishery management regime. Further details on the Five Nations’ Rights-based sale fishery can be found in the applicable IFMP Section 10.3 and in the 2023/24 FMP.

Several Nuu-chah-nulth First Nations have communal commercial fisheries access to WCVI Chinook. The Hupacasath and Tseshaht First Nations have negotiated Economic Opportunity agreements that facilitate communal commercial fisheries for Somass River Chinook and other salmon species. These two nations, as well as the Ditidaht First Nation and the Yuułuʔiłʔatḥ

(Ucluelet) First Nation have had Excess to Salmon Spawning Requirements fisheries for surplus WCVI hatchery Chinook salmon. The Huu-ay-aht First Nation has a mark-selective terminal sale fishery for Sarita River Chinook that was enabled by Maa-nulth Treaty provisions.

1.3. SOCIO-ECONOMIC CONTEXT AND FISHERIES OVERVIEW

WCVI Chinook are vulnerable to marine fisheries during most of their life, with fisheries primarily targeting ages 3 and above. WCVI Chinook are harvested in fisheries operating in Alaskan waters and all the way south along the coastline until entering their natal rivers (some of which even support freshwater recreational fisheries). Fisheries in Alaska and Northern BC harvest WCVI Chinook as both immature fish feeding in the area and as mature adults during their return migration to their natal stream. Southern fisheries along the central BC coast and WCVI harvest mostly mature Chinook that are migrating to their spawning grounds. The far northerly marine distribution of WCVI Chinook constrains Canada's ability to conserve WCVI Chinook through fishing regulations, since approximately half of the annual fishery-related mortality (catch plus incidental mortality) occurs in Southeast Alaska (SEAK; CTC 2023a; Table C-6). WCVI-origin Chinook stocks can also comprise a major proportion (ranging from 5–50%) of First Nation, recreational, and commercial catches along the Northern and Central Coasts of BC (NCBC; CTC 2023b).

Large returns of WCVI hatchery-origin Chinook in the 1980s and early 1990s resulted in rapid growth of directed Chinook fisheries along the WCVI. Catches during the peak fishing period from August–September were primarily (90–100%) WCVI Chinook. Since 1994, these fisheries were restricted in response to declines in WCVI abundance and later to protect declining Interior Fraser Coho salmon. With the exception of terminal fisheries targeting hatchery surpluses (Alberni Inlet, Barkley Sound, and Tlupana Inlet) or mixed stocks (Juan de Fuca), catches of WCVI Chinook in most terminal fishing areas are relatively low.

WCVI Chinook salmon continue to be an important economic driver for WCVI communities and First Nations. WCVI fishery management has transitioned away from prioritizing large, mixed-stock commercial fisheries and places more emphasis on Chinook as a basis for recreational fishery tourism, regular gillnet and seine fisheries targeting hatchery returns, and First Nation FSC and commercial fisheries (see section 1.2, above). Significant economic benefits are realized from fisheries, as can be inferred from exploitation rates presented in Table C 5. In the late-1990s, various management measures were implemented to reduce harvest on WCVI Chinook in response to concerns of declining abundance (DFO 2023a). Current fishery management measures are considered precautionary and aim to promote stock growth. Despite these measures, WCVI natural-origin Chinook abundance has remained low for over three decades (see section 5).

The average annual calendar year fishery exploitation rate (CYER) in pre-terminal fisheries, including release mortality (from capture-related injuries), is estimated to be 35% or about 90,000 Chinook annually (Figure 1.1.; Table C-6). Terminal fisheries targeting Robertson Creek Hatchery and Conuma River Hatchery Chinook are more variable than pre-terminal, with total allowable catches depending on forecasted annual returns. On average, terminal fisheries account for a 25% exploitation rate and have ranged between 2% and 50% historically. Pre-terminal fisheries are primarily regulated through the Pacific Salmon Treaty, while terminal fisheries are regulated domestically by DFO resource management.

1.3.1. Pacific Salmon Treaty

Allowable harvest impacts in pre-terminal fisheries are defined in the Canada–USA Pacific Salmon Treaty (PST), which includes marine south from SEAK to coastal Oregon. The PST management framework for Chinook considers two component types of fisheries: Aggregate Abundance-Based Management (AABM) and Individual Stock-Based Management (ISBM) fisheries.

AABM mixed stock fisheries are managed to an annual total allowable catch based on the forecast aggregate abundance of all stocks and harvest rates stipulated by the PST. The remaining fisheries are classified as ISBM fisheries, whose CYERs are regulated domestically by either Canada or the USA. ISBM fisheries that regularly intercept WCVI Chinook include fisheries along the Central Coast of BC and terminal areas of the WCVI. In Canadian AABM and ISBM fisheries, all sectors participate, including First Nation Treaty, FSC, and Economic Opportunity fisheries, recreational fisheries, and commercial net and troll fisheries. It should be noted that the PST does not cover bycatch in non-salmon fisheries such groundfish trawl in either country and does not extend to areas such as western Alaska and the Bering Sea, where WCVI Chinook have historically been intercepted, meaning that catch estimates are biased low (Figure 3.16).

For more information on PST-related Chinook fisheries, refer to the Pacific Salmon Commission Joint Chinook Technical Committee (CTC) annual reports at www.psc.org.

1.3.2. Domestic Fishery Management

Fisheries management of the WCVI SMU is described in annual Integrated Fisheries Management Plans (IFMP) for Southern BC Salmon. Since 1995, domestic fishery management has limited fishery exploitation on WCVI Chinook in Canadian waters to levels less than what is allowable under the PST. In 1996, a closure was implemented from Haida Gwaii to the WCVI during the peak migration period. In 1997, an exploitation cap was placed on AABM and ISBM fisheries in Canada that intercept WCVI natural-origin Chinook (Figure 1.1.). The exploitation cap varied from 10–15% depending on the forecast returns to Clayoquot Sound, which was treated as a wild refugium. The exploitation rate for Clayoquot was the exploitation for Robertson Creek Hatchery Chinook excluding catches from fisheries in Barkley Sound and Alberni Inlet. The Northern Troll fishery has been restricted to an annual interception limit of 3.2% for WCVI Chinook, which is evaluated bi-weekly through catch composition sampling.

Most WCVI terminal area fisheries are managed to achieve spawner targets based on the forecast number of eggs returning. Specific fisheries management measures have included: implementation of a special management corridor extending one nautical mile out from the surfline, a maximum size ‘slot limit’ (designed to conserve large egg-bearing females), time and area closures, daily limit restrictions and, more recently, mark-selective (based on adipose fin clips) fisheries in some areas. Harvest opportunities for Chinook in terminal fishing areas outside of the approaches to the major hatcheries have been restricted using area closures within 2 km of most Chinook river mouths, spot area closures along migration paths, reductions in daily limits, and maximum size limits. Kyuquot Sound and Clayoquot Sound have been closed to all fishing except First Nations rights-based food fishing. Many First Nations discourage their members from fishing near river mouths. In contrast, regular harvest opportunities occur in terminal locations where hatchery surpluses are identified, such as Alberni Inlet, Tlupana and Matchlee inlets, and Nitinat Lake.

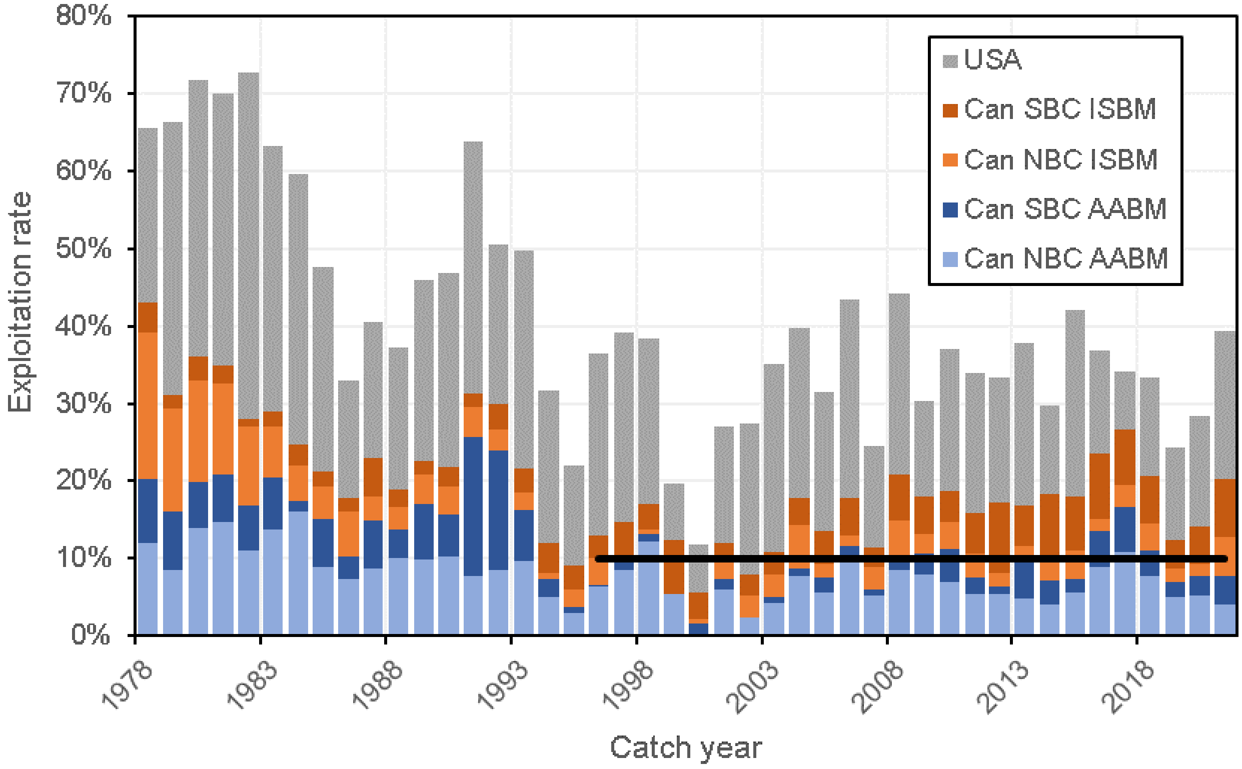

Figure 1.1. Distribution of calendar year exploitation rate (CYER), which includes incidental mortalities, among key Canadian and USA pre-terminal fisheries. "NBC" and "SBC" in the legend denote Northern and Southern BC, respectively. CYER estimates are based on Robertson Creek Hatchery Chinook coded-wire tag recoveries. The solid black line shows the 10% exploitation rate limit for Canadian AABM fisheries (blue bars).

2. DATA SOURCES AND ASSESSMENT FRAMEWORK

One goal of the assessment framework for WCVI Chinook is to support annual fisheries management, whether pre-terminal (*i.e.* AABM) fishery management through the Pacific Salmon Treaty process or terminal (*i.e.* ISBM) fisheries. Since 1985, as part of the Pacific Salmon Treaty implementation, Robertson Creek Hatchery Chinook became the Coded-Wire-Tag (CWT) indicator population, representing the entire WCVI SMU. In addition, a suite of escapement (spawners plus hatchery brood) indicators distributed along the WCVI provides trend and status information as well as biological samples for hatchery proportions, age and sex composition. Fishery monitoring includes catch estimation by fishery, sampling of CWTs, and biological sampling.

Another goal of the assessment framework is to improve understanding of the status and productivity of the SMU and component populations over time. Key factors driving productivity are determined through a life cycle assessment, starting with qualitative risk assessment and identification of knowledge gaps and then moving to more quantitative risk assessment (e.g., Irvine et al. 2024). While the freshwater phases of the Chinook life cycle are relatively straightforward to study, the ocean phases have historically been regarded as a "black box" (Burke et al. 2016). Recent research efforts on the WCVI have focused on the early marine period, while the bulk of the historical data underlying this report come from the freshwater rearing phase and the sexually-mature adult phase. Monitoring smolt production from natural spawners has been infrequent over the period of spawner data since 1953; but the recent focus on life cycle assessment has resulted in fry/smolt assessment in rivers such as Sarita, Tranquil, San Juan, and Somass. Data collected from all life phases have been brought to bear in this report where available.

Data used and methodologies employed for counting and sampling WCVI Chinook are outlined below. Unfortunately, natural mortalities from predation, disease, etc. are rarely or opportunistically monitored.

2.1. SPAWNER ESTIMATION

Spawner numbers are estimated to determine if the conservation objective of maintaining heterogeneous stock structure is being met by spreading risk over a broad range of environmental conditions (DFO 2005; Riddell, 1993; Serchuck et al. 1999). The assessment framework consists of a hierarchy of spawner enumeration and sampling effort and methods, explained below and categorized according to objectives for the spawner escapement estimate type. The DFO "nuSEDS" database has six estimation categories (see Table C-1 for details):

1. True abundance with high resolution and reliability,
2. True abundance with medium resolution and reliability,
3. Relative abundance with high resolution and reliability,
4. Relative abundance with medium resolution and reliability,
5. Relative abundance with low resolution and reliability,
6. Presence or absence.

The scope of current population estimates is estimated to account for >90% of WCVI Chinook spawner abundance. For assessment purposes, years with no escapement surveys, or when no stock composition data were available from mixed-stock fishery catches, were typically infilled based on data from adjacent years or systems (methodology and source data available from Brown & Holt 2024). The full list of WCVI Chinook rivers is provided in Table C-2.

The Somass River has the largest Chinook population on the WCVI largely due to Robertson Creek Hatchery production. As mentioned, this is the CWT indicator for the WCVI Chinook SMU and therefore requires accurate and precise estimates of abundance and estimated CWT recoveries in the fisheries, river spawners, and hatchery swim-ins (i.e., Category 1, above). Since 1986, upstream passage counts have been conducted at the Stamp River fishway. Beginning in 1990, a video camera system was employed to record Chinook migrating through the fishway. The design has been refined over the years such that counts of Chinook passage are now recorded continuously throughout the entire upstream migration period. The resulting data are highly precise and are considered accurate estimates of total spawner abundance in the Stamp River watershed, including Robertson Creek Hatchery.

Spawner estimates to an additional 24 Chinook rivers align with Categories 3–4. In these rivers, Chinook are consistently enumerated using periodic visual surveys during their return and spawning period; of which 17 have been identified as key escapement indicator systems with either no enhancement or lower levels of enhancement (see list in Table 4.). Counts are expanded for observation error based on survey conditions and an average "survey life" of fish based on the historic time series, with some flexibility to account for year-specific conditions. The "area-under-the curve" (AUC) method is applied to derive total escapement estimates from periodic counts (Ames, 1984; English et al. 1992; Irvine et al. 1992). Variations of the method are widely applied to estimate salmon escapement in jurisdictions from California north to Alaska (Cousens et al. 1982; Bue et al. 1998). The AUC method was applied for WCVI systems because it was cost-effective and also because the intensive indicator stocks that were chosen originate from relatively small, clear river systems where Chinook spawning is mostly confined to the mainstem portions of the rivers. The snorkel survey method used has generally high observer efficiencies, although observer efficiency can be low during periods of high rainfall and turbid water. Survey life of Chinook spawners varies from 5–45 days, with a median of approximately 20 days. Flow and water level conditions as well as ancillary information such as wildlife observations, behavior notes, and fishery-based information are assessed in the review of data to determine which surveys to include in the analysis and to choose an appropriate survey life in the AUC calculations (McHugh and Dobson 2013; Dunlop 2022). High flows, increased turbidity, and bad weather preventing access to remote locations can result in lower quality estimates.

To assess the relative accuracy of the WCVI extensive indicator program, a 2010–2013 radio tagging program confirmed the parameters typically applied in Chinook estimates were reasonably consistent with more detailed measurements using mortality-sensing radio tags (McHugh and Dobson 2013). In addition, the Mowachaht-Muchalaht First Nation in Nootka Sound conducted mark recapture surveys on the Burman River from 2007–2018. Tags were applied and recaptured in the holding pool just below the survey section (extent of tidal influence). The numbers of Chinook in the pool during the migration period were estimated using AUC and mark recapture (Dunlop 2019), but a lack of closure resulted in confounded parameters, limiting the value of resulting estimates, which are not reported here.

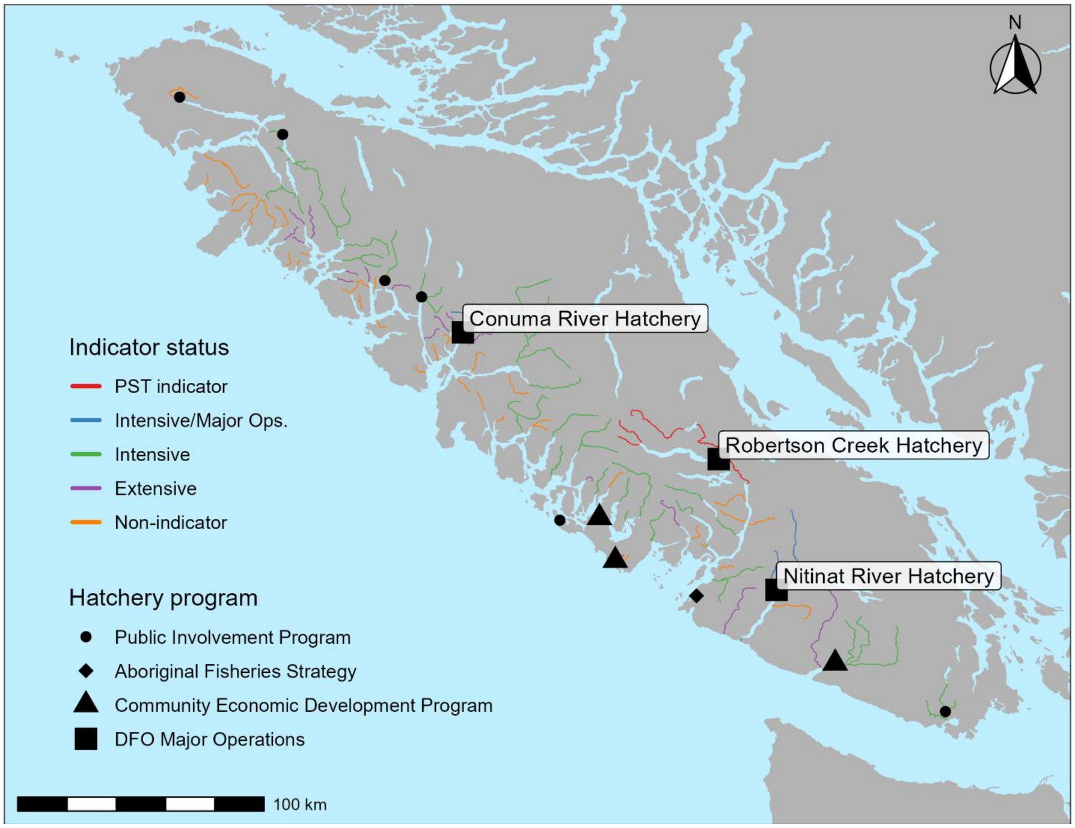

Figure 2.1. WCVI rivers and major tributaries with observations of Chinook (coloured lines), plus locations of hatcheries releasing Chinook along the WCVI (points). Line colours indicate the intensity of monitoring focused on each river. The Somass River is a Pacific Salmon Treaty indicator stock and is assessed most rigorously. The Conuma and Nitinat rivers are monitored annually by DFO hatchery operations staff. Intensive indicators are assessed quantitatively with targets of 6–8 surveys each year. Extensive indicators are surveyed opportunistically, typically on the order of once every 3–5 years.

Another 36 Chinook populations are generally assessed as Categories 5–6, providing relative abundance at a low resolution and low reliability or simply presence or absence. These populations are not used as indicators.

In addition to the three major DFO hatcheries on the WCVI—Nitinat, Conuma, and Robertson—there are three Community Economic Development Program hatcheries, six Public Involvement Program hatcheries, and one Aboriginal Fisheries Strategy hatchery (Figure 2.), which collectively conduct minor Chinook enhancement programs on 10 WCVI rivers, and contribute to escapement monitoring in these systems.

Approaches to estimate WCVI Chinook escapements vary depending on funding, priority, logistics, environmental conditions, etc. There have been many reviews of escapement monitoring approaches including that of Parsons and Skalski (2010). These authors provided general guidance on which methods tended to provide the most statistically reliable estimates and which were not recommended. Generally, passage counts were considered the most reliable, provided suitable infrastructure is available, although species composition can be an issue if using an acoustic system rather than visual. Area-under-the-curve techniques were recommended when salmon are visible and amendable to counting (i.e., "observer efficiency" is high). Mark-recapture methods were not recommended except when it is possible to meet the required assumptions (see Velez-Espino et al. 2016). For example, populations are typically not closed (as required by Peterson or Schafer methods), requiring more complex open models to be applied; mortalities may be dependent on arrival time (the Jolly-Seber method cannot adjust for this bias); fish may arrive and die between sampling periods (the Manly-Parr method cannot adjust for this bias). Mark-recapture may be the best option for larger systems where the closure assumption can be met and visibility is an issue. Peak count methods (adults or redds) were not recommended as the relationship between the peak count and escapement is variable from year to year.

On the WCVI, passage counts are applied where possible, with AUC employed elsewhere and peak estimates taken as a fallback when necessary. Handling mortality on vulnerable populations, lack of population closure, and cost generally precludes the broad application of mark-recapture methods in our area.

2.2. FISHERY CATCHES

WCVI Chinook are caught in terminal fisheries operating in the coastal inlets along the WCVI as well as in pre-terminal fisheries from the Bering Sea down to the southern USA. Catches of WCVI Chinook in terminal fisheries are estimated by local DFO Resource Management and Stock Assessment staff. Catches of WCVI Chinook in pre-terminal fisheries are estimated by the PSC using coded-wire tag recoveries (see below), which are compiled from various agency databases and fishery managers by the PSC Chinook Technical Committee (CTC) and reported annually (e.g., CTC 2023c). However, WCVI Chinook are also intercepted as bycatch in non-salmon fisheries, such as trawl fisheries, which are not included in the CTC reports. Similarly, the CTC reports are limited to the PST area, so WCVI Chinook caught in salmon-directed fisheries along the Aleutian Islands and other parts of the Pacific are not included.

2.2.1. Coded-Wire-Tag sampling and analysis

CWTs were introduced in the 1970s and provide information on ocean distribution, smolt-to-adult survival, maturation rates, and fishery exploitation rates for numerous CWT indicator populations along the west coast of Canada and the USA. A description and review of the CWT program is provided in an early PSC review report (PSC 2005). The CTC developed sampling guidelines and an analytical framework for CWT to estimate these key stock and fishery variables and publishes annual reports.

Robertson Creek Hatchery is the CWT indicator population representing the entire WCVI Chinook SMU. Approximately 600,000 CWT are implanted annually, or about 10% of the total production from Robertson Creek Hatchery. Results are available in CTC annual reports (e.g., CTC 2023a,b). Since 2000, all WCVI hatcheries, other than Robertson Creek, implant CWTs in smaller portions of their releases (or not at all) due to prohibitive costs of marking and recovery. Robertson Creek is therefore the only WCVI hatchery stock that generates sufficient data each year to be used as an indicator.

Some hatcheries, including Conuma, Sarita, and Robertson Creek, have begun mass-marking (adipose fin clipping without implanting CWTs) their annual Chinook production. Both CWT and mass-marked fish can be visually identified as hatchery-origin by their missing adipose fin; however, only CWT fish can have their origin determined (by reading the numeric code etched into the CWT), unless tissues are collected from mass-marked fish to allow a genetic assignment using PBT. Brood year data associated with CWT, PBT, and occasionally otolith thermal mark readings can also be used to accurately determine ages of hatchery-origin Chinook (see section 2.3, below).

There are uncertainties inherent in the CWT program that affect the accuracy of the exploitation rate analysis—a full list is given in CTC (2023b). Additional uncertainties and potential biases are also described in Weil et al. (2024). The CWT indicator program assumes that the biology, distribution, and behaviour of the CWT indicator stock (i.e., Robertson Creek) is representative of other Chinook populations in the SMU. Particularly, it assumes similarities in: maturation rates, size-at-age, marine distribution, fishery exploitation, smolt-to-adult survival, and migration timing. However, Robertson Creek Hatchery Chinook likely have different survival compared to natural-origin Chinook, mature quicker, grow to smaller size-at-age, and have a different migration timing compared to other populations, especially those in the northwest Vancouver Island area (see section 3.3). These differences could result in biased estimates of survival and pre-terminal exploitation for natural-origin Chinook. Systematic genetic sampling in pre-terminal fisheries to estimate the compositions of both hatchery- and natural-origin WCVI Chinook in catches would be required to assess this possible bias.

2.2.2. Terminal fisheries catch monitoring

Terminal Chinook fisheries along the WCVI include: commercial net fisheries; First Nation net, troll, and rod & reel fisheries; and recreational fisheries (individuals and fishing guide/lodge operations). Chinook catches in all of these fisheries are monitored by DFO, but approaches vary depending on the fishery.

Commercial and First Nation Chinook catches are reported directly by individual fishers or vessel operators. Commercial catches are reported directly to DFO while First Nation catches are reported to First Nation fishery managers.

Recreational Chinook catches are estimated via DFO’s creel survey, which combines catch data from interviews conducted with individual fishers, fishing trip reports provided by fishing guides and lodges, and recreational vessel counts collected during aerial surveys. Methods for generating total catch estimates are described in English et al. (2002) and Atkinson et al. (2024) for the Strait of Georgia creel survey; similar methods and survey designs were implemented commencing in Alberni Inlet and Barkley Sound in 1984 and across the entire WCVI in 1991. Catch estimates from the creel program are aggregated by month because data are generally too sparse to support precise estimates at finer temporal resolutions.

2.3. BIOLOGICAL SAMPLING

Biological samples from Chinook salmon have been routinely collected from fishery catches, hatchery programs, and WCVI rivers by DFO and partner organizations since the early 1980s. Most fisheries are intensively sampled, with sample rates of 10% in key terminal fisheries. The most intensive escapement sampling occurs on the Stamp River to meet both the requirements of fishery management and the PSC indicator at Robertson Creek Hatchery (*q.v.* section 2.2.1). There is consistent sampling of broodstock at other hatcheries along the WCVI. Unfortunately, sampling of carcasses in ‘wild’ rivers typically yields few samples due mainly to challenging environmental conditions and small population sizes.

Biological sampling includes body size (length and/or weight), age (both total and freshwater or marine), sex, origin (whether spawned in a hatchery or naturally in a WCVI river), and natal stock (i.e., home river or hatchery). Body size is typically assessed via length, which is measured using a measuring board or stick. Age is most often determined by examining sclerochronology of salmon scales. Fish origin is determined with one or more of the following:

1. CWTs provide hatchery of origin and brood year.
2. Genetic stock identification can be used to identify WCVI Chinook to their natal CU with >80% confidence and SMU with >90% confidence (Beacham et al. 2021). This method is used extensively in delineation of catch to SMU, CU, and often river. These samples have also been used in STRUCTURE analysis (Withler et al. 2017, Weil et al. 2024) to assess influence of straying in ancestry of natural spawners.
3. Parentage-based tagging (PBT) provides with near 100% confidence the hatchery of origin, brood year, and sex of the fish. PBT is a relatively recent application along the WCVI. As such, adult returns with all ages identifiable through PBT are just beginning at the timing of this report and are not broadly included in our analyses. PBT will be an important tool for future management and assessment of WCVI Chinook.
4. Otolith marking during egg and early rearing life stages is achieved by manipulating incubation water temperatures to create distinctive bands (“thermal marks”) that allow identification of a natal hatchery, each of which applies a unique code. Thermal marking in WCVI hatcheries started in the mid-1990s and has been the basis of estimating proportion hatchery- and natural-origin within spawning populations (Weil et al. 2024).

2.4. ANALYTICAL FRAMEWORK

2.4.1. Run Reconstruction

DFO assimilates assessment information from enumeration programs and biological sampling to reconstruct annual terminal runs and total production of WCVI Chinook by SMU, CU, WCVI sound (or Pacific Fishery Management Area), and sometimes river (e.g., Somass). The terminal run (abundance) is the sum of WCVI Chinook catch and escapement in the terminal area (WCVI portion of the ISBM area defined in the Pacific Salmon Treaty). The total production is the terminal run plus pre-terminal catch of adult WCVI Chinook in the same year. To calculate the terminal run, estimates of annual catch and escapement from across WCVI stock assessment programs are assimilated, and sampling results are applied within time and area strata to apportion the counts among ages and populations following methods of Chasco, Hilborn, and Punt (2007).

The accuracy and precision of the run reconstructions depend on the quality of escapement and catch data including stock composition estimates in terminal WCVI fisheries. The total terminal WCVI run estimate is the sum of all individual indicator populations’ reconstructions. In 2015, a

3-year cost-sharing agreement with the Pacific Salmon Commission allowed DFO to expand the terminal run reconstruction program by increasing tissue, otolith, and scale sampling across several WCVI fisheries. As a result, the precision and detail of the terminal run reconstruction is considerably improved from 2015–present versus in earlier years (Luedke et al. 2019).

The estimated ocean exploitation rate of WCVI Chinook (see below) is applied against the reconstructed terminal run to back-calculate the assumed number of Chinook harvested in pre-terminal fisheries.

2.4.2. Cohort and Exploitation Rate Analyses

Robertson Creek Hatchery estimated CWT recoveries are the basis for estimating pre-terminal fishery exploitation, maturation rates, and marine survival. The PSC CTC annual exploitation rate analysis (e.g., CTC 2023b) estimates WCVI Chinook stock contribution and exploitation rates in 71 key fishery groupings, ranging from SEAK to the terminal WCVI area. Incidental mortality rates are estimated for each fishery annually (see Appendix D in CTC 2023a) following the methodologies developed in CTC (1997). The Cohort Analysis (e.g., Vélez-Espino et al., 2011) yields estimates of Robertson Creek Hatchery Chinook smolt to age-2 survival as well as maturation rates. Acknowledged weaknesses of the approach are: the assumption that exploitation, maturation, and survival of Robertson Creek Hatchery Chinook and natural-origin WCVI Chinook are the same or similar, and Chinook catch estimates in non-sanctioned and illegal fisheries are excluded from the analyses.

2.4.3. Annual Abundance Forecast

Riddell et al. (1996) outlined the analytical framework for forecasting returns of Stamp River and Robertson Creek Hatchery Chinook. For each brood year, information generated from the CTC's cohort analysis and used in forecast models includes: survival to age-2; ocean exploitation rates by fishery and age; and age-specific maturation rates. Total production is then determined by expanding all estimated CWTs by the total release/CWT ratios for the selected tag codes and then correcting this using recent average observed total returns/CWT-based estimates. To forecast future production of RCH Chinook, or "pre-fishery abundance," two sibling regression models are applied that use information from younger age classes to predict the production of older age classes:

- Model 1 uses total terminal return at a younger age class (independent variable) to predict total production (the surviving cohort in the ocean) of a subsequent age or ages from the same brood year. The dependent variable is the total (total pre-terminal fishing mortality plus terminal run) production at a subsequent age or ages.
- Model 2 uses estimated total production (fishing mortality plus escapement) of particular age classes to predict total production of subsequent ages (i.e., the surviving cohort from the same brood year).

Relationships among all possible age class combinations were examined using these two models. The actual models used for the forecast were based on the strongest correlations (highest R^2 values). In the case where more than one age class is used as a predictor (e.g., ages 2 & 3 fish to predict age 4s), the observed abundances of those ages were summed. Estimates of surviving cohort include natural mortality factors and are estimated as the pre-fishery abundance of the youngest age being predicted. Assuming recent (10-year) average maturation rates, the remaining cohort is assigned either to the expected terminal run or to the surviving cohort remaining at sea. The terminal return to Barkley Sound/Alberni Inlet is forecast after accounting for expected removals in pre-terminal fisheries. A forecast range is generated from the historical distribution of the deviations between the observed and forecast run size.

See Brown (2023) for a summary of the current best-performing predictors and management adjustments.

2.4.4. Stock-Recruitment Analysis

Stock-recruitment analysis of Chinook populations requires annual estimates of abundances and age compositions. Presently, only the Stamp River has been sampled rigorously and consistently enough to produce a defensible time series of stock-recruit data. However, the Stamp River is a heavily impacted watershed with high levels of hatchery influence (91% hatchery-origin spawners, on average; Table C-4) and extensive urban development, logging, and hydropower activities. It is therefore assumed that stock-recruit parameters estimated using the Stamp River population are not representative of natural-origin Chinook populations along the WCVI.

Among the natural populations, no single system has been sufficiently sampled to parameterize a stock-recruitment relationship. Previous efforts used pooled age data to estimate an aggregate stock-recruit time series. These data (Table 4.1; Table A-1) are considered in our investigation of stock reference points in section 4. However, the component age data and population size estimates underlying this data are confounded with unknown hatchery influences and are therefore of limited use in understanding natural-origin Chinook productivity on the WCVI. It is recommended that future stock assessment program development focus on expanding biological sampling programs in natural river systems to collect more age data from confirmed natural-origin fish.

2.5. ENVIRONMENTAL DATA

Myriad data are collected from across WCVI freshwater and marine environments. DFO Stock Assessment operates a network of ‘hydromet’ stations across Vancouver Island rivers, which log data on river water levels, water temperatures, air temperatures, local rainfall, and barometric pressure (available online here). The DFO Salmonid Enhancement Program collects detailed data on all hatchery water sources, including the Nitinat and Conuma rivers, and Robertson Creek. DFO science conducts numerous marine ecological monitoring programs off the WCVI, including plankton tows, salmon prey base assessments, CTD casts, and fixed-point observatories. Environment and Climate Change Canada, the Canadian Hydrographic Service, and the Water Survey of Canada collect data on ocean temperatures, tides and currents, and river discharges, respectively (see https://www.cioos.ca/ for an integrated resource on publicly available Canadian oceanographic data). The BC Ministry of Water, Land, and Resource Stewardship also monitors streamflow conditions from a range of systems across the WCVI (see http://bcrfc.env.gov.bc.ca/freshet/map_all_wsc.html). Various additional environmental monitoring programs are conducted by WCVI First Nations, municipalities, NGOs, and private companies; an overview of these programs is beyond the scope of this report.

The plethora of environmental data available for the WCVI provides useful information for understanding Chinook population dynamics. Data custodians and scientists conducting environmental research programs across the WCVI were invited to speak at the Freshwater and Marine Risk Assessment Workshops for WCVI Chinook that were held from 2015–2022 (Irvine et al. 2024; draft Freshwater Risk Assessments are currently available from West Coast Aquatic, Port Alberni, BC). During these workshops, pertinent data were presented on riverine and oceanographic conditions, which helped inform on the likely factors affecting the stock’s productivity (see section 6, below).

3. BIOLOGY AND STOCK STRUCTURE

Chinook originating from the West Coast of Vancouver Island (WCVI) are roughly in the middle of the species' latitudinal distribution in western North America. Chinook salmon (*Oncorhynchus tshawytscha*) are generally the largest of seven Pacific salmon species.

The WCVI Chinook SMU extends from the Sooke Basin in the southern end to Quatsino Sound in the north of WCVI (Figure 3.1.). The area includes 7 large sounds. Approximately 78 rivers have historic observations of Chinook presence, including 32 rivers in SWVI CU, 39 rivers in NoKy CU, and 7 rivers in NWVI CU; (see Figure 2.; Table C-2). The freshwater portion of the SMU is contained within the Western Vancouver Island Ecoregion, which is subdivided into 3 "ecosections"; the NWVI CU belongs to the Nahwitti Lowland Ecosection, while the SWVI and NoKy CUs belong to the Windward Island Mountains Ecosection (Demarchi 2011).

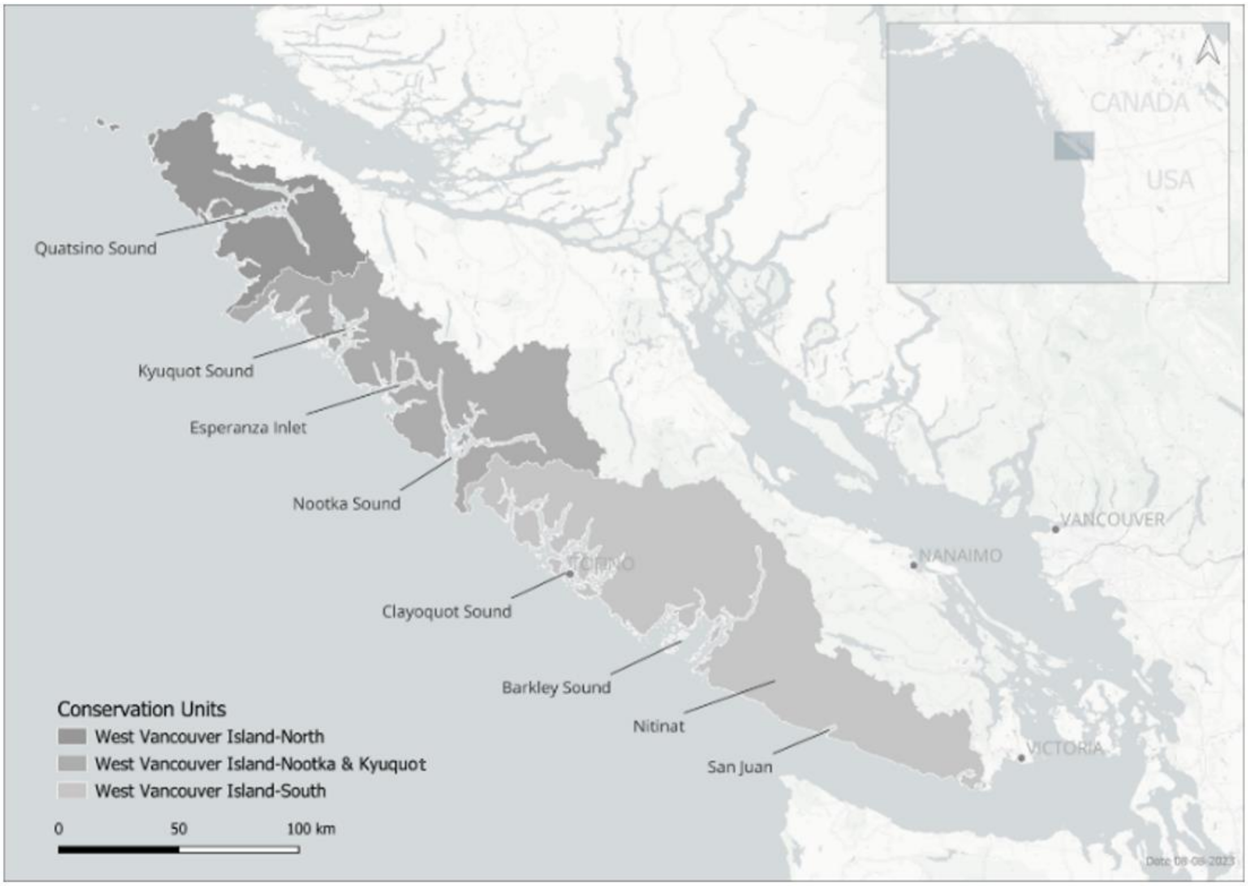

Figure 3.1. The WCVI Stock Management Unit (SMU) consists of 3 Wild Salmon Policy Conservation Units (CU) with about 50 rivers consistently supporting Chinook populations as well as their associated nearshore marine environment. Adapted from Holt et al. (2022b).

Spawner abundances vary significantly among the SMU's 78 identified Chinook populations. For the purposes of this report, we consider rivers with at least a few Chinook observed in a majority of years surveyed to contain a Chinook population. Visual surveys of Chinook abundance coupled with information on areas of available spawning habitat have allowed us to infer the relative sizes of these populations (Table C-2). The 25 largest WCVI Chinook populations are monitored intensively, with rigorous annual abundance surveys and routine efforts to collect biological samples from spawners.

On the WCVI, Chinook mature on average at approximately 4 years old, ranging from 2–7 years, with older age classes having a high proportion female and large body size. In this section, we review the stock structure and biology through the life cycle of WCVI Chinook.

3.1. SMU AGGREGATE ABUNDANCE

Assuming that freshwater habitat limits Chinook population sizes, summing watershed areas (as estimated in Holt et al. 2023b) for the 49 largest systems yields an estimated spawning at replacement (S_{REP}) on the order of 80,000 Chinook (Table C-3). This approach is based on accessible watershed area and assumes relatively healthy habitat conditions. However, many watersheds across the WCVI are degraded relative to those used to parameterize the watershed area model due to historic forestry and other industrial activities. Aggregate capacity of these 49 systems in their current degraded state is therefore likely much lower than 80,000 due to lower population productivity.

As described in section 1, natural-origin Chinook spend their entire life cycle in the wild but one or both parents may have been hatchery-origin. Recent estimates of natural-origin WCVI Chinook spawner abundance have been on the order of 25,000–30,000 (excluding age-2 'jacks') based on terminal run reconstructions. Adding harvest of approximately 15,000 based on 35% average ocean exploitation rate results in a total average annual abundance of 40,000–45,000 adult natural-origin Chinook (Figure 3.2).

Hatchery enhancement significantly increased the total abundance of WCVI Chinook. The vast majority (approximately 85%; Figure 3.2) of WCVI Chinook production originates from hatcheries. Until only recently, most hatchery Chinook were not visually distinguishable from natural production and routinely mixed with natural-origin spawners. The recent 10-year mean of total annual production from the WCVI Chinook SMU is estimated at over 250,000 Chinook (Figure 3.2).

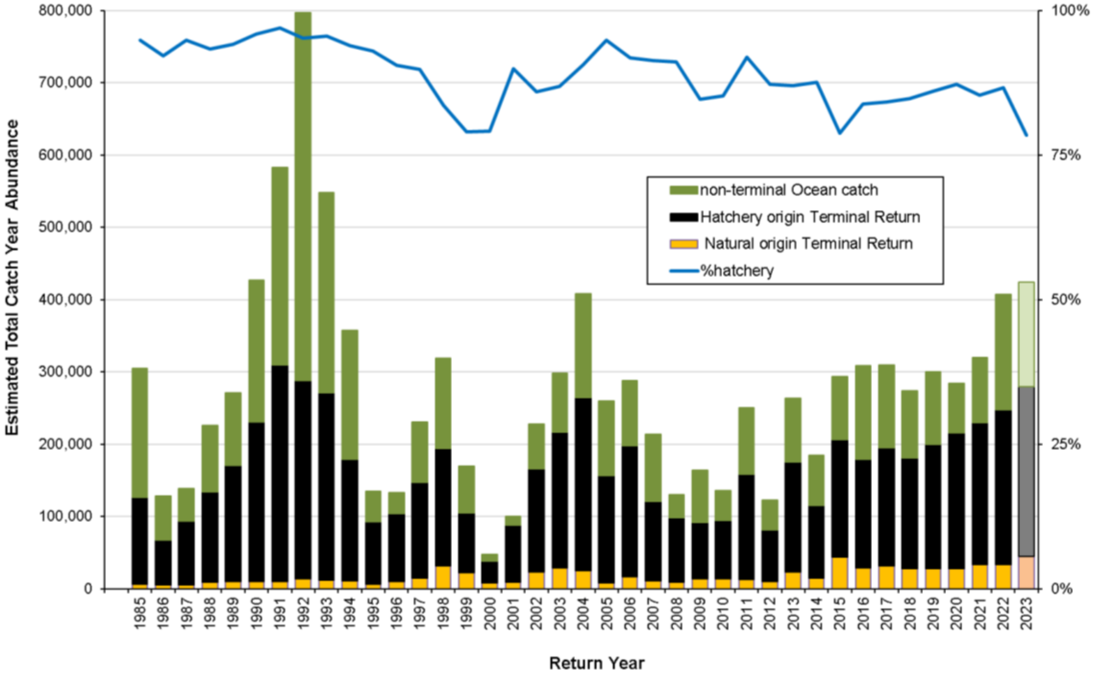

Figure 3.2. Annual estimates of adult total catch year abundance of WCVI Chinook salmon. Bar segments indicate the proportion of each estimate in pre-terminal fisheries, hatchery-origin terminal return, and natural-origin terminal return. The blue line, with reference to the secondary y-axis, shows the estimated percent hatchery-origin for each year's return (~85% on average). Data for 2023 are preliminary.

3.2. STOCK STRUCTURE

WCVI Chinook are a distinct lineage group within the north Pacific (see Figure 1 on page 560 in Riddell et al. 2018). Within the WCVI Chinook SMU there are 3 CUs (Figure 3.1.; Holtby & Ciruna 2007; DFO 2013; Brown et al. 2019): CK-31 “West Vancouver Island-South” CU (SWVI), CK-32 “West Vancouver Island-Nootka and Kyuquot” CU (NoKy), and CK-33 “West Vancouver Island-North” CU (NWVI). The genetic relatedness or hierarchical clustering of WCVI Chinook populations is illustrated in the dendrogram Figure 3.3.

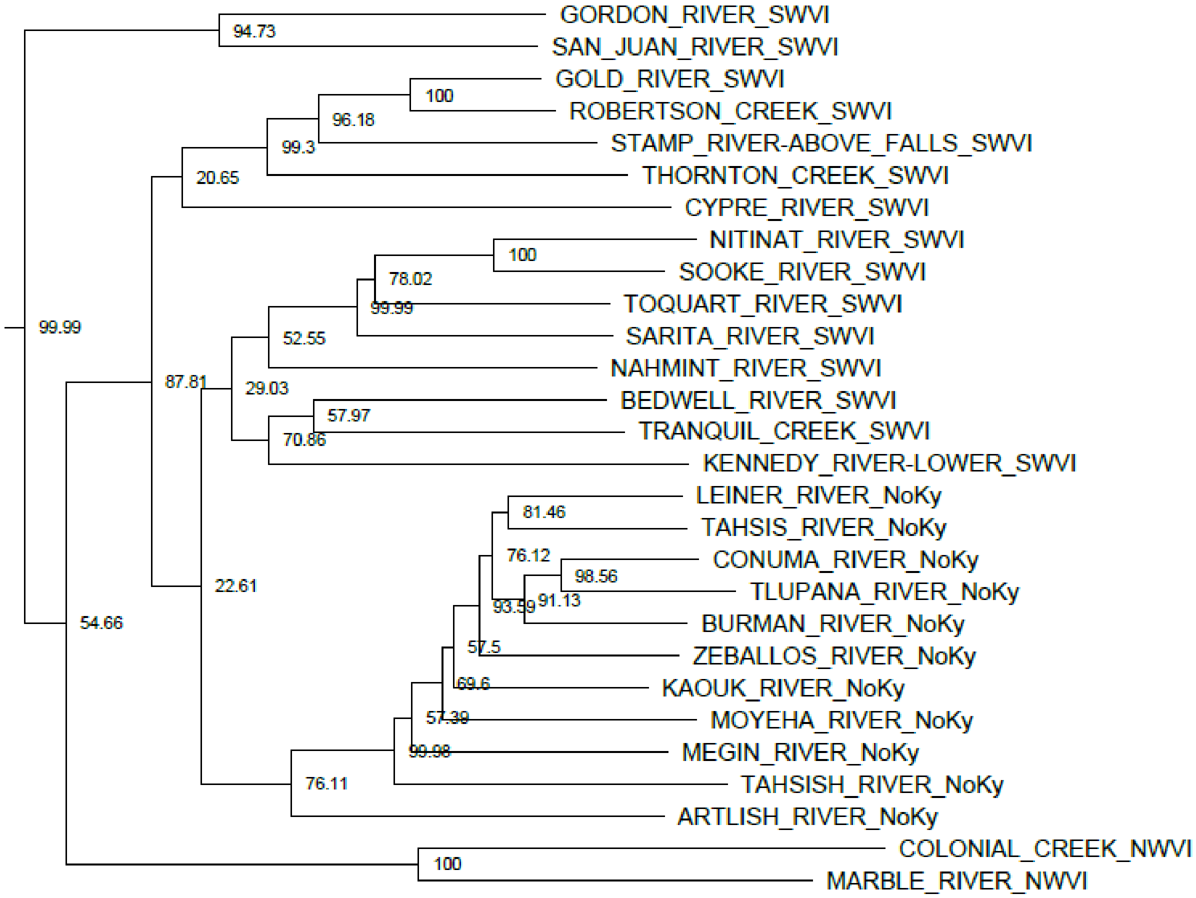

Figure 3.3. The dendrogram constructed based on data described in Beacham et al. (2021) describes genetic relatedness between 28 sampled Chinook populations along the WCVI. Note that the clustering of Gold, Megin, and Moyeha populations within non-natal Conservation Units (CUs) is a result of influence by hatchery strays; the genetic makeup of these populations more closely reflects hatchery populations from neighbouring CUs (Robertson in SWVI and Conuma in NoKy).

The regional genetic diversity across WCVI Chinook populations has declined since the introduction of hatchery enhancement in the 1970s and 1980s. Withler et al. (2017) used a STRUCTURE analysis to evaluate the level of native genetics in sampled Chinook populations, indicating some genetic homogenization of WCVI Chinook, with the 3 major hatcheries at Conuma, Robertson Creek, and Nitinat dominating influence in numerous other populations. Withler et al. (2017) also reported that genetic diversity of populations supported by these major facilities has mostly been maintained since inception. Weil et al. (2024) reviewed these results along with otolith-thermal-mark-based estimates of hatchery contribution to natural spawners and reported that the level of genetic change over time was influenced by the level of hatchery enhancement of the local population, the location relative to the sources of hatchery straying, and environmental factors affecting straying.

3.3. BIOLOGY AND LIFE CYCLE

In this section we review knowledge of key biological characteristics of WCVI Chinook in relation to available knowledge, relying on summaries of Chinook life histories by Healey (1991) and Riddell et al. (2018), studies in other areas of significance to WCVI Chinook, and knowledge gained from local monitoring and assessment. We follow the life cycle phases (Table 3.1), summarizing available knowledge and assumptions regarding mortality estimates at each stage. Then in section 3.4 we review parameterized life cycle tables for three illustrative WCVI Chinook populations spanning the WCVI, including:

1. The Sarita River, a mid-sized indicator river in Barkley Sound with hatchery enhancement and heavily degraded aquatic habitat. The Huu-ay-aht First Nation initiated significant monitoring and assessment and improved stock management on the Sarita, which has provided important insights that are likely applicable to many rivers along the WCVI.
2. The Moyeha River, a small river in Clayoquot Sound in a pristine and protected watershed in Strathcona Provincial Park, with no direct hatchery enhancement. This is a ‘wild’ indicator river monitored by the Ahousaht First Nation along with local stewardship partners.
3. The Kaouk River, a mid-sized river in Kyuquot Sound with no direct hatchery enhancement and degraded aquatic habitat. This is a ‘wild’ indicator river monitored in collaboration with the Ka:'yu:'k't'h'/Che:k'tles7et'h' First Nation.

Healey (1991) and Riddell et al. (2018) review the wide variety of life history strategies in Chinook salmon with different lineages characterized by geographic region, juvenile life history strategy, ocean migration and distribution, and adult return timing. WCVI Chinook are distinguishable from other Chinook populations on these bases:

- Geographic—populations arise from rivers draining into the West Coast of Vancouver Island;
- Juvenile life history—sub-yearling (or ocean-type) indicating limited duration of 0–5 months rearing in freshwater;
- Ocean distribution—during their oceanic life phases, WCVI Chinook are far-north migrating to the coastal waters of southern Alaska and the Aleutian Islands;
- Adult return timing—adult spawners returning to natal rivers during the mid-summer through fall months.

Additional factors in freshwater, estuarine, and nearshore marine ecosystems have resulted in adaptations in WCVI Chinook that make them genetically distinct from nearby SMUs (Moran et al. 2013).

The life cycle of a WCVI Chinook population is rendered in Figure 3.4, with specific stages listed in Table 3.1. Application of the life cycle table includes estimating abundance at each stage along with mortality rates between stages to create a deterministic representation of a specific population under average conditions across all ages of return. The main use of these life cycle tables has been to support workshop participants assessing biological impact (mortality impacts on the return to river) as part of an assessment of risk from potential factors limiting productive capacity (Irvine et al. 2024). The results of the freshwater and marine risk assessments are presented in section 6.

Parameterization of the life cycle model is based on literature (such as Healey 1991, Bradford 1995, Riddell et al. 2018), as well as local knowledge from a variety of projects past and present across the WCVI. Much of our understanding of ocean distribution and migration comes from CWT recoveries. Risk assessments resulted in increased emphasis on assessing productivity of natural spawners, including assessment of hatchery introgression into natural spawning, assessment of spawning success through assessments of juvenile abundance and growth in freshwater, as well as early marine distribution, growth, and migration behavior. Risk assessments identified potential early marine survival bottlenecks, resulting in development in 2022 of a suite of projects to quantify key ecosystem interactions and sources of mortality during the early marine period of WCVI Chinook.

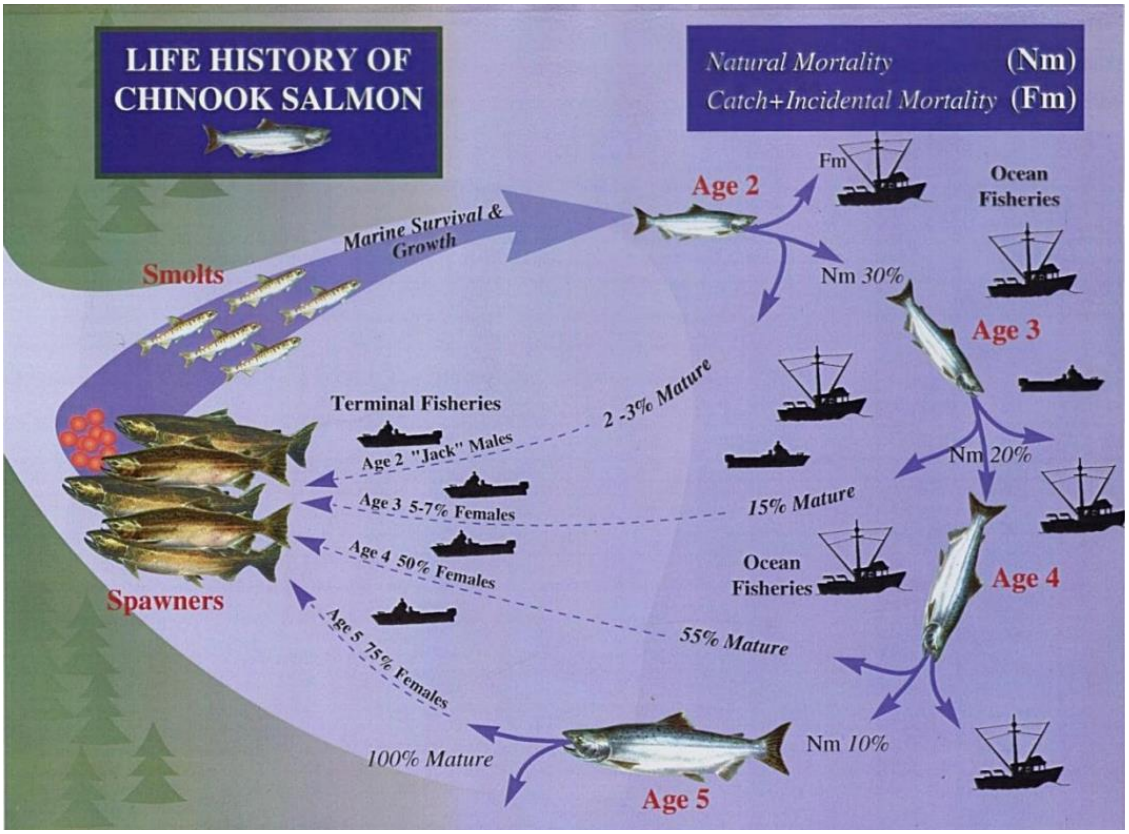

Figure 3.4. A rendering of the life cycle of WCVI Chinook salmon from spawning in WCVI rivers to rearing in the northern BC and southeast Alaskan ocean waters and returning mature adults back to the WCVI natal rivers. From Riddell et al. (2013).

Table 3.1. Description of WCVI Chinook life cycle stages by ecosystem unit.

Ecosystem Units	**Life Cyle Stage**
Estuary / River	1. Adult return to estuary - river mouth
River	2. Adult spawners (avg fecundity 3900, 40% female)
River	3. Eggs Incubating.
River	4. Inriver post-hatch fry, natural mortality.
River / Estuary	5. Fry/Smolts out.
WCVI marine	6. Juvenile first marine year natural mortality.

Ecosystem Units	**Life Cyle Stage**
CBC marine	7. Juvenile second marine year natural mortality.
NBC marine	8. Age 2 abundance.
North Pacific	9. Ages 3-6 rearing abundance after natural mortality.
Coastwide	10. Preterminal fisheries mortality.
WCVI marine	11. Return migration natural mortality along WCVI.
WCVI marine	12. Terminal marine fisheries mortality.
WCVI marine	13. Adult return.
Estuary and in-river	14. Add non-local strays
Estuary and in-river	15. Estuary / in-river fisheries mortality.
Estuary and in-river	1. Adult return to estuary - river mouth / pre-spawn

3.3.1. Adult return and upstream migration

We begin our overview of the WCVI Chinook life cycle phases with mature adults returning to their natal rivers to spawn. Timing of the peak (50% date) of arrival of mature Chinook to terminal areas of the WCVI is approximately 3-4 weeks earlier in northwest Vancouver Island (NWVI) compared to southwest Vancouver Island (SWVI) which includes the Clayoquot, Barkley, Nitinat, San Juan, and Sooke areas. We estimated the 50% date using pooled CWT recoveries in the area of the outer boundary of PFMA 25 (Esperanza Inlet and Nootka Sound). The 50% date for those Chinook returning to the NWVI was July 25 while the peak timing of Chinook returning to the SWVI was 3 weeks later on August 16. CWT data also indicate additional travel time to the heads of the natal inlets; the 50% date to Alberni Inlet is approximately August 28, or about 4 weeks difference in timing to the peak in Nootka Sound. These estimates of return timing are based on 23 years of CWT recoveries (Figure 3.5).

