Marine Risk Assessment for Natural-Origin West Coast Vancouver Island Chinook Salmon (*Oncorhynchus tshawytscha*)

James R. Irvine, Wilf Luedke, Isobel Pearsall, Akash Sastri, Christian Carson, Claire Menendez, Jessica Hutchinson, Kristi M. Miller-Saunders, and Tim Hawkins

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Abstract

Irvine, J.R., Luedke, W., Pearsall, I., Sastri, A., Carson, C., Menendez, C., Hutchinson, J., Miller-Saunders, K.M., and Hawkins, T. 2024. Marine Risk Assessment for Natural-Origin West Coast Vancouver Island Chinook Salmon (*Oncorhynchus tschawytscha*). Can. Tech. Rep. Fish. Aquat. Sci. 3603: ix + 308 p.

Marine factors potentially limiting natural-origin West Coast Vancouver Island (WCVI) Chinook were identified and ranked during and following seven virtual multi-stakeholder workshops held in 2022. Factors identified as High Risk were most frequent during a salmon's 1st marine year, and more so in the future than currently. Carry-over effects between freshwater and early marine life were High Risk while during a salmon's 1st marine year, prey abundance and pathogens, and parasites such as sea lice were High Risk. Overall, High Risk factors included changing water temperatures, habitat availability, and predation; size-selective fisheries-induced demographic changes were significant for subadult and adult salmon. Recommendations included continuing to adapt hatchery practices to reduce High Risk losses in diversity that should increase resilience as well as implementing measures that promote habitat protection and restoration. Important information gaps included marine survival time series for natural-origin salmon and determining where salmon live after their 1st marine year. To better understand limiting factors, the continued application of multi-stakeholder approaches involving local knowledge-holders, particularly First Nations, is needed. For factors that interact synergistically, ecosystem models will help identify risks, including those under anthropogenic control that if mitigated, may provide the greatest increases in survival and returns of natural-origin WCVI Chinook.

Résumé

Irvine, J.R., Luedke, W., Pearsall, I., Sastri, A., Carson, C., Menendez, C., Hutchinson, J., Miller-Saunders, K.M., and Hawkins, T. 2024. Marine Risk Assessment for Natural-Origin West Coast Vancouver Island Chinook Salmon (*Oncorhynchus tschawytscha*). Can. Tech. Rep. Fish. Aquat. Sci. 3603: ix + 308 p.

Les facteurs marins potentiellement limitants pour le saumon chinook d'origine naturelle de la côte ouest de l'île de Vancouver (WCVI) ont été identifiés lors d'ateliers virtuels multipartites tenus en 2022. Les facteurs identifiés comme étant à haut risque étaient plus fréquents pendant la première année marine d'un saumon, et plus encore à l'avenir qu'actuellement. Notamment les effets de report entre l'eau douce et la vie marine précoce, l'abondance des proies, les agents pathogènes et les parasites. Les changements de température de l'eau, la disponibilité de l'habitat, la prédation et les pêcheries sélectives étaient aussi des facteurs à haut risque. Les recommandations comprenaient l'adaptation des pratiques d'écloserie pour réduire les pertes de diversité, la protection et la restauration des habitats. L'information concernant la survie en mer des saumons d'origine naturelle et leur localisation après la première année marine est particulièrement incomplète. Pour mieux comprendre les facteurs limitants, la poursuite d'approches multipartites impliquant les détenteurs de connaissances locales, en particulier les Premières Nations, est nécessaire. Les modèles écosystémiques aideraient à identifier les risques, y compris ceux sous contrôle humain, dont l'atténuation pourrait augmenter la survie et les retours de saumons chinook d'origine naturelle de la WCVI.

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1. INTRODUCTION

1.1 Overview and Background Information

To improve our understanding of risks to natural-origin West Coast Vancouver Island (WCVI) Chinook salmon (*Oncorhynchus tshawytscha*), we briefly consider information on other Chinook populations and reasons for changes in their abundance. At the scale of the North Pacific, many Chinook populations are in decline. Aggregate catch data from the five North Pacific Anadromous Fish Commission (NPAFC) member countries (Canada, Japan, the Republic of Korea, the Russian Federation, and the United States of America) provide a crude index of abundance, which show that catches during a recent decade (2011-2021) were ~18% lower than the previous one (NPAFC 2022). In Alaska, despite significant fishery reductions, Chinook runs continue to be poor (Munro 2022; Brenner et al. 2022) while south of the Canadian border, two Chinook populations are listed as endangered under the US Endangered Species Act and seven are threatened (NOAA 2022).

Widespread patterns of declining Chinook numbers and sizes (Dorner et al. 2018; Ohlberger et al. 2018; Atlas et al. 2023) led some authors to conclude that these changes were driven largely by large-scale oceanic factors (Welch et al. 2021), which can be exacerbated by competition with pink salmon (*O. gorbuscha) (*Buckner et al. 2023). However, Riddell et al. (2013), investigating mechanisms responsible for shifting abundances of Chinook in southern BC, concluded that both local and large-scale factors are important. Local factors during a salmon's first year of life can operate in freshwater, estuarine, and nearshore marine ecosystems. Riddell et al. were unable to attribute causes for declines other than inferring that low early marine survivals were contributing. Local processes including those in freshwater were important however, as demonstrated by stock-specific deviations in survival rates and productivity for various stocks, including WCVI Chinook.

In Canada, the Committee on Endangered Species in Canada (COSEWIC) is responsible for the scientific assessment of species that may be at risk of extinction. However, a legal requirement to protect a species at risk happens only if the species is listed under the Species at Risk Act (SARA), which also considers social and economic factors (Irvine et al. 2005). In 2020, COSEWIC focused on Chinook salmon populations with high levels of artificial hatchery releases (COSEWIC 2020). Included in this group were three Designatable Units (DUs) from the WCVI, each of which aligned geographically with a Wild Salmon Policy (WSP) Conservation Unit (CU) (Holtby and Ciruna 2007; DFO 2005). These three units are the focus of this report, which when combined, constitute one Stock Management Unit (SMU) (Figure 1.1).

Changes within Canada to the management, assessment, and legislative requirements for endangered species are relevant to WCVI Chinook. Canada's WSP, released in 2005, sought to restore and maintain healthy and diverse Pacific salmon populations and their habitat (DFO 2005), but its recommendations were not binding. That same year, Fisheries and Oceans Canada (DFO) Science Advisory meetings were held that identified that fishery harvest rates for stocks below their Limit Reference Point (LRP) were to be kept to an absolute minimum to comply with the Precautionary Approach (DFO 2006). DFO identified the need for Rebuilding Plans for stocks below their LRP (DFO 2009), and Rebuilding Plans became legally required when the Fisheries Act was amended in 2019 (DFO 2022a). Included in the amendments were Fish Stocks Provisions (FSP) that required the Minster to (a) maintain stocks at levels necessary to promote their sustainability, and (b) to develop and implement rebuilding plans (DFO 2022a, DFO 2022b). WCVI Chinook were added to the Fishery (General) Regulations in April 2022, necessitating the development and implementation of a Rebuilding Plan within 2 years, which this document aims to support.

COSEWIC (2020) considers "wild salmon" to be as defined in the WSP (DFO 2005), 2nd generation natural spawners (i.e., those that ''had spent their entire lives in the wild and originated from parents that were also produced by natural spawning and continuously lived in the wild"). Because of the near impossibility of determining the origin of the parents of a salmon caught in the field, COSEWIC publications use the Proportionate Natural Influence (PNI) metric as a measure of hatchery influence on the wild population:

$$PNI = \frac{pNOB}{pNOB + pHOS}$$

Where $pNOB$ is proportion natural-origin brood stock used in the hatcheries and $pHOS$ is proportion hatchery-origin spawners in the natural environment. To estimate numbers of wild spawners, PNI is multiplied by the total number of spawners in the natural environment. Unfortunately, because the confidence limits on estimates of wild spawner abundance for WCVI Chinook were extremely wide, and the information necessary to do the calculations was not available at the DU or CU level, COSEWIC relied on consensus opinion for their estimates of wild spawner numbers and trends in abundance (COSWIC 2020).

1.2 The Importance of Understanding Reasons for Declining Abundance

The consensus opinion of small and declining numbers of wild salmon returning to the two southerly WCVI DUs, DU 24 (West Vancouver Island, Ocean, Fall (South)) and DU 25 (WCVI, Ocean, Fall (Nootka & Kyuquot)), resulted in COSEWIC THREATENED status categorizations (i.e., likely to become endangered if nothing is done to reverse factors leading to their extirpation). There was insufficient monitoring information for COSEWIC to assess the status of the more northerly DU 26 (West Vancouver Island, Ocean, Fall, Table 1.1), resulting in a DATA DEFICIENT status categorization (COSEWIC 2020). This corroborated findings from an earlier integrated status assessment carried out under the WSP; red (i.e., poor) status for the two southern CUs and unknown for the northern CU (DFO 2016). More recently, Holt et al. (2023) included WCVI Chinook in their evaluation of LRPs for several SMUs.

Major threats to WCVI Chinook identified by COSEWIC (2020) included human-caused ecosystem modifications that were primarily in freshwater, releases of hatchery salmon with resulting impacts from competition and the transfer of genetic material (i.e., introgression), declining marine survival as well as impacts from climate change and severe weather (Table 1.2).

WCVI Chinook fit the classical definition of ocean type Chinook – i.e., virtually all migrate to sea as sub-yearling smolts, entering the North Pacific Ocean near where in most years the North Pacific Current from Asia approaches the North American coast (Bifurcation Zone, Figure

1.2). They appear to have a primarily coastal marine distribution, and as they approach maturity, return in the fall to spawn. They inhabit approximately 60 rivers currently supporting from fewer than 100 to more than 100,000 spawners annually, the latter in rivers with major hatcheries. Twenty of the 60 rivers have some form of enhancement to supplement natural spawning, including major hatcheries on the Stamp, Conuma, and Nitinat rivers.

Hatcheries contribute an average of about 80% of the annual numbers of returning WCVI Chinook to the two southern DUs (COSEWIC 2020). Robertson Creek Hatchery (RCH) Chinook salmon are an indicator stock for WCVI Chinook exploitation rate and distribution patterns. Annual assessments of various WCVI hatchery and natural population aggregates and abundance forecasts for RCH provide information on stock status that is used when managing ocean terminal fisheries. The forecasts are key inputs to the annual PSC Chinook Technical Committee annual model calibration that calculates abundance indices and associated allowable catch levels for the WCVI and North-Central BC and Southeast Alaska Aggregate Abundance-Based Management (AABM) fisheries (e.g., CTC 2022). WCVI Chinook management is complex, requiring trade-offs between maximizing socio-economic benefits, including fishing opportunities and achieving spawner egg targets in key systems. A relatively recent management objective is minimizing adverse effects of hatchery fish on natural spawning populations.

For thousands of years, Chinook and their conspecifics helped shape the culture, economy, and religions of T'Souke, Pacheedaht, and 14 nuučaanuł (Nuu-chah-nulth) and Quatsino Nations along the WCVI. WCVI Chinook are now caught in First Nation, sport, and commercial fisheries from Vancouver Island to Alaska. Their far northerly marine distribution challenges Canada's ability to conserve them since a significant proportion of the catch occurs in Alaska, likely including some in the Bering Sea (Larson et al. 2013). Allowable harvest impacts in areas under joint Canada - US management are determined as required by provisions in the Pacific Salmon Treaty (PSC 2022). In Canada, fisheries are also subject to domestic considerations, such as conservation and allocation. Concern for low status natural origin WCVI Chinook has constrained harvest in mixed-stock Canadian and Alaskan fisheries, including those in North-Central BC and WCVI.

In summary, the best available information prior to the Marine Risk Assessment (MRA) workshops summarized later in this report showed that numbers of natural-origin WCVI Chinook have undergone significant declines in abundance in recent decades, although the relative importance of local versus broad scale factors was unclear. An improved understanding of these factors is required by both fisheries and hatchery managers and will be needed to complete the required Rebuilding Plan.

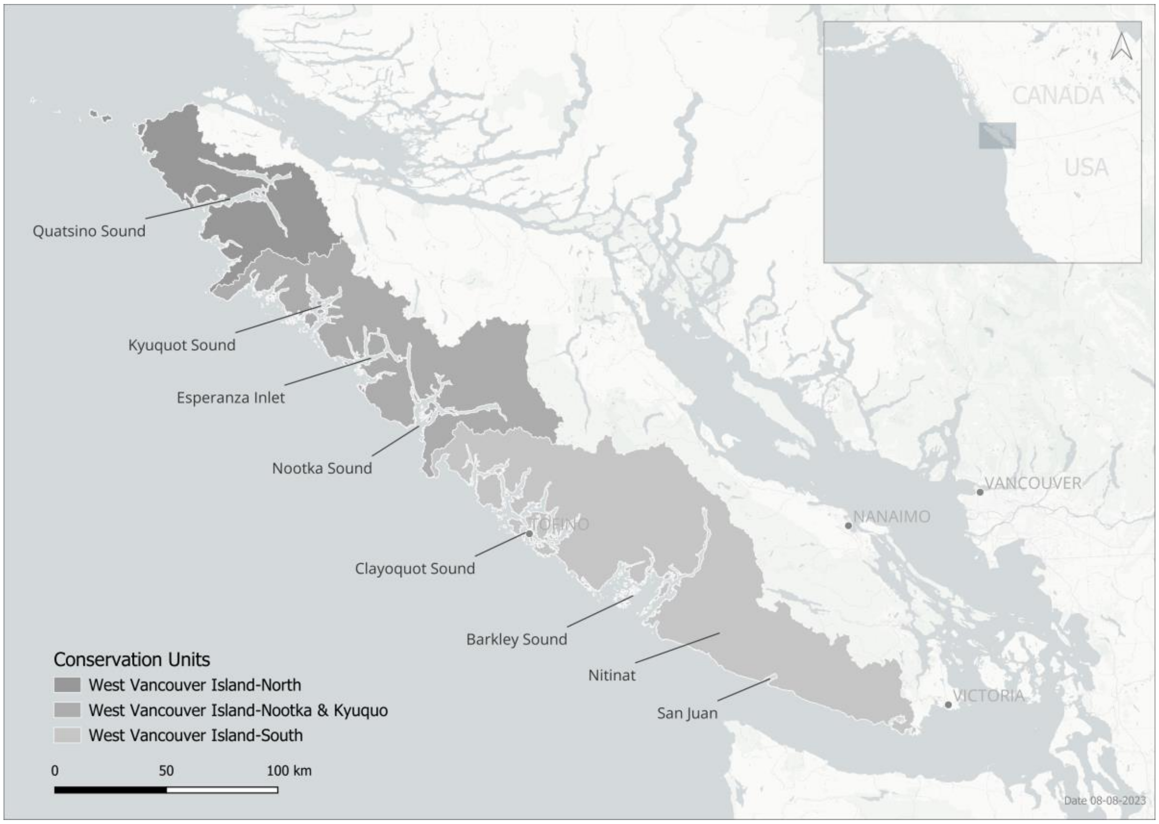

Figure 1.1 **Map adapted from Holt et al. (2023) showing the WCVI Chinook Stock Management Unit (SMU), its component Conservation Units (CUs) or Designatable Units (DUs), and major inlets or sounds.**

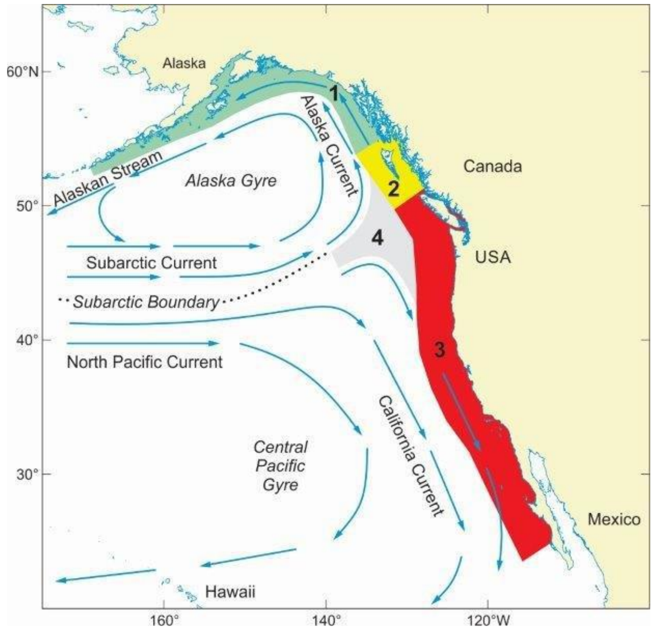

Figure 1.2 **Ocean circulation in the Northeast Pacific including West Coast Vancouver Island (Figure from Norgard et al. 2019). Note that locations of currents and zones vary among years. Area 1 is the Coastal Downwelling Zone, Areas 2 is the upwelling/Downwelling Transition Zone, Areas 3 is the Coastal Upwelling Zone, and Areas 4 is the Bifurcation Zone.**

Table 1.1 **Summary of status information for West Coast Vancouver Island (WCVI) Chinook Salmon Designatable (DU)/Conservation Units (CU) from COSEWIC (2020).**

DU	DU Short Name	CU ID	Status	Reason For Designation	Major Threats
24	WCVI/Ocean /Fall (South)	CK-31	Threatened	Small and declining numbers, consensus opinion indicates <10,000 wild mature Adults within 1 subpopulation	Hatchery releases, ecosystem modifications, agricultural and forestry effluents, marine harvest and survival, climate change and severe weather
25	WCVI/Ocean /Fall (Nootka & Kyuquot)	CK-32	Threatened	Small and declining numbers, consensus opinion indicates <10,000 wild, mature Adults within 1 subpopulation and continuing decline is inferred. Number of mature fish may meet Endangered, criterion	Hatchery releases, ecosystem modifications, marine harvest and survival, tourism/recreation areas, industrial effluents, agriculture/forestry issues, avalanches/landslides and droughts, climate change and severe weather
26	WCVI+WCCI /Ocean/Fall	CK-33	Data Deficient	Only 1 monitoring site that is heavily enhanced by hatchery releases. Data insufficient to assess status	Hatchery releases

1.3 Workshop Approach and Objectives

A series of MRA workshops were held virtually during 2022 to update information on marine risk factors for the upcoming Rebuilding Plan required for WCVI Chinook. DFO, in collaboration with nuučaanuł (Nuu-chah-nulth) and Pacheedaht Nations, and with the support of various area-based and other experts and organizations assembled relevant background information for presentation at these sessions. A separate series of workshops focused on the freshwater life history will be reported on separately.

Given the inability of COSEWIC to quantitatively assess abundance trends for wild salmon (2020), and our desire to incorporate information from various knowledge holders, we focused on "natural-origin" salmon, which are the offspring of natural spawning although the origin of their parents is unknown. In contrast, hatchery-origin salmon are the offspring of salmon spawned in a hatchery. Presentations and findings from the MRA workshops covered the entire marine range of WCVI hatchery- and natural-origin WCVI Chinook salmon, from the time fish entered seawater as smolts, until they returned to freshwater to spawn as Adult salmon. The geographic range extends from estuaries along the WCVI, northward beyond Haida Gwaii, and westward to include portions of the Gulf of Alaska and the southeastern Bering Sea.

The primary goals of the Marine Risk Assessment workshops reported here were to:

a) identify and rank the principal factors limiting the current (based on previous 10 years) and future (50 years) productivity and survival of natural-origin WCVI Chinook salmon;
b) identify knowledge gaps constraining our understanding of these limiting factors; and
c) develop mitigation options (recommendations) for future work to improve our understanding of marine factors limiting our ability to rebuild natural-origin WCVI Chinook, as well as remediation and recovery strategies.

2. METHODS

2.1 Marine Risk Assessment Workshop Approach

Seven facilitated MRA workshops were held virtually during 2022 (Table 2.1). First Nations and other area-based knowledge holders contributed to all workshops. Workshop 1 set the stage for subsequent workshops by having salmon biologists and other knowledge holders provide high level overviews of WCVI Chinook life history including migratory patterns, age structure and sizes while oceanographers described likely relevant marine conditions experienced by these salmon (Appendix 7.1). Workshops 2-7 (Appendices 7.2 – 7.7) used a Risk Assessment Methodology for Salmon (RAMS) to evaluate risk.

Table 2.1 Marine Risk Assessment Workshops During 2022.

No.	Date (2022)	Title
1	Feb 2-3	Setting the Stage – WCVI Chinook & Their Physical Environment (Appendix 7.1)
2	Feb 22-23	Physical Habitat and Water Quality Changes to Marine Ecosystems Affecting WCVI Chinook (Appendix 7.2)
3	Apr 5-6	Contaminants, Pathogens, Parasites, and Harmful Algal Blooms (Appendix 7.3)
4	May 3-4	Nutrition and changes in Prey Quality, Availability, Timing, and Composition (Appendix 7.4)
5	May 24-25	Predation Affecting WCVI Chinook (Appendix 7.5)
6	Aug 2-3	Hatchery Impacts (Appendix 7.6)
7	Sept 27	Harvest Risk Assessment (Appendix 7.7)

2.2 Risk-Assessment Methodology for Salmon (RAMS)

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 assesses the degree to which declines in the productive capacity of Pacific salmon has resulted from specific biological factors or environmental states. It also assesses the expected outlook within the context of anticipated (2050) climate change impacts, whether through changes in biological/ecosystem processes or environmental states.

RAMS uses a highly structured framework, where risk from each of a comprehensive suite of potential limiting factors (LF's, Table 2.2) is assessed for relevant life history stages (LSs). Each LF has an hypothesis, and some have benchmarks as well as potential causal mechanisms.

At each MRA Workshop, science-based information provided by leading researchers was supplemented by existing knowledge from First Nations and other local knowledge holders. Subject-experts were asked to provide information on how important specific limiting factors might be restricting the health, growth, abundance, survival, and/or distribution of WCVI Chinook. Information included 1) presentations on results of relevant programs and projects, 2) relevant data and literature, 3) discussion on the LFs and existing evidence, 4) identification of any data limitations, gaps in knowledge and uncertainties, and 5) suggestions for required projects, next steps and action items (Appendices 7.1 – 7.7). Time was allocated for questions from participants and general discussion.

During each workshop, for each LF, participants reviewed the information each of four (LS’s).

- LS1: Early marine rearing period from the time of smolt entry in late spring through to their first winter, assumed to be primarily in local WCVI Sounds;
- LS2: First marine winter, assumed to be primarily within WCVI nearshore waters;
- LS3: The subsequent marine period that commenced with the coastal migration northward of young fish and included their extended (1-6 years) marine residence in northern BC and Southeast Alaska and possibly Bering Sea until the beginning of their return migration, and;
- LS4: Return marine migration of maturing Chinook southwards to WCVI until fish commence their upstream freshwater migration.

Note that in some workshops life stages were combined based on agreement that there was insufficient information to separate risks between life stages (e.g., LS1 and LS2 = Juvenile and LS3 and LS4 = Adult).

The generalized conceptual model of risk determination is shown in Figure 2.1 where risk is determined from the two variables, Likelihood (or Exposure), and Biological Impact (or Consequence).

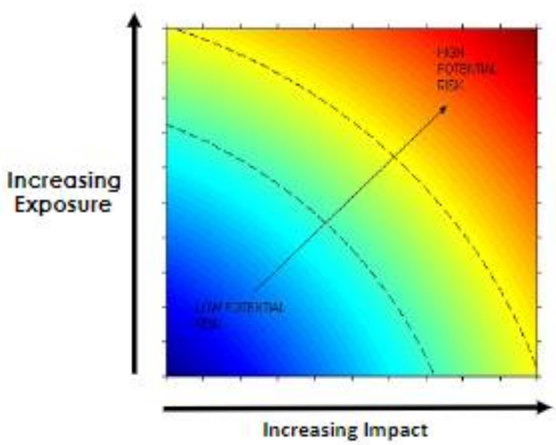

Figure 2.1 Biological Risk – a product of exposure (likelihood) and impact (consequence).

Table 2.2 Limiting Factors Assessed During the 2022 Marine Risk Assessment Workshops

Workshop No. & Name	LF	Category	Limiting Factor
1 Setting the Stage		Size and Condition	Various biotic and abiotic indicators, broadscale and local
2 Physical Habitat and Water Quality	1	Size and Condition	Carry-over impacts from previous life-history phase
	2	Physical Habitat	Degraded habitat quality
	3	Physical Habitat	Reduced habitat availability or connectivity
	4	Water Quality	Direct impacts of water temperature changes
	5	Water Quality	Direct impacts of hypoxia or reduced dissolved oxygen
	6	Water Quality	Direct impacts of changes to salinity
	7	Water Quality	Direct impacts of changes to ocean acidity
3 Parasites, pathogens, harmful algae and contaminants	8	Contaminants	Exposure to deleterious substances or containments
	9	Pathogens	Disease and pathogens
	10	Parasites	Infection by parasites
	11	Harmful Algae blooms	Harmful algal blooms
4 Nutrition and Changes in Prey Quality, Availability, Timing, and Competition	12	Nutritional Quality	Quality of available prey
	13	Prey Availability	Limited prey abundance
	14	Timing	Phenological mismatch
	15	Competition	Intra-specific competition for prey
5 Predation	16	Predation	Predation by marine mammals
	17	Predation	Mortality or fitness reduction due to due to elevated predation levels by birds
	18	Predation	Predation by fish
	19	Predation	Novel predators shifting or expanding their range
6 Hatchery Strategies - Management, Abundance, Genetics and Distribution	20	Hatcheries and Genetics	Reduction in genetic diversity and integrity, or changes in biological characteristics such as fecundity, maturation rate, sex ratios, size at age, etc.
	21	Hatcheries and Genetics	Mortality, growth and/or fitness reduction due to inter/intra-specific competition
	22	Hatcheries and Genetics	Mortality, growth and/or fitness reduction due to elevated predation
	23	Hatcheries and Genetics	Mortality growth, and/or fitness reduction due to hatchery disease patterns and/or pathogen transfer
7 Harvest	24	Harvest	Overfishing within regulations
	25	Harvest	Overfishing outside regulations
	26	Harvest	Fishing-caused changes in biological characteristics such as fecundity, maturation rate, sex ratios, size at age, etc.

The exposure variable has two components: i) the spatial extent to which the LF overlaps with the spatial distribution of the WCVI Chinook at each life stage and ii) the temporal extent to which the LF overlaps with the temporal distribution of the WCVI Chinook at each life stage. Each component was scored 1-5 using the following benchmarks:

Spatial exposure

Score	Approximate Percentages by Life Stage
Very Low (1)	<10% of usable habitat or the population is impacted
Low (2)	10-30% of usable habitat or the population is impacted
Medium (3)	31-50% of important habitat or the population is impacted
High (4)	51%-70% of important habitat or the population is impacted
Very High (5)	>70% of important habitat or the population is impacted

Temporal exposure

Score	Approximate Frequency
Very Low (1)	Once per decade (very rare)
Low (2)	2 times per decade (uncommon)
Medium (3)	3 to 4 times per decade (sometimes occurs)
High (4)	5 to 7 times per decade (frequent)
Very High (5)	8 + times per decade (almost every year)

To determine overall likelihood scores (1-5) in the MRA, spatial and temporal values were input into a likelihood matrix (Figure 2.2a). Biological impact scores (1-5), needed along with likelihood scores to estimate biological risk (Figure 2.2b), were based on a simple life-cycle model that used mortality rate information and/or expert opinions associated of when mortality occurred (e.g., pre-spawn mortality, overwinter incubation mortality, in river parr/smolt mortality from downstream trapping, smolt to age 2 mortality from cohort analysis, fishery and later natural mortality, etc.), as well as key biological characteristics such as fecundity, natural vs. hatchery smolt size, timing, distribution, maturation rate, etc. This model was used to evaluate the effect of changing mortality during each LS (see example in Appendix 7.6 presentations *section 7.6.5*), recognizing that mortality estimates were based largely on hatchery Coded-Wire-Tag recoveries from Robertson Creek Hatchery salmon, which may or may not reflect natural-origin WCVI Chinook. Resulting 'Current Biological Risk' scores (1-5) were determined from the risk matrix shown in Figure 2.2b and the (x, y) coordinates of biological impact, likelihood. Biological impact scores of 1-5 corresponded to 1 (less than 10%), 2 (11-20%), 3 (21-30%), 4 (31-50%), and 5 (>50%) declines in returns respectively.