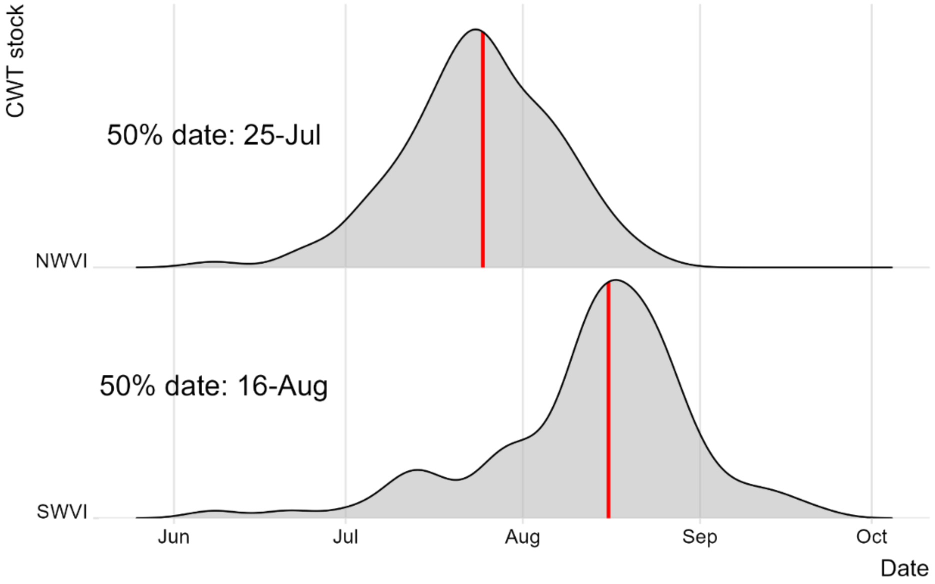

Figure 3.5. Distribution of WCVI Chinook CWT recoveries in outer Area 25 from 1991–2015. NWVI-origin Chinook is mostly Conuma River hatchery CWT, and SWVI Chinook is mostly Robertson Creek Hatchery CWT. Red vertical lines show the median date for each stock.

If environmental conditions are not conducive to passage into the river, WCVI Chinook delay their migration upriver and instead ‘pool’ in the sounds and inlets along the WCVI, often for extended periods. The duration, distribution, and behavior during this pooling period is driven by river conditions such as high water temperatures, low discharge, and freshet timing, as well as conditions in the inlets such as water temperature, dissolved oxygen levels, and algae blooms. Low river discharge is often be exacerbated by the large gravel aggradations that are common in the lower reaches of many rivers along the WCVI and act as natural barriers to Chinook passage. Under good conditions, peak upstream migration of WCVI Chinook typically occurs by mid-September in NWVI and early- to mid-October in SWVI. Median stream survey life (residence period) is approximately 20 days (McHugh and Dobson 2013, Dick 2020). Dunlop’s (2022) work with the Mowachaht/Muuchalaht First Nation in the Burman and Conuma rivers reported that river freshet timing was correlated to residence time (Figure 3.6).

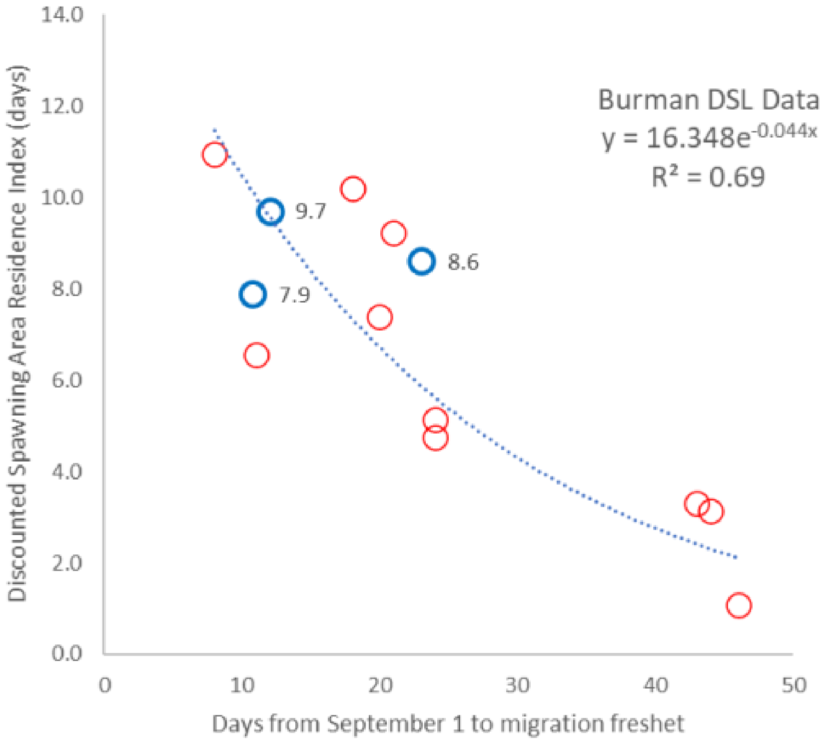

Figure 3.6. Relationship between Discounted Survey Life (DSL) in the spawning area and the length of the delay in migration from 1 September. Open red circles are 2009–2018 Burman River Chinook salmon DSL estimates. The Conuma River DSL estimates are blue open circles. From Dunlop (2022).

Spawning location within a river can significantly affect spawning success (e.g., Williamson et al. 2010 regarding Wenatchee River Chinook). Spawner distribution within the Sarita River appears to have a significant effect on spawning success, as measured by the number of fry produced (Figure 3.7). The ability for Chinook to migrate further upstream in the Sarita is significantly affected by discharge and timing of the fall freshet. In years when the freshet occurred late spawners did not migrate as far upstream, and so were distributed mostly into the lower reaches of the river where spawning habitat is less favourable, resulting in poor egg-to-fry survival. In contrast, years with earlier freshets allowed spawners to travel farther up the river, resulting in higher egg-to-fry survival (Figure 3.7). Potential causal mechanisms for poorer survival of eggs deposited in the lower river versus the upper river include higher flows and greater bed scour and sedimentation.

Pre-spawn mortality levels can be considerable under conditions of exceptional low or high flows and/or high water temperatures. Carcass sampling in the Stamp River since 2000 indicated an average of 10.5% pre-spawn mortality with a coefficient of variation of 62%, where pre-spawn mortality is based on female carcasses with >50% egg retention (DFO unpublished data, Jeff Till, Fisheries and Oceans Canada, Nanaimo, British Columbia, pers. comm.). During periods of high water temperatures and low flows, pre-spawn mortality rates can reach 40–50%, likely owing to heightened stress and disease. Local knowledge holders along the WCVI cite pinniped predation as a potentially important unquantified driver of mortality on returning adults (Sainsbury et al. 2024), especially when river conditions delay upstream migration or when high river water temperatures create physiological stress in migrating Chinook. Black bears and other terrestrial mammals are additional sources of predation.

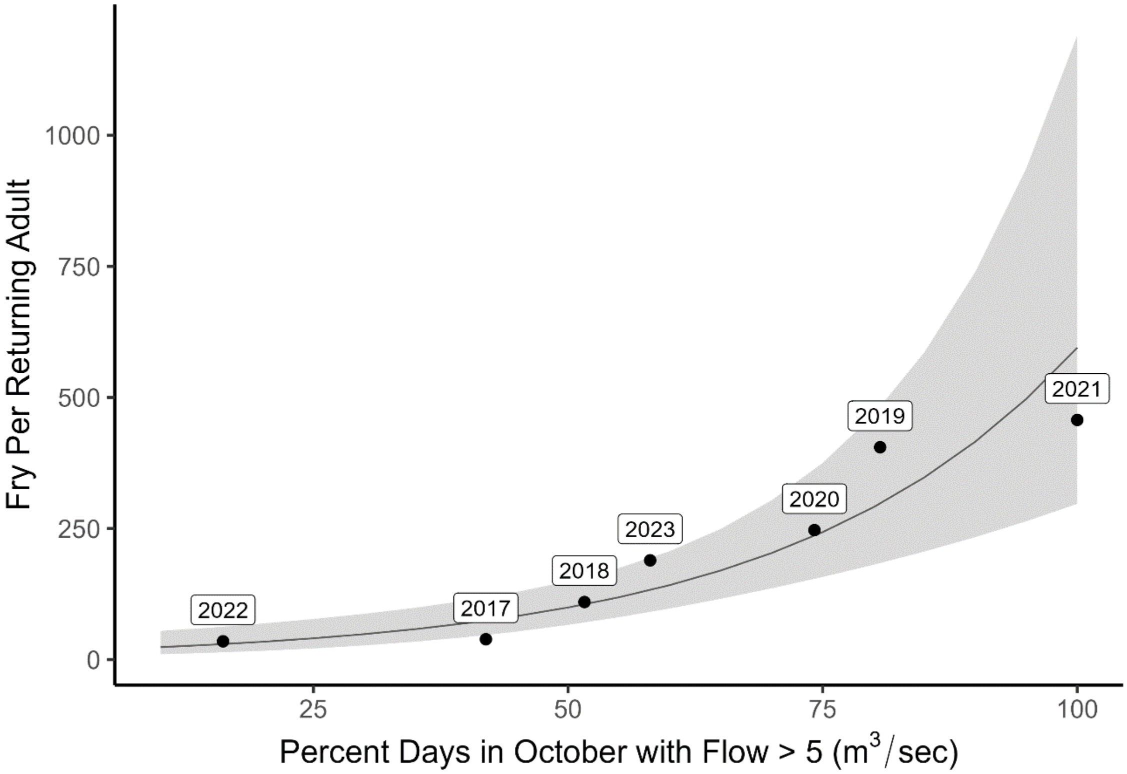

Figure 3.7. Predicted fry per returning adult (line) and 95% confidence interval (grey band) from a log-linear regression of percent of days in October with mean daily discharge on the Sarita River greater than 5 $m^3 \cdot s^{-1}$ and observed fry per returning adult. When flows in the Sarita exceed 5 $m^3 \cdot s^{-1}$, Chinook are able to surpass significant gravel bars in the lower river and access better spawning habitat further upstream. From Kaitlyn Manishin, LGL Limitedpers. comm.

We also note that not all WCVI Chinook return to their natal river; a small proportion stray to other rivers. Weil et al. (2024) assessed stray rates of Chinook from WCVI populations, reporting that stray rates increase when river or inlet conditions delay immigration into the rivers of origin. A key conclusion was that even low stray rates from large donor populations, such as large scale production hatcheries, have had significant influence on small recipient populations (see further discussion in sections 5.4 & 6.3).

3.3.2. Spawning

Peak spawn time for WCVI Chinook depends on environmental conditions but is generally about mid to late September in NWVI and in mid to late October in SWVI. WCVI Chinook are generally observed spawning in mainstems of rivers and larger tributaries with sufficient thalweg and sub-surface flow and depth. Generally, WCVI rivers are relatively short (between 2–97 km of mainstem accessible length), run through narrow, steep-sided valleys, and have significant areas of suitable gravel size and sub-gravel flows.

Healey (1991) reviewed studies on redd characteristics for ocean-type Chinook. He reported a mean redd area of 17–24 m^2 but also cited studies showing redd distribution being uniformly spaced as a result of spawning pairs defending an area four times larger than the redd itself. Healey (1991) also reported that most studies emphasized the importance of sub-gravel flow in the suitability of redd sites. The depth of egg deposition also varies according to spawner size (larger fish can dig deeper), water depth, and flow velocity.

The average percent of WCVI Chinook spawners that are female at each age is <1% at age two (called 'jills'—i.e., female jacks), 10% female at age 3, 55% female at age 4, and 80% female at ages 5–7. These averages are based mostly on Robertson Creek Hatchery broodstock and Stamp River deadpitch sampling, but appear to be indicative of most WCVI Chinook populations.

The number of female spawners in any one year depends on the initial age 2 cohort abundance, maturation rate, size/age-specific fishery exploitation, and size/age-specific natural mortality. Females mature later so have longer exposure to sources of mortality in the ocean life stages. The average proportion female in the Stamp River natural-origin return to river was 43% over the brood years 1998–2017, with a wide variation between 18% and 74% (Coefficient of Variation 35%; Fisheries and Oceans Canada, South Coast Area Stock Assessment, Nanaimo, BC, unpublished data). The deterministic life cycle tables presented in this report typically start with 40% female and an average age-at-return of 4 years.

3.3.3. Egg and alevin life stages

Fecundity is significantly correlated with fish size and therefore age (Healey 1991). Based on sampling at the Robertson Creek and Conuma hatcheries only, fecundity is an average of 3,000, 3,600, 4,600 for ages 3, 4, 5+ females, respectively (data available in Brown & Holt 2024). This level of fecundity would be at the lower end of the range reported by Healey (1991). Natural-origin Chinook have been observed to be an older average age at return, so an average 3,900 eggs per female is used as a starting point for life cycle tables. However, there is evidence from broodstock sampling for several WCVI populations that size-at-age and therefore fecundity is declining (see section 5.5).

Egg size is measured during spawning of hatchery broodstock, with reported egg weight as an average across all sizes and ages of females. Average egg weights from southwest Vancouver Island hatcheries ranged between 340 mg and 410 mg from 2021–2024. These weights are within the range reported in Beacham and Murray (1990). Further work is required to assess egg size-at-age and assess whether egg size is changing over time.

Female Chinook dig redds in suitable gravels in which they deposit their eggs, with larger females typically digging deeper redds, which provide incubating eggs better protection from mortality events resulting from bedload scour. Other prominent sources of mortality on incubating eggs include predation, sedimentation, high water temperatures, low dissolved oxygen levels, freezing, and dewatering. Healey (1991) reported that less than 30% survival of eggs is typical and that survival can be as low as 1%.

Significant work is underway in WCVI rivers to assess riverbed scour as a key cause of mortality. Recent work on the San Juan River indicated bed scour down to 30–50 cm depth during high winter flows (Kelsey Tikka, University of British Columbia, Vancouver, British Columbia, pers. comm.). Similar studies are underway in the Sarita and Tranquil rivers. This depth of riverbed scour combined with downstream sedimentation suggests there is potential for high egg mortality levels in WCVI watersheds with degraded hydrology. Effects of degradation are potentially greater in lower reaches compared to reaches farther up the river (see section 3.3.1 and Figure 3.7).

Hydrological droughts are also increasing in frequency under climate change, resulting in higher probability of dewatering eggs. Healey (1991) reported alevins were most sensitive to dewatering, surviving at less than 4% when subjected to short periods of emersion. Eggs were much less sensitive to dewatering as long as they remained damp.

Beacham and Murray (1990) reported benchmarks for water temperatures during incubation, including 3°C and 16°C for lower and upper benchmarks at which 50% mortality in Chinook eggs was observed. For alevins, the lower and upper benchmarks were 2°C and 14°C. While surface water temperatures along the WCVI reach near 0°C during the winter, sub-surface water temperatures experienced by eggs are influenced by warmer ground water. Sub-surface water temperatures are not routinely studied or measured in WCVI rivers. Ground water temperatures supplying WCVI hatcheries are about 8°C year-round (Lyndy Vroom, Fisheries and Oceans Canada, Operations Manager at Conuma Hatchery, pers. comm.).

Beacham and Murray (1990) reported that egg incubation time was related to both the temperature experienced during incubation and the size of eggs from which they originated. Alderdice and Velsen (1978) reported a time to 50% hatch ranging from 159 days at constant 3°C incubation temperature to 32 days at 16°C. Work by Geist et al. (2006) on Snake River (northwest USA) fall run Chinook showed temperature ranges in the river affecting the time from fertilization to hatch by up to 20 days, and from hatch to emergence as fry by up to 24 days.

On a river such as the Sarita River in SWVI, peak spawning (about mid-October) to peak fry emergence (about mid-March) is approximately 150 days. River temperatures can get down to near freezing but generally range between 3–7°C between November-February. Conuma and Nitinat hatcheries use mostly ground water at about 8°C during egg incubation and alevin stages, under which eggs hatch in about 65 days and alevin development to fry emergence also spans about 65 days, resulting in an approximately 130-day egg-to-fry development period (Lyndy Vroom and Caroline Cherry, Fisheries and Oceans Canada, respective Operations Managers at Conuma and Nitinat hatcheries, pers. comm.).

3.3.4. Freshwater rearing and emigration

Alevins emerge from the gravel as fry that must seek food externally. This process coincides with the complete resorption of the yolk sac and generally occurs at night to minimize predation (Healey 1991). Upon emergence, the fry swim to find suitable rearing habitat or are displaced downstream to lower river rearing or estuary habitat.

In this section we provide available information from WCVI Chinook to assess size and growth in freshwater as well as their subsequent “carry-over effects” on survival in early marine life. Ruggerone et al. (2009) analysis of Yukon River Chinook salmon scales showed that first marine year growth was positively correlated to growth in freshwater. Furthermore, they showed growth during subsequent years at sea was positively related to growth during the previous year.

Beacham and Murray (1990) report that the most important determinant of fry size (length and weight) is the size of eggs from which they originated. Environmental conditions, especially temperature and oxygen during the egg incubation and alevin stages also were related to fry size. These authors suggested that size of salmon alevins and fry may be important in determining subsequent growth and survival, and if there is a fry size at emergence for optimal survival, then the appropriate initial egg weight can be selected and water temperature possibly controlled during development to produce fry of the optimum size.

Size of eggs and newly emergent fry appear similar along the WCVI. We reviewed egg weights from hatchery broodstock collections and subsequent fry length and weight at ponding (prior to feeding). Figure 3.8 originates from Beacham and Murray (1990) on top of which we plotted egg and fry weights from available 2021–2024 data for Vancouver Island hatcheries (Salmonid Enhancement Program, Fisheries and Oceans Canada, unpublished data). Note that plotted values are averages across ages and years and therefore do not capture variation in annual age composition of spawners or environmental conditions affecting the growth of embryos. Eggs of Stamp River and Robertson Creek Hatchery origin Chinook are the largest. Nitinat River Hatchery origin Chinook eggs are the smallest. We assumed eggs taken in the broodstock collections also represent the size of eggs laid naturally in the river.

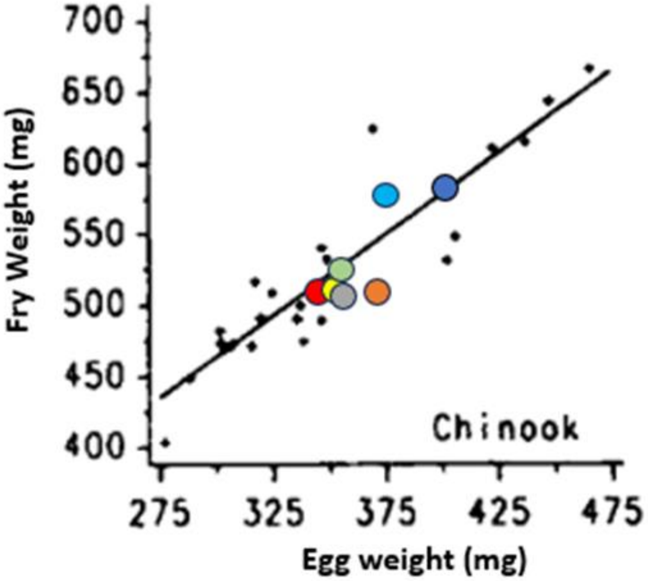

Figure 3.8. Coloured points show average egg weight (mg) and fry weight (mg) at ponding (prior to any feeding) from stocks taken into WCVI hatcheries from 2021–2024. Stocks include the Stamp (dark blue), Nitinat (red), Sarita (yellow), Nahmint (orange), Conuma (grey), Burman (green), and Gold (light blue) rivers. These data are plotted on top of Beacham and Murray's (1990) relationship (black dots and trendline) for various BC stocks, incubated at constant 8°C.

Size data for naturally produced fry from the Sarita River were provided by Huu-ay-aht First Nation supported by LGL Limited from collection of downstream migrants using a rotary screw trap in the lower reaches of the river (LGL 2025). Samples taken prior to 1 March were assumed to represent newly emerged fry. The average size of fry captured in February from 2019–2024 was 511 mg weight (range 450–590 mg) and 40mm fork length (range 37.7–42.5 mm). The average egg weight was 346 mg (range 343–357 mg). These data suggest Sarita River natural-origin fry are similar in size to several WCVI hatchery fry shown in Figure 3.8. The similarity in egg and fry size between sampled rivers suggests that environmental conditions after fry emergence are likely more important factors in determining cohort survival.

After emergence, sub-yearling fry move downstream through active migration and/or passive displacement. Healey (1991) summarized downstream fry and smolt migrations in East Coast of Vancouver Island rivers, including the Cowichan, Big Qualicum, and Nanaimo rivers. In each case, there was a bimodal distribution in downstream migration, with a first peak of fry migrants in early- to mid-April, then a decline to low levels, and a second mode of smolt migration peaking in late-May to early-June. The early fry migration generally comprised the majority of the total downstream migration. Healey (1991) therefore concluded that river discharge and intra- and inter-specific interactions likely play a role in stimulating the early downstream movement of Chinook fry. High flows would displace the smallest and least capable swimmers. Density dependent mechanisms were also important factors in downstream migration, such as limited rearing capacity and social interactions (dominance of largest emerging fry in setting up territories). The downstream movement was assumed to be a redistribution of fry to suitable rearing habitat in the lower river and estuary. Healey (1991) considered this evidence that the majority of the sub-yearling Chinook smolts were produced in estuaries, especially in the Nanaimo, which had the highest proportion of migrants out by the end of April. Healey also noted extreme variation in the size and timing of the peaks in the Big Qualicum River.

Juvenile migration in WCVI rivers seems to exhibit a bimodal pattern with a much greater portion migrating in the early period compared to the ECVI rivers in Healey (1991). Monitoring has been most intensive on the Sarita (LGL 2025, Figure 3.9) where migration extended from early February through June. Migration rates were highest in March and declined to very low levels by the end of April. Early migrants (February–April) represented about 95% of the total annual out-migration of juvenile Chinook. Generally, the size of these early natural-origin fry out-migrants was small at about 40 mm and 0.5 g, with very little variation from February through April (Figure 3.10). We refer to these fry migrants as “early/small”.

Less than 5% went out in May to early June with a peak near mid- to late-May (Figure 3.9). These May-June migrants showed significantly higher freshwater growth at 60–70 mm length and 3–5 g weight (Figure 3.10). We refer to these migrants as “late/large;” Healey (1991) called these “fingerlings.” He and many authors since (e.g., Willmes et al. 2024) describe plasticity in the timing and size of smolts in relation to river discharge, temperature, habitat and food availability and quality. Diversity in the timing and size of out-migrating Chinook smolts appears to be an important factor in the resilience to habitat degradation and effects of climate change, and ultimately survival to mature adult. Similar reports of two migration-timing and size classes of smolts stem from the Bedwell (Dick 2020) and San Juan rivers (Katie Davidson, Fisheries and Oceans Canada, Nanaimo, British Columbia, pers. comm.).

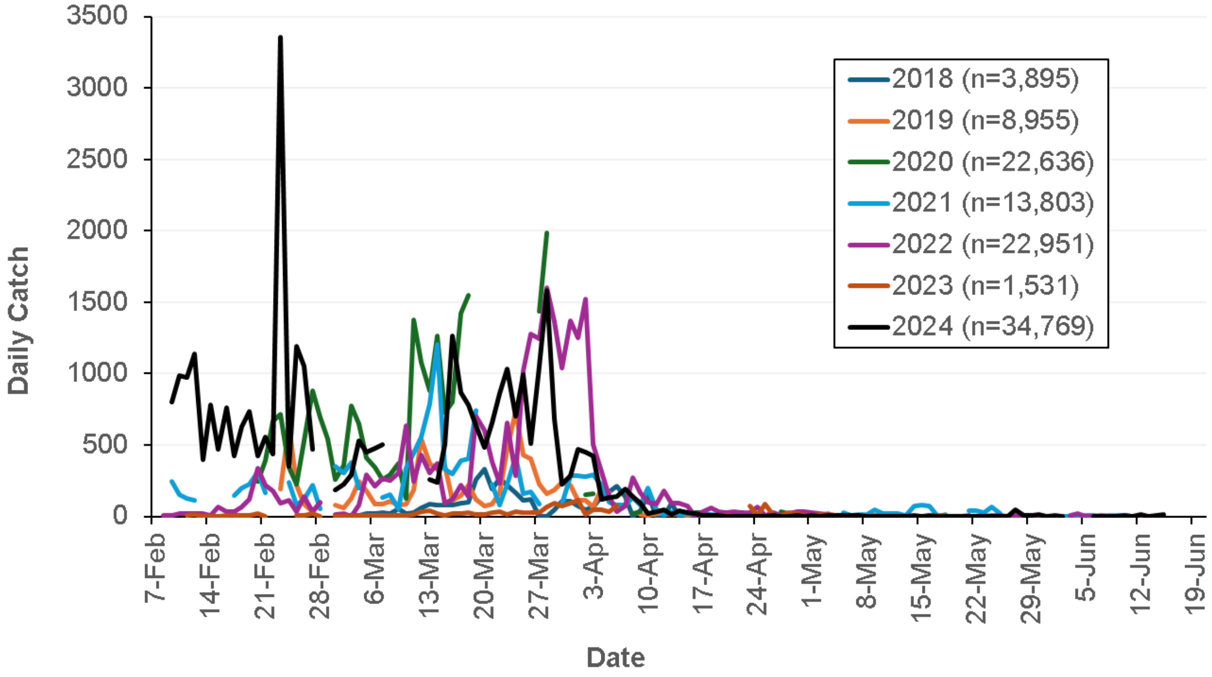

Figure 3.9. Daily catches of emigrating natural-origin Chinook fry and smolts in the Sarita River 2018–2024, assessed using a rotary screw trap in the lower river. The total annual catch 'n' is included in the legend parentheses. Note.—the maximum count of 3356 Chinook on 23 February 2024 was truncated to highlight the low number of migrants in May. Excerpted from LGL 2025.

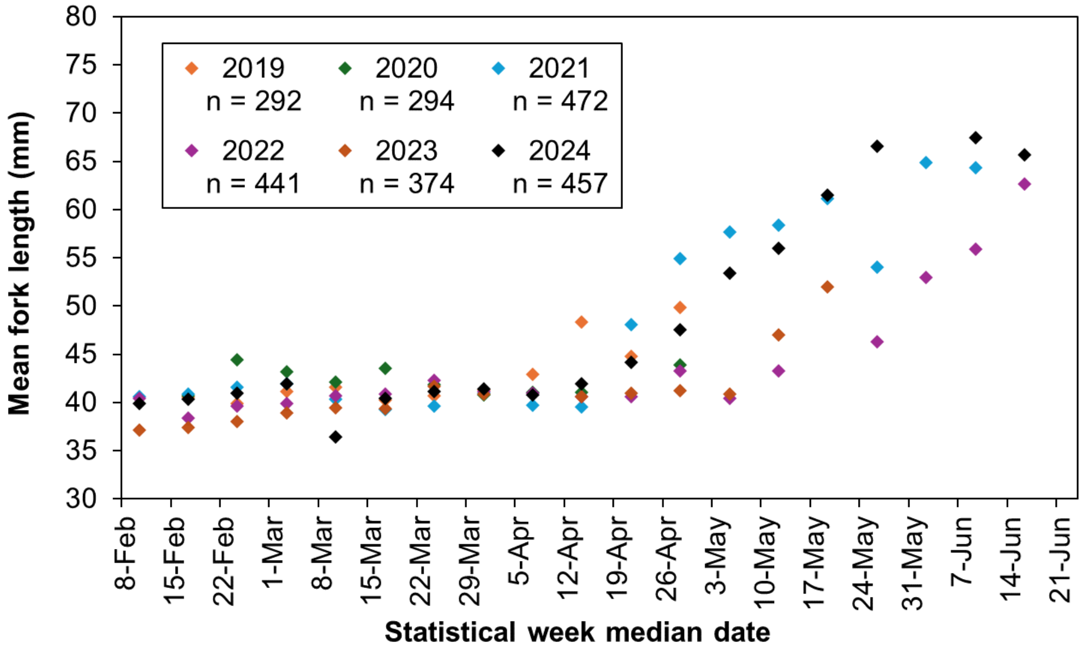

Figure 3.10. Weekly average fork lengths of emigrating natural-origin Chinook fry and smolts sampled in the Sarita River 2019–2024, assessed using a rotary screw trap in the lower river. Water temperatures in May 2022 (q.v. black points) were colder than in other years, potentially indicating delayed food availability and therefore delayed growth. Excerpted from LGL (2025).

Healey (1991) reported that there was little knowledge of the relative importance of factors influencing downstream movement and use of the river habitat for rearing. Potential factors include genetics, density dependence related to habitat quality and quantity, food availability and quality, and environmental conditions such as hydrological regime (discharge) and temperature. An example of well utilized rearing habitat is shown in Figure 3.11.

Figure 3.11. Highly utilized edge habitat of roots and overhanging Nootka Rose bush on the Cowichan River. Photo credit: James Craig.

Healey (1991) reported that 95% of Chinook fry diets in freshwater consist of aquatic and terrestrial invertebrates. The results of Huu-ay-aht First Nation (LGL 2025) sampling of stomachs of emigrating Chinook fry captured in the Sarita River is presented in Figure 3.12 for 2022, 2023, and 2024. Stomach fullness was reported by month. Generally, the proportion of fish with food in stomachs increased from March through June (note: not ready at this time is numbers of fish with food in stomachs, which would likely show a decline across months). Reasons for empty stomachs could include limited food availability, limited availability of suitable rearing habitat, environmental conditions such as flow velocity, or there could be an innate tendency for immediate downstream migration to the estuary. Healey (1991) described Nanaimo River Chinook as having a greater tendency or predisposition toward estuary rearing. A similar pattern appears to be present for Sarita Chinook. Stomach sampling in the Sarita estuary indicates that the majority of stomachs there were full or nearly full (Figure 3.13).

Dietary composition of sampled stomachs was diverse across seven orders of invertebrates, with the vast majority unknown insects and dipterans (e.g., crane fly). Amphipods, copepods, and arachnids were also important food (LGL 2025).

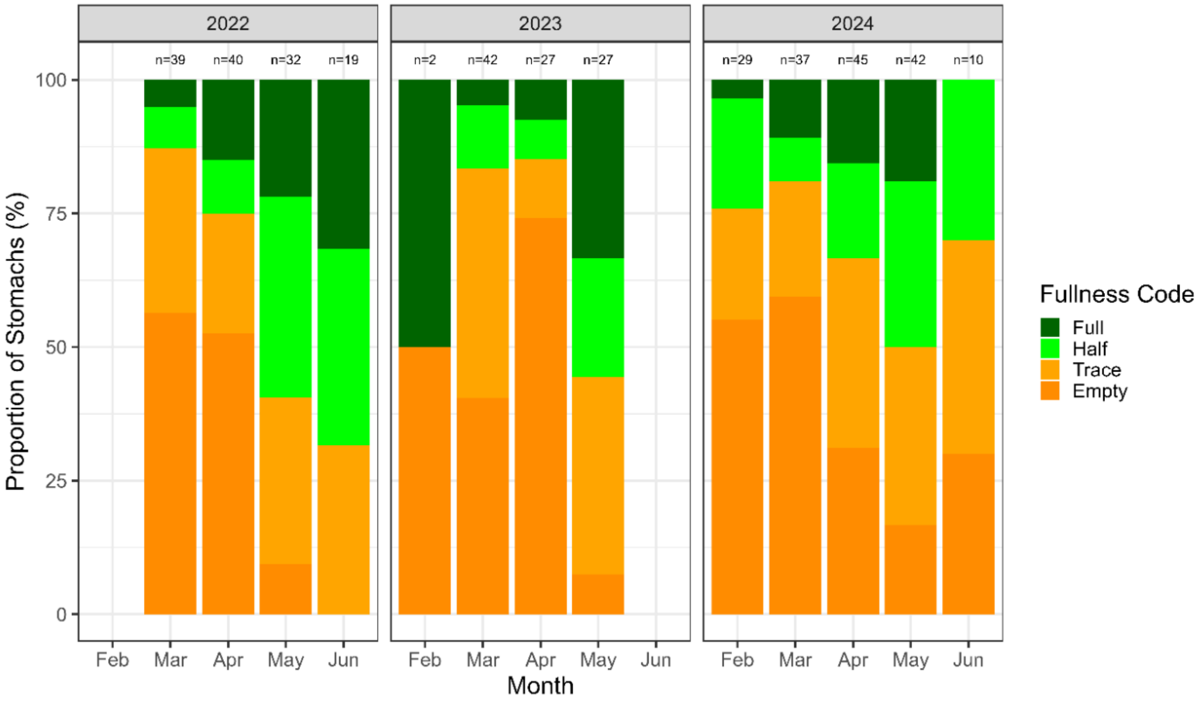

Figure 3.12. Proportional stomach fullness of emigrating natural-origin Chinook fry and smolts sampled in the Sarita River by year and month. Excerpted from LGL 2025.

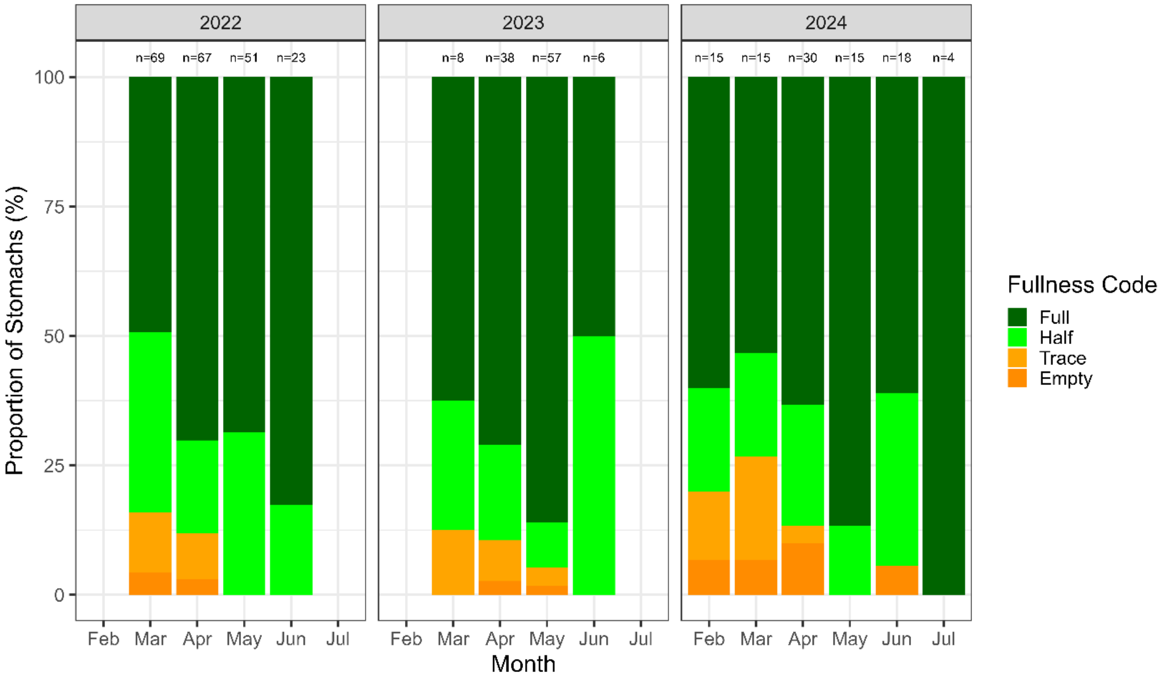

Figure 3.13. Proportional stomach fullness of natural-origin Chinook smolts sampled in the Sarita estuary by year and month. Excerpted from LGL 2025.

The observed behavior of fry in the Sarita River can lead to different conclusions. One is that these fry are predisposed or adapted to rearing in the estuary. Healey (1991) proposed that migration of Nanaimo River Chinook fry was not a consequence of limited rearing habitat in the river, since large numbers of fry consistently reared in the estuary regardless of fry abundance in the river. An alternative hypothesis is that the observed out-migration is a density dependent response to limited rearing habitat and food availability, related to the degraded nature of the Sarita watershed. Another alternative is density independent factors such as high flows forcing the fry into the estuary. Of course these are all likely related, for example, lack of suitable rearing habitat, coupled with small size of emergent fry, and high flows due to degraded watershed hydrology all contribute to the estuary as the primary rearing habitat for Sarita Chinook.

We assumed 30% as an average fry-to-smolt mortality based on the conclusions of Healey (1991). However, Healey (1991) did note that fry-to-smolt mortality rates during downstream migration could be much higher, citing assessments of estuary abundance in the Nitinat and Nanaimo estuaries that could only account for 30% of the estimated downstream migration. Potential sources of mortality could include predation by birds, fish, terrestrial mammals, and pinnipeds. Recent passive integrated transponder (PIT) tagging studies on the Cowichan River showed high predation related mortality rates when flows were low and low predation related mortality rates when flows were high (Kevin Pellett, Fisheries and Oceans Canada, Nanaimo, British Columbia, pers. comm.). That is to say, fish vulnerability to predation was directly related to river flows.

Given the uncertainty in mortality in freshwater life cycle stages, it seems prudent to combine freshwater mortalities into egg-to-smolt mortality for use in life cycle tables. Summary of data provided in Healey (1991) and Bradford (1995) reported an average 87.5% egg-to-smolt mortality rate (12.5% survival). Many of the watersheds in theses analyses were disturbed by human activity, typical of many WCVI rivers. One exception is the Moyeha River, which is wholly protected within Strathcona Provincial Park, so we assume an egg to smolt mortality rate at the low end of the reported range at 70%.

3.3.5. Carry-over effects from fry to subsequent life stages

Schindler et al. (2010) reported that understanding the impacts of different hydrological and temperature regimes on the success of freshwater life history strategies is key to understanding climate change impacts, especially in watersheds with decreasing annual snowpacks, increasing high flow events, and increasing droughts.

The vast majority of the early/small out-migrants would be considered fry; Clarke and Hirano (1995) report that ocean type Chinook salmon are not capable of entering full sea water immediately after absorption of the yolk sac, they develop full hypo-osmoregulatory capacity within two to three months post-emergence. Therefore the early/small out-migrants likely become smolts in the estuary. Those that rear in the river and migrate out after May 1 are considered true smolts.

One important aspect is the potential effect of timing and size (and resulting growth) of out-migrating smolts on subsequent life stages, from estuary rearing to returning adults, as documented by Ruggerone et al. (2009) for Yukon River Chinook. Larger smolts result in a younger age at maturity (Healey 1991, Scheuerell 2005). More specific to the WCVI, recent trials at Nitinat Hatchery showed that releasing hatchery smolts at smaller sizes resulted in older age-at-maturity compared to hatchery smolts at larger sizes (Doherty and Cox 2018).

Specific to the Sarita River Chinook, an analysis by LaForge et al. (in prep[1]) provided significant insight into the relationship between freshwater rearing and subsequent life history. They used otolith microchemistry to assess the survival of fry out-migrants to adult returns, building on work by Campbell et al. (2017). One result was that natural-origin juveniles out-migrating early and at small sizes returned at older ages compared to those emigrating later and at large size, corroborating observations on hatchery-origin Chinook at Nitinat Hatchery.

Laforge et al. (in prep[1]) also showed that survival rates were related to sizes of out-migrant fry and smolts. Since the brood year specific returns from the out-migration assessments are not yet available, they pooled available data across the period 2018–2023 to develop an average out-migration and average adult return. The resulting average survival of natural-origin fry/smolt out-migrants on the Sarita was significantly lower than that of hatchery-origin fish; which is typical of other WCVI river systems (Weil et al. 2025).

However, the preliminary results from otolith microchemistry analysis of natural-origin Chinook spawners by LaForge et al. (in prep[1]) indicated a positive relationship between timing and size of natural-origin fry/smolts and survival rate. The average survival from fry/smolt to terminal return for the 'late/large' group was about 10 times higher than for the 'early/small' group. Furthermore, the 'late/large' natural-origin group had a similar or better survival rate than the hatchery releases. This could suggest significant local adaptation pressures on natural-origin fry. Note that the natural origin adult spawners on the Sarita River were typically 80–90% in recent years (prior to significant mark selective fisheries in the Sarita River). This means natural-origin fry/smolts likely had one or both parents of hatchery origin.

The differential survival between the two timing/size groups of the out-migrating natural-origin juveniles resulted in a significant portion of the returning natural-origin adults coming from the late/large smolts (Figure 3.14). These results suggest that natural-origin fry from one or both hatchery parents spawning naturally in the river are subject to strong selection pressure within the river. Juveniles that can rear extended periods in the river and grow larger have a greater smolt-to-adult survival than those leaving early and small. The low abundance of this 'late/large' life history type likely depends on a combination of factors, including: predisposition to rear in the estuary as per Healey's (1991) view of Nanaimo River Chinook, size of emerging fry relative to river discharge as well as limited availability and quality of rearing habitat and food in the river.

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[1] LaForge, N.L., Quindazzi, M.J., Luedke, W., Vos, A. Liao, X., and Ross, A.R. In preparation. Marine Entry and Fork Length Relationships of WCVI Chinook for Sarita River based on Otolith Microchemistry. Can. Tech. Rep. Fish. Aquat. Sci.

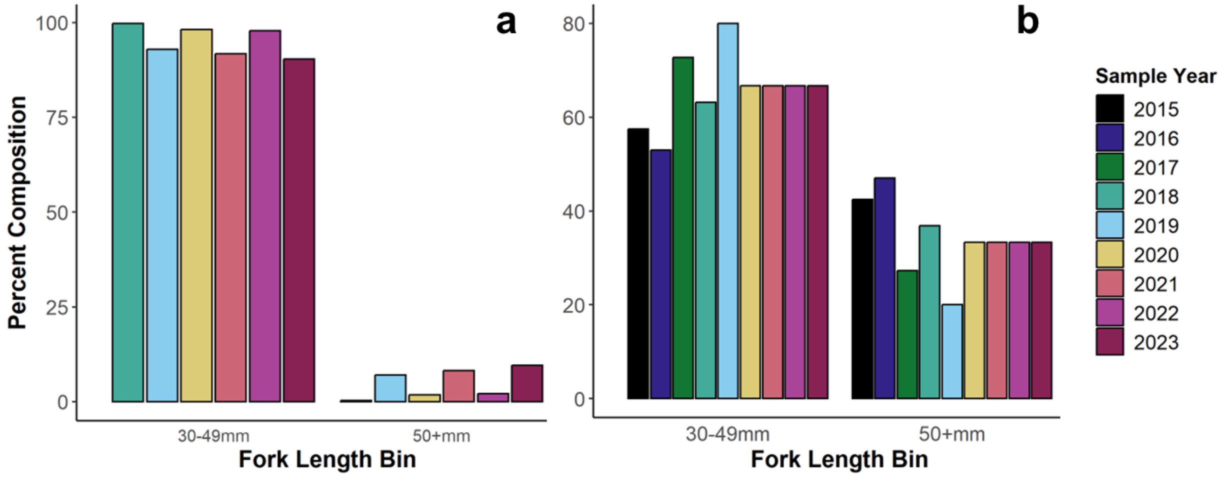


Figure 3.14. Smolt size composition (fork length at marine entry) of (a) Sarita Chinook natural-origin out-migrants and (b) natural-origin spawners, showing how the high survival rate of a small proportion of the 'late/large' smolts (50+ mm) results in a significant portion of the returning adults. Excerpted from LaForge et al. (in prep[1]).

3.3.6. Marine survival rates

Natural mortality occurs through the extent of the smolt (emigrating out of the river) to adult life phases of WCVI Chinook salmon. Since there is significant uncertainty in partitioning natural mortality among the marine life phases, we start by providing estimates of total smolt-to-adult survival rates.

Cohort analysis using Robertson Creek Hatchery Chinook estimated CWTs has been conducted annually (e.g. CTC 2023b) to estimate the survival rate of hatchery smolts to age-2 pre-fishery recruits (lower panel in Figure 3.15). The average survival rate from the beginning of the time series in 1973 to the 1990 ocean entry year was 7.3%. Between 1991–1999 there were two strong El Niño events, each affecting 3 consecutive brood years, which resulted in an average survival rate of 1.9% and extremely low spawner abundances across the WCVI. Since 2000, the average smolt to age-2 survival rate is estimated at approximately 3.6%.

The same cohort analysis is also used to estimate smolt to adult survival rate (upper panel Figure 3.15). Based on this analysis, the long-term average smolt to adult survival rate for RCH smolt releases is 1.7%.

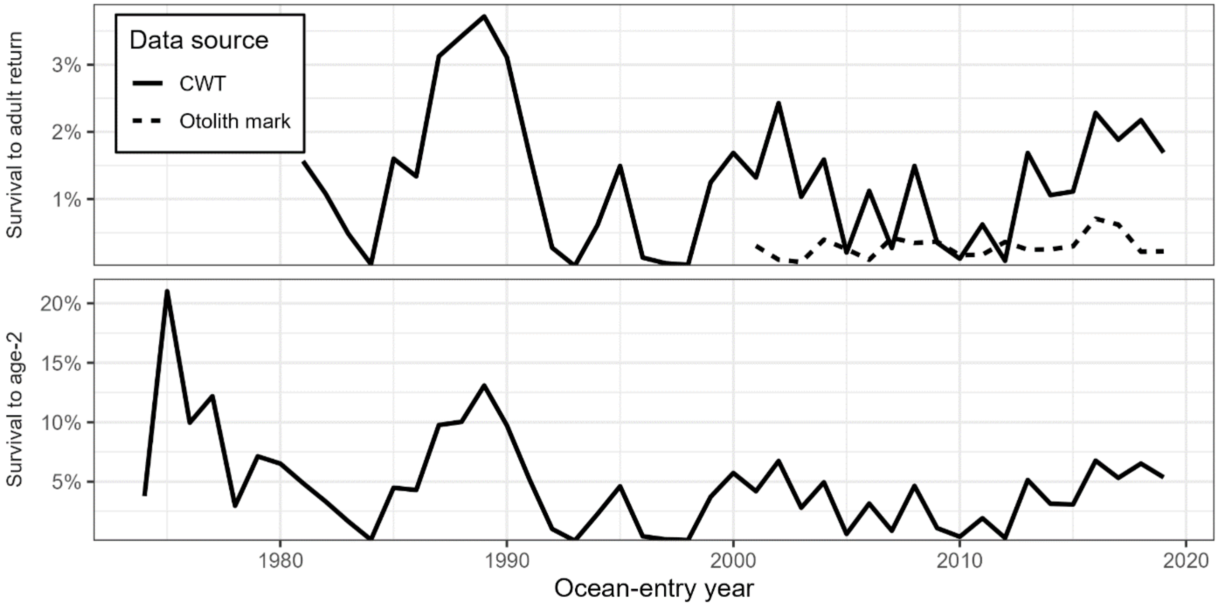


Figure 3.15. Estimates of Stamp River Chinook smolt survival across two time periods and using two methods. Survival to age-2 is estimated by cohort analysis of Robertson Creek Hatchery CWTs (CTC 2023). Survival to adult return is estimated by reconstructing the terminal return of Robertson Creek Hatchery CWTs, as well as by reconstructing natural spawner abundances from an extensive annual otolith thermal mark sampling program that is conducted in the system. The two lines in the top panel can therefore be considered as distinct survival estimates for hatchery- (solid line) and natural-origin (dashed line) Chinook.

It is likely that the survival rate of hatchery releases is not indicative of natural produced smolts along the WCVI (Figure 3.15). We review the data from the two key populations along the WCVI where data exist to derive smolt to adult survival rate estimates, the Stamp River and Sarita River.

3.3.6.1. Stamp River natural production

To estimate the smolt to adult survival from the natural (river) spawners on the Stamp, we derived natural smolts produced and natural recruits to the terminal area (PFMA 23) as described below. Section 2 includes a description of intensive enumeration and sampling of returns to the Stamp / RCH indicator population, with sampling for mark rate, CWT recovery, otoliths for thermal mark analysis, scales for age, length, sex, pre-spawn mortality / egg retention, etc. From these data, effective river spawners (Table C-5) were derived as estimated abundance by sex adjusted to account for estimated pre-spawn mortality. Egg deposition was derived as effective female spawners times average fecundity by age (age 5 = 4,600 eggs, age 4 = 3,600 eggs, age 3 = 3,000 eggs). Resulting smolt production was derived as eggs deposited times a constant egg-to-smolt survival rate of 12.5% based on the average of data summarized in Healey (1991) and Bradford (1995).

The natural-origin terminal area recruit abundance of Stamp/ RCH Chinook (‘TermRec’ in Table C-5) was determined using two methods. First we subtracted age-specific expanded CWT estimates of hatchery abundance from age-specific estimates of catch plus escapement of Stamp River Chinook returns to derive natural-origin terminal area recruits. Results were assigned to brood years. A second method estimated natural-origin terminal area recruits (‘TermRec’ in Table C-5) by age using otolith thermal mark proportions to estimate hatchery Chinook abundance by age, which we subtracted from age-specific estimates of catch plus escapement of Stamp River Chinook returns to derive natural-origin terminal area recruits. Results were assigned to brood years. Based on CWT, the natural origin smolt to terminal adult survival rate was 1.5% but only 0.3% based on otolith thermal marks (Table C-5).

These are maximum estimates of smolt-to-adult survival since pre-terminal fisheries (that is, fisheries outside of Barkley Sound and Alberni Inlet) were not included. This was due to inconsistent otolith sampling in pre-terminal fisheries, compared to consistent coastwide CWT sampling. Based on CWT sampling and the exploitation rate analysis conducted by the CTC (2023b), the pre-terminal fishery exploitation rate is an average of 33% across all ages over the period 2000–2022. We used this average exploitation rate to expand both CWT-based and otolith-based estimates of terminal area recruits, which resulted in smolt to adult survival rates of 2.2% using the CWT method and 0.4% using the otolith thermal mark method (Table C-5). Future work could apply annual age-specific exploitation rate to catch year terminal returns; however, the relatively consistent fisheries exploitation and the significantly increased uncertainty in age-specific exploitation rates suggests this might not make a significant difference in the results.

The natural-origin terminal area recruits presented in Table C-5 using the expanded CWT method are consistently greater than those estimated using thermal marks. This difference in estimates of natural-origin recruits perpetuated into very different estimates of survival rates for river produced smolts to adult recruits. The thermal mark estimate is assumed to more accurately reflect the poor survival of progeny from WCVI Chinook natural spawner populations.

Weil et al. (2024) reported that expanded CWT under-estimated hatchery contribution to the Stamp River / Robertson Creek Hatchery catch and escapement by 20–30%, assuming thermal marks provided the most accurate estimate. We recommend using only the otolith based assessment in the historic data. Future assessments may use other mass markings such as adipose fin clips or parentage based tags (PBT).

3.3.6.2. Sarita River

Weil et al. (2024) reported that proportion natural-origin spawners in the Sarita River averaged about 15%, which means that most natural-origin fry and smolts had likely one or both hatchery-origin parents. Note that there are efforts to improve the natural influence in the spawners. In more recent years, the Huu-ay-aht First Nation began selective removal of adipose clip (marked) adult Chinook, in effect managing hatchery spawner contributions to hatchery broodstock and river spawning.

In addition, the efforts by the Huu-ay-aht First Nation resulted in the Sarita River emerging as a key indicator of natural-origin juvenile Chinook production for the WCVI Chinook SMU. Since 2017, the Huu-ay-aht First Nation has been conducting full assessment of juvenile salmon out-migration from the Sarita River in Barkley Sound and return migration of mature Chinook into the river (LGL 2025). The assessments have been supported by 100% marking of hatchery-origin Chinook with adipose fin clip, thermal mark, and PBT, which is resulting in accurate identification of hatchery- and natural-origin juveniles and returning adults. Abundance of natural-origin juvenile out-migration is estimated for two groups: early/small fry out-migration before 1 May and late/large smolts out-migration after 1 May. Natural-origin adult abundance includes spawners, in-river catch, and catch in terminal fisheries along the WCVI. Otolith micro-chemistry is used to delineate the natural-origin adult return into the same two juvenile out-migration groups (see Laforge et al. in prep[1]).

At this time brood year specific survival rates can only be determined for the 2018 brood year. These preliminary results in Laforge et al. (in prep[1]) indicate a very low (<0.1%) survival rate for the natural-origin fry to terminal adult, and more than ten times higher survival rate for the natural-origin late/large smolts. These natural-origin late/large smolts also appeared to survive significantly better than hatchery origin fed fry and smolts released after 1 May and equal size or bigger than the natural-origin group.

The lack of information to complete survival rates for more brood years resulted in developing an ‘average’ for each group where all available data 2018–2023 was pooled in Laforge et al. (in prep[1]). The resulting survival rates show a similar pattern with natural-origin early/small fry having a very low survival rate to adult and the natural-origin late/large smolts survival higher than the hatchery releases.

3.3.6.3. Implications along the WCVI

The survival rates of natural-origin fry and smolts in the Sarita and Stamp are so low that they may not sustain a natural population (see section 3.4, below). It is unclear how indicative these results are of the other WCVI Chinook populations. Some populations, especially in Clayoquot Sound, have been stable at very low spawner levels for almost 3 decades. There is evidence in Weil et al. (2024) that this stability is in part due to strays; in two years of sampling (2015 and 2017), the Megin River had greater than 50% hatchery strays with total spawner abundance in the order of 50–60 Chinook. In the Moyeha River, one out of three years sampled had proportion hatchery strays greater than 50%. These are protected and relatively pristine watersheds, so likely have fewer sources of egg-to-smolt mortality compared to the Sarita River. Perhaps these rivers rely more on the late/large smolts which have higher survival. However, it is also likely that low smolt-to-adult survival in the early marine period is the key determinant of the low population size (Irvine et al. 2024). In contrast, in Kyuquot Sound the indicator populations of Tashish, Artlish, Kaouk appear stable at moderate abundance levels, which suggests higher survivals, whether freshwater and/or marine.

3.3.7. Nearshore rearing and first marine year

Healey (1991) described a bimodal pattern of out-migration in the Cowichan, Nanaimo, and Big Qualicum rivers, similar to that found in the Sarita River. Healey (1991) suggested that the early migrants rear and smolt in the estuary. Laforge et al. (in prep[1]) used otolith microchemistry to also determine estuary residence time. They found that the later/large out-migrants had a significantly longer estuary residence time than the early/small out-migrants. These results suggest that the Sarita estuary may be less suitable for rearing prior to May, perhaps indicating a mismatch in timing between estuary entry of the fish and zooplankton and insect food availability.

Ruggerone et al. (2009) showed that freshwater growth (and so size at out-migration) was positively correlated to subsequent growth in estuary and early marine habitats. Ruggerone and Volk (2004) reported that condition and timing of pre-smolts and smolts entering the estuary and marine environments was a key determinant of cohort survival. In Irvine et al. (2024) this relationship was called a ‘carry-over effect’ in assessing the potential sources of mortality or risk faced by juvenile Chinook during the early marine life phase. Irvine et al. (2024) also identified the first marine year as key in determining final adult cohort abundance.

Smolts entering the estuary and marine waters appear to rear in their local sound for much of the spring and summer period before moving northward along the WCVI (Tanasichuk et al., 2014; Jessy Bokvist, Fisheries and Oceans Canada, Nanaimo, BC, pers. comm.). Tucker et al. (2011, 2016) reported juvenile Chinook rearing in WCVI sounds through the winter months. This behaviour of extended rearing in local marine waters resulted in a high exposure ranking when risk to juvenile Chinook in the early marine life phase was assessed by Irvine et al. (2024). This risk assessment identified potential sources of mortality during this life phase and are summarized below in section 6 and Table 6.1.

3.3.8. Migration north and marine residence

Northward migration continues with juvenile Chinook leaving the WCVI area and moving along the BC central coast and on to northern BC and Alaskan waters. The migration appears to have a nearshore orientation which can be characterized as a density gradient from inshore out to several miles offshore, and appears to be a characteristic of WCVI Chinook throughout their life cycle. Evidence of the second year of migration comes from purse seine bycatch of small Chinook with CWTs in summer Sockeye fisheries in Rivers Inlet in the late 1970s and early 1980s revealed WCVI-origin Chinook were abundant at this time, requiring fishery management actions to minimize this mortality.

The nearshore orientation continues through this phase. WCVI CWT recoveries per unit within the southeast Alaskan archipelago were higher inshore relative to offshore. Genetic analyses of catch in recreational and commercial troll fisheries around Haida Gwaii indicated a density gradient of WCVI Chinook, highest within 1 nautical mile of shore (Winther and Beacham 2006). Nevertheless, there is some uncertainty in the nature of the density gradient from nearshore to offshore, given the recovery of WCVI CWTs in trawl fisheries in and around the Aleutian Archipelago (Figure 3.16) and a lack of research and fishery sampling offshore in the Gulf of Alaska.

Most WCVI Chinook spend several years in the Gulf of Alaska waters feeding and growing (Figure 3.16). Healey (1991) summarized feeding and growth of ocean type Chinook in the north Pacific; suggesting a seasonal pattern of growth, with rapid summer growth and slower winter growth. Growth rate was positively correlated with maturation rate. Healey also reported that feeding conditions during the last year at sea were most important in determining final adult size at each age class.

Healey (1991) also summarized diet studies (*circa* 1980–1983) of Chinook caught in northern BC and southeast Alaskan waters, with fish (especially herring, sandlance, and pilchards) being the primary food.

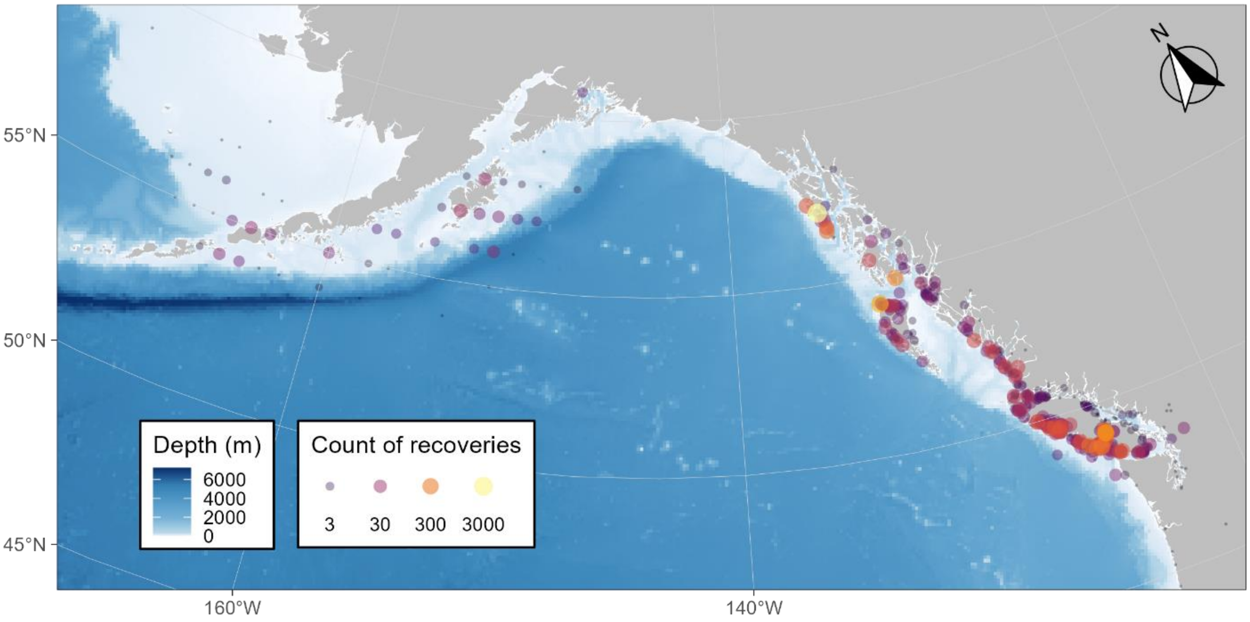


Figure 3.16. Recoveries of Chinook salmon CWTs released from WCVI hatcheries (primarily Robertson Creek) during 1975–2022. Recoveries plotted over land are from freshwater fisheries. Spatial resolution is low (1° of latitude/longitude) for fisheries in western Alaska (>140°W) compared to others in the data.