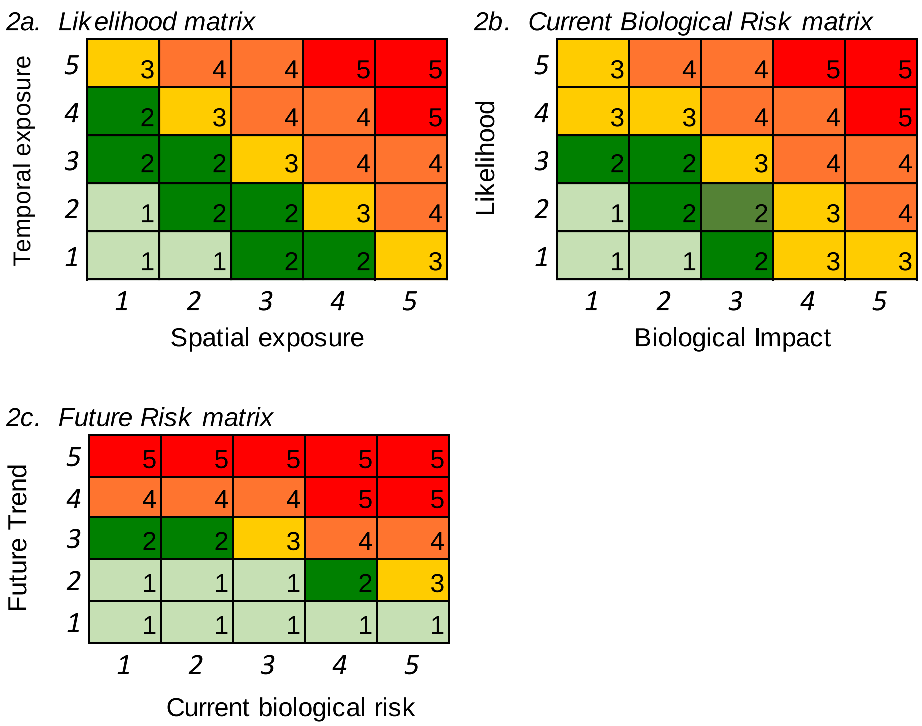

Figure 2.2 **Risk matrices used in the WCVI MRA to estimate Likelihood (a), Current Biological Risk (b), and Future Risk (under climate change, c). Colour coded scores 1-5 equated to Very Low, Low, Moderate, High, and Very High respectively.**

In all cases, participants were encouraged to provide written rationales for how particular scores were derived. Presenters and participants often provided quantitative or qualitative trend information for LFs that allowed the group to score the ‘Current Trend’ (1-5 respectively indicating a trend suggesting the factor is decreasing, somewhat decreasing, not changing, somewhat increasing, significantly increasing). Next there was discussion leading to the expected ‘Future Trend’ under climate change, with the same scoring 1-5. Together, the Current Biological Risk score and the Future Trend scores determined the Future Biological Risk (Figure 2c) of each limiting factor with the following Potential Actions:

Biological Risk	Potential Action
Very Low (1)	No mitigation required at this time; level 1 assessment is sufficient, no further action.
Low (2)	Full justification / rationale needed; no specific mitigation strategy or further mitigation needed.
Moderate (3)	Mitigation may be considered if benefit/cost is high (generally cost is low due to opportunity to link to management actions directed at a different issue. Depending on confidence additional study or information (Level 2) is required for review of risk assessment and performance report
High (4)	Mitigation plan required. If confidence is Low or Moderate then additional information should be a priority. Identify jurisdiction and develop planning process. Identify causal mechanisms and options, evaluate benefit/cost and feasibility, develop plan.
Very High (5)	Mitigation should be a priority. If confidence is Low or Moderate then prioritize additional information, research, monitoring, and/or modelling. Identify jurisdiction and develop planning process. Identify causal mechanisms and options, evaluate benefit/cost and feasibility, develop plan, prioritize implementation.

In any risk assessment, there will be uncertainty associated with predicting impacts of an LF on fish or fish habitat. To capture this uncertainty, participants provided Confidence scores for each impact score:

Confidence	General Rationale
Low (1-2)	• Data exist but considered poor, or conflicting; or • No data exist; or • Substantial disagreement among experts
Moderate (3)	• Data exist but some gaps; or • Some disagreement between experts
High (4-5)	• Data exist and are considered sound; or • Consensus between experts; or • Risk is constrained by logical consideration

When a lack of data or knowledge prevented a risk rating being assigned, this was categorized as a Data Gap. Those results that workshop participants felt were most crucial to address and/or likely to have a potentially high impact on populations, were labelled as High Priority Data Gaps for further research or investigations. Other Data Gaps were labelled as Low Priority.

Factors affecting survival and fitness don’t act in isolation; their effects may be compounding, synergistic, or inter-related. Two or more LFs combined may have a greater effect together than when expressed individually. To alleviate misrepresenting the role of LFs, efforts were made to acknowledge those that were identified in the literature or at the workshop in the risk rating discussions.

Outputs from RAMS included:

- Consolidation and documentation of published reports, GIS resources, and unpublished observations and information provided by experts prior to and during the MRA workshops;
- Identification of the expert participants, their affiliations and areas of expertise for contributions to the MRA workshops;
- Pre-workshop products including: a backgrounder on the stock/CU status; habitat/ecosystem status reports; a series of stock information tables outlining information on specific habitat requirements, limiting factors, benchmarks and indicator status;
- An Excel file with RAMS scoring results; LFs prioritized by Current and Future risk as well as confidence.
- Prioritized list of high risk and high confidence LFs that require identification and evaluation of management responses; high priority LFs with low confidence that require additional research, assessment, or monitoring to increase confidence.
- Documentation and next steps for incorporation into a recovery potential assessment and rebuilding plan for WCVI Chinook.

2.3 Variation from the general approach

LFs were not scored during Workshop 1 (Appendix 7.1). Scoring in subsequent workshops followed the general RAMS approach described above, but there were differences among workshops in how the approach was applied. Detailed descriptions of workshop presentations and scoring results are provided in Appendices 7.1-7.7.

In Workshops 2 and 6 (Appendix 7.2 and Appendix 7.6), participants scored each LF for a) the combined LS1 and LS2 'juvenile' life stages, and b) the combined LS3 and LS4 'adult' life stages. For Workshops 3, 4, 5, and 7 (i.e., Appendices 7.3, 7.4, 7. 5, and 7.7), each of the four life history stages (i.e., LS1-LS4) was scored separately except during Workshop 3 when LS3 was not thought to be relevant and hence not scored.

Risks were generally assessed for both natural-origin Chinook and hatchery-origin Chinook, but results are only provided for the former since there was agreement that effects on hatchery fish would be equal to or lower than on natural-origin fish, and that the focus of our assessment was risk to natural-origin fish.

2.4 Workshops 2-5 Risk Determination

During workshops 2-5, participants scored each limiting factor – life stage combination based on their interpretation of the presentations and subsequent discussion. Resulting separate frequency distributions for Likelihood, Impact, Future Impact, and Confidence for each LF assessed needed to be converted to singular scores. Since common statistics (e.g., mean, median, mode, range and standard deviation) often appeared inadequate due to small sample sizes and skewed statistical distributions, we used a consensus-based team approach to arrive at singular scores. We illustrate this approach with the following example from Workshop 2 (Appendix 7.2, Physical Habitat and Water Quality Changes) for LF3 (mortality or fitness reduction due to reduced habitat availability or connectivity) for the Juvenile life stage (Figure 2.3).

Figure 2.3 **Frequency distribution plots of participant scores for LF3-Juvenile (Workshop 2). Scoring for Likelihood, Impact, Future Trend (top row), and Confidence 2 (left graph, 2nd row) and resulting distribution plots of Current and Future Risk. Review scores for each of these were decided by small group consensus and are presented in the second row of each plots' title with the resulting calculated risks also shown as Review Result. Note if n<4, then confidence=low (i.e., 1) regardless of distribution. Current and Future Risk scores were based on risk tables that resulted from application of matrices in Figure 2.2.**

The team consisted of several key presenters and workshop organizers, each of whom was familiar with the WCVI and its Chinook, had knowledge of RAMS, and agreed to be impartial with respect to the relative importance of individual LFs. The team reviewed frequency distribution plots for participants' scorings, statistics describing the various distributions, and summaries of participant discussions and comments.

For this example, the team decided on review scores of 4, 3, and 4 for likelihood, impact, and Future Trend respectively (Figure 2.3). The resulting x, y coordinates based on impact, likelihood applied to the Current Risk matrix in Figure 2.2b produced a 'review result' of 4 which is shown in the title of participant distribution plot of Current Risk. Next, the review result for Future Risk score was calculated to be 5 (very high) from Figure 2.2c based on the Current Risk and Future Trend scores of 4 and 4. This meant that the risk to WCVI Chinook of LF3 is expected to increase in the future, although confidence is only moderate.

To evaluate whether the small group review results reflected risks differently than statistical means, we compared estimates derived for Future Risk as above with computed means. We 1) computed basic correlation statistics (R^2 and p) and 2) compared High and Very High LF rankings. Current and Future Biological Risk scores for all limiting factors and life stages were collated and ranked based on 1) Current Biological Risk, 2) Future Biological Risk and by 3) the percentage of workshop participants that had individually scored the LF as a high or very high risk

2.5 Workshops 6 and 7 Risk Evaluation

These workshops used a group consensus scoring approach (commonly applied in RAMS), which greatly simplified the interpretation of results. The facilitator worked with the workshop participants to generate consensus scores for Likelihood (in time and space) and Impact for each limiting factor, as well as single consensus scores for Current and Future trends for each LF and an overall Confidence rating. These scores were input into an Excel spreadsheet and the Current and Future Biological Risk scores were automatically derived from the consensus scores.

2.6 Workshops 2-7 Risk Evaluation Synthesis

As described above, there were differences among individual workshop approaches that limited our ability to compare results among workshops, including the application of mathematical models or quantitative statistical analyses. To determine whether there were differences among workshops in overall rankings of LF's evaluated, we combined results for Workshops 2-7, weighting current and future risk classifications equally. We performed several simple analyses after grouping LFs in the Current and Future Risk as: 1. High Risk (LFs were Very High and/or High in each of Current and Future Risk): 2. Moderate Risk (risks were Moderate in at least one category) or 3: Low Risk (risks were Low or Very Low in at least one category). We examined:

a) differences among workshops in the proportion of LF's ranked as High, Moderate or Low Risk,
b) differences among the 4 major life stages in the proportion of LF's ranked as High, Moderate or Low Risk,
c) differences between Juvenile (combining Juvenile, LS1 and LS2) and Adult (combining Adult, LS3 and LS4) salmon in the proportion of LF's rated as High, Moderate or Low Risk, and
d) all LFs in each Risk Category by life stage.

3. RESULTS

Valuable information was obtained from each workshop even though we were unable to carry out detailed quantitative analyses. We start with major findings from each of the workshops (3.1-3.7) and then synthesize findings including a simple analysis of results from the entire set of workshops (3.8). In some cases, the results presented below were updated following the workshops. Please refer to Workshop Appendices 7.1 – 7.7 for detailed descriptions of individual Workshops.

3.1 WCVI Marine Assessment Workshop 1 - Setting the Scene – WCVI Chinook and Their Physical Environment

The focus of this workshop was on ecosystem and climate indicators relevant to conditions experienced by salmon over broad marine areas although some indicators specific to locations and times where WCVI Chinook lived were also identified and described.

There was consensus of a High Risk being likely of reduced fish size and/or condition resulting in significantly lower survival and/or fitness during specific or subsequent (i.e., carry over effect) life stages. Various potential biotic (Juvenile Chinook abundance, zooplankton variety and abundance) and abiotic (water temperature, Pacific Decadal Oscillation, Ocean Niño Index (ONI), temperature, upwelling, coastal stratification, dissolved oxygen, North Pacific Current bifurcation index, water current and wind direction and speed) indicators were described. It was noted that the frequency of marine heat waves has increased in the last decade with major ecosystem effects.

The primary recommendation from Workshop 1 was to identify and retrospectively evaluate the utility of indices such as those above but to also include local indicators. These indicators should be selected to represent conditions experienced by WCVI Chinook to better understand and ultimately predict interannual patterns of survival and growth. In addition, building models to investigate effects of climate change on WCVI Chinook was encouraged.

Key to identifying local indicators is a good understanding of where WCVI Chinook live during their four marine life stages. There was general consensus that WCVI Chinook spend most of their marine lives north of Vancouver Island. Their migration is limited in their first year with most residing in the vicinity of WCVI through their first spring and summer (LS1) and continuing until the end of their first marine winter (LS2). A northward migration takes them into northern BC and Alaskan waters to rear (LS3) prior to their migration back to natal systems along the WCVI (LS4). Please refer to Results 3.8 for updated information on the marine distribution of WCVI Chinook.

3.2 WCVI Marine Risk Assessment Workshop 2 - Physical Habitat and Water Quality Changes to Marine Ecosystems Affecting WCVI Chinook

In general, risk factors were rated higher for Juvenile salmon than for Adults (Table 3.1). This corresponds with expectations. The early marine period is widely acknowledged as a period of relatively high mortality for salmon and in two systems discussed at the workshop (Sarita and Bedwell), a high proportion of natural-origin fish smolt at very small sizes, making them vulnerable to sub-optimal early marine, including estuary, conditions. Risk factors were also generally higher for the future than the present. Again, this finding seems reasonable given that several of the habitat LFs examined are expected to become more problematic with climate change, to the detriment of many salmon.

Workshop 2 Correlations between Future Risk Scores and statistical mean Future Risk (FRisk) Scores were not significant (R^2=0.14; p=0.22) and risk categorizations using these approaches varied. We remained most confident in the Group review group rankings.

High (current) to Very High (Future) Risk ratings were recorded for Juvenile WCVI Chinook for local habitat quality and availability as well as water quality related to dissolved oxygen and temperature.

Table 3.1 Ranked (Very High to Low) Current and Future Risk Rankings for Limiting Factors (LFs) Considered During Workshop 2

Limiting Factor	Life Stage	Review Result Current Risk	Review Result Future Risk
LF2 Local habitat quality	Juvenile	High	Very High
LF1 Carry-over impacts	Juvenile	High	Very High
LF3 Local habitat availability	Juvenile	High	Very High
LF4 Local water temperature	Juvenile	High	Very High
LF4 Local water temperature	Adult	High	Very High
LF5 Local Dissolved oxygen	Juvenile	High	Very High
LF3 Local habitat availability	Adult	Mod	Very High
LF2 Local habitat quality	Adult	Mod	High
LF5 Local Dissolved oxygen	Adult	Mod	High
LF1 Carry-over impacts	Adult	Mod	Mod
LF6 Local salinity	Juvenile	Low	Mod
LF6 Local salinity	Adult	Low	Mod
LF7 Ocean acidity	Juvenile	Low	Mod
LF7 Ocean acidity	Adult	Low	Mod

Adult WCVI Chinook returning to spawn also face stressors that may impact their spawning success. In order of priority, workshop participants ranked water temperature, local habitat availability and quality, plus dissolved oxygen as the highest risks for Adult salmon.

Risk associated with changing water temperature and oxygen (limiting factors 4-5) were judged to increase for both Juvenile and Adult salmon in the future. We learned that these conditions often develop in the inner inlets in late summer – early fall, especially in Alberni Inlet.

For Juvenile Chinook, workshop discussion focused on the ability of these fish to avoid or escape conditions of poor water quality. New salmon Fit-Chip technology, described in Appendix 7.2, which can identify the presence of specific environmental stressors, like thermal and low DO stress, has already provided insight into this question, showing that broadly across southern BC, Chinook are showing signatures of thermal stress equivalent to extended 18 ^{o}C exposure and low DO stress in the marine environment, suggesting that they may prioritize feeding opportunities in the upper water column over avoidance of environmental stress. More research employing Fit-Chips specifically on WCVI Chinook is underway, which should improve our understanding of the spatial distribution of Juvenile Chinook in areas and times of poor water quality, identified as a knowledge gap.

Limiting factor 1 (carry-over effects from previous life stages) was rated high for the present and very high in the future for Juvenile salmon and moderate for both these periods for Adult salmon. Appendix 7.2 describes how participants concluded that fish which experienced rapid growth in freshwater and/or the estuary had a major survival advantage over fish that did not, especially when marine productivity was low and/or competition was high. These carry-over effects can also relate to smolt readiness, loads and richness of freshwater pathogens, and toxin exposures from freshwater. More work on carry-over effects in relation to health and condition of hatchery releases, and, the importance of habitat and water quality factors, is being undertaken through initiatives begun in 2022.

3.3 WCVI Marine Risk Assessment Workshop 3 - Parasites, Pathogens, Harmful Algae and Contaminants Affecting WCVI Chinook

Of the limiting factors assessed in Workshop 3 (Appendix 7.3), those relating to pathogens (LF9) and parasite infections (LF10) rated highest, with impacts of parasites principally in Juvenile Chinook life stages rather than Adults (Table 3.2). A key reason for this result was that discussion of "parasites" was largely restricted to sea lice, which are macro ectoparasites known to exert strongest impacts on small Juvenile fish. However, there are a plethora of micro-parasites, including fungi and protists, which can exert impacts at all life-stages, which were assessed along with viruses and bacterial pathogens under LF9.

Correlations between Future Risk Scores and statistical mean Future Risk Scores were not significant (R^2=0.14; p=0.22) and risk categorizations using these approaches varied. We remained most confident in the Group review group rankings, which form the basis for our analysis and discussion below.

While current impacts for pathogens and parasites were ranked as High, they increased to Very High in the future, in part because of known or suspected synergistic relationships with climate change, and elevated risks for some pathogens/parasites from of open-net salmon farms. Of all the regions in BC, open-net salmon farms in WCVI sounds carry the largest potential for impact to Chinook, as Juvenile WCVI Chinook salmon spend up to a full year co-habiting with high density farms, exposing wild and hatchery Chinook to various pathogens and parasites.

Models depicting pathogen hot spots throughout southern BC verify that over the fall/winter period, the WCVI sounds show an overabundance of pathogens in natural-origin Chinook salmon compared to other regions of the coast. While fish farms are not the only source of pathogens, the farms are under human control, and their impacts can therefore be mitigated if required.

Table 3.2 Ranked (Very High to Low) Current and Future Risk Rankings for Limiting Factors (LFs) Considered During Workshop 3

Limiting Factor	Life Stage	Review Result Current Risk	Review Result Future Risk
LF9 Disease-pathogens	LS2	High	Very High
LF10 Infection-parasites	LS1	High	Very High
LF9 Disease-pathogens	LS1	High	Very High
LF10 Infection-parasites	LS2	High	Very High
LF8 Contaminants	LS1	High	Very High
LF9 Disease-pathogens	LS4	Mod	High
LF8 Contaminants	LS4	Mod	High
LF8 Contaminants	LS2	Mod	High
LF11 Harmful algae	LS1	Low	Mod
LF11 Harmful algae	LS2	Low	Mod
LF11 Harmful algae	LS4	Low	Mod
LF10 Infection-parasites	LS4	Low	Mod

Contaminants (LF8) rated as a Moderate (LS2, LS4) or High (LS1) Current Risk, and High (LS2, LS4) or Very High (LS1) Future Risk. However, there was a fair degree of uncertainty in these rankings, reflected in their low confidence rating. While there was a compelling presentation on elevated contaminant concentrations from road-runoff, flame-retardant, pulp mill effluent, and agricultural pesticides within WCVI sounds, there were no data directly relating these to impacts to WCVI Chinook salmon, an area that requires further research. However, there was agreement that the impacts of contaminants were likely more important when considering cumulative impacts with other stressors, including increased susceptibility to infectious diseases. Future studies need to consider contaminant effects in cumulative effects modeling on Chinook to provide more certainty on the intrinsic and extrinsic conditions associated with the strongest impacts, required to develop effective mitigation. Given that contaminants are largely human-derived, some associated risks can be mitigated through appropriate government regulations.

Harmful algae were given a Low Current Risk rating, with an increase to Moderate for future trends due to established associations with climate change and ocean acidification, although these rankings carried a Low confidence. There is good evidence that harmful algae negatively impact survival of salmon cultured in open-net farms, where fish often cannot move deep enough in the water column to escape bloom events. Many workshop participants assumed that natural-origin fish would sense and avoid bloom events, but empirical evidence is required to verify or refute this assumption. Despite the ability to move deeper into the water column, we know that natural-origin Chinook and sockeye salmon expose themselves for enough time to high SSTs in the summer to induce thermal stress signatures and will remain in oxygen depleted water at depth despite the availability of normoxic, cool water available at mid-depth. This behaviour is likely due to a tradeoff between optimized feeding opportunities and avoidance of predators. As such, it is possible that fish will still enter surface bloom areas to feed, but whether they remain there long enough to be impacted is unknown. This area requires more research, especially given a projected increasing risk with climate change.

3.4 WCVI Marine Risk Assessment Workshop 4 - Nutrition and Changes in Prey Quality, Availability, Timing and Composition Affecting WCVI Chinook

The limiting factors related to nutrition, change in prey quality, abundance, timing and composition for both Current and Future Risks were generally rated higher for Juveniles relative to sub-Adult and Adult salmon (Table 3.3). The one exception was prey abundance during the multi-year sub-Adult (LS3) phase. Our understanding of factors affecting salmon during this extended life history period is limited due to little non-fishery sampling. In general, risks were rated higher during the future than the current period, in line with changes anticipated due to climate change (see also Figure 3.1 and Figure 3.2).

Table 3.3 Ranked (Very High to Low) Current and Future Risk Rankings for Limiting Factors (LFs) considered during Workshop 4

Limiting Factor	Life Stage	Review Result Current Risk	Review Result Future Risk
LF13 Prey abundance	LS3	High	Very High
LF13 Prey abundance	LS1	High	Very High
LF12 Prey quality	LS2	High	Very High
LF12 Prey quality	LS1	High	Very High
LF15 Intra-specific competition	LS1	High	Very High
LF14 Mis-match with prey	LS1	High	Very High
LF13 Prey abundance	LS4	High	High
LF15 Intra-specific competition	LS2	High	High
LF13 Prey abundance	LS2	Mod	High
LF12 Prey quality	LS3	Mod	High
LF14 Mis-match with prey	LS3	Mod	Mod
LF14 Mis-match with prey	LS2	Mod	Mod
LF15 Intra-specific competition	LS3	Low	Mod
LF12 Prey quality	LS4	Low	Low
LF15 Intra-specific competition	LS4	Low	Low
LF14 Mis-match with prey	LS4	Low	Low

These ratings aligned with expectations of high mortality during the early marine period, material presented during this workshop (Section 5), and other workshops and literature. Most nutrition limiting factors rated as High (mostly for Juvenile life stages but also sub-Adult) for Current risk were rated as Very High for Future Risk. However, the High Current Risk ratings for 'Intra-specific competition' [LF15] for first marine winter and 'Prey Abundance' [LF 13] for the returning Adult life stage both retained High Future Risk ratings.

Correlations between Future Risk Scores and statistical mean Future Risk Scores were significant (R^2=0.52; p=0.002) although risk categorizations using these approaches varied. We remained most confident in the Group review group rankings, which form the basis for our analysis and discussion below.

Low Risk scores for both Current and Future Risks were given for returning Adults (LS4) for 'Prey Quality' [LF12], 'Mis-match with Prey' [LF14] and 'Intra-specific Competition'[LF15]. Those Moderate and Low Current Risk scores that did change increased from Current Low and Moderate to Moderate and High Future Risk ratings and were associated with Juvenile (LS1, LS2) and sub-Adult (LS3) life stages. As previously mentioned, life stages were defined as: LS1) represent the first ocean summer as Juveniles; LS2) the first ocean fall and winter as Juveniles; LS3) sub-Adult to Adult rearing; and LS4) mature Adult migration to natal stream.

For Juveniles, risks were rated higher during the first marine summer than fall winter with the exception of intra-specific competition during the current period. For example, the Current Risk rating for 'Prey Abundance' [LF13] during the first Juvenile summer was High and Very High for Current and Future respectively while for the subsequent fall/winter it was Moderate and High. The Limiting Factor, 'Mis-match with Prey' [LF14] was rated as High for summer and Moderate Current risk for Juveniles during their first fall/winter. Future Risk for 'Mis-match with Prey' was rated as Very High for summer Juveniles, consistent with predicted variability of Chinook outmigration timing /duration. Many Current Risks rated High were Very High for Future Risk, which seems reasonable given expectations for increased future variability of prey availability, quality, composition, and timing. Only Limiting Factors 'Prey Abundance' for returning Adults and 'Intra-specific Competition' for winter Juveniles retained a High rating for both Current and Future Risks.

For returning Adults, apart from prey abundance, current and Future Risk were rated as Low, reflecting increased survival with life stage, reduced feeding, and limited knowledge (and moderate confidence ratings) of how variable prey availability, quality, and timing, influence Adult survival.

3.5 WCVI MRA Workshop 5 - Predation Affecting WCVI Chinook

The primary objective of Workshop 5 was to assess how four Limiting Factors (LF): Predation by Marine Mammals (LF16); Predation by Birds (LF17); Predation by Fish (LF18); and Predation by Novel Predators (LF19); influenced survival, mortality and/or fitness reduction of WCVI Chinook across 4 marine life phases (LS1-4) (Appendix 7.5). We provide more detail for this workshop than others because of the need to carry out post-workshop analysis.

The first day started with an overview of Chinook life history and the Risk Assessment Methodology for Salmon (RAMS). Presentations and discussion specific to one or more of the limiting factors made up the rest of the day. The second day consisted of a discussion on the presentations and information shared on the previous day and an overview of the detailed scoring surveys. Presenters and other workshop attendees were invited to fill out an online survey with their risk rankings in order to develop an overall risk rating in the context of the RAMS. Unfortunately, relatively low numbers of participants completed the survey, making the validity of the results questionable.

Following completion of the workshop, a small group met to review the distribution of scores from all participants who scored limiting factors individually and assign a risk ranking for each limiting factor. Detailed results for each limiting factor are provided in Appendix 7.5, and a summary of the group results is provided below (Table 3.4).

Table 3.4 **Ranked (Very High to Very Low) Current and Future Risk Rankings for Limiting Factors (LFs) Considered During Workshop 5**

Limiting Factor	Life Stage	Review Result Current Risk	Review Result Future Risk
LF16 Predation marine mammals	LS4	High	High
LF18 Predation by fish	LS1	High	High
LF16 Predation marine mammals	LS3	High	High
LF17 Predation by birds	LS1	High	High
LF18 Predation by fish	LS2	High	Mod
LF16 Predation marine mammals	LS2	Mod	Mod
LF16 Predation marine mammals	LS1	Mod	Mod
LF18 Predation by fish	LS3	Mod	Very Low
LF19 Predation by novel predators	LS1	Low	Low
LF17 Predation by birds	LS3	Low	Very Low
LF17 Predation by birds	LS2	Very Low	Very Low
LF17 Predation by birds	LS4	Very Low	Very Low
LF18 Predation by fish	LS4	Very Low	Very Low
LF19 Predation by novel predators	LS2	Very Low	Very Low
LF19 Predation by novel predators	LS3	Very Low	Very Low
LF19 Predation by novel predators	LS4	Very Low	Very Low

Interestingly, correlations between Future Risk Scores and statistical Mean Future Risk Scores were significant (R^2=0.55; p=0.001) although risk categorizations using these approaches varied and sample sizes were small. For example, of the four LFs rated as High for Future Risk, only one of these would be High if we used Mean Values (LF16 LS4), while one would be Moderate (i.e., 3; LF16 LS3) and two would be Low (i.e., LF 18 LS1 and LF17 LS1). We remained most confident in the Group review group rankings.

Workshop presentations and discussions demonstrated that predator-prey relationships are complex. Predation varies spatially and temporally, and more data are often needed to adequately represent when and where Chinook are being consumed. Predation can affect Chinook salmon populations through direct consumption and can also influence population demographics through size-selective predation on larger fish resulting in decreases in size and age of fish on the spawning grounds. Potential mechanisms included some related to foraging theory; the combination of time spent within habitat for cover vs. time spent in more open water. Mechanisms discussed included effects of reduced kelp forests, invasive European Green Crab (*Carcinus maenas*) impacting eel grass, loss of estuary sedge grasses, and human uses such as aquaculture net pens, each of which may result in young salmon moving into suboptimal habitat, leading to increased exposure to predators.

A High Risk from predation by marine mammals was identified for returning Adult (LS4) and sub-Adult (LS3) WCVI Chinook, both now and in the future. Some differences in predation risks were noted among marine mammals. For example, coastal predators and terminal predators would have different influence on the four Chinook life stages. Coastal predators, such as Steller sea lions (*Eumetopias jubatus*) and Killer Whales (*Orcinus orca*), are expected to consume mainly larger fish; therefore, sub-Adult and Adult life stages would be more vulnerable to predation by these species. Harbour seals (*Phoca vitulina*) are primarily terminal predators that target pre-spawning Adults as they return to estuaries and rivers. Smaller Chinook runs would be more vulnerable to this type of predation, especially if barriers, degraded holding habitat, and low water levels slow their migration. The risk from harbour seal predation on Juvenile Chinook is Moderate; however, there may be specific locations where seals learn to feed on concentrations of out-migrating Juveniles resulting in a High Risk for those populations.

Risk of predation by fish ranged from a High Risk for the early marine stage LS1 to Very Low for the final life stage LS4. In fact, predation risk from birds, novel predators and other fish was Very Low. Other fish species, such as hake, mackerel, and salmon sharks are known to consume salmon although the magnitude of impact of this type of predation for LS2 and LS3 is uncertain.

A High Risk from predation by birds was identified for LS1. Great Blue Herons (*Ardea herodias*) have been shown to be important predators on out-migrating smolts; small smolts appear to be most susceptible. Risks from bird predation in estuaries may increase during low flows. Risks to subsequent life stages was generally Very Low, presumably in part due to Chinook being larger.

Predation risk from novel predators was Low or Very Low across all life stages under both current and future conditions. Limited data were available to assess this limiting factor; however, it was not identified as a high priority for further research.

3.6 WCVI Marine Risk Assessment Workshop 6 – Hatcheries

During this workshop (Appendix 7.6), assessment of key risks posed by hatcheries and hatchery fish on natural-origin WCVI Chinook physiology, survival and fitness during their marine life history was carried out using the RAMS process. The hypotheses addressed were that hatchery production a) reduces overall genetic diversity and integrity, thereby reducing fitness, b) increases competition and/or predation, the latter by drawing in predators to areas occupied by both hatchery- and natural-origin Chinook, or c) increases disease, pathogen diversity or loads in natural-origin fish, ultimately resulting in reduced growth, survival and/or fitness of wild WCVI Chinook.

Facilitated discussions resulted in consensus that there is a Very High Risk of hatchery rearing on growth, survival and fitness of natural-origin WCVI Chinook due to impacts on genetic diversity and integrity and/or biological characteristics (LF21, Table 3.5). Evidence was provided to show that WCVI stocks display declining genetic diversity due to hatchery introgression into natural-origin stocks. 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, for which most rivers had an estimated PNI (proportionate natural influence) less than 0.25.

Table 3.5 Ranked (Very High to Very Low) Current and Future Risk Rankings for Limiting Factors (LFs) Considered During Workshop 6). LF23 Adults were not scored

Limiting Factor	Life Stage	Reviewed Confidence	Review Result Current Risk	Review Result Future Risk
LF20 Loss of genetic or demographic diversity	All	**Mod**	Very High	Very High
LF21 Intra/inter specific competition	Juvenile	**Low**	High	Very High
LF22 Predation	Adult	**Low**	High	High
LF21 Intra/inter specific competition	Adult	**Mod**	Mod	Mod
LF22 Predation	Juvenile	**Mod**	Mod	Mod
LF23 Disease or pathogens from hatchery	Juvenile	**Low**	Mod	Mod

Hatcheries have the potential for large magnitude ecological impacts on natural-origin populations, and these impacts 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 that competitive impacts are possible. Impacts of inter/intraspecific competition from hatchery fish was scored by consensus as a High Risk that could result in reduced growth, fitness and survival of natural-origin WCVI Chinook during early rearing in WCVI nearshore regions and sounds, and evidence was presented on the similarity of diets between hatchery- and natural-origin fish during this period. Future Risk was scored as Very High because of climate change impacts on the food web and possible enhanced competitive pressures due to lower prey abundance (Table 3.1). 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) as a consequence of large numbers of hatchery fish was also rated High although confidence was low. The additional effect of predation on Juvenile Chinook was scored Moderate with Moderate confidence.

Finally, the workshop examined whether hatcheries and hatchery production could result in an increased source of pathogens, increased pathogen richness, and/or pathogen transfer from hatchery to natural-origin fish. Pathogen richness in freshwater showed few differences between hatchery- and natural-origin fish but was highly variable among stocks/years. While the evidence is not strong that hatcheries universally pose a pathogen transfer risk to wild salmon, this is an area of active research, specifically pertaining to WCVI

Chinook. Consequently, the limiting factors associated with impacts of pathogens were scored as Moderate (Table 3.1) with Low confidence.

Recommendations for improvements (i.e., increases) to PNI include a) managing hatchery production (i.e., producing the fewest fish necessary to achieve program goals and objectives), 2) removal of excess hatchery-origin Chinook from the spawning population, and 3) management of pNOB (proportion of natural-origin broodstock in the hatchery) and PNI in populations supplemented with hatchery fish to best maintain natural-origin influence and reduce the risk of natural-origin extirpation. Pilots are underway along WCVI to address low PNI and assist with stray management: Conuma, Sarita and Burman Chinook populations are being mass marked, and Huu-ay-aht First Nation have implemented a plan to maintain hatchery production but improve PNI by selective terminal harvest of hatchery marked Chinook in the Sarita. SEP also has implemented other measures to help reduce straying (e.g., relocating seapens closer to natal estuaries/freshwater influence, switching from seapen releases to river or lake releases, etc.) and the potential effects from straying, to improve survival and reproductive fitness of hatchery Chinook and reduce ecological interactions between hatchery and natural-origin Chinook.

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 potential for pathogen transfer between these categories of salmon were highlighted as key data needs and current knowledge gaps. Ultimately, given the potential for severe genetic and ecological risks of hatcheries, addressing these knowledge gaps is highly recommended.

3.7 WCVI Marine Risk Assessment Workshop 7 - Harvest Impacts on WCVI Chinook

Pertinent background to this risk assessment workshop includes presentations summarized in Appendix 7.7 (Sections 5 and 6). WCVI Chinook are far north migrating (as far as the Bering Sea but primarily in Southeast Alaskan and northern BC waters) where they rear for 1-7 years. Most will go to sea during their first year of life then mature and return to the WCVI at ages 2 (~2-3%), 3 (~20%), 4 (>50%), and 5 (~20%), although a few natural populations have small proportions maturing at ages 6 or 7. WCVI Chinook are therefore vulnerable to marine fisheries across several ages, with most recruiting to fisheries beginning at age 3. Their 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. Female WCVI Chinook tend to mature later than males. About 85% of mature age 5+ WCVI Chinook are female compared to about 10% of mature age 3 fish.

The average annual calendar year fishery exploitation rate (CYER), including release mortality (from capture-related injuries), is estimated to be 35% for Chinook returning to Clayoquot Sound (mid-section of the SMU) based on non-terminal recoveries of Robertson Creek Hatchery CWT (PSC 2023). 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 approached 50%. Removing large, predominantly female salmon is problematic in several ways—large females tend to produce more eggs and dig deep redds (nests) that may improve resiliency to climate change impacts, such as extreme river discharge events.

Based on the available information and knowledge of the workshop participants, the risk posed by the limiting factors were assessed (Table 3.6).

Table 3.6 Ranked (Very High to Low) Current and Future Risk Rankings for Harvest Limiting Factors (LFs) Considered During Workshop 7

Limiting Factor	Life Stage	Reviewed Confidence	Review Result Current Risk	Review Result Future Risk
LF26 Changes in demographics due to fishing	LS4	**Mod**	High	Very High
LF24 Overfishing	LS4	**High**	Mod	Mod
LF24 Overfishing	LS3	**High**	Low	Low
LF25 Illegal fishing	LS3	**Low**	Low	Low
LF25 Illegal fishing	LS4	**Mod**	Low	Low
LF26 Changes in demographics due to fishing	LS3	**Mod**	Low	Low

Fisheries-related demographic changes caused by size-selectivity in fisheries targeting mature returning Chinook (LS4) were the highest ranked risk; High during the current period, increasing to Very High in the Future (Table 3.6). Demographic changes included reduced sizes and proportions of female spawners as well as their fecundity, egg size, and redd depth. In contrast, demographic changes affecting immature (LS3) fish were Low; fisheries generally do not target immature Chinook.

LF24 Overfishing in ‘regulated’ fisheries on mature returning Chinook was the 2nd highest risk factor (Moderate during the Current and Future). Although the 35% average CYER suggests that the stock is fished at a sustainable level, large and old and predominantly female salmon are harvested at high rates. WCVI Chinook fishery management includes Pacific Salmon Treaty (PST) and domestic considerations. Harvest levels were reduced by about 50% since the inception of the Treaty in 1985. Actions to further reduce CYER are limited since much of the catch is taken in Alaskan waters. Additional restrictions taken in Canadian northern troll fisheries reduced catch levels below allowable levels specified in the PST. Similar actions to reduce fishery impacts continue to be implemented along the WCVI with closures adjacent to river mouths and along the migration path.

The PST-defined allowable catch is based on the aggregate of hatchery- and natural-origin salmon; which can result in over-fishing on low productivity natural stocks such as occur in Clayoquot Sound. A higher risk ranking may be warranted in these specific cases. In contrast, workshop participants rated overfishing of immature and generally small WCVI Chinook as a Low Risk (LF24, LS3). CYER on ages 2, 3, and, in some years, age 4 are lower than the overall average.

LF25 illegal or unsanctioned fishing on immature WCVI Chinook (LS3) was also Low Risk, with the proviso that little is known about impacts of non-salmon fisheries such as trawl fisheries targeting Walleye pollock (*Gadus chalcogrammus*) and Pacific hake (*Merluccius* *productus*), among other species. Similarly, workshop participants indicated a need for better information regarding CYER impacts from non-PST fisheries, especially in Alaskan/northern US marine waters in which WCVI Chinook may rear. With warming oceans, there is likely to be an increased prevalence of WCVI Chinook farther west along the Aleutian Islands and into the Bering Sea seeking cooler waters and more abundant prey. Workshop participants identified this as an important knowledge gap; more work was suggested on monitoring impacts in these fisheries, and that the PST should be acknowledging catch of Canadian Chinook in all Alaskan fisheries, not just those directly targeting salmon.

Most participants thought LF25 Illegal or unsanctioned fishing on mature Adults (LS4) was a Low Risk; although some participants provided knowledge at the local population / river level where these fisheries likely play a major role in stock decline. It was difficult to substantiate or quantify the level of impact suggested by these illegal or unsanctioned fishing activities.

3.8 Workshops 2-7 Synthesis

To better understand the distribution of WCVI Chinook during Life Stages 3 and 4, we updated the catch locations of salmon released with coded-wire tags (CWTs) presented at Workshop 4 (Figure 3.1 and 3.2 below). These data included recoveries in trawl catches in near the Aleutian Islands in the Bering Sea and Gulf of Alaska, as well as fisheries samples within the Salish Sea and south off the coast of Washington and Oregon.

Coded-wire tag (CWT) fishery data for Robertson Creek and other hatcheries were similar and consistent with a northward movement of some sub-Adult salmon in their 2nd marine summer, occasionally as far away as the Bering Sea north of the Aleutian Islands. By far most samples were from salmon fisheries near shore where unpublished information from genetic analysis shows a density gradient from high nearshore to lower offshore. International research trawl surveys in offshore waters catch relatively few Chinook (e.g., King et al 2022), at least in part due to large Chinook being able to avoid slow moving trawl nets (S. Urawa, Fisheries Research Institute, Sapporo, Japan, pers. comm.). Catches of multiple age classes of WCVI Chinook within the Strait of Georgia are difficult to explain, as are individuals sampled in Puget Sound and off of Washington/Oregon.

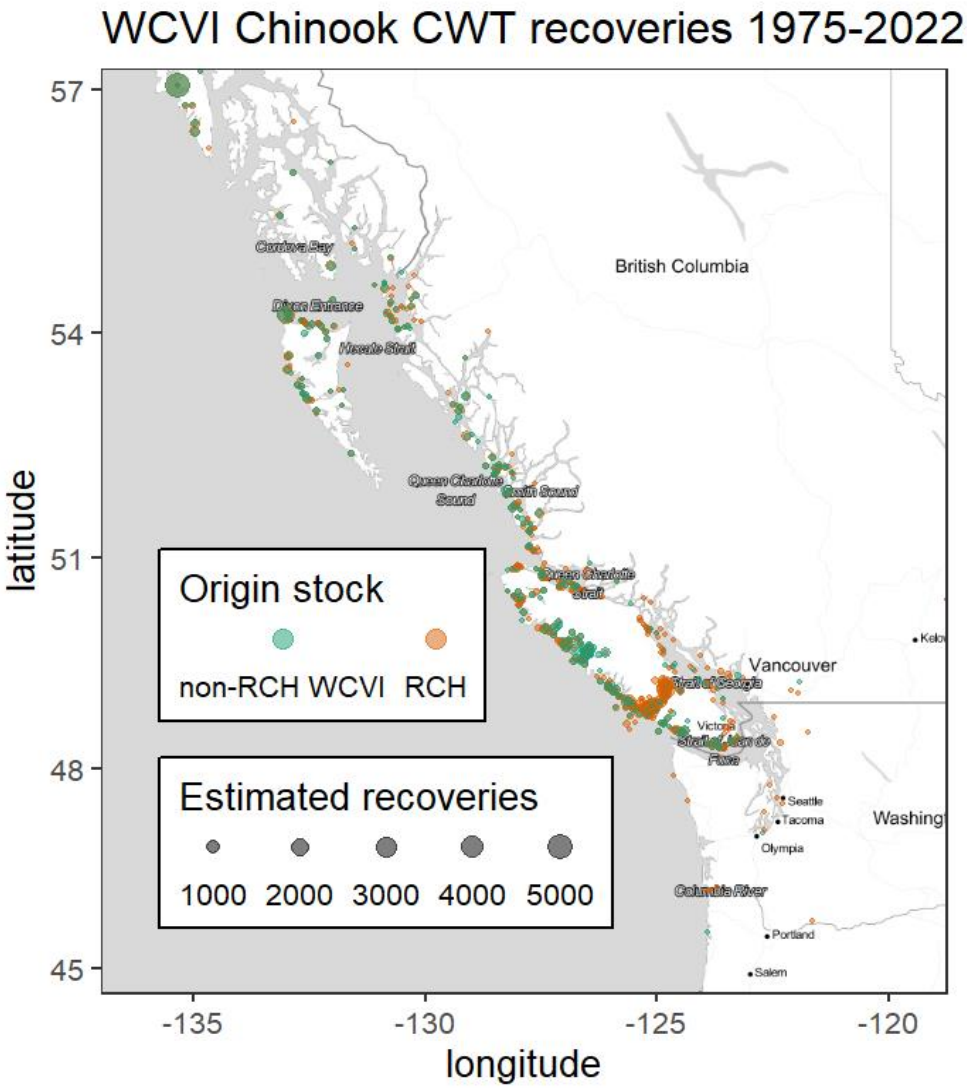

Figure 3.1 **WCVI Chinook Salmon CWT recovery locations released from Robertson Creek Hatchery (RCH) and other hatcheries (non-RCH) during 1975-2022. Alaska non-Pacific Salmon Treaty fisheries excluded.**

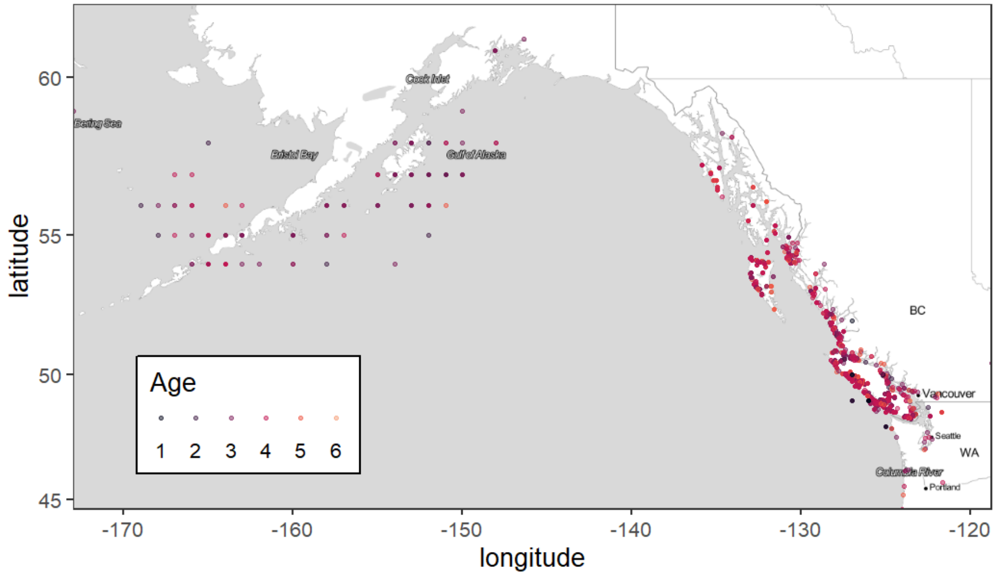

Figure 3.2 WCVI Chinook Salmon CWT recovery locations (release locations combined) during 1975-2022 by age class, including catches in Alaska non-Pacific Salmon Treaty fisheries (e.g., Alaskan groundfish fisheries).

As described in Methods (Section 2.3.3), Current and Future Risk scores were scored as Very Low (1), Low (2), Moderate (3), High (4) or Very High (5) at the workshops. For the results presented below we combined Very Low and Low as well as High and Very High to yield 3 risk categories, Low, Moderate, and High. We began by examining differences between Current and Future periods) (Figure 3.3) recognizing the limitations of any findings since different LF's were evaluated among workshops. For Workshops 2 (habitat) and 3 (parasites etc.), Future Risk ratings tended to be more pessimistic (i.e., more High Risk and fewer Low Risk) than ratings for the Current Period; this was not apparent for other workshops. The other striking findings were for Workshop 6 (hatcheries), where all the LF's were rated High or Moderate Risk for both time periods, and for Workshops 5 (predation) and 7 (harvest) where most LF's were rated Low Risk, again for both Current and Future time periods.

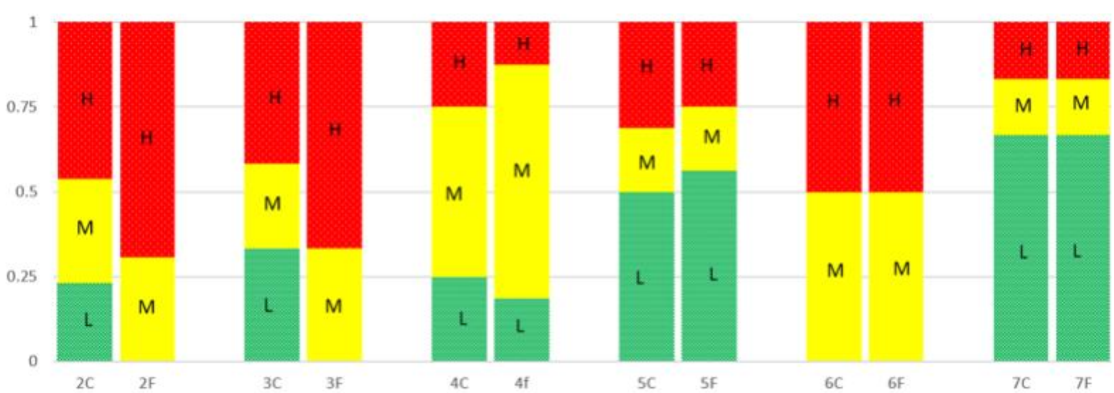

Figure 3.3 Proportion of LF's by Workshop ranked as Low (L), Moderate (M), or High (H) for current (C) and future (F) periods. Numbers of LF's for Workshops 2 (Physical Habitat, Water Quality), 3 (Parasites, Pathogens etc.), 4 (Prey), 5 (Predation), 6 (Hatcheries), and 7 (Harvest) were 14, 12, 16, 16, 6, and 6 respectively.

Looking next at risk ratings for different life stages (Figure 3.4), we see a consistent pattern (i.e., for all pairs of histograms) with participants rating more LFs as High Risk and/or fewer as Low Risk for the Future than Current time period. The earliest Life Stage 1 had the greatest proportion of LF's rated as High Risk, in stark contrast to Life Stages 3 and 4 when most LF's were Low Risk. The same pattern was seen after combining these results with those from Workshops 2 and 6 where fish were categorized as either Juvenile (i.e., LS 1 and 2) or Adult (LS 3 and 4) salmon; The majority of Juvenile LF's were High Risk while for Adult salmon, the majority of LF's were Low Risk (Figure 3.4, final 2 pairs of histograms), again confirming that workshop participants regarded WCVI Chinook as being more at risk during their first marine year than later on.

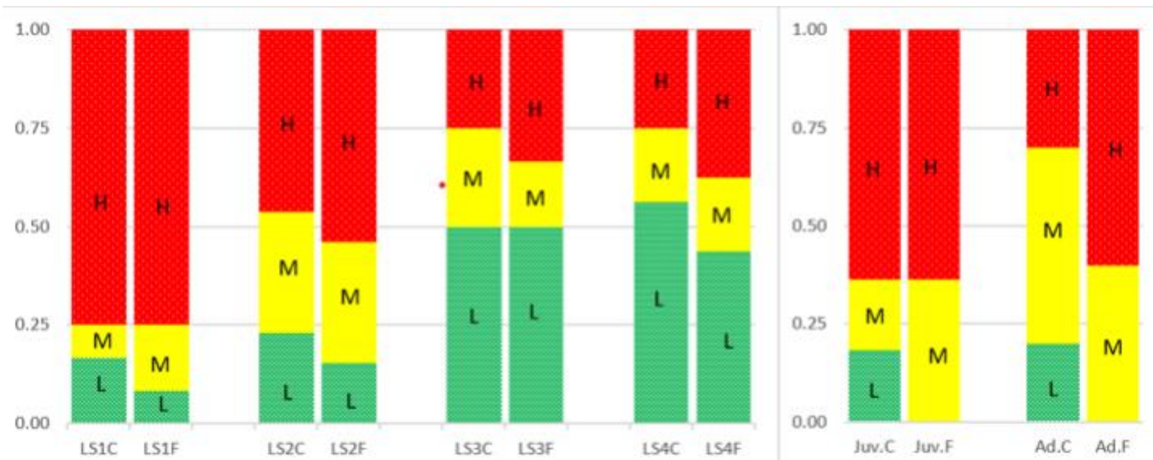

Figure 3.4 **Proportion of LF's for each of LS1-4 ranked as Low (L), Moderate (M), or High (H) Risk from Workshops 3, 4, 5, and 7 for current (C) and future (F) periods (first 4 pairs of histograms). Numbers of LF's for LS1– LS4 were 12, 12, 11, and 15 respectively. Final 2 pairs of histograms - proportion of LF's for Juvenile (Juv) and Adult (Ad) life stages ranked as Low (L), Moderate (M), or High (H) from Workshops 2-7. Numbers of LF's for Juvenile and Adult salmon were 34 and 35 respectively.**

Finally, we sorted results by life stage from Workshops 2-7 amongst the 69 LFs into Very High/High, Moderate, and Low Risk ratings (Table 3.7), weighting Current and Future periods equally.

Table 3.7 **Summary of LFs from Workshops 2-7 organized by Risk Rating (Very High/High (Red), Moderate (Yellow) and Low (Green) and Life Stage for Natural-origin WCVI Chinook Salmon Listed Numerically Low to High (Average of Current and Future Periods). 'n' is the the Number of LFs within each Risk Category. LFs refer to the Life Stage in the Previous Column. See Methods 2.2 for Descriptions of how LFs were Assigned into Risk Categories and Text Below for Further Explanation.**

<table>
<tr><th>Risk Category</th><th>Life Stage</th><th>Limiting Factors</th><th>Life Stage</th><th>Limiting Factors</th><th>Life Stage</th><th>Limiting Factors</th><th>Life Stage</th><th>Limiting Factors</th></tr>
<tr><td rowspan="4">Very High (n=1), High (n=26)</td><td rowspan="4">Juvenile & Adult</td><td rowspan="4">Habitat Availability (LF3),Water Temperature (LF4), Loss of Genetic or Demographic Diversity (LF20) VERY HIGH RISK</td><td rowspan="2">Juvenile</td><td rowspan="2">Carry-over Effects (LF1), Habitat Quality (LF2), Dissolved O2 (LF5), Hatchery Competition (LF21)</td><td rowspan="2">LS1
LS2</td><td rowspan="2">Pathogens (LF9), Parasites (10), Prey Quality (LF12), Competition (LF15)</td><td>LS1</td><td>Contaminants (LF8), Prey Abundance (LF13), Match Mismatch (LF14), Predation by Birds (LF17) & Fish (LF18)</td></tr>
<tr><td>LS2</td><td>N/A</td></tr>
<tr><td rowspan="2">Adult</td><td rowspan="2">N/A</td><td rowspan="2">LS3
LS4</td><td rowspan="2">Prey Abundance (LF13), Predation by Marine Mammals (LF16)</td><td>LS3</td><td>N/A</td></tr>
<tr><td>LS4</td><td>Fishing Effects on Demographics (LF26)</td></tr>
<tr><td rowspan="4">Moderate (n=17)</td><td rowspan="4">Juvenile & Adult</td><td rowspan="4">N/A</td><td rowspan="2">Juvenile</td><td rowspan="2">Hatchery Predation (LF22), Disease/pathogens from Hatchery (LF23)</td><td rowspan="2">LS1
LS2</td><td rowspan="2">Predation by Marine Mammals (LF16)</td><td>LS3</td><td>N/A</td></tr>
<tr><td>LS4</td><td>Contaminants (LF8), Prey Abundance (LF13), Match Mismatch (LF14)</td></tr>
<tr><td rowspan="2">Adult</td><td rowspan="2">Carry Over Effects (LF1), Habitat Quality (LF2), Dissolved O2 (LF5), Hatchery Competition (LF21)</td><td rowspan="2">LS3
LS4</td><td rowspan="2">N/A</td><td>LS3</td><td>Prey Quality (LF12), Match Mismatch (LF14)</td></tr>
<tr><td>LS4</td><td>Contaminants (LF8), Disease-pathogens (LF9), Overfishing (LF24)</td></tr>
<tr><td rowspan="4">Low (n=25)</td><td rowspan="4">Juvenile & Adult</td><td rowspan="4">Salinity (LF6), Acidity (LF7)</td><td rowspan="2">Juvenile</td><td rowspan="2">N/A</td><td rowspan="2">LS1
LS2</td><td rowspan="2">Harmful Algae (LF11), Predation by Novel Predators (LF19)</td><td>LS3</td><td>N/A</td></tr>
<tr><td>LS4</td><td>Predation by Birds (LF17)</td></tr>
<tr><td rowspan="2">Adult</td><td rowspan="2">N/A</td><td rowspan="2">LS3
LS4</td><td rowspan="2">Predation by Fish (Lf18) & Novel Predators (LF19), Illegal Fishing (LF25)</td><td>LS3</td><td>Competition (LF15), Overfishing (LF24), Demographic Fishing Effects (LF26)</td></tr>
<tr><td>LS4</td><td>Parasites (LF10). Harmful Algae, (LF11), Prey Quality (LF12), Match Mismatch (LF14), Competition (15)</td></tr>
</table>

We provide examples to help interpret Table 3.7. Reading from left to right, the first major row is the only one with two Risk Categories (i.e., Very High and High), which allowed us to identify the one LF that was rated Very High Risk for both Juvenile and Adult salmon during the current and future periods. LF20 (loss of genetic or demographic diversity was Very High Risk while LF3 (habitat availability) and LF4 (water temperature) were High Risk (Column 3) for both Juvenile and Adult salmon. Column 5 shows that LF1, LF2, LF5, and LF21 were High Risk for Juvenile salmon (Column 4) only. Column 7 shows LF9, LF10, LF12, and LF15 were High Risk for LS1 and LS2 while LF13 and LF16 for LS3 and LS4 and the final pair of columns show that LF8, LF13, LF14, LF17 and LF18 were High Risk for LS1 and LF26 for LS4.