Natural mortality during the marine life phase results from predators such as salmon sharks (Seitz et al. 2019; Weitkamp and Garcia 2022), orcas (Ohlberger et al. 2019), and pinnipeds (Adams et al. 2016, Nelson et al. 2019) as well as interspecific competition for food in the north Pacific, which may result in slower growth and/or riskier foraging behaviour (Walters & Juanes 1993, Lewis et al. 2015, Ruggerone and Irvine 2018).

3.3.9. Return migration

3.3.9.1. Returns by age

Each year a portion of each WCVI Chinook cohort rearing in northern waters begin their migration back to the WCVI. The proportion of the remaining cohort abundance (after fisheries and younger fish have already returned) which mature and begin the return migration to the WCVI, is called the maturation rate. The CTC (2023b) report recent 12-year average age-specific maturation rates of Chinook returning to the SWVI CU, based on Robertson Creek Hatchery CWT recoveries as 2% at age-2, 26% at age-3, 79% at age-4, and 100% of age 5+ Chinook mature and begin their return migration. The average age-at-maturity is approximately 4 years and is the basis for the deterministic life cycle tables.

Another way of looking at maturation rate is the average proportion of the cohort returning to spawn at ages 2, 3, 4, or 5+. The abundance of WCVI Chinook spawners in any one year depends on the abundance of 3 main cohorts, including age 3 from the spawner brood 3 years ago (of which 10% are female), from the spawner brood 4 years ago (55% female), and from the spawner brood 5 years ago (80% female). Age 2 returns are virtually all males and so not included.

For Robertson Creek Hatchery releases for brood years 1998–2018 the average proportion of return at ages 3, 4, 5+ was estimated at 40%, 52%, and 8% respectively. The natural origin return at age from Stamp River spawners showed a greater proportion of older fish, with average proportion returning at ages 3, 4, or 5+ estimated at 28%, 56%, and 16% respectively (using Stamp River data from brood years 1998–2018). These results indicate that hatchery origin Chinook return at younger and so smaller size than natural origin Chinook from the WCVI.

Healey (1991) indicated that maturation rate was positively correlated with size of smolt. Similar results were observed on the WCVI; Doherty and Cox (2018) based on different size releases from Nitinat Hatchery and LaForge et al. (in prep[1]) based on natural origin return to the Sarita River. The latter used otolith microchemistry to estimate timing and size at out-migration for fish surviving to spawn in the Sarita River. These results showed later timing (late April through early June) and larger size out-migrants (> 50 mm and >2 g) returned at 40% age 3, 53% age 4, and 7% age 5; which was similar to the age at return for the hatchery releases. Hatcheries along the WCVI typically release smolts at 3–7 g in late April through early June. In contrast, the early (February to mid April) and small (<50 mm and <1 g) out-migrants from the Sarita River returned at 21% age 3, 49% age 4, and 29% age 5.

Stamp River spawner samples indicate a significant decline in average proportion of the hatchery origin cohort returning at age 5 and a lesser decline in the natural origin return.

Brown et al. (2019) showed declining age-at-maturity for Robertson Creek Hatchery origin Chinook. Hatchery brood stock sampling (Figure 5.7.) showed a declining size at age for hatchery origin Chinook along the WCVI.

3.3.9.2. Migration pattern

Migration timing from the northern waters likely begins in early June for NWVI Chinook and 3 weeks later for SWVI Chinook, based on difference in timing to the WCVI (see Figure 3.5). This is corroborated by analysis of 13 years (2003–2016) of DNA from Chinook catch in the northern BC commercial troll fishery. This analysis indicated declining WCVI abundance (i.e., WCVI Chinook catch per unit effort) through June, assumed to reflect emigration of maturing NWVI Chinook out of the area, then increasing abundance from early July through mid August, which is assumed to reflect SWVI Chinook passing through the area of the northern BC troll fishery from more northerly waters (Ivan Winther, Fisheries and Oceans Canada, pers. comm.).

3.4. PARAMETERIZED LIFE CYCLE TABLES

We apply available information to Chinook life cycle tables for 3 exemplary rivers along the WCVI: the Sarita River in Barkley Sound, the Moyeha River in Clayoquot Sound, and the Kaouk River in Kyuquot Sound. The biological benchmarks for these rivers are presented in Table 3.2.

Table 3.2. Biological benchmarks (S_{gen}, S_{MSY}, S_{REP}) for 3 levels of productivity for example Chinook populations.

Watershed	Accessible Watershed Area (km^2)	Basis: Life Cycle Model (Low productivity)			Basis: Run Reconstruction (Moderate productivity)			Basis: Parken Habitat Model (High productivity)		
		S_{gen}	S_{MSY}	S_{rep}	S_{gen}	S_{MSY}	S_{rep}	S_{gen}	S_{MSY}	S_{rep}
Sarita R	84 km^2	250	560	1,300	210	550	1,300	49	440	1,300
Moyeha R	116 km^2	350	780	1,800	290	760	1,800	68	620	1,800
Kaouk R	101 km^2	300	680	1600	150	610	1600	59	530	1600

3.4.1. Sarita River (Barkley Sound) Chinook

Here we parameterize the life cycle table for Chinook in the Sarita River, a moderate population (annual average of ≈2,500 spawners) that is data rich compared to similar populations. The Sarita River watershed has been heavily impacted by historic forestry (Barry 2010), which along with climate change related high flow events in the fall-winter has resulted in extreme discharge events (e.g., changing from ~1 cms to almost 700 cms within 24 hrs in October 2024), likely impacting spawning and incubation, and possibly further habitat degradation affecting subsequent rearing in the river. Climate change is resulting in prolonged summer droughts and extended periods of very low river flows in the Sarita that can exclude Chinook spawners from large portions of the watershed until later in the fall when they would normally spawn. The estimated spawner capacity of the system based on the Parken et al. (2006) habitat model is about 1,300 Chinook (Table 3.2).

DFO works with the local Huu-ay-hat First Nation to enhance Sarita River Chinook using Nitinat Hatchery as a satellite rearing facility. Broodstock and/or eggs from the Sarita are taken to Nitinat Hatchery and reared to the fed fry and smolt stage, then transported back and released into the Sarita River. Further, since about 2016 the Huu-ay-aht First Nation has conducted intensive assessment of spawners and juvenile outmigration, plus mass marking of hatchery releases and a terminal mark selective fishery on returning adults.

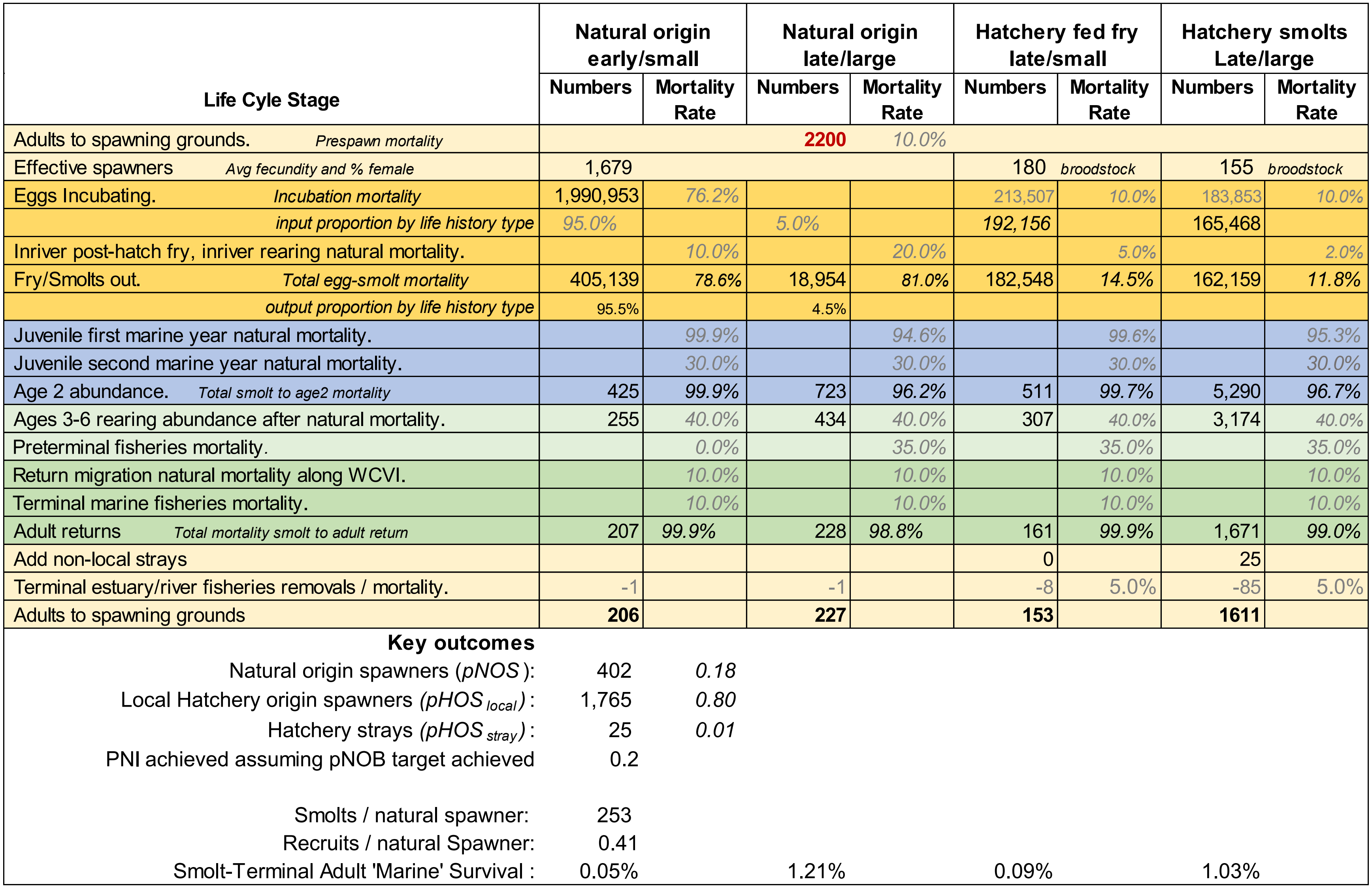
A life cycle assessment uses information to inform abundance at each life stage and likely mortality rates from one life stage to the next. This then becomes a tool to assess risk, identify specific causes of mortality, and assess benefit/cost of potential mitigative actions (e.g., lower incubation mortality by stabilizing hydrological processes to reduce winter freshets causing riverbed scour).

Figure 3.17 shows a typical life cycle for Sarita given local and other knowledge as described in previous sections of this report. For this simple deterministic model we use averages from available data for the 5 year period 2017–2021, including:

- Total estimated adults into the river after fisheries, subject to pre-spawn mortality. Typically 10–15% of the returning adults have been natural-origin; most are local hatchery-origin.
- Effective spawners with average age and sex composition and fecundity. After relatively low pre-spawn mortality estimate of 10% (based on sampling egg retention in carcasses and local knowledge about predation) and broodstock removals, leaving about 2,000 natural spawners with an average of about 40% female with an average fecundity of 3,900 eggs/female. We expect ≈2 million eggs are deposited in redds.
- Incubating eggs and mortality to fry stage and then smolt stage. Note that for the Sarita we delineate emergent fry into 2 groups—early/small fry migrants and late/large smolts—based on downstream trap information (see section 3.3.4). The Huu-ay-aht downstream trapping since 2017 resulted in an average of about 330,000 out-migrating fry/smolts (actual range 100,000–600,000; LGL 2025). This represents 90% egg-to-smolt mortality resulting in about 161 smolts/spawner. Habitat degradation along with high peak winter discharge causing bedload scour was identified as a very high risk in the Sarita River freshwater risk assessment. We expect is representative of other systems with degraded habitat along the WCVI. In comparison, we projected nearly 500 smolts/spawner for the Moyeha River, a pristine watershed in Clayoquot Sound (see section 3.4.2).
- As indicated in the general biology description, we have learned much from the otolith microchemistry work initiated in the Sarita (section 3.3.5). The natural-origin smolts have 2 distinct categories of small/early fry out-migrants and large/later smolt out-migrants with the latter being less than 5% of the total out-migration but having about 10-fold higher survival rate and contributing 30–40% to the total return (LaForge et al. in prep[1]).
- The next time we see these fish is as age 2 when they begin to recruit to fisheries and return to spawn as ‘jacks’. We divided mortalities into first and second year at sea, assuming most of the mortality happens in the first year. Fewer than 1% of the natural-origin smolts are thought to survive the first marine year (or greater than 99% mortality rate), compared to approximately 1.5% survival of hatchery smolts (or about 98.5% mortality rate; see section 3.3.6, above). After the first spring and summer in the local sound, these young-of-year Chinook migrate northward into Clayoquot Sound and then more northerly sounds of the WCVI. Improved understanding of the magnitude and mechanisms of mortality during the first year at sea is the goal of the ‘WCVI Follow the Fish’ research suite of projects.
- The next life cycle stage aggregates ages 3–6 natural ocean rearing mortality, preterminal fisheries mortality from southeast Alaska to include abundance but separates natural and fishery related mortality to the terminal area of WCVI, natural mortality during the return migration, terminal marine fisheries mortality, and finally in-river fisheries related mortality. Fisheries mortality rates are described in section 6.2. The Sarita River flows into Barkley Sound and the approach waters to the Somass River, where intense fishing pressure targets Robertson Creek Hatchery Chinook each August and September. This proximity to the terminal fishing area of Robertson Creek Chinook results in an approximately 40%

fishery exploitation rate on Sarita River Chinook (35% pre-terminal outside PFMA 23 plus 5% recreational fishery in Barkley Sound).

- We assume the ocean natural mortality rate is the same across all populations along the SWVI and is based on those used in the Pacific Salmon Commission Chinook Technical Committee cohort analysis for Robertson Hatchery Chinook (CTC 2023b).
- In more recent years the Huu-ay-aht First Nation began more intensive mark-selective fisheries in the river to actively manage Proportional Natural Influence (PNI; Anderson et al. 2020). This harvest was modest during the period represented in this life cycle table at about 20% but has increased recently along with increased terminal returns.



Life Cycle Stage	Natural origin early/small Numbers	Natural origin early/small Mortality Rate	Natural origin late/large Numbers	Natural origin late/large Mortality Rate	Hatchery fed fry late/small Numbers	Hatchery fed fry late/small Mortality Rate	Hatchery smolts Late/large Numbers	Hatchery smolts Late/large Mortality Rate
Adults to spawning grounds. *Prespawn mortality*			**2200**	*10.0%*				
Effective spawners *Avg fecundity and % female*	1,679				180	*broodstock*	155	*broodstock*
Eggs Incubating. *Incubation mortality*	1,990,953	*76.2%*			213,507	*10.0%*	183,853	*10.0%*
input proportion by life history type	*95.0%*		*5.0%*		*192,156*		165,468	
Inriver post-hatch fry, inriver rearing natural mortality.		*10.0%*		*20.0%*		*5.0%*		*2.0%*
Fry/Smolts out. *Total egg-smolt mortality*	405,139	*78.6%*	18,954	*81.0%*	182,548	*14.5%*	162,159	*11.8%*
output proportion by life history type	95.5%		4.5%					
Juvenile first marine year natural mortality.		*99.9%*		*94.6%*		*99.6%*		*95.3%*
Juvenile second marine year natural mortality.		*30.0%*		*30.0%*		*30.0%*		*30.0%*
Age 2 abundance. *Total smolt to age2 mortality*	425	*99.9%*	723	*96.2%*	511	*99.7%*	5,290	*96.7%*
Ages 3-6 rearing abundance after natural mortality.	255	*40.0%*	434	*40.0%*	307	*40.0%*	3,174	*40.0%*
Preterminal fisheries mortality.		*0.0%*		*35.0%*		*35.0%*		*35.0%*
Return migration natural mortality along WCVI.		*10.0%*		*10.0%*		*10.0%*		*10.0%*
Terminal marine fisheries mortality.		*10.0%*		*10.0%*		*10.0%*		*10.0%*
Adult returns *Total mortality smolt to adult return*	207	*99.9%*	228	*98.8%*	161	*99.9%*	1,671	*99.0%*
Add non-local strays					0		25	
Terminal estuary/river fisheries removals / mortality.	-1		-1		-8	5.0%	-85	5.0%
Adults to spawning grounds	**206**		**227**		**153**		**1611**	
Key outcomes								
Natural origin spawners (*pNOS*):	402	*0.18*						
Local Hatchery origin spawners *($pHOS_{local}$)* :	1,765	*0.80*						
Hatchery strays *($pHOS_{stray}$)* :	25	*0.01*						
PNI achieved assuming pNOB target achieved	0.2							
Smolts / natural spawner:	253							
Recruits / natural Spawner:	0.41							
Smolt-Terminal Adult 'Marine' Survival :	0.05%		1.21%		0.09%		1.03%	

Figure 3.17. Typical mortality and abundance of natural and hatchery-origin Chinook from the Sarita River, by life cycle phase. See also Table 3.1.

3.4.2. Moyeha River (Clayoquot Sound) Chinook

In this section, we provide a representation of an average life cycle for the Moyeha River Chinook, building on information provided in previous sections. The Moyeha River is one of the key ‘wild’ indicator populations for the WCVI Chinook SMU (see section 2.1, above) so has consistent observations during spawner migration and spawning, but little direct information from other life stages.

The Moyeha River flows into Clayoquot Sound and is protected against human development within Strathcona Provincial Park. Its protection from human disturbance makes the Moyeha one of the most intact watersheds and estuaries on the WCVI. Despite this nearly pristine watershed, the Moyeha River has a low spawner abundance (average of 93 spawners over the last 12 years). Our parameterized life cycle table for Moyeha Chinook starts with a 20-year average spawner abundance of 100 adults. The estimated Chinook abundance is based on visual swim counts by the same individual who has been enumerating returns to the Moyeha River since the beginning of the ‘indicator’ time series in 1993. Reliability of the spawner abundance is considered to be relatively high for most of the time series (note that some years were excluded from the average due to weather related poor survey coverage). Since the mid-1990s, the spawner abundance in the Moyeha has been consistently below the estimated S_{gen} biological benchmark (Table 3.2).

There is no direct hatchery enhancement of Chinook on the Moyeha River. However, past deadpitch sampling provided some evidence of hatchery strays from the Nootka-Kyuquot CU, with $pHOS_{stray}$ ranging between 0.18–0.54; Table C-4). Based on these few samples, we assumed 42 strays per year; indicating that strays may be important to sustaining Chinook in this population. This assumption may be low based on recent visual observations of adipose fin clipped Chinook in the Moyeha River (related to mass marking at Conuma Hatchery). As a result, the Moyeha population would be categorized as ‘Wild-Stray influenced’ by Withler et al. (2018; see section 5.4).

Discussions between technical, Indigenous, and other local knowledge holders during risk assessment workshops (Irvine et al. 2024) suggested predation and terminal area mortality was not a significant issue on the Moyeha, with agreement that a mortality rate of 10% was appropriate, leaving 90 effective spawners. Assuming 40% female and 3900 eggs per female, this Moyeha example projects approximately 140,000 eggs deposited (Figure 3.18).

In-river mortalities are applied for the incubation phase. Healey (1991) suggested a mean egg to fry survival of 30% (~70% mortality) in undisturbed habitats. Based on the pristine nature of the Moyeha watershed, and so reduced potential egg mortality from bedload scour and sedimentation, we applied 60% mortality rate between the egg and emergent fry stages.

Note that Healey (1991) also suggested that incubation mortality was lower than fry mortality along the WCVI; this is not consistent with the consensus at risk assessment workshops that egg losses were one of the greatest sources of natural mortality. Some limited sampling of smolts on the Moyeha indicated a similar range of body sizes and conditions to those in the nearby Bedwell River, where smolts are sampled regularly (Jared Dick, Uu-a-thluk and Candice Picco, Ha’oom Fisheries Society, Tofino, British Columbia, personal communications). The vast majority of smolts sampled from the Bedwell River, as well as from the Sarita River further south in Barkley Sound, are in the size range of 40mm and 0.5g (Figure 3.10; Figure 3.14).

We therefore assumed most Chinook fry in the Moyeha River rapidly migrate to the estuary, resulting in a relatively low in-river fry mortality of 20%; the same as the Sarita River. This results in a total egg-to-smolt mortality of 68% and 45,000 projected smolts or nearly 500 smolts per spawner (Figure 3.18). This is more than double the smolt per spawner output of the Sarita River.

Irvine et al. (2024) identified that the timing and size of smolts created a ‘carry-over effect’ that might increase the risk to these fish, specifically the need for suitable conditions for health and growth in the estuary and nearshore marine waters in Clayoquot Sound. Like the watershed, the estuary is relatively pristine, and so likely more conducive to growth.

Life Cyle Stage	**Number natural origin Chinook**	**Average Mortality**	**Hatchery Chinook abundance (marked)**	**Average mortality**
1. Adult return to estuary - river mouth	**100**	*10.0%*		
2. Adult spawners *(avg fecundity 3900, 40% female)*	90		-	*broodstock*
3. Eggs Incubating. *Incubation mortality*	140,400	*60.0%*	0	*0.0%*
4. Inriver post-hatch fry, natural mortality.		*20.0%*		*10.0%*
5. Fry/Smolts out. *Total egg-smolt mortality*	44,928	*68.0%*	0	-
6. Juvenile first marine year natural mortality.		*99.5%*		*96.9%*
7. Juvenile second marine year natural mortality.		*30.0%*		*30.0%*
8. Age 2 abundance. *Total smolt to age2 mortality*	170	*99.6%*	0	-
9. Ages 3-6 rearing abundance after natural mortality.	102	*40.0%*	0	*40.0%*
10. Preterminal fisheries mortality.		*35.0%*		*35.0%*
11. Return migration natural mortality along WCVI.		*10.0%*		*10.0%*
12. Terminal marine fisheries mortality.		*0.0%*		*0.0%*
13. Adult returns *Total mortality smolt to adult return*	60	*99.9%*	0	-
14. Add non-local hatchery strays			40	
15. Terminal estuary/river fisheries mortality.	0		0	0.0%
1. Adult return to estuary - river mouth / pre-spawn	**60**		**40**	

Key outcomes			
Natural origin spawners (*pNOS*):	60	*0.60*	
Local Hatchery origin spawners *($pHOS_{local}$)* :	-	*0.00*	
Hatchery strays *($pHOS_{stray}$)* :	40	*0.40*	
PNI achieved assuming pNOB target achieved	-		
Smolts / natural spawner:	499		
Recruits / natural Spawner:	1.13		
Smolt-Terminal Adult 'Marine' Survival :	0.13%		-

Figure 3.18. Presumed mortality and abundance of natural-origin Moyeha River Chinook by life cycle phase. See also Table 3.1.

The two components of risk are exposure and biological impact. These smolts likely reside in Clayoquot Sound for months resulting in a very high exposure score in the risk assessment (Irvine et al. 2024). As a result, our estimated mortality of these small smolts through the first marine year is high at 99.6% (Figure 3.18), which is similar to the mortality rate estimated for small/early emigrants from the Sarita River (see above, section 3.3.6.2). Understanding the size and timing of smolts as well as ecology of this pristine watershed could be the ‘control’ in assessing impacts of habitat degradation in other WCVI watersheds.

Tanasichuk et al. (2014) and Tucker et al. (2016) showed that local young-of-year Chinook reside in Barkley Sound through the spring and summer. Preliminary results from juvenile sampling in Clayoquot Sound suggest same is true of Moyeha River Chinook (Jessy Bokvist, Fisheries and Oceans Canada, Nanaimo, BC, personal communication), resulting in a high exposure to risks in the area. By the end of summer to early fall, young-of-year Chinook from Clayoquot Sound appear to migrate northward in the nearshore waters off WCVI. Overwinter mortalities are assumed to be in the order of 30%. As the migration northward continues and these Chinook rear in northern Pacific waters, additional natural mortality is assumed to be in the order of 20%. As they mature and migrate home to the Moyeha River we assume an additional 10% enroute natural mortality (Figure 3.18).

These Chinook are vulnerable to directed Chinook fisheries starting at age 3 with more minor impacts at age 2. Based on Robertson Creek Hatchery CWT coastwide recoveries (not including Alberni Inlet fisheries, non-salmon fishery bycatch, and salmon fisheries outside the PST control) over the past 20 years, the average Catch Year Fishery Total Mortality or Exploitation Rate (CYER) is about 35% (Figure 1.1.), which we assume to be the total fishing related mortality on Moyeha River Chinook.

After deducting all natural mortality and fishery mortality, an average of 75 Moyeha Chinook return to the river. Periodic sampling has indicated that the Moyeha River often receives stray Chinook originating from other watersheds along the WCVI (Weil et al. 2024). Based on limited samples, we estimated about 25 per year, resulting in 100 Chinook returning to this river.

This characterization of the life cycle of Moyeha River Chinook provides insight into the persistence of this population at very low levels. The freshwater environment is assumed to be favourable, such that a relatively high proportion of deposited eggs successfully hatch and develop into fry and then smolts that migrate to the estuary. However, mortalities during the first year rearing in the nearshore marine environment are inferred to be very high, which propagates through the life cycle phases to limit the numbers of returning adult spawners. Periodic influxes of spawners straying from other systems are assumed to be supplementing and partially sustaining the Moyeha River Chinook population abundance.

3.4.3. Kaouk River (Kyuquot Sound) Chinook

In contrast to indicator populations in the SWVI Conservation Unit, the spawner abundances in rivers in Kyuquot Sound within the Nootka-Kyuquot Conservation Unit have been increasing (see Appendix D, Figure D-4).

The Kaouk is an escapement indicator, so has consistent surveys during spawner migration and spawning, and reliable spawner abundance information. Most other knowledge of the life cycle of Chinook in rivers in Kyuquot Sound is adapted from research conducted in the SWVI along with local knowledge. However, new work is underway beginning in 2024 to assess smolt survival in the Kaouk River. Researchers are operating an RST and conducting mark-recapture efforts on smolts (R. Bocking, LGL Ltd., Victoria, BC, pers. comm.). Results are expected to be available starting in 2026.

The Kaouk River, like many watersheds in Kyuquot Sound and similar to the Sarita watershed, has had significant logging resulting in degraded hydrological processes. As a result of this similarity and of the current absence of smolt data specific to the Kaouk, we applied in-river mortality rates from the Sarita River to the Kaouk River. The result was 400 average spawners producing about 67,000 smolts (Figure 3.19), with a similar smolt per spawner output as the Sarita River (

Figure 3.17).

To balance the life cycle table at 400 adult returns, and assuming natural mortality in the north Pacific is relatively similar between WCVI Chinook populations, the first year marine mortality had to be significantly lower for Kaouk Chinook (97.9% mortality rate) compared to 99.5% for Moyeha Chinook. This suggests that Chinook residing in Kyuquot Sound during the early marine period have approximately 4 times higher survival compared to those in Clayoquot Sound.

Fishery related mortality for the Kaouk River Chinook was estimated at 30% (compared to 35% for Moyeha Chinook). This was deduced from Robertson Creek Hatchery CWT based estimates of exploitation rate by excluding CWT recoveries south of PFMA 26/126. Kyuquot Sound is closed to Chinook retention in fisheries so we assumed no terminal fishery mortality.

Life Cyle Stage	**Number natural origin Chinook**	**Average Mortality**	**Hatchery Chinook abundance unmarked**	**Average mortality**	**Hatchery Chinook abundance marked**
1. Adult return to estuary - river mouth	**400**	*10.0%*			
2. Adult spawners *(avg fecundity 3900, 40% female)*	360		-	*broodstock*	-
3. Eggs Incubating. *Incubation mortality*	561,600	*85.0%*	0	*0.0%*	0
4. Inriver post-hatch fry, natural mortality.		*20.0%*		*10.0%*	
5. Fry/Smolts out. *Total egg-smolt mortality*	67,392	*88.0%*	0	-	0
6. Juvenile first marine year natural mortality.		*98.0%*		*96.9%*	
7. Juvenile second marine year natural mortality.		*30.0%*		*30.0%*	
8. Age 2 abundance. *Total smolt to age2 mortality*	952	*98.6%*	0	-	0
9. Ages 3-6 rearing abundance after natural mortality.	571	*40.0%*	0	*40.0%*	0
10. Preterminal fisheries mortality.		*30.0%*		*35.0%*	
11. Return migration natural mortality along WCVI.		*10.0%*		*10.0%*	
12. Terminal marine fisheries mortality.		*0.0%*		*10.0%*	
13. Adult returns *Total mortality smolt to adult return*	360	*99.5%*	0	-	0
14. Add non-local hatchery strays			0		40
15. Terminal estuary/river fisheries mortality.	0		0		0
1. Adult return to estuary - river mouth / pre-spawn	**360**		**0**		**40**

Key outcomes

Total spawning stock after inriver fishery (1):	400	*includes brood stock*	
Total spawning stock after broodstock removal:	400		
Terminal harvest (marked hatchery origin):	-		
Incidental mortality of unmarked natural origin Chinook:	-		
Natural origin in brood stock (*pNOB*):	-	-	
Did broodstock exceed SEP 30% guideline:	no		
Natural origin spawners (*pNOS*):	360	*0.90*	
Local Hatchery origin spawners *(pHOS $_{local}$)* :	-	*0.00*	
Hatchery strays *(pHOS $_{stray}$)* :	40	*0.10*	
PNI achieved assuming pNOB target achieved	-		
Natural Prod Rate of change = Risk Impact score:	0.00		
Smolts / natural spawner:	187		
Recruits / natural Spawner:	1.59		
Smolt-Terminal Adult 'Marine' Survival :	0.53%	-	-

Figure 3.19. Presumed mortality and abundance of natural-origin Kaouk River Chinook by life cycle phase. See also Table 3.1.

3.5. BIOLOGY SUMMARY

- There is a general understanding of WCVI Chinook biology and population dynamics. Much of this knowledge stems from hatchery populations and CWT recoveries for marine distribution, survival rates of hatchery releases, and fishery exploitation. Monitoring and research at various life cycle phases in systems such as the Sarita River in outer Barkley Sound and the Bedwell River in Clayoquot Sound is improving our understanding but there are still significant knowledge gaps, such as the ranges in productivity among populations, and the factors affecting mortality, growth, and inter-dependence with the ecosystem they inhabit through their life cycle.

- Figure 3.17, Figure 3.18, and Figure 3.19 attempt to characterize the life cycle of populations in three different WCVI Sounds, in order to support risk assessments and determination of conservation, restoration, and enhancement activities. These simple life cycle models integrate our collective knowledge from a variety of populations across the WCVI and elsewhere and apply relevant knowledge and assumptions to reflect the dynamics of each example Chinook population. We start with specific knowledge such as numbers of spawners, pHOS in the spawners, average fecundity and age composition, ocean exploitation rates, etc. to develop a model we think reflects the average dynamics. These models create common understanding of specific factors or risks limiting population-specific productivity. We also use the life cycle models to prioritize and direct monitoring and research to address knowledge gaps at various life stages.
- These examples indicate that the freshwater environments of the Sarita River in Barkley Sound and the Kaouk River in Kyuquot Sound produce fewer smolts per spawner compared to the Moyeha River in Clayoquot Sound. This may be due to the histories of extensive forestry activity in the Sarita and Kaouk compared to the pristine, protected watershed of the Moyeha. However, the very low level of Chinook abundance in the Moyeha River suggests that early marine mortality in Clayoquot Sound is much greater than in Kyuquot Sound.
- Recent studies to assess productivity and sources of mortality in freshwater as well as the early marine rearing period are providing significant insights. For example, timing and size of smolts out-migrating to the estuarine and marine waters is correlated with survival; later migrating and larger natural-origin smolts have a higher survival rate. The examples identified differences in early marine mortality between Sounds, prompting research into this question that should inform future assessments. Another example is research on the effect of high river discharge events on spawning, freshwater egg incubation mortality, and smolt production.
- Key conclusions from these example life cycle models include:
  - that spawner abundance in some systems has been ‘propped up’ or stabilized at low levels by non-local hatchery strays;
  - that significant numbers of pre-smolts and smolts are reaching the estuary, however, significantly less in systems with degraded hydrological process such as the Sarita;
  - that there are different size and timing of out-migrating natural origin smolts, and that these differences in timing and size are correlated to early marine survival, which is a key driver of cohort abundance;
  - that early marine mortality is likely significantly higher in Clayoquot Sound compared to Kyuquot Sound; although little is understood about sources and mechanisms of marine mortality.

- Additional information on assigned risk from potential causal factors of mortality rates used in the models is presented in section 6.
- The simple and deterministic model used to describe example populations has been parameterized with the limited data related to mortality between life stages. There is also no density dependence, which limits the model to describing populations that are assumed to be in an equilibrium state. This simple model is an initial step in understanding population dynamics of WCVI Chinook. The knowledge and insights gained are often the basis for time varying life-history models such as employed by Holt et al. (2023b). Most of these use stock-recruit type models to simulate change through time, resulting in limited ability to assess risk of specific causes of mortality or directly assess benefits of change in each causal factor. Life cycle assessments are increasingly important in determining risk factors and mitigation strategies, as outlined in Knudsen and Michael (2009) and Bull and Luedke (2024).

4. STOCK REFERENCE POINTS

The Fish Stocks provisions recommend four reference points: Limit Reference Point (LRP), Upper Stock Reference (USR), Target Reference Point (TRP), and Removal Reference (RR), where candidate reference points should be relevant to the assessment and management framework of the SMU (i.e., are consistent with the scale and type of information that is collected and how the assessment is used to support decision making; DFO 2009). Here we provide biological benchmarks at the scale of rivers (or populations), inlets, and CUs, and follow previously used methods (e.g., Holt et al. 2023a) to inform the development of the listed reference points at the SMU scale. Following Holt and Irvine (2013), we define biological benchmarks as levels of abundance or distribution that "demarcate zones of population status based on conservation and production considerations. These scientifically derived benchmarks contrast with management reference points that generally require additional shorter-term socioeconomic information best obtained through public consultations." However, under the Fish Stocks provisions, the LRP is determined solely by DFO Science based on biological considerations, whereas the USR, TRP, and RR are science-informed but can include other management and socioeconomic considerations (DFO 2009). Importantly, biological benchmarks defined under Canada's Wild Salmon Policy (WSP) are identified at the scale of CUs, whereas reference points can be identified at aggregate spatial scales.

4.1. METHODS FOR DERIVING BENCHMARKS

Biological benchmarks define boundaries of Green, Amber, and Red status zones for CUs under the WSP. These zones represent increasingly depleted populations requiring increasing management intervention. The lower biological benchmark between the Red and Amber zones is identified as a level "high enough to ensure there is a substantial buffer between it and any level of abundance that would lead a CU as being at risk of extinction by COSEWIC [Committee on the Status of Endangered Wildlife in Canada]" (DFO 2005). In practice, the lower benchmark is commonly set at S_{gen} (spawner abundances that will result in recovery to S_{MSY} in the absence of fishing under equilibrium conditions) for assessments under the Wild Salmon Policy.

The lower benchmark, S_{gen}, was previously evaluated via simulation and was identified among candidates (such as 40% of S_{MSY} and various proportions of spawners at maximum or *MSY* recruitment) as being relatively precautionary in the face of variability in productivity (Holt 2009). These benchmarks assume an underlying relationship between spawner abundances and adult recruitment, which is common practice for deriving benchmarks and reference points for salmon even though variability in spawner recruitment relationships is typically large and model fits are often poor (Adkison 2021). Where spawner-recruitment time series are poor quality or not available, additional or alternative methods for determining benchmarks have been developed that employ habitat characteristics (Parken et al. 2006, Shortreed et al. 2000) or use spawner abundances alone (Holt et al. 2018).

The upper benchmark between the Amber and Green zones is identified as "the level expected to provide, on an average annual basis, the maximum annual catch for a CU" (DFO 2005), and in practice is set at 80% or 85%[2] of S_{MSY} for assessments under the WSP (Holt et al. 2009, Grant et al. 2013). Biomass at MSY (B_{MSY}) is often used as a limit to define overfished populations in other jurisdictions (Marentette and Krondlund, 2020), and alternative higher thresholds have been suggested to align with ecosystem-based approaches and Indigenous Knowledge systems (Frid et al. 2023).

For the CUs and inlets within this SMU, we consider three sources of data to derive benchmarks and abundance-based reference points for WCVI Chinook salmon: coarse spawner-recruitment time series at the CU level, habitat-based information, and a life-history model based on expert opinion (*q.v.* section 3.3). First, we considered the spawner-recruitment time series. For WCVI Chinook, robust CU-specific time-series of exploitation or catches are not currently available to inform recruitment time series, limiting our ability to derive plausible spawner-recruitment based benchmarks. Recruitment times series have previously been estimated by assuming a common exploitation time series among CUs based on a single hatchery population in the WCVI-South CU (Robertson Creek in the Somass River system; D. Dobson, pers. comm.; available from Brown & Holt 2024). However, exploitation rates are likely variable among CUs and between hatchery and natural-origin populations. We recommend further work identifying CU-specific recruitment estimates for natural-origin populations and ages at maturity, and did not further consider benchmarks derived solely from spawner-recruitment relationships here. However, for benchmarks based on alternative methods that required estimates of population productivity, in sensitivity analyses we considered productivity estimates derived in spawner-recruitment modelling using the assumption of a common exploitation rate among CUs, which should be considered cautiously acknowledging the shortcomings of the derived recruitment time-series.

To generate estimates of population productivity at the CU level from spawner-recruitment time series, we assumed a simple Ricker model of the form:

$$(1) \qquad R = Se^{(\ln(\alpha) - \beta S)} e^{\gamma}, \qquad \gamma \sim N(-\frac{{\sigma_R}^2}{2}, \sigma_R)$$

Where *R* is CU-specific recruitment, *S* is CU-specific spawner abundances, $ln(\alpha)$ is the productivity parameter *i.e.*, $ln\ (\frac{recruits}{spawners})$ at low spawner abundances, β is a density-dependence parameter equal to the inverse of spawners at maximum recruitment, S_{MAX}, γ are normally distributed deviates with standard deviation σ_R and mean corrected for log-back-transformation

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[2] 80% B_{MSY} was provided as a provisional Upper Stock Reference delineating Cautious and Healthy zones within Canda's Precautionary Approach Framework (DFO 2009) and 80% S_{MSY} has subsequently been used as an upper benchmark for Pacific salmon CU status (e.g., DFO 2013, Grant et al. 2013, Grant et al. 2020). An exception is assessments for Chinook Salmon which have typically used 85% S_{MSY} as an upper benchmark to align with Pacific Salmon Treaty thresholds of status at 85% S_{MSY} (DFO 2016). Alternatives to the lower and upper benchmarks could be considered in future investigations, such as S_{MSY} as an upper benchmark to align with common international practice of using B_{MSY} as a target or desired state (Marentette & Kronlund 2020), but was beyond the scope of this Research Document.

adjustment, $-\sigma_R{}^2/2$. Modelling was implemented in R and TMB and code is available in Brown & Holt (2024). Parameter estimates and model fits are provided in Appendix A.

Second we considered habitat-based benchmarks derived from accessible watershed areas for Chinook salmon (Parken et al. 2006; Liermann et al. 2010), which have been previously used for the biological assessment of Chinook CUs (DFO 2016, Holt et al. 2023b) and described in Parken et al. (2006) and Liermann et al. (2010). In summary, the accessible watershed-area model harnesses the relationship between accessible watershed areas for Chinook salmon and the biological quantities, spawner abundances at replacement, S_{REP} (also called spawner abundances at equilibrium, S_{eq}) and S_{MSY}, to predict those biological quantities where spawner-recruitment time-series are not available. While other habitat variables, such as stream length and gradient may better correlate with population abundances, accessible watershed area was chosen because it is relatively easy to calculate over the broad geographic range of populations considered and performed well in predicting biological quantities (Parken et al. 2006). The model was parameterized based on synoptic time-series from 25 natural-origin populations of Chinook salmon for which spawner-recruitment time-series were available (Parken et al. 2006). These populations originated from northern California to central Alaska, covering both stream- and ocean-type life-histories, and ranged in accessible watershed area from 93–114,434 km^2 (median = 1,696 km^2). Hatchery populations were excluded. Details for the 25 populations are provided in Appendix A of Parken et al. (2006). Despite the range of watershed areas for the synoptic time series extending beyond the areas for WCVI Chinook populations (range: 12–856 km^2, median = 101 km^2), the ocean-type synoptic populations were deemed to be broadly representative of the ocean-type WCVI Chinook populations assessed here (see Figure 4.1 for range of watershed areas as used in integrated accessible watershed-area model).

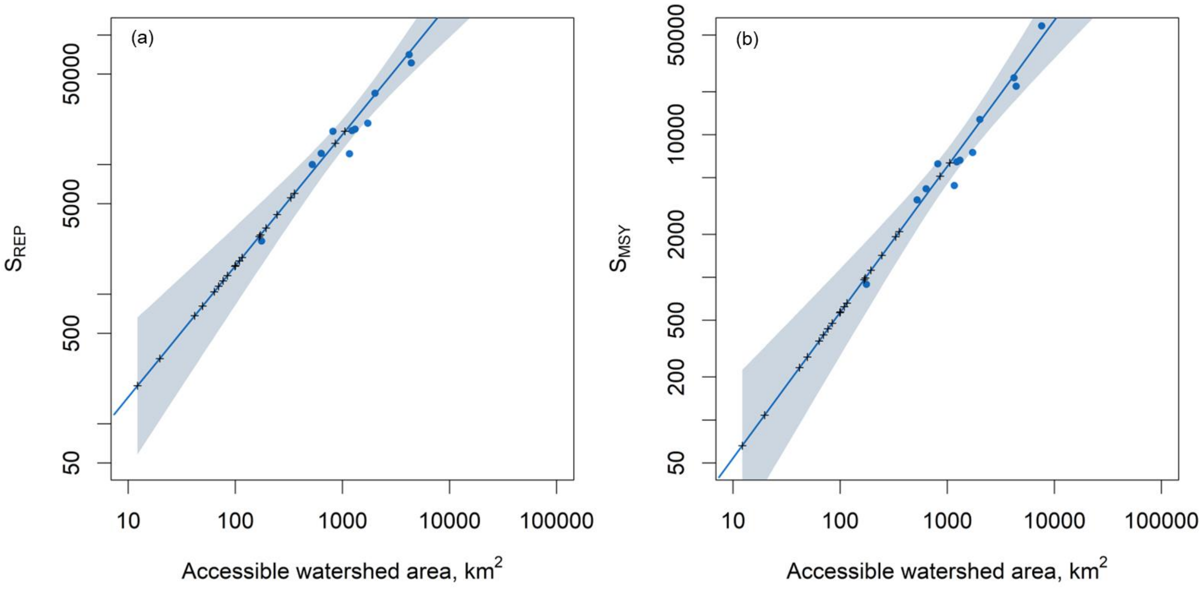


Figure 4.1. Relationship between accessible watershed area and (a) S_{REP} and (b) S_{MSY} for ocean-type Chinook populations based on the integrated watershed-area model described in the text. Blue dots show the empirical data from Parken et al. (2006) underpinning the relationship. Black crosses are the accessible watershed areas for WCVI (ocean-type) Chinook systems considered in our stock reference point analyses; these points are plotted along the mean prediction line (blue). Shaded areas show the 95% confidence bounds for the empirical data (blue). Axes are shown on a log scale.

We first used the accessible watershed-area model to predict S_{REP} for WCVI Chinook escapement indicator populations, and then calculated S_{MSY} and S_{gen} for those populations using values of S_{REP} and independent estimates of $ln(\alpha)$ derived from a life cycle model for WCVI Chinook (as described below). This approach mirrors that used in (Holt et al. 2023b) to derive benchmarks for WCVI Chinook indicators to inform the development of SMU-level reference points, as described in more detail below.

The accessible watershed-area model was updated from the model of Parken et al. (2006) in two ways. First, following Liermann et al. (2010), the model was statistically integrated in that the spawner-recruitment relationships for individual populations and the relationship between accessible watershed area and $ln(S_{\mathrm{REP}})$ were estimated simultaneously instead of sequentially to allow uncertainties to be propagated from spawner-recruitment analyses to the estimation of benchmarks ('integrated accessible watershed area model'). Second, following Liermann et al. (2010), we included hierarchical structure in stock-recruitment analyses accounting for similarities in productivity within ocean-type and stream-type populations within the synoptic time-series (Liermann et al. 2010; see below).

The integrated accessible watershed-area model is summarized here. For the spawner recruitment time-series, we used a simple Ricker model,

(2) $R_i = S_i e^{(\ln(\alpha_i) - \beta_i S)} e^{\tau},\ \tau \sim N\left(-\frac{{\sigma_{R,i}}^2}{2}, \sigma_{R,i}\right), ln(\alpha_i) \sim N(\mu_{\alpha,stream} + \mu_{\alpha,ocean} \cdot LH, \sigma_\alpha)$

where R_i, S_i, $ln(\alpha_i)$, β_i, and $\sigma_{R,i}$ are defined above, assigned for each population i in the synoptic data set, τ are normally distributed deviates with standard deviation $\sigma_{R,i}$ and mean corrected for back-transformation adjustment from log-space, $-{\sigma_{R,i}}^2/2$, $\mu_{\alpha,stream}$ is the mean of the hyperdistribtuion of $ln(\alpha_i)$ for stream-type populations, $\mu_{\alpha,ocean}$ is a factor added for ocean-type populations, LH is a binary variable, 0 or 1, for stream and ocean-type populations respectively, and $\sigma_\alpha$is the standard deviation of the hyperdistribution. We estimated independent hyperdistributions for stream- and ocean-type populations following Liermann et al. (2010), as populations with these life-histories tend to differ in productivity.

As in Parken et al. (2006) and Liermann et al. (2010), we assumed an allometric relationship between accessible watershed area and benchmarks, S_{REP} and S_{MSY}, with independent parameters for stream- and ocean-type fish given known differences in how populations with those life-histories access watersheds. Similar to Liermann et al. (2010), both life-history types were estimated in the same model with a factor added to differentiate ocean- from stream-type populations:

(3a) $S_{REP} = \exp(\nu_{0,stream} + \nu_{0,ocean} \cdot LH) \cdot WA^{(\nu_{1,stream} + \nu_{1,ocean} \cdot \mathrm{LH})} \cdot \exp(\epsilon_\nu), \epsilon_\nu \sim N(-\sigma_\nu^2/2, \sigma_\nu)$,

and,

(3b) $S_{MSY} = \exp(\delta_{0,stream} + \delta_{0,ocean} \cdot LH) \cdot WA^{(\delta_{1,stream} + \delta_{1,ocean} \cdot \mathrm{LH})} \cdot \exp(\epsilon_\delta), \epsilon_\delta \sim N(-\sigma_\delta^2/2, \sigma_\delta)$,

which was linearized to:

(3c) $ln(S_{REP}) = \nu_{0,stream} + \nu_{0,ocean} \cdot LH + (\nu_{1,stream} + \nu_{1,ocean} \cdot \mathrm{LH}) \cdot ln(WA) +$
$\epsilon_\nu, \varepsilon_\nu \sim N(-{\sigma_\nu}^2/2, \sigma_\nu)$

and,

(3d) $ln(S_{MSY}) = \delta_{0,stream} + \delta_{0,ocean} \cdot LH + (\delta_{1,stream} + \delta_{1,ocean} \cdot \mathrm{LH}) \cdot ln(WA) +$
$\epsilon_\delta, \varepsilon_\delta \sim N\left(-\sigma_\delta^2/2, \sigma_\delta\right)$

Where, in equations 3a and (3c, $\nu_{0,stream}$ is the y-intercept of the linear model predicting $ln(S_{\mathrm{REP}})$ for stream-type populations, and $\nu_{0,ocean}$ is a factor added to the y-intercept for ocean-type populations, $\nu_{1,stream}$ is the slope of the model for stream-type populations, and $\nu_{1,ocean}$ is a factor added to the slope for ocean-type populations, and ϵ_ν are random normal deviates with standard deviation, σ_ν and mean $-\sigma_\nu{}^2/2$ to account for back-transformation adjustment from a log-normal distribution. In equations 3b and 3d, $\delta_{0,stream}$ is the y-intercept of the linear model predicting $ln(S_{\mathrm{MSY}})$ for stream-type populations, and $\delta_{0,ocean}$ is a factor added to the y-intercept for ocean-type populations, $\delta_{1,stream}$ is the slope of the model for stream-type populations, and $\delta_{1,ocean}$ is a factor added to the slope for ocean-type populations and ϵ_δ are random normal deviates with standard deviation, σ_δ and mean $-\sigma_\delta{}^2/2$ to account for back-transformation adjustment from a log-normal distribution.

Note, in the estimation procedure, the $\ln(\nu_{1,stream})$ and $\ln(\delta_{1,stream})$ were estimated to ensure that the slopes of the linear regressions were positive (i.e., as watershed areas increased, so did estimates of benchmarks). Modelling was implemented in R v4.4.1and TMB v.1.9.14. See Appendix B for likelihood penalties, and parameter estimates for the watershed-area model.

Our intent was to use the same underlying synoptic time-series, models forms, and assumptions previously published by Parken et al. (2006) and Liermann et al. (2010) to the extent possible, instead of developing new models to estimate benchmarks (see below for discussion of future work on possible model improvements).

One exception is the assumption about productivity when applying the accessible watershed area model to predict S_{MSY} and S_{gen}. Parken et al. (2006) used the accessible watershed area to predict both S_{REP} and S_{MSY} (but not S_{gen}) from watershed areas, from which productivity, $ln(\alpha)$, can be inferred, by solving for $ln(\alpha)$ in an explicit solution of S_{MSY} (Scheuerell 2016) after substituting $b = \ln(\alpha)\,/S_{REP}$:

(4) $$(1 - b \cdot S_{MSY}) \cdot e^{(\ln(\alpha) - b \cdot S_{MSY})} = 1$$

Because S_{REP} and S_{MSY} are predicted from the same independent variable, accessible watershed area, and are constrained by the synoptic time-series, the inferred value of productivity is constant across populations in predictions, as found in preliminary analyses. When the integrated watershed area is used to predict both S_{REP} and S_{MSY}, the inferred value of $ln(\alpha)$ from the underlying synoptic time-series is 2.3 (~9.8 recruits per spawner at low spawner abundances). This inferred value was deemed to be higher than plausible for WCVI Chinook. Many of the WCVI Chinook populations categorized as 'Wild' or 'Wild-stray influenced' are persisting at very low levels, often with support of strays from hatcheries or other populations. Therefore, we considered two additional methods for estimating productivity, as described below, and as in Holt et al. (2023b).

Although S_{REP} also varies somewhat with productivity, this parameter is less sensitive to variability in productivity compared with S_{MSY} which is estimated at lower spawner abundances where $ln(\alpha)$ is more influential. Therefore, we chose to use population-specific S_{REP} predictions from the integrated watershed-area model as a measure of capacity and independent estimates of productivity to calculate S_{MSY} and S_{gen}, where S_{gen} was estimated by solving the Ricker equation with recruitment set to S_{MSY}:

(5) $$S_{MSY} = S_{gen} e^{\left(\ln(\alpha) - \beta S_{gen}\right)}$$

and S_{MSY} was calculated here using the explicit formulation of Scheuerell (2016).

In future updates, alternative benchmarks based on Bayesian state-space stock-recruitment models could be developed to explicitly account for uncertainty in underlying data, incorporating prior information on capacity based the accessible watershed-area model and productivity based on a life cycle model (as described above). Deriving these models was beyond the scope of the current working paper.

The first additional method for estimating productivity was from CU-specific estimates of $ln(\alpha)$ derived from the run-reconstructions of WCVI Chinook (D. Dobson, DFO Science, pers. comm.) and stock-recruitment modelling (see above), where $ln(\alpha)$ values range from 1.14–1.58 (Figure 4.2, Table 4.1, and Figure A-5 for a comparison Ricker curves derived from the run reconstruction with alternative assumptions about productivity). This run reconstruction approach is limited by unrealistic assumptions in underlying recruitment time-series and confounding of natural and hatchery production, resulting in relatively high mean productivity estimates.

Therefore, we considered a second additional method for estimating productivity (and third source of information for estimating benchmarks) from a semi-quantitative life-history model for WCVI Chinook (W. Luedke, DFO South Coast Stock Assessment, pers. comm.) which approximated a relatively low mean of $ln(\alpha)$ of 1 with high uncertainty (standard deviation [SD] = 0.5). This approach separated natural-origin from hatchery-origin production, with the following assumptions derived from life-stage specific studies of WCVI Chinook populations: 4,000 eggs per spawner, 40% effective female spawners, 90% mortality from eggs to smolt, and 98.3% marine mortality for natural-origin fish from populations not impacted by density dependence, resulting in approximately 2.7 recruits per spawner or $ln(\alpha) = 1$. Lower and upper 95% confidence limits were approximated at $ln(\alpha)$ of 0 and 2, representing scenarios of and 3,500 eggs/spawner, 40% effective female spawners, 95% egg to smolt mortality and 98.6% marine mortality, and of 4500 eggs/spawner, 40% effective female spawners, 85% egg to smolt mortality, and 97.2 % marine mortality, respectively. This represents a standard deviation of approximately 0.5.

We bootstrapped benchmarks by sampling from spawner-recruitment parameters, productivity, $ln(\alpha)$, and capacity $ln(S_{REP})$ values independently which over-estimates uncertainty in benchmark values given assumed covariance between them. Plausible covariance values can be estimated from meta-analyses of spawner-recruitment relationships to reduce uncertainties in benchmark estimates in future assessments, and is the topic of ongoing research.

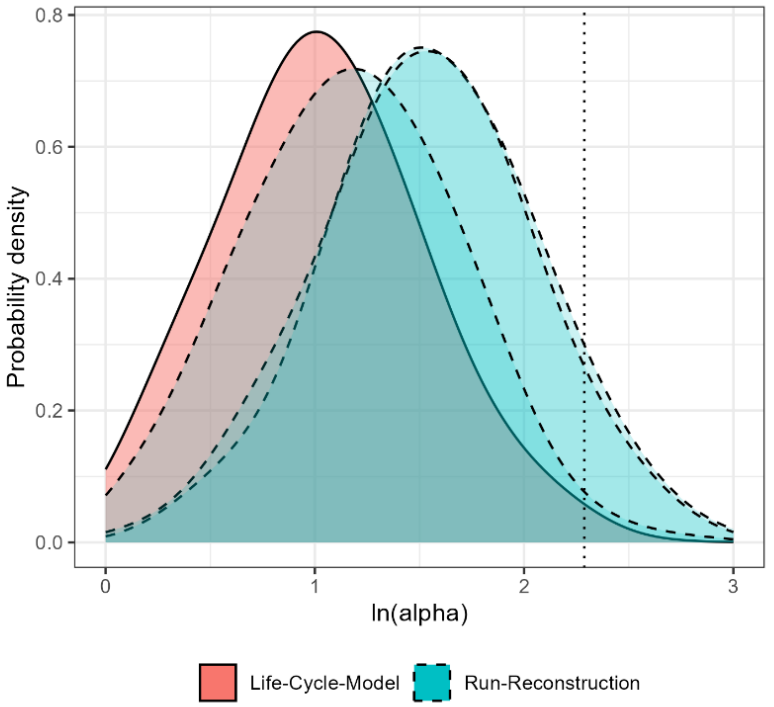


Figure 4.2. Three assumptions about productivity used to derived habitat-based benchmarks based on a semi-quantitative life cycle model (red curve with solid line), CU-specific mean productivities, $ln(\alpha)$ *derived from CU-level run-reconstructions (3 blue curves representing South-West Vancouver Island, North-West Vancouver Island, and Nootka and Kyuquot CUs from left to right), and a constant productivity based on assumptions of the accessible watershed-area model (Parken et al. 2006; vertical dotted line), as described in more detail in the text.*

4.2. POPULATION-LEVEL BENCHMARKS

Three sets of benchmarks were estimated using S_{REP} from the integrated watershed-area model and three assumptions about productivity: high productivity derived from the underlying integrated watershed-area model, moderate productivity based on the run-reconstruction information, and low productivity based on the life cycle model (Figure 4.3, for S_{gen}, Table C-3, for S_{MSY} and S_{REP}). As productivity declines, S_{MSY} and S_{gen} usually increase since under low productivity more spawners are needed to maximize yield, and as S_{MSY} increases, the minimum abundances associated with rebuilding to S_{MSY} in one generation generally increases. Thus, S_{gen} and S_{MSY} were lowest under the high productivity assumption and highest under the low productivity assumption; with the moderate productivity assumption resulting in intermediate S_{gen} and S_{MSY}. Importantly, these results indicate large uncertainties in benchmark estimates (e.g., Figure 4.3 and Table B-2), which results in large uncertainties in reference points at the aggregate scale. Because of implausible (high) productivity estimates from the integrated watershed-area model and unrealistic assumptions in the run-reconstruction underlying spawner-recruitment estimates of productivity, we focus on benchmarks derived from the life cycle model estimates of productivity for evaluating status, though all are shown for completeness.