Important results from this table worth highlighting in addition to the significance of hatchery-related losses in genetic or demographic diversity, habitat availability and water temperature included: carry-over effects (LF1) between freshwater and early marine life stages were perceived as High Risk while effects carried over from Juveniles to Adults were regarded as only Moderate Risk; there were far more LFs rated as High Risk for Juvenile salmon (Juvenile, LS1, LS2) than for subAdult and maturing salmon (Adult, LS3, LS4); pathogens (LF9), parasites (LF10) prey quality (LF12) and competition (LF15) were important for both LS1 and LS2 while prey abundance (LF13) and predation by marine mammals (LF16) were High Risk for LS3 and LS4; and water salinity (LF6) acidity (LF7) were Low Risk for Juvenile and Adult salmon. Because results in Table 3.7 are averaged for Current and Future periods, one must examine Tables 3.1 – 3.6 and Figs. 3.3 and 3.4 to see expected changes over time.

4. DISCUSSION

4.1 Multi-Stakeholder Approach

Effective sustainable salmon management requires a thorough understanding of the factors controlling survival at each life stage, as well as carry-over effects from one life stage to the next. Since management and recovery efforts tend to rely on understanding and addressing issues affecting freshwater productivity, there is often perceived to be an inadequate and fragmented understanding of issues affecting productivity in estuarine and marine environments, the focus of this report. Chinook and other salmon experience some of their most rapid growth and highest mortality rates during their early marine lives (Duffy and Beauchamp 2011), leading to recent restoration efforts based on estuarine carrying capacities (Hall et al. 2023); there are also many examples that demonstrate the importance of oceanographic processes and competition during their later marine lives (Buckner et al. 2023). This report documents what we learned with respect to risk factors operating throughout the marine lives of WCVI Chinook salmon.

An extended peer community can enrich the production of scientific knowledge by providing local knowledge that is contextual and case-specific (Lidskog 2008). The Nuu-chah-nulth have long been aware of the poor status of natural-origin WCVI Chinook and they and local knowledge holders participated in the MRA workshops described in this report. The Nuu-chah-nulth, elected Chiefs, and representatives from the 14 participating Nations recently updated their strategic plan for the future that includes the sustainable management of all aquatic resources (Uu-a-thluk 2023). The 2022 MRA workshops were science-based. Going forward we encourage "Two-eyed Seeing" as a means of enabling multiple perspectives (e.g., complementary indigenous and western science knowledge) as described by Reid et al. (2020) and Frid et al. (2023).

4.2 Workshop Findings Related to the Scientific Literature

There was some overlap but also noteworthy differences in the LFs judged to be at High, Moderate and Low Risk for young (Juvenile) salmon (i.e., Juvenile, LS1, LS2) compared to older (Adult) salmon (i.e., Adult, LS3, LS4) (Table 3.7). Hatchery-related reduced fitness due to losses in genetic or demographic diversity (LF20) was perceived as the highest ranked risk overall (Table 3.5). WCVI Chinook displayed declining genetic diversity due to hatchery introgression into natural-origin stocks, and some river populations had a low PNI (Proportionate Natural Influence) (3.6 Workshop 6 Hatcheries). Literature evidence of hatchery introgression for Chinook from other areas has been mixed; introgression was found for fall run Chinook populations in Central California (Williamson and May 2005) and Idaho (Matala et al. 2012) while in Oregon, hatchery supplementation efforts had minimal effects on the genetic diversity of Chinook Salmon populations investigated by Van Doornik et al. (2013).

Carry-over effects (LF1) between freshwater and early marine life stages were perceived as High Risk (increasing to Very High in the Future), while effects carried over from Juveniles to Adults were regarded as Moderate Risk (Table 3.1, Table 3.7). There are various potential mechanistic explanations, including epigenetics where earlier life experiences alter the way genes function without changing the genes themselves. Much of the epigenetic research on salmon has focused on whether artificial selection in hatcheries results in reduced fitness (e.g., Le Luyer et al. 2017). Since WCVI Chinook released from hatcheries tend to be larger than natural-origin salmon, this may result in hatchery fish being less reliant on estuarine habitats than natural-origin fish, potentially reducing impacts on natural-origin fish from avian and piscine predators.

Because marine survivals are only measured for hatchery-origin and not for natural-origin WCVI salmon, we cannot say for certain whether one group survives better or worse than the other or whether survival differences vary among years depending on marine conditions. Campbell and Claibourne (2016) found that size at ocean entry of returning Puget Sound Chinook varied over time with fish that left as 30-60 mm "fry" constituting a significant proportion of returns in some years, and being absent in other years. Their study also demonstrated that although small fry entering the ocean can sometimes be important contributors to the next generation, fish that had left freshwater as larger smolts always made up the majority of fish surviving to Adulthood. In a separate study, Ruggerone et al. (2009) found that scale growth for Yukon River (Alaska) Chinook during each life stage was significantly correlated with growth during the previous year (i.e., 1st marine growth year vs. freshwater growth; 2nd marine year vs. 1st marine year, etc.). This implies that slow-growing fish remain slow-growing for their entire lives.

Our interpretation of workshop results after considering findings in the literature leads us to conclude that 1) getting a head start with rapid growth in fresh water or hatcheries may provide a survival advantage for young Chinook salmon, especially when marine productivity is low and/or competition is high, 2) carry over from one life cycle stage to the next can be significant, especially during the early marine period, and 3) there is a need to quantify differences in survival of small vs. large natural-origin smolts and reasons for survival differences among years. Determining whether there have been reductions in the marine survival of natural-origin smolts and if this contributed to their apparent poor status is a high priority.

Carry-over effects from freshwater are not limited to size at ocean entry, but can also include factors such as infection status, smolt stage, stressor exposure, and toxin exposure. While there is evidence that size at release from hatcheries is positively correlated with survival, postponing releases so that larger fish can be released may result in fish being released outside of the optimal smoltification window, including when fish begin reverting physiologically to a freshwater phenotype (termed de-smolting) (Houde et al. 2019a). Pre-smolts introduced to saltwater survive poorly, especially when exposed to additional stressors such as high temperature and low oxygen (Houde et al. 2019b). Moreover, as temperature rises during spring to summer, fish released too late will have an increased probability of encountering stressful temperatures while they are still in a critical period of salinity adaptation. Further, elevated temperatures under climate change appears to result in earlier smoltification, and truncation of the smolt timing window (Bassett et al. 2018). Hence, establishing the smoltification status is a crucial step in optimizing release timing, and hatchery managers should proceed cautiously when considering whether to delay releases into the spring/early summer, as the benefit of increased size at release reducing predation may be countered by lower adaptability to saltwater and higher vulnerability to environmental stressors, and potential mismatch with prey resources. Examination of early growth patterns for WCVI Chinook returning to freshwater is encouraged, as are experiments to evaluate relationships between smolt size and marine survival for hatchery- and natural-origin salmon.

Future Risk ratings tended to be more pessimistic for physical habitat and water quality than Current Risk ratings (Fig. 3.3). More specifically, the perceived risk to Chinook salmon of losing physical habitat was generally high (quality and availability for Juveniles, availability only for Adults), as was water quality (water temperature, dissolved O_2, and contaminants for Juveniles, higher than optimal terminal marine water temperatures for Adults) and these are expected to increase with time (Tables 3.1 and 3.7). As described above, the early life stages of WCVI salmon are likely vulnerable to suboptimal estuarine and near shore conditions, much more so than returning Adult salmon. Potential mechanisms include reduced kelp forests, invasive European Green Crab impacting eel grass, loss of estuary sedge grasses, and human uses such as aquaculture net pens, each of which may result in increased exposure to predation. Adult salmon were judged to be at risk from predation by marine mammals (seals, sea lions) during their return migration including in estuaries while Juvenile salmon were more susceptible to predation by fish and herons and other birds (Table 3.7; see also 3.5 Workshop 5 Predation).

Changes in water acidity (Juvenile and Adult salmon) and salinity (Juveniles), both of which are expected to be affected by climate change (e.g., Okey et al. 2018), were rated as Low Risk during the Current period but Moderate in Future (Table 3.1). Dissolved O_2 levels have been declining along the WCVI continental shelf following peaks in the 1980's (Crawford and Peña 2016, Whitney et al. 2007) and sea surface temperatures are predicted to increase between 0.5° and 2.0°C degrees during 2065-2078 (Foreman et al. 2014). Detailed results from 3.2 Workshop 2 Physical Habitat Water Quality (Table 3.1) document that Future Risk ratings were higher than Current, as expected with climate change, for all but one habitat/water quality LF (Juveniles and Adults). Workshop 2 participants commented that water temperatures and dissolved O_2 levels deleterious to Juvenile and Adult salmon are often set up in the inner WCVI inlets in late summer – early fall, and the frequency is likely to increase in the future. Consensus on whether Juvenile Chinook are able to avoid or escape areas of poor water quality was not reached, resulting in the spatial distribution of Juvenile Chinook in areas and times of poor water quality being identified as a knowledge gap.

Future Risk ratings tended to be more pessimistic than Current Risk for parasite and pathogens (Fig. 3.3). Of the Limiting Factors assessed in Workshop 3 Parasites, Pathogens etc., those relating to pathogens (LF9) and parasite infections (LF10) were rated highest. Parasite impacts were judged to be primarily during LS1 and LS2 (Table 3.2 and 3.7), largely because discussion focused on sea lice, which are known to exert their strongest impacts on small Juvenile fish. Micro-parasites that include fungi and protists, which can impact all life-stages, were assessed along with viruses and bacterial pathogens under pathogens (LF9). Current impacts for pathogens and parasites ranked as High increased to Very High in the future, in part because of known or suspected synergistic relationships with climate change (reviewed in: Gallana et al. 2013; Miller et al. 2014), and elevated risks for some pathogens/parasites from spillback impacts of open-net salmon farms (e.g. Shea et al. 2022; Mordecai et al. 2021; Bass et al. 2022). Juvenile Chinook salmon spend up to a year living in areas with farms, exposing both hatchery- and natural-origin Chinook to various pathogens and parasites (see key literature in 7.3 Workshop 3 Parasites, Pathogens etc.). While salmon farms are not the only source of pathogens, they are under human control, and their impacts can therefore be mitigated if required. In 7.4 Workshop 4 Nutrition there was also a compelling presentation on elevated contaminant concentrations from road-runoff, flame-retardant, pulp mill effluent, and agricultural pesticides within WCVI sounds, but there are no data directly relating these to impacts on WCVI Chinook salmon, an area that requires further research.

The Limiting Factors related to nutrition, changes in prey quality, availability, timing and composition for both Current and Future Risks (Appendix 7.4 Workshop 4 Nutrition) were generally rated higher for Juveniles than sub-Adult and Adult salmon as expected from published research including early findings of Pearcy (1992), and for future relative to current conditions (7.2 Workshop 2, Table 7.3) as expected with climate change. Prey abundance was perceived as High Risk for all life stages except LS2 (overwintering Juveniles) (Table 3.3) although several presentations and comments referenced the relative absence of information and need for focused study on feeding and nutrition for subAdult (LS3) Chinook. Since salmon compete for a common pool of limited resources in the Gulf of Alaska where pink salmon can be very abundant during odd-numbered years, food available to WCVI Chinook may be reduced via a trophic cascade (Ruggerone et al. 2023), potentially reducing their growth and survival as inferred for other salmon (Davis et al. 2005, Ruggerone and Connors 2015, Cline et al. 2019).

In two systems discussed at 7.2 Workshop 2 Physical Habitat and Water Quality (Sarita and Bedwell), a high proportion of natural-origin fish smolted at small sizes, making them vulnerable to sub-optimal early marine including estuary conditions. Beamish and Mahnken's (2001) hypothesis that the early marine life is a critical period for young Pacific salmon has been supported by numerous researchers (e.g., Claiborne et al. 2020; Bass et al. 2022; Woodson et al. 2013) although a significant correlation between early marine and total survival, necessary to confirm this hypothesis, has not been demonstrated for WCVI Chinook.

Our understanding of the role of predation is incomplete, in part because of a lack of research on this topic, but also due to the limited number of participants that completed the survey in Appendix 7.5. A High Risk from predation by birds was identified for LS1. Great Blue Herons can be important predators on out-migrating smolts; small smolts appear to be most susceptible. Risks from bird predation in estuaries may increase during low flows. Other fish species, such as hake, mackerel, and salmon sharks are known to consume older Chinook salmon although the magnitude of impact of this type of predation is unknown. A High Risk from predation by marine mammals was identified for sub-Adult (LS3) and returning Adult (LS4) WCVI Chinook, both now and in the future. Coastal predators, such as Steller sea lions and Killer Whales are expected to consume mainly larger fish; therefore, sub-Adult and Adult life stages would be most vulnerable to predation. Harbour seals are primarily terminal predators that target pre-spawning Adults as they return to estuaries and rivers and small Chinook runs are most vulnerable to this type of predation, especially if barriers, degraded holding habitat, and low water levels slow migration. The perceived risk from harbour seal predation on Juvenile

Chinook was moderate; however, there may be specific locations where seals learn to feed on concentrations of out-migrating Juveniles resulting in a High Risk for those populations.

In addition to hatchery-related losses in genetic and demographic diversity, there is some evidence that hatchery production tends to increase competition and/or predation, as well as disease and pathogen loads in natural-origin fish, ultimately resulting in reduced growth, survival and/or fitness (3.6 Workshop 6 Hatcheries and 7.6 Workshop 6 Hatcheries). Partial to complete diet overlap between natural- and hatchery-origin WCVI Chinook occurs for at least some life stages, suggesting that competitive impacts are possible. Impacts of inter/intraspecific competition from hatchery fish was scored by consensus as a High Risk that could result in reduced growth, fitness and survival of natural WCVI Chinook during early rearing in WCVI nearshore regions and sounds; evidence was presented on the similarity of diets for young hatchery and natural-origin fish. Numerous information gaps were identified related to impacts of competition on later life stages, including by hatchery-produced and wild pink and chum salmon in the Gulf of Alaska, primarily originating from Alaska, Japan, and Russia.

Variability across time and space (i.e., non-stationarity) complicates salmon risk assessments, especially with climate change. Participants rated more LFs as High Risk and/or fewer as Low Risk for the future than current period (Fig. 3.4). To evaluate temporal variability, researchers commonly partition salmon survival and growth time series according to ecological regimes (e.g., Irvine and Fukuwaka 2011, Welch et al. 2021), which are periods of high and lower salmon productivity periods. Malick et al. (2017) found that both the location where the North Pacific and Subarctic Currents reach North America, and their strength could strongly influence population dynamics of salmon from BC and Washington State. 7.1 Workshop 1 Setting the Scene presentations described how shifts in the location of this bifurcation index, as well as increased frequency of marine heat waves, might alter early ocean conditions experienced by young WCVI Chinook. Fisher et al. (2020) documented a range of biological impacts from reduced chlorophyll to major shifts in the copepod community at the scale of the Northeast Pacific in response to marine heat waves. When the bifurcation location is shifted north, this may result in a southward displacement of lipid rich northern zooplankton, benefiting young salmon, and when the bifurcation location is shifted south, this may cause more lipid poor southern zooplankton to be carried to the north. The effects of these shifting horizontal ocean processes on WCVI Chinook productivity are unknown. Xu et al. (2020) recommended that the North Pacific Current Bifurcation Index as well as the Aleutian Low Pressure Index should be included in Chinook forecast models under climate change.

Ocean indicators relevant to WCVI Chinook will vary over time and among life stages and locations. Limiting factors might also determine the carrying capacity (i.e., maximum number of Chinook salmon that can be supported) of an ecosystem. As described in 7.1 Workshop 1 Setting the Scene, published US National Oceanic and Atmospheric Administration (NOAA) oceanographic ecosystem indicators (NOAA Fisheries 2023) successfully explained only some high and low WCVI Chinook smolt to age 2 survivals, and few during recent years. This was not surprising since these indicators were selected to represent conditions experienced by salmon entering the ocean off the Oregon and Washington coasts, well south of Vancouver Island. In most years, the northern California Current extends northward into the region off

WCVI but in some years it does not (Figure 1.2). Recommendations included the augmentation of these southern indicators with additional local indicators specific to WCVI Chinook life history stages and the need to evaluate these retrospectively to better understand and ultimately predict interannual patterns of survival and growth for WCVI Chinook.

A good understanding of the implications of temporally varying marine stressors requires detailed data on marine growth and survival by ocean year, as well as age-specific locations, all of which are lacking for WCVI Chinook. With climate change, marine heatwaves are becoming more common. Lindley et al. (2021) concluded that during the summers of 2014-2016, surface water temperatures were so high that there was virtually no suitable habitat for Chinook salmon in the eastern North Pacific. Hatchery CWT fishery data were generally consistent with a northward movement of sub-Adult salmon in their second marine summer, occasionally as far away as the Bering Sea north of the Alaska panhandle. Catches of multiple age classes within the Strait of Georgia are intriguing; as are samples from Puget Sound and south of Vancouver Island (Figure 3.1 and 3.2). Close examination of genetic data for Chinook caught at these locations may help to better understand the marine distribution of WCVI Chinook.

Because WCVI Chinook are far north migrating (some as far as the Bering Sea but primarily in Southeast Alaskan and northern BC waters), they are vulnerable to marine fisheries during most of their life. Many recruit to fisheries beginning at age 2 but since they are smaller than the minimum retention size limit, they are released, with poorly understood mortality. 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. Female WCVI Chinook tend to mature later than males. About 85% of mature age 5+ WCVI Chinook are female compared to about 10% of mature age 3 fish. Because older fish are exposed to more fisheries over their lifetime than younger fish, and some fisheries may target larger and older fish, particularly when they are quota-based, recent exploitation rates on large age 5 fish have approached 50% (7 Workshop 7 Harvest), which is likely not sustainable.

Fisheries-related demographic changes caused by size-selectivity in fisheries targeting mature returning Chinook (LS4) were the highest ranked harvest risk, increasing from High during the current period, to Very High in the future (Table 3.6). Recent fecundity declines documented for many Chinook populations are largely explained by reductions in fish length (Malick et al. 2023). Overfishing in 'regulated' fisheries on mature returning Chinook was the 2nd highest risk factor (Moderate during the current and future). LF25 Illegal or unsanctioned fishing on immature WCVI Chinook (LS3) was Low Risk, with the proviso that little is known about impacts of non-salmon fisheries including trawl fisheries targeting Pollock and Hake and other species.

4.3 Shortcomings of Our Approach

Differences amongst individual workshop approaches limited our ability to directly compare results among workshops, including the application of mathematical models or quantitative statistical analyses. Nevertheless, the consensus-based approach successfully evaluated risk for multiple LFs during Workshops 2-7. Relating assessments to the literature helped distinguish findings that are most likely valid from others that might be spurious.

The integrity of results gathered during any workshop will depend on who attends and contributes; participants often have diverse perspectives on the level of biological and socio-economic risk they find acceptable. We did our best to achieve consensus among participants, recorded instances when there was major disagreement among participants and when this occurred, tried to be appropriately precautionary in our conclusions and recommendations. And, as mentioned earlier, our approach was western science-based and should be better tied with indigenous knowledge systems in the future.

Participants supported the expert opinion provided in COSEWIC (2020) that natural-origin WCVI Chinook populations remain at low levels, showing little if any signs of rebuilding, in spite of various management actions taken over the last 20 years. However, time series data illustrating declines for natural-origin salmon are very limited and essentially non-existent for northern Vancouver Island populations; assuming that declines are occurring, it is not clear whether they are episodic or long-term. In addition, there are no marine survival time series for natural-origin WCVI Chinook.

A weakness in our approach was that most LFs 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 O_2 that can be dissolved in water declines, which can have deleterious consequences to many species, including salmon. It is beyond the scope of this report to document all the interactions potentially affecting WCVI Chinook, whether they are negative or positive. Future research should evaluate the cumulative, antagonistic, and synergistic interactions among factors identified as Moderate to High Risk to WCVI Chinook salmon. 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.

For risks that interact synergistically, it may be feasible to effect positive shifts in survival by manipulating just one factor under human control. For example, localized effects of fisheries, aquaculture, hatcheries, processing plants, agricultural runoffs, forestry, pulp mills, mining, and urban development can potentially influence contaminant, harmful algae, and pathogen levels, water quality properties within estuaries (oxygen, temperature, acidity, salinity), predator abundance, and habitat abundance and quality. While climate change worldwide is also under human influence, it is not a factor that can be readily controlled, at least on the time-scales necessary to ensure sustainability of WCVI Chinook. It is important to understand that environmental climate change can elevate susceptibility to pathogen transmission and disease and may affect the bloom cycles of harmful algae. Harmful algal blooms may also be affected by organic loading associated with industrialization, aquaculture, fish processing plants, and agriculture, all under human control. Some pathogen risks can be enhanced by high density culture environments (aquaculture, hatcheries) and fish processing plants, also under human control. Hence, understanding whether and how these factors interact to create enhanced risks can inform the most effective mitigation measures that can be controlled by shifts in human activity.

4.4 Major Conclusions, Knowledge Gaps and Recommendations Going Forward

The primary goals of this MRA for WCVI Chinook salmon as stated in the Introduction were to:

a) identify and rank the principal factors limiting the current (based on previous 10 years) and future (50 years) productivity and survival of natural-original WCVI Chinook salmon;
b) identify knowledge gaps constraining our understanding of these limiting factors; and
c) develop mitigation options (recommendations) for future work to improve our understanding of marine factors limiting our ability to rebuild natural-origin WCVI Chinook, as well as remediation and recovery strategies.

Principal factors limiting the current and future productivity and survival of natural-origin WCVI Chinook salmon were discussed, identified and ranked during seven multi-stakeholder workshops. Workshop results were summarized (3. Results Section) and, recognizing short comings of our approach, interpreted (4. Discussion Section) based on knowledge gained from the workshop series with reference to the published literature where possible. Knowledge gaps constraining our understanding of these limiting factors were identified, which culminated in the identification of future work recommended to improve our understanding of factors limiting WCVU Chinook marine survival and productivity that we list below.

Sufficient knowledge was gained to help direct activities in the short term although additional work is needed to develop mitigation options in support of remediation and recovery plans. Each workshop identified High Risk limiting factors for both Juvenile and Adult Chinook salmon, which showed there is no single limiting factor that will rebuild natural-origin WCVI Chinook. An integrated approach to rebuilding is needed, including management measures to promote habitat restoration. Going forward, continued cooperation and collaboration among multiple stakeholders including representatives from tribal, federal, provincial, and municipal governments, sport and commercial fishing, environmental organizations, academia, and the interested public will be required, along with careful consideration of how to implement the two-eyed seeing framework (Reid et al. 2020). Hatchery practices should be adapted to reduce negative impacts on natural-origin salmon and better understand survival patterns of the latter. Next steps should include an evaluation of the cumulative, antagonistic, and synergistic interactions among factors that have been identified as Moderate to High Risk to WCVI Chinook salmon. Finally, we shouldn't let a lack of information stop us from taking steps to support natural-origin salmon now, but need to be prepared to proactively update these strategies as new information becomes available.

We list major conclusions (1., 2., …*text italicised*) from the MRA below. The ordering is based loosely on the sequence our workshops (i.e., not prioritized). Most conclusions result from our ranking of limiting factors, many of which are reported in the Discussion. Each conclusion (or group of conclusions) is followed by one or more examples of studies or approaches we recommend be considered fill information gaps, validate conclusions, and/or reduce uncertainty (a., b., c.,… text not italicised).

1. *Ocean Indicators*

   Ocean indicators relevant to WCVI Chinook will vary over time and among life stages and locations. Limiting Factors might also determine the carrying capacity of an ecosystem (i.e., maximum number of Chinook salmon that can be supported).

   a. Supplement the southern indicators described in Workshop 1 with additional indicators specific to WCVI Chinook life history stages and locations.
   b. Retrospectively evaluate potentially useful ocean ecosystem indices relevant to natural-origin WCVI Chinook life history stages to better understand and ultimately predict interannual patterns of survival and growth for WCVI Chinook. Some of these may vary among years depending on oceanographic conditions.

2. *Marine Distribution*

   Most WCVI Chinook remain in coastal waters close to WCVI until the end of their first winter (i.e., LS1 and LS2), and then move northward along the coast. However, we have a poor understanding of where they live and factors that may limit their survival and growth during LS3 where the assumption is that the fish remain nearshore in northern BC and SE Alaska. How best then to interpret CWTs from WCVI Chinook that have turned up in fisheries as far north and west as the Bering Sea and south to the Columbia River, as well as in the Salish Sea and Johnstone Strait?

   a. Determine stock compositions using genetics from samples of Chinook salmon from multiple locations other than WCVI.

3. *Habitat*

   The perceived risk to natural-origin Chinook salmon of losing physical habitat was generally high (quality and availability for Juveniles, availability only for Adults), as was changing water quality (water temperature, dissolved 0_2, and contaminants for Juveniles, higher than optimal terminal marine water temperatures for Adults).

   And

   LS1 and LS2 had the greatest proportion of LFs rated as High Risk.

   And

   Future Risk ratings were higher than current for all but one habitat/water quality LF (Juveniles and Adults), as expected with climate change.

   a. Continue to monitor and protect habitat and water quality, especially in estuarine and other nearshore areas, and relate these to salmon growth and survival, the latter accomplished ideally with controlled experiments.
   b. Determine the prevalence and distribution of physiological stress (including smolt stage/osmotic stress) induced by elevated temperatures and lower dissolved O_2 in the estuarine and marine environments. Consider applying Fit-Chip technology to Juvenile salmon occupying Sound environments throughout their first year at sea.

4. *Contaminants, Pathogens, Parasites and Carry-over Effects*

Carry-over effects (LF1) between freshwater and early marine life stages were perceived as High Risk while effects carried over from post-smolt Juveniles to Adults were regarded as Moderate Risk.

And

Carry-over effects from freshwater include size at ocean entry as well as infection status, smolt stage, stressor exposure, and toxin exposure.

And

Current impacts for pathogens and parasites ranked as High increased to Very High in the future, in part because of known or suspected synergistic relationships with climate change and elevated risks for some pathogens/parasites.

a. Test the hypothesis that natural-origin salmon being smaller at ocean entry than hatchery-origin salmon causes them to survive less well, and if so, then why? For example, is this in part because small fish are more reliant on estuarine habitats than larger fish, with consequently increased impacts from avian and piscine predators, and later access to piscine prey? Or is it because natural-origin salmon carry higher burdens of freshwater pathogens or toxicants than hatchery fish? Consider coded-wire tagging groups of natural- and hatchery-origin Chinook to evaluate these hypotheses as well as to test the validity of using hatchery fish as proxies for natural-origin fish.

b. Evaluate carry-over effects in relation to smolt readiness, loads and richness of freshwater pathogens, and toxin exposures from freshwater, particularly for hatchery releases. Develop a modernized, proactive system for health monitoring during hatchery production and, if appropriate, identify husbandry practices to reduce stress and pathogen exposure to optimize health of hatchery releases.

c. To address indirect effects of environmental stress, consider using environmental DNA metabarcoding coupled with salmon Fit-Chip technology to identify how stressors affect the distribution of young natural- and hatchery-origin salmon, their prey, predators, pathogens, and competitors. Apply network analyses to identify species within early marine ecosystems that are positively and negatively associated with salmon abundance and health.

5. *Nutrition*

LFs related to nutrition, changes in prey quality, availability, timing and composition for both Current and Future Risks were generally rated higher for Juveniles relative to sub-Adult and Adult salmon, and for Future relative to Current conditions.

And

Pink salmon-caused trophic cascades can affect plankton and sockeye salmon and potentially also WCVI Chinook during LS3 in the Gulf of Alaska

a. Determine if food is limiting in WCVI sounds by conducting focused studies on feeding and nutrition in relation to growth, health, and distribution of Chinook in sound environment.

b. Evaluate the utility of augmenting traditional plankton sampling and microscopic enumerations with molecular profiling of plankton samples and eDNA metabarcoding of filtered water to provide more rapid, wide-ranging metrics of food availability for salmon. Salmon diet analyses could be augmented similarly using molecular tools.
c. Obtain and analyze time series of annual WCVI Chinook marine growth and otolith microchemistry patterns by ocean year. Develop models to assess nutritional impacts during LS3 on return salmon abundance using numbers of potentially competing salmon within the Gulf of Alaska as a means to address potential food limitation.

6. *Predation*

Herons and other birds can pose significant risk during LS1, particularly if water levels are low. LS3 and LS4 are at highest risk from coastal predators such as Steller sea lions and Killer Whales. Harbour seals that target pre-spawning Adults as they return to estuaries and rivers can potentially expose small runs to significant risk.

a. Continue to monitor and report on predators of WCVI Chinook. Environmental DNA studies can supplement visual monitoring to provide a broader picture of predator distributions in relation to Chinook salmon distributions, although it cannot differentiate life-stage.
b. Address the hypothesis that predators preferentially prey on salmon of lower condition, and thereby at low to moderate abundance, which may enhance the health of salmon populations by removing infected, highly stressed fish.
c. Consider ways to increase minimum flows and estuary complexity (hiding spaces) as well as nearshore habitat restoration, and removal/relocation of log booms (seal haul out platforms).

7. *Hatcheries*

Hatchery-related losses in genetic and/or demographic diversity (LF20) leading to reduced fitness is the highest ranked factor perceived by participants as limiting the survival and productivity of natural-origin WCVI Chinook, both now and in the future.

And

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 introgression of hatchery spawners on fitness of natural spawners.

a. Evaluate and report on the scientific, social, and economic costs and benefits of approaches to increase PNI (proportionate natural influence) including: i) managing hatchery production to produce the fewest fish necessary to achieve program goals and objectives, ii) full marking of hatchery fish and associated mark-selective fisheries, iii) removal of excess hatchery-origin Chinook from the natural spawning population, and iv) management of pNOB (proportion of natural-origin broodstock) and PNI in general in rivers supplemented with hatchery fish to best maintain natural-origin influence and reduce the risk of natural-origin extirpation.

8. <u>*Harvest*</u>
Fisheries-related demographic changes caused by size-selective fisheries targeting mature returning Chinook was rated as High Risk, potentially leading to reduced sizes and proportions of female spawners as well as their fecundity, egg size, and redd depth.
<u>*And*</u>
Overfishing in 'regulated' fisheries on mature returning Chinook was the 2nd highest risk factor (Moderate during the current and future).
   a. Obtain better information on non-sanctioned and illegal fisheries and encourage the inclusion of these catches in future Chinook stock assessments.
   b. Expand the proportion of hatchery-origin fish that are fin-clipped for mark selective fisheries.
   c. Investigate ways to minimize the capture of large female WCVI Chinook.
   d. Evaluate the possibility of determining allowable catches based on numbers of natural-origin Chinook.

9. <u>*Stock Status and Marine Survival*</u>
Although we did not evaluate stock status, participants identified that limited information was available for the northern DU and were concerned that marine survival time series for natural-origin WCVI Chinook are non-existent.
   a. Assemble and examine whatever appropriate information is available for the northern CU (DU) including that of First Nations.
   b. Report on the management actions taken over the last 20 years.
   c. Investigate ways of estimating survival for natural-origin smolts including monitoring and tagging smolts as they leave freshwater.

10. <u>*Interactions Among Factors and Climate*</u>
Cumulative and synergistic interactions among factors may ultimately be major drivers of poor growth and survival of natural-origin WCVI Chinook salmon by shifting their distribution into suboptimal areas. Synergistic interactions will enhance the impacts of some factors relative to others, and identifying these relationships is a crucial step needed to identify appropriate management actions to mitigate factors under human control.
<u>*And*</u>
Linkages between our changing climate and many LFs were documented including elevated risks for some pathogens, parasites, and contaminants.
   a. Determine causal mechanisms and potential mitigation options for key LFs including benchmarks and limit reference points.
   b. Evaluate ecosystem factors positively and negatively associated with Juvenile salmon distributions during early marine life that can be applied to differentiate healthy and unhealthy ecosystems for targeted remediation. Water quality,

distributions of key prey and predators, pathogens and contaminants should all be considered in the context of developing ecosystem health indices.

c. Determine causal mechanisms and potential mitigation options for key LFs including benchmarks and limit reference points.
d. Develop ecosystem models to investigate compounding, synergistic and inter-related effects among LFs identified as Moderate to High Risk to WCVI Chinook salmon (positive and negative) with a specific focus on future climate change impacts. In recognition that long-standing ocean indices may not continue to provide the same power at predicting salmon returns under climate change, evaluate the inclusion of newer indices gained from research on risk factors contributing to marine survival, which may include more localized, within Sound indices as well as more northerly indices of oceanographic conditions.
e. Related to the above, 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. Models should explore impacts of removal of factors under human control.

11. *Future Collaborations*
Continue to improve our understanding of historical shifts in salmon abundance and the role of local and broad-scale factors affecting WCVI Chinook
And
Establish key data needs and additional knowledge gaps that may include continued and improved monitoring, open data, PNI management, and assessment of interactions between natural-origin and hatchery fish throughout their life cycle.

a. Continue to use a multi-stakeholder approach that involves local knowledge-holders and especially First Nations.
b. Investigate additional collaborative projects with academics including university faculty and graduate students.

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7. APPENDICES

Detailed descriptions of the seven virtual workshops that were summarized in the earlier Results Section of the main report follow. During Workshop 1, a broad overview of what was known about the ecology and life history of WCVI Chinook was provided and then participants reviewed potentially important oceanographic indicators. At all six later workshops, participants investigated and ranked the importance of various marine risk factors.

The Workshops built upon each other and so there were differences in how each was organized and reported on. There were no restrictions on attendance, but participation varied depending on the topic covered and peoples' availability. To ensure that everyone had a common basic understanding, we started each of Workshops 2-7 with brief overview presentations on our goals, what had been learned to date, and a summary of what was known of WCVI Chinook status and life history. This was then generally followed by a series of presentations by knowledgeable experts, each followed by a brief question and answer discussion, and near the end of the workshop, a final discussion and summary of what had been learned.

Drafts of the Appendices were developed by different individuals and later reviewed by all report co-authors. Appendices are appended to the main report so that Workshop participants and others can see the materials covered and conclusions reached at each Workshop. We tried to supply similar levels of detail for each of these workshop reports but did not spend much time standardizing the structure of each Appendix, as some readers will no doubt notice. Presentation summaries, received from most presenters, varied in terms of their completeness and documentation. Each was reviewed for obvious errors and typos, but not for scientific accuracy or style. Our intent was to provide basic summaries of what was presented, discussed, and learned at each Workshop, not to generate peer-reviewed scientific documents.

7.1 Workshop 1 – Setting the Scene

WCVI Chinook and Their Physical Environment
Feb 2-3, 2022

7.1.1 Background

The first of seven workshops intended to 1) create understanding of existing knowledge on WCVI Chinook salmon and 2) investigate factors limiting their survival and productivity during their marine life stages and 3) identify knowledge gaps.

7.1.2 Objective(s)

1) To set the stage for subsequent workshops by having salmon biologists provide high level overviews of WCVI Chinook life history including migratory patterns, age structure and sizes while oceanographers describe likely relevant marine conditions experienced by these salmon. 2) To identify preliminary oceanographic indicators of biological or physical processes relevant to WCVI Chinook salmon that will help understand and ultimately predict changes in their growth and/or survival. 3) To evaluate the hypothesis that reduced fish size and/or condition would result in lower survival and/or fitness during a particular or subsequent (i.e., carryover effect) life stage.

7.1.3 Summary of Results

As described in presentations summarized in Section 5 below, the focus at this workshop was on ecosystem and climate indicators relevant to conditions experienced by salmon over broad areas although some indicators specific to locations and times where WCVI Chinook lived were also identified and described.

There was consensus of a high risk being likely of reduced fish size and/or condition resulting in significantly lower survival and/or fitness during specific or subsequent (i.e., carry over effect) life stages. Various potential biotic (Juvenile chinook abundance, zooplankton variety and abundance) and abiotic (water temperature, Pacific Decadal Oscillation, Ocean Niño Index (ONI), temperature, upwelling, coastal stratification, dissolved oxygen, North Pacific Current bifurcation index, water current and wind direction and speed) indicators were described.

The primary recommendation from Workshop 1 was to identify and retrospectively evaluate the utility of indices such as those above but including local indicators selected to represent conditions relevant to conditions experienced by WCVI Chinook to better understand and ultimately predict interannual patterns of survival and growth for WCVI Chinook. In addition, the development of models to investigate impacts of climate change on WCVI Chinook was encouraged (see Section 7.1.6).

7.1.4 Agenda

Day 1

9:00 am	Welcome, introductions, review entire MRA workshop schedule, review workshop #1 objectives and agenda – Marc LaBrie
9:30 am	Introduction of West Coast Vancouver Island (WCVI) Chinook Rebuilding Initiative - Larry Johnson & Wilf Luedke & Saya Masso
10:15 am	Overview of the Freshwater Risk Assessment Findings (Research)- Jessica Hutchinson & Miranda Smith
11:00 am	Break
11:15 am	WCVI Stock Assessment- Stock trends, Enhancement & Exploitation – Wilf Luedke
12:00 pm	Break for lunch
1:00 pm	Overview of WCVI Oceanography (Peter Chandler, Charles Hannah, Roy Hourston, Akash Sastri,)
1:45 pm	Physical and biogeochemical modelling off the BC coast (Laura Bianucci, Amber Holdsworth, Angelica Pena, Mike Foreman)
2:30 pm	Break
2:40 pm	NEPSTAR Overview: Northeast Pacific Salmon Tracking and Research: Linking Ocean Conditions and Salmon Behaviour (Roy Hourston)
2:50 pm	Bathymetry coverage and CHS ADCP current measurement program (Stacey Verrin)
3:00 pm	Break
3:15 pm	Introduction to Follow the Fish Sessions – Jim Irvine & Wilf Luedke
3:30 pm	Facilitated Discussion – Marine Phase 1 = early marine period (summer/fall) in estuarine regions -> Marine Phase 2 = 1st marine winter in coastal sounds
4:15 pm	Adjourn

Day 2

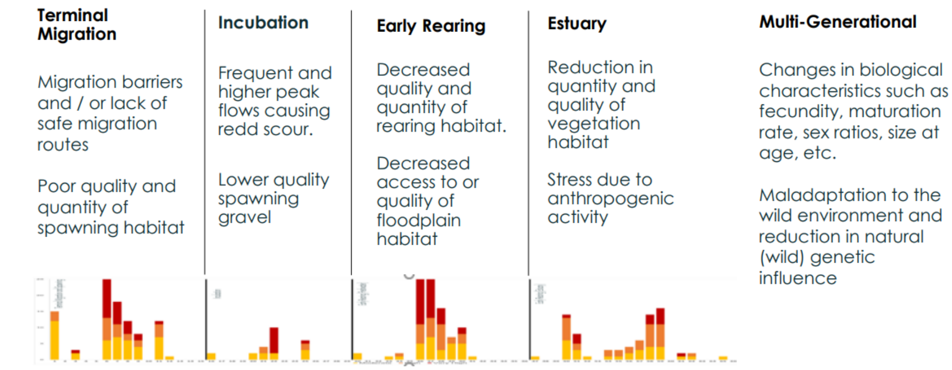
9:00 am	Welcome, thoughts from yesterday, 9.30am Follow the Fish Cont'd - Marine Phase 3 = immature Ages 3-5, starting North of Vancouver Island, moving beyond Haida Gwaii and along Aleutians (continental shelf) and coastal Gulf of Alaska -> Marine Phase 4 = primarily Ages 4-5, primarily coastal migration returning to WCVI and estuaries.
9:30 am	Smolt Outmigration (Bob Bocking & Jared Dick)
10:00 am	Follow the Fish – First marine Winter (Oct-March) (Marc Trudel)
10:20 am	The Coast-wide Decline in Survival of West Coast Chinook Salmon (David Welch, Aswea Porter & Erin Rechisky)

11:40 am	Non-Stationary drivers of Pacific salmon productivity (Michael Malick and Jim Irvine)
11:00 am	2020-21 WCVI Microtrolling Pilot (Jessy Bokvist)
11:30 am	Facilitated Discussion – do conditions typically experienced by these fish limit salmon growth and/or survival including temperature, vertical stratification, water quality, productivity.
12:00 pm	Break for lunch
1:00 pm	Facilitated Discussion – Biological- A review of non-fishery information specific to these life history stages of WCVI Chinook including mortality, growth, migration routes and speed, use of nearshore vs off-shore waters, proportions returning by age.
1:20 pm	Oceanographic - Review of physical processes typically experienced by these fish that may limit salmon growth and or survival such as climate (e.g., water temperature, El Nino), non-stationarity in space and time, downwelling, coastal stratification, current direction and speed, upwelling, productivity. Information contributions welcome.
1:45 pm	Physical and biogeochemical modelling off the BC coast (Laura Bianucci, Amber Holdsworth, Angelica Pena, Mike Foreman)
3:30 pm	Facilitated Discussion Continued – What we learned, major knowledge gaps, next steps (Jim Irvine, Isobel Pearsall, Wilf Luedke).
4:15 pm	Adjourn

7.1.5 Presentation and Discussion Highlights

a) Overview of the Freshwater Risk Assessment Findings (Research)- Jessica Hutchinson & Miranda Smith

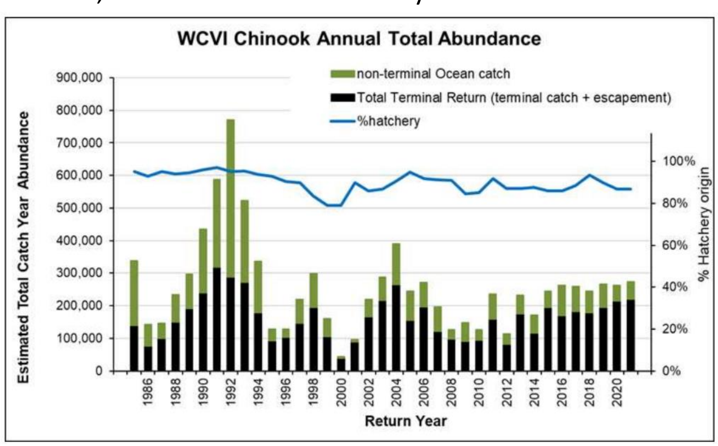
- Summarized freshwater risk assessment process that reviewed potential limiting factors for Areas 23-26
- Significant degradation of important habitat due to human activities.
- Effects are amplified by climate change impacts; higher winter flows and lower summer-fall flows, higher temperatures, bedload movement and gravel aggradation, etc.
- Increased mortality of returning Adults through predation and temperature stress
- Increased mortality and / or reduced fitness during the most vulnerable life history stages (i.e. incubation and early rearing) from these alterations are producing fewer and smaller fish upon entry into the marine environment.
- The multi-generational impacts from hatcheries and depressed wild stocks have also reduced the fitness and survival of WCVI chinook in some systems, though the true impacts on populations remains to be quantified.

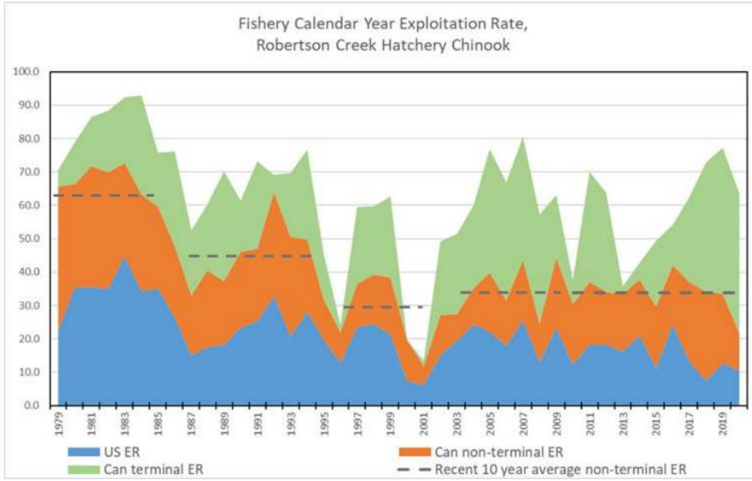


Distribution of ranks by limiting factor and life stage across the WCVI

b) WCVI Stock Assessment- Stock trends, Enhancement & Exploitation – Wilf Luedke

- Summarized information on WCVI Chinook salmon that support Nuu-chah-nulth, Pacheedaht, Quatsino, T'Souke First Nations
- 180,000 recent annual WCVI Chinook catch by First Nations, recreational, and commercial fisheries from Alaska to southern BC
- Spawning - fall (Oct) spawners; NWVI earlier than SWVI; female spawners usually 30-50; fecundity is relatively low, generally < 4000 eggs
- Smolts - "ocean" type; go to sea 0- 4 months (Mar-Jun)
- Near shore rearing; northward migrating, far north migrating (some caught in Bering Seas)
- Lifespan 2-6years; age 4 is the mean age at maturation; younger for males – older for females
- Smolt to Adult survival and fisheries exploitation rates based on Robertson Creek Hatchery (RCH) coded-wire tags
- Estimated historic unfished abundance 75,000 but 20,000 avg returns 1953-72 so hatcheries built that produce 10-15 million smolts annually
- Returns now ~180,000 of which 85% hatchery fish

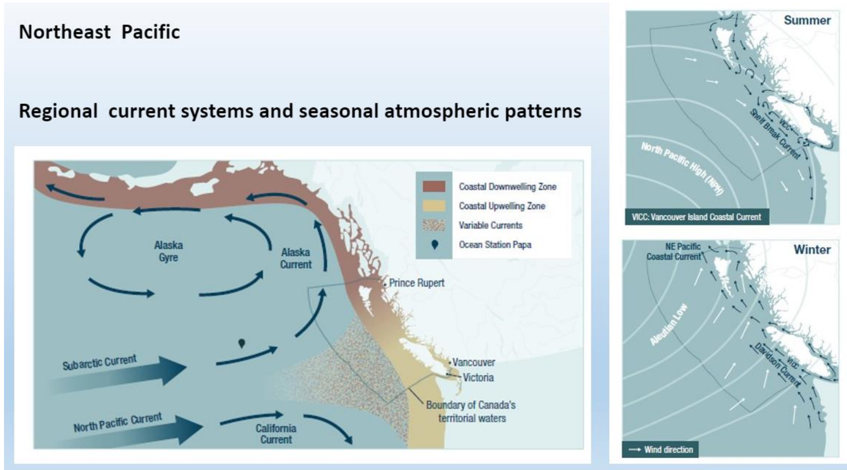




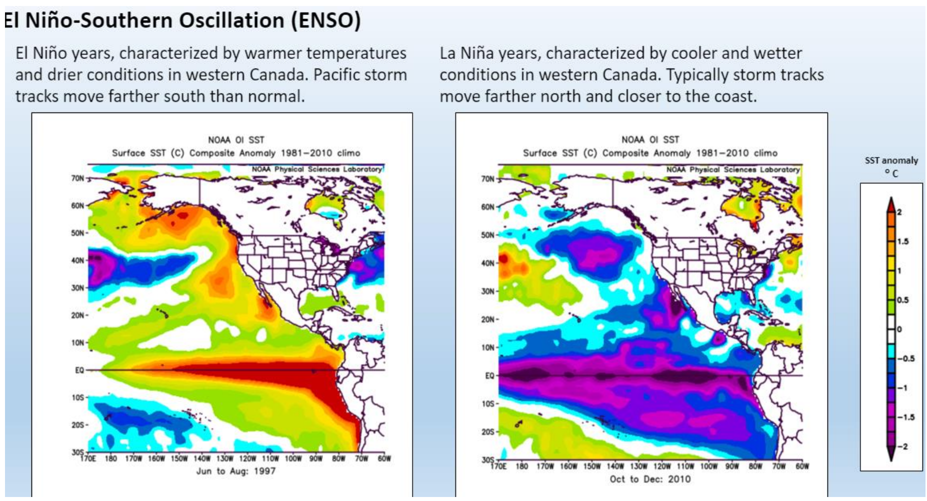
- 60+% average exploitation prior to the 1985 Pacific Salmon Treaty. Increases in hatchery production, along with reduced catch ceilings, was intended to reduce impacts on natural origin Chinook
- 45% exploitation into the 1990s. Additional reduction in fisheries in mid 1990s.
- 35% non-terminal exploitation on Clayoquot Sound Chinook
- But 40% average fishery exploitation rate remained on the older age classes, which were mostly female, resulting in setting terminal fisheries targets, migration corridors, maximum size limits, area closures, etc.
- To protect wild stocks, Kyuquot and Clayoquot classified as wild refugia - enhancement discouraged. Positive response in Kyuquot but no response in Clayoquot
- Hatcheries causing reduced genetic diversity in natural spawning populations; PNI (proportion natural influence) < 0.25
- RCH smolt to Adult survival ~3% while natural spawned smolt survival only ~0.5-1%, early marine survival may be bottleneck
- Basic life history model introduced

c) Physical Oceanography - Peter Chandler, Charles Hannah, Roy Hourston, Tetjana Ross, Guoqi Han

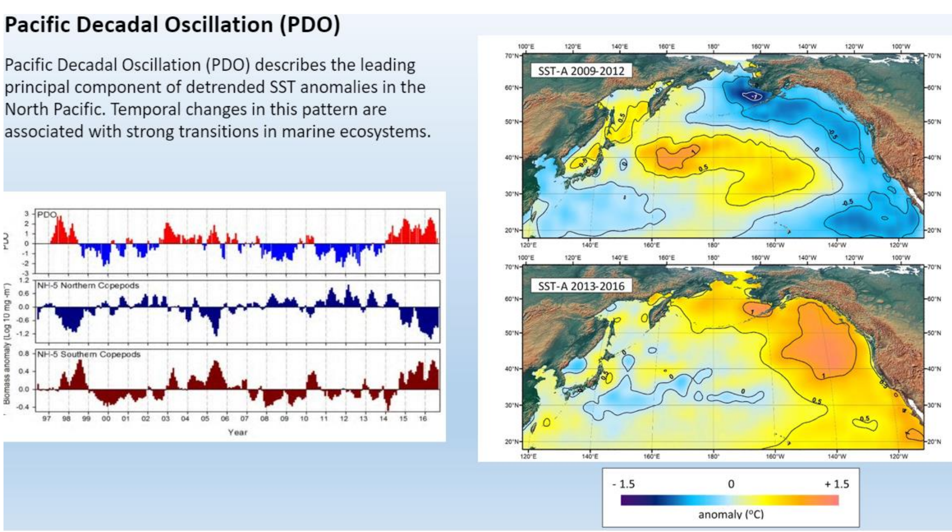
- Focused on open ocean and shelf with thoughts on inlets
- Region dominated by eastward flowing Subarctic and N Pacific currents. Coastal currents strongly influenced by seasonal atmospheric (e.g., wind) pattern changes



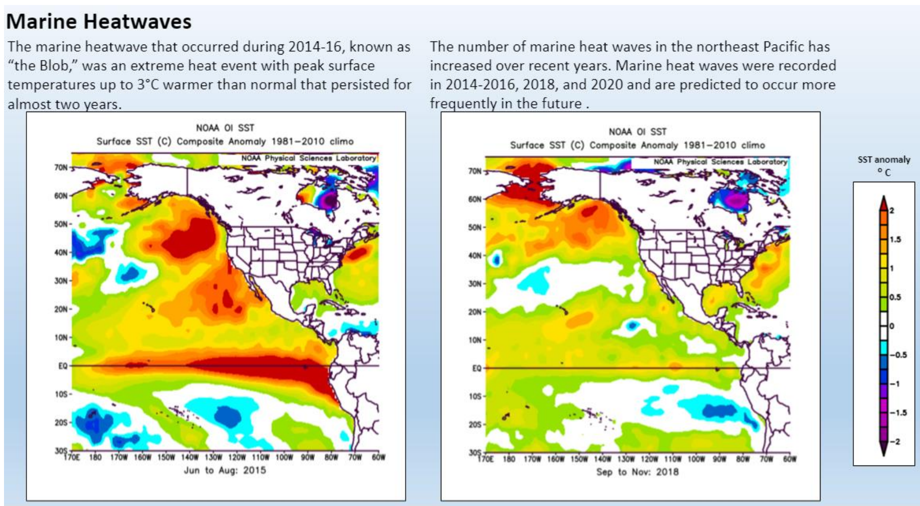
- Major differences in temperature and precipitation between El Nino and La Nina years



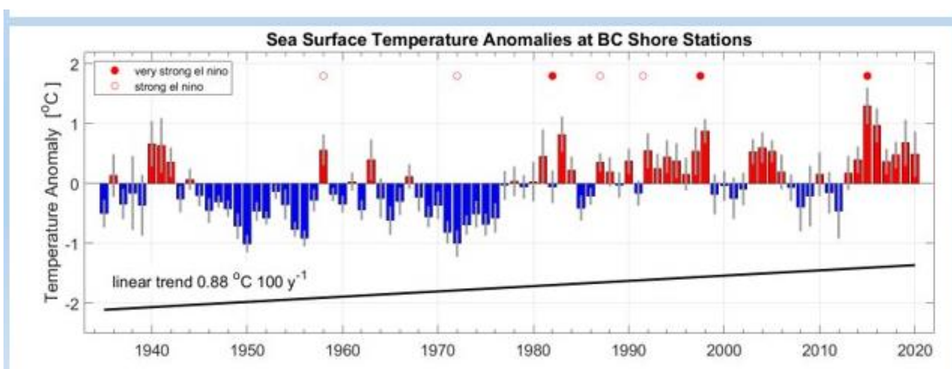
- Pacific Decadal Oscillation (PDO) related to temperature anomalies that are correlated with abundance of northern (high lipid) and southern (lower lipid) copepod communities. Moira Galbraith has zooplankton indices.