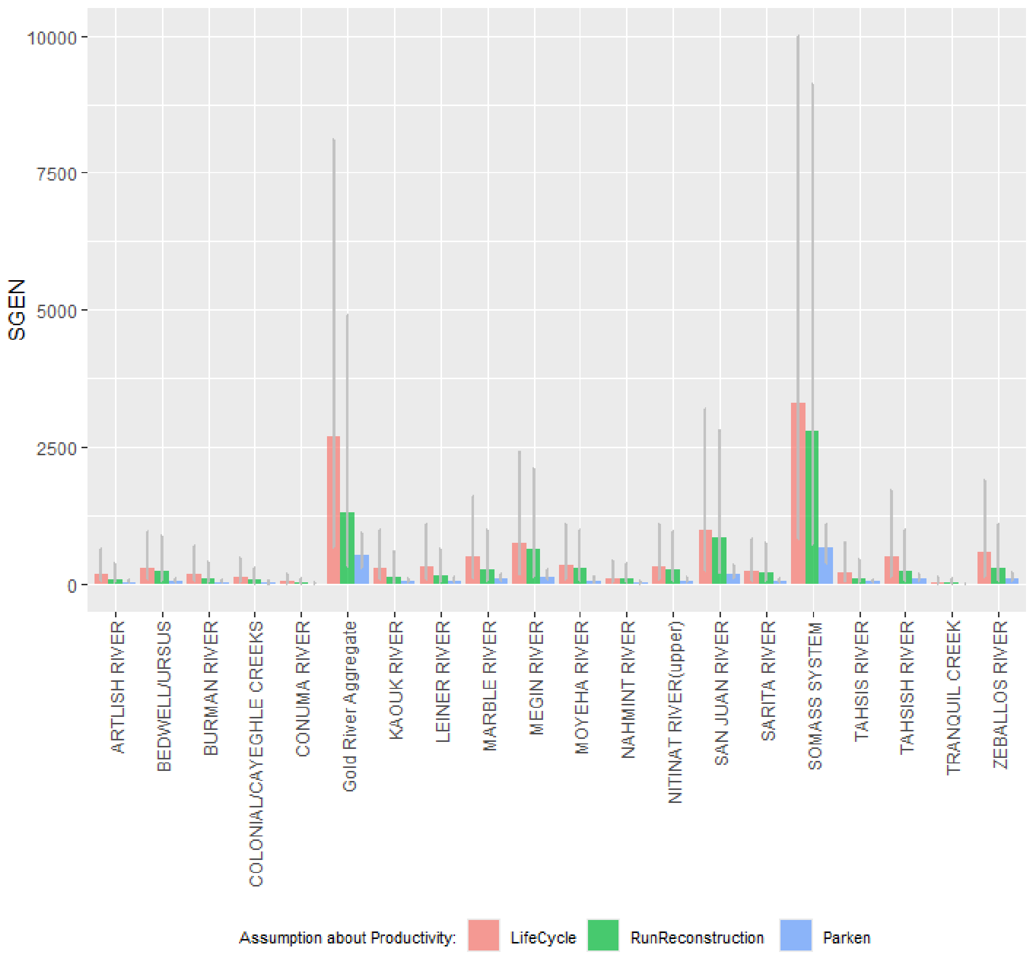


Figure 4.3. Benchmark spawner abundances that result in recovery to spawners at maximum sustained yield in one generation under equilibrium conditions (i.e. S_{gen}) for escapement indicator populations, derived from the integrated watershed-area model, according to three assumptions about productivity based on a life cycle model, CU-specific run-reconstructions, and assumptions of Parken et al. (2006).

Table 4. Median values of S_{gen}, S_{MSY}, S_{REP} for 17 key escapement indicator watersheds derived from the integrated watershed-area model, under 3 different productivity assumptions: low productivity based on Life Cycle (LC) model, moderate productivity based on Run Reconstruction (RR) of terminal returns to key areas of the WCVI, and Parken (P) based on application of methods in Parken et al. (2006).

CU	**PFMA**	**System**	**Accessible watershed area (km^2)**	**S_{GEN} (LC)**	**S_{MSY} (LC)**	**S_{REP} (LC)**	**S_{GEN} (RR)**	**S_{MSY} (RR)**	**S_{REP} (RR)**	**S_{GEN} (P)**	**S_{MSY} (P)**	**S_{REP} (P)**
SWVI	20	San Juan	330	1000	2300	5300	860	2200	5300	200	1800	5300
SWVI	23	Nahmint	42	120	270	640	100	270	640	24	220	640
SWVI	23	Sarita	84	250	560	1300	210	550	1300	49	440	1300
SWVI	24	Bedwell	99	290	660	1500	250	650	1500	58	530	1500
SWVI	24	Megin	245	750	1700	3900	630	1600	3900	150	1300	3900
SWVI	24	Moyeha	116	350	780	1800	290	760	1800	68	620	1800
SWVI	24	Tranquil	12	33	74	170	28	72	170	6.5	59	170
SWVI Total			**928**	**2793**	**6344**	**14610**	**2368**	**6102**	**14610**	**556**	**4969**	**14610**
NoKy	25	Burman	70	200	460	1100	100	420	1100	41	370	1100
NoKy	25	Gold	856	2700	6000	14000	1300	5400	14000	530	4800	14000
NoKy	25	Leiner	109	330	730	1700	160	660	1700	64	580	1700
NoKy	25	Tahsis	77	230	510	1200	110	460	1200	45	400	1200
NoKy	25	Zeballos	194	590	1300	3100	290	1200	3100	120	1000	3100
NoKy	26	Artlish	64	190	420	970	91	380	970	37	330	970
NoKy	26	Kaouk	101	300	680	1600	150	610	1600	59	540	1600
NoKy	26	Tahsish	172	520	1200	2700	250	1100	2700	100	930	2700
NoKy Total			**1643**	**5060**	**11300**	**26370**	**2451**	**10230**	**26370**	**996**	**8950**	**26370**
NWVI	27	Cayeghle	49	140	320	740	74	290	740	28	250	740
NWVI	27	Marble	167	500	1100	2600	260	1000	2600	100	900	2600
NWVI Total			**216**	**640**	**1420**	**3340**	**334**	**1290**	**3340**	**128**	**1150**	**3340**
Grand Total			**2787**	**8493**	**19064**	**44320**	**5153**	**17622**	**44320**	**1680**	**15069**	**44320**

4.3. DEVELOPMENT OF REFERENCE POINTS AT THE SMU SCALE

4.3.1. Candidate Limit Reference Points (LRPs)

We applied two alternate methods to derive LRPs at the scale of SMUs:

1. Simple summing of population-level benchmarks to aggregate spatial scales, and
2. Application of the CU-status LRP, where CU statuses were assessed using WSP methodologies (Holt et al. 2009; Holt et al. 2023a,b) implemented with the Rapid Status Algorithm (DFO 2024).

4.3.1.1. Aggregate abundances: summation of S_{gen} values

We focused on these two methods because in a recent review of LRPs for Pacific salmon, the CU-status LRP was recommended for the purposes of assessing SMU status under the Fish Stocks provisions (Holt et al. 2023a,b), and because the status of WCVI CUs depends in large part on spawner abundances relative to biological benchmarks. Therefore, we considered various approaches to summing population-level benchmarks to aggregate scales.

The first method was to simply sum the population-level lower benchmarks (S_{gen}) within the desired spatial scale, either the inlet, the CU, or the SMU (Table 4.1, repeated for each assumption about productivity). This summation method does not account for differing productivities among populations or low covariance among populations, inlets or CUs, requiring additional emphasis on achieving adequate distribution of abundance within the spatial scale chosen. Indeed, DFO (2023b) stated that the summation of population-level benchmarks (with no secondary components such as distribution) was not recommended to derive aggregate escapement goals for the assessment on Skeena and Nass Sockeye. Although summing of benchmarks to the inlet- or CU- scale may be reasonable for WCVI Chinook if productivities are similar within inlets and CUs, aggregation to the scale of SMU would fail to account for the general consensus that productivities are lower among populations in the SWVI CU compared to those in the NoKy and NWVI CUs (Table 4.1; Appendix D). Accordingly, LRPs arising from abundances summed across CUs should also be combined with distributional, genetic, demographic, or other information pertinent to a status assessment (see section 4.4). Distribution can include status of component populations and distribution of statuses among them. Here we call these reference points simply “abundance-based reference points” to differentiate them from CU-status based LRPs recommend for assessing SMU status described below.

In section 5.3, a variety of abundance based reference points (sum of S_{gen} values and sum of 85% S_{MSY} values) are identified for the SMU by summing benchmarks from various subsets of underlying populations. This analysis illustrates the sensitivity of SMU status to choice of indicator populations, and shows that while status is deemed healthy when all or most indicators are included, status becomes critical when analyses focus on core natural indicators. These analyses further illustrate the important distributional nature of status; high abundances for some components imply healthy status, while others are depleted with poor status. Status above the critical zone is achieved when status of core natural indicators are above lower benchmarks.

4.3.1.2. CU-based LRP: Recommendation to address Precautionary Approach requirements

Second, we applied a CU-based LRP as recommended by Holt et al. (2023a) calculated from the proportion of component CUs with Red statuses based on a multidimensional approach to CU assessments developed under the WSP (Holt et al. 2009) implemented using the Rapid

Status algorithm (DFO 2024). The multidimensional approach to assessments under Canada's WSP includes metrics on current spawner abundances, short and long-term trends in abundances, and the distribution of spawning. Benchmarks are established for each metric and an overall multidimensional estimate of CU status is obtained by integrating status among metrics, in the past using expert-driven processes (Grant and Pestal 2013; DFO 2015; DFO 2016; Grant et al. 2020). In this way, CUs missing data for any single metric can still be evaluated against remaining metrics, making the framework applicable across a relatively broad range of data types and hence CUs (Holt et al. 2009).The rapid status algorithm assigns a *Red* (poor), *Amber* (intermediate), or *Green* (good/healthy) status, with a *Low, Medium,* or *High* confidence rating, to CUs with applicable data (Pestal et al. 2023; DFO 2024). The algorithm is a set of decision rules that approximate the decision-making process that experts used in previously implemented WSP integrated assessments of CU status to combine information across multiple metrics (Grant and Pestal 2013; DFO 2015; DFO 2016; Grant et al. 2020). Importantly, justification and rationale for CU statues were often coincident among previously published processes when underlying data availability, trends and metrics were similar. Based on these similarities, an emergent set of decision rules were extracted to inform the basis of the algorithm. Then, the performance of a range of decision rules was evaluated by comparing their respective rapid statuses against WSP integrated statuses assigned from past expert-driven processes. The top-performing algorithm was recommended for application as part of the Rapid Status Algorithm. Specifically, this algorithm assigns a WSP rapid status depending on a series of answers to dichotomous Yes/No questions based on available CU data, metrics and benchmarks. WSP rapid statuses are derived from the combination of metrics applied, and their individual status values compared to metric thresholds with expert input and review. See Appendix D, Pestal et al. (2023) and DFO (2024) for further details.

Only populations with low hatchery contribution were included in CU assessments of status for WCVI Chinook. Following Withler et al. (2018) and Holt et al. (2023b), PNI values were used to indicate hatchery contribution, and only populations where the average PNI greater than 0.5 were included. Two exceptions were Nahmint and Tahsis, which were included in Holt et al. (2023b) but excluded here due to PNI values that averaged close to 0.5 (0.54 and 0.58, respectively) and were highly variable over time (range 0.19–0.99 and 0.18–1.00, respectively), especially in recent years. The core escapement indicators included in the CU assessments were: Bedwell, Megin, Moyeha (West Vancouver Island-South CU), Artlish, Kaouk, Tahsish (West Vancouver Island- Nootka and Kyuquot CU), and Cayeghle and Marble (West Vancouver Island-North CU). See section 5 and Appendix D for more details. For WCVI Chinook, CU-statuses depended largely on spawner abundances relative to CU-level biological benchmarks, as shown in Figure D-2, Figure D-4, and Figure D-6.

4.3.2. Candidate Upper Stock References (USRs)

We identified USRs at 85% of S_{MSY} to align with upper biological benchmark for CUs (see section 4.1). We applied two alternate methods to derive aggregate abundance S_{MSY} values for USRs:

1. simple summing of population-level benchmarks to aggregate spatial scales, as for LRPs, and
2. an equilibrium trade-off analysis to identify the aggregate spawner abundance that maximizes yield while allowing for variable productivities among component CUs (DFO 2023b; Connors et al. 2022).

To derive candidate USRs we included all escapement indicators except those associated with major hatchery facilities (Conuma, Somass, and Nitinat; see Table 4.1). The choice of including all escapement indicators except major hatcheries is less stringent than the choice of including only populations dominated by natural-origin spawners when developing CU-status LRPs, and reflects the important ecological value of populations with both hatchery- and natural-origin fish when delineating 'healthy' status. While we have included Gold River in our analyses due to its expansive accessible watershed area relative to other WCVI Chinook systems (Table 4.), hatchery contributions from out-of-basin strays comprise a high proportion of spawning abundances in the Gold (see section 5.4 below; Weil et al. 2024), and it could be considered from removal in future analyses.

As above for LRPs, the first method used to derive USRs was to simply sum the population-level benchmark S_{MSY} values within the desired spatial scale, either the inlet, the CU, or the SMU (Table 4.1), and then identify 85% of the summed aggregate S_{MSY}. The resulting estimated LRP is 16,241 Chinook spawners for the WCVI SMU. One limitation of the summation approach is that it does not account for differing productivities among populations or low covariance among populations, inlets, or CUs (as described above), requiring additional emphasis on achieving adequate distribution of abundance within the spatial scale chosen.

Although an alternate USR that accounted for divergent productivities was considered based on an equilibrium trade-off analysis (method 2), this USR was derived from reconstructed spawner recruit time series with high uncertainties and assumptions that are unlikely to be met (see section 4.1). It is presented here for comparison but is not recommended for implementation as a USR.

In this analysis, the equilibrium spawning population size was calculated for each of the three CUs under exploitation rates varying between 0–99% (as in DFO 2023b). Given the lack of population-specific productivity data, this method was not possible to apply at a finer individual population level. Equilibrium spawning population size, S_{eq}, was calculated using the equation:

$$S_{eq} = \frac{ln\,\alpha - (-\,ln(1-U))}{\beta} \quad (6)$$

Where $ln(\alpha)$ is the CU-specific Ricker productivity parameter (Table 4.1), U is the exploitation rate, and β is the CU-specific Ricker beta, i.e., the slope of the regression of $ln\,(\frac{recruits}{spawners})$ versus spawners (Table 4.1).

Table 4.1. Stock-recruit parameters applied in equilibrium trade-off analysis. Mean productivity values were obtained from run reconstruction data and are listed in Table 10 of Holt et al. (2023b). The standard deviation in productivity was derived from the life cycle model, which was larger than the statistical uncertainty in $ln(\alpha)$ from the run reconstruction.

Parameter	**WCVI-South**	**WCVI-Nootka & Kyuquot**	**WCVI-North**
Ricker $ln(\alpha)$ (mean)	1.14	1.58	1.53
Standard deviation in Ricker $ln(\alpha)$	0.5	0.5	0.5
$ln(S_{REP})$ (mean)	9.711	10.247	8.196
Standard deviation in $ln(S_{REP})$	0.286	0.285	0.32

We then used the S_{eq} values to calculate a corresponding equilibrium harvest, H_{eq}, for each CU using the equation:

(7) $$H_{eq} = (S_{eq} \cdot e^{ln(\alpha) - \beta \cdot S_{eq}}) - S_{eq}$$

Where S_{eq} is the equilibrium spawning population size, as defined in equation (6, $ln(\alpha)$ is the CU-specific Ricker productivity parameter (Table 4.1), and β is the CU-specific Ricker beta, i.e., the slope of the regression of $ln(\frac{recruits}{spawners})$ versus spawners (Table 4.1).

We bootstrapped 1000 S_{eq} and H_{eq}, values for each CU and exploitation rate (0–99% in 1% increments) by randomly drawing $ln(\alpha)$ and $ln(S_{REP})$ values from CU-specific normal distributions with means and SDs listed in Table 4.1, and then calculating $\beta = \frac{\ln \alpha}{S_{REP}}$. We then summed S_{eq} and H_{eq} values from each random draw across CUs to get 1000 aggregate SMU-level values for each exploitation rate increment. We also used the values in Table 4.1 to calculate CU-specific U_{MSY} values using the explicit solution of Scheuerell (2016) (Equation 9) and then calculated the number of CUs that would be above U_{MSY} at a given exploitation rate increment. Finally, we plotted the median of the aggregate S_{eq} values for each exploitation rate increment against the median and interquartile range of H_{eq} values in an equilibrium trade-off plot that illustrates the equilibrium spawning stock biomass for the SMU where harvest is maximized (DFO 2023b). Code and data to reproduce this analysis is available in Brown & Holt (2024).

The resulting plot (Figure 4.4.) shows the number of CUs for which the exploitation rate exceeds CU-based U_{MSY} values along a range of exploitation rates to demonstrate trade-offs between aggregate yield and overfishing at the CU-level. Unlike the summation method, this approach considers variation in productivity among CUs, but like the summation method, it is an equilibrium-based method that does not account for random variation in population dynamics or covariance among populations or CUs. The equilibrium S_{MSY} aggregate across the 17 rivers listed in Table 4.1 is estimated at 18,705 Chinook spawners (interquartile range: 10,021–26,221), i.e., the spawner abundance where equilibrium harvest is highest (Figure 4.4.). As in the first method, we can take 85% of this equilibrium S_{MSY} as the upper biological benchmark, which is 15,899 (IQR: 8,518–22,288). This result is similar to the estimate derived from taking 85% of summed S_{MSY} values assuming productivities derived from the run reconstruction (14,979; Table 4.1). This simple equilibrium calculation of aggregate S_{MSY} is based on maximum-likelihood estimates of spawner recruitment parameters and could be revised with Bayesian estimation in the future. It is provided here for demonstration purposes, given caveats in the underlying recruitment time-series, as described above.

Neither method to estimate USRs adequately considers the distribution of productivity among inlets and CUs, leading to the possble scenario where one dominant CU with high abundances enable the SMU to be above USR despite poor status of remaining inlets or CUs. We recommend further consideration on how distributional objectives could be considered in USRs.

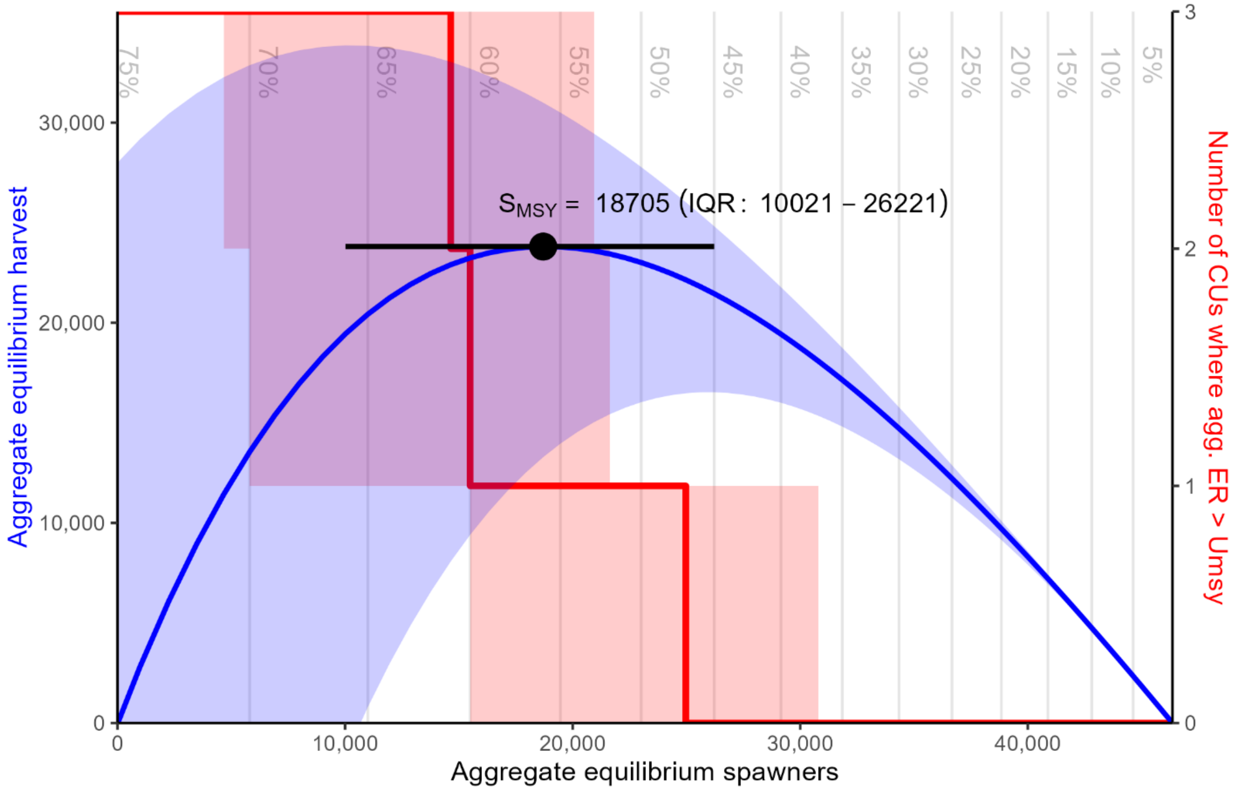


Figure 4.4. Aggregate equilibrium trade-off plot for the WCVI Chinook SMU with three component CUs modelled using run reconstruction productivity estimates, as in Table 4.2. For 1% increments of aggregate exploitation rate (ER; shown in 5% increments as vertical grey bars), the figure shows estimated median (blue line) and interquartile range (IQR; blue shaded area) for aggregated spawner abundance (bottom axis) and aggregate catch (left axis). The corresponding number of CUs where the aggregate ER exceeds estimated CU-specific U_{MSY} is plotted with respect to the right y-axis; the IQR of CU-specific U_{MSY} estimates informs the red shaded area. The black point and whiskers show the estimated midpoint and IQR of S_{MSY}—the equilibrium spawner abundance where harvest is maximized.

4.3.3. Candidate Removal References (RR)

We considered U_{MSY} as a proxy for the removal reference to align with the common practice internationally of using F_{MSY} (fishing mortality at MSY levels) as an upper limit (Marentette and Kronlund 2020). Two methods for estimating U_{MSY} were considered: the approximation of U_{MSY} from Hilborn and Walters (1992) assuming a common $ln(\alpha)$ among populations and CUs from the WCVI Chinook life cycle model, and an equilibrium trade-off analysis assuming CU-specific $ln(\alpha)$ from run reconstructions and $ln(S_{REP})$ from the integrated watershed-area model (Table 4.1) as described in the section above.

U_{MSY} was estimated at 43% using the explicit solution of U_{MSY} (Scheuerell 2016):

$$U_{MSY} = 1 - W(e^{1-\ln(\alpha)}) \tag{8}$$

and estimated productivity ($ln(\alpha) = 1$) generated from the life cycle model for WCVI Chinook (see section 4.1, above), which assumes low productivity with no difference between CUs. However, the bootstrapped 95% uncertainty interval and IQR for U_{MSY} were large (1–72% and 30–54% respectively) given the large uncertainty in productivity values from the life cycle model (standard deviation $ln(\alpha) = 0.5$).

Second, using equilibrium trade-off analysis (described above in 4.3.2) and run reconstruction data, we estimated the equilibrium harvest rate—the aggregate U_{MSY}—at approximately 56% (IQR: 45–66%; *i.e.* the exploitation rate where H_{eq} is maximized; Figure 4.4.). Note that a 56% exploitation rate would exceed the estimated U_{MSY} for SWVI CU (48% using parameter values from Table 4.1) due to its estimated lower productivity. Note, this U_{MSY} estimate for SWVI may even overestimate the U_{MSY} for component populations with especially low productivity, such as reflected in life cycle model for the Moyeha, which suggests an exploitation rate any higher than the current 35% would cause further decline in the population (section 3.4). The broad confidence intervals in aggregate equilibrium harvest reflect the large uncertainty in underlying CU-level productivities.

These removal reference estimates assume exploitation is equal across ages within a cohort. Data presented in section 6.2 (Figure 6.3) indicate higher exploitation rates on older, mostly female Chinook. The result is that the removal reference should also have some secondary components, such as age or size limits to ensure age-specific removal rates are sustainable.

4.3.4. Candidate Target Reference Points (TRPs)

While the USR delineates the lower bound of the 'healthy zone' in DFO's Precautionary Approach Framework often calculated relative to MSY levels, the target reference point (TRP) is associated with an objective or target for the fishery. Here, we differentiate the TRP from the USR, where the proposed TRP was associated with the goal of maintaining component inlets above lower biological benchmarks to align with biological objectives of (a) being above CU-status based LRPs and (b) maintaining and rebuilding abundances of inlets within CUs. This TRP is provided as a candidate for demonstration purposes; others can be developed that account for additional biological and socio-economic objectives (DFO 2021c). Indeed, Science is tasked with informing, but not recommending specific TRPs because "the USR (when interpreted as a reference point) and TRP are not determined solely by biological considerations and therefore not by the Science Sector" (DFO 2021c). Candidate target reference points identified here may also be appropriate as long-term rebuilding targets. We applied projection-based methods to derive a candidate TRP, as the level of aggregate SMU abundances associated with desired component status objectives, using methods described by Holt et al. (2023a,b). Details on methods and equations for generating projection-based reference points are provided in Holt et al. (2023b), and are outlined below.

In summary, the candidate TRP was estimated from projected time-series of inlet abundances and statuses, where those time-series characterized an emergent relationship between aggregate SMU-level spawner abundance and the probability of all component inlets being above their lower benchmark, S_{gen}. We identified a candidate biological target at the level of abundances associated with all inlets being above lower benchmarks with a specified probability over the long-term (i.e., at equilibrium). We used inlets instead of CUs to capture the distributional objective of maintaining and rebuilding abundances at a finer spatial scale. The geographic separation of inlets and relative low stray rates among them (Weil et al. 2024) precludes meaningful rescue effects among inlets within management time frames. Time-series of spawner abundances at the inlet scale are provided in Figure 4.5. Parameter estimates for the population dynamics differed from those in Holt et al. (2023b) for WCVI Chinook as a larger number of populations were included here (all escapement indicators except major hatcheries, Conuma, Somass, Nitinat; Table 4.1), compared with only populations with low hatchery contribution used in Holt et al. (2023b), as indicated by average PNI levels >0.5.

Although this method requires inlet-specific population parameters, including spawner-recruitment parameters and mean proportion in age-at-maturity, unlike methods described for candidate LRPs and USRs described above, the projection-based approach explicitly propagates uncertainty from parameters to the estimate of the TRP, such that the TRP is more precautionary when underlying parameters are less certain. Therefore, we considered inlet-specific parameters derived from the run-reconstruction and spawner-recruitment analyses when developing a candidate projection-based TRP despite their limitations, described in section 4.1.

Individual inlet spawner and recruitment times-series were projected forward from equilibrium spawner abundance levels, given assumed population parameters (including Ricker stock-recruitment model) and their uncertainties. Projections were run with random draws of Ricker parameters (1) given uncertainties in their estimation, annual recruitment deviations that covaried among inlets, and annual variability in ages-at-maturity. Projections included an exploitation rate of 30% (approximating current levels) and incorporated random variability in exploitation over time and among inlets (‘implementation uncertainty’).

Following Holt et al. (2023b), we assumed mean $ln\ (\alpha)$ and standard deviation in recruitment residuals (σ_R) from the run-reconstruction and spawner-recruitment analyses by CU (see section 4.1) with relatively large uncertainties in $ln\ (\alpha)$ derived from life cycle model (see Figure 4.2, blue curves), where all inlets within a CU had the same assumed mean productivity and standard deviation in recruitment residuals. Inlet-specific estimates of Ricker β were derived from inlet-specific S_{REP} estimates form the integrated watershed-area model, where watershed areas were aggregated to the inlet level, and Ricker $\beta = \frac{\ln \alpha}{S_{REP}}$).

We parameterized correlations in recruitment residuals among inlets from the observed correlations in spawner abundances among inlets (Figure 4.6), as inlet-specific recruitment time-series were not available. Although this parameterization may overestimate covariance in recruitment, Holt et al. (2023b) found that the resulting simulated pairwise correlations of spawner abundances provided comparable correlations to those observed for WCVI chinook. We assumed mean proportions at age as estimated from the run-reconstruction, with multivariate logistic distributed error parameterized from the run-reconstruction time-series. All code to generate these parameters are available in Brown & Holt (2024).

Interannual variability in exploitation was assumed to be beta distributed to constrain values to between 0–1, and was parameterized from time-series of pre-terminal exploitation rates from 2010–2019 for the Robertson Creek hatchery indicator (see Holt et al. 2023b). Following Holt et al. (2023b), we assumed that variability in exploitation rate among inlets was half that of variability over time; data to inform that value are currently not available for WCVI Chinook. Holt et al. (2023b) found that pairwise correlations in spawner abundances among inlets were not sensitive to changes in variability in exploitation rates among inlets within plausible bounds (from 0 to equal to the variability in exploitation over time for Robertson Creek). Parameters used in projections are provided in Table B-2.

Projections were run over 30 years and 80,000 random Monte Carlo trials, the number required to stabilize key outputs: candidate reference points. For each trial, inlet-specific lower benchmarks, S_{gen}, were calculated from the randomly drawn Ricker parameters (by solving Equation (5), and the status of each inlet above or below S_{gen} was recorded annually. To derive candidate reference points, the proportion of year-trial combinations where all inlets were above lower benchmarks was calculated for various bins of aggregate escapement, from near zero to above summed equilibrium abundances for all inlets. Candidate reference points were identified from the emergent relationship between aggregate escapement and the proportion of Monte Carlo trials where all inlets were above lower benchmarks (as a proxy for probability of this occurrence).

We identified a candidate reference point at 50% probability of all inlets being above lower benchmarks (43,900, Figure 4.7). Although Holt et al. (2023b) identified projection reference points at higher probability thresholds, large uncertainties in the inlet-specific dynamics and low pairwise covariance for populations included in this analysis resulted in aggregate abundances where inlets were only infrequently all above their lower benchmarks such that candidate reference points at higher probabilities could not be identified. This was especially true within the CK-31 CU, South-West Vancouver Island (Clayoquot, Barkley, San Juan). These 3 inlets required relatively high aggregate abundances to be above their lower benchmarks (Figure 4.7).

The 66% probability level is associated with 'likely outcome' under likelihood categorizations developed by the International Panel on Climate Change (Mastrandrea et al. 2010), and the 75% probability level represents 'high' probability under DFO's draft risk tolerance designations within the Precautionary Approach Framework (DFO 2009). Aggregate abundances associated with these higher probabilities of all inlets being above lower benchmarks could not be estimated.

Unlike USRs and RRs that are based on estimated and calculated quantities and provided with uncertainty intervals, the candidate TRP presented here is a probabilistic outcome that explicitly accounts for underlying uncertainties in its derivation, becoming more precautionary as underlying parameters become more uncertain. In future work, uncertainty in TRPs may be specified by identifying upper and lower aggregate abundances associated with acceptable upper and lower probabilities levels within the constraints of the projections (e.g., with a maximum upper limit of approximately 60% in this application, Figure 4.7).

One caveat of this projection-based reference point is the sensitivity to exploitation scenario, where the current implementation assumes status quo exploitation (Holt et al. 2023b). We recommend re-evaluation of projection-based reference points as different management scenarios are considered and implemented. In general, when exploitation rates are reduced to near zero, projection-based reference points tend to decline as fewer spawners are needed to ensure all inlets are above lower benchmarks (see Holt et al. 2023b). Under relatively high exploitation, a much higher aggregate abundance is needed to ensure all component inlets are above lower benchmarks.

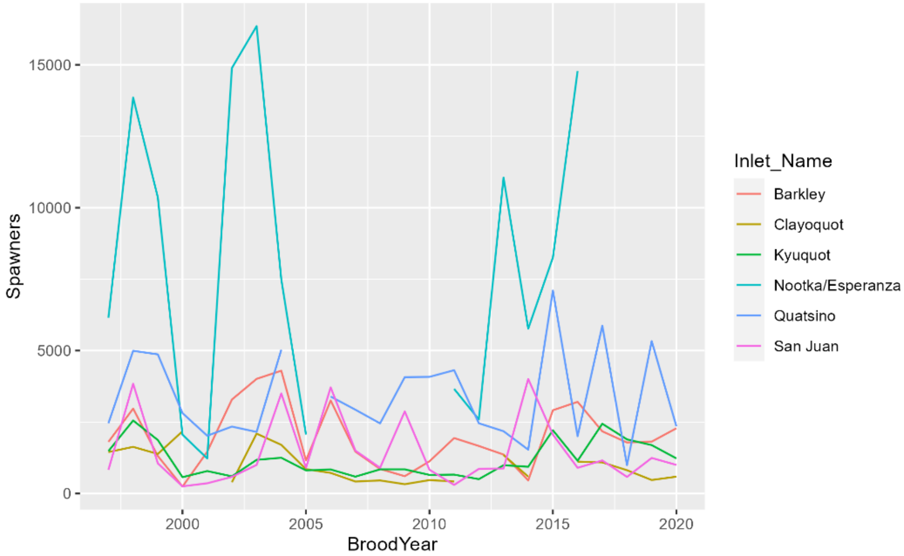


Figure 4.5. Time-series of spawner abundances by inlet, calculated as the sum of indicator populations excluding major hatchery facilities.

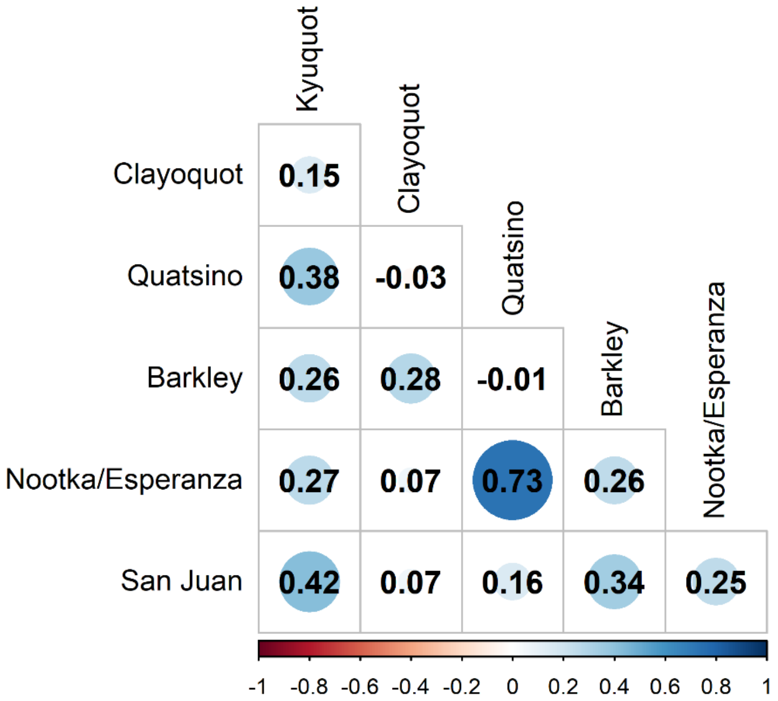


Figure 4.6. Bubble plot showing correlations of spawner abundances among inlets over the years of 1995–2020.

Although projection methods have previously been suggested as candidate LRPs (Holt et al. 2023a,b), here we suggest that candidate reference points associated with an as-likely-as-not (50%) outcome of all inlets being above their lower benchmarks may be more appropriate as a TRP, a biological objective within an MSE framework, or as an interim or long-term rebuilding targets instead of an LRP. The candidate reference point at 50% probability of all inlets being above lower benchmarks is above candidate USR based on equilibrium trade-off analyses (15,899), and abundances associated with a 60% probability of all inlets being above lower benchmarks, which approaches the sum of capacity estimates for all systems (≈80,000).

In future analyses, projection-based reference points could be improved by estimating covariances with more recent escapement data, as well as possible PBT information on stock-specific catches.

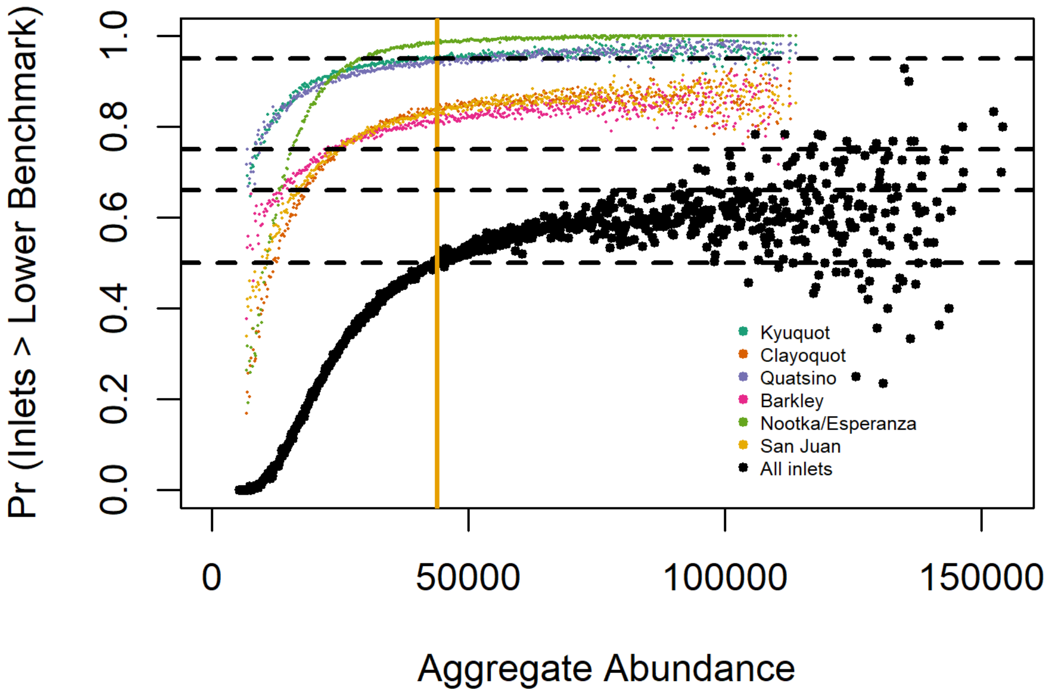


Figure 4.7. Probability of all inlets being above their lower benchmark along a gradient in aggregate abundances within bins of abundances of 200 fish, derived from projections over 30 years and 50,000 Monte-Carlo Trials, using parameters described in the text and including in Table B-2. Each dot is the proportion of Monte-Carlo trials where all inlets were > lower benchmarks. Candidate reference points at p = 0.5 (yellow vertical line) is highlighted, where p is the probability of all inlets being above their lower benchmarks. Black dots represent the probability of all inlets being above lower benchmarks , and coloured dots show the probability of individual inlets being above their lower benchmark along a gradient in aggregate abundance. Results from all inlets are derived from the same random draws in the projections. Coloured dots are bounded at ~100,000 aggregate abundances in projections.

4.3.5. Uncertainties

Intrinsic population-specific productivity, and the resulting distribution of productivities across the populations making up the SMU, is a key source of uncertainty in the derivation of reference points, captured in both wide confidence intervals in benchmark and reference point estimates and sensitivity of those benchmarks and reference points to underlying source of productivity information. An improved understanding of population-specific productivities could inform risk-based approaches for evaluating impacts of aggregate management actions (e.g., aggregate exploitation rates) on specific populations of concern. Conversely, this improved understanding would provide support in setting priorities and evaluating trade-offs for restoration and other management decisions that include objectives to rebuild component populations within an aggregate SMU. This is the complexity of managing an SMU comprised of many component populations.

Ongoing escapement monitoring and assessment of pHOS, as well as research through a suite of collaborative ‘Follow the Fish’ projects focusing on early marine survival, may improve estimates of life cycle productivity that were derived from the life cycle model in section 3.4. Benchmarks should be revised as estimates of mortality rates, productivity, and the extent and distribution of Chinook in the watershed-area model are updated.

Large uncertainties in underlying population-level benchmarks result in large uncertainties in aggregate abundance reference points estimated from simple summations and equilibrium trade-off analyses, as shown by the large confidence intervals in Figure 4.4., Table B-1.

These methods utilize available population abundance estimates for the 17 key escapement indicators, which are to varying degrees confounded by uncertain contributions of hatchery-origin fish. There is considerable variation in the proportion natural-origin spawners (pNOS) within and among populations, which adds uncertainties to status determination (Table 4.2).

Table 4.2. Populations included in the estimation of aggregate-abundance reference points with average spawner abundance and average proportion natural-origin spawners (pNOS) based on available thermal mark analysis (counts = years sampled), over 3 generations (12-year period) 1999–2010 and 2011–2022. Designation is based on Withler et al. (2018).

CU	PFMA	System	Current Withler et al. (2018) designation	Average spawners 1999–2010	Average pNOS 1999–2010	Count of pNOS 1999–2010	Average spawners 2011–2022	Average pNOS 2011–2022	Count of pNOS 2011–2022
SWVI	20	San Juan	Integrated-hatchery	1455	0.18	2	1172	0.59	3
SWVI	23	Nahmint	Integrated-transition	373	0.50	11	430	0.71	10
SWVI	23	Sarita	Integrated-hatchery	1550	0.13	12	1849	0.19	11
SWVI	24	Bedwell	Integrated-wild	112	-	0	441	0.85	8
SWVI	24	Megin	Wild-stray influenced	66	-	0	43	0.42	2
SWVI	24	Moyeha	Wild-stray influenced	144	0.45	1	71	1.00	2
SWVI	24	Tranquil	Integrated-wild	804	-	0	233	0.96	9
SWVI Total				**650**	**0.31**	**26**	**619**	**0.65**	**45**
NoKy	25	Burman	Integrated-hatchery	971	0.39	7	3729	0.16	12
NoKy	25	Gold	Integrated-hatchery	4158	0.40	1	2928	0.28	9
NoKy	25	Leiner	Integrated-hatchery	438	0.66	3	763	0.37	11
NoKy	25	Tahsis	Integrated-hatchery	594	0.67	6	621	0.30	9
NoKy	25	Zeballos	Data deficient	250	0.40	6	241	-	0
NoKy	26	Artlish	Wild-stray influenced	228	-	0	322	0.61	2
NoKy	26	Kaouk	Wild-stray influenced	341	0.93	2	364	0.89	5
NoKy	26	Tahsish	Wild-stray influenced	333	-	0	813	0.60	5
NoKy Total				**810**	**0.53**	**25**	**1233**	**0.38**	**53**
NWVI	27	Cayeghle	Data deficient	557	-	0	361	-	0
NWVI	27	Marble	Integrated-wild	2696	0.95	4	2845	0.93	5
NWVI Total				**1673**	**0.95**	**4**	**1603**	**0.93**	**5**

4.4. ADDITIONAL OR ALTERNATIVE REFERENCE POINTS

4.4.1. Hatchery-Influence Reference Point

Abundance-based reference points for natural-origin WCVI Chinook are confounded by hatchery production, including hatchery strays into unenhanced watersheds. There are only 2 areas (Clayoquot Sound and Kyuquot Sound) where significant ‘wild’ Chinook populations return to moderate-sized rivers. Most moderate-sized Chinook rivers on the WCVI are periodically or regularly supplemented through hatchery production, or are close enough to enhanced systems to regularly receive sizeable influxes of hatchery strays. To differentiate among rivers on the degree of hatchery supplementation, Withler et al. (2018) proposed designations (or objectives) with specific reference points for either pHOS or PNI (Table 4.3).

Table 4.3. From Withler et al. (2018). Designations for individual salmon populations that vary in the degree of influence of integrated hatchery programs and the proposed genetic guidelines for hatchery management. Note that designations C–E apply only to populations that receive direct enhancement.

Designation	**$pHOS_{eff}$** **$pHOS_{census}$**	**pNOB**	**PNI**	**pWILD**	**Comments**
Wild	≤ 0.02 ≤ 0.03	n/a	n/a*	≥ 0.92	Designated wild populations that do not have hatchery programs (for at least two generations); strays from out-of-basin hatchery production are limited to <3% per year.
Wild-stray influenced	>0.02 >0.03	n/a	n/a	*< 0.92*	Population receives strays from an out-of-basin hatchery. A very large fraction of fish may be wild but gene flow modelling suggests a long-term decline in *PNI* as *pHOS* increases.
Integrated wild	≤ 0.19 ≤ 0.23	≥ 0.77	≥ 0.80	≥ 0.50	Hatchery production is managed to keep wild fish ≥50% of the spawning population.
Integrated-transition	≤ 0.47 ≤ 0.53	≥0.47–<0.77	≥0.50–<0.80	≥0.13–<0.50	*PNI* > 0.5 ensures natural-origin influence predominates but wild fish are in the minority.
Integrated-hatchery	> 0.47 > 0.53	< 0.47	< 0.50	< 0.13	Net gene flow from hatchery environment; most fish are hatchery-origin. Few fish are wild.

Implementation of Withler et al. (2018) requires knowledge of WCVI salmon populations’ current genetic designations and a plan to move toward an objective designation (Box 4.1). A designation at the CU or SMU level would be difficult given the likely distribution of hatchery contribution among component populations. A status of integrated wild or integrated-transition (Table 4.3) is required to meet WSP objectives and SEP is currently developing guidance on how PNI objectives should be distributed among populations within CUs.

Box 4.1

> *"There is inherent difficulty in determining how to properly assess a CU* [or SMU] *when it is uncertain that a CU (sustained with one or more populations of wild fish) would still exist in the absence of hatchery production for conservation or harvest purposes. The development of a standardized approach to WSP assessment efforts necessitates a method to relate the level and duration of hatchery influence in a salmon population to the level of risk that the hatchery fish pose to the natural adaptive and productive characteristics of the hatchery-influenced and surrounding wild populations. Poor quality and/or limited natural habitat and high harvest levels may also pose genetic risks to wild salmon populations but the focus of this study is to examine risks to genetic diversity arising primarily from enhancement.*
>
> *Recent advances in scientific understanding of salmon population structure and adaptation, and the effects of gene flow between natural- and hatchery-origin salmon, should be updated into hatchery planning process. A 2013 independent science panel report on southern British Columbia Chinook Salmon recommended that SEP hatchery programs should be brought into better alignment with WSP principles. With guidelines that more explicitly identify the potential genetic risk to enhanced populations from hatchery production, managers and stakeholders can make decisions that explicitly align with their risk tolerance during development of hatchery program objectives. A comprehensive review of US hatcheries has been underway since 2000, established and funded by the US Congress. The Hatchery Scientific Review Group (HSRG) established under this program developed three principles of hatchery management that can also be applied in the Canadian process. These principles with respect to hatcheries are to operate with well-defined goals, scientifically defensible programs, and informed decision making."*
>
> —Withler et al. (2018)

4.4.2. Demographic Reference Points

Further information gathering will be required to develop demographic reference points. It is clear from several lines of evidence that age-at-maturity and size-at-age are declining in WCVI Chinook (*q.v.* section 5.5). However, there is very little baseline data to describe a more natural or unperturbed population demographic structure. First Nations and other local knowledge holders agree that sizes of WCVI Chinook salmon have decreased dramatically (by *circa* 30–50%) since the mid-1900s (Sainsbury et al. 2024). This historic knowledge may be the best baseline available to describe future demographic objectives for the SMU. We recommend close collaboration with key First Nation elders and other local knowledge holders on the WCVI to qualitatively describe demographics across areas (perhaps sounds). These qualitative data could provide a basis to develop demographic reference points for rebuilding.

In general, larger Chinook are predominately females and older females carry more eggs. Therefore, as the average age and size of Chinook returning to the WCVI increases, so too will the number of eggs, and thus fewer spawners will be required to produce strong future cohorts. Active management of terminal area fisheries in Alberni Inlet (Stamp River watershed), Muchalaht Inlet (Burman and Gold rivers), Tlupana Inlet (Conuma and Canton rivers) has evolved into the development of adult escapement targets (and so total allowable catches) based on the projected numbers of adults required to achieve abundance-based egg targets in rivers. Annual assessment of age composition, sex ratios, and fecundity-at-age is required to ensure maintenance of effective spawning abundance, in the form of spawner escapement targets based on eggs.

4.4.3. Distribution of Abundance Reference Points

None of the abundance-based candidate reference points identified above in section 4.3 adequately capture SMU status on their own. Estimated abundances of natural-origin Chinook returning to WCVI rivers in recent years (2015–2023; Figure 3.2) are above both candidate USRs identified in section 4.3.2. However, these abundances are not equally distributed among populations or CUs; returns to several rivers have been quite strong while returns to other key rivers (predominately the Megin and Moyeha in Clayoquot Sound) have remained very low. This disparity in returning abundances constrains the WCVI Chinook SMU to the critical zone (*q.v.* section 5.2).

The distribution of spawning across diverse landscapes is linked to population resilience and sustainability (Bradford and Braun 2021). Distributional reference points that consider the spread of spawning among populations may indicate risks associated with narrowing of spatial distribution thereby limiting access to diverse landscapes. Although distributional objectives and reference points and have not yet been established for this SMU, as a starting point, we recommend that the Rapid Status Algorithm (DFO 2024; Appendix D) be upheld as an important tool for assessing SMU status relative to the statuses of component CUs. This approach accounts for distribution of abundances among CUs within the SMU, and focuses on populations within CUs that are dominated by natural-origin fish. In this approach, the SMU status is constrained to the lowest CU status to ensure distribution of abundances are respected in rebuilding objectives.

4.5. SPECIES AT RISK SURVIVAL AND RECOVERY TARGETS

The Government of Canada (GC) Species at Risk Policy on Recovery and Survival (GC 2021) defines survival as being achieved when species are in a stable (or increasing) state, exist in the wild in Canada, and are not at significant risk of extirpation or extinction. The following factors contribute to survival: stability over time, resilience (i.e., ability to rebound from disturbance), redundancy (e.g., widespread distribution), connectivity among population components, and protection from human-caused threats (GC 2021).

In addition, recovery is defined as:

A return to a state in which the risk of extinction or extirpation is within the normal range of variability for the species, as indicated in part by its population and distribution characteristics. This is informed by the species' natural condition in Canada, which is defined as its condition prior to the significant impact of human activities that led to the species being listed as Endangered, Threatened, or Extirpated under SARA […] and is not necessarily the same as a return to the population size and distribution it would have had in the absence of human activity (GC 2021).

While this definition for recovery indicates that recovery can be informed by conditions prior to human impact, for exploited species like WCVI Chinook salmon, these targets can account for managed fisheries impacts and can be much lower than unfished capacity (~80,000 spawners, Table C-3).

Recovery targets identified for the Species at Risk Program (SARP), differ from rebuilding targets identified under the Fish Stock provisions in at least three ways. Identifying recovery targets for SARP is the responsibility of Science and represents a minimum level that is considered within the natural range of variability for the population, informed by the population's natural condition. SARP targets are identified at the scale of DU, a biological designation. In contrast, rebuilding targets signal the end point of the rebuilding plan and the transition to integrated management within the IFMP, and are informed by Science but consider additional socioeconomic considerations; SARP targets do not consider socioeconomic factors. Rebuilding targets are identified by Resource Management at the scale of the SMU, though can consider distributional metrics within the SMU. While lower biological benchmarks used to inform LRPs are often aligned with survival targets (DFO 2021b; DFO 2022b), rebuilding targets identified under the Fish Stocks provisions are typically intermediate between SARP survival and recovery targets. Rebuilding targets are set sufficiently above the LRP to have a high probability of exceeding it (DFO 2021c), and rebuilding targets are typically much lower than levels considered for a recovery target by SARP.

Here we propose survival and recovery targets for two WCVI DUs, DU 24 (West Vancouver Island, Ocean, Fall [South]) and DU 25 (West Vancouver Island, Ocean, Fall [Nootka and Kyuquot]), aligned with DFO guidance on recovery targets (DFO 2011), the 2021 Species at risk policy (GC 2021) and recent applications to Pacific salmon (Table C-7). In general, we identified these targets as:

- **Survival Target**: Set at a level to approximate the objective that a DU not be characterized as Endangered or Threatened by COSEWIC or as the Red biological status of the Wild Salmon Policy (WSP).
- **Recovery Target**: Approximates the level at which the DU's long term persistence is secured, approximated with the objective of a COSEWIC Not At Risk Status and WSP Green or 'healthy' status.

Both WCVI DUs were designated as threatened by COSEWIC because of low abundances (fewer than 10,000 wild mature individuals) and threats (dominated by genetic risks from hatcheries) that were expected to continue resulting in declines in wild mature individuals (COSEWIC 2020). The COSEWIC criterion for small and declining populations—criterion C2a(ii)—was used to identify threatened status for both DUs, where population size was inferred from total abundances adjusted for natural-origin spawning, and continual declines were inferred from ongoing threats due to competition, genetic introgression and straying from hatcheries (COSEWIC 2020). As noted in previous RPAs for Pacific salmon (DFO 2021b; DFO 2022b; Table C-7), the targets recommended here are a simplified interpretation of COSEWIC and WSP thresholds for designating status, and do not account for subjective interpretations and additional biological information that can impact status. Therefore, achieving survival or recovery targets does not guarantee a change in COSEWIC or WSP status.

Both survival and recovery targets were identified using time series from populations dominated by natural-origin spawners, to align with criteria for WSP assessments for integrated-hatchery and integrated-wild populations (as defined in DFO 2018), and to address the reason for COSEWIC threatened designation related to threats from hatchery introgression from high proportions of hatchery-origin fish on the natural spawning grounds. High abundances resulting from hatchery production are therefore not considered when evaluating status against survival and recovery targets.

Two sets of metrics and benchmarks were identified for the survival target based on generational abundances and trends in abundances:

1. the greater of S_{gen} and 1,000 fish relative to recent generational average spawner abundances, and
2. a positive population growth over the most recent 3 generations if abundances are ≤10,000 and <30% decline over the most recent generation if >10,000.

These abundance and trend benchmarks are associated with WSP status being above the Red zone, and COSEWIC statuses of Special Concern or higher. Both benchmarks must be met or exceeded for the survival target to be met.

The survival target is nested within the recovery target, as the survival target must be met for recovery while also achieving generational average spawner abundances >85% S_{MSY} (WSP upper abundance-based benchmark, aligned with green WSP status).

In addition, we recommend that status against survival and recovery targets consider hatchery influences and associated genetic risks (Withler et al. 2018), though we have not recommended explicit targets (as in DFO 2022b). The preservation of natural adaptions is important for the survival and recovery of populations within integrated hatchery systems, which can be achieved by minimizing genetic risks of introgression from hatcheries, as indicated with PNI values for populations within DUs. For populations to be considered recovered, we recommend that PNI values be greater than those for integrated-wild (≥0.8), which ensures at least half of the population is considered ‘wild’, i.e., are second generation natural spawners. The PNI threshold associated with integrated-hatchery (≥0.5) is recommended to reflect survival of natural adaptations, by ensuring at least half the population is natural-origin. However, there is uncertainty on how these thresholds at the population level translate to assessments at aggregate DU or CU scales. Guidance on genetic risks from hatchery introgression at the CU- (and DU-) scale and recommendations for assessments is in development by DFO’s Salmonid Enhancement Program. That guidance may contribute to development of genetics-based survival and recovery targets at the DU scale. Ultimately, the choice of the acceptable number and distribution of integrated-hatchery and integrated-wild populations within a DU will likely be informed by trade-offs between genetic risks and value of hatcheries for other biological and socioeconomic objectives and has not yet been determined.

Because time series of the proportion of natural-origin spawners have not been consistently available for WCVI populations (Table 4.2; Table C-2), our recommendations have focused on total spawner abundances for populations not dominated by hatchery influences (e.g., those with PNI ≥0.5). However, PBT and other emerging methods may be a used in the future to estimate proportions of hatchery-origin spawners for populations coast-wide, enabling refined estimates of natural-origin spawners. These analyses could supplement, but not replace, analyses focusing on populations dominated by natural-origin spawners.

Table 4.4. Potential survival and recovery targets for DU 24, West Vancouver Island, Ocean, Fall (South), and DU 25 (West Vancouver Island, Ocean, Fall (Nootka and Kyuquot), including populations that are considered to be integrated-hatchery and integrated wild (Bedwell, Megin, Moyeha for DU24 and Artlish, Kaouk, and Tahsish for DU 25). Both abundance and trend thresholds need to be met for targets to be attained.

	Survival Targets		**Recovery targets**	
DU	**Abundance (maximum of S_{gen} and 1,000 spawners)**	**Trend**	**Abundance (maximum of 85% S_{MSY} and 1,000 spawners)**	**Trend**
DU-24	1390 (derived from summing population-specific values in Table C-3)	Positive trend over 3 generations if abundance ≤10,000 or <30% decline over the most recent	2669 (derived from summing population-specific values in Table C-3)	Requires that the trend component of the survival target is met.

DU	Survival Targets		Recovery targets	
	Abundance (maximum of S_{gen} and 1,000 spawners)	Trend	Abundance (maximum of 85% S_{MSY} and 1,000 spawners)	Trend
		generation when abundance is >10,000.		
DU-25	1010 (derived from summing population-specific values in Table C-3)	Positive trend over 3 generations if abundance ≤10,000 or <30% decline over the most recent generation when abundance is >10,000.	1955 (derived from summing population-specific values in Table C-3)	Requires that the trend component of the survival target is met.

4.6. SUMMARY OF REFERENCE POINTS

- Neither of the candidate LRPs (summation of S_{gen} values across populations or CU-status based derived form the rapid status algorithm) by themselves adequately capture the variability in status or productivity among WCVI Chinook populations. However, the CU-status based LRP that is based on rapid status algorithm could be adapted to consider distribution among populations and inlets, PNI, demographic changes, and variability in productivity, caveats that are currently included in the narrative for rapid status assessment (Appendix D).
- In an SMU such as WCVI Chinook, which is comprised of many different populations with a range of productivities, abundance-based reference points estimated at the aggregate scale should be accompanied by secondary references such as distribution of abundance among populations, hatchery genetic influence, and demographics, which capture other characteristics of serious harm. Additional reference points specific to key life-stage sources of mortality could also be considered (e.g. watershed process indicators, number and size of smolts produced, condition factors for juvenile Chinook during their early marine phase, etc.).
- Large uncertainties in watershed-area-based benchmarks and CU-specific productivity estimates result in large uncertainties in abundance-based reference points, and RRs.
- The aggregate removal reference, U_{MSY}, was estimated at 43% based on life cycle models, and 57% using the run reconstruction data, each with large uncertainty. However, these estimates of removal references and exploitation rates are based on an average across ages within a cohort. Data presented in section 6.2 indicate higher exploitation rates on older mostly female Chinook. This result suggests that the removal reference should also have some secondary components, such as age/size limits to ensure age-specific removal rates are sustainable. We also note that the current terminal area fishery management regime does have priority, with local management actions to further protect the least productive populations, especially in Clayoquot Sound.