- El Nino and PDO are useful large scale indices but may need some refinement to deal with different flavours of El Nino in Eastern and Central Pacific. These may only be useful to explain extreme years.
- The frequency of marine heat waves has increased in the last decade with major ecosystem effects



- Lighthouses and ECCC weather buoys are good sources of SST data. BC's daily sea surface temperatures have increased by ~0.7C in last 80 yrs



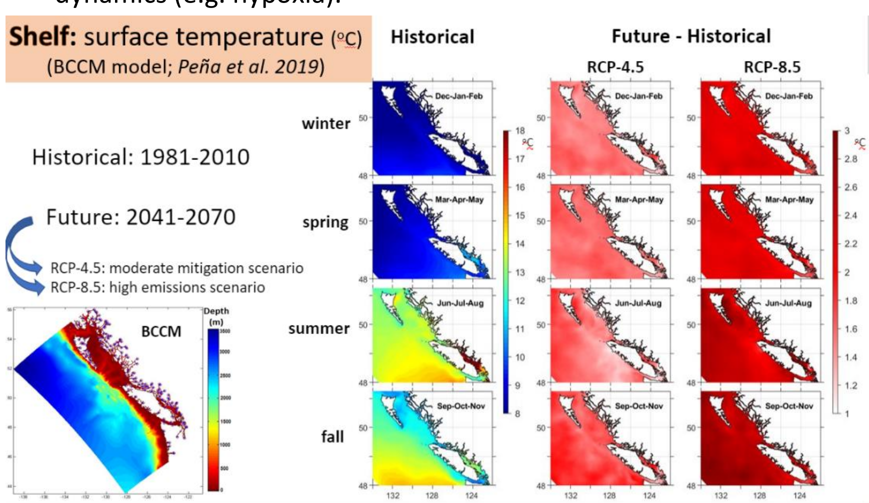
- Lots of shelf data that could be useful but need analysis with WCVI salmon in mind
  - During winter, rotating masses of warm, nutrient-rich waters up to 250 km in diameter may drift from off Haida Gwaii transporting heat and nutrients (Haida Eddies)
  - Summer low oxygen concentrations in subsurface waters common but does this matter to salmon?
  - Stronger than average upwelling-favourable winds generally associated with increased coastal productivity. Do the upwelling winds at 42 N matter more to BC than the ones at 48 N?
  - Shelf data may not matter?
- This compilation of the temperature, salinity, and oxygen data in BC Inlets includes some WCVI inlets https://ios-osd-dpg.github.io/bc-inlets/

- Surprisingly, the data suggest the deep water inlets of WCVI are NOT warming.

- WCVI fjords often connected to continental shelf by relatively narrow and shallow entrances, leading to stark gradients in water column density, salinity, oxygen, and nutrients
- Is Alberni Inlet the only one where salmon are getting squeezed by low oxygen from below and high temperature from above?

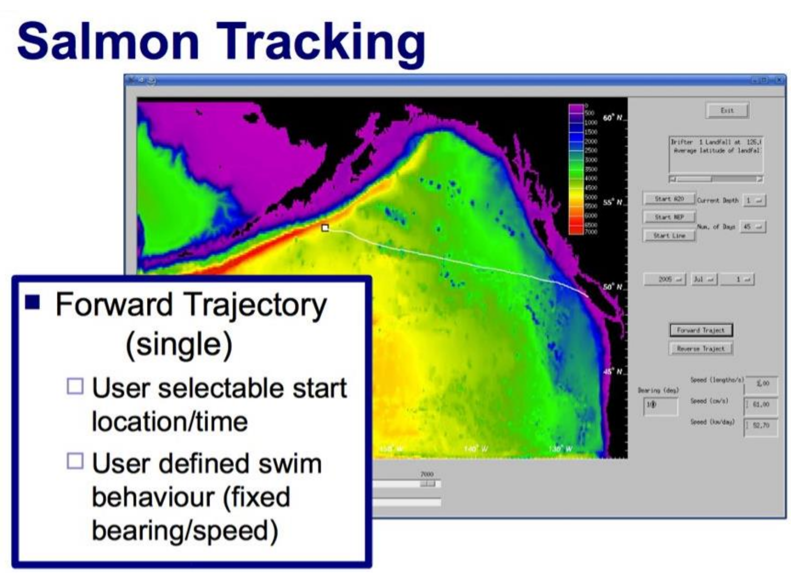
d) Physical and Biogeochemical Modelling off the BC Coast (Laura Bianucci, Amber Holdsworth, Angelica Peña, Mike Foreman, and Di Wan)

- Described hydrodynamic and biogeochemical models used to study the continental shelf and closer to shore (coastal, primarily modelling in inlets)
    - 2 important papers describe dissolved oxygen and other biogeochemical variables over the shelf (Peña et al., 2019 and Holdsworth et al., 2021.)
- Presented results demonstrating that the region is becoming warmer, and more stratified and perhaps fresher; low oxygen/acidic waters shoaling and encroaching onto the shelf; extreme states of hypoxia, acidification, and warming are more extreme and more frequent, with milder minimum temperatures
- Two model grids that could project shelf conditions into inlets of relevance to WCVI Chinook salmon
    - WCVI (with biogeochemistry) with a focus on Nootka and Clayoquot sounds and hypoxia
    - Quatsino Sound
    - Primary application is to inform decisions on siting and management of aquaculture facilities; also used to study physical and biogeochemical dynamics (e.g. hypoxia).



- To use models to investigate impacts of climate change on Chinook, one should: 1. Identify the area of interest and the resolution needed. Find an appropriate model or build one; 2. Use the numerical model to understand the effects of climate change in the environment, and 3. Apply empirical/statistical models to understand how these environmental effects will impact Chinook

e) NEPSTAR Overview: NorthEast Pacific Salmon Tracking and Research: Linking Ocean Conditions and Salmon Behaviour (Rick Thomson, Roy Hourston, Michael Folkes, and Scott Tinis)
   - Simple statistical models can work well given useful input data
   - NEPSTAR currently is used for Fraser sockeye and pink salmon to forecast return timing and northern diversion rates to the Pacific Salmon Commission
   - Could be used for WCVI Chinook or other species
   - Approach is to establish lagged linear correlations between a single salmon statistic and one or more environmental variables such as ocean temperatures, currents, and wind stress (as a surrogate for surface currents). Then an ensemble of multiple linear regression models are used to predict salmon migration behaviour – timing and diversion.
   - Salmon Tracking was another area of salmon migration behaviour investigated via simulated migration trajectories. User-defined start locations in the northeast Pacific Ocean and dates, as well as swim behaviour (fixed bearing and speed with a small random component) were imposed on modelled ocean currents. This allowed simulating where a fish might end up on the west coast given various starting locations in the Northeast Pacific, as well as where a fish might have originated given its location and date of arrival on the west coast.

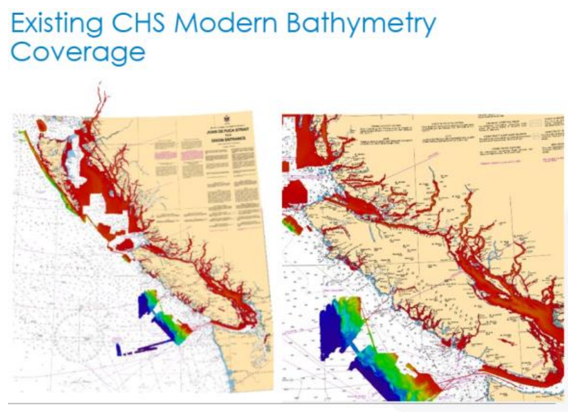


   - This research could be applied to investigate the marine migration of WCVI Chinook. For e.g., develop modelled salmon swim trajectories in the NE Pacific to better understand the relative importance of the Gulf of Alaska vs. Nearshore areas.
   - Thomson and Hourston have a PSSI project to transition NEPSTAR to use the ECCC's operational ocean forecast system for the North Pacific. This would improve the ability to be truly operational.

- Also building a fish trajectory model to sample the environment that a fish would see.
- See Thomson & Hourston. 2011; and Folkes et al. 2018.

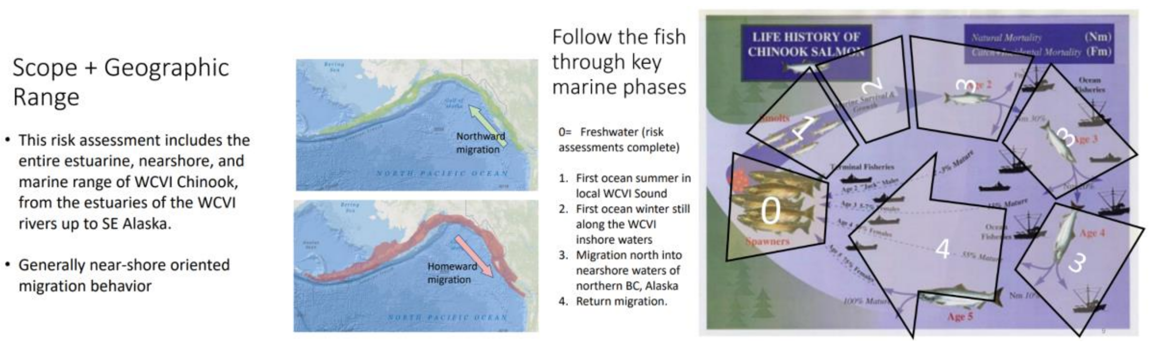
f) Canadian Hydrographic Service Pacific (Stacey Verrin)

- CHS carries out hydrographic and GPS surveys and provides tide and current data

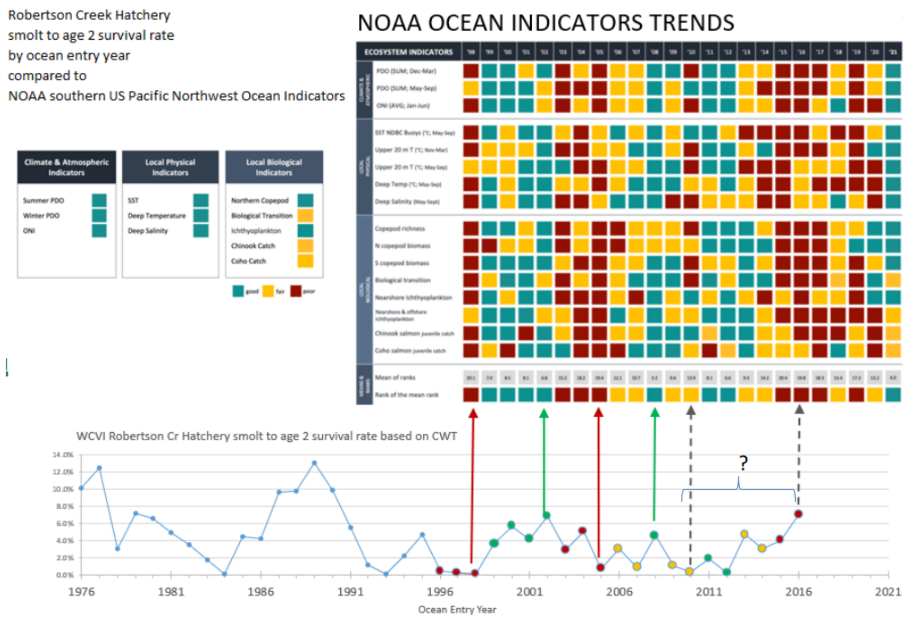


g) Introduction to Follow the Fish Sessions (Jim Irvine & Wilf Luedke)

- For remainder of this workshop and subsequent workshops, intent is to "follow the fish" after young WCVI Chinook leave freshwater, spend their initial summer and winter along the WCVI (Marine Phases 1 & 2) and then move northward and westward, eventually returning to WCVI (i.e., Phases 3-4).

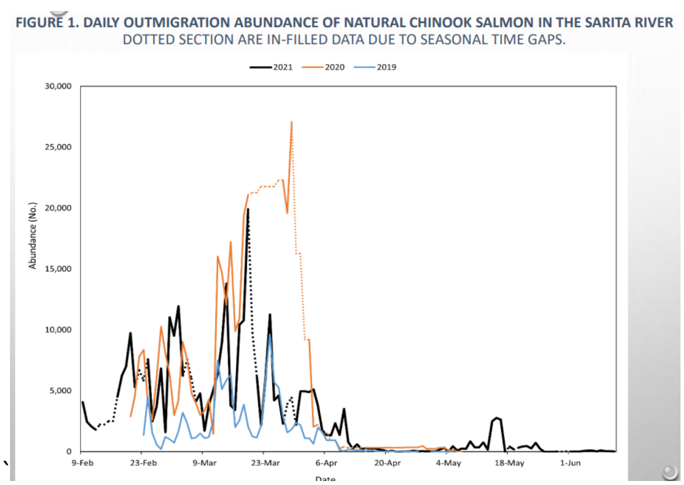


- We need to identify physical and biological ocean indicators specific to WCVI Chinook as has been done by NOAA for coastal Washington/Oregon and Fraser River sockeye (Xu et al. 2020). Southern indicators are reasonably good at explaining peaks and valleys in survival of Robertson Ck Chinook; can we do better with WCVI-specific indicators?



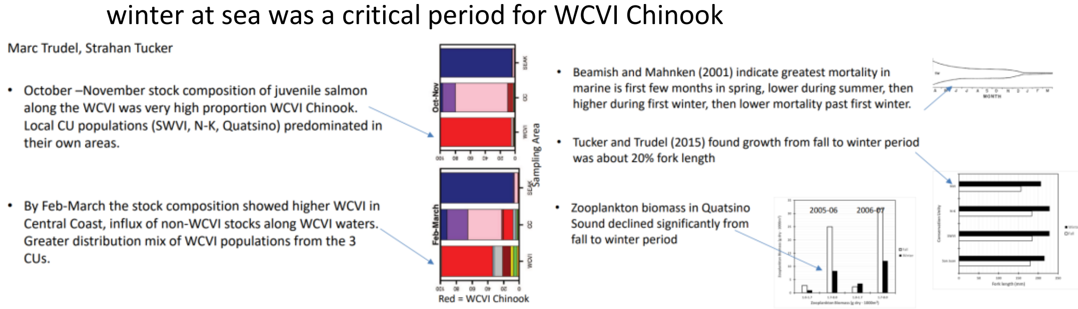
h) Follow the Fish - Smolt Outmigration (Bob Bocking & Jared Dick)

- Summarized chinook smolt outmigration studies in several WCVI rivers



i) Follow the Fish - First marine Winter (Oct-March) (Marc Trudel)

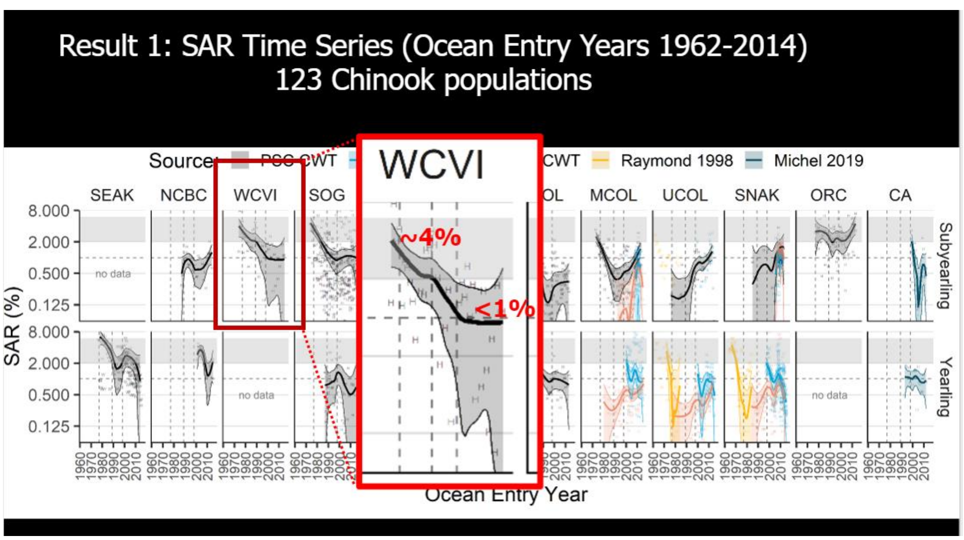
- Reported on studies carried out during 1998-2011 that investigated whether the 1st winter at sea was a critical period for WCVI Chinook



- Overall, WCVI Juvenile Chinook remain off WCVI for a year before migrating north. WCVI Juvenile Chinook are mostly distributed from their ocean entry point to Quatsino Sound and stocks mix in the inlets and shelf.
- Hatchery and wild Chinook salmon exhibited similar migration pattern over large scales
- Migration patterns were similar among years despite large variations in ocean conditions, indicating that migration may be genetically programmed
- While overwinter mortality appears to be high, winter may not be a critical period for WCVI Chinook despite a reduction in prey availability
- Limited evidence of size-selective mortality
- Energy depletion increases with size (rather than decreases)
- Feeding occurs during winter
- A correlation between total survival and winter survival has not been established

j) Follow the Fish - The Coast-wide Decline in Survival of West Coast Chinook Salmon) (David Welch, Aswea Porter & Erin Rechisky)

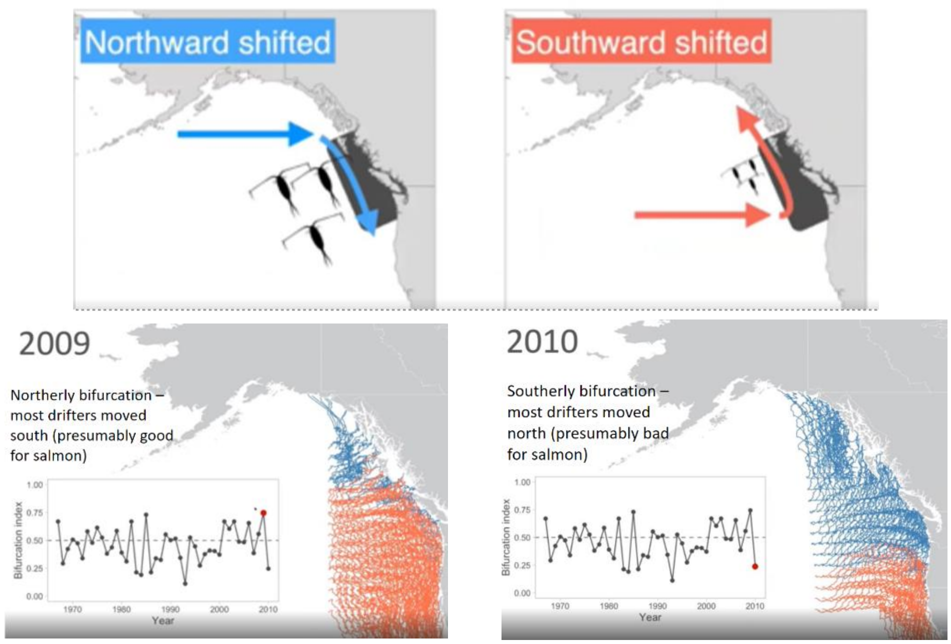
- Looked at smolt to Adult survivals (SARs) for ~123 Chinook stocks from Canada and USA including WCVI
- Survivals collapsed for many populations, including WCVI, to only ~1%. How is it possible that so many Chinook populations fall to similarly low levels but occupy different parts of the ocean and freshwater?



- Need to look for survival drivers affecting all regions of the coast and both life history types (spring (stream) and fall (ocean)) what do can we say about commonalities?
- Freshwater habitat impacts are not the cause since wild SE Alaska SARs decreased (but habitat is essentially pristine) and they essentially have no freshwater stage for smolts

- Increases in marine predation seem to be a reasonable explanation – shark aggregations have been documented in coastal waters of BC

k) Non-stationary Drivers of Pacific Salmon Productivity (Michael Malick and Jim Irvine)
- Horizontal ocean processes (currents, eddies) can affect salmon productivity (recruits/spawners) but effects will vary across space and time
- For example, the intensity and location of where the North Pacific Current reaches North America varies among years and has been shown to affect productivity of sockeye, pink and chum salmon but has not been examined for Chinook
- When the bifurcation location is shifted north, this appears to result in a southward displacement of lipid rich northern zooplankton, benefiting young salmon in our region. In contrast, when the bifurcation location is shifted south, this appears to cause more lipid poor southern zooplankton to be carried to the north, reducing food quality for salmon



l) 2020-21 WCVI Microtrolling Pilot (Jessy Bokvist)
- Used modified recreational gear on downriggers from small vessels to catch Chinook Juveniles in their first winter at sea
- Preliminary stock composition results appear to imply that WCVI Juvenile Chinook “sound hop” and stay nearshore during northern migration
- Migration may be slow and continuous throughout the winter as shown by interception of Barkley Sound Chinook present in all sounds during all months surveyed
- Ongoing microtrolling results expected to provide more definitive results

7.1.6 Workshop Synthesis

There was consensus of a high risk being likely of reduced fish size and/or condition resulting in significantly lower survival and/or fitness during specific or subsequent (i.e., carry over effect) life stages. Various potential biotic (Juvenile chinook abundance, zooplankton variety and abundance) and abiotic (water temperature, Pacific Decadal Oscillation, Ocean Niño Index (ONI), temperature, upwelling, coastal stratification, dissolved oxygen, North Pacific Current bifurcation index, water current and wind direction, and speed) indicators were described.

Four marine life stages were considered:

- LS1 (first marine spring, summer and fall in estuary and nearshore marine) along WCVI
- LS2, first marine winter along WCVI)
- LS3 (subsequent marine rearing of ages 2-4+ north of Vancouver Island ending when fish begin their homeward migration, and
- LS4 (Adult fish migrating back to the WCVI and into estuaries)

Published NOAA oceanographic indicators (https://www.fisheries.noaa.gov/west-coast/science-data/ocean-ecosystem-indicators-pacific-salmon-marine-survival-northern) explained most high and low smolt to age 2 survivals during 1998-2008 but were less successful for more recent years (see presentation above). The group wondered if the reason the NOAA indicator set failed in recent years was due to climate change effects? Or perhaps some of these indicators were not relevant to WCVI?

The NOAA indicators were developed to explain salmon survival trends for US salmon populations in the Northern California current. It seems reasonable that climate and oceanographic indicators (i.e., winter and summer PDO, ONI), which are linked to broad SST and climate-related patterns over large areas, might be expected to help explain WCVI Chinook survival and growth patterns. The same is not the case with local NOAA indicators, however. WCVI Chinook sometimes enter the Northern California Current and in other years enter the Gulf of Alaska Current, depending on the location of the bifurcation index (see presentation above). It makes sense therefore that local NOAA physical and biological indicators should be replaced by values that are more likely relevant to WCVI Chinook. Many of these potentially useful indicators were described in presentations above but the work needed to evaluate correlations with changes in WCVI Chinook survival and/or growth have not been undertaken. The main recommendation from Workshop 1 is to identify and test whether indicators specific to WCVI Chinook would do a better job than the suite of indices used by US scientists.

Following is a preliminary list of fishery independent oceanographic indicators of potential use to understanding WCVI Chinook survival/growth trends, based on presentations at Workshop 1, augmented by discussions and literature review afterwards. We expect that this list will be refined and expanded during subsequent workshops. As discussed above, the list includes NOAA climate and oceanographic indicators while the local indicators have been selected to represent conditions likely applicable as the salmon migrate between Alaskan and BC waters (see Follow the Fish presentation above).

Potential Climate and Oceanographic Indices

- Ocean Niño Index (ONI; a general El Index)
- Niño 1+2 (index Eastern Pacific El Ninos)
- Niño 3+4 (index of Central Pacific El Ninos and large Eastern Pacific ones)
- Pacific Decadal Oscillation (PDO) (linked to increase/decrease in northern zooplankton (Hipner et al. 2020)), North Pacific Gyre Oscillation (NPGO)
- Aleutian Low Index
- Bakun index at 42 N (remoted driver of Upwelling off Vancouver Island.
- North Pacific Bifurcation Index (latitude where North Pacific Current bifurcates into the southward flowing California Current and the northward Alaska Current)

WCVI Inlet Indices (Relevant for Marine Phases 1 & 2)

- Summer, fall and winter inlet temperature, salinity, and oxygen data (e.g., https://ios-osd-dpg.github.io/bc-inlets/
- Northern and southern copepod indices and ratios of copepods to gelatinous zooplankton (e.g., Moira Galbraith)
- Zooplankton data from Barkley Sound (and other locations where available)
- Juvenile chinook abundance (microtrolling and other estimates; see above presentations)

Coastal Shelf Ocean Indices (Relevant for Marine Phases 3 and 4)

- Coastal air temperatures
- Seasonal average water temperatures selected based on our understanding of when and where Chinook are likely to be. For example, a linear array of SST from BC lighthouses and Environment and Climate Change Canada's (ECCC) weather buoys from Laperouse Bank to Dixon Entrance.
- Seasonal average temperatures from near shore sites along the Alaska coast to the Bering Sea (e.g., Alaska Integrated Ocean Observing System (AIOOS).
- Seasonal average of an average SST over the BC shelf - the average of the BC lighthouse SST contains contain about 50% of the monthly mean SST variability.
- An index of extreme temperatures at each SST station identified above (BC and Alaska). This could be indexed by something life growing degrees days (the sum of the daily temperatures above some reference temperature.
- Possibly the size and location of marine heat waves although the temperature indices above should capture the warm events.
- Possibly indices of nutrient rich Haida Eddies although if these Chinook spend their lives on the shelf, Haida Eddies may not affect them.
- Subsurface conditions from the BC shelf mooring program. For example, there is ~30 years of data at the EO1 mooring over the 100 m isobath off Estevan Point). The best coverage is temperature and salinity (35 m and 75 m and sometimes 95 m). In recent years there has been oxygen. Bottom salinity could be a metric of the timing

of upwelling in the spring. Also, there is information on velocity in the water column (Vancouver Island Coastal Current).

- The water column data over the shelf from Line P and Laperouse monitoring programs could be mined (temperature, salinity, oxygen, nutrients). This is separate from the zooplankton indices above.
- Ocean Network Canada (ONC) has bottom pods in Folger Pass near the mouth of Barkley Sound. These provide real time data (temperature, salinity, oxygen).
    - The shallow Folger Pass pod is ~25 m depth https://amloceanographic.com/blog/post/foul-free-folger-pinnacle
    - The Folger Deep pod is ~at 100 m depth. The oxygen sensor (when it works) seems to provide a useful indicator of bottom oxygen on the southern Vancouver Island shelf. Salinity can be a useful indicator of upwelling timing.

Recommendations

a. Identify and retrospectively evaluate the utility of indices such as those above including local indicators selected to represent conditions relevant to conditions experienced by WCVI Chinook to better understand and ultimately predict interannual patterns of survival and growth for WCVI Chinook.
b. Consider developing models to investigate impacts of climate change on WCVI Chinook (i) Identify the area of interest and the resolution needed. Find an appropriate model or build one; (ii) Use the numerical model to understand the effects of climate change in the environment, and (iii) Apply empirical/statistical models to understand how these environmental effects will impact Chinook.
c. Consider applying NEPSTAR approach to investigate the marine migration of WCVI Chinook. For e.g., develop modelled salmon swim trajectories in the NE Pacific to better understand the relative importance of the Gulf of Alaska vs. Nearshore areas.