- A projection-based reference point is provided as a candidate TRP or long-term rebuilding target, which explicitly accounts for uncertainties in productivity among inlets and uncertainties in underlying population dynamics and habitat-based benchmarks.

Table 4.5. Summary of candidates presented for development of reference points.

Reference Point	Candidates presented		Comments
Limit Reference Point (LRP)	CU-status: all CUs must be above *Red* zone		We recommend the CU-status method as an LRP for the WCVI Chinook SMU.
	WCVI-South CU	S_{gen}: 2803 (low productivity)	The low productivity assumption is most realistic for populations in the SMU. All escapement indicators except those associated with major hatchery facilities are included in summations (Table 4.).
		S_{gen}: 2368 (moderate productivity)	
		S_{gen}: 556 (high productivity)	
	WCVI-Nootka-Kyuquot CU	S_{gen}: 5060 (low productivity)	
		S_{gen}: 2451 (moderate productivity)	
		S_{gen}: 996 (high productivity)	
	WCVI-North CU	S_{gen}: 640 (low productivity)	
		S_{gen}: 334 (moderate productivity)	
		S_{gen}: 127 (high productivity)	
	Summed population S_{gen} values: 8503 (low productivity), 5153 (moderate productivity), 1679 (high productivity)		This summation does not account for variable productivity among CUs. Could be considered as a “fishery reference point – lower” but is not recommended as an LRP.
Upper Stock Reference (USR)	85% of summed population S_{MSY} values: 16204 (low productivity), 14979 (moderate productivity), 12809 (high productivity)		Summing S_{MSY} values across the SMU is subject to the same limitations as summing S_{gen} values, as noted above for LRP.
	85% of S_{MSY} from equilibrium trade-off analysis (moderate productivity assumption): 15899 (IQR: 8518–22288)		This analysis was derived from reconstructed spawner recruit time series with high uncertainties and assumptions that are unlikely to be met.
Removal Reference (RR)	U_{MSY} from estimate of uniform low productivity across the SMU: 43% (30–54%)		These removal reference estimates assume exploitation is equal across ages within a cohort. Data presented in section 6.2 (Figure 6.3) indicate higher exploitation rates on older, mostly female Chinook.
	U_{MSY} from equilibrium trade-off analysis (moderate productivity assumption): 56% (IQR: 45–66%)		
Target Reference Point (TRP) –	50% probability that all Inlets are above their individual S_{gen} values: 43900		Large uncertainties in the inlet-specific dynamics and low

Reference Point	Candidates presented	Comments
example identified to achieve a biological goal for the distribution of spawning among inlets		pairwise covariance for populations resulted in aggregate abundances where inlets were infrequently all above their lower benchmarks. Therefore, candidate reference points at higher probabilities could not be identified
Hatchery-influence reference point	None	Further collaboration with SEP is recommended to determine PNI objectives that are relevant at the CU or SMU level.
Demographic reference point	None	Further information on historic demographics is required to develop demographic reference points. We recommend surveying local knowledge holders as a first step.

5. STOCK STATUS

5.1. BACKGROUND

Past status assessments include: Riddell et al. (2002), which reported a continuing concern for natural-origin Chinook populations along the WCVI; DFO (2016), which assessed two of the three CUs in this SMU, SWVI and NoKy, as Red status in an integrated Wild Salmon Policy assessment; and COSEWIC (2020), which assessed both the SWVI and NoKy CUs as *Threatened*, and NWVI as *Data Deficient*. Threatened statuses were determined primarily from genetic risks of hatchery enhancement and habitat threats from forestry. The NWVI CU was designated data deficient because it contains only one escapement indicator population which is periodically hatchery enhanced.

Based on total accessible habitat area within WCVI watersheds, and the Parken et al. (2006) method, we estimated a capacity of 80,000 Chinook for 49 watersheds on the WCVI (Table C-3). Capacity has likely declined due to habitat degradation (Sainsbury et al. 2024), except in a few places. For example, a fish ladder built at Stamp Falls fishway in 1927 and rebuilt in 1955 opened up significant areas of new spawning habitat for Stamp River Chinook.

The total spawning abundance of WCVI Chinook is in the order of 60,000 in recent years (Figure 5.1). However, the majority of these spawners are counted in 3 of the larger rivers where major DFO hatcheries have been operating since the early 1980s. Soon after, smaller hatcheries were built or satelliting was initiated out of the major SEP hatcheries. Many of these rivers are also key escapement indicators. The result is that a significant portion of the total spawning abundance is either first or subsequent generation hatchery production.

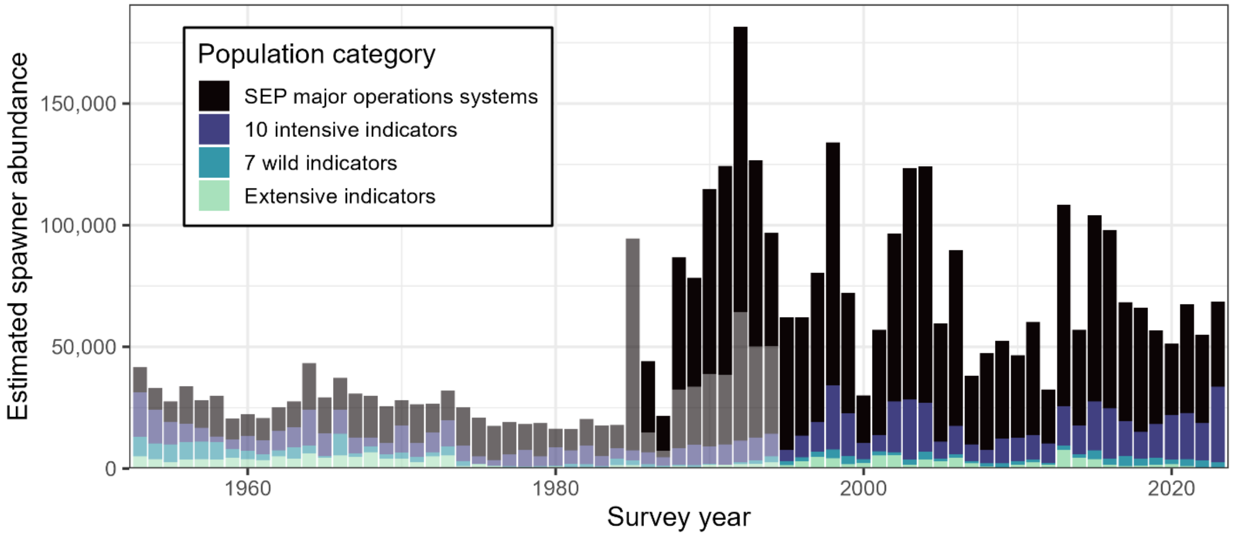
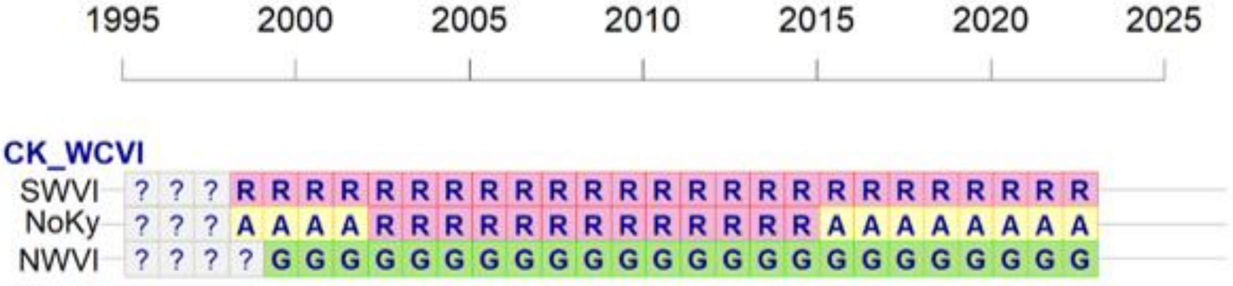


Figure 5.1. WCVI Chinook spawner abundance by return year 1953–2023. Bars are coloured to differentiate populations into categories based on their levels of hatchery influence and survey rigour. Bars that are partially transparent earlier in the time series show years and populations where abundances were estimated qualitatively by fishery officers. By 1995, all populations in the time series were being monitored more rigorously using snorkel surveys and quantitative methods. The Stamp River (included in the black bars) has been monitored using daily counts from a fishway since 1986.

The inability to track natural-origin and hatchery-origin spawners through the full time series and across populations has created uncertainty in the status assessments provided in this document. Accordingly, we employ various methods to assess the status of natural-origin WCVI Chinook.

5.2. ABUNDANCE RELATIVE TO CU-STATUS LRP

The most recent application of Wild Salmon Policy methods for CU assessments, implemented with the Rapid Status Algorithm (DFO 2024), identified Red status for SWVI, Amber status for Nootka and Kyuquot, and Green status for NWVI (Appendix D). Similar to DFO (2016), metrics on abundances and short- and long-term trends were integrated to determine overall status for each CU. However, unlike DFO (2016), populations with PNI values >0.5 were included, even those with ongoing hatchery enhancement, following recommendations from Withler et al. (2018). This means that the NWVI CU was not considered data deficient. Using the CU-status LRP, this SMU falls below 100% of CUs above the red zone. This Red status is driven by persistent poor status of two natural indicators: Megin and Moyeha.



CK_WCVI

SWVI	?	?	?	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
NoKy	?	?	?	A	A	A	A	R	R	R	R	R	R	R	R	R	R	R	R	R	A	A	A	A	A	A	A	A
NWVI	?	?	?	?	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G

Figure 5.2. Retrospective status assessments of CUs based on the Rapid Status Algorithm for WSP assessments.

5.3. STATUS USING AGGREGATE ABUNDANCE REFERENCE POINTS

Status assessments often focus on aggregate spatial scales, which can be incongruent with perspectives from First Nations knowledge holders, field technicians and biologists, and other local knowledge holders. These local experts often have the best understanding of the size and nature of the local population in relation to historic or other views of what once was or could be a healthy population. But from this viewpoint of a specific population, it is not readily apparent how it contributes to local genetic diversity or how it fits within the range of abundances across the whole SMU. Moreover, as analysts, we make assumptions about the mean and deviations of these attributes to describe and model a potential future. This lack of connection between the former local view and the analysts' more global view often create confusion.

Data limitations are a source of this issue, especially for WCVI Chinook. The historical assessment framework for WCVI Chinook (see section 2) was to focus effort on the key CWT hatchery indicator on the Stamp River, plus have a limited number of escapement indicators distributed along the WCVI to assess general abundance trends. In addition, there has been no clear visual differentiation between hatchery- and natural-origin Chinook over the past four decades, which confounds our understanding of natural Chinook productivity. Efforts were initiated to thermally mark otoliths to assess pHOS, but sampling has been opportunistic and intermittent in many cases, leaving considerable uncertainty in the nature of the abundance values used in status assessments.

For these reasons, we take a stepwise approach to the inclusion of data and populations in the status assessment to illustrate the sensitivity of status to choices among indicator populations and the distribution of statuses across these indicators. For the purpose of this exercise, we aggregated WCVI Chinook populations into 4 sets, each of which intends to be an index of the SMU abundance:

Set 1. Includes all available information for the total SMU spawner abundance, representing 100% of the total estimated SMU spawner abundance.

Set 2. Excludes the SEP major operations hatchery systems and comprises about 33% of the total estimated SMU spawner abundance.

Set 3. Further excludes all the inconsistently surveyed populations and all populations with no estimates of pHOS for any recent years (see Table 4.2, Table C-2), resulting in 19 populations comprising about 26% of the total estimated SMU spawner abundance.

Set 4. Excludes all populations except 7 core 'wild' indicator populations: the Bedwell, Megin, and Moyeha in Clayoquot Sound; the Artlish, Kaouk, and Tashish in Kyuquot Sound; and the Marble in Quatsino Sound. Together, these populations represent only 7% of the total estimated SMU spawner abundance, but are considered the best indicators of wild Chinook within the SMU due to assumed low presence of hatchery Chinook.

Aggregate spawner abundance (or escapement) using the most recent 12-year average (2012–2023) in each set is assessed against S_{gen} values as a lower benchmark and candidate USR = 85% S_{MSY} for that set of Chinook populations, where both benchmarks were estimated based on the life cycle model assumption of a low productivity, $ln(\alpha)$ = 1 (section 4.1) and summed across the component populations. The results are provided in Table 5.1, which summarizes data in Table C-3.

Table 5.1. Results of status assessment for 4 different aggregations of the WCVI populations, all intended to represent the SMU. Aggregations range from 100% down to 7% of the 12-year average (2012–2023) spawner abundance. Note that hatchery- and natural-origin spawners are confounded in the estimated spawner abundances and these status assignments are thus inappropriate for natural-origin Chinook.

Parameter	Set 1	Set 2	Set 3	Set 4
Number of populations included (% of maximum)	46 (100%)	43 (93%)	19 (41%)	7 (15%)
Sum of accessible watershed area (% of maximum) in km^2	4545 (100%)	3357 (74%)	2684 (59%)	964 (21%)
12-year average spawners	68724	22634	17810	4865
Summed S_{gen}	13635	9950	8000	2900
85% of summed S_{MSY}	26129	19015	15286	5559
Aggregate SMU status	>85% S_{MSY}	>85% S_{MSY}	>85% S_{MSY}	>S_{gen}
Number of populations <S_{gen}	19	19	3	2
Number of populations >S_{gen}	7	7	6	4
Number of populations >85% S_{MSY}	20	17	10	1

The result is that all the sets except Set 4 exceed the USR, despite half or more of the component populations falling below the USR or even S_{gen}. In sets 1 and 2, 'less reliable' escapement estimates from generally smaller rivers with small populations are included, with 19 (41%) assessed as falling below S_{gen}. In sets 3 and 4, three and two populations, respectively (16% and 27% of all populations in each set), were below S_{gen}; these are the Megin and Moyeha in both sets 3 and 4, and additionally the Sucwoa in Set 3. Spawner abundances in Table 5.1 are confounded by hatchery-origin fish, lending very low confidence to individual-population and SMU-aggregate status assignments.

To illustrate the potential impacts of including hatchery-origin spawners in our assessment of status, we repeated the status assessments for sets 3 and 4 using the sparse pHOS data that are available for these systemsTable C-2. We applied the average pHOS value (across however many years of data were available for each population since 2010; max = 12 years, min = 2 years; Table 4.2) to the 12-year average spawner abundance to calculate a crude estimate of natural-origin spawners in each population (Table 5.2).

Table 5.2. Results of status assessment for 2 aggregations of WCVI populations that have reliable time series of spawner estimates and some data available to estimate pHOS. Note that the estimates of natural spawners here are conjectural and are provided solely to demonstrate the potential impact of including hatchery-origin spawners in assessing aggregate status against abundance-based benchmarks.

Parameter	Set 3	Set 4
Number of populations included (% of maximum)	19 (41%)	7 (15%)
Sum of accessible watershed area (% of maximum) in km^2	2684 (59%)	964 (21%)
Estimated average annual natural-origin spawners	*7848*	*4098*
Summed S_{gen}	8000	2900
85% of summed S_{MSY}	15286	5559

Parameter	Set 3	Set 4
Aggregate SMU status	$<S_{\text{gen}}$	$>S_{\text{gen}}$
Number of populations $<S_{\text{gen}}$	11	4
Number of populations $>S_{\text{gen}}$	3	2
Number of populations >85% S_{MSY}	5	1

Applying these pHOS data does not increase our confidence in the status assignments but it does highlight the potential for hatchery-origin fish to artificially inflate SMU status. Comparing Table 5.1 and Table 5.2 shows that several of the indicator populations are being propped up by hatchery enhancement—9 populations that were previously assessed as exceeding 85% S_{MSY} or S_{gen} now fall below S_{gen}.

Next, we conducted the same assessment by CU (Table 5.3). We applied WSP statuses of *Red, Amber,* or *Green*, according to the same thresholds used above: S_{gen} as a lower benchmark and 85% S_{MSY} as an upper benchmark. The results are similar to the aggregate SMU assessment; the number of red status populations within each aggregate set often outnumber the populations with amber or green status. Within Set 3, Zeballos River in NoKy CU and the Megin and Moyeha rivers in SWVI CU are all below S_{gen}. Again, the confounding of hatchery- and natural-origin fish in these abundance estimates lends low confidence to the status assignments.

Table 5.3. Results of status assessment for 4 different aggregations of populations by Conservation Unit (CU). Assessment was of the (2012–2023) 12-year average spawner abundance against the Life Cycle model S_{gen} and 85% S_{MSY} values. Note that hatchery- and natural-origin spawners are confounded in the estimated spawner abundances and these status assignments are thus inappropriate for natural-origin Chinook.

	SWVI				**NoKy**				**NWVI**			
Parameter	Set 1	Set 2	Set 3	Set 4	Set 1	Set 2	Set 3	Set 4	Set 1	Set 2	Set 3	Set 4
Number of populations (% of total)	21 (100%)	19 (90%)	9 (43%)	3 (14%)	23 (100%)	22 (96%)	9 (39%)	3 (13%)	2 (100%)	2 (100%)	1 (50%)	1 (50%)
Sum of accessible watershed area (% of total) in km^2	2406 (100%)	1237 (51%)	1023 (43%)	460 (19%)	1923 (100%)	1904 (99%)	1494 (78%)	336 (17%)	216 (100%)	216 (100%)	167 (77%)	167 (77%)
12-year average spawners	34713	6883	5198	532	30738	12479	9713	1433	3273	3273	2900	2900
Summed S_{gen}	7146	3516	2903	1390	5849	5794	4597	1010	640	640	500	500
85% of summed S_{MSY}	13791	6779	5605	2669	11131	11029	8747	1955	1207	1207	935	935
Aggregate CU status	Green	Green	Amber	Red	Green	Green	Green	Amber	Green	Green	Green	Green
Number of populations $<S_{gen}$	9	9	2	2	10	10	1	0	0	0	0	0
Number of populations $>S_{gen}$	3	3	2	1	4	4	4	3	0	0	0	0
Number of populations >85% S_{MSY}	9	7	5	0	9	8	4	0	2	2	1	1

The conclusion from this simple assessment is that natural-origin Chinook populations continue to effect ‘Red’ CU status assignments in WSP assessments (see section 4 and Appendix D). However, WSP assessments focus only on natural systems that predominately produce natural-origin or wild fish. There is insufficient information on the origin (natural versus hatchery) of spawning Chinook in most WCVI systems to assess status against a broader aggregate of natural spawners.

In addition, this assessment method shows that simple summation of river-specific reference points at various spatial scales can be informative if combined with additional or secondary reference levels, such as: distribution of abundance (e.g., number of populations at each WSP status level), trends in abundance (as are considered in the CU status assessments under the WSP, Appendix D), levels of hatchery influence and hatchery-origin spawners, and demographic considerations (e.g., number of eggs, number of female spawners, effective spawner abundance).

Of course, choosing a spatial scale for an aggregate abundance LRP or USR for WCVI Chinook salmon has some trade-offs of monitoring cost, inclusion of First Nations and other community knowledge, etc. The approach of using secondary reference levels was employed by the Interior Fraser Coho Recovery Team (2006), where the proposed LRP for the SMU had specific reference levels for distribution of the abundance.

Ideally, this work would aggregate only natural-origin Chinook spawners, but our current ability to identify the proportion natural-origin spawners is incomplete, variable, and potentially biased in the indicator systems used in this report. As recommended in Withler et al. (2018), visual mass marking of hatchery production, along with identification using Parentage Based Tagging will support future assessments based on natural production.

5.4. STATUS OF HATCHERY GENETIC INFLUENCE AND GENETIC DIVERSITY

Genetic introgression from hatchery-origin Chinook spawning with natural-origin Chinook has been occurring since the 1980s, which Withler et al. (2017) described as homogenization of genetics towards the three major WCVI hatchery populations (Figure 5.3). Withler et al. (2018) and Anderson et al. (2020) also describe a potential loss of fitness as a result of high hatchery-influence (e.g. inbreeding and domestication selection) and straying (e.g., outbreeding depression). However, R. Withler (Fisheries and Oceans Canada, Nanaimo, British Columbia, pers. comm.) also indicated that genetic diversity within the three major hatchery systems has been maintained through the integrated hatchery program and random mating practices.

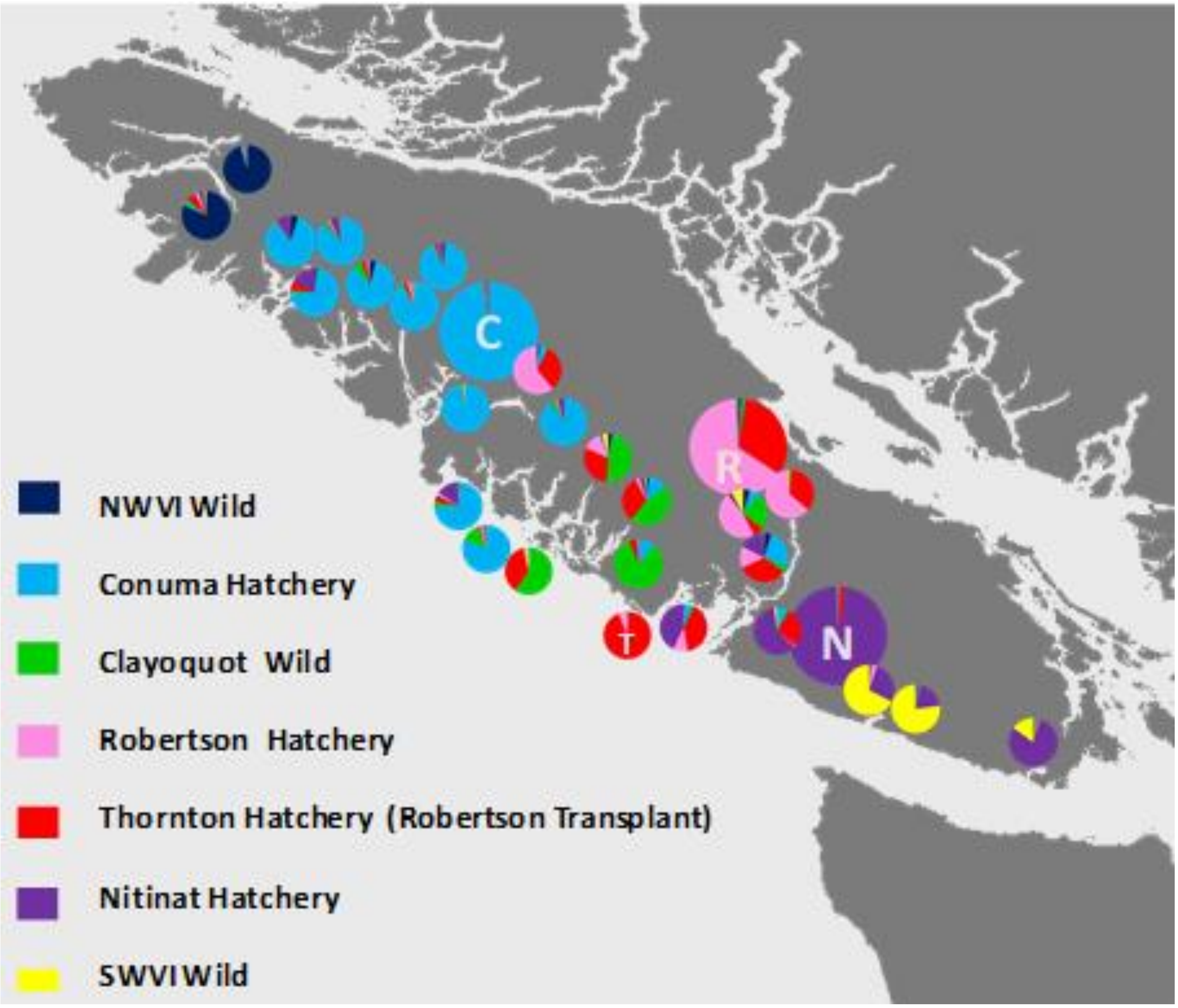


Figure 5.3. (from Withler et al. 2017). Genetic ancestries of Chinook populations sampled between 2013–2015 along the West Coast of Vancouver Island. The size of the pie slice indicates the average proportion of the sample identified by STRUCTURE analysis to be of a given genetic ancestry corresponding to the colour in the legend.

The degree of hatchery genetic influence within natural populations can be measured using the PNI metric and its components of proportion hatchery-origin spawners (pHOS) and proportion natural-origin broodstock (pNOB; HSRG 2014; Withler et al. 2018). Weil et al. (2024) reported that 60% of sampled WCVI spawning populations, including those with and without hatchery enhancement, had an average pHOS greater than 0.5, indicating that hatchery influence was dominating. We integrated all available data and knowledge from 2010 onwards (Table C-2) relevant to proportions of hatchery fish on WCVI Chinook to broadly categorize the populations into the Withler et al. (2018) designations (Table 4.4):

- **Integrated-hatchery**—Twelve populations are in this category. These include:
  - The three SEP major operations systems, on the Conuma, Stamp, and Nitinat rivers, each of which has a production facility with annual release targets exceeding 1 million Chinook, lead to high returns of over 10,000 adults per year, on average. Proportionate natural influence (PNI) in these rivers is generally less than 0.1. These production lines

  are for harvest and support major commercial, recreational, and First Nation fisheries, that are actively managed during fishing season.
  - An additional nine rivers are regularly enhanced and supported by a combination of community and federal hatcheries, including Burman, Gold, Hucuktlis, Leiner, Tahsis, San Juan, Sarita, Sooke, and Thornton systems. Most of these populations are enhanced primarily for harvest purposes, while others focus on rebuilding efforts. When the primary focus is harvest, these programs tend to place more emphasis on wild salmon values relative to the major hatchery programs mentioned above. Consequently, PNI guidelines may be implemented to limit production levels, as seen in the Sarita River, to ensure that natural influence is maintained to a higher degree. Work is needed to establish PNI benchmarks for more of these populations, along with the development of enhancement plans that set clear harvest and wild salmon goals, operate hatchery programs using scientifically sound methods, and ensure continuous monitoring and adaptive management. These nine populations experience significant ongoing hatchery straying, with an average $pHOS_{stray}$ of 0.22 (range: 0.03–0.56, where data are available).

- **Integrated-transition**—There is one population under this designation: Nahmint (average PNI = 0.59). Nahmint has also been high stray-in rates (average $pHOS_{stray}$ >10%), which led to the initiation of a genetic screening program on broodstock. This screening program has been in place since 2015 and has continued to present day. Production targets were also reduced in 2022 to help achieve integrated-wild status.

- **Integrated-wild**—There are five populations in this category:
  - Bedwell, Cypre, Tranquil: these populations are periodically enhanced and continue to experience straying issues. Previous contributions of strays into these systems are believed to be underestimated due to limited thermal mark sampling. Since the implementation of Conuma Chinook mass marking, snorkel counts have detected significant numbers of marked (clipped) fish, despite only limited marked natal releases into these systems.
  - Marble: Despite a production target of 1 million smolts, actual releases average only 184,000 smolts annually. This shortfall, combined with moderate natural-origin returns, results in a population that is predominantly wild.
  - Toquaht: Limited PNI data is available for Toquaht Chinook, but available data suggests the population is predominately wild. The origin of the current Toquaht Chinook is from previous transplants from primarily Nitinat River.

- **Wild-stray influenced**—There are eight populations in this category: Artlish, Kauok, Kauwinch, Megin, Moyeha, Sucwoa, Tlupana and Tashish. While data is limited, the $pHOS_{stray}$ rates across these systems appears to be high (>0.3), significantly exceeding the threshold recommended for maintaining long-term population fitness. According to Withler et al. (2018), a $pHOS_{stray}$ rate of less than 3% is advised to prevent the reduction of fitness in wild populations over time. The consistently high stray rate in these systems raises significant concerns about maintaining genetic integrity and ensuring the resilience of wild stocks, emphasizing the challenge of balancing hatchery practices with the conservation of wild salmon populations. It is worth noting that Sucwoa and Tlupana were formerly enhanced systems, with PNI designations of integrated-hatchery at the time. However, since the cessation of enhancement following 2012 and 2014 brood years, respectively, these populations have been appropriately redesignated.

- **Data deficient**—Low data availability precludes us from designating the remaining 52 Chinook populations. Many of these populations are in remote areas such as northern Clayoquot Sound, Esperanza Inlet, Kyuquot Sound, and Quatsino Sound. These systems have periodic enumeration surveys conducted by local First Nations fisheries guardians, local stewardship groups, or DFO staff/contractors depending on available funding. Based on extrapolations from these periodic assessments as well as watershed area and local knowledge, these small systems have low abundance and as an aggregate likely account for less than 5–10% of the total annual return of WCVI Chinook. These rivers are assumed to have the designation of Wild-stray influenced (>3% strays) or Wild (<3% strays), but influences from hatchery strays are likely significant in many of these systems. The full list can be found in Table C-2.

In summary, of the 20 enhanced populations in the SMU for which we have sufficient data (18), 12 (67%) exhibit an average PNI below 0.50. A PNI below 0.50 signifies that gene flow from the hatchery-origin population is predominant. Detailed PNI values by year and population along the WCVI are provided by Weil et al. (2024) (*q.v.* Figure 5.4 and summary data provided in Table C-2, Table C-4).

Annual PNI values along the WCVI are significantly lower than in other parts of southern BC (Figure 5.4). This level of hatchery genetic influence and introgression into natural spawning populations has been concerning to some local First Nations and other local knowledge holders (Sainsbury et al. 2024). Moving forward, PNI and pHOS$_{stray}$ thresholds need to be established on a river-by-river basis to preserve the genetic diversity and long-term fitness of populations across the CUs and SMU.

Once these thresholds are established, a variety of hatchery management tools—such as mass marking, program size reductions, mark-selective fisheries, stray screening/removal programs, selective broodstock collection, and genetic screening—can be employed to achieve the desired outcomes at the population, CU, and SMU levels. Comprehensive enhancement plans will be essential for documenting these population-specific goals and the tools necessary to meet them. More detailed discussion on these issues and the associated recommendations can be found in section 9.2.

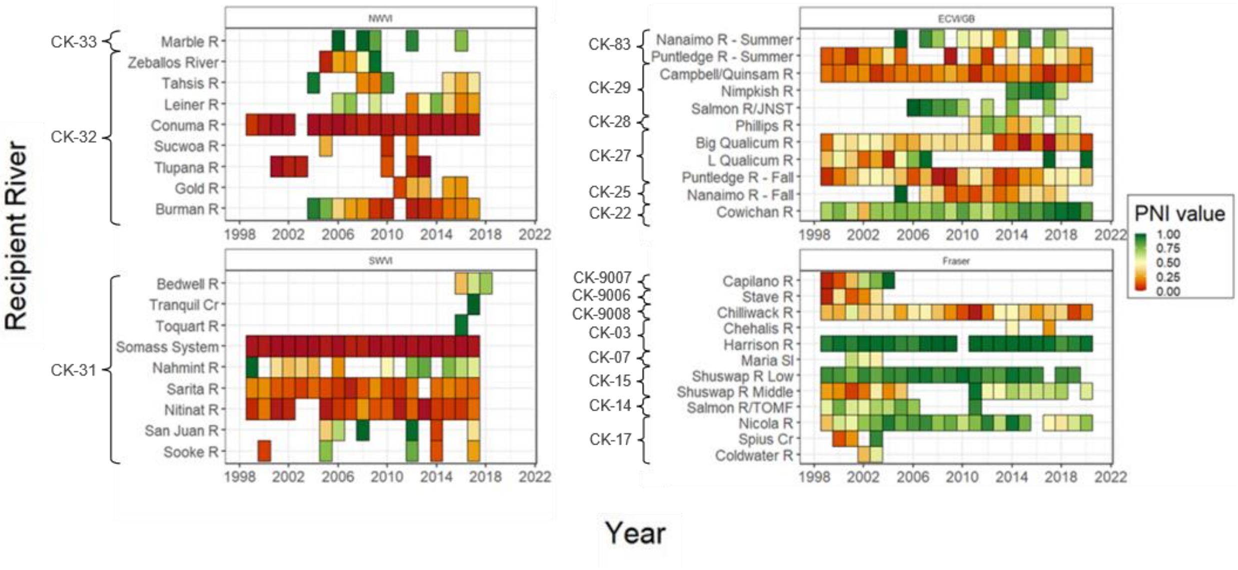


Figure 5.4 (from Weil et al. 2024). Heat map of proportionate natural influence (PNI) estimates calculated annually for rivers in SBC, presented by Conservation Unit (CU) and geographic region for 41 spawning populations. NWVI = Northwestern Vancouver Island; SWVI = Southwestern Vancouver Island; ECVI/GB = East Coast Vancouver Island/Georgia Basin; Fraser = Fraser River Drainage.

5.5. STATUS DUE TO DECLINE IN NUMBER OF EGGS RETURNING TO THE RIVER

In the recent decade there appears to be a divergence between the abundance of spawners and the number of eggs deposited (Figure 5.5), resulting from fewer and smaller spawning females, which is characterized as a broad shift in the demographics of WCVI Chinook.

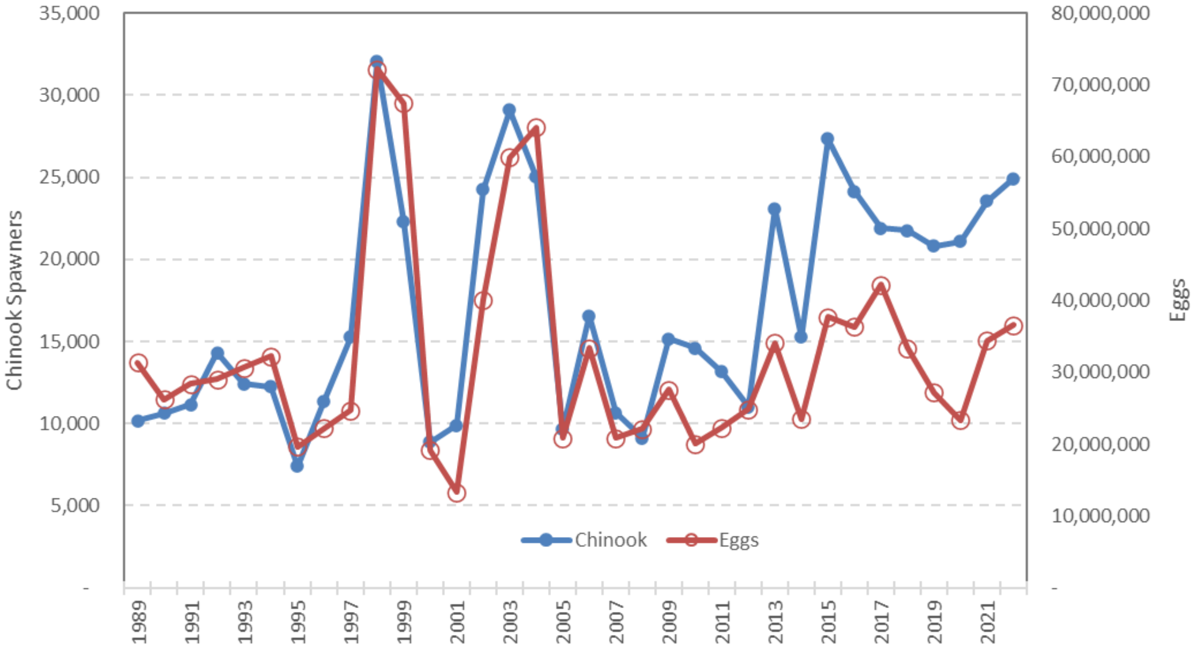


Figure 5.5. Chinook spawners and estimated eggs based on average annual age composition across the 17 escapement indicators (not including the 3 big hatchery systems) and average fecundity by age (3,000, 3,600, and 4,600 eggs for ages 3, 4, and 5 Chinook, respectively).

The demographic shift of WCVI Chinook populations includes declines in both age-at-maturity and size-at-age over recent decades (Figure 5.6., Figure 5.7., Figure 5.8.), suggesting that even under stable population sizes, 'effective spawner' abundances are declining (Ohlberger et al. 2020).

To assess whether WCVI Chinook have been getting smaller, we analyzed 15,781 biological samples collected from the WCVI sport fishery between 1983–2023 and 71,947 samples collected from WCVI escapement programs between 1998–2023. These data were fit with a linear mixed effects model (LMM), where year, data source (sport or escapement), age (3–5), and their interactions were included as fixed effects, and origin stock was included as a random intercept with a random slope of year to allow for stock-specific rates of change. The fitted model indicates that Chinook lengths are declining by approximately 5% (95% CI: 4–6%) per decade in sport fishery samples and by approximately 4% (95% CI: 3–5%) per decade in escapement samples (LMM; year × data source: $X^2_1 = 32.6$, $p < 0.001$; Figure 5.6., Figure 5.7.).

In addition to getting smaller, maturation rates are increasing in ages 3 and 4 Robertson Creek Chinook (PSC 2016; Figure 5.8.). While maturation rates are considerably higher in hatchery stocks compared to natural stocks (PSC 2016), some of the factors driving the increasing maturation rates in ages 3 and 4 Robertson Creek Chinook may have similar effects on maturation rates in other WCVI Chinook populations (discussed in section 8.4.5). Sex ratios in WCVI Chinook increasingly skew toward females as age-at-maturity increases, and fecundities of female Chinook increase as a function of body size.

The observed decreases in both size-at-age and age-at-maturity are thus compounding to reduce the numbers of eggs that are returning to WCVI rivers each year (Figure 5.5). These are not isolated trends; Chinook salmon from numerous populations along the Pacific Coast of North America have been getting smaller and younger over the past four decades (Ohlberger et al., 2018). Ohlberger et al. (2020) reported a decline in female size-at-age and egg size resulting in approximately 30% decline in the reproductive potential of Yukon River Chinook. They recommend that spawner quality should be considered when developing management reference points. Note that management of WCVI terminal fisheries has been incorporating age composition and fecundity by age into terminal management stock reference points.

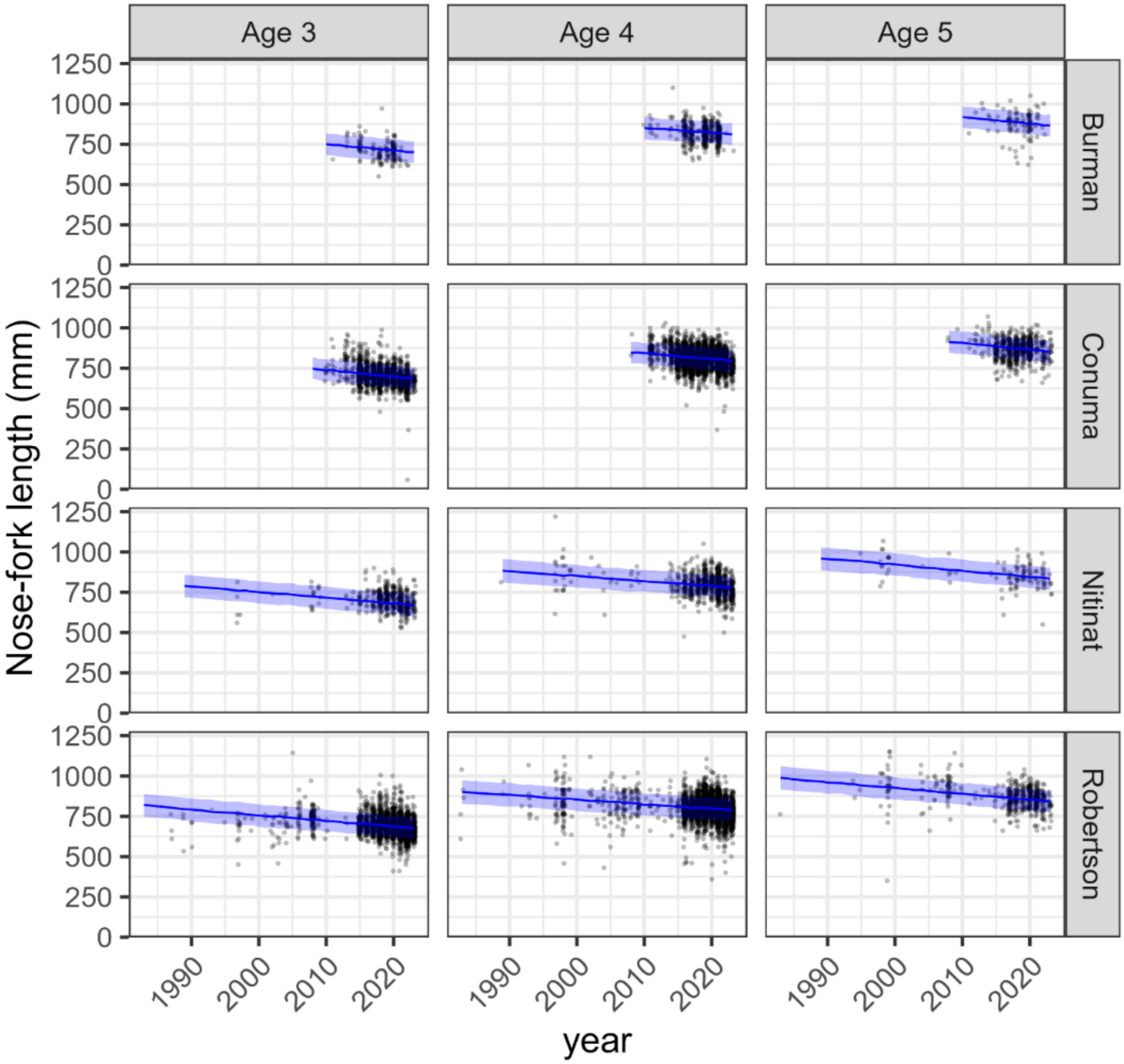


Figure 5.6. Time series of nose-to-fork lengths of WCVI-origin Chinook sampled in DFO creel surveys since 1983. Black points show measurements for individual fish and are jittered along the x-axis to reduce overlap among points within each year. The blue lines and shaded areas show linear mixed effects model predictions and 95% confidence intervals, respectively, for each stock and age. Only stocks with ≥10 years of data were considered. Data availability is considerably higher in the last decade owing to the expansion of biological sampling in the creel program, which has allowed many more fish to be aged and assigned to a natal stock.

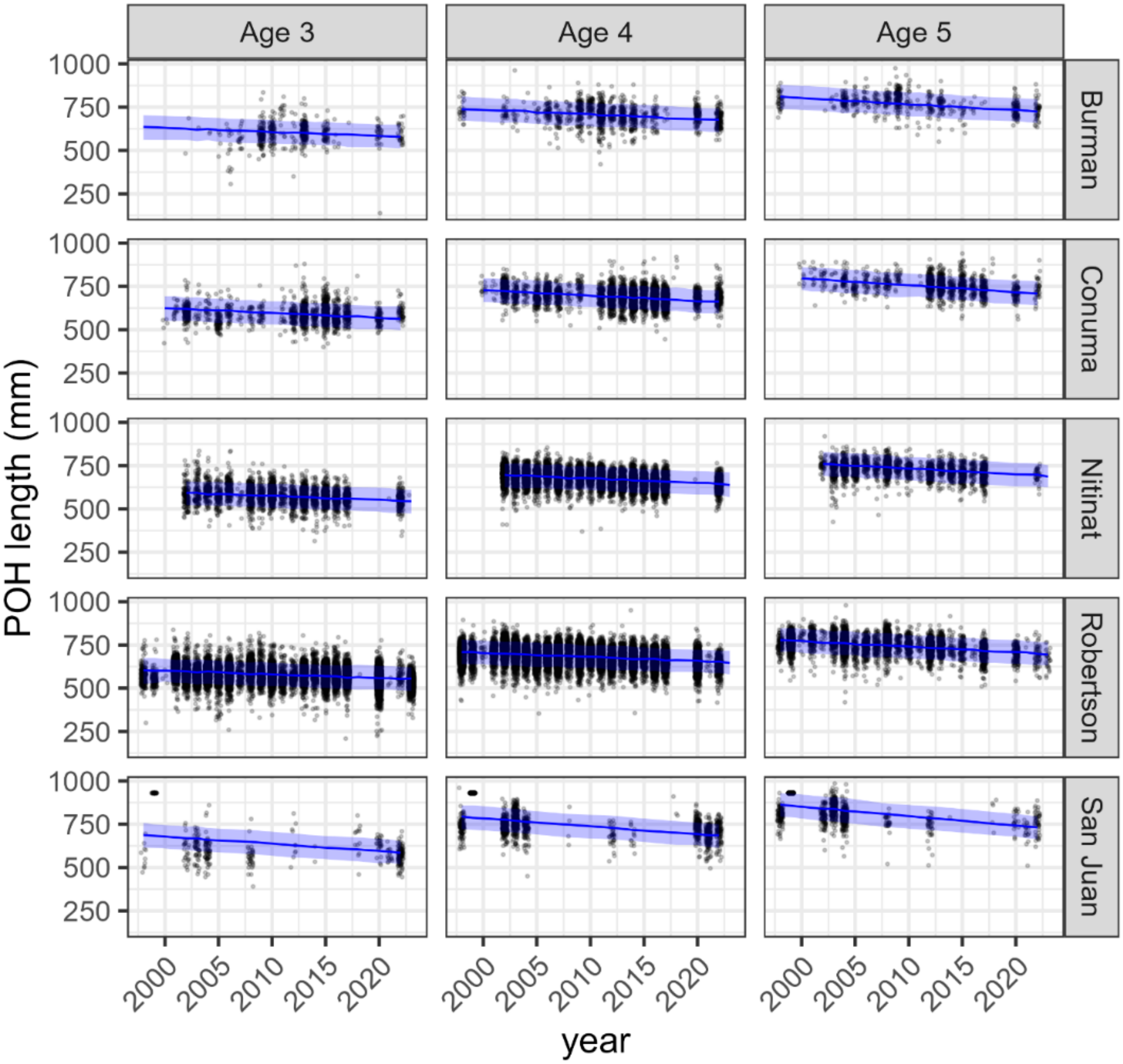


Figure 5.7. Time series of post-orbital to hypural (POH) lengths of WCVI-origin Chinook sampled in escapement programs since 1998. Black points show measurements for individual fish and are jittered along the x-axis to reduce overlap among points within each year. The blue lines and shaded areas show linear mixed effects model predictions and 95% confidence intervals, respectively, for each stock and age. Only stocks with ≥10 years of data were considered.

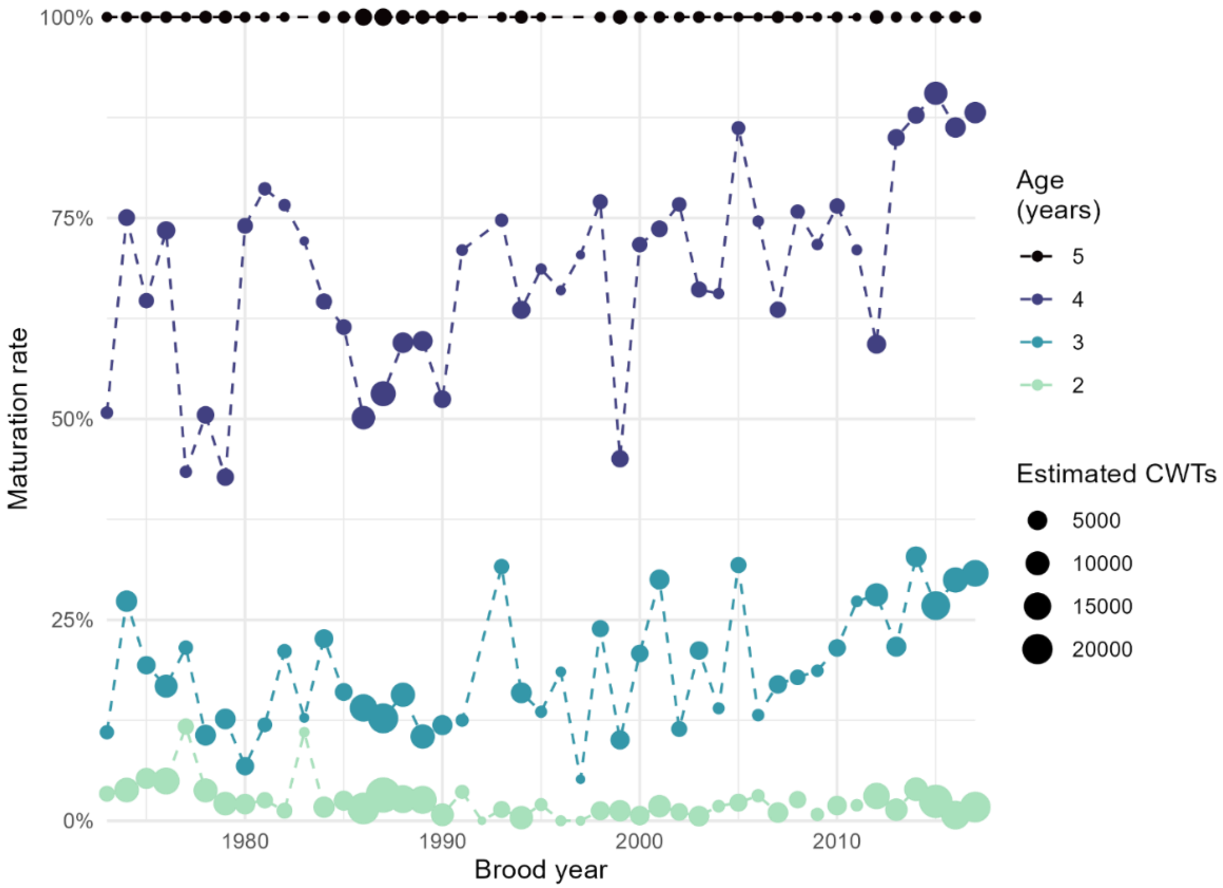


Figure 5.8. Estimated maturation rates (proportion of Chinook at each age that return to spawn) of Robertson Creek Hatchery Chinook. Estimates are based on a cohort analysis of CWT data that is conducted annually by the Chinook Technical Committee of the Pacific Salmon Commission (CTC 2023a).

5.6. STATUS SUMMARY

- Natural-origin Chinook within this SMU should be considered as critical status, for reasons of low returns in key natural populations especially in Clayoquot Sound, loss of genetic diversity across the SMU and so likely loss of resilience and potential for rapid rebuilding, and changing demographics with fewer eggs due to fewer and smaller spawning females. This critical status aligns with status relative to CU-status LRP derived from the rapid status algorithm which is determined from core natural-origin escapement indicators, but in contrast to CU-status LRP, the approach here includes consideration of genetic influence/introgression from hatcheries and demographic variability, which are currently only indirectly considered in CU-status assessments (Appendix D).
- Indicator populations considered to be ‘wild’ or ‘wild-stray influenced’ (Withler et al. 2018) appear to be persisting at low levels, since the precipitous decline in the 1990s. The smaller, less productive populations in Clayoquot Sound continue to be the focus of the concern. Other populations in the Withler et al. (2018) categories of ‘Integrated-wild’ and ‘Integrated-transition’ are being supported by hatchery production. The hatchery production cannot be visually differentiated from natural-origin Chinook resulting in uncertainty in status of the natural-origin fish in these systems. Recent assessment of hatchery influence and introgression (PNI and $pHOS_{stray}$, respectively,) from local hatchery production and

out-of-basin strays in Weil et al. (2024) suggested a majority of surveyed populations should be categorized as ‘Integrated-hatchery’, indicating that hatchery genetic influence is dominating.

- Assessing status on an abundance-based LRP proved to be problematic for the WCVI because of diversity in status among components populations that tend to be discounted at aggregate scales. Status assessment should carefully consider a broad suite of methods, including those that capture distribution among natural-origin populations, and broad understanding of the SMU and the ecosystem the fish depend on.
- To derive SMU status, we recommend pairing CU statuses with other reference information, such as:
    - population-scale assessments indicating persistent poor status of escapement indicators within Clayoquot Sound
    - high levels of hatchery influence across large portions of the SMU
    - reductions in age and size at maturity likely reducing population productivity
    - low smolt to adult survival rate
    - or other specific components of the natural-origin life cycle

6. FACTORS LIMITING STOCK PRODUCTIVITY

Here we expand on limiting factors identified in previous sections, focusing on probable causes of decline for natural-origin Chinook. Major sources of information are COSEWIC (2020), Weil et al. (2024), Holt et al. (2023b), Irvine et al. (2024) and unpublished freshwater risk assessment data and reports (available from West Coast Aquatic, Port Alberni, BC).

Recent risk assessments evaluated probable causes for the decline and persistent low abundance of natural-origin WCVI Chinook using the Risk Assessment Methodology for Salmon (RAMS; Irvine et al. 2024). RAMS was applied during workshops where users assessed the degree to which declines in the productive capacity of salmon resulted from specific biological factors or environmental states. Also assessed was the expected outlook within the context of anticipated (year 2050) climate change impacts, whether through changes in biological or ecosystem processes or environmental states. RAMS is based on risk assessment guidelines developed by US EPA (1998), FAO and WHO (2008), and DFO (2013) as well as an approach used by Hobday et al. (2011) to inform ecosystem-based fisheries management in Australia. RAMS is a multi-level iterative process with review and reassessment as new information improves understanding of the biology-ecosystem linkage. Technical, Indigenous, and other local knowledge holders were important participants at all workshops (Irvine et al. 2024).

Freshwater RAMS workshops focused on 20 WCVI rivers and their estuaries; a WCVI-wide summary is currently under review. Seven marine RAMS workshops focused on the following key probable causes of decline:

1. basin-scale oceanographic processes
2. water quality, contaminants
3. pathogens, parasites, harmful algae
4. nutrition and prey
5. predation
6. hatchery
7. harvest

Irvine et al. (2024) summarizes the marine risk assessment process and results, including the identified highest risks, priority knowledge gaps, and recommendations for further assessment and mitigation.

6.1. ASSESSMENT OF PROBABLE CAUSES OF DECLINE

Principal factors limiting the productivity and survival of natural-origin WCVI Chinook salmon are summarized by life stage, primarily from the freshwater and marine workshops held over the last several years (Table 6.1). In the text following, major factors were categorized, independent from life stage. A weakness in our approach was that most limiting factors were evaluated independently from each other. Yet we know there are many interactions in any ecosystem. For example, as water temperature increases, the amount of oxygen that can be dissolved in water declines, which can have deleterious consequences to salmon. It is beyond the scope of this report to document all the interactions potentially affecting WCVI Chinook, whether negative or positive. Future research should evaluate the cumulative, antagonistic, and synergistic interactions among factors identified as high risks. Moreover, we require a greater understanding of the mechanistic relationships between human activities and resultant risks. Ecosystem modelling can address cumulative and synergistic associations among factors, especially as they pertain to climate change and anthropogenic activities that could be mitigated.

Table 6.1. Summary of highest ranked limiting factors affecting natural origin-WCVI Chinook survival during major life stages as determined through freshwater and marine risk assessment workshops.

Life Stage	Limiting Factors and Mechanisms (Interactions with Climate Possible at all Stages)
Adult upstream migration	Climate change leading to low and variable river discharge. Habitat degradation altering channel morphology, limiting or delaying access to spawning grounds.
Adult spawning	Climate change and habitat degradation increase the frequency and intensity of peak flow events, destabilizing spawning gravel and increasing bedload movement, scour, and sedimentation. Reduced spawning success due to unstable conditions for egg incubation. Changing demographics: smaller females dig shallower redds and produce fewer eggs. Genetic input from hatchery fish (particularly stray hatchery fish) reduces genetic and demographic diversity, impacting the fitness of future generations.
Egg incubation and fry emergence	Climate change and habitat degradation exacerbate the frequency and magnitude of peak flow events, disrupting sediment regimes (e.g., surplus sediment, changes in composition, bedload movement). Egg displacement and disruption of fry emergence due to altered sedimentation and scour.
In-river rearing	Degradation of freshwater habitats reduces habitat complexity, variety, and connectivity. Limited rearing space, reduced fish growth, and lower survival rates. Increased reliance on estuarine habitats for rearing.

Life Stage	Limiting Factors and Mechanisms (Interactions with Climate Possible at all Stages)
Estuarine rearing and first marine winter	Carry-over effects from freshwater stages (e.g., smolt size and readiness) impact survival in estuarine and marine environments. Phenological mismatches between prey availability and smolt migration timing. Changes in river discharge patterns increase sediment deposition, reducing habitat complexity. Habitat degradation in the estuary (e.g., loss of salt marsh and eelgrass). Competition with larger hatchery smolts and juveniles for prey. Predation by birds, fish, and seals. Exposure to pathogens, parasites (e.g. sea lice), and toxic contaminants.
Later marine Residence (1–5 years)	Interspecific competition with hatchery salmon and other salmon species for limited prey. Demographic declines in size-at-age and age-at-maturity driven by size-selective natural and fishery mortality.
Return migration to WCVI natal rivers	Habitat degradation and climate change can alter holding habitat and behaviour by delaying access to rivers, which increases Chinook vulnerability to predation, primarily by marine mammals such as seals and sea lions that exploit Chinook at key geographical bottlenecks like river mouths.

6.2. FISHING

Recognizing declining productivity and the impacts of consecutive El Niño periods in the 1990s, a suite of fishery management measures was implemented through the Pacific Salmon Treaty and domestically within the IFMP (DFO 2023a), commencing in 1995, the return year for age 4 Chinook that entered the ocean in 1992. Despite decades of precautionary fishery management intended to promote stock growth, WCVI natural-origin Chinook abundance has remained low for the most recent 7 generations (~25 years), especially in Clayoquot Sound.

Fishing mortality of natural-origin Chinook is estimated by determining Calendar Year Exploitation Rates (CYER; CTC 2023b)—which include release mortalities (see CTC 1997; Appendix D in CTC 2023a)—from regulated non-terminal fisheries for Robertson Creek Hatchery Chinook released with CWTs. Tags are retrieved annually from various fisheries and in spawner escapements. Non-terminal CYERs for the WCVI Chinook SMU have been ≈35% over the last 20 years (Figure 6.1). Approximately 50% of the non-terminal harvest occurs in southeast Alaska (Figure 1.1.), in accordance with Chapter 3 of the PST agreement on Chinook fisheries. Canadian fisheries extend from northern BC south through the WCVI. Terminal fisheries are not included in the 35% CYER as they are directed at Chinook from the Conuma and Robertson Creek Hatchery populations, and therefore intercept few natural-origin Chinook. Also not included are unsanctioned and illegal fisheries, for which gathering better information is recommended (Irvine et al. 2024).

The sustainability of the current fishing regime was assessed using “Kobe plots” (FAO 2007; Merino et al. 2020; Figure 6.2) that were designed using the two candidate methods for developing U_{MSY} and S_{MSY} (see section 4.3.2). Exploitation rates have been consistently below the estimated U_{MSY} for the stock aggregate across all areas and age classes since the mid-1990s, suggesting fisheries have likely been operating within sustainable limits. Recent exploitation rates correspond to a low probability of causing further stock declines and do not appear to be impeding stock rebuilding. However, as documented below, several limitations with this analysis result by not considering age-specific exploitation rates, the broad spatial distribution of fish and fisheries, and relying on hatchery-origin salmon to represent natural-origin and wild salmon.

WCVI Chinook are vulnerable to marine fisheries across several ages, with most recruiting to fisheries beginning at age 3. Their broad spatial distribution means that northern salmon fisheries harvest a mixture of rearing and mature Chinook, while central coast and southern BC fisheries encounter mostly mature salmon migrating home to WCVI rivers. Because older fish are exposed to more fisheries over their lifetime than younger fish, and some fisheries may target larger and older fish, recent average exploitation rates on large age 5 fish have been as high as 50% (Figure 6.3), considerably higher than the average exploitation of 35%. Removing large, predominantly female salmon is problematic in several ways—including that large females tend to produce more eggs and dig deeper redds than smaller females, removing them may decrease resiliency to climate change impacts, such as extreme river discharge events.

The recent marine risk assessment rated fisheries-related demographic changes caused by size-selectivity in fisheries targeting returning Chinook as high-risk during the current period, increasing to very high in the future (Irvine et al. 2024). Demographic changes included reduced sizes and proportions of female spawners as well as their fecundity, egg size, and redd depth. Overfishing of mature returning Chinook in regulated fisheries was rated as Moderate Risk.

Actions to reduce fishery impacts have been implemented along the WCVI in terminal fishing areas, including area closures adjacent to estuaries, spot closures along the return migration path, reductions in daily limits, and maximum size limits. A fork length of 80 cm as a maximum for retention in the recreational fishery has been implemented in some areas and times to protect large females.

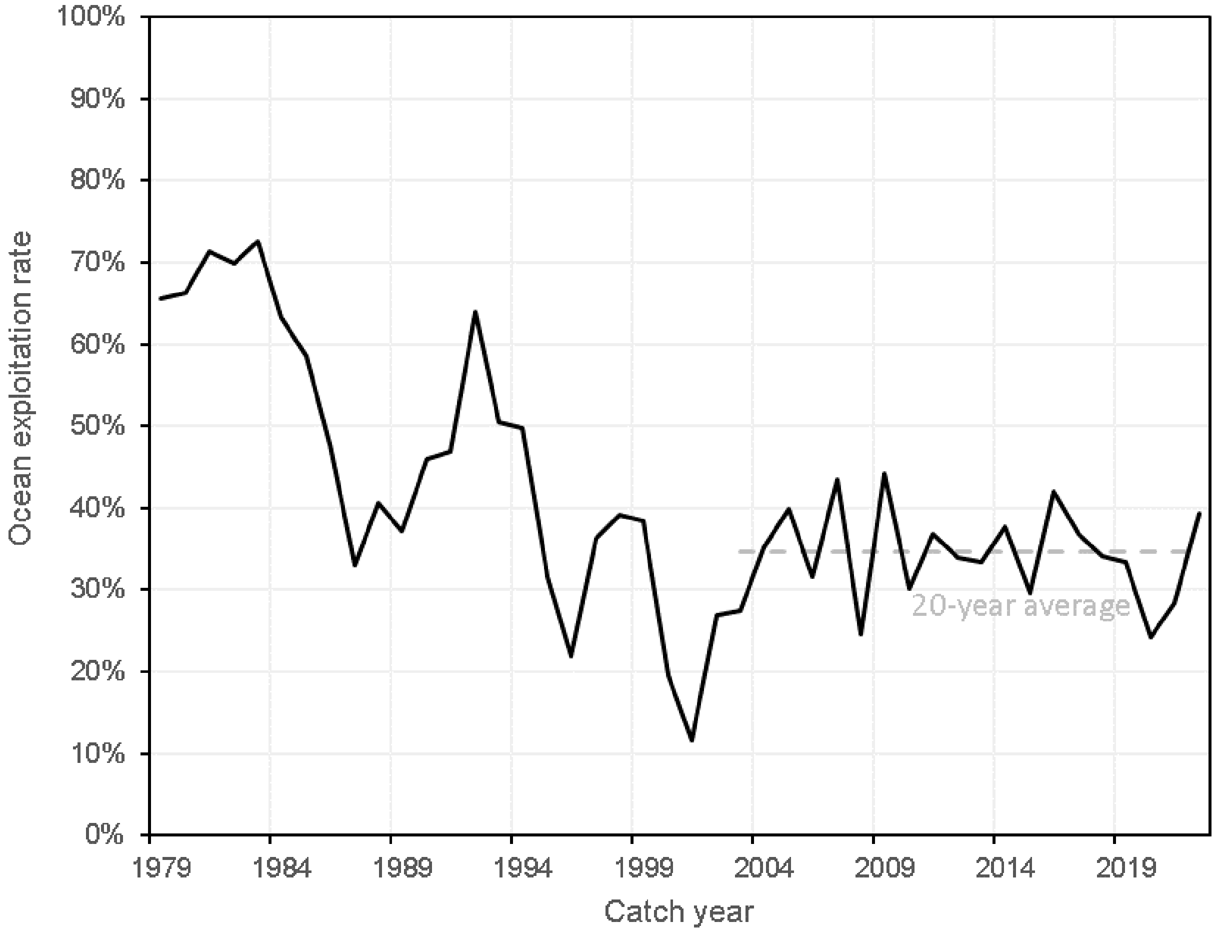


Figure 6.1. Estimated catch year exploitation rates on WCVI Chinook in pre-terminal fisheries. Data are from the CTC's annual exploitation rate analysis of Robertson Creek CWT recoveries (e.g., CTC 2023b). The recent 20-year (2003–2022) average exploitation rate is 35%.

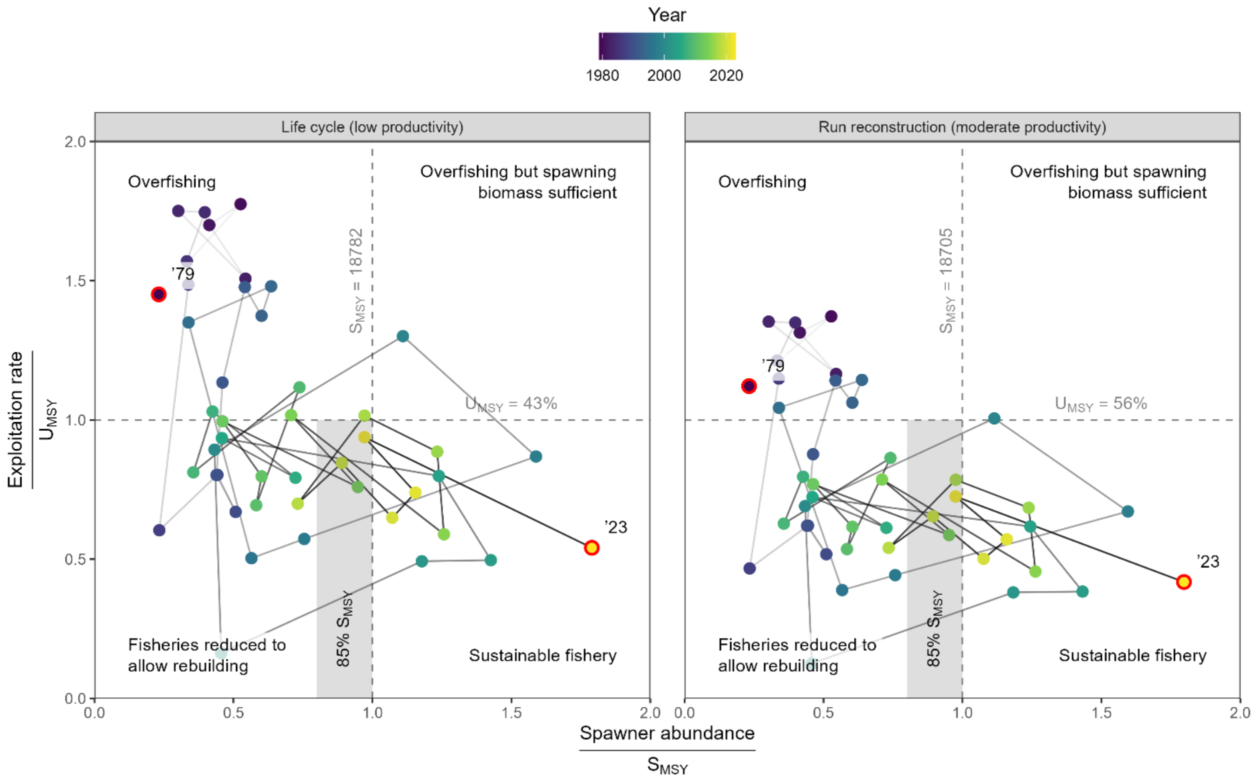


Figure 6.2. Kobe plots of WCVI Chinook exploitation and spawning escapement, under low and moderate productivity assumptions. The numerator data are the same in both panels—"spawner abundance" is the sum of escapements to the 17 escapement indicators (Table 4.), and "exploitation rate" is the estimated ocean exploitation rate on Robertson Creek Hatchery Chinook (Figure 6.1). S_{MSY} and U_{MSY} are based on different assumptions in each panel. Under the life cycle model (left panel), U_{MSY} and S_{MSY} assume constant productivity across the SMU (Figure 4.2). Under the run reconstruction model (right panel), U_{MSY} and S_{MSY} stem from the equilibrium trade-off analysis (section 4.3.2; Figure 4.4.). The shaded line connects points from adjacent years; the connecting line darkens as years progress toward 2023, the most recent year. The first and last years in the time series (1979 and 2023, respectively) are labelled '79 and '23 for clarity. The shaded grey area shows years when spawner abundances were >85% S_{MSY} with harvest rates below U_{MSY}.

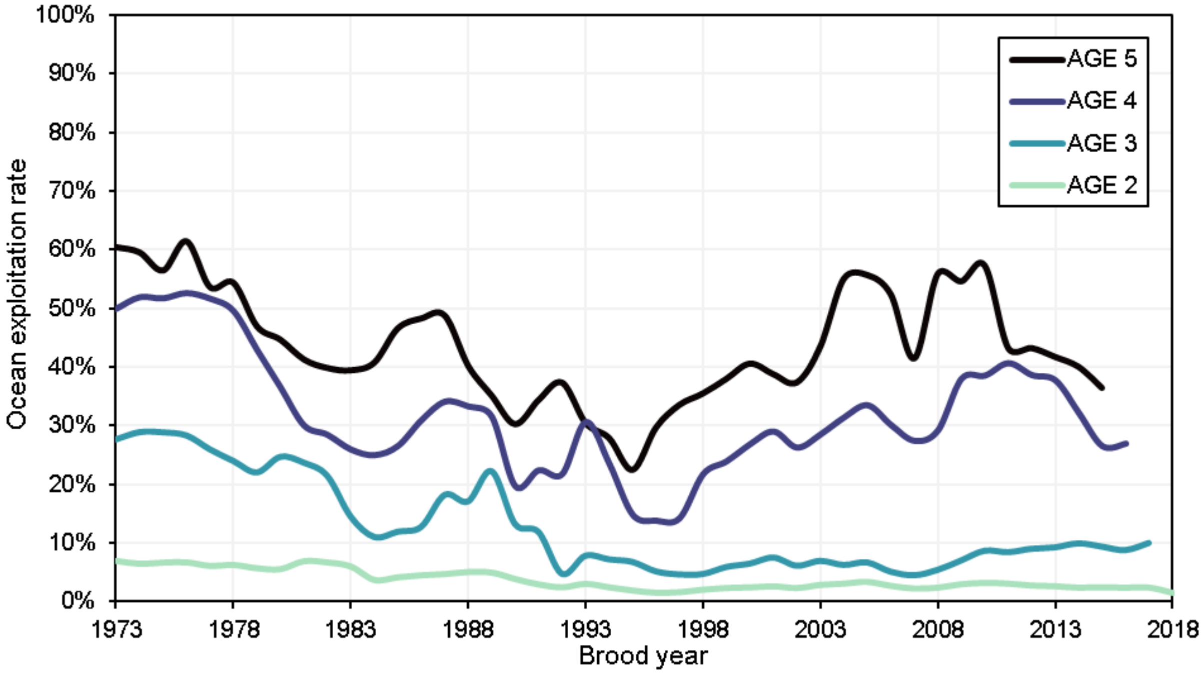


Figure 6.3. Three-year rolling average age-specific exploitation rates of WCVI Chinook in PST-monitored pre-terminal fisheries for brood years 1973–2020. Data for 5-year-old Chinook from 1983, 1992, and 1997 were omitted due to low CWT recovery numbers that generated anomalous estimates. Annual exploitation rates were estimated by cohort analysis using Robertson Creek Hatchery Indicator Stock CWT recoveries. Brood years are plotted along the x-axis to group fish from the same cohort, e.g., Chinook of all ages from brood year 2000 would have migrated to the ocean together in early 2001 and been susceptible to being caught in pre-terminal fisheries as age-2's in 2002, age-3's in 2003, etc.

6.3. HATCHERIES AND HATCHERY-ORIGIN FISH

There is extensive literature describing the effects of hatcheries on natural-origin and wild salmon including Anderson et al.'s (2020) comprehensive review of the biological, social, and economic benefits and risks of Washington State salmon hatcheries. Withler et al. (2018) describe how to assess hatchery genetic influence on Canadian Chinook populations and determine quantitative benchmarks. Recently, Irvine et al. (2024) built upon these earlier works in their assessment of the key marine risks posed by hatcheries and hatchery fish on natural-origin WCVI Chinook physiology, survival and fitness.

Although estimates of wild and natural-origin Chinook abundance prior to the initiation of hatchery production are sparce, there is consensus that returns to the WCVI increased markedly because of the hatcheries (Figure 5.1). Approximately 15 million juvenile hatchery Chinook are released annually into 20 rivers (Figure 6.4). Recent adult abundance estimates average around 250,000, of which approximately 85% are hatchery-origin (Figure 3.2). As mentioned earlier in this document, hatchery production provides significant economic and social benefits to First Nations, commercial, and recreational fishers and others. However, high levels of hatchery production are known to negatively impact *wild* Chinook populations (Anderson et al. 2020). In their recent risk assessment for WCVI Chinook using RAMS, Irvine et al. (2024) ranked current and future hatchery associated risks for losses of diversity, competition, predation, and diseases or pathogens. The next several paragraphs are adapted from their report.

Facilitated workshop discussions resulted in consensus that there was a Very High Risk of effects from hatchery Chinook on the fitness of natural-origin WCVI Chinook due to impacts on genetic and/or demographic diversity. Confidence in this assessment was moderate. Evidence provided showed declining genetic diversity due to hatchery introgression into natural-origin stocks (e.g. genetic homogenization towards the three largest enhanced populations on WCVI: Nitinat, Stamp, and Conuma). This was particularly true in Nootka Sound where there are high stray rates into some systems. Long-term genetic integrity was also highlighted as a concern for some enhanced WCVI systems, many of which had an estimated PNI less than 0.25 (Figure 5.4; Table C-4; Irvine et al. 2024).

Hatcheries also have the potential for large magnitude ecological impacts on natural-origin salmon populations although these are not fully understood, nor adequately evaluated or assessed. Partial to complete diet overlap between natural- and hatchery-origin Chinook occurs for at least some life stages, suggesting possible competitive impacts. Impacts of inter/intraspecific competition from hatchery fish was scored as a High Risk that could result in reduced growth, fitness and survival of natural-origin WCVI Chinook during early marine rearing, and evidence was presented on the similarity of diets between hatchery- and natural-origin fish. Risk was scored as Very High in the future because of climate change impacts on the food web and possible enhanced competitive pressures due to lower prey abundance. However, confidence in the assessment of inter/intraspecific competition was low for both juvenile and adult salmon. Numerous data gaps were identified related to impacts of competition during later life stages, including by hatchery- and wild Pink and Chum salmon in the Gulf of Alaska. Increased predation on natural-origin adult salmon (e.g., by marine mammals) because of large numbers of hatchery fish was also rated High although confidence was low (Irvine et al. 2024).

Hatchery spawning practices, particularly random mating—the current guideline implemented by SEP programs—can have both positive and negative impacts on salmon population genetics, including the size and age-at-return of salmon populations (DFO 2024c). Random spawning protocols, while aiming to avoid deliberate directional selection, may inadvertently reduce the selection pressures found in natural environments. In the wild, larger individuals often have advantages in accessing mates and defending prime spawning grounds, which helps maintain larger body sizes and older ages of return in the population. Artificial mating in hatcheries can remove these advantages, potentially selecting for smaller, younger fish over time, as larger body size does not confer any competitive advantage in hatchery programs where random spawning is implemented (i.e. an inadvertent directional “lack” of selection relative to natural spawning). This lack of selective pressure for larger fish may lead to decreased fecundity and fitness, as larger females typically produce more eggs.

While hatchery practices, such as random spawning, may contribute to the declining size and age-at-return of WCVI Chinook salmon, other factors are also likely at play. Environmental changes, including ocean warming and altered food availability, as discussed in other sections, can influence growth rates and age-at-maturity. Additionally, fishery-mediated selection, where larger salmon are preferentially harvested (*q.v.* section 6.2) exacerbates these trends by disproportionately removing larger, older fish from the population. Another factor may be predation, particularly by Killer Whales, which are believed to preferentially target larger salmon, further reducing the average size of returning adults (Ohlberger et al. 2019). Studies have noted similar declines in non-enhanced populations, suggesting that these trends may be driven by a combination of hatchery practices, environmental pressures, and predator dynamics, rather than hatchery practices alone. Nonetheless, it is recommended that hatchery practices evolve to better reflect natural selection processes. By aligning spawning practices more closely with natural conditions, hatcheries could help address issues related to declining size and age-at-return, including other maladaptive selection pressures.

Finally, the marine risk assessment workshop examined whether hatcheries and hatchery production could result in more pathogens, increased pathogen richness, and/or pathogen transfer from hatchery to natural-origin fish. There were few differences between hatchery- and natural-origin fish in pathogen richness and there was little evidence that hatcheries posed a pathogen transfer risk (Irvine et al. 2024).

Pilots are underway along WCVI to address low PNI and assist with stray management: Conuma, Sarita, Thornton, Robertson, Gold, Tahsis, Leiner, and San Juan Chinook populations are being mass marked. Huu-ay-aht First Nation in collaboration with Nitinat Hatchery have implemented a plan to maintain hatchery production but improve PNI by selective terminal harvest of hatchery marked Chinook in the Sarita while targeting unmarked Chinook for broodstock. To improve survival and fitness of hatchery Chinook and reduce ecological interactions between hatchery and natural-origin Chinook, SEP has implemented measures to reduce and minimize effects from straying on natural-origin salmon such as relocating seapens closer to natal estuaries/freshwater influence and switching from seapen releases to river or lake releases to improve imprinting on natal river (Irvine et al. 2024).

Many risks remain as knowledge gaps and the need for continued and improved monitoring, open data, PNI management, assessment of interactions between natural- and hatchery-origin fish throughout their life cycle, as well as evaluation of the potential for pathogen transfers were highlighted as key data needs and knowledge gaps. Ultimately, given the potential for severe genetic and ecological risks of hatcheries, addressing these knowledge gaps is highly recommended (Irvine et al. 2024).

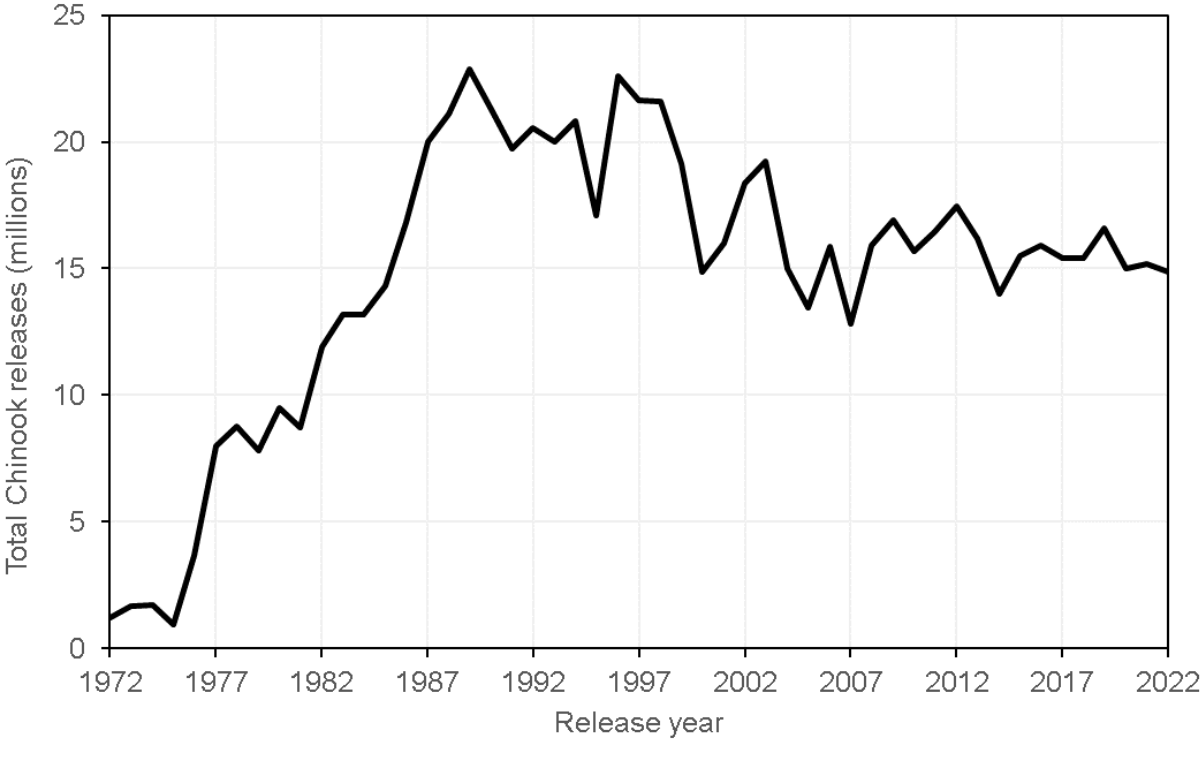


Figure 6.4. Time series of Chinook smolts released from all WCVI hatcheries. The vast majority (99.8%) of smolts are released as young-of-the-year (i.e., after ~90 days in the hatchery)—0.2% of smolts in the time series are released as yearlings (i.e., after ~1 year in the hatchery).

6.4. PHYSICAL HABITAT IN FRESHWATER AND ESTUARIES

Habitat factors that directly limit natural production were assessed several times over the last nine years, most recently during 2021–2023, resulting in the identification of various *high* and *very high* risk factors (*italicized*) listed by life stage:

- Adult upstream migration: Migration occurs primarily in August/September although timing and survival can depend on river discharge, physical barriers, and temperature. *High water temperatures* and *low discharge* in autumn are often barriers that delay upstream migration, especially for early migrating fish and populations (Figure 6.5).
- Spawning: Peak spawning generally occurs from late September to mid-October although it can vary by a couple weeks depending on timing of upstream migration and water conditions. Chinook tend to spawn in middle reaches of watersheds, upstream of areas of smaller substrate used by chum salmon. In many systems, strays from neighbouring rivers augment natural-origin spawners. In some systems and years, adult mortality can also occur from diseases/parasites and predation. *Unstable riverbed gravels* result from *high river discharge*; resulting *bed load movement, scour, and sedimentation* increases egg displacements because smaller females (changing demographics) with reduced fecundity dig shallower redds.
- Egg incubation: Eggs develop into alevins during the winter following spawning with fry emergence from the spawning gravel early the following spring. Mortalities can be high depending on river scour, sand/silt deposition, predation, and multiple redd construction in limited spawning habitat. *High peak flows* during winter and subsequent *scouring of redds* further increases mortality due to egg displacement. *High winter temperatures* can accelerate egg development, resulting in earlier than optimal hatching, which may result in mismatch with food availability.
- Fluvial rearing and downstream migration: Almost all fry leave freshwater within 3 months following emergence, typical of “ocean-type” Chinook. COSEWIC (2020) determined that the loss or degradation of freshwater rearing habitat was a primary reason for the apparent decline in WCVI salmon. Subsequent freshwater risk assessments confirmed that the quality and quantity of suitable freshwater and floodplain habitat for freshwater rearing were serious concerns, more so in the NoKy than SWVI. This was particularly true in logged watersheds such as the Sarita, while of little concern in unlogged watersheds such as the Megin and Moyeha. *Spring droughts* move river margins away from riparian vegetation, reduce rearing habitat, fish growth and time spent in freshwater increasing reliance on estuaries.
- Estuarine and early near-shore rearing: Most WCVI Chinook remain in coastal waters close to WCVI until the end of their first winter and then appear to begin a generally northward migration. *Changing river discharge* patterns causing *increased sediment loads reduces sedge grasses, eel grass, and overall habitat complexity* that increases mortality of young salmon. The perceived risk to natural-origin Chinook of losing *nearshore marine habitat* was high, as was *changing water quality* (*water temperature, dissolved* 0_2, and *contaminants* while future risk ratings were generally higher, as expected with climate change (Irvine et al. 2024).

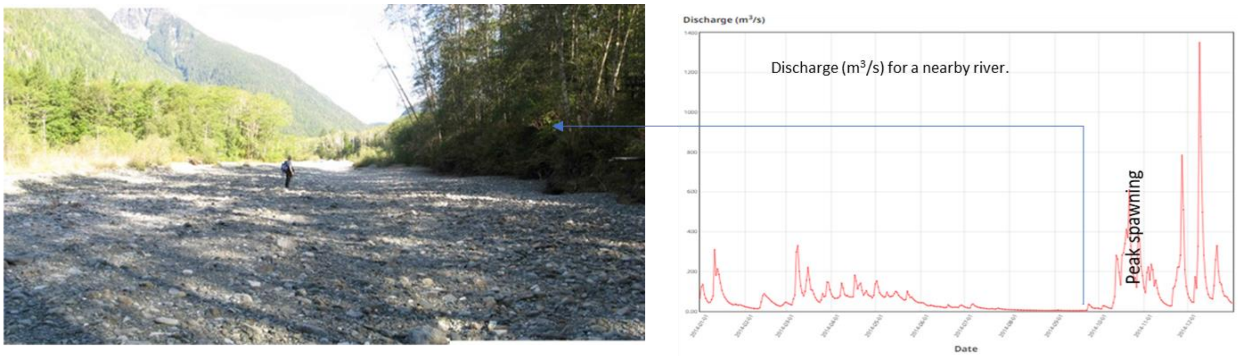


Figure 6.5. Low flow-caused upstream migration barrier in the Tahsis River, WCVI, 4 Sept 2014 (left side), normally near peak upstream migration (blue line extending from right side hydrograph. Rain shortly after increased flows, allowing spawning in early October (right side).

Carry-over effects between freshwater and early marine life stages, which can be related to smolt size and readiness (habitat availability), freshwater pathogen loads and toxin exposures (habitat suitability) were perceived by marine risk workshop participants as high risk, increasing to very high in the future (Irvine et al. 2024). Ongoing research and monitoring in the Sarita River documented that most smolts leave by mid-April and their size is relatively constant (40–45 mm and ≈0.5 g; Figure 3.10). However, there are other smolts, far fewer in number, that leave later in the spring (Figure 3.9).

Recent research applying laser ablation techniques to determine saltwater entry size of surviving adult salmon returning to the Sarita River found that small smolts produced ~50–60% of the natural-origin return while the much less abundant larger smolts produced ≈40%, and they survived at about twice the rate as similar sized hatchery smolts (Figure 3.14; Quindazzi, University of Victoria, Victoria, British Columbia personal communication). These findings reinforce the value of conserving important habitats in both freshwater and estuaries and suggest potentially significant stock rebuilding benefits by increasing their amounts and quality.

6.5. ECOLOGICAL CHANGES IN THE MARINE ECOSYSTEM

Here we consider effects of marine ecological changes not directly pertaining to physical habitat that can occur at various times during their marine lives. As mentioned, most WCVI Chinook remain in coastal waters close to WCVI until the end of their first winter and then migrate primarily northward. Their nearshore distribution early in this life phase may provide some buffer against deleterious effects from large scale oceanographic events such as the ‘blob’ of warm ocean waters in the north Pacific from 2014–2016 and again in 2019, which reduced survivals for WCVI Sockeye and Chum salmon that migrate offshore. Nevertheless, the marine risk assessment concluded that the exposure of WCVI-origin Chinook to local risk factors was very high.

The following were identified as high and very high risks for WCVI Chinook during their early lives in the nearshore marine ecosystem (Irvine et al. 2024):

- carry-over effects between freshwater and early marine (e.g., small smolts are more vulnerable);
- strong and/or frequent El Niño events reducing marine survival;
- reduced fish health due to marine pathogens/parasites in areas where infection rates are high (see for example a recent article highlighting conservation concerns for wild salmon from pathogens spread from salmon aquaculture; Krkosek et al. 2024);

- reduced prey abundance or quality or phenological mismatch;
- lack of physical habitat refugia;
- poor water quality, high temperature and low dissolved oxygen, contaminants;
- hatchery competition;
- bird and fish predation.

High and very high risks for maturing adults during their extended (1–6 years) marine residence in northern BC and Alaskan waters as well as while migrating back to terminal WCVI areas to spawn included (Irvine et al. 2024):

- strong and/or frequent El Niño events reducing marine survival,
- competition for food / prey abundance,
- predation by pinnipeds and other species such as salmon sharks.

There was significant uncertainty in some risk rankings at all marine life stages. A collaborative suite of research projects was initiated to ‘Follow the Fish’ from smolt outmigration through the first year at sea. Recommendations for early and later marine life stage projects are provided in the marine risk assessment report (Irvine et al. 2024).

6.6. PREDATION

Predation can have significant effects on salmon, especially small populations that can be vulnerable during multiple life history stages. For example, fish and sometimes invertebrates may prey on eggs in riverbeds during incubation. Birds, fish, terrestrial mammals, and pinnipeds are all frequent predators of Chinook fry during their freshwater rearing and downstream migration. Larger fish, including salmon sharks, as well as sea lions and orcas (and humans) prey on adult Chinook during their marine residence. Various predators including seals and bears prey on adults holding in estuaries and rivers as well as on the spawning grounds.

Predation on adult Chinook by marine mammals has been a significant research focus (e.g., Middlemas et al. 2006; Chasco et al. 2017). Abundances of several marine mammals that prey on adult Chinook salmon in the Northeast Pacific have increased over the past three decades, coincident with widespread legal protections (Chasco et al. 2017). These predators have learned to improve their hunting efficiency by targeting salmon at key bottlenecks, such as river mouths or significant migration barriers in rivers (Wright et al. 2007), and additionally by targeting larger fish that have the highest energy content (Ohlberger et al. 2019). The impacts of predation on adult salmon are therefore 2-fold: the current high abundances of Chinook predators can consume significant numbers of returning adults (Chasco et al. 2017), and size-selective predation likely contributes to demographic shifts (Ohlberger et al. 2019) described in section 5.5. Marine risk assessment workshop participants identified a high risk to adult Chinook from marine mammal predators as a result (Irvine et al. 2024). The highest risks are likely posed by predators such as seals or sea lions (Olesiuk 2018) that aggregate in terminal areas and could inflict significant mortalities on small, vulnerable WCVI Chinook populations if upstream migration is impeded (e.g., by drought), causing the fish to become concentrated and thereby affording efficient predation opportunities. While previous research on Chinook salmon predation has largely focused on marine mammals, we note that salmon sharks are likely also significant consumers of Chinook in some areas (Seitz et al. 2019).

Predation on Chinook during the egg through juvenile life stages has received relatively little research attention compared to predation on adults, but marine risk assessment workshop participants nevertheless indicated that birds and fish pose high risks to WCVI Chinook during these early life stages (Irvine et al. 2024). Other predators such as insects and pinnipeds were assumed to pose lower risks at earlier life stages, but further research and information gathering is required.

We must also acknowledge that predation is often the “end point” where mortality is observed, but in many cases other risk factors likely increase vulnerability of Chinook to mortality, including via predation. It is therefore important not only to consider direct rates of consumption by various predators but also to determine if predators are simply availing of Chinook in weakened states as a result of previous exposure to other limiting factors, such as poor rearing habitat, toxins, or catch-and-release fishing.

6.7. CLIMATE RELATED EFFECTS

Climate change effects are apparent for all life history stages of WCVI Chinook. Recent freshwater and marine risk assessments found that future risk ratings tended to be higher than current, as expected with climate change and increasing anthropogenic activity. Freshwater climate-change effects included increased high water temperatures, more aggressive hydrological patterns, and extended periods of drought, all of which can profoundly affect instream salmonid habitats. As climate change continues, the frequency and intensity of peak discharge events are expected to increase, which, coupled with logging, roadbuilding, changes in drainage patterns, and channel incision, are expected to increase the overall “flashiness” of systems. Increased levels of sediment instability from changes to hydrology and sediment inputs, especially in a changing climate, may further impact the viability of eggs in redds and decrease egg-to-fry survival. Hydrological droughts during the summer and early fall can restrict and delay Chinook from moving into rivers to spawn, increasing their duration of exposure to predators and harmful algal blooms while holding and waiting for a freshet.

In the marine environment, the frequency of marine heat waves has increased in the last decade, conveying a range of biological impacts from reduced chlorophyll to shifts in the copepod community (Fisher et al. 2020). These climate-related effects, combined with changes in the location and strength of where the North Pacific and Subarctic Currents reach North America, may strongly influence salmon populations including Chinook (Malick et al. 2017). Lindley et al. (2021) concluded that during the summers of 2014–2016, surface water temperatures were so high that there was little suitable habitat for Chinook salmon in the eastern North Pacific. Finally, trophic cascades initiated by highly abundant Pink salmon can affect plankton and Sockeye salmon in the Gulf of Alaska and may also impact WCVI Chinook (Irvine et al. 2024; Ruggerone et al. 2023).

6.8. SUMMARY OF LIMITING FACTORS

Declining survivals and productivity of natural-origin WCVI Chinook result from the cumulative effects of many factors. In other words, there is no single factor responsible for the decline and ongoing poor status of natural-origin WCVI Chinook but rather multiple factors, many of which interact with the changing climate. Below we list the most important factors, starting with those that are related to anthropogenic activities that might possibly be mitigated.

- **Loss of genetic diversity.** Hatchery practices should continue to be adapted to reduce negative impacts on natural-origin salmon that include domestication, selection, and fitness.
- **Declines in effective population spawners.** Many factors discussed in this section are responsible for smaller Chinook salmon returning to watersheds throughout the Northeast Pacific, including the WCVI. The effect is smaller proportions of females in many runs and fewer eggs in those females that spawn.

- **Physical habitat changes and losses that include** declines in the quality and availability of productive salmon habitat as well as changes in water quality (temperature, dissolved oxygen, and contaminants).
- **Contaminants, Pathogens, Parasites and Carry-over Effects** between freshwater and early marine that includes smolt size and timing at ocean entry as well as infection status, smolt stage, stressor exposure, and toxin exposure.
- **Nutrition-related factors** including changes in prey quality, availability, time and composition including pink salmon-caused trophic cascade effects potentially affecting growth of subadults in the Gulf of Alaska.
- **Predation** can have significant effects on salmon, especially small runs that can be vulnerable during all life history stages.

7. EXPECTED POPULATION TRAJECTORY

The expected population trajectory is discussed qualitatively due to data limitations discussed in sections 2.4.1, 2.4.4, 4.4.1, and 5.3 around estimating natural-origin Chinook abundance.

Habitat degradation and other pressures are impacting the survival of natural-origin WCVI Chinook. However, the aggregate abundance of both natural-origin and hatchery-origin WCVI Chinook has been increasing over the last decade (Figure 3.2). In contrast, populations such as the Moyeha in Clayoquout Sound have been low and stable for 3 decades, which is likely to continue unless there are significant interventions such as hatchery enhancement.

Population trajectories in natural-origin escapement indicators have been partially masked by strays originating from higher productivity hatchery stocks.

Marine survival rates have also improved relative to very low periods in the early 1990’s and 2000’s that precipitated the stock’s decline (Figure 3.15). The ocean environment, particularly from 2020–2022, has been favourable for Chinook survival. However, this may not be sustained, given evidence of accelerating climate change and the resulting negative impacts on river hydrological processes, and on marine food webs, predation, and more. Additionally, natural-origin Chinook populations, such as the Moyeha River in Clayoquot Sound, have not responded to the recent favourable ocean conditions, suggesting other limiting factors continue to constrain productivity within some components of the SMU. As a result, it is unlikely that natural-origin populations within this SMU, such as the Moyeha in Clayoquot Sound, will increase in abundance without hatchery enhancement.

Fishery impacts on WCVI Chinook in Canadian fisheries have been managed since 1995; with a 10% exploitation limit in Canadian AABM fisheries plus terminal closures to protect populations with high proportion natural-origin spawners such as in Kyuquot Sound and Clayoquot Sound. Removal of remaining fishery impacts in Canadian waters would have some effect on the current rate of change. The overall average CYER is comprised of Alaskan and Canadian fishery impacts; with the Alaskan fishery impacts since 2010 averaging 15% (range of 8–24%; Figure 1.1.) and Canadian fishery impacts averaging about 15% for a population like the Kaouk in Kyuquot Sound and 20% for a population such as the Moyeha in Clayoquot Sound (*q.v.* section 3.4). Eliminating Canadian fishery impacts would marginally change the slope of current trajectories. Using the life cycle for the Kaouk River (Figure 3.19), eliminating all Canadian harvest would reduce the fishing mortality from 30% to 15%, which would increase the smolt-to-adult survival from 0.54% to 0.66%, and would result in a positive growth rate of about 21% per generation. Using Figure 3.18 for the Moyeha River in Clayoquot Sound, eliminating all Canadian harvest would reduce the fishing mortality from about 35% to 15%, which would increase smolt-to-adult survival from 0.14% to 0.18%. The trajectory of natural-origin production would remain negative for this population at −13%, with its persistence most likely explained by inputs from hatchery strays. Eliminating all fishing mortality would further increase smolt-to-adult survival in the Kaouk River to 0.76%, resulting in a positive growth rate of 43% per generation. For Moyeha Chinook, eliminating all fishing mortality would further increase smolt-to-adult survival to 0.2%, resulting in a positive growth rate of 2% per generation, which, considering the considerable uncertainty in this estimate, is likely too similar to 0% to expect population growth.

An integrated approach across the “3 H’s” of Habitat, Harvest, Hatcheries is required to have a meaningful change in trajectory of natural-origin WCVI Chinook and to address the 3 issues identified as affecting status: low abundances in key indicator populations, reduced genetic diversity, and changing demographics. Habitat protection and restoration are required, but note that significant results from these activities alone will take decades to emerge. In the near term, hatchery interventions, through mass marking, appropriate mark-selective removals, and hatchery release limits to attain and/or maintain >50% genetic influence from natural-origin Chinook, are required. Section 9, below, details recommended mitigation options to influence the stock’s trajectory.

Hatchery genetic management is evolving and upcoming changes in DFO’s Major Operations programs on the WCVI will help to mitigate the genetic declines. Some of these measures include new or augmented fish culture measures or methods to improve imprinting, hatchery production reductions, and reductions in seapen programs. Negative trends are also being observed in size-at-age and maturation rates, which are leading to lower effective spawner abundances. These trends are assumed to be driven by size-selective mortality in fisheries, predation, hatcheries, and stressful environmental conditions. Declines in population effective spawners due to demographic changes are expected to continue if these factors are not addressed.

Given that many of the limiting factors discussed above and in section 6 are not currently being addressed, it is likely the productivity of natural-origin WCVI Chinook will either remain constrained or deteriorate further. Populations that are currently below their LRPs may continue to persist at low levels or may become extirpated. Populations that have shifted above their LRPs in recent years may level off or begin to decline once again under increasing pressures associated with climate change. Effective and well-integrated management measures will be required to rebuild struggling populations and to improve resiliency against increasingly challenging environmental conditions.

8. REPORT SUMMARY

The following summary covers the primary objectives identified in section 1.1.

8.1. STOCK BIOLOGY, STRUCTURE, AND LIFE CYCLE

The WCVI Chinook SMU consists of 78 populations spanning from Sooke Basin in the south to Quatsino Sound in the north. The SMU is comprised of 3 WSP Conservation Units and COSEWIC Designatable Units.

WCVI Chinook exhibit a consistent and distinct life history: they are ocean-type, fall run, and far-north migrating. They reach sexual maturity from 2–7 years, with a mean maturation age of 4 years. Females mature older than males, such that a majority of ages 5+ Chinook are female. WCVI Chinook remain in the nearshore waters of the WCVI through most of their first marine year, a period and area of high mortality. The ocean rearing zone from ages 2–7 extends throughout much of the Gulf of Alaska and sometimes north of the Aleutian Islands.

Assessment has tended to focus on adult monitoring to meet fishery management needs, resulting in limited understanding of mortality by life stage or hatchery influences on natural populations. Recent increased monitoring and research through the life cycle resulted in development of a simple life cycle model that reflects our collective knowledge on the life cycle dynamics of WCVI Chinook populations. This model, described earlier, supports our investigation of key survival and productivity bottlenecks at various life stages including research focused on life stages from freshwater egg incubation through the first ocean year. The life cycle model is however based on limited data and knowledge about WCVI Chinook population dynamics, especially with respect to later marine life history life stages. We account for this uncertainty by including large uncertainties in associated productivity estimates.

8.2. CANDIDATE REFERENCE POINTS

These by themselves do not adequately capture the variability in status between the least and most productive populations so we recommend that they be accompanied by secondary references that consider distribution of abundance among populations, genetic diversity, and demographics. Reference points (LRPs, USRs, RR) suffer from uncertainties in underlying habitat-based benchmarks estimated at the population level, and assumptions about population-specific productivities and demographics that may be unrealistic. A projection-based reference point for natural-origin Chinook is provided as a candidate TRP (at 43,900 for 50% probability of all component inlets being above lower benchmarks), which could be used as a rebuilding target, or a biological objective within an MSE, which explicitly account for some uncertainties.

8.3. STOCK STATUS AND TRENDS

Natural-origin Chinook within the WCVI SMU are in critical status (i.e., below the LRP). Contributing factors are low abundances in key natural indicator systems, reduced genetic diversity, and changed demographics with fewer eggs due to fewer and smaller spawning females. These factors reduce the resilience and potential for rebuilding.

This status categorization is the product of multiple lines of evidence:

1. The most recent application of Wild Salmon Policy methods for CU assessments, implemented with the Rapid Status Algorithm (DFO 2024), identified Red status for SWVI, resulting in the SMU being below the CU-status LRP. However, this Red status is driven by the persistent poor status of two natural indicators Megin and Moyeha rivers in Clayoquot Sound and does not account for hatchery influence or demographics.
2. The mixing of local or out-of-basin stray hatchery-origin Chinook and natural-origin Chinook in the spawning populations has been occurring since the 1980s. As a result, there has been a decline in genetic diversity across WCVI Chinook populations and more specifically homogenization with the 3 major hatchery populations at Conuma, Robertson Creek, and Nitinat dominating influence. Based on the PNI metric developed by the Hatchery Science Review Group in Washington State (Anderson et al. 2020), most WCVI Chinook populations have PNI <0.5, indicating net gene flow is from the hatchery environment and <25% of fish are WSP wild.
3. Declining age-at-maturity and size-at-age are resulting in fewer eggs being deposited. Fewer and smaller female Chinook are returning compared to decades ago, which means that even relatively large spawning populations bring fewer eggs back to WCVI rivers.

In contrast to these lines of evidence supporting depleted status, the overall annual abundance (catch plus spawners) of this SMU has averaged 300,000 Chinook over the last 10 years, albeit with over 80% estimated to be of hatchery-origin. The total WCVI Chinook spawner abundance has been in the order of 60,000 in recent years, which exceeds summed lower benchmarks and may approach the capacity of the WCVI rivers to produce Chinook. However, using the assumption of 80–90% hatchery-origin Chinook (Figure 3.2) suggests only 7,000–14,000 of the spawners are of natural-origin, which is at or below the summed lower benchmark (e.g., Table 5.2). The distribution of these spawners is also skewed to the rivers with hatcheries, while rivers such as the Megin and Moyeha in Clayoquot Sound, among others, have few spawners and are assessed as being at critical status.

8.4. FACTORS LIMITING NATURAL-ORIGIN CHINOOK PRODUCTIVITY AND CONTRIBUTING TO THEIR DECLINE

There is no single factor responsible for the decline and ongoing poor status of natural-origin WCVI Chinook but rather multiple factors, many of which interact with the changing climate (Table 6.1). Size-selective mortalities inflicted by fisheries, predators, and the physical environment are causing a demographic shift in WCVI Chinook populations. These demographic changes include reduced sizes and proportions of female spawners with resulting decreases in fecundity, egg size, and redd depth. WCVI Chinook are more abundant today compared to the era preceding major hatchery production, but the preponderance of hatchery-origin salmon that stray and breed with wild salmon has reduced the overall regional diversity of WCVI Chinook populations.

Physical habitat perturbations, including both habitat quality and habitat availability, as well as water quality (temperature, dissolved oxygen, and contaminants) are a concern for many WCVI watersheds and estuaries. Nutrition-related factors including changes in prey quality, availability, timing, and composition are important factors in some rivers and the nearshore marine ecosystem but also potentially affect the growth of subadults in the Gulf of Alaska. Predation can be significant, including by other fish on eggs and fry, by herons and other birds on juveniles in their early marine lives, and by coastal predators including salmon sharks, Steller sea lions, harbour seals, and killer whales on subadults and adults. These predation pressures may subject small populations of Chinook to significant risk.

8.4.1. Fishery harvest

Although the aggregate Removal Reference, U_{MSY}, for the WCVI Chinook SMU is uncertain, fishery management has been focused on limiting harvest impacts since the mid-1990s. The abundance of most indicator stocks increased during this period, but some key stocks remain unproductive, persisting at very low levels. Fishery interceptions of natural-origin Chinook salmon are not estimated in most marine areas but instead are inferred from Robertson Creek Hatchery CWT recoveries. The marine distribution and run timing of all WCVI hatchery and natural Chinook stocks are assumed to be similar, but the lack of direct data on natural-origin catch precludes us from concluding that fishery harvest levels are sustainable (other than on the Robertson Creek Hatchery stock). However, size-selectivity in fishery harvest appears to be contributing to demographic shifts, wherein returning WCVI Chinook are getting smaller and younger over time with increasing proportions of males, resulting in lower effective spawner abundances. Natural sources of mortality (e.g. predation, physiological stress from high temperatures in-river) can also exhibit size- or sex-selectivity, compounding the negative demographic effects of size-selective fishing.

8.4.2. Hatchery salmon and hatchery effects

Decades of significant hatchery production along the WCVI resulted in loss of regional genetic diversity and corresponding resilience of the SMU. Hatchery-related losses in genetic and/or demographic diversity leading to reduced fitness was the highest ranked factor perceived by marine risk assessment participants as limiting the survival and productivity of natural-origin WCVI Chinook, both now and in the future (Irvine et al. 2024). In addition, it was recognized that salmon hatcheries (in general) have the potential for large magnitude ecological impacts on natural-origin salmon populations, the most pertinent of which is the impact of genetic influence of hatchery spawners, particularly from hatchery strays, on fitness of natural spawners.

The recent decadal average total abundance of WCVI Chinook is approximately 300,000, of which over 80% are hatchery-origin. Natural-origin spawners constitute ~20% of the total Chinook escapement or ~25,000–30,000 out of a total escapement of 140,000 (recent 10-year average), of which an unknown portion are wild.

8.4.3. Changing Freshwater and Estuarine Habitat

This report summarizes findings from both marine (Irvine et al. 2024) and freshwater risk assessment processes, each of which identified key habitat and water quality factors potentially limiting survival of natural-origin Chinook. Degradation of many WCVI watersheds, mainly due to widespread forestry, combined with climate change, is impacting freshwater life stages including reduced quality and quantity of spawning habitat, increased incubation mortality from riverbed scour, and loss of rearing habitat. Carry-over effects between freshwater and early marine life stages, which can be related to smolt size and readiness (habitat availability), were perceived by marine risk workshop participants as high risk, increasing to very high in the future. In the ocean, habitat related risk factors were rated higher for juvenile salmon than for adults, as expected given our understanding of significant mortality during the early marine life stage. Marine workshop participants rated water temperature, local nearshore habitat availability, as well as dissolved oxygen as the highest habitat-related risks for adult salmon.

8.4.4. Changing Marine Ecosystem and Climate

The extremes of cohort survival are correlated with El Niño's and La Niña's and accompanying changes in the WCVI marine ecosystem such as the prey base, predator abundance, and water quality. Two strong El Niño events in the 1990s, each lasting 3 years, resulted in a precipitous decline in survival from which some natural-origin stocks have not recovered. In more recent years, habitat degradation combined with climate change related patterns in winter river discharge (i.e., warmer winters with rain on snow events creating extreme discharge events) have likely increased freshwater mortality during egg incubation, while the resulting changes in watershed structure and ecosystem health have reduced freshwater rearing potential. The latter has likely resulted in a 'carry-over' effect of less robust smolts entering the ocean that are vulnerable to unfavorable nearshore marine conditions in WCVI sounds.

Climate change effects are apparent for all life history stages of WCVI Chinook. Recent freshwater and marine risk assessments found that future risk ratings tended to be higher than current, as expected with climate change and increasing anthropogenic activities. Freshwater climate change effects included increased water temperatures, more aggressive hydrological patterns, and extended periods of drought. As climate change continues, the frequency and intensity of peak discharge events are expected to increase, which coupled with logging, roadbuilding, changes in drainage patterns, and channel incision, are expected to increase the overall "flashiness" of systems. Increased levels of sediment instability from changes to hydrology and sediment inputs, especially in a changing climate, may further impact the viability of eggs in redds and decrease egg-to-fry survival.

In the marine environment, the frequency of marine heat waves has increased in the last decade, resulting in a range of biological impacts from reduced chlorophyll to shifts in the copepod community (Fisher et al. 2020). These climate-related effects, combined with changes in the location and strength of where the North Pacific and Subarctic Currents reach North America may strongly influence salmon populations including Chinook (Malick et al. 2017). Lindley et al. (2021) concluded that during the summers of 2014–2016, surface water temperatures were so high that there was little suitable habitat for Chinook salmon in the eastern North Pacific. Finally, trophic cascades driven by abundant pink salmon that affect plankton and sockeye salmon in the Gulf of Alaska may also impact WCVI Chinook (Irvine et al. 2024). There are more salmon in the North Pacific than at any time in the past century and the resulting crowding combined with climate-related warming has been associated with shifts in salmon productivity, body size, and age-at maturation (Connors et al. 2024).

8.4.5. Underpinnings of demographic shifts

Throughout this report, we have emphasized how observed declines in size-at-age and age-at-maturity are reducing productivity of Chinook populations across the SMU. Here, we briefly review potential underlying factors that have been discussed in earlier sections. We provide no speculation as to the relative contributions of each factor and acknowledge that we could be excluding other potentially significant factors. A thorough investigation of the reasons for declining effective spawner abundances in WCVI Chinook should be undertaken to prioritize relevant mitigation measures.

Chinook body size and age-at-maturity are shaped by genetic and environmental effects (Berejikian et al. 2011). Age-at-maturity is highly heritable in Chinook at *circa* 50–60% for males and *circa* 40% for females (Hankin et al. 1993; Heard et al. 2002). Consequently, any factors that inflict higher mortality on certain age classes will have a selective effect on the age composition (and consequently average body size) of future generations. Fishing and predation-related mortality can thereby exert top-down effects on Chinook population demographics (Heard et al. 2007; Ohlberger et al. 2019). Size-selective removals of larger, older fish reduce the prevalence of genes selecting for older age-at-maturity in the spawning population (Lewis et al. 2015).

Age-at-maturity of Chinook is also subject to bottom-up effects related to freshwater growth. Faster freshwater growth is associated with younger age-at-maturity (Vøllestad et al. 2004; Tattam et al. 2015), as reflected in results from research on Sarita Chinook (section 3.3.6.2). Factors that can stimulate faster freshwater growth rates include warmer water temperatures, favourable feeding conditions (i.e., abundant food and few predators), and maternal effects (i.e., smaller egg size leads to faster freshwater growth) (Healy 1991; Heath et al. 1999). In addition to the issues associated with random mating practices (discussed above in section 6.3), hatcheries can also stimulate faster freshwater growth by providing abundant food and exclusion of natural predators. SEP has understood this for decades and partially compensates by applying slow feeding schedules for Chinook.

In summary, observed demographic shifts in WCVI Chinook populations are likely affected a variety of both top-down and bottom-up processes, several of which can be altered or controlled. Interventions targeting both pathways will be required to mitigate the loss of mature body size in WCVI Chinook.

9. MITIGATION OPTIONS AND RECOMMENDATIONS

9.1. FISHERY HARVEST

Harvest impacts were assessed as moderate risks to natural-origin Chinook. Key concerns related to the effects of age-specific fishing mortality, increased harvest mortality due to hatchery abundances (i.e., non-selective fisheries), and uncertain removals in fisheries that may harvest WCVI Chinook as bycatch. At the forefront of potential mitigation is mass marking and mark-selective fisheries. Mass marking hatchery fish allows them to be distinguished from wild salmon, allowing for more effective management of fisheries to protect wild populations. Mark selective fisheries facilitate the selective harvest of marked hatchery fish while releasing wild fish, as well as facilitate reductions in stray magnitude relative to non-selective fisheries. Recommended rebuilding and mitigation strategies are:

- Reduce fishery related mortality of large natural-origin Chinook that are over-represented by large and old females to improve egg deposition rates and mitigate artificial selection for small body sizes and earlier maturation.
- Leveraging existing or expanded mass marking programs, consider and evaluate the use of appropriate mark-selective fisheries to reduce direct harvest mortality on unmarked, natural-origin Chinook, in concert with appropriate consultation, comprehensive baseline data, and fishery monitoring.
- Account for unreported catch, including bycatch in trawl and other non-salmon fisheries.
- Expand the reporting area of CWT catch by stock to fisheries outside the current PST area, most notably western Alaska. Determine stock compositions using genetics from samples of Chinook salmon from multiple locations other than WCVI.

9.2. HATCHERIES

Key concerns from the recent WCVI Chinook risk assessment were related to negative genetic effects associated with high hatchery influences in natural spawning populations (e.g., domestication and inbreeding), straying (e.g., outbreeding depression), increased competition, and potential disease transfer. There is a pressing need for the rigorous implementation of modern hatchery reform measures and guidelines, such as those from the Hatchery Science Review Group (see Anderson et al. 2020) and Wither et al.'s (2018) genetically-based targets for Canadian Pacific Chinook salmon populations. These measures are essential to mitigate the risks posed by hatchery Chinook on the fitness, genetic diversity, and demographic diversity of natural-origin Chinook. Mass marking, mark-selective fisheries and removal programs, and PNI management are some of the key strategies to achieve this goal. Mass marking allows for pHOS, $pHOS_{stray}$, and pNOB management, which are the critical levers for improving natural-origin spawners within a population and ultimately limiting hatchery genetic influence.

Progress on modern hatchery reform has been steady, yet the extent and impact of changes remain limited, due to issues like data gaps, stakeholder alignment, resource manager hesitancy to make robust or timely adaptations, and scientific uncertainty. However, swift, intensive, and decisive implementation of these reform measures will be essential to meaningfully mitigate genetic and fitness risks to natural-origin Chinook populations. Additionally, ongoing research and monitoring to ensure alignment with advancing hatchery and ecosystem science are critical.

WCVI Chinook are but one of many populations and species that coexist in the North Pacific. Salmon numbers are at or near record numbers (Ruggerone and Irvine 2018) and density dependent effects, particularly by pink salmon, have been documented for many species (Ruggerone et al. 2023). Consideration should be given to the recommendation of Connors et al. (2024) that salmon nations (including Canada) might implement a tax on industrial-scale releases of hatchery salmon as a potential way to raise funds for future research.

Recommended rebuilding and mitigation strategies are:

- As part of the hatchery reform process outlined above, identify and implement PNI management targets and measures for enhanced WCVI Chinook populations, including greater implementation of other genetic management measures more broadly (e.g., cessation of out-of-CU transplants, genetic screening of broodstock, dedicated stray removal programs, and improvements to hatchery production imprinting).
- Expand Chinook mass marking to the Robertson Creek (Stamp River) and Nitinat River production populations, while maintaining it at Conuma to facilitate stray management and assessment. Additionally, extend mass marking to community facilities and other federal hatchery programs, prioritizing populations where mass marking is critical for supporting PNI designation goals, where the capacity to effectively use mass marking as a tool exists (e.g., via mark-selective broodstock and/or in-river stray removals programs). Moreover, where appropriate, extend mass marking programs to facilitate mark-selective fisheries, as identified by Fisheries Management and associated consultation processes, that would be expected to result in net benefits (increases in natural-origin Chinook escapement abundances) to WCVI natural-origin Chinook populations.
- Manage hatchery program size to a level that best meets stated objectives while managing and mitigating risks (e.g., minimize surplus production to program requirements), as identified by enhancement plans. Additionally, prioritize addressing straying issues at the source population (e.g., through production reductions) rather than solely at the recipient population level.
- Enhanced hatchery science, research, and experimentation (e.g., the development of updated hatchery spawning guidelines that promote natural selection processes), with ongoing integration of the latest best scientific advice and practices where applicable and supported.
- WCVI Chinook populations with persistently low abundance face an increasing risk of genetic diversity loss and depensatory pressures (e.g., predation), heightening their vulnerability to extinction. To mitigate these risks and support recovery, hatchery programs and associated resources should be considered as possible critical, strategic tools for conserving and rebuilding these endangered populations, in concert with appropriate genetic management measures, while concurrently addressing other potential limiting factors.