7.1.7 Key Literature[2]

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7.1.8 Participants' Names and Affiliations

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Andrew	Unknown
Andrew Bateman	PSF
Andrew Munro	ADFG
Andrew Thomson	DFO
Anita Blakley	LGL
Ashley Dobko	DFO
Ashley Popovich	Catalyst Paper
Barb Cannon	Creative Salmon
Beau Doherty	Independent
Bob Bocking	LGL
Brad Beaith	DFO
Brian Hunt	UBC
Byron Charlie	Ahousaht
Cameron Forbes	Recreational fisher
Cameron Freshwater	DFO
Carol Schmitt	Independent
Cecilia Addy	City of Port Alberni
Chantal Nessman	DFO
Charles Hannah	DFO
Cheryl Greengrove	University of Washington
Chris Ashton	Commercial seine
Chris Burns	LGL
Dan Doubinin	BC
Dani Robertson	Uu-a-thluk
Danny O'Farrell	Ahousaht
Dave Burt	Independent
Dave Rolston	Tseshaht
David Miller	Ehatisaht
David Welch	Independent
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Diana McHugh	DFO
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Evgeny Pakhomov	UBC
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Jennifer Yakimishyn	Parks Canada
Jeremy Maynard	Recreational fisher
Jess Edwards	Ha'oom
Jessica Hutchinson	Redd Fish
Jessy Bokvist	DFO
Jim Irvine	DFO
Jim Lane	Uu-a-thluk
Joe Curley	Tla-o-qui-aht
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Jonquil Crosby	Yuułuʔiłʔatḥ
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Krysten Rutherford	DFO
Lance Stewardson	Independent
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Laura Sitter	DFO
Leah Sneddon	DFO
Les Sam	Tseshaht
Lu Guan	DFO
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Monique Gillette	Ka:'yu:'k't'h'/Che:k'tles7et'h'
Neil Dangerfield	DFO
Nick Bohlender	DFO
Nick Brown	DFO
Pat Deakin	City of Port Alberni
Patrick James	Mowachaht/Muchalaht
Patrick Pata	UBC
Paul Dore	Recreational fisher
Paul Sieber	Ditidaht
Paul Tate	Ditidaht
Penny Cote	Alberni-Clayoquot Regional District
Peter Chandler	DFO
Peter deKoning	DFO
Peter Hall	DFO
Peter McKenzie	Cermaq
Phil Edgell	Alberni Valley Enhancement Society
Pieter Van Will	DFO
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Sam Noble	NOOTKA
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Sarah Fowler	DFO
Sarah Rosen	Cedar Coast Field Station
satiixab ditidaht	Ditidaht
Saya Masso	Tla-o-qui-aht
Scott Porter	Slam Bang Lodge
Sean Cox	SFU
Shane Johnson	LGL
Simon John	Fishing guide
Stacey Verrin	DFO
Steve Emmonds	DFO
Suzanne Earle	DFO
Svetlana Esenkulova	UVic
Tim Hawkins	West Coast Aquatic
Tom Bird	DFO
Valerie Berseth	Carleton University
Wendy Callendar	DFO
West Coast Aquatic	facilitator
Wilf Luedke	DFO
Will Duguid	UVic
Yuri Zharikov	Parks Canada
Zoran Knezevic	Port Alberni Port Authority

7.2 Workshop 2 – Physical Habitat, Water Quality

Physical Habitat and Water Quality Changes to Marine Ecosystems Affecting WCVI Chinook
February 22-23, 2022

7.2.1 Background

The second of seven workshops intended to 1) create understanding of existing knowledge on WCVI Chinook salmon, 2) investigate factors limiting their survival and productivity during their marine life stages, and 3) identify knowledge gaps.

7.2.2 Objective(s)

To assess and rank marine risk factors potentially limiting survival, growth and/or fitness of WCVI Chinook during their Juvenile (first summer, fall and winter) and Adult (marine rearing plus return migration) phases. Factors assessed included reductions due to carry-over effects and due to changes in physical habitat and water quality (Table 7.1).

Table 7.1 Limiting factors (LFs) assessed during Workshop 2.

LF	Category	Limiting Factor Description
1	Cumulative or Carry-over effects	Survival, growth and/or fitness reduction due to carry-over reduced condition in previous life-history phase.
2	Physical Habitat	Survival, growth and/or fitness reduction due to degraded habitat quality
3	Physical Habitat	Survival, growth and/or fitness reduction due to reduced habitat availability or connectivity
4	Water Quality	Survival, growth and/or fitness reduction due to direct impacts of water temperatures
5	Water Quality	Survival, growth and/or fitness reduction due to direct impacts of hypoxia or dissolved oxygen levels
6	Water Quality	Survival, growth and/or fitness reduction due to direct impacts of changes to salinity
7	Water Quality	Survival, growth and/or fitness reduction due to direct impacts of changes to ocean acidity

7.2.3 Summary of Results

In general, risk factors were rated higher for Juvenile salmon than for Adults (Table 7.2). This corresponds with expectations. The early marine period is widely acknowledged as a period of relatively high mortality for salmon and in two systems discussed at the workshop (Sarita and Bedwell), a high proportion of naturally spawned fish smolt at very small sizes, making them vulnerable to sub-optimal early marine including estuary conditions. Risk factors were also generally higher for the future than the present. Again, this seems reasonable given that several of the habitat LFs examined are expected to become more problematic with climate change, to the detriment of many salmon.

High (current) to Very High (future) risk ratings were recorded for Juvenile WCVI Chinook for local habitat quality and availability as well as water quality related to dissolved oxygen and temperature. Potential mechanisms discussed included some related to foraging theory; the combination of time spent within habitat for cover-protection versus time spent in more open water finding food results in fish being more vulnerable to predation in open water. Potential mechanisms discussed included reduced kelp forests, invasive Green Crab impacting eel grass, loss of estuary sedge grasses, and human uses such as aquaculture net pens, each of which may result in increased exposure to predation.

Table 7.2 Ranked (high to low) current and future risk rankings for limiting factors (LFs) considered during Workshop 2 (see Section 6 for details).

Limiting Factor	Life Stage	Review Result Current Risk	Review Result Future Risk
LF2 Local habitat quality	Juvenile	High	Very High
LF1 Carry-over impacts	Juvenile	High	Very High
LF3 Local habitat availability	Juvenile	High	Very High
LF4 Local water temperature	Juvenile	High	Very High
LF4 Local water temperature	Adult	High	Very High
LF5 Local Dissolved oxygen	Juvenile	High	Very High
LF3 Local habitat availability	Adult	Mod	Very High
LF2 Local habitat quality	Adult	Mod	High
LF5 Local Dissolved oxygen	Adult	Mod	High
LF1 Carry-over impacts	Adult	Mod	Mod
LF6 Local salinity	Juvenile	Low	Mod
LF6 Local salinity	Adult	Low	Mod
LF7 Ocean acidity	Juvenile	Low	Mod
LF7 Ocean acidity	Adult	Low	Mod

Adult WCVI Chinook returning to spawn also face stressors that may impact their spawning success. In order of priority, workshop participants ranked water temperature, local habitat availability and quality, plus dissolved oxygen as the highest risks for Adult salmon.

Risk associated with changing water temperature and oxygen (limiting factors 4-5) increased for both Juvenile and Adult salmon in the future. We learned that these conditions are often set up in the inner inlets in late summer – early fall. In Alberni Inlet, the bottom fiber mat may amplify these conditions.

For Juvenile Chinook, workshop discussion focussed on the ability of these fish to avoid or escape conditions of poor water quality. The spatial distribution of Juvenile Chinook in areas and times of poor water quality was identified as a knowledge gap.

Limiting factor 1 (carry-over effects from previous life stages) was rated high for the present and very high in the future for Juvenile salmon and moderate for both these periods for Adult salmon. Section 6 below describes how these results were interpreted considering work by others that suggests that it appears that getting a head start with rapid growth in fresh water is a major survival advantage, especially when marine productivity is low and/or competition is high. Carry-over effects can also relate to smolt readiness, loads and richness of freshwater pathogens, and toxin exposures from freshwater. More work on carry-over effects in relation to health and condition of hatchery releases, and, the importance of habitat and water quality factors, is being undertaken through a "Follow the Fish" initiative begun in 2022.

7.2.4 Agenda

Day 1

9:00 am	Welcome and today's plan. Marc LaBrie, facilitator, West Coast Aquatic
9:40 am	Introduce Limiting Factors. Jessica Hutchinson, Central West Coast Forest Society (CWFS): Review Risk Assessment Methodology for Salmon (RAMS) Methodology for Day 2 (Scoring), Life History Survival Model Review. Wilf Luedke, Jim Irvine, DFO
9:40 am	Follow the Fish – First marine Winter (Oct-March) (Marc Trudel)
	Morning Session 1: Water Properties Impacting WCVI Chinook
10:30 am	Open Ocean Water Properties. Maycira Costa, University of Victoria
10:45 am	Water Properties in Clayoquot Sound. Cheryl Greengrove, University of Washington
11:45 am	Questions and Discussion
	Afternoon Session 2: Changes to Physical Habitat Impacting WCVI Chinook
1:00 pm	Eelgrass Habitats and Threats in Coastal British Columbia. Jennifer Yakimishyn, Parks Canada
1:15 pm	Kelp Populations and Changes in Barkley Sound. Sam Starko, University of Victoria, and Chris Neufeld, Bamfield Marine Station
1:30 pm	Water-Based Log Handling Impacts to Marine Nearshore Habitats in WCVI Miranda Smith and Mike Wright, MC Wright & Associates
1:50 pm	Anthropogenic Pollutants Affecting Migratory Corridors. Capt. Josh Temple, Coastal Restoration Society
2:05 pm	Impacts of Invasive Green crab. Tom Therriault and Renny Talbot, DFO
2:20 pm	WCVI Marine Debris Standing Stock Assessment. Renny Talbot, Rugged Coast
2:35 pm	Physical Impacts from Salmon Aquaculture – Kerra Shaw (DFO)
2:50 pm	Questions and Discussion
	Afternoon Session 3
3:15 pm	Live Ocean Tool - Parker MacCready (UW), Seasonal and Interannual Changes in the Oceanography of WCVI Inlets – Rich Pawlowicz (UBC), Physical-chemical water properties in Alberni Inlet – Howard Stiff (DFO), The Power of Physiology

	when Characterizing a Fish's Resilience to Climate Change and its Health. Tony Farrell, University of British Columbia (Emeritus)
3:30 pm	Environmental Physical Impacts from Salmon Aquaculture Stress, and Stressor Resilience: What We Have Learned from Multi-stressor Challenge Studies. Kristi Miller, DFO
3:50 pm	Questions and Discussion
4:00 pm	General discussion and input from all participants
4:30 pm	Adjourn

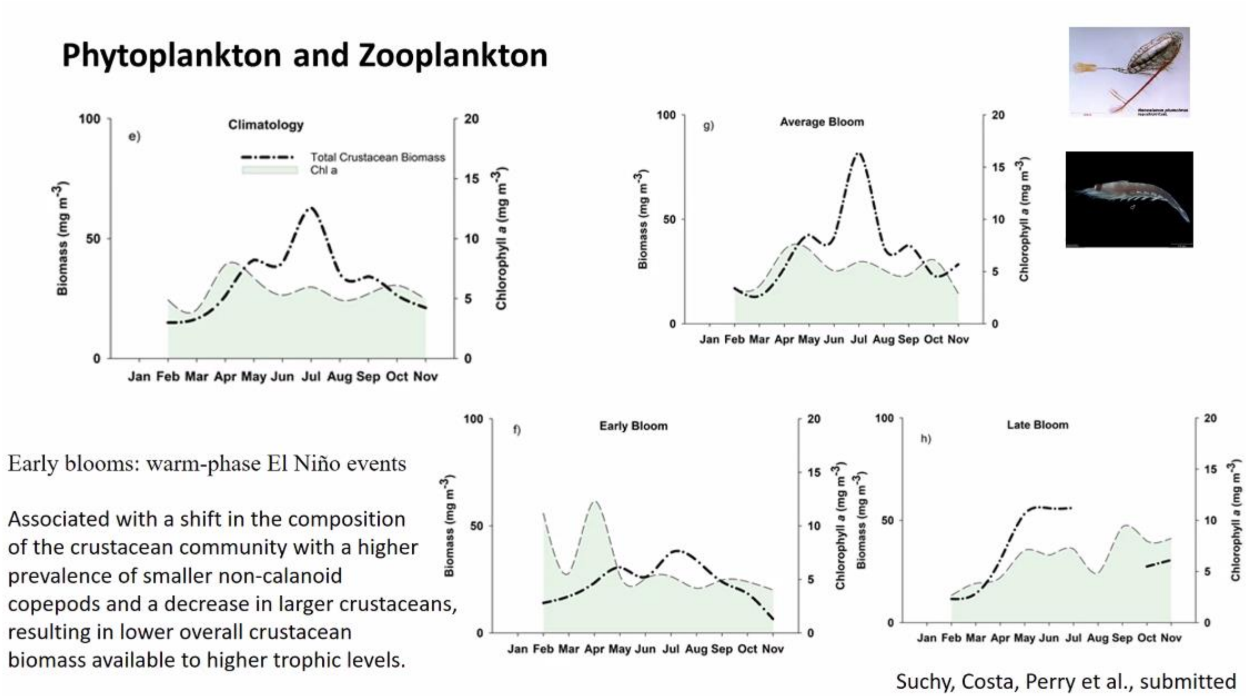
Day 2

9:00 am	Overview of Day 1, Discussion about the Limiting Factors presented on Day 1
9:45 am	Introduction to the Scoring Procedure (See RAMS overview document)
10:00 am	Begin scoring of Limiting Factors
1:30 pm	Risk Rating Committee and Day 1 Presenters: Review Scoring

7.2.5 Presentation and Discussion Highlights

Presentation 1 – Open Ocean Water Properties (Maycira Costa – University of Victoria)

- Spectral remote sensing laboratory – collaboration with PSF, etc. during Salish Sea Marine Survival Project. The focus is on Eelgrass, kelp, and ocean conditions. All the work that they do is large scale – through satellite or aerial photography.
- Eelgrass fragmentation has occurred over the last 100 years.
    - Decrease in area of eelgrass - average 41%. Average increase in shape index: 76%
- Kelp habitat and Juvenile salmon – can be challenging to monitor
    - Kelp forests had higher density of Juvenile chinook than non-kelp habitats. We have seen reductions in kelp distribution along the WCVI.
    - Warmer water temperatures contribute to kelp forest loss. Kelp abundance increases with colder temperatures.
- Phytoplankton and Zooplankton
- Match/mismatch hypothesis between fish size and timing of the zooplankton bloom. Interannual variations in zooplankton recruitment are evident. Phytoplankton bloom initiation tends to happen by the end of march in the Strait of Georgia. On WCVI, there are two phytoplankton blooms, one in the spring and one in the fall. Need more work on the timing and variability in relation to WCVI Chinook. Zooplankton graze on phytoplankton, so bloom timing affects zooplankton biomass and timing.



Presentation 2 – Water Properties in Clayoquot Sound (Cheryl Greengrove, University of Washington)

- Data collected throughout Clayoquot Sound and Effingham Inlet in Barkley Sound starting in 2000.
- Collecting: Temperature, salinity, density, oxygen, fluorescence, transmissivity, discrete samples of nutrients, phytoplankton, sediments, and surface microplastics.
- Wind is primarily along the coast, leading to upwelling and downwelling.
- Shallow sills at entrances to inlets
- Mixed Semi-diurnal tides with a range of 4.3m/14ft.
- PDO and ENSO significantly affect oceanography.
- Conclusion: All of these data can be used to evaluate whatever you want in terms of marine survival.

Presentation 3 – Live Ocean Tool (Parker MacCready, University of Washington)

- LiveOcean is a UW Seattle Research model that makes daily forecasts for the PNW and Salish Sea
    - 3-day forecast into the future.
    - 30 vertical layers, making it 3-Dimensional
    - Wind, HYCOM ocean fields, USGS and Canadian Rivers, TPXO Tides all go into the ROMS modeling system.
    - You can find the website by googling: liveocean.
    - NANOOS NVS Data Explorer is a useful web tool for exploring mapped models – nvs.nanoos.org/Explorer

Presentation 4 - Seasonal and Interannual Changes in the Oceanography of WCVI inlets (Rich Pawlowicz, University of British Columbia)

- Term definition re: oxygen in water
  - Anoxia – no oxygen – fatal
  - Hypoxia – still fatal for fish, 2mg/L
  - BC Water quality guidelines for DO in Marine and Estuarine waters is 8mg/L
- Seasonal Cycle
  - On the shelf, in the summer/early fall the 8mg/L line is close to the surface.
  - In Barkley Sound, there is frequently places/times where there is almost no water above 8mg/L
- How Upwelling works
  - Upwelling exists when longshore wind induces offshore surface water movement, drawing up deeper water.
  - Upwelling events are when inlets are flushed with new water
- Conclusions
  - Using hypoxia/anoxia as a benchmark is useful and interesting, but it may be more useful to understand variation in oxygen levels around 8mg/L in the upper water column as a biological performance indicator
  - There is a need for more study and monitoring to improve data collection and understanding of oceanography across WCVI.

Presentation 5 - Physical- Chemical water properties in Alberni Inlet (Howard Stiff, DFO)

- Are Ocean climate factors overwhelming industrial effluent impacts on Inlet D.O.?
  - The presentation was developed for Sockeye, but has applicability to Chinook
  - Temperature, salinity, and Oxygen are pretty much stable from 10m down to bottom. Salmon tend to migrate above that and hold below that.
- Oceanography.
  - There are sills at Sproat Narrows and Stamp Narrows, and an outer sill in Trevor Channel. There is a 'drop-off' at Polly's Point in the inner inlet 'harbour' area.
  - In the Somass River, water temperatures greater than 19-20 degrees C act as a "thermal barrier" to sockeye migration.
  - In the outer estuary and inner inlet, in July-August, water quality deteriorates from high surface / near surface temperatures and low dissolved oxygen lower in the water column. The latter is created by low sub-halocline mixing rates and low dissolved oxygen, likely from Biological Oxygen Demand from industrial effluents. The result is sockeye pooling for extended periods in poor water quality in the inner Inlet; causing stress.
  - Oxygen appears to always be an issue for holding Sockeye in Alberni Inlet. Mean July-August DO:
    - We saw a 4mg/L decline in DO since the 1940s. Since the 90s we are seeing improvement but much greater variability.

        - Temperature-oxygen squeeze – on warm years, fish need to go deeper to get cooler water, but dissolved oxygen is more concentrated on the surface.
    - Chinook come in later in late August through early October, when river water is cooling and inlet conditions are improving, in most years. The inlet is being renewed at least once every year.
- Conclusion:
    - High variability of upper inlet DO conditions long after mill effluent improvement indicate that there are other factors driving DO concentrations than just mill effluent biological oxygen demand

Presentation 6 - Eelgrass Habitats and Threats in Coastal British Columbia (Jennifer Yakimyshin, Parks Canada)

- Where does eelgrass grow - Sandy, muddy sediment types, sheltered water, 10-20 degrees C is ideal, salinity tolerance from 10-35 ppt, depth range from 0-5m, but can be deeper if water is clear
- Eelgrass Ecosystem Services
    - Creates a critical coastal habitat.
- Parks Canada has a variety of eelgrass sampling sites.
    - 409 marine and anadromous fish species recognized in BC.
    - 108 marine and 5 anadromous fish found in these study sites.
    - Coho and Cutthroat are most of the salmonids found in these sites.
- Influence of marine heatwaves on eelgrass fish
    - Nearshore fish species respond very differently than continental shelf species to marine heat waves.
    - The temporal lag in CPUE is 1-2 years from Marine Heat Wave.
    - Spatial variations in response. Barkley vs Clayoquot fish communities experienced this differently.
- Threats to Eelgrass
    - Threats that limit light or physical disturbance are the main concern.
    - Threats and their severity must be considered in the face of climate change
        - Increased freshwater runoff
        - Shift in algal blooms earlier in season
        - Alterations in Marine nutrient input
        - Early growth of smothering algal species such as Ulva
        - Increased epiphytic growth – algae that grows on the leaves
        - Wasting disease – a protein that has had huge impacts on the Atlantic coast.
    - WCVI Threats
        - Sediment aggradation in estuaries
        - Sedimentation from adjacent land-use activities
        - Shading (i.e. from docks or moorings)

        - Physical disturbance or trampling from repetitive activities
        - Invasive species: European green crabs.
    - Other threats
        - Dredging/trawling/infilling/marina development
        - Shoreline hardening
        - Pollution
        - Aquaculture gear on eelgrass (physical disturbance/shading)

Presentation 7 - Impacts of recent warming on WCVI's kelp forest habitats (Sam Starko, University of Victoria, and Chris Neufeld, Bamfield Marine Station)

- Kelp forests are sensitive to marine heatwaves. Observed in Australia and here in BC
- Kelp like cooler water, with inshore water (i.e. inlets) being more sensitive to temperature changes
- Bamfield Marine Sciences Centre has been looking at giant kelp and bull kelp distribution in outer Barkley Sound.
    - 40% of kelp forests have been lost in Barkley Sound.
    - The loss of kelp is from areas further into Barkley Sound. The closer to the Alberni Inlet the worse kelp is doing.
    - Inshore sites have declined relative to all time points.
    - Some forests have persisted, there may be refugia.
        - Refugial forests are below the thermocline. Some kelp even stay laterally along the bottom rather than extend upwards.
- Sand/sediment excludes urchins and enables deep refugial forests. Warmer surface waters are pushing kelp down deeper but are being eaten by urchins at the lower level.
- Need to understand how refugia play a role in re-establishing populations.
- There are no otters in Barkley Sound to eat urchins.

Presentation 8 - Water-based log handling impacts to marine nearshore habitats on WCVI (Miranda Smith and Mike Wright, M.C. Wright and Associates)

- Impacts from water-based log handling?
    - Deposition of fine, coarse, and Large woody debris in intertidal and subtidal habitats.
    - Burial of natural habitats and infaunal species depression
    - Impacts of as little as 1cm of deposition can adversely affect suspension feeders
    - Reduced DO levels and presence of bacteria mats.
    - Single stem storage caused a lot of sunk logs.
    - Impacts from historical footprints can last decades, up to centuries.
    - Historical log dump footprint a minimum of 10-15 ha
    - Foreshore often built up to get the right angle for log dumps.
- Water-based log handling is still a critical component (80% of wood felled today is sorted or transported in water.
    - Active steps being taken towards improved mitigation measures, a reduction in footprints, and remediation.

    - Partnership opportunities for remediation work in excellent candidate sites.
- Siting mitigation measures
    - Where possible, direct-to barge operations are encouraged.
    - No new dump construction in sensitive estuaries (i.e. estuaries, boot and cloud sponge walls).
    - Operations strongly encouraged to remain within the footprint of historical operations.
- Upland mitigation measures
    - Designed to get bark off before water or not at all
- In-water mitigation measures
    - Some measures to collect woody debris
- Restoration opportunities
    - Identification of historical foreshore infill areas no longer required to support operations
    - Eelgrass transplants
    - Artificial reef construction
        - Find areas of historical log handling footprints and introduce rocks to add complexity and cover.
    - Kelp propagation
        - Habitat offset for new dump construction. Project to assess if this could be a remediation tool for the forestry sector.
        - Can inoculate gravel and release into barren areas
        - Can propagate via baskets with gravel

Presentation 9 – Anthropogenic pollutants affecting migratory corridors (Captain Josh Temple, Coastal Restoration Society)

- Sources of Contaminants
    - Land-based – Agriculture, urban development, industry, stormwater
    - Marine-based – Oil spills, abandoned vessels, aquaculture, ghost gear
- Effects of marine pollutants – Altered behaviour, metabolic dysfunction, impaired immune function, increased disease susceptibility
- Persistent organic pollutants
    - Found from point source pollution, things like tire compounds and hydrocarbons
- Metals – can be significant pollutants from derelict vessels
- Petroleum hydrocarbons – have long residency in water and soil
- Plastics and microplastics
    - WCVI at the end of a large conveyor belt that brings pacific garbage to WCVI coast
    - Juvenile salmon eat a lot of microplastics confusing them for prey.

Presentation 10 – WCVI European Green Crab Distribution, Impacts and Management (Tom Therriault and Renny Talbo, DFO)

- European Green Crab (EGC) was found all throughout WCVI during the first survey in 2006. Now EGC exists throughout southern Salish Seam WCVI, Central Coast and Haida Gwaii.
- Too early in the colonization event to consider EGC naturalized in BC
- EGC potential impacts
  - Potentially significant impacts on smaller shellfish in BC
  - Outcompeting native crabs – almost all crabs in Barkley Sound are EGC
  - Significant devastation of eelgrass by EGC
- DFO Aquatic Invasive Species Program – small team starting in 2007
  - Coordinates AIS management actions, regulatory implementation etc.
  - Focus has been on the most cost-effective management during early stages of invasion

Presentation 11 – WCVI Marine Debris Standing Stock Assessment (Renny Talbot, Rugged Coast)

- Rugged Coast is a Nanaimo based registered charity created to help fill data gaps and aid restoration of remote habitats.
- Approximately 750km of shoreline surveyed between Barkley Sound and Hunter Island. The highest accumulation of debris occurs on southern facing low elevation beaches such as Brooks peninsula, Estevan point, and Guise Bay. International and Domestic debris found. Debris includes fishing debris: net, floats, rope, etc.; Plastic debris; Bottles and jugs.
- The primary issue with debris is ingestion by fish or birds. Plastic can be a binding site for Persistent organic pollutants, causing toxicant transfer.
- Marine debris will continue to be an issue on our coast
- Removal of macroplastics will aid stress reduction on Chinook.

Presentations 12 & 13. – Impact of Anthropogenic Changes to Light/Noise in WCVI Sounds, Physical Impact of Salmon Aquaculture (Kerra Shaw, DFO)

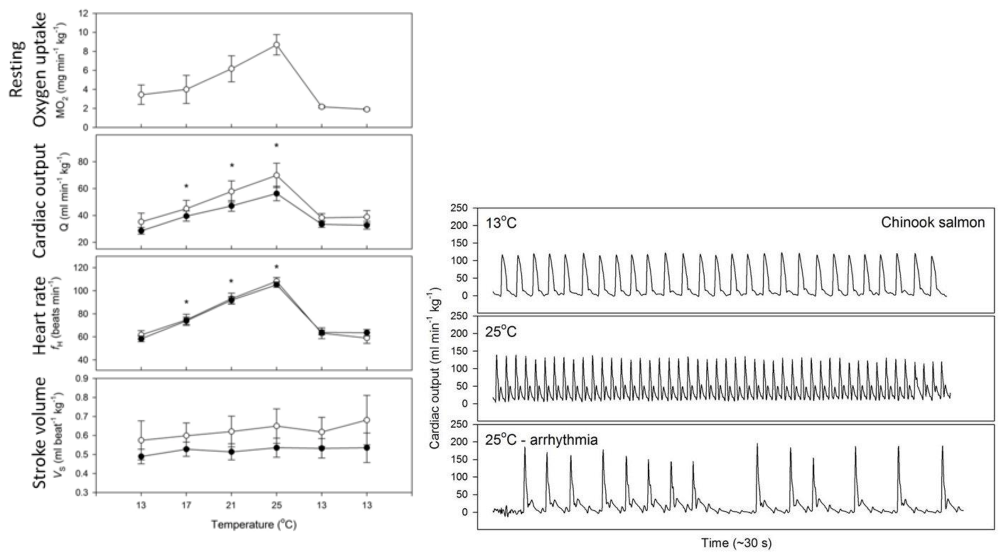
- There has been salmon farming in BC for 40 years and accompanying 40 years of research.
- Currently 48 licensed finfish farms on WCVI, 34 of which are active.
  - 3 licensed farms in Barkley Sound, none are active
  - 21 in Clayoquot Sound, 20 are active
  - 10 in Nootka/Esperanza Sound(s), 8 are active
  - 6 licensed farms in Quatsino Sound, 4 are active
  - 4 licensed farms in Kyuquot Sound, 2 active and grow sablefish.
- Most farms are in water deeper than 50m and can be as deep as 200m. Most farms are over 50m away from shore, providing a buffer away from the intertidal area, where many sensitive habitats are located.