9.3. FRESHWATER HABITAT

Freshwater factors assessed as high to very high risk, included barriers to fish upstream migration due to low flows, high winter flows causing mortality of eggs due to sedimentation and scour, reduced quality and quantity of river edge and estuarine habitat for rearing and growth, and predation. Watershed process-based restoration has a significant rebuilding time, and the sooner projects begin, the sooner positive effects on salmon survival may result. Recommended rebuilding and mitigation strategies are:

- Use risk assessment results, life cycle assessments, and other sources of data and knowledge to identify and map important habitats for salmon. Incorporate these areas into local planning processes such as land use, water use, etc. and protect as much spawning habitat as possible from sources of human disturbance.

- Use the same information and tools as above to develop watershed restoration strategies and plans that protect and restore Chinook habitat on WCVI.
- Implement habitat protection measures to preserve existing high value salmon habitats from threats such as logging, urban development, or other anthropogenic disturbances.
- Develop and implement a prioritized list of short-term freshwater habitat restoration projects that address high risk limiting factors that will provide immediate benefit to WCVI Chinook, in conjunction with longer term process-based restoration programs.
- Engage in multi-jurisdictional processes to ensure salmon habitat is a key consideration during land, water, and resource use planning.

9.4. ESTUARINE AND NEARSHORE MARINE HABITAT

Key risks were degraded estuarine rearing habitat due to sedimentation. WCVI Chinook rear for extended periods within the Sounds of the WCVI, resulting in high exposure to risks such as disease and pathogens, water quality, and predation. Recommended rebuilding strategies are:

- Establish protected areas in estuaries and nearshore habitats that are critical nursery grounds for juvenile WCVI Chinook.
- Restore estuarine and nearshore marine habitat complexity, e.g., work on sedge grass, eel grass, and kelp forest habitats that have been impacted and degraded.
- Consider migration corridors and key habitats for juvenile WCVI Chinook in aquaculture siting and marine use planning processes.
- Adjust aquaculture operations to reduce exposure of local juveniles to parasites and pathogens.

9.5. PREDATION

Predation poses a significant threat to adult Chinook salmon during their return migration to WCVI rivers, particularly those belonging to small, depressed populations (e.g., depensatory effects). Increased abundances of marine mammals, such as seals and sea lions, have been linked to heightened predation pressure on adult Chinook in terminal areas, and might be impeding the recovery of certain Chinook populations (WSAS 2022). Understanding the dynamics of predation is essential, as these processes are important to comprehend alongside other complex ecological factors affecting salmon recovery, such as habitat degradation and other anthropogenic stressors.

- Gather information on pinniped population sizes across the WCVI and use this information to identify areas where small, vulnerable Chinook populations are likely exposed to high predation pressure.
- Following the guidance set forth by the Washington State Academy of Science (WSAS 2022), consider implementing localized pinniped deterrence and removal programs, focusing on seals and sea lions in areas where they pose the highest predation risk to vulnerable Chinook populations. Engage with First Nations to incorporate traditional ecological knowledge regarding predation management, recognizing their historical practices and insights. Ultimately, experimental approaches must change pinniped populations at spatial and temporal scales that can meaningfully impact the ecosystem.

- Monitor and evaluate interventions: establish robust monitoring programs to assess the effectiveness of predator deterrence and removal measures and their impacts on Chinook population recovery. Other approaches (e.g., modelling) to studying this ecosystem dynamic are not expected to yield fundamentally new insights (WSAS 2022).

9.6. OCEAN ECOSYSTEM

Evidence suggests that climate-related increasing and more variable ocean temperatures, in conjunction with competition among salmon at sea, can have significant implications on growth and survival of Chinook salmon (Connors et al. 2024). We recommend:

- Retrospectively evaluate potentially useful ocean ecosystem indices relevant to natural-origin WCVI Chinook marine life stages to better understand and ultimately predict interannual patterns of survival and growth for WCVI Chinook.
- Studies evaluating density dependent effects of competition by hatchery-origin and other salmon on WCVI Chinook growth and survival (see Holt et al. 2008).
- Step up strategies to combat global climate change, which is negatively impacting marine food web productivity.

9.7. IMPROVED COLLABORATION IN IMPLEMENTING MITIGATIONS

Balancing conservation of natural-origin Chinook in the Stock Management Unit with the benefits conferred from hatchery production requires improved collaborative governance and planning. Further work with resource managers, academics, First Nations and stakeholders is required to identify specific prescriptions and evaluate and prioritize those options within a cost–benefit and feasibility framework.

- Maintain collaboration and integration with local knowledge holders including WCVI First Nations to coordinate and provide strategic guidance in support of WCVI Chinook rebuilding.

10. RECOMMENDATIONS FOR IMPROVED KNOWLEDGE AND UNDERSTANDING

Here we identify key measures that should be adopted in future scientific activities focusing on the SMU that will address the most important data gaps limiting the present assessment:

1. **Incorporate tools to differentiate spawner abundance by hatchery- versus natural-origin.** The inability to visually differentiate hatchery- from natural-origin spawners in abundance surveys and samples is a major confounding factor in WCVI Chinook stock assessment. We recommend that visual identification (i.e., mass marking) of hatchery-origin Chinook be implemented to facilitate evaluations of natural-origin Chinook abundance. In addition, ubiquitous application of PBT by WCVI hatcheries would simplify assessments of pHOS and hatchery versus natural compositions in catches along the WCVI. Increased laboratory capacity for processing genetic samples is required to better monitor straying and fishery interceptions of natural-origin fish.

- **Improve integrated monitoring and assessment of the fish and ecosystem through the life cycle framework.** A more holistic approach will improve identification of survival bottlenecks and causal mechanisms. Expand the ‘Follow the Fish’ program into a more fulsome ecosystem assessment that covers the entire life cycle and the inclusion of existing non-salmon species work. Conduct targeted studies to better understand the impacts of various predators on Chinook during all life stages, with an emphasis on smolts and returning adults. Additionally, investigate other stressors that may increase Chinook individual or population vulnerability to predation, such as habitat loss, pollution, and changes in water quality. Focused studies on feeding and nutrition in relation to growth, health, and distribution of Chinook are encouraged along with examination of marine growth and otolith microchemistry patterns by ocean year. Results could eventually be applied into ecosystem modelling to determine likely cumulative and synergistic associations among limiting factors, especially as they pertain to climate change and anthropogenic activities that, if mitigated, could increase the productivity of natural-origin WCVI Chinook. Development of an additional CWT indicator program on the WCVI to assess reliability of Robertson Creek Population as an indicator for the entire SMU.

2. **Investigate climate-related interactions.** Evaluate whether i) Cumulative and synergistic interactions among factors cause poor growth and survival of natural-origin WCVI Chinook salmon by shifting their distribution into suboptimal areas, ii) consider areas within freshwater and estuaries for potential remediation, iii) Develop ecosystem models to investigate compounding, synergistic and inter-related effects (positive and negative) with a specific focus on future climate change impacts, iv) Develop a stop light approach modified from that developed by the National Oceanographic and Atmospheric Administration to be specific to marine locations and times WCVI Chinook are found, with annual updates to inform people and processes of expected change to marine ecosystems. Modifications to include new local climate/environmental indices such as within Sound indices as well as more northerly indices of oceanographic conditions. v) Initiate cumulative effects ecosystem modeling to provide more certainty on the intrinsic and extrinsic conditions associated with the strongest impacts needed to develop effective mitigation approaches. Modelling to include, but not be limited to those stressors that are primarily human-derived (e.g., contaminants, fishing, hatcheries, logging, aquaculture, and other forms of industrialization) and therefore have the potential to be mitigated.
3. **Investigate and improve understanding of WCVI Chinook habitat responses to common disturbances** and land use impacts in WCVI streams, including development and application of conceptual models of stream evolution in response to disturbance and restoration interventions. Continue to monitor habitat and water quality and relate these to salmon growth and survival. Be cognizant of carry-over effects from smolts leaving freshwater and entering estuarine and marine waters. Improving survival in marine waters may require a more ‘robust’ smolt. Continue to evaluate direct and indirect effect of environmental stress and survival differences between natural- and hatchery-origin fish including the continued use of otolith microchemistry. Develop a central GIS data portal to provide layers to public and other government agencies relevant to critical salmon habitats.
4. **Improve biological sampling of adult returns.** Stock assessment programs collecting fish samples (e.g., scales for age, DNA, etc.) need to be expanded into Chinook indicator streams to allow annual estimates of age compositions in the natural-origin component of the SMU. This in turn will eventually allow parameterization of stock–recruit models, which could provide a quantitative basis for the development of future reference points.
5. **Identify additional quantitative reference points** on population characteristics beyond aggregate abundances (e.g., demographic diversity, distribution of abundance, degree of hatchery influences), and a scheme should be developed to integrate them into a single determination of status at the SMU-scale, such as the Rapid Status Algorithm allows for CU-scale assessments. This includes consideration of how distribution can be considered in Upper Stock References.
6. **Improve collaboration and information gathering and integration of data** from outside DFO sources and knowledge holders. The application of multi-stakeholder information gathering and assessment approaches involving local knowledge-holders, particularly First

Nations, will continue to be important for building a collective understanding of the SMU. The WCVI is a broad and remote area, where rigorous scientific studies are limited by high financial and personnel costs. The local people living along the WCVI are thereby an invaluable knowledge resource, without which many aspects of the present report would have faltered.

7. **Increased hatchery science, research, and experimentation**, which includes (1) developing a long-term enhancement research and experimental plan through collaborative work with First Nations, academia, and other external scientific professionals, (2) developing science advice on appropriate level of enhancement within a Conservation Unit (CU) to be consistent with Wild Salmon Policy, and (3) prioritize research that develops solutions to potential problems and quantifies factors affecting the relative reproductive success and long-term fitness of Chinook salmon populations influenced by hatcheries, including marine density dependent effects. This research should include an assessment of the potential benefits and risks of new conservation and rebuilding enhancement programs on the long-term fitness and viability of natural-origin Chinook salmon populations.

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APPENDIX A. DATA AND MODEL FITS FOR SPAWNER RECRUITMENT ANALYSES ON RECONSTRUCTION TIME-SERIES

A.1. DATA

Ricker models were fit to the three CUs within the WCVI Chinook SMU using spawner and recruitment time-series compiled by Diana Dobson (DFO, pers. comm., 1987–2015, summarized below). These models assumed exploitation rates were the same across CUs and were equivalent to those estimated at the Robertson Creek hatchery for hatchery-origin fish. Because the validity of this assumption is uncertain and likely to be unrealistic, the run reconstruction was not used as a basis for estimating benchmarks for CUs or evaluating status. However, Ricker parameter estimates derived from these models were used in sensitivity analyses for benchmark derivation and in projections to demonstrate possible target reference points.

A.2. RESULTS

Parameter estimates are provide in Table A-1.

Table A-1. Ricker parameter estimates for 3 CUs of WCVI Chinook

CU	$\boldsymbol{ln(\alpha)}$ **(SE)**	$\boldsymbol{\beta}$ **(SE)**	$\boldsymbol{\sigma}$ **(SE)**
WCVI South	1.14 (0.29)	0.00099 (0.0015)	0.80 (1.16)
WCVI Nootka & Kyuquot	1.58 (0.25)	0.00093 (0.0013)	0.69 (1.14)
WCVI North	1.53 (0.29)	0.00030 (0.0013)	0.68 (1.14)

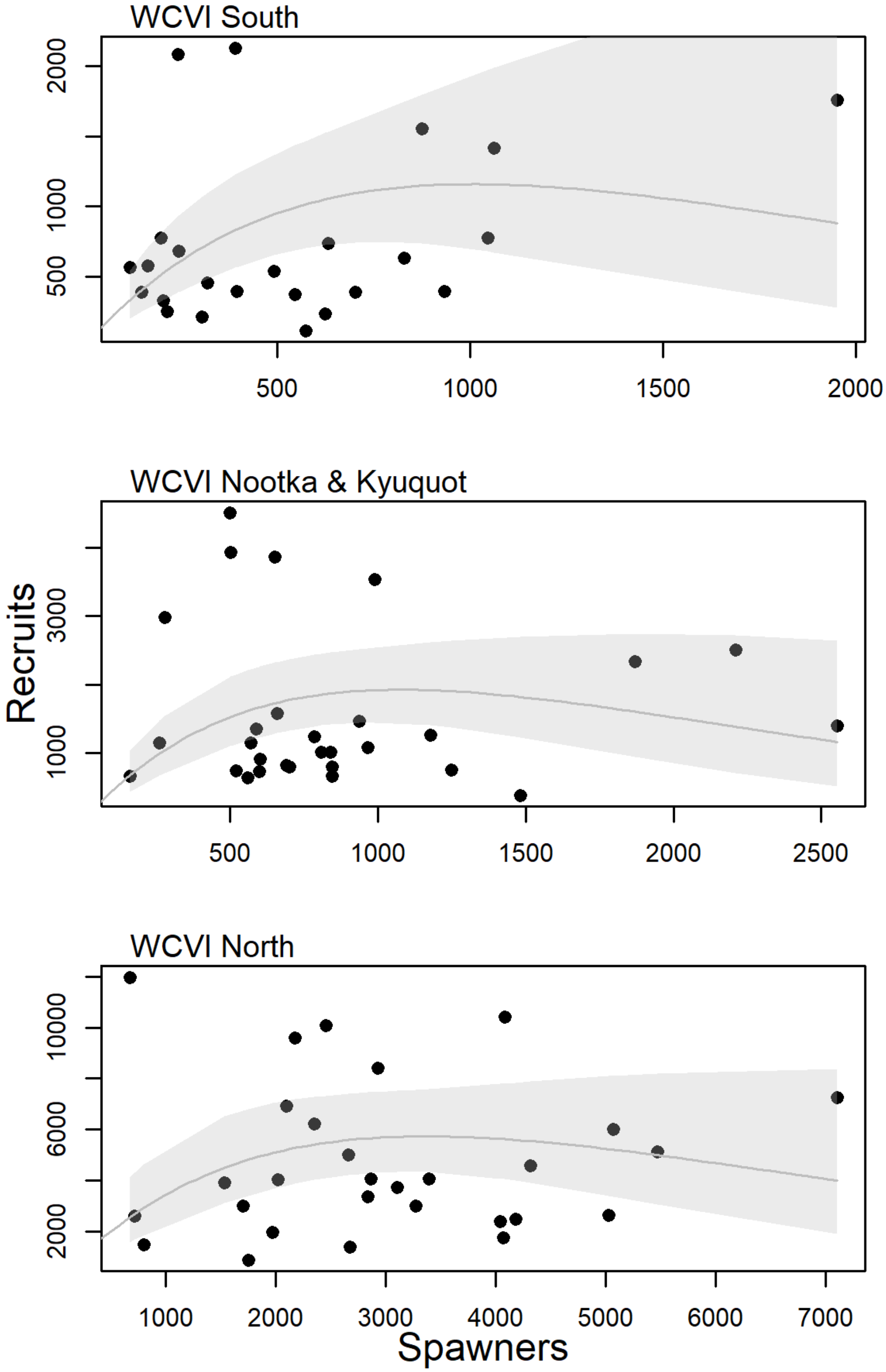

Figure A-1. Fits of Ricker stock-recruitment models with 95% confidence intervals for 3 WCVI Chinook CUs.

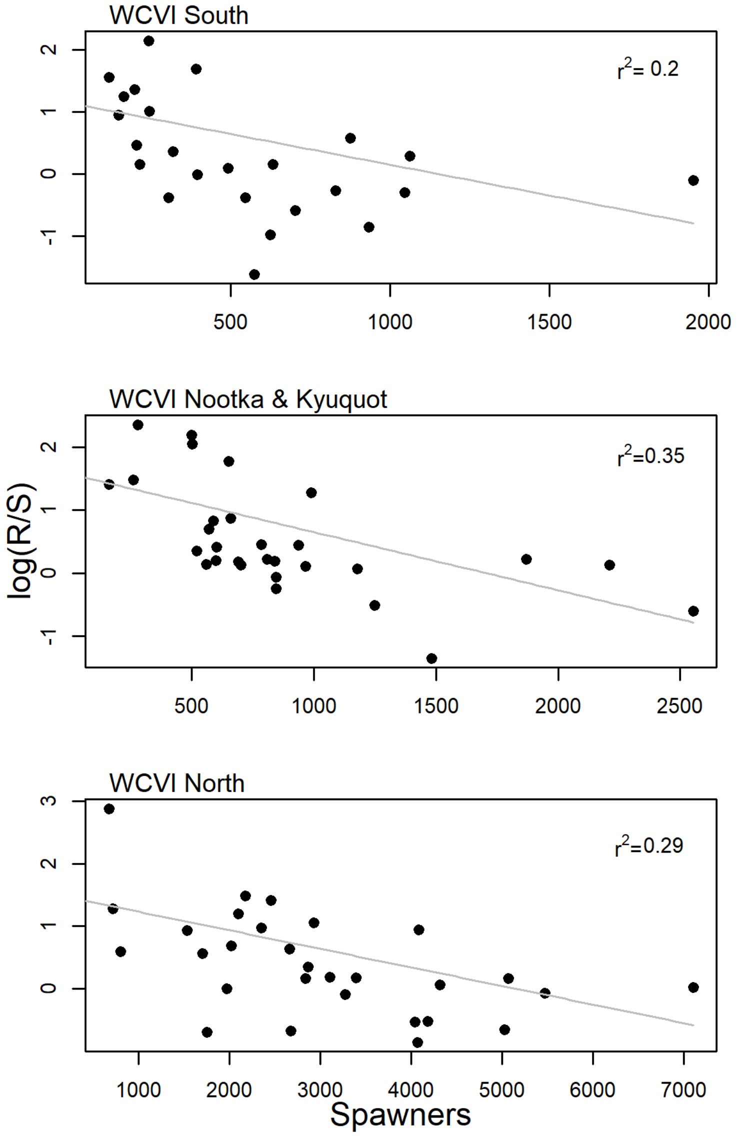

Figure A-2. Fits of linearized Ricker model with R^2 value for 3 WCVI Chinook CUs.

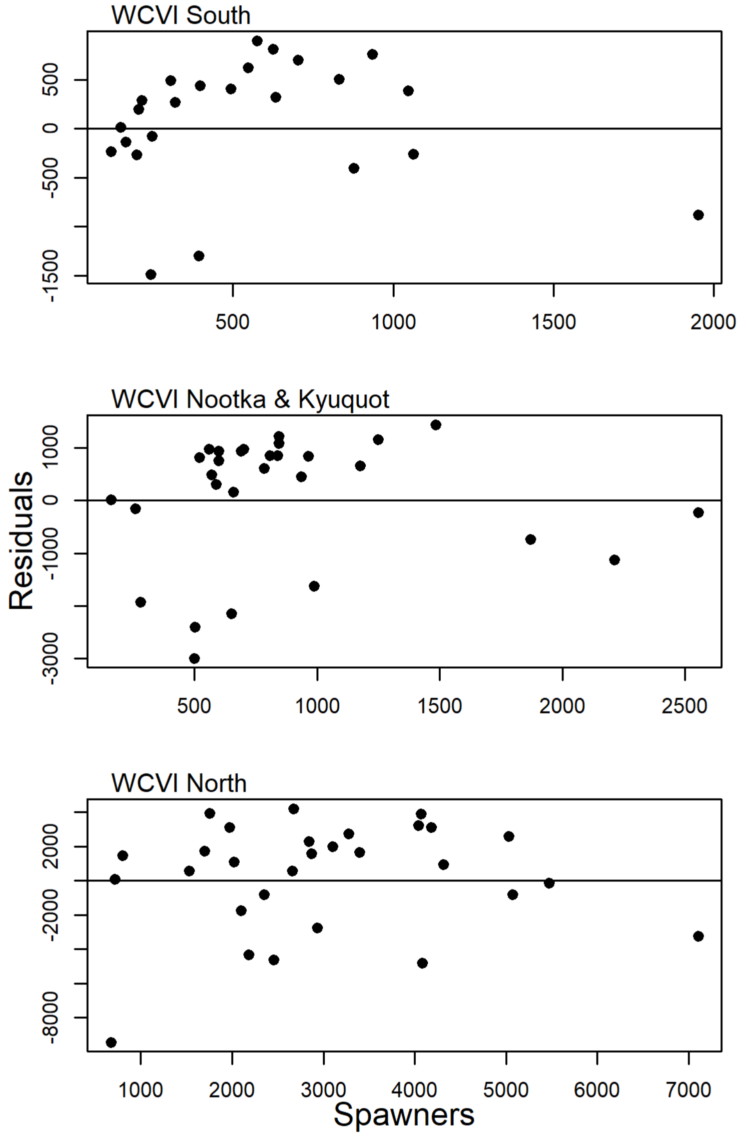

Figure A-3. Residual plots of Ricker fits for 3 WCVI Chinook CUs.

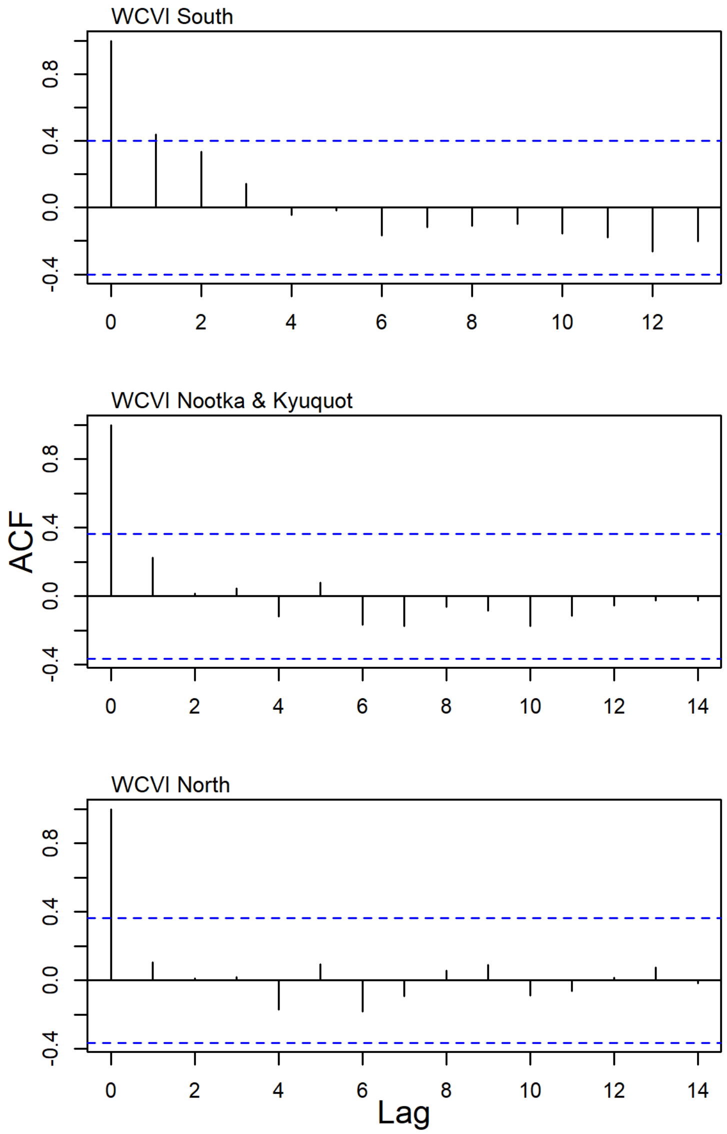

Figure A-4. Autocorrelation Function (ACF) plots of residuals from Ricker fits for 3 WCVI Chinook CUs.

We further compared Ricker models derived from model fits above, and those using alternative productivity, $\ln(\alpha)$, estimates derived from assumptions about productivity from the watershed-area model and its underlying synoptic data sets, and from the life cycle model for WCVI chinook. For plotting purposes, the assumption about density dependence, β, were the same among productivity assumptions to scale predictions to the same level.

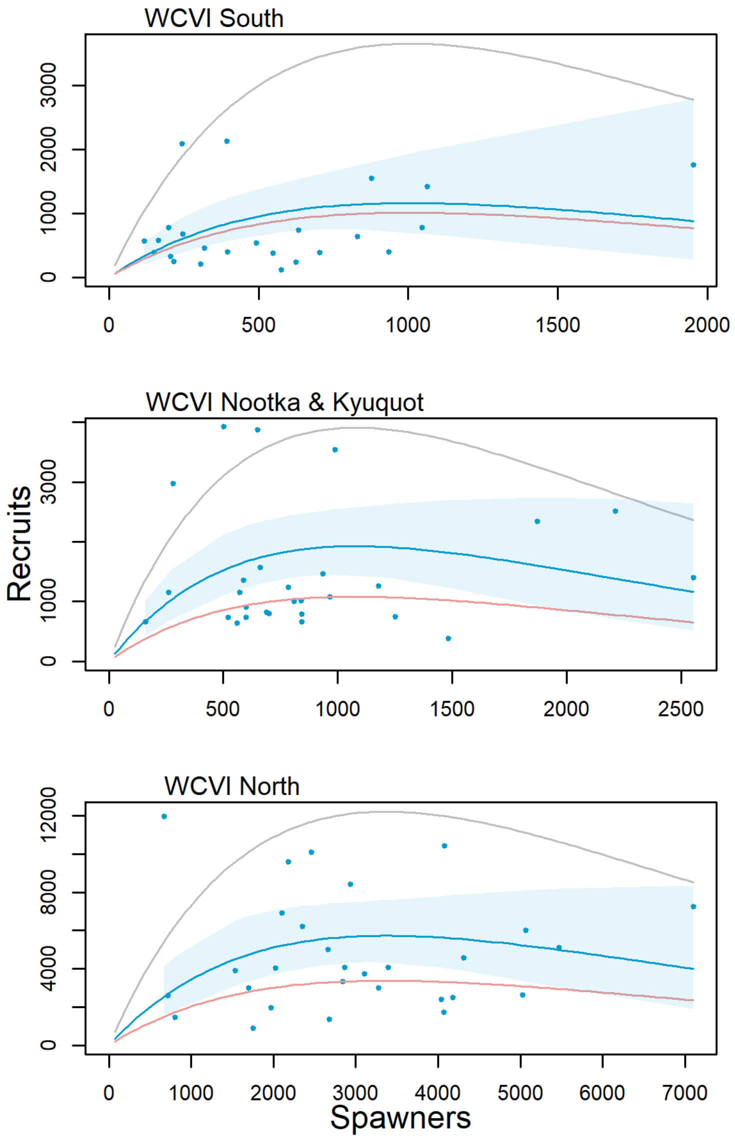

Figure A-5. Ricker models as in Figure A1 but with blue shading (line representing the MLE fit with 95% confidence intervals), with alternative mean productivity, $\boldsymbol{\ln(\alpha)}$, estimates derived from the assumption about productivity from the watershed-area model and its underlying synoptic data sets (grey line), and from the life cycle model for WCVI chinook (pink line). Colours are the same as for the productivity assumption in Figure 4.1.

A.3. FUTURE WORK

Further work is required to compile updated spawner-recruitment time-series that account for hatchery contributions and differential vulnerability of CUs to fisheries. Future iterations could also consider alternative model structures, including those with autocorrelation, survival covariates, and hierarchical structure, and state-space models with informative priors on capacity and productivity.

A.4. REFERENCES

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APPENDIX B. SUPPORTING TEXT AND PLOTS FOR BENCHMARKS AND REFERENCE POINTS

B.1. LIKELIHOOD PENALTIES FOR INTEGRATED WATERSHED-AREA-MODEL

For the Ricker spawner recruitment relationships within the integrated watershed-area model, we identified minimally informative likelihood penalties to restrict parameter estimates to plausible values.

$$\mu_{\alpha,stream} \sim N(1.5,2)$$

$$\mu_{\alpha,ocean} \sim N(0,2)$$

$$\sigma_i \sim InvGamma(0.1,0.1)$$

$$\sigma_\alpha \sim InvGamma(0.1,0.1)$$

For the regression between *ln*(S_{MSY}), or *ln*(S_{REP}) and ln(accessible watershed area), a variety of likelihood penalties were considered for σ_{v} and σ_{δ} including inverse gamma, normal, bounded normal and uniform distributions. An inverse gamma distributed likelihood penalty was applied to provide plausible values for variance estimates.

$$\sigma_{\mathrm{v}} \sim InGamma(1,1)$$

$$\sigma_{\delta} \sim InGamma(1,1)$$

These likelihood penalties force variances away from zero due to challenges assigning variance among Ricker and watershed-area regression components of the model. We recommend that the likelihood penalties on variance terms be updated in future model iterations to better capture plausible values and improve convergence, and/or that alternative forms of the model, as used in Liermann et al (2010) be considered instead.

Table B-1. Parameter values for the linear regressions between ln(accessible watershed area) and ln(S_{REP}) or ln(S_{MSY}) (Equation 3).

Predicted variable	Parameter	Description	Estimate	Standard Error
$ln(S_{REP})$	$\nu_{0,stream}$	Y-intercept for stream-type populations	4.25	0.42
	$\nu_{0,ocean}$	Deviation in Y-intercept for ocean-type from stream-type	−1.51	1.04
	$\ln(\nu_{1,stream})$	Ln of the slope for stream-type populations	−0.41	0.08
	$\nu_{1,ocean}$	Deviation in the slope for ocean-type populations	0.35	0.14
	$\ln(\sigma_\nu)$	Ln of the standard deviation in residuals	−0.99	0.16
$ln(S_{MSY})$	$\delta_{0,stream}$	Y-intercept for stream-type populations	3.28	0.42
	$\delta_{0,ocean}$	Deviation in Y-intercept for ocean-type from stream-type	−1.65	1.04

Predicted variable	Parameter	Description	Estimate	Standard Error
	$\ln(\delta_{1,stream})$	Ln of the slope for stream-type populations	−0.41	0.08
	$\delta_{1,ocean}$	Deviation in the slope for ocean-type populations	0.36	0.14
	$\ln(\sigma_{\delta})$	Ln of the standard deviation in residuals	−1.01	0.16

Table B-2. Input parameters for projection-based reference points.

Parameter description (Equation in text)	Value (by inlet for Ricker parameters)		Source
Ricker productivity parameter, $\ln(\alpha)$ (Equation 2)	Kyuquot	1.58	Spawner recruitment analyses applied to run reconstruction at the CU level, see Section 4.1
	Clayoquot	1.14	
	Quatsino	1.53	
	Barkley	1.14	
	Nootka/Esperanza	1.58	
	San Juan	1.14	
Ricker density dependence parameter, β (Equation 2)	Kyuquot	0.000238	Derived from S_{REP} estimated from integrated watershed area and productivity from run reconstructions, see Section 4.1
	Clayoquot	0.0000945	
	Quatsino	0.000358	
	Barkley	0.000391	
	Nootka/Esperanza	0.0000601	
	San Juan	0.000147	
Ricker standard deviations in residuals, σ_R (Equation 2)	Kyuquot	0.69	Spawner recruitment analyses applied to run reconstruction at the CU level, see Section 4.1
	Clayoquot	0.80	
	Quatsino	0.68	
	Barkley	0.80	
	Nootka/Esperanza	0.69	
	San Juan	0.80	

Parameter description (Equation in text)	Value (by inlet for Ricker parameters)		Source
Covariance in Ricker residuals among inlets	See Figure 4.6 in the text		Covariance in spawner abundances among inlets, see Section 4.3.4
Mean proportions of ages at maturity (ages 2–5)	Kyuquot	0.01, 0.10, 0.48, 0.40	Derived from run-reconstruction at CU level, see Section 4.1
	Clayoquot	0.02, 0.14, 0.45, 0.38	
	Quatsino	0.02,0.15, 0.47, 0.36	
	Barkley	0.02, 0.14, 0.45, 0.38	
	Nootka/Esperanza	0.01, 0.10, 0.48, 0.40	
	San Juan	0.02, 0.14, 0.45, 0.38	
Variability in age at maturity, from multivariate logistic distribution	Kyuquot	0.7	Derived from run-reconstruction at CU level, see Section 4.1
	Clayoquot	0.7	
	Quatsino	0.8	
	Barkley	0.7	
	Nootka/Esperanza	0.7	
	San Juan	0.7	
Initial spawner abundances (spawner abundances at equilibrium)	Kyuquot	5649	Integrated watershed-area model, see Section 4.1
	Clayoquot	8649	
	Quatsino	3626	
	Barkley	2090	
	Nootka/Esperanza	22360	
	San Juan	5546	
Mean exploitation rate	30%		Holt, K. et al. (2023b)
Minimum exploitation rate	5%		Holt, K. et al. (2023b)

Parameter description (Equation in text)	Value (by inlet for Ricker parameters)	Source
Coefficient of variation in exploitation rate over time, e.g., related to implementation uncertainty	0.17	Parameterized from time-series of pre-terminal exploitation rates from 2010–2019 for the Robertson Creek hatchery indicator. See Holt, K. et al. (2023b)
Coefficient of variation in exploitation among inlets	0.085	Holt, K. et al. (2023b)

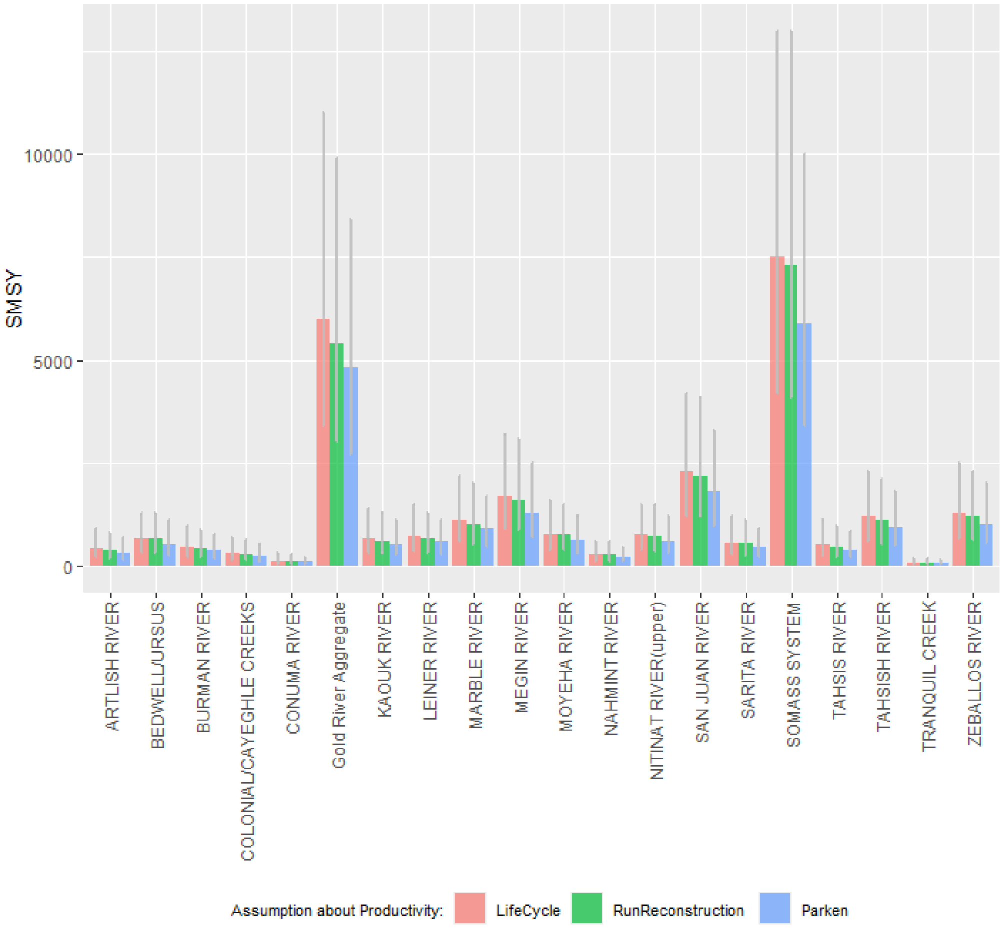

Figure B-1. Benchmarks, spawner abundances at maximum sustained yield, SMSY, for escapement indicator populations, derived from habitat-model described in Parken et al (2006) and implemented in Holt et al. (2023b), according to three assumptions about productivity based on a life cycle-model, CU-specific run-reconstructions, and assumptions of Parken et al. (2006).

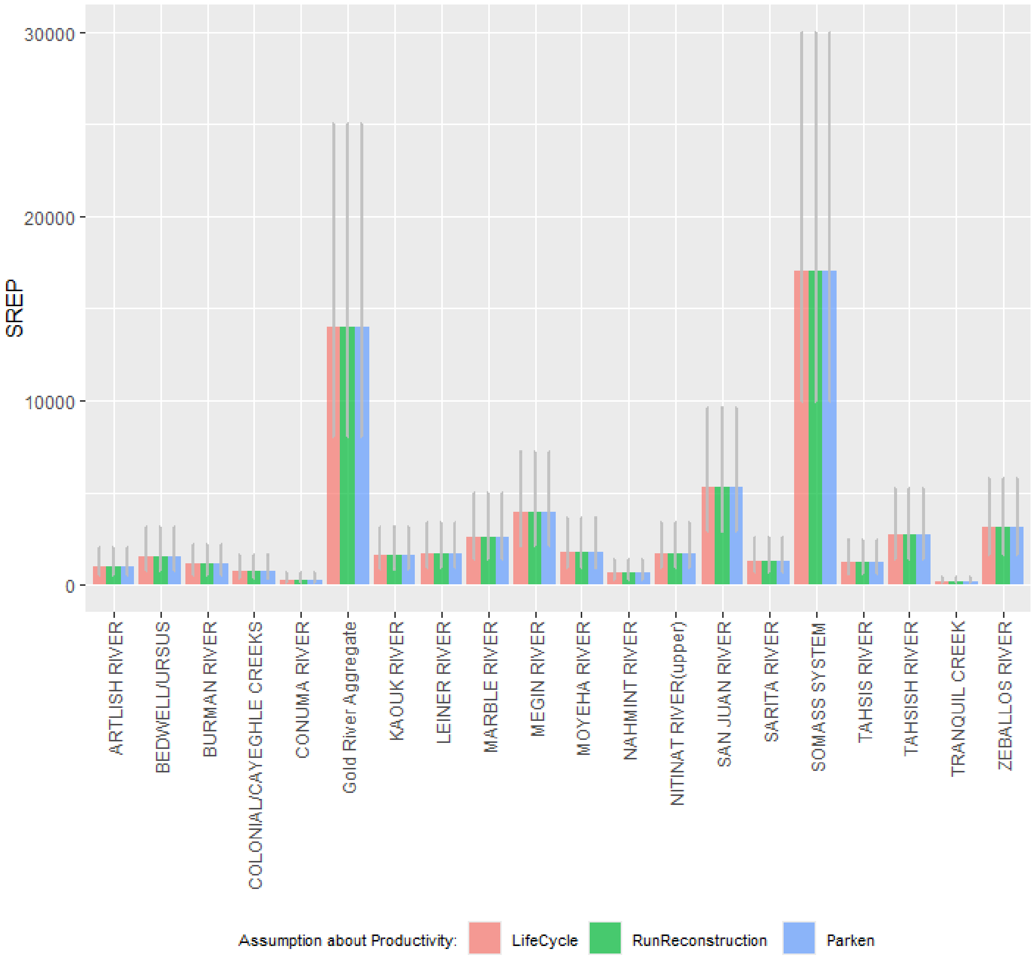

Figure B-2. Benchmarks, spawner abundances at replacement, S_{REP}, for escapement indicator populations, derived from habitat-model described in Parken et al (2006) and implemented in Holt et al. (2023b). We assumed these values do not depend on productivity.

APPENDIX C. SUPPORTING DATA TABLES

Table C-1. DFO nuSEDS database table of guidance for determining estimate type, based on associations between survey method, reliability, accuracy and precision. SIL is Stream Inspection Log and SEN is Summary Estimate Narrative. Direct or indirect survey life here indicates whether direct observations/estimates are made in monitoring, or indirect extrapolation is used from other studies.

Estimate Type	**Survey Method(s)**	**Analytical Method(s)**	**Reliability (within stock comparisons)**	**Units**	**Accuracy**	**Precision**	**Documentation**
Type-1, True Abundance, high resolution	total, seasonal counts through fence or fishway; virtually no bypass	simple, often single step	reliable resolution of between year differences >10% (in absolute units)	absolute abundance	actual, very high	infinite i.e.+ or − zero%	detailed SIL(s), SEN, field notes or diaries, published report on methods
Type-2, True Abundance, medium resolution	high effort (5 or more trips), standard methods (e.g. mark-recapture, serial counts for area under curve, etc.)	simple to complex multi- step, but always rigorous	reliable resolution of between year differences >25% (in absolute units)	absolute abundance	actual or assigned estimate and high	actual estimate, high to moderate	detailed SIL(s), SEN, field notes or diaries, published report on methods
Type-3, Relative Abundance, high resolution	high effort (5 or more trips), standard methods (e.g. equal effort surveys executed by walk, swim, overflight, etc.)	simple to complex multi- step, but always rigorous	reliable resolution of between year differences >25% (in absolute units)	relative abundance linked to method	assigned range and medium to high	assigned estimate, medium to high	detailed SIL(s), SEN, field notes or diaries, published report on methods
Type-4, Relative Abundance, medium resolution	low to moderate effort (1- 4 trips), known survey method	simple analysis by known methods	reliable resolution of between year differences >200% (in relative units)	relative abundance linked to method	unknown assumed fairly constant	unknown assumed fairly constant	complete SEN or equivalent with sufficient detail to verify both survey and analytical procedures

Estimate Type	Survey Method(s)	Analytical Method(s)	Reliability (within stock comparisons)	Units	Accuracy	Precision	Documentation
Type-5, Relative Abundance, low resolution	low effort (e.g. 1 trip), use of vaguely defined, inconsistent or poorly executed methods	unknown to ill defined; inconsistent or poorly executed	uncertain numeric comparisons, but high reliability for presence or absence	relative abundance, but vague or no i.d. on method	unknown assumed highly variable	unknown assumed highly variable	incomplete SEN, only reliable to confirm estimate is from an actual survey
Type-6, Presence or Absence	any of above	not required	moderate to high reliability for presence/absence	(+) or (−)	medium to high	unknown	any of above sufficient to confirm survey and reliable species i.d.

Table C-2. WCVI watersheds with multiple observations of Chinook spawners, including from local and Indigenous knowledge, with indicator status designations (see section 2.1), average hatchery-influence designations 2010–present (2023) (based on Withler et al. 2018; see section 4.4.21) sourced from Weil at al. (2024) with updated data from SEP where available, average hatchery releases (excluding egg and unfed releases) from 2010–present (2023)—including years with no releases—and the name of the hatchery facility that contributes releases to each system.

CU	Mainstem	Major tributaries	Indicator type	Current Withler Designation	Average hatchery releases (2010+)	Enhancement facility
SWVI	Gordon River		Extensive	Data deficient		
SWVI	San Juan River	Harris Creek, Lens Creek	Intensive	Integrated-hatchery	393,953	San Juan River Hatchery
SWVI	Sooke River	Charters River, De Mamiel Creek	Intensive	Integrated-hatchery	699,164	Sooke River Hatchery
SWVI	Klanawa River		Extensive	Data deficient		
SWVI	Caycuse River		Non-indicator	Data deficient		
SWVI	Nitinat River	Little Nitinat River	Intensive/Major Ops.	Integrated-hatchery	3,454,786	Nitinat River Hatchery
SWVI	Ca'aqu'a Creek		Non-indicator	Data deficient		
SWVI	Coeur d'Alene Creek		Non-indicator	Data deficient		
SWVI	Consinka Creek		Non-indicator	Data deficient		
SWVI	Cous Creek		Non-indicator	Data deficient		

CU	Mainstem	Major tributaries	Indicator type	Current Withler Designation	Average hatchery releases (2010+)	Enhancement facility
SWVI	Effingham River		Extensive	Data deficient		
SWVI	Franklin River		Non-indicator	Data deficient		
SWVI	Macktush Creek		Non-indicator	Data deficient		
SWVI	Mercantile Creek		Non-indicator	Data deficient		
SWVI	Smith Creek		Non-indicator	Data deficient		
SWVI	Hucuktlis River	Clemens Creek	Intensive	Integrated-hatchery	34,304	Nitinat River Hatchery
SWVI	Nahmint River		Intensive	Integrated-transition	47,853	Robertson Creek Hatchery
SWVI	Sarita River	South Sarita River	Intensive	Integrated-hatchery	391,653	Nitinat River Hatchery
SWVI	Somass River	Stamp River, Ash River, Drinkwater Creek, McBride Creek	PST indicator	Integrated-hatchery	6,393,606	Robertson Creek Hatchery
SWVI	Thornton Creek		Extensive	Integrated-hatchery	174,100	Thornton Creek Hatchery
SWVI	Toquaht River		Intensive	Integrated-wild	75,079	Thornton Creek Hatchery
SWVI	Bedwell River	Ursus Creek	Intensive	Integrated-wild	18,637	Tofino Hatchery
SWVI	Cypre River		Intensive	Integrated-wild	38,454	Tofino Hatchery
SWVI	Ice River		Non-indicator	Data deficient		
SWVI	Kennedy River	Clayoquot River, Sand River	Intensive	Data deficient		
SWVI	Sydney River		Non-indicator	Data deficient		
SWVI	Tofino Creek		Non-indicator	Data deficient		
SWVI	Watta Creek	Shelter Creek	Non-indicator	Data deficient		
SWVI	Megin River	Talbot Creek	Intensive	Wild-stray influenced		
SWVI	Moyeha River		Intensive	Wild-stray influenced		
SWVI	Warn Bay Creek		Extensive	Data deficient		
SWVI	Tranquil Creek		Intensive	Integrated-wild	15,633	Tofino Hatchery
NoKy	Burman River		Intensive	Integrated-hatchery	254,011	Conuma River Hatchery

CU	Mainstem	Major tributaries	Indicator type	Current Withler Designation	Average hatchery releases (2010+)	Enhancement facility
NoKy	Conuma River		Intensive/Major Ops.	Integrated-hatchery	2,851,245	Conuma River Hatchery
NoKy	Gold River	Ucona River, Heber River, Upana River, Muchalat River	Intensive	Integrated-hatchery	262,245	Conuma River Hatchery
NoKy	Leiner River	Perry River	Intensive	Integrated-hatchery	120,569	Tahsis River Hatchery
NoKy	Brodick Creek		Non-indicator	Data deficient		
NoKy	Chum Creek		Non-indicator	Data deficient		
NoKy	Eliza Creek		Non-indicator	Data deficient		
NoKy	Canton Creek		Extensive	Data deficient		
NoKy	Hammond Creek		Non-indicator	Data deficient		
NoKy	Hoiss Creek		Non-indicator	Data deficient		
NoKy	Jacklah River		Non-indicator	Data deficient		
NoKy	Deserted Creek		Non-indicator	Data deficient		
NoKy	Espinosa Creek		Extensive	Data deficient		
NoKy	Kleeptee Creek		Non-indicator	Data deficient		
NoKy	Mamat Creek		Non-indicator	Data deficient		
NoKy	Marvinas Bay Creek		Non-indicator	Data deficient		
NoKy	Little Zeballos River		Extensive	Data deficient		
NoKy	Mooyah River		Non-indicator	Data deficient		
NoKy	Park River		Non-indicator	Data deficient		
NoKy	Tsowwin River		Extensive	Data deficient		
NoKy	Sucwoa River		Extensive	Wild-stray influenced	2,093	Conuma River Hatchery
NoKy	Tahsis River		Intensive	Integrated-hatchery	82,572	Tahsis River Hatchery
NoKy	Tlupana River		Extensive	Wild-stray influenced	13,291	Conuma River Hatchery
NoKy	Zeballos River		Intensive	Data deficient		Zeballos River Hatchery

CU	Mainstem	Major tributaries	Indicator type	Current Withler Designation	Average hatchery releases (2010+)	Enhancement facility
NoKy	Artlish River		Intensive	Wild-stray influenced		
NoKy	Kaouk River	Rowland Creek	Intensive	Wild-stray influenced		
NoKy	Kauwinch River		Extensive	Wild-stray influenced		
NoKy	Tahsish River	Kwois Creek	Intensive	Wild-stray influenced		
NoKy	Amai Creek		Extensive	Data deficient		
NoKy	Chamiss Creek		Non-indicator	Data deficient		
NoKy	Clanninick Creek		Non-indicator	Data deficient		
NoKy	Kashutl River		Extensive	Data deficient		
NoKy	Easy Creek		Extensive	Data deficient		
NoKy	Nasparti River		Non-indicator	Data deficient		
NoKy	Malksope River		Extensive	Data deficient		
NoKy	Power River		Non-indicator	Data deficient		
NoKy	McKay Cove Creek		Non-indicator	Data deficient		
NoKy	Narrowgut Creek		Extensive	Data deficient		
NoKy	Ououkinsh River		Non-indicator	Data deficient		
NWVI	Marble River	Lippy Creek, Benson River, Malook Creek	Intensive	Integrated-wild	183,704	Marble River Hatchery
NWVI	Cayeghle Creek	Colonial Creek	Intensive	Data deficient		
NWVI	East Creek		Non-indicator	Data deficient		
NWVI	Goodspeed River		Non-indicator	Data deficient		
NWVI	Keith River		Non-indicator	Data deficient		
NWVI	Klaskish River		Non-indicator	Data deficient		
NWVI	Mahatta Creek		Non-indicator	Data deficient		

Table C-3. Reference points for all WCVI streams that have currently available accessible watershed area ("Acc. WS area") data. Acronyms given in parentheses beside reference points indicate the productivity assumption that values were derived from: LC = Life Cycle, RR = Run Reconstruction, and P = Parken (see section 4.1 for details). The columns "Mean esc. (2010+)" and "Mean pNOS (2010+)" contain the estimated mean values for spawner escapement (abundance) and proportion of natural-origin spawners, respectively, from 2010–present (2023).

CU	**Mainstem**	**[1]Acc. WS area (km^2)**	**Mean esc. (2010+)**	**S_{gen} (LC)**	**S_{MSY} (LC)**	**S_{REP} (LC)**	**S_{gen} (RR)**	**S_{MSY} (RR)**	**S_{REP} (RR)**	**S_{gen} (P)**	**S_{MSY} (P)**	**S_{REP} (P)**	**[2]WSP status**	**Mean pNOS (2010+)**
SWVI	Gordon River	47	64	140	310	710	110	300	710	27	240	710	Red	
SWVI	Sooke River	58	566	170	380	880	140	370	880	33	300	880	Green	
SWVI	San Juan River	330	1146	1000	2300	5300	860	2200	5300	200	1800	5300	Amber	41%
SWVI	Nitinat River	112	12533	330	750	1700	280	730	1700	66	590	1700	Green	8%
SWVI	Effingham River	18	22	51	120	270	44	110	270	10	92	270	Red	
SWVI	Hucuktlis River	17	82	47	110	250	40	100	250	9.4	84	250	Amber	
SWVI	Mercantile Creek	13	25	36	81	190	30	79	190	7.1	64	190	Red	
SWVI	Somass River	1057	15297	3300	7500	17000	2800	7300	17000	660	5900	17000	Green	13%
SWVI	Sarita River	84	1762	250	560	1300	210	550	1300	49	440	1300	Green	13%
SWVI	Thornton Creek	2	910	5	11	26	4.2	11	26	0.99	9	26	Green	
SWVI	Nahmint River	42	428	120	270	640	100	270	640	24	220	640	Green	69%
SWVI	Toquaht River	56	166										Green	94%

CU	Mainstem	[1]Acc. WS area (km^2)	Mean esc. (2010+)	S_{gen} (LC)	S_{MSY} (LC)	S_{REP} (LC)	S_{gen} (RR)	S_{MSY} (RR)	S_{REP} (RR)	S_{gen} (P)	S_{MSY} (P)	S_{REP} (P)	[2]WSP status	Mean pNOS (2010+)
SWVI	Ice River	13	3	36	81	190	30	79	190	7.1	64	190	Red	
SWVI	Kennedy River	248		760	1700	4000	640	1700	4000	150	1300	4000	Red	
SWVI	Bedwell River	99	411	290	660	1500	250	650	1500	58	530	1500	Amber	85%
SWVI	Sydney River	14	6	39	87	200	33	85	200	7.7	69	200	Red	
SWVI	Tofino Creek	10	2	27	61	140	23	60	140	5.4	49	140	Red	
SWVI	Watta Creek	22	6	62	140	330	53	140	330	12	110	320	Red	
SWVI	Tranquil Creek	12	232	33	74	170	28	72	170	6.5	59	170	Green	96%
SWVI	Megin River	245	40	750	1700	3900	630	1600	3900	150	1300	3900	Red	42%
SWVI	Moyeha River	116	81	350	780	1800	290	760	1800	68	620	1800	Red	82%
SWVI	Cypre River	39	931	110	250	590	95	250	590	22	200	590	Green	97%
NoKy	Conuma River	20	18259	55	120	290	27	110	290	11	98	290	Green	2%
NoKy	Tlupana River	20	511	56	130	290	27	110	290	11	100	290	Green	9%
NoKy	Burman River	70	3660	200	460	1100	100	420	1100	41	370	1100	Green	9%
NoKy	Sucwoa River	25	65	71	160	370	35	140	370	14	130	370	Red	11%

CU	**Mainstem**	**[1]Acc. WS area (km^2)**	**Mean esc. (2010+)**	**S_{gen} (LC)**	**S_{MSY} (LC)**	**S_{REP} (LC)**	**S_{gen} (RR)**	**S_{MSY} (RR)**	**S_{REP} (RR)**	**S_{gen} (P)**	**S_{MSY} (P)**	**S_{REP} (P)**	**[2]WSP status**	**Mean pNOS (2010+)**
NoKy	Gold River	856	2705	2700	6000	14000	1300	5400	14000	530	4800	14000	Amber	23%
NoKy	Canton Creek	10	2138	27	61	140	13	56	140	5.4	49	140	Green	
NoKy	Deserted Creek	6		16	36	84	7.8	33	84	3.2	29	84	Red	
NoKy	Espinosa Creek	5	38	12	28	65	6	25	65	2.5	22	65	Green	
NoKy	Kleeptee Creek	14	91	39	87	200	19	79	200	7.7	69	200	Green	
NoKy	Little Zeballos River	43	31	120	280	650	61	250	650	25	220	650	Red	
NoKy	Mooyah River	8	48	21	47	110	10	42	110	4.1	37	110	Green	
NoKy	Park River	10		27	61	140	13	55	140	5.4	49	140	Red	
NoKy	Tsowwin River	26	23	73	170	390	36	150	390	15	130	390	Red	
NoKy	Leiner River	109	737	330	730	1700	160	660	1700	64	580	1700	Green	32%
NoKy	Tahsis River	77	603	230	510	1200	110	460	1200	45	400	1200	Green	36%
NoKy	Zeballos River	194	231	590	1300	3100	290	1200	3100	120	1000	3100	Red	
NoKy	Kauwinch River	44	110	130	290	670	62	260	670	25	230	670	Red	
NoKy	Tahsish River	172	778	520	1200	2700	250	1100	2700	100	930	2700	Amber	60%

CU	Mainstem	[1]Acc. WS area (km^2)	Mean esc. (2010+)	S_{gen} (LC)	S_{MSY} (LC)	S_{REP} (LC)	S_{gen} (RR)	S_{MSY} (RR)	S_{REP} (RR)	S_{gen} (P)	S_{MSY} (P)	S_{REP} (P)	[2]WSP status	Mean pNOS (2010+)
NoKy	Artlish River	64	305	190	420	970	91	380	970	37	330	970	Amber	61%
NoKy	Easy Creek	12	14	33	74	170	16	67	170	6.5	59	170	Red	
NoKy	Malksope River	20	22	56	130	290	27	110	290	11	100	290	Red	
NoKy	McKay Cove Creek	1	0	3.5	8	19	1.7	7.2	19	0.7	6.3	19	Red	
NoKy	Narrowgut Creek	17	2	46	100	240	22	94	240	9.1	82	240	Red	
NoKy	Ououkinsh River	17	19	46	110	240	23	95	240	9.2	83	240	Red	
NoKy	Kaouk River	101	350	300	680	1600	150	610	1600	59	540	1600	Amber	91%
NWVI	Cayeghle Creek	49	373	140	320	740	74	290	740	28	250	740	Green	
NWVI	Marble River	167	2900	500	1100	2600	260	1000	2600	100	900	2600	Green	93%

[1] Note, accessible watershed areas of the non-indicator systems (i.e., those not included in Table 4.) tend to be much smaller than those of the indicators (<100 km^2), and the associated uncertainties in benchmarks are high, as shown in Figure 4.6. These low watershed areas extend outside of the range used to develop the model.

[2] Based on reference points derived from the Life Cycle productivity assumption and mean spawner abundance values listed in the fourth column, which are confounded by hatchery-origin fish.

Table C-4. From Weil et al. (2024). Mean escapement, hatchery contribution and proportionate natural influence (PNI) for recipient rivers in the WCVI region between 1998–2021. Mean proportions of local hatchery-origin spawners (pHOS$_{local}$), strayed hatchery-origin spawners (pHOS$_{stray}$), strayed hatchery-origin spawners originating from outside the CU (pHOS$_{stray}$,OCU), proportionate natural influence (PNI), and PNI from local-only spawners (PNI$_{local}$) are described for each river. Mean PNI values are colour-coded based on benchmarks from Withler et al. (2018): Integrated Wild (IW) = Green; Integrated-Transition (IT) = Orange; Integrated-Hatchery (IH) = Red. Data are presented by Conservation Unit (CU), and the data type used in the estimate is indicated (CWT = coded-wire tag, TM = thermal mark). Rivers in grey and marked with an asterisk indicate systems that did not have >20 samples taken in any year of the analysis.

CU	**Recipient River**	**Region**	**Data**	**Escapement**	**pHOS$_{local}$**	**pHOS$_{stray}$**	**pHOS$_{stray,OCU}$**	**pHOS**	**PNI$_{local}$**	**PNI**	**Designation**
CK-033	Marble R	Quatsino Sound	TM	3028	0.06	0.00	0.00	0.06	0.91	0.91	IW
CK-032	Artlish R	Kyuquot Sound	TM	333	0.00	0.39	0.01	0.39	--	--	–
	Kaouk River*		TM	429	0.00	0.04	0.00	0.24	--	--	–
	Kauwinch River*		TM	104	0.00	0.60	0.00	0.60	--	--	–
	Tahsish River		TM	648	0.00	0.52	0.00	0.52	--	--	–
	Conuma R	Nootka Sound	TM	21916	0.96	0.01	0.00	0.97	0.03	0.03	IH
	Burman R		TM	2630	0.63	0.16	0.02	0.79	0.29	0.25	IH
	Gold R		TM	2397	0.17	0.61	0.59	0.78	0.62	0.26	IH
	Leiner R		TM	691	0.30	0.30	0.01	0.60	0.69	0.47	IH
	Sucwoa R		TM	96	0.01	0.86	0.04	0.87	0.83	0.17	IH
	Tahsis R		TM	739	0.29	0.26	0.01	0.55	0.76	0.58	IT
	Tlupana R		TM	379	0.15	0.79	0.01	0.94	0.45	0.07	IH
	Zeballos River		TM	248	0.50	0.10	0.06	0.60	--	--	–
CK-031	Bedwell R	Clayoquot Sound	TM	222	0.00	0.15	0.09	0.15	1.00	0.85	IW
	Cypre R		TM	780	0.00	0.03	0.03	0.03	--	--	–
	Megin River*		TM	74	0.00	0.58	0.58	0.58	--	--	–
	Moyeha River*		TM	124	0.00	0.18	0.18	0.18	--	--	–
	Tranquil Cr		TM	543	0.00	0.04	0.00	0.04	1.00	1.00	IW
	Robertson Cr		TM	41965	0.91	0.00	0.00	0.91	0.01	0.01	IH

CU	Recipient River	Region	Data	Escapement	pHOS$_{local}$	pHOS$_{stray}$	pHOS$_{stray,OCU}$	pHOS	PNI$_{local}$	PNI	Designation
	Nahmint R	Barkley Sound	TM	519	0.28	0.11	0.01	0.40	0.61	0.57	IT
	Sarita R		TM	2022	0.77	0.03	0.00	0.80	0.15	0.14	IH
	Toquart R		TM	290	0.00	0.06	0.06	0.06	1.00	0.95	IW
	Nitinat R	Nitinat - Sooke	TM	21151	0.89	0.00	0.00	0.89	0.09	0.09	IH
	San Juan R		TM	1831	0.32	0.05	0.03	0.37	0.59	0.58	IT
	Sooke R		TM	770	0.48	0.05	0.00	0.53	0.48	0.48	–

Table C-5. Assessment of natural spawner productivity of Stamp River Chinook spawners, including terminal area recruits, recruits/spawner, and smolt to adult survival rate using natural-origin recruits determined using both CWT and otolith thermal marks (TM).

Brood Year	River Spawners[1]	Natural Smolts[2]	Smolts per spawner	[3]Terminal Recruits (CWT)	Recruits per Spawner (CWT)	Survival Rate (CWT)	[3]Terminal Recruits (TM)	Recruits per Spawner (TM)	Survival Rate (TM)
2000	17,250	2,300,408	133	24,800	1.44	1.08%	7,017	0.41	0.31%
2001	37,311	7,389,727	198	70,117	1.88	0.95%	7,328	0.20	0.10%
2002	20,197	3,955,536	196	19,853	0.98	0.50%	2,549	0.13	0.06%
2003	31,768	5,752,023	181	65,380	2.06	1.14%	22,827	0.72	0.40%
2004	5,995	1,299,957	217	8,154	1.36	0.63%	3,340	0.56	0.26%
2005	22,499	4,541,364	202	17,250	0.77	0.38%	4,465	0.20	0.10%
2006	8,289	1,143,973	138	17,008	2.05	1.49%	4,862	0.59	0.43%
2007	21,567	3,894,156	181	56,406	2.62	1.45%	13,567	0.63	0.35%
2008	9,232	2,004,318	217	14,619	1.58	0.73%	7,378	0.80	0.37%
2009	3,412	556,438	163	7,594	2.23	1.36%	933	0.27	0.17%
2010	14,416	2,414,854	168	12,784	0.89	0.53%	4,211	0.29	0.17%
2011	1,738	216,996	125	18,610	10.71	8.58%	790	0.45	0.36%
2012	29,543	4,084,157	138	52,250	1.77	1.28%	10,162	0.34	0.25%

Brood Year	River Spawners[1]	Natural Smolts[2]	Smolts per spawner	[3]Terminal Recruits (CWT)	Recruits per Spawner (CWT)	Survival Rate (CWT)	[3]Terminal Recruits (TM)	Recruits per Spawner (TM)	Survival Rate (TM)
2013	14,317	2,564,947	179	34,086	2.38	1.33%	6,498	0.45	0.25%
2014	14,313	2,488,008	174	30,797	2.15	1.24%	7,449	0.52	0.30%
2015	.22,506	4,214,566	187	61,708	2.74	1.46%	29,884	1.33	0.71%
2016	8,139	1,393,573	171	44,785	5.50	3.21%	8,657	1.06	0.62%
2017	28,595	4,669,525	163	53,305	1.86	1.14%	10,209	0.36	0.22%
2018	34,325	7,257,073	211	13,374	0.39	0.18%	16,305	0.48	0.22%
Average[4]					**3.56**	**2.25%**		**0.77**	**0.44%**

[1] Effective spawners after estimated pre-spawn mortality applied to sex and age specific escapement estimates.

[2] Calculated using effective female spawners times average fecundity of 4600, 3600, 3000 for ages 5, 4, and 3 females, respectively

[3] Natural origin recruits to terminal Area 23: total catch and escapement minus hatchery origin from 2 methods. *Note.*—terminal recruits do not include pre-terminal fishery exploitation of 33% (Average 2000–2022 CYER).

[4] Adjusted to include pre-terminal exploitation rate of 33%.

Table C-6. Percent catch year exploitation rate (CYER; also called distribution of total fishery related mortality and escapement within a catch year) for Robertson Creek Hatchery CWTs. PSC fishery aggregates are from PSC 2023 Chinook Technical Committee Exploitation Rate Analysis (CTC 2023). AABM =Aggregate Abundance Based Management fisheries; ISBM = Individual Stock Based Management fisheries; SBC = Southern British Columbia; NBC = Northern British Columbia; SEAK = South East Alaska; 'terminal' includes Alberni Inlet (Area 23) fisheries and 'ocean' CYER includes only pre-terminal (i.e., outside Area 23) fisheries.

Catch Year	Canada NBC AABM	Canada SBC AABM	Canada NBC ISBM	Canada SBC non-terminal ISBM	Total Canada ocean CYER	Total USA (mostly SEAK) CYER	Total ocean CYER	Canada terminal CYER	Total CYER	Total Escaped	PST period avg. total ocean CYER
1979	12.0%	8.3%	18.8%	3.9%	43.0%	23.0%	65.6%	5.1%	70.7%	29.3%	
1980	8.5%	7.6%	13.3%	1.6%	31.0%	35.3%	66.4%	12.6%	78.9%	21.1%	

Catch Year	Canada NBC AABM	Canada SBC AABM	Canada NBC ISBM	Canada SBC non-terminal ISBM	Total Canada ocean CYER	Total USA (mostly SEAK) CYER	Total ocean CYER	Canada terminal CYER	Total CYER	Total Escaped	PST period avg. total ocean CYER
1981	13.9%	5.9%	13.3%	3.0%	36.1%	35.5%	71.6%	14.8%	86.5%	13.5%	
1982	14.7%	6.2%	11.6%	2.3%	34.9%	35.0%	69.9%	18.4%	88.3%	11.6%	
1983	11.1%	5.7%	10.3%	1.0%	28.0%	44.7%	72.7%	19.7%	92.4%	7.6%	
1984	13.8%	6.7%	6.6%	1.8%	28.9%	34.3%	63.2%	29.6%	92.9%	7.1%	68.2%
1985	16.0%	1.4%	4.7%	2.5%	24.6%	34.9%	59.6%	16.2%	75.8%	24.0%	
1986	8.9%	6.3%	4.2%	1.9%	21.2%	26.5%	47.7%	28.4%	76.1%	23.9%	
1987	7.4%	2.8%	5.7%	1.9%	17.8%	15.1%	33.0%	19.5%	52.5%	47.5%	
1988	8.8%	6.0%	3.2%	5.0%	23.0%	17.5%	40.5%	19.7%	60.2%	39.7%	
1989	10.1%	3.6%	2.9%	2.4%	19.0%	18.2%	37.2%	32.9%	70.2%	29.8%	
1990	9.9%	7.0%	3.9%	1.7%	22.5%	23.4%	46.0%	15.5%	61.5%	38.5%	
1991	10.2%	5.5%	3.6%	2.5%	21.7%	25.2%	46.9%	26.2%	73.1%	26.9%	
1992	7.7%	18.0%	3.8%	1.7%	31.2%	32.7%	63.9%	5.2%	69.1%	30.9%	
1993	8.5%	15.5%	2.7%	3.1%	29.8%	20.7%	50.6%	19.2%	69.7%	30.3%	
1994	9.7%	6.6%	2.2%	3.2%	21.7%	28.2%	49.8%	26.8%	76.6%	23.4%	
1995	5.0%	2.4%	0.7%	3.9%	12.0%	19.6%	31.6%	13.7%	45.3%	54.3%	46.1%
1996	3.0%	0.7%	2.3%	3.1%	9.1%	12.9%	22.0%	2.1%	24.1%	75.9%	
1997	6.5%	0.1%	3.4%	3.0%	13.0%	23.4%	36.4%	23.1%	59.5%	40.4%	
1998	8.6%	1.5%	0.4%	4.2%	14.7%	24.4%	39.2%	20.5%	59.7%	40.3%	
1999	12.2%	0.9%	0.6%	3.4%	17.1%	21.3%	38.4%	24.4%	62.8%	37.2%	
2000	5.5%	0.0%	0.0%	6.8%	12.3%	7.3%	19.6%	0.0%	19.6%	80.4%	
2001	0.0%	1.6%	0.5%	3.4%	5.6%	6.2%	11.8%	1.7%	13.5%	86.5%	
2002	6.0%	1.3%	2.1%	2.6%	12.0%	15.0%	27.0%	22.2%	49.2%	50.8%	

Catch Year	Canada NBC AABM	Canada SBC AABM	Canada NBC ISBM	Canada SBC non-terminal ISBM	Total Canada ocean CYER	Total USA (mostly SEAK) CYER	Total ocean CYER	Canada terminal CYER	Total CYER	Total Escaped	PST period avg. total ocean CYER
2003	2.4%	0.0%	2.9%	2.6%	7.9%	19.6%	27.4%	23.9%	51.4%	48.6%	
2004	4.3%	0.7%	2.9%	3.0%	10.9%	24.3%	35.2%	24.9%	60.1%	39.6%	
2005	7.7%	1.0%	5.5%	3.5%	17.8%	22.0%	39.8%	37.0%	76.8%	23.1%	
2006	5.6%	1.8%	1.9%	4.2%	13.6%	18.0%	31.5%	35.4%	66.9%	33.1%	
2007	10.3%	1.4%	1.3%	4.8%	17.8%	25.7%	43.4%	37.0%	80.5%	19.5%	
2008	5.2%	0.8%	3.0%	2.5%	11.4%	13.1%	24.5%	32.9%	57.4%	42.6%	
2009	8.5%	1.1%	5.3%	5.9%	20.8%	23.4%	44.2%	18.8%	63.0%	37.0%	31.2%
2010	8.0%	2.7%	2.5%	4.8%	18.0%	12.4%	30.4%	7.4%	37.8%	62.2%	
2011	7.1%	4.1%	3.6%	4.0%	18.8%	18.2%	37.0%	33.1%	70.1%	29.9%	
2012	5.4%	2.1%	3.1%	5.2%	15.9%	18.2%	34.0%	29.8%	63.8%	36.2%	
2013	5.4%	1.1%	1.6%	9.1%	17.1%	16.2%	33.4%	2.3%	35.7%	64.3%	
2014	4.8%	5.4%	1.4%	5.2%	16.8%	21.0%	37.8%	4.9%	42.7%	57.3%	
2015	4.1%	3.1%	2.3%	8.8%	18.3%	11.4%	29.7%	19.6%	49.3%	50.4%	
2016	5.7%	1.6%	3.7%	6.9%	17.8%	24.2%	42.1%	12.2%	54.3%	45.7%	
2017	8.9%	4.8%	1.6%	8.5%	23.8%	13.2%	37.0%	25.6%	62.5%	36.3%	
2018	10.8%	5.8%	3.0%	7.0%	26.5%	7.6%	34.1%	38.6%	72.7%	26.9%	
2019	7.8%	3.2%	3.5%	6.3%	20.7%	12.6%	33.3%	43.9%	77.3%	22.7%	34.9%
2020	4.2%	2.1%	2.5%	3.9%	12.6%	11.8%	24.4%	46.4%	70.8%	27.8%	
2021	5.0%	2.5%	1.5%	6.5%	15.5%	14.0%	29.6%	39.4%	68.9%	31.1%	
2022	4.2%	3.7%	5.1%	7.4%	20.4%	19.0%	39.4%	29.1%	68.5%	31.6%	31.1%

Table C-7. Review of recent recovery and survival targets defined in Pacific salmon Recovery Potential Assessments (RPAs) as required for the Species at Risk Program, listed in chronological order.

RPA	Recovery target	Justification	Survival Target	Justification	Guidance on targets provided by
Sakinaw Sockeye (Ramshaw et al. 2019)	Sgen in any given year, 80% SMSY in any given year, and distribution to all 5 spawning areas,	Sakinaw Sockeye Recovery Team (see details in plan)	'Interim Recovery Milestones': average of 500 fish over 4 year period, average of 1000 fish over 4 year period, positive growth	Sakinaw Sockeye Recovery Team (see details in plan)	Government of Canada (GC) (2016)
IFR coho (DFO 2019)	Note, this is called a 'recovery target', but may be closer to a 'survival target' as defined by GC 2021. Three-year geometric mean of natural-origin spawner abundance, relative to 36,935, observed abundances that met a distribution goal of 1000 spawners per subpopulation (CU).	Based on IFCRT documents			DFO (2011)
Cultus sockeye (DFO 2020)	7000 spawners, 4-year average (mix of hatchery and natural-origin), PNI>0.72. *considered an interim recovery goal as it's in the red WSP zone. Also, recommendation that PNI should be > that associated with integrated-wild systems (Withler et al. 2018) though may be less that this at onset of recovery	From Cultus Recovery Plan, similar to historical values to avoid depensatory mortality at low abundances	2,500 spawners (4-year average) with no single year less that 500.	To avoid Endangered status (criterion C, with declining trend)	DFO (2014)
Fraser Sockeye	Recovery target #2: 80% SMSY, the WSP upper abundance benchmark	Approximates the objective of COSEWIC for	Recovery target #1: Two paths for assessment with different targets: In Path A,	Approximates the objective that a DU not be	DFO (2014)

RPA	Recovery target	Justification	Survival Target	Justification	Guidance on targets provided by
(RPR in 2019) (DFO 2020)	relative to recent generational average	Not At Risk or Wild Salmon Policy (WSP) Green	DUs that have between 1,000 – 10,000 mature individuals in the last generation must also have an increasing three generation slope. In Path B, DUs that have abundances larger than 10,000 mature individuals can have a three generation decline no greater than 30%. DUs with mature individuals in the last generation that are less than 1,000 or less than the stock-specific WSP Sgen benchmark do not meet either Recovery Target.	characterized as Endangered or Threatened by COSEWIC or as the Red biological status of the WSP	
Note, in 2021, GC provided guidance on developing survival thresholds as minimum level when not at significant risk of extirpation and Recovery Feasibility Thresholds that are above survival thresholds are associated with improvement in status since when it was determined to be at risk, not rely on human interventions, and account for persistent limitations in recovery (GC 2021)					
SBC CK- 11 Dus (DFO RPR 2020-2021) (DFO 2021)	Greater of 85% SMSY or 1000 fish, relative to generational average, with either positive population growth or <30% decline depending on if abundances < or > 10,000	target at which the DU's long term persistence is secured, comprised of generational average spawner abundance benchmark and the three-generation trend in spawner abundance (with additional inferred target of	Greater of Sgen and 1000 fish, relative to generational average, with either positive population growth or <30% decline depending on if abundances < or > 10,000	approximates conditions such that a DU would not be characterized as Endangered or Threatened by COSEWIC, comprised of generational average spawner abundance benchmark and the three-generation trend in spawner	DFO (2011)

RPA	Recovery target	Justification	Survival Target	Justification	Guidance on targets provided by
		being above WSP amber status)		abundance (with additional inferred target of being above WSP red status)	
SBC CK 4 DUs (DFO 2022)	Same as above, but with recommendation that PNI> threshold for wild-integrated populations, recognizing this may not be possible at start for recovery or for CWT assessment purposes	Same as above	Same as above	Same as above	DFO (2011), GC (2021)
Proposed WCVI Chinook 2 DUs (this report; see section 4.5 for details)	Maximum of 85% SMSY and 1000 spawners relative to generational average spawner abundances, having achieved the survival target.	The level at which the DU's long term persistence is secured, approximated with the objective of a COSEWIC Not At Risk Status and WSP Green or 'healthy' status.	Maximum of Sgen and 1000 spawners relative to generational average spawner abundances, with positive trend in abundances over the most recent 3 generations. Note, if abundances are >10,000 trend must be <30% decline over 3 generations.	The level that approximates the objective that a DU not be characterized as Endangered or Threatened by COSEWIC or as the Red biological status of the Wild Salmon Policy (WSP).	DFO (2011), GC (2021)

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APPENDIX D. WILD SALMON POLICY RAPID STATUS SUMMARY AND CU-STATUS LRP

D.1. BACKGROUND: KEY TERMINOLOGY AND PRINCIPLES OF THE RAPID STATUS ALGORITHM

D.1.1. Key terminology

- **Metrics:** quantitative metrics developed for WSP status assessment: relative abundance; absolute abundance; long-term trend in abundance; and percent change (short-term trend in abundance).
- **Benchmarks:** specific values identified under the WSP to delineate between Red, Amber, and Green status zones for each metric. For example, 50% is the lower benchmark for the long-term trend metric, that delineates this metric's Red and Amber status zones. This metric compares the ratio of the current generational average (geometric mean) spawner abundance to the long-term average (geometric mean) to lower (50%) and upper (75%) benchmarks.
- **WSP rapid status algorithms:** sets of decision rules that approximate the decision making process that experts used in WSP integrated status assessments; see Figure D-3, Figure D-5, and Figure D-7 for the application of the rapid status algorithm to 3 WCVI Chinook CUs as used in the WSP rapid status process.

D.1.2. Principles of the rapid status algorithm

1. Rapid statuses for CUs are developed based on conservation biology principles (Mace and Lande 1991; Mace et al. 2008; Caughley 1994; McElhany et al. 2000; Rodrigues et al. 2006), and are aligned with scientific peer-reviewed publications for WSP CU status assessments (Holt 2009; Holt et al. 2009; Grant et al. 2011; Grant and Pestal 2012; DFO 2015, 2016; Brown et al. 2019; Grant et al. 2020). This ensures that Pacific salmon statuses are scientifically objective, consistent, and comparable across BC and Yukon CUs. Standardized metrics also need to be widely applicable and relatively easy to use and update regularly.
2. Rapid status assessments require the vetting of data and resulting statuses by CU experts.
3. Continual learning and refinement of the rapid status algorithm is the final core principle. This means that data sets and status metrics for each CU will be regularly reviewed and updated, and that the rapid status algorithm itself will be reviewed through on-going work with CU experts.

D.2. DATA

Data sets to assess WSP status of Southern BC Chinook were first developed for the integrated status workshops (DFO 2016). Key steps in the data processing approach are:

1. Categorize survey sites based on level of hatchery releases contributing to the natural spawners at each site;
2. Identify persistent indicators among survey sites;
3. Use persistent indicators with low or unknown enhancement for the CU time series;
4. Infill gaps in site-level time series based on average proportional contribution.

CU-specific data and settings updated by Brown et al. (2020) and the resulting time series were used by COSEWIC for their status assessments (COSEWIC 2020). Code to select and treat NuSEDs (New Salmon Escapement Database System) data for this work are maintained by the DFO Salmon Stock Assessment Unit (A. Vélez-Espino).

For WCVI Chinook, recent work by Holt et al. (2023b) to develop methods for defining Limit Reference Points (LRP) for Stock Management Units (SMU) resulted in further revisions to the site classifications through the inclusion of Proportional Natural Influence (PNI) considerations and with advice by DFO South Coast Area Stock Assessment CU experts. The PNI criteria resulted in the inclusion of DFO NuSEDS escapement sites where the average PNI over the site's time series was greater or equal to 0.5 (DFO 2022a; Holt et al. 2023b).

Discussions with DFO South Coast Area Stock Assessment experts in April–May 2023 confirmed that systems with high hatchery contributions as measured by PNI should not be included in CU-level time series for WSP rapid statuses. However, the populations Nahmint and Tahsis which were included in Holt et al. 2023b were excluded here due to high hatchery contribution. The revised list of included populations is documented in Table D-1. In addition, Holt et al. (2023b) developed system-specific, habitat-based benchmarks for relative abundance (S_{gen}, 85% S_{msy}), which were not previously available for status assessment of most Southern BC Chinook CUs. These benchmarks were updated based on revised list of populations used here (Table D-2; Table D-2).

Table D-1. Conservation Units (CUs) included in this Stock Management Unit (SMU) and lists of the most abundant populations within each CU. Pop id numbers in brackets beside each system name refer to those in the nuSEDS database (q.v. section 2.1).

CU No	CU name	Populations (pop id's: population identification numbers in brackets)
CK-31	West Vancouver Island-South_FA_0.x	**Indicator systems included in the CU time series:** Clayoquot Sound: Bedwell (pop id: 45190), Megin (41178), and Moyeha (41123) Indicator systems excluded from the CU time series due to level of hatchery releases include and/or poor quality escapement indices: Nahmint (1270) Nitinat (40363), San Juan (40253), Sarita (40458), Somass-Sproat-Great Central System (3306), Sooke (40153), and several smaller systems.
CK-32	West Vancouver Island-Nootka and Kyuquot_FA_0.x	**Indicator systems included in the CU time series:** Kyuquot Sound: Artlish (41873), Kaouk (41863), Tahsish (41883) Indicator systems excluded from the CU time series due to level of hatchery releases and/or poor quality escapement indices include: Tahsis (41518), Burman (41328), Conuma (41438), Gold (41348), Leiner (41498), and Zeballos (41713).
CK-33	West Vancouver Island-North_FA_0.x	**Indicator systems included in the CU time series:** Quatsino Sound: Marble (39958), Colonial (39918), and Cayeghle (44792, 39908) No indicator systems were excluded from the CU time series due to level of hatchery releases.

CU No	CU name	Populations (pop id's: population identification numbers in brackets)
		<u>Marble:</u> dominates production in this CU. For the period 2002-2022, this site meets the criteria for a persistent population documented in Brown et al. (2020), where at least 50% of estimates are Type-4 (medium resolution relative-abundance estimates, see Table C-1) or better with no more than 5 years in a row of missing estimates. During this period there were 14 Type-3/4 estimates (moderate to high resolution relative-abundance estimates) and 7 Type-5 estimates (the lowest certainty above a presence/absence). Years with lower resolution (Type-5) estimates come from higher water over longer periods later in the season, preventing visual surveys for escapement enumeration, when most of the spawning occurs. <u>Colonial/Cayeghle</u>: has similar issues with high water, though will drop back into swimmable range for visual surveys a lot faster than Marble, so there are fewer cases of not being able to get in for months. These sites also meet the criteria for persistent populations (Brown et al. (2020).

Table D-2. Relative abundance-based benchmarks for each of the WCVI Chinook CUs (85% S_{MSY} = upper benchmark; S_{gen} = lower benchmark). The median (50% Interval) are the values used in the algorithm. Updated February 2024 from Holt K. et al (2023b) model output.

CU #	CU name	Populations	S_{gen} (median)	85% S_{MSY} (median)
CK-31	West Vancouver Island-South_FA_0.x	Bedwell/Ursis	290	660
		Megin	740	1,600
		Moyeha	340	770
TOTAL			**1,370**	**2,576**
CK-32	West Vancouver Island-Nootka and Kyuquot_FA_0.x	Artlish	190	420
		Kaouk	300	670
		Tahsish	510	1,200
TOTAL			**1,000**	**1,947**
CK-33	West Vancouver Island-North_FA_0.x	Cayeghle	140	330
		Marble	500	1,100
TOTAL			**640**	**1,216**

D.3. RAPID STATUS SUMMARY

D.3.1. SMU LRP status based on WSP rapid status

This SMU falls below the LRP, since one CU, West Vancouver Island-South_FA_0.x (CK-31) WSP rapid status (2022) is ***Red,*** with *High* confidence (Table D-3 and Table D-4; Figure D-1). The WSP rapid status for the other two CUs in this SMU are *Amber* with *High* confidence*:* West Vancouver Island-Nootka and Kyuquot_FA_0.x (CK-32); and *Green* with *High* confidence*:* West Vancouver Island-North_FA_0.x (CK-33). Note, although the algorithm indicates that the West

Vancouver Island-North_FA_O.x CU is *High* confidence based on the metrics used (DFO 2024a; Table D-4), there is additional uncertainty for some years in the time series where escapement estimates are relatively poor resolution although they meet minimum data quality requirements (see Data Section, above). Data dashboards of metrics relative to benchmarks are shown by CU in Figure D-2, Figure D-4, and Figure D-6. The application of the decision tree to derived rapid statuses are shown by CU in Figure D-3, Figure D-5, and Figure D-7, with associated tables of decision nodes in Table D-5, Table D-6, and Table D-7.

For WCVI Chinook CUs, WSP status is derived from indicator populations that are not dominated by hatchery-origin fish (i.e., from indicator populations with proportional natural influence, PNI, >0.5). However, across all three CUs, most indicator populations have some hatchery enhancement and of the six river populations which had no local hatchery enhancement, all had an average proportion of hatchery-origin strays >0.18, which far exceeded the benchmark set out by Withler et al. (2018) for wild-stray influenced populations under the WSP ($pHOS_{stray} > 0.03$) (DFO 2024b). While WSP rapid status algorithm does not consider the degree of hatchery-contribution within populations not deemed hatchery dominated, this factor further supports critical status for this SMU. In addition, declining trends in size-at-age and age-at-maturity (DFO unpublished data; JTC 2016; Ohlberger et al. 2018) indicate the reproductive potentials of WCVI Chinook populations are declining (Ohlberger et al., 2020). Sex ratios in Chinook increasingly skew toward females as age-at-maturity increases, and fecundities of female Chinook increase as a function of body size. Thus, as WCVI Chinook get smaller and younger, fewer females are returning to spawn each year, and those females are each carrying fewer eggs compared to previous generations. As a result, spawner benchmarks for WCVI CUs are likely not stable under stable habitat conditions because effective female spawners are declining over time.

The status of WCVI-North CU has additional uncertainty and may be over-optimistic in assigned Green status due significant historical hatchery production in Marble River and possible high levels of genetic introgression. Genetic impacts may persist despite lower hatchery production in recent years and could result in reduced population productivity and resilience which may not be easily detectable using standard abundance and trend metrics. Status that ignores genetic impacts may provide an incomplete WSP assessment. Future assessments of this CU could further consider hatchery genetic effects and change in demographic parameters.

Further background on the WSP rapid status approach and methods are provided in DFO 2024a, Pestal et al. 2023.

The expert review process employed for WCVI Chinook WSP status was modified from the method described in Pestal et al. 2023. Instead of conducting a dedicated review specifically for the Rapid Status Scanner outputs detailed in this appendix, these outputs were reviewed as part of the broader CSAS process governing the development of this entire report. In addition, the escapement estimates that were inputted into the Rapid Status Scanner are subjected to annual reviews by local experts from DFO and WCVI First Nation and stewardship groups.

Table D-3. Summary of the WSP rapid statuses for each CU within the WCVI Chinook SMU.

Assessment parameter	**CU #31**	**CU #32**	**CU #33**
CU name	West Vancouver Island-South_FA_0.x	West Vancouver Island-Nootka and Kyuquot_FA_0.x	West Vancouver Island-North_FA_0.x
WSP Rapid Status	🟥 Red	🟧 Amber	🟩 Green
Status Confidence	High	High	High

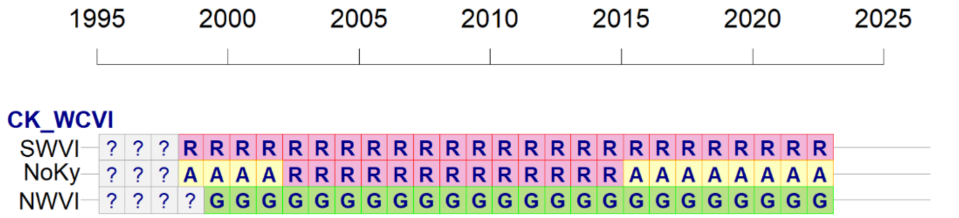
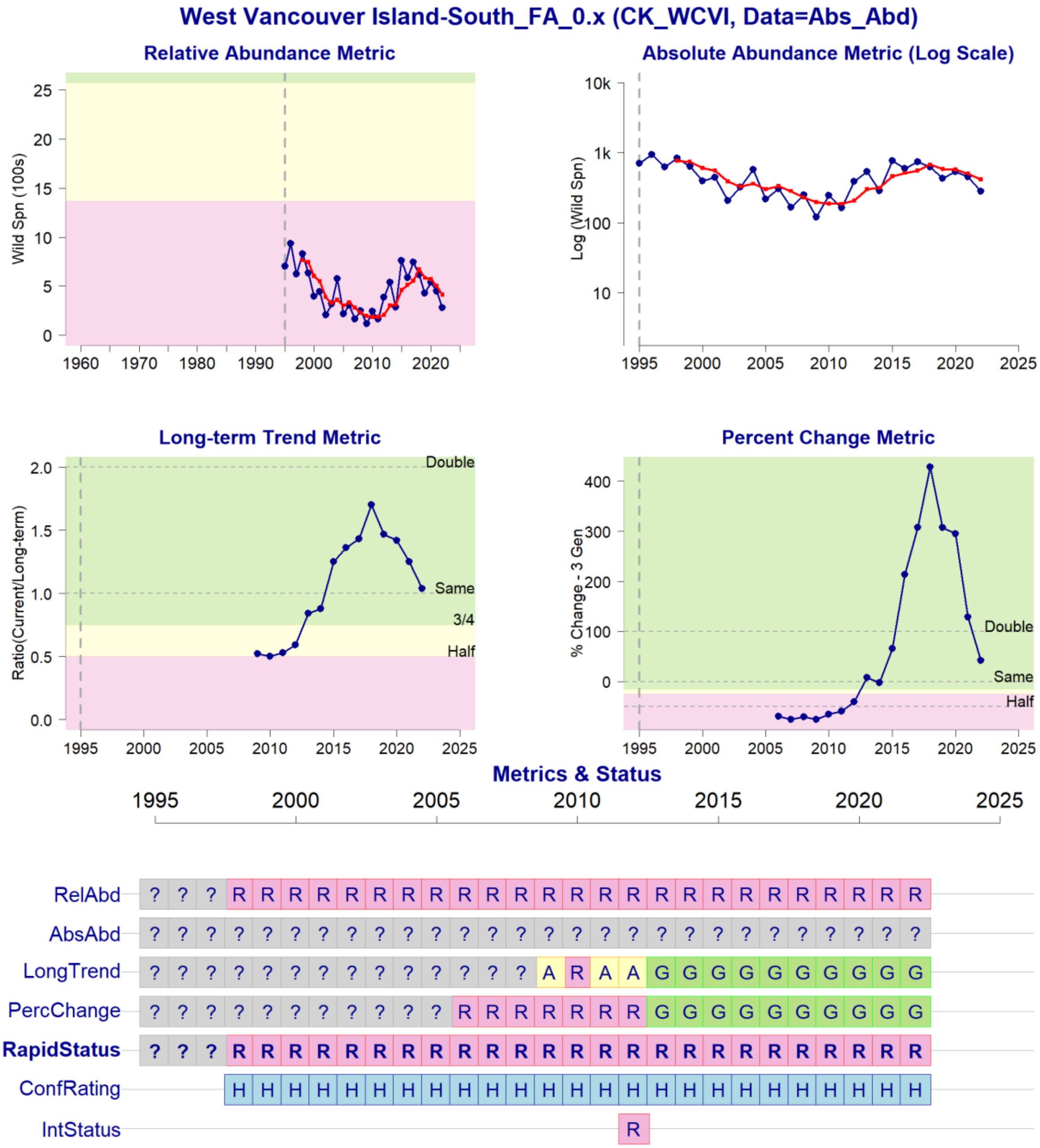


Figure D-1. WCVI Chinook WSP rapid statuses for years with applicable data. Each row summarizes the rapid statuses available for each CU in this SMU. SWVI: West Vancouver Island-South_FA_0.x (CK-31); NoKy: West Vancouver Island-Nootka and Kyuquot_FA_0.x (CK-32); NWVI: West Vancouver Island-North_FA_0.x (CK-33).

Table D-4. WSP rapid statuses for 2022: The WSP rapid status algorithm was used to assess annual statuses for each WCVI Chinook CU. Background in DFO 2024a and Pestal et al. 2023.

CU #	**CU Name**	**WSP Rapid Status (2022)**	**WSP rapid status node**
CK-31	West Vancouver Island-South_FA_0.x	RED, HIGH CONFIDENCE	The current year's (2022) WSP rapid status is Red with High confidence. The recent generational average falls well below the relative abundance metric lower benchmark (Sgen). Sgen is 1,370, and is the sum of the site-specific habitat-based Sgen lower benchmarks (Node 19) (Figure D-2; Figure D-3; Table D-5). The absolute abundance metric could not be applied, since the time series does not capture most of the wild spawners. This Red WSP rapid status has been consistent throughout the time series from 1998–2022 (Figure D-1). The 2012 WSP rapid status of Red matches the WSP integrated status (DFO 2016). Although not used to assess WSP rapid status for this CU, the short-term trend (percent change) metric has remained in the Green status zone since 2012. The lower relative abundance benchmark is lower than the absolute abundance metric threshold of 1,500, based on conservation biology risks related to small population size.

CU #	CU Name	WSP Rapid Status (2022)	WSP rapid status node
CK-32	West Vancouver Island-Nootka and Kyuquot_FA_0.x	AMBER, HIGH CONFIDENCE	The current year's (2022) WSP rapid status is Amber with High confidence. The recent generational average falls between the relative abundance metric lower (Sgen: 1,000) and upper threshold (85% Smsy: 1,947) (Node 37) (Figure D-4; Figure D-5; Table D-6). These thresholds are the sum of site-specific habitat-based Smsy. The absolute abundance metric could not be applied, since the time series does not capture most of the wild spawners. The WSP rapid status has varied between Amber (1998-2001) to Red (2001–2013) and back to Amber (2014–2022). The 2012 WSP rapid status of Red matches the WSP integrated status (DFO 2016). Although not used to assess WSP rapid status for this CU, the short-term trend (percent change metric) has varied between Amber, Red and Green status throughout the time series. The short-term trend has been Green since 2015. The lower relative abundance benchmark is lower than the absolute abundance metric threshold of 1,500, based on conservation biology risks related to small population size.
CK-33	West Vancouver Island-North_FA_0.x	GREEN, HIGH CONFIDENCE*	The current year's WSP rapid status (2022) is Green with High confidence. The recent generational average falls well above the relative abundance metric upper benchmark (85% SMSY: 1,216) (node 36) (Figure D-6; Figure D-7; Table D-7). The relative abundance benchmarks are the sum of site-specific habitat-based SMSY. The absolute abundance metric could not be applied, since the time series does not capture most of the wild spawners. This Green status has been consistent throughout the time series, from 1998–2022. No WSP integrated status was completed in 2012 (DFO 2016); at the time as Marble and Cayeghle were categorized as sites with high level of hatchery contribution. However, for data associated with the current 2022 WSP rapid status assessment are considered appropriate given the average PNI is greater than 0.5; these are not considered highly enhanced systems by Withler et al. (2018) guidelines. Although not used to assess WSP rapid status for 2022, the short-term trend (percent change) metric has varied between Amber, Red, and Green throughout the time series. This metric has been Green in the last two years. The lower relative abundance benchmark is lower than the absolute abundance metric threshold of 1,500, based on conservation biology risks related to small population size. *Note although the algorithm indicates that this CU status is High confidence based on the metrics used, and while data meet the minimum requirements to be included as a persistent site, there is additional uncertainty in escapement data for some years where they are considered poorer resolution (see Data section above).



	1995					2000					2005					2010					2015					2020		
RelAbd	?	?	?	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
AbsAbd	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?
LongTrend	?	?	?	?	?	?	?	?	?	?	?	?	?	?	A	R	A	A	G	G	G	G	G	G	G	G	G	G
PercChange	?	?	?	?	?	?	?	?	?	?	?	R	R	R	R	R	R	R	G	G	G	G	G	G	G	G	G	G
RapidStatus	**?**	**?**	**?**	**R**	**R**	**R**	**R**	**R**	**R**	**R**	**R**	**R**	**R**	**R**	**R**	**R**	**R**	**R**	**R**	**R**	**R**	**R**	**R**	**R**	**R**	**R**	**R**	**R**
ConfRating				H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H
IntStatus																		R										

Figure D-2. Metrics and Status for West Vancouver Island-South_FA_0.x (CK-31, WCVI). Panels on top show the four standard WSP metrics, calculated based on the available time series of spawner abundances. Bottom panel summarizes the status for each individual metric and shows the resulting rapid status for the CU with a confidence rating. The integrated status in 2023 (IntStatus) of Red, aligns with the corresponding WSP rapid status of Red, presented in the final row.

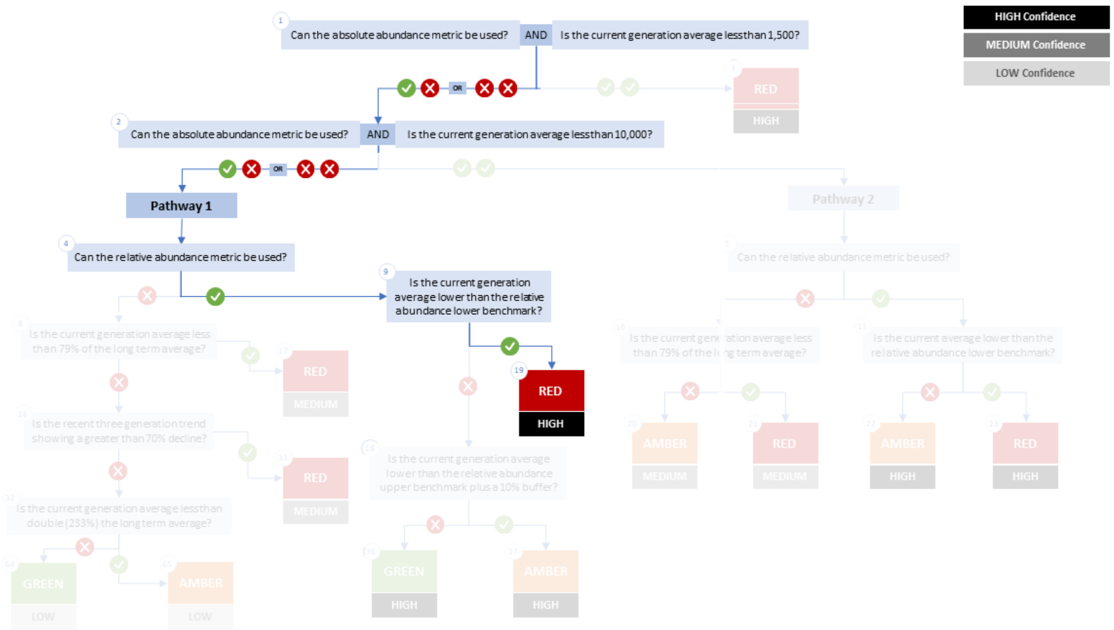
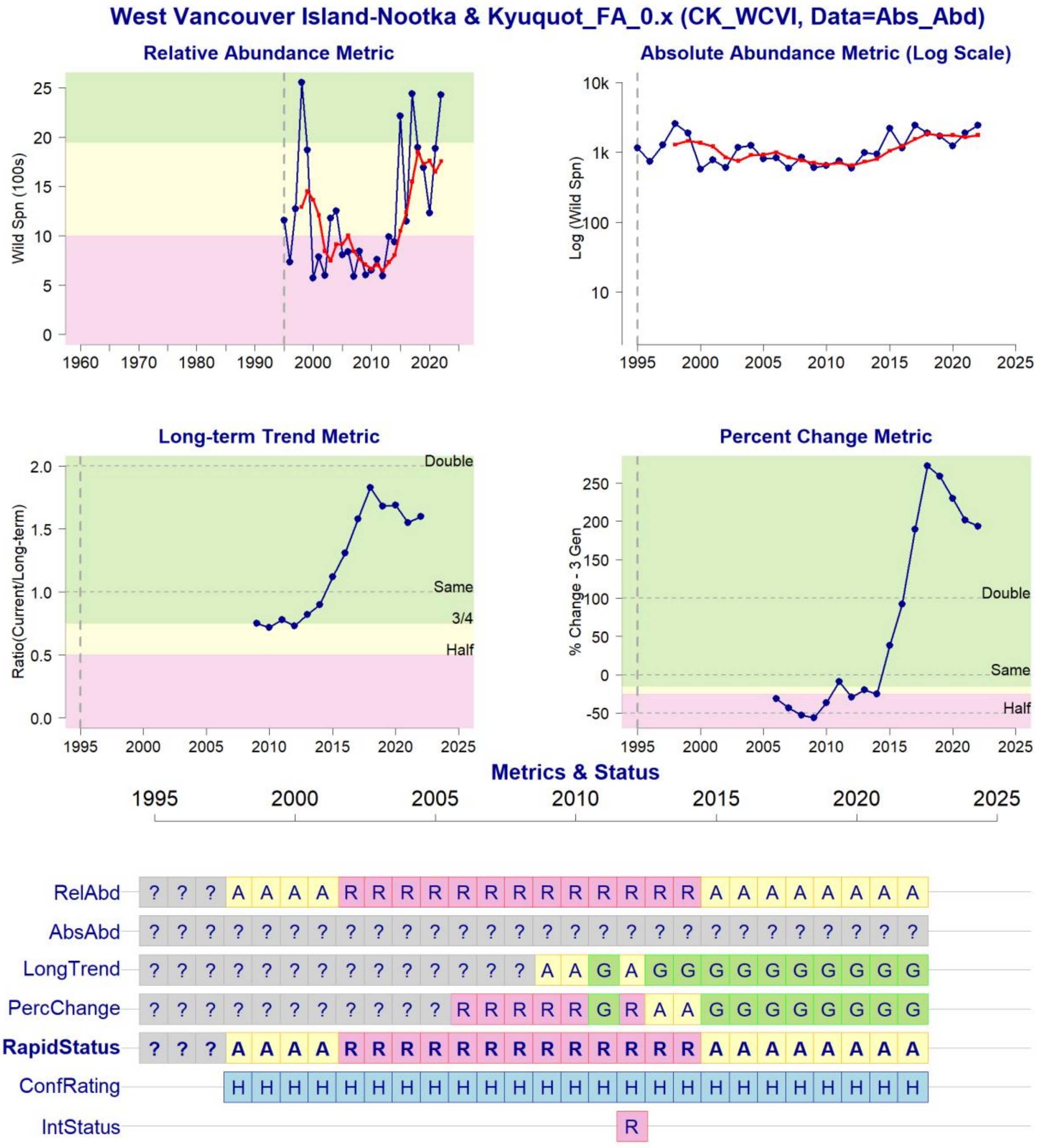


Figure D-3. Algorithm pathway taken to assess status for West Vancouver Island-South_FA_0.x (CK-31, WCVI) in 2022. The absolute abundance metric does not apply to this CU (nodes 1 and 2), the relative abundance metric applies to this CU, and the current generation average abundance falls below the lower threshold (1,370) for the relative abundance metric (node 4). Status for this CU is therefore designated as Red with High confidence at Node 19.

Table D-5. Decision tree path given data and metric values for West Vancouver Island-South_FA_0.x (CK-31, WCVI); this aligns with Figure C3 above. For each node, the algorithm decision is made by comparing the CUs current metric value to the metric threshold and answering Yes or No, running through sequential nodes and decisions until the final WSP rapid status for that CU and year is reached.

Node	Metric	CUs current value	Metric Threshold	Algorithm Decision
1	absolute abundance	NA (does not apply)	Less than 1,500	NO
2	absolute abundance	NA (does not apply)	Less than 10,000	NO
4	relative abundance	YES	NA	YES
9	relative abundance	413	1,370	YES
19	FINAL STATUS NODE			RED



RelAbd	?	?	?	A	A	A	A	R	R	R	R	R	R	R	R	R	R	R	R	R	A	A	A	A	A	A	A	A
AbsAbd	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?
LongTrend	?	?	?	?	?	?	?	?	?	?	?	?	?	?	A	A	G	A	G	G	G	G	G	G	G	G	G	G
PercChange	?	?	?	?	?	?	?	?	?	?	?	R	R	R	R	R	G	R	A	A	G	G	G	G	G	G	G	G
RapidStatus	**?**	**?**	**?**	**A**	**A**	**A**	**A**	**R**	**R**	**R**	**R**	**R**	**R**	**R**	**R**	**R**	**R**	**R**	**R**	**R**	**A**	**A**	**A**	**A**	**A**	**A**	**A**	**A**
ConfRating				H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H
IntStatus																		R										

Figure D-4. Metrics and Status for West Vancouver Island-Nootka and Kyuquot_FA_0.x (CK-32, WCVI). Panels on top show the four standard WSP metrics, calculated based on the available time series of spawner abundances. Bottom panel summarizes the status for each individual metric and shows the resulting rapid status for the CU with a confidence rating. The integrated status in 2023 (IntStatus) of Red, aligns with the corresponding WSP rapid status of Red, presented in the final row.

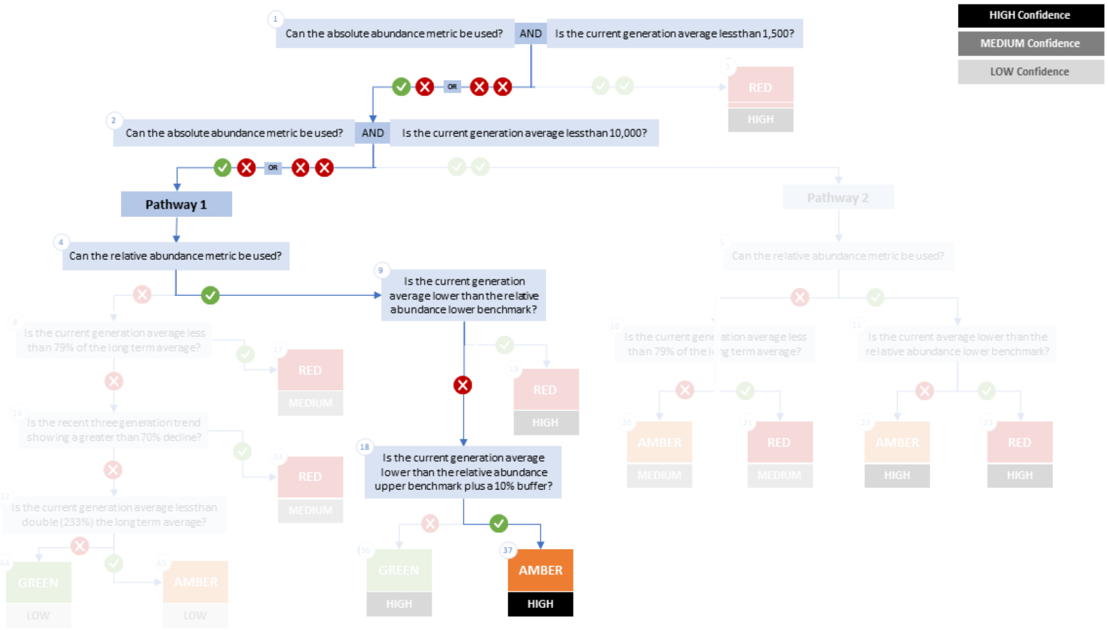
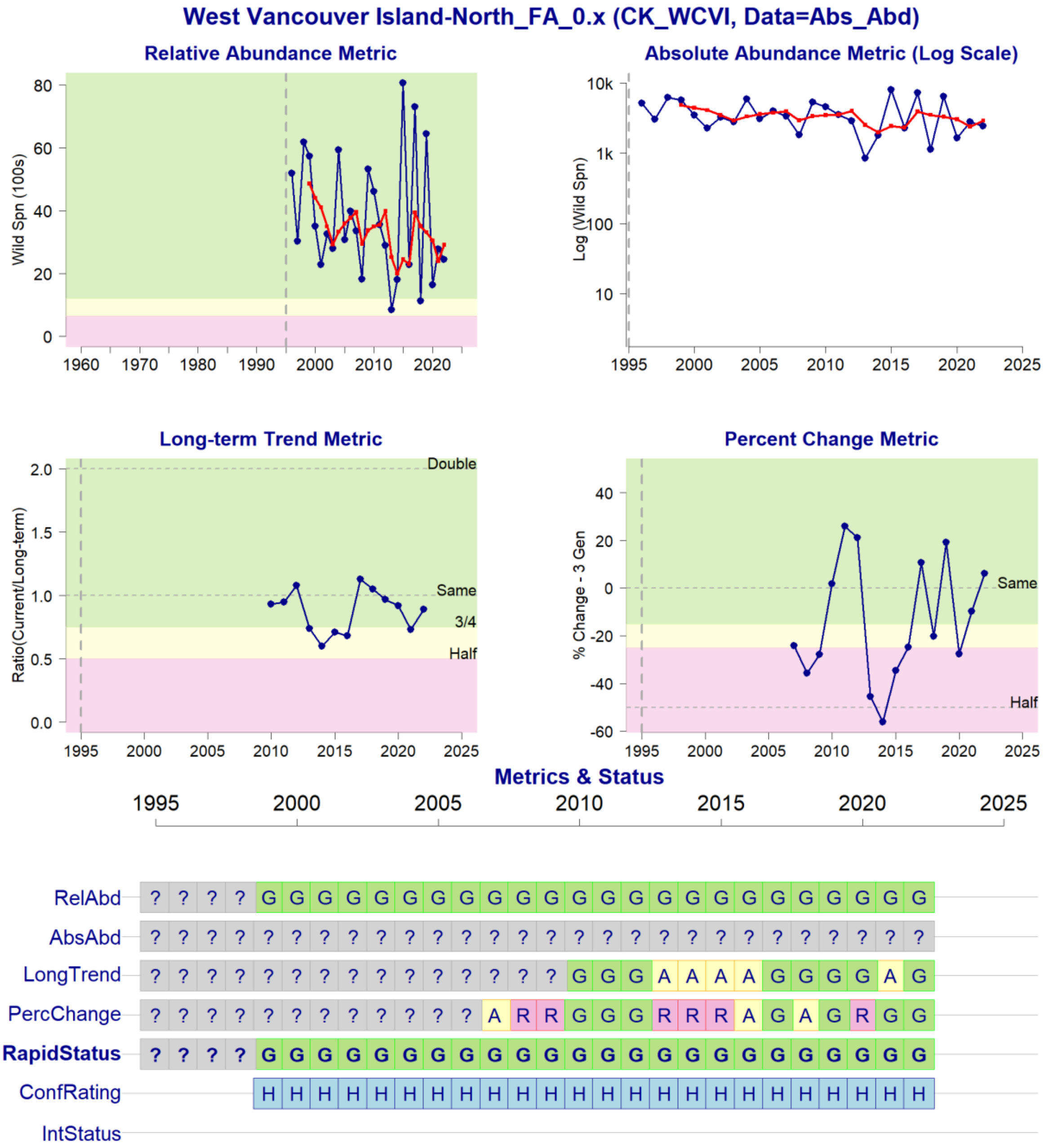


Figure D-5. Algorithm pathway taken to assess status for West Vancouver Island-Nootka and Kyuquot_FA_0.x (CK-32, WCVI) in 2022. The absolute abundance metric does not apply to this CU (nodes 1 and 2), the relative abundance metric applies to this CU, and the current generation average abundance falls above the lower threshold (1,000) (node 9) and below the upper threshold (1,947) for the relative abundance metric (node 18). Status for this CU is therefore designated as Amber with High confidence at Node 37.

Table D-6. Decision tree path given data and metric values for West Vancouver Island-Nootka and Kyuquot_FA_0.x (CK-32, WCVI); this aligns with Figure C3 above. For each node, the algorithm decision is made by comparing the CUs current metric value to the metric threshold and answering Yes or No, running through sequential nodes and decisions until the final WSP rapid status for that CU and year is reached.

Node	Metric	CUs current value	Metric Threshold	Algorithm Decision
1	absolute abundance	NA (does not apply)	Less than 1,500	NO
2	absolute abundance	NA (does not apply)	Less than 10,000	NO
4	relative abundance	YES	NA	YES
9	relative abundance	1,756	1,000	YES
18	relative abundance	1,756	1,947	
37	FINAL STATUS NODE			AMBER



	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
RelAbd	?	?	?	?	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G
AbsAbd	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?
LongTrend	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	G	G	G	A	A	A	A	G	G	G	G	A	G
PercChange	?	?	?	?	?	?	?	?	?	?	?	?	A	R	R	G	G	G	R	R	R	A	G	A	G	R	G	G
RapidStatus	**?**	**?**	**?**	**?**	**G**	**G**	**G**	**G**	**G**	**G**	**G**	**G**	**G**	**G**	**G**	**G**	**G**	**G**	**G**	**G**	**G**	**G**	**G**	**G**	**G**	**G**	**G**	**G**
ConfRating					H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H
IntStatus																												

Figure D-6. Metrics and Status for West Vancouver Island-North_FA_0.x (CK-33, WCVI). Panels on top show the four standard WSP metrics, calculated based on the available time series of spawner abundances. Bottom panel summarizes the status for each individual metric and shows the resulting rapid status for the CU with a confidence rating. No integrated status (IntStatus) was conducted for this CU in 2012.

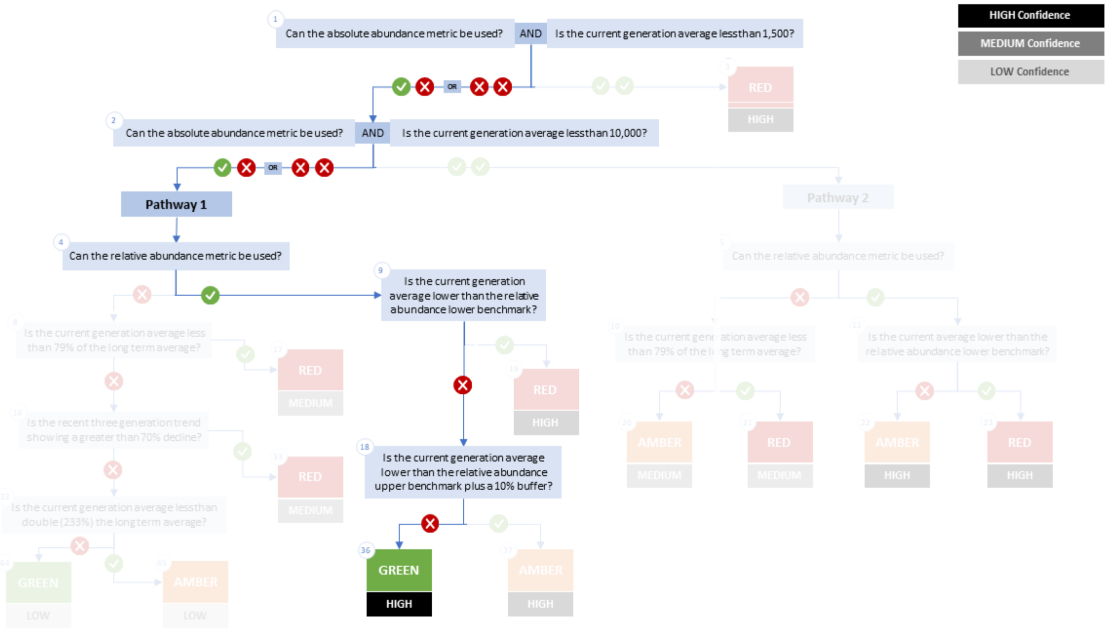


Figure D-7. Algorithm pathway taken to assess status for West Vancouver Island-North_FA_0.x (CK-33, WCVI) in 2022. The absolute abundance metric does not apply to this CU (nodes 1 and 2), the relative abundance metric applies to this CU, and the current generation average abundance falls above the lower threshold (640) (node 9) and upper threshold (1,216) for the relative abundance metric (node 18). Status for this CU is therefore designated as Green with High confidence at Node 36.

Table D-7. Decision tree path given data and metric values for West Vancouver Island-North_FA_0.x (CK-33, WCVI); this aligns with Figure C3 above. For each node, the algorithm decision is made by comparing the CUs current metric value to the metric threshold and answering Yes or No, running through sequential nodes and decisions until the final WSP rapid status for that CU and year is reached.

Node	Metric	CUs current value	Metric Threshold	Algorithm Decision
1	absolute abundance	NA (does not apply)	Less than 1,500	NO
2	absolute abundance	NA (does not apply)	Less than 10,000	NO
4	relative abundance	YES	NA	YES
9	relative abundance	2,906	640	YES
18	relative abundance	2,906	1,216	YES
36	FINAL STATUS NODE			GREEN

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APPENDIX E. RECOVERY POTENTIAL ASSESSMENT (RPA) ELEMENTS CROSSWALK

Table E-1. RPA Elements crosswalk.

RPA Element(s)	Associated sections
1–3: Biology, Abundance, Distribution and Life History Parameters.	Addressed in sections 3 & 5.
4–7: Habitat and Residence Requirement.	Addressed in sections 3, 6.4, & 6.5
8–11: Threats and Limiting Factors to the Survival and Recovery.	Addressed in sections 5 & 6
12: Propose candidate abundance and distribution target(s) for recovery.	Addressed in section 4.5
13: Project expected population trajectories over a scientifically reasonable time frame, and trajectories over time to the potential recovery target(s), given current population dynamics parameters	Addressed in section 7
14: Provide advice on the degree to which supply of suitable habitat meets the demands.	Addressed in sections 6.4 & 6.5
15: Assess the probability that the potential recovery target(s) can be achieved under current rates of population dynamics parameters, and how that probability would vary with different mortality (especially lower) and productivity (especially higher) parameters.	Addressed in section 7
16–21: Scenarios for Mitigation of Threats and Alternatives to Activities	Addressed in section 9
22: Allowable Harm Assessment	Not addressed