- DFO Site Application Assessment; DFO assesses a site for proximity to the following:
    - Salmonid-bearing streams and important salmon use areas. Sites must be more than 1km from estuaries.
    - Vital, major, or high importance areas such as wild shellfish beds
    - Sensitive fish habitat: e.g., glass sponge reefs, rockfish nurseries, eelgrass, or kelp beds
    - Areas used extensively by marine mammals
    - SARA-listed species; typically Northern abalone
    - Other wild fish species and their habitats
- Benthic Impact
    - Benthic monitoring is necessary because one of the most direct impacts of fish farms is organic waste from fecal matter. Benthic organic waste can reduce the habitat quality on the seabed. These days, there is much less food waste from fish pellets.
    - DEPOMOD is a model used to predict the 'worst case' impacts to sea floor before a farm is installed.
    - Soft bottom monitoring requirements include sediment sampling and analysis.
    - Hard bottom monitoring requirements: Remote Underwater Vehicle operation is required for visual inspection. Beggiatoa is a bacteria that is white that forms on fecal mats
    - 100% of farms must monitor their benthic impacts. Usually approximately 80-90% stay under all their thresholds and can restock with fish. If you don't meet your compliance thresholds, you must fallow (unstock) your farm and revise.
- Use of underwater lights
    - Underwater lights are used to delay the start of sexual maturation to improve meat quality.
        - Possible impacts include: Light can be an attractant or deterrent, Attracted fish may enter cages, Could affect predation.
- Farm fish predation of wild fish
    - Sampling of farmed fish for predation of Juvenile wild fish. 11 wild fish were found in 14,100 farmed salmon stomachs. Prevalence of 0.08%. Chinook ate more than Atlantic. Of the 11 fish, 10 were confirmed as pacific herring, 1 unknown.
    - Was predation different when lights were on or not? Lights did not seem to make a difference to predation. Lights are not used in Chinook farms.
- Noise. Acoustic deterrents were banned in the early 2000s. The sites now just produce noise from generators and engines.

Presentation 14 – The power of physiology when characterizing a fish. Tony Farrell (UBC)

- It is clear that there is a rank order of environmental risk directly impacting fish.
    - Temperature and DO > Temperature > DO > Acidity > Salinity.

- But data are insufficient to make reliable risk predictions of the level of impact on a fish. The following are key mechanisms affecting cardiorespiratory performance and health.
    - O2 uptake is a reliable predictor of Cardiorespiratory performance of fish. When an Adult fish swims faster, it consumes exponentially more oxygen. Different populations within a species have different aerobic scope. Fraser sockeye use oxygen faster than coho. The further the river migration, the greater the aerobic scope. The faster the river, the greater the heart's pumping capacity. Most work has been done on Sockeye, but Chinook seem to be approximately similar in characteristics.
    - Arrhythmia is another aspect of cardiorespiratory performance. It can be too warm for a salmon's heart, especially around 25 degrees C, causing arrhythmia.
    - Hypoxia tolerance can be measured. Fish progressively exposed to hypoxia will eventually lose equilibrium and roll over.



- Risk Assessments are challenging. Percentage likelihood of risk is not always correlated with experience/reality by the fish. In conclusion, new knowledge must be generated on biologically relevant impacts on Chinook salmon of changing environmental conditions such as temperature and hypoxia, microbial pathogens etc. Potentially at population and life stage levels.

Presentation 15 – Environmental stress and stressor resilience: What we have learned from multi-stressor challenge studies (Kristi Miller, DFO)

- We have the next generation tools to study cumulative impacts of stressors and disease in salmon. Using genomics to assess cumulative environmental stressors. How do we actually know that salmon in the wild are being stressed by the stressors we know can have impacts from the lab?
    - Salmon Fit-Chips
        - Based on curated biomarker panels co-activated under specific stressor responses/disease states in non-lethal gill biopsy samples;

        - Microfluidics quantitative PCR technology
        - Transcriptome data mined to identify biomarker panels predictive of disease and stressor states, followed by multi-stressor challenge studies to refine biomarkers and develop Random Forest Classifiers to recognize specific stressor/disease states;
        - Includes a biomarker panel that can recognize fish becoming moribund (high likelihood of natural death within 24-48 hours) p
- Multi-stressor challenge trials to validate biomarkers also uncovered relationships between stressors and survival
    - Coho trial indicated that there may be a synergistic effect of impacts from salinity, temperature, and oxygen.
        - With Chinook, there was only a synergistic effect when all three stressors were present.
    - Thermal Stress Response and recovery
        - Wild fish may remain stressed even if they move in and out of high temperature waters.
            - 3-day recovery from 18C, 2-day recovery from 14C (to a 10C thermal state)
- Migratory Juvenile sockeye findings from Fraser River stocks tracked over first 6 weeks of ocean residence
    - Thermal stress is dominant stressor observed, highly correlated with SST revealing that while sockeye could avoid warm surface waters by moving lower into the water column, feeding opportunities at the surface may take precedence over protection from thermal stress.
    - Salinity (osmotic) stress is highly correlated with imminent mortality (morbidity) across seasons and years, as it was in multi-stressor challenge studies
    - However, salinity stress and imminent mortality are highest as fish move from natal rearing areas to the ocean.
- Can we mitigate salinity stress to increase survival?
    - We would need to identify potential sources
        - Disruption in smoltification
        - Infection of gill or kidney tissue
        - Wounding and infection/ulcers on skin
- In many cases, we can’t control the environments that the fish live in, but we can influence the condition of hatchery releases to ensure they are optimally smolted and carry limited infections/disease

7.2.6 Workshop Synthesis

7.2.6.1 Distribution Plots and Comment Summaries

Distribution plots follow sequentially for Juvenile (1st marine year) and Adult (subsequent life history until fish return to freshwater) salmon starting with LF1. Although risk was assessed for both naturally produced Chinook and those of hatchery-origin, we do not present the latter since there was agreement that effects on hatchery fish would either be lowest, or not important to this discussion. Numbers of individuals who did not rate a particular LF were recorded. Workshop participants were encouraged to input comments as they evaluated each relevant LF and LS; summaries are provided below.

Workshop results were tabulated and basic statistics (e.g., mean, median, mode, range, and standard deviation) computed for each LF and LS. These statistics were frequently inadequate due to small sample sizes and skewed statistical distributions. To help interpret these frequency distributions, a small team met during March 2023 and developed single consensus Review Scores for each of Likelihood, Impact, Future Trend, and Confidence. A brief comparison between consensus Review and Mean Scores follows in 6.2.

Here we briefly describe the distribution results for only the first example (Figure 7.1, LF1, Juvenile salmon). The same approach was used for all LFs. Refer to the Methods Section in the main report (i.e., before Appendices) for more detailed descriptions.

Each LF and LS has six distribution plots:

- Likelihood, Impact, and Future Trend (top row).
- Participant's Confidence in their scoring, Current Risk, and Future Risk (over the next 30 years (2nd row).

The plots in the first row and the left-hand plot in the second row of Figure 7.1 display score distributions as well as consensus Group Scores; i.e., Review Scores for Likelihood (upper left plot) was 4, Impact (upper middle plot) was 3, Future Trend (upper right plot) was 4, and Confidence (lower left-hand plot) was 2 (Moderate).

Risk matrices were applied to determine Current and Future Risk distributions and single risk category review results based on the scores for Impact, Likelihood and Current Impact, Future Trend respectively. For details, see the text in the main RAMS methods section earlier in this report.

LF1: Mortality or fitness reduction due to carry-over impacts from previous life-history phase. The hypothesis is that carry-over effects result in reduced growth, survival and/or fitness.

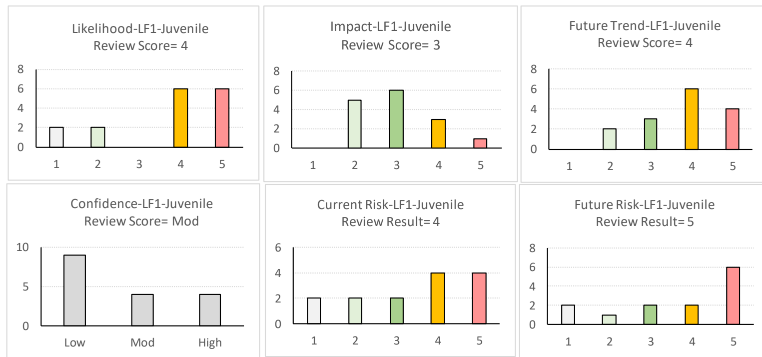


Figure 7.1 **Frequency distribution plots of participant scores by Limiting Factor and Life Stage for Likelihood, Impact, Future Trend, and Confidence. Review scores are based on a group consensus review of these plots. Current and Future Risks and associated frequency distribution plots and Review Scores are calculated based on risk matrices (see Methods in Main report). If n<4, then confidence=low (i.e., 1) regardless of distribution.**

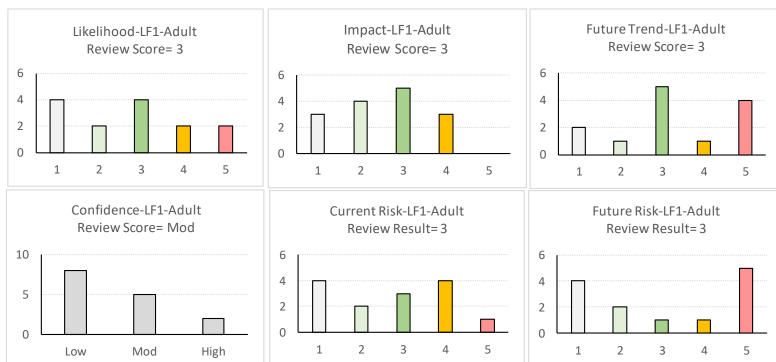


Figure 7.2 **Frequency distribution plots of participant scores by Limiting Factor and Life Stage for Likelihood, Impact, Future Trend, and Confidence. Review scores are based on a group consensus review of these plots. Current and Future Risks and associated frequency distribution plots and Review Scores are calculated based on risk matrices (see Methods in Main report). If n<4, then confidence=low (i.e., 1) regardless of distribution.**

To supplement LF1 (Carry Over effect) distribution results, we describe findings from a pertinent presentation at Workshop 1 by Trudel as well as two relevant studies that examined scale growth patterns. Trudel commented that for a period such as the early marine life to be considered critical, it is necessary to show a correlation between survival at that stage and total survival. This has not been done for WCVI Chinook. Campbell and Claibourne (2016) found that size at ocean entry of returning Puget Sound Chinook varied among years with fish that left as 30-60 mm "fry" constituting a significant proportion of returns in some years and being absent in other years. In a separate study, Ruggerone et al. (2009) found that scale growth during each life stage for Yukon River (Alaska) Chinook was significantly correlated with growth during the previous year (i.e., 1st marine growth year vs. freshwater growth; 2nd marine year vs. 1st marine year, etc.). Campbell and Claibourne's study demonstrated that small fish (i.e., fry) entering the ocean can sometimes be important contributors to the next generation although fish that had left freshwater as larger smolts always made up the majority of fish surviving to Adulthood. The latter study suggests that slow-growing fish remain slow-growing for their entire lives. In summary, it appears that getting a head start with rapid growth in fresh water is a major survival advantage, especially when marine productivity is low and/or competition is high.

Workshop participants reported that river basins with large portions of the estuary intact were most likely to exhibit a fry life history in their returning Adults. This has potentially major implications for habitat restoration and recovery efforts. This work supports the idea that increased habitat capacity for a given life stage will benefit population abundance.

LF1 Summary of Comments:

- The focus should be on naturally produced young-of-year (y-o-y) Chinook that tend to be smaller than hatchery fish and likely have different mortality issues such as predation.
- Epigenetic effects need study; such as carry over effects from smaller Adults -> smaller eggs -> smaller fry -> poor survival at sea.
- Lack of rearing in rivers is seen as a major risk leading to poor early marine survival.
- GAP: need otolith micro-chemistry results to see if size is a determining factor in survival. One participant has proposals for estuary sampling by tide and depth – with most samples in the Bedwell estuary coming near the drop-off.

LF 2. Mortality or fitness reduction due to degraded habitat quality. The hypothesis is reduced or degraded habitat quality results in reduced growth, survival and/or fitness.

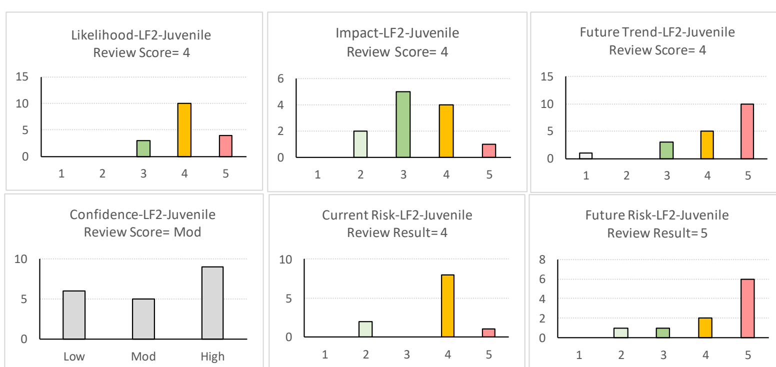


Figure 7.3 **Frequency distribution plots of participant scores by Limiting Factor and Life Stage for Likelihood, Impact, Future Trend, and Confidence. Review scores are based on a group consensus review of these plots. Current and Future Risks and associated frequency distribution plots and Review Scores are calculated based on risk matrices (see Methods in Main report). If n<4, then confidence=low (i.e., 1) regardless of distribution.**

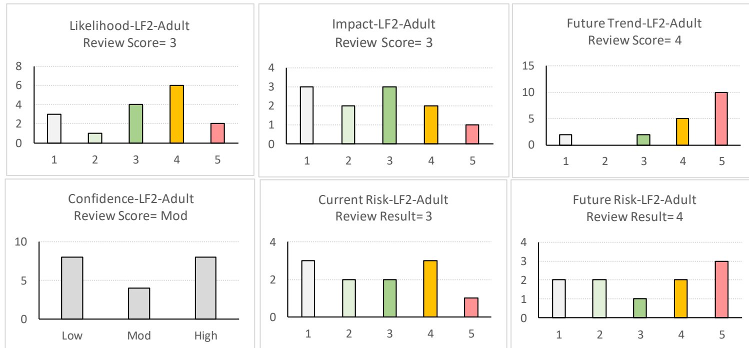


Figure 7.4 **Frequency distribution plots of participant scores by Limiting Factor and Life Stage for Likelihood, Impact, Future Trend, and Confidence. Review scores are based on a group consensus review of these plots. Current and Future Risks and associated frequency distribution plots and Review Scores are calculated based on risk matrices (see Methods in Main report). If n<4, then confidence=low (i.e., 1) regardless of distribution.**

Possible mechanisms discussed included ecosystem damage, degradation, climate change, infrastructure (aquaculture facilities, dock, log booms), dredging, invasive species (green crab), range expansion, microplastics, shipping traffic, lights, sound. Technical and local knowledge described key changes in the nearshore habitats since 1990, especially kelp, grasses, and impacts from invasive species such as Green Crab.

LF2 Comment summary:

- The greatest effect on the first spring-summer at sea is in the near shore environment; much less effect on older ages. For April-June period it is important to understand the relative distribution of wild and hatchery young of year (y-o-y).
- Multiple comments on lack of info on change in distribution and density of kelp forests in nearshore marine or complexity of estuaries (e.g., eel or sedge grasses) along the WCVI as key habitat for wild Juveniles entering the sea.
- Habitat loss for wild y-o-y seems very location-specific. Should we expect more variation among populations? Several comments that a big change in estuary and nearshore habitat may be occurring because of green crab abundance.
- Logging related impacts such as Wright's presentation on log dumps might have an effect but doesn't seem an extensive issue compared to estuary and kelp forest habitat.
- Comments on micro-plastics in the literature suggest limited ingestion and rapid removal from stomach by Chinook (see Collicutt et al. 2019; Spanjer et al. 2020).
- Agreement that low DO and high water temp in the head of Alberni Inlet is causing stress for Sockeye. Maybe not as much for Chinook later in the season. Described mitigation measures in the head of Alberni Inlet – diffusers at depth.
- GAP. Lack of info on distribution of y-o-y Chinook in relation to environment and habitat to say anything definitive about causal mechanisms. Multiple factors may be involved (see Hyatt et al. 2015; Stiff et al. 2018).

- KEY issues.   Kelp forest, eel and sedge grass abundance, green crab, fragmentation of habitat by nearshore development, pollution such as micro-plastics/sewage including aquaculture/ etc.
- MITIGATION OPTIONS.   Green crab control. Improve aquaculture siting criteria in relation to complex habitat for y-o-y Chinook such as eel grass, kelp, where currents/tides create local 'upwelling' perhaps through DEPOMOD.

LF3: Mortality or fitness reduction due to reduced habitat availability or connectivity. The hypothesis is reduced or degraded habitat availability or connectivity results in reduced growth, survival and/or fitness.

Figure 7.5 **Frequency distribution plots of participant scores by Limiting Factor and Life Stage for Likelihood, Impact, Future Trend, and Confidence. Review scores are based on a group consensus review of these plots. Current and Future Risks and associated frequency distribution plots and Review Scores are calculated based on risk matrices (see Methods in Main report). If n<4, then confidence=low (i.e. 1) regardless of distribution.**

Figure 7.6 **Frequency distribution plots of participant scores by Limiting Factor and Life Stage for Likelihood, Impact, Future Trend, and Confidence. Review scores are based on a group consensus review of these plots. Current and Future Risks and associated frequency distribution plots and Review Scores are calculated based on risk matrices (see Methods in Main report). If n<4, then confidence=low (i.e., 1) regardless of distribution.**

LF3 Comments Summary:

General Summary:

- Lack of direct data about impact of habitat connectivity seen as a data gap - Data gaps on full extent of subtidal impacts needs to be quantified
- Habitat loss, particularly kelp forests, perceived as having a high impact on Chinook survival
- Kelp beds, eelgrass and nearshore habitat all seen to be reducing over time, and this lack of habitat is impacting Chinook survival, although there is not any research directly showing the link between habitat loss and Chinook survival. The presumption though is that you cannot run if you cannot hide.
- Thick mats of logging detritus seem to be impacting physical space and water quality relied upon by Juvenile salmon – Needs more data collection to determine extent of remediation effort required

LF4: Mortality or fitness reduction due to direct impacts of water temperatures. The hypothesis is that temperature changes result in reduced growth, survival and/or fitness.

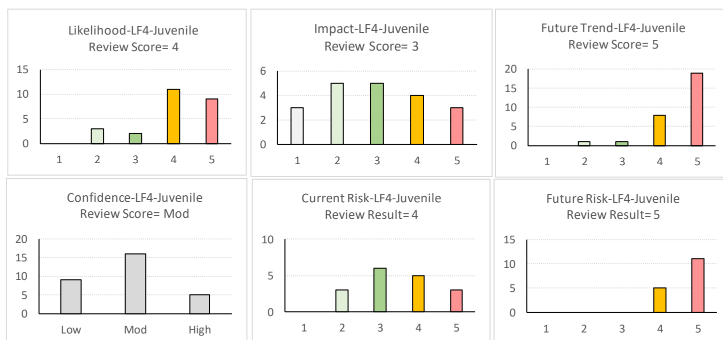


Figure 7.7 **Frequency distribution plots of participant scores by Limiting Factor and Life Stage for Likelihood, Impact, Future Trend, and Confidence. Review scores are based on a group consensus review of these plots. Current and Future Risks and associated frequency distribution plots and Review Scores are calculated based on risk matrices (see Methods in Main report). If n<4, then confidence=low (i.e., 1) regardless of distribution.**

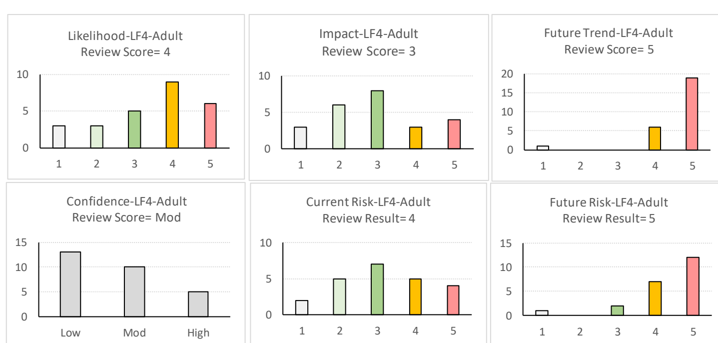


Figure 7.8 **Frequency distribution plots of participant scores by Limiting Factor and Life Stage for Likelihood, Impact, Future Trend, and Confidence. Review scores are based on a group consensus review of these plots. Current and Future Risks and associated frequency distribution plots and Review Scores are calculated based on risk matrices (see Methods in Main report). If n<4, then confidence=low (i.e., 1) regardless of distribution.**

Potential mechanisms include extremes, variability, climate change, currents, habitat alteration, oceanography, upwelling, El Niño years, La Niña years, marine heatwaves, wind, precipitation, bathymetry, tides. A key aspect of water quality was that the combination of high temperature and low DO together posed the highest risk, creating stress on young fish, which could lead to higher vulnerability to subsequent risks (cumulative effects).

LF 4 Comments Summary:

General Summary - Juveniles:

- Participants recognize that increasing water temperature will increase stress on salmon, especially as Juveniles in their rearing streams
- Feel like there is a lack of information about how this increasing temperature will combine with other oceanographic changes like dissolved oxygen (DO) and salinity.
- If Juvenile salmon experience high water temperatures while they are still using nearshore environments, they have no way to escape, and will be affected by thermal stress if temperatures are high. If this occurs during a prolonged period of time, thermal stress can directly cause mortality, but it can also indirectly affect fish by increasing pathogen risks, changing the prey field, reducing their ability to evade predators, etc.
- Risk of LF4 is generally perceived to be increasing due to climate change.
- Research data suggests, however, that sockeye in both FW and SW are still affected by surface temperatures, even when they are diurnally migrating in and out of high temperature environments. Challenge studies show that thermal stress from exposure to 18 degree or higher water can take several days to recover from, so if fish are spending half of their time near surface, they may be continuously stressed. This is an area we need more specific data from Chinook for--something that we will follow up with salmon Fit-Chips.
- Data gap on where the 0-1yr chinook are found in the nearshore habitat and unknown how habitat use, and temperature differ between sounds. It is unknown how the temperature impacts Chinook survival. Climate change will substantially increase temperatures in the future, even with/if mitigations are implemented today.
- Data Gap: Where are Chinook spending most of their time, especially as Juveniles? Are they able to avoid high water temperatures when they occur?

General Summary -Adult:

- Participants had low confidence in this ranking
- Risk to Adults perceived as lower than Juveniles, as Adults spend more of their time in deeper, cooler waters, and are more easily able to move away from stressful water temperatures.
- Participants believe that temperature changes over time will impact chinook distribution along WCVI.

- Comments about increased risk in the future, as water temperature continues to rise there may be decoupling of Adult migration and plankton blooms as water temperature increases
- Concern about return migrating salmon hitting temperature barriers if inlets or section so rivers get too warm.

LF5: Mortality or fitness reduction due to direct impacts of hypoxia or dissolved oxygen levels.

The hypothesis is that hypoxia results in reduced survival, growth and/or fitness.

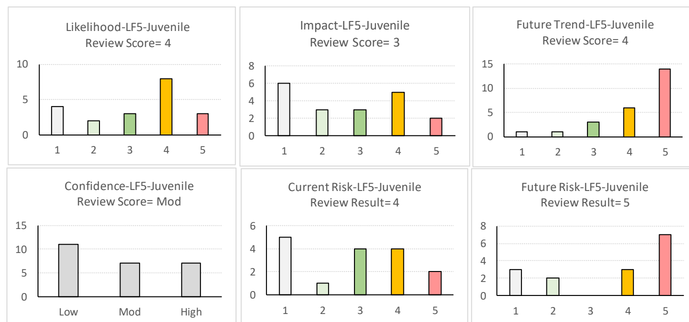


Figure 7.9 **Frequency distribution plots of participant scores by Limiting Factor and Life Stage for Likelihood, Impact, Future Trend, and Confidence. Review scores are based on a group consensus review of these plots. Current and Future Risks and associated frequency distribution plots and Review Scores are calculated based on risk matrices (see Methods in Main report). If n<4, then confidence=low (i.e., 1) regardless of distribution.**

Figure 7.10 **Frequency distribution plots of participant scores by Limiting Factor and Life Stage for Likelihood, Impact, Future Trend, and Confidence. Review scores are based on a group consensus review of these plots. Current and Future Risks and associated frequency distribution plots and Review Scores are calculated based on risk matrices (see Methods in Main report). If n<4, then confidence=low (i.e., 1) regardless of distribution.**

LF5 Comments Summary

General Summary – Juveniles

- Data on impact of hypoxia is limited for Chinook salmon, but generally perceived to not be a majorly limiting factor, due to the fact that hypoxia is extremely spatially and temporally restricted.

- Risk is seen as higher for young Chinook, as there are many areas where young Chinook experience low oxygen environments
- Participants see DO and hypoxia to be a cumulative impact with other water quality factors, such as temperature, and that these water quality factors will increase in risk over time with climate change.

General Summary – Adults:

- Data appear limited, and the extent to which Adult Chinook experience low oxygen environments is unknown.
- Participants are unsure with their ranking of the LF and life stage
- Overall impacted of DO and hypoxia is expected to increase over time with climate change
- Specific to upper Alberni inlet – DO seems to limit Adult return migration during harsh years. Thermal and DO barriers impact Sockeye, and early Chinook return migration. See Stiff et al. (2018), Thomson & Krassovski (2015) and Stone et al 2018 for more info

LF6: Mortality or fitness reduction due to direct impacts of changes to salinity. The hypothesis is that changes in salinity result in reduced growth, survival and/or fitness.

Figure 7.11 **Frequency distribution plots of participant scores by Limiting Factor and Life Stage for Likelihood, Impact, Future Trend, and Confidence. Review scores are based on a group consensus review of these plots. Current and Future Risks and associated frequency distribution plots and Review Scores are calculated based on risk matrices (see Methods in Main report). If n<4, then confidence=low (i.e., 1) regardless of distribution.**

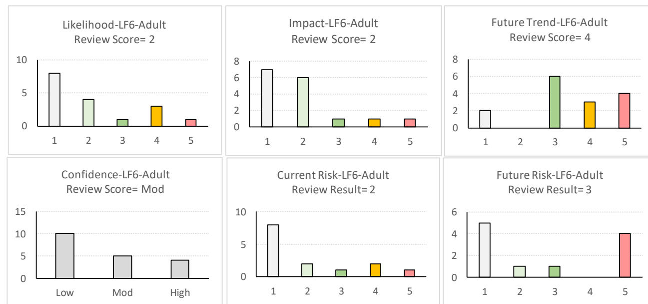


Figure 7.12 **Frequency distribution plots of participant scores by Limiting Factor and Life Stage for Likelihood, Impact, Future Trend, and Confidence. Review scores are based on a group consensus review of these plots. Current and Future Risks and associated frequency distribution plots and Review Scores are calculated based on risk matrices (see Methods in Main report). If n<4, then confidence=low (i.e. 1) regardless of distribution.**

LF 6 Commentary – Naturally Produced Juveniles

General Summary – All Life Stage:

- Data appears limited, and participants are unsure of impacts
- Expect that the impact would be higher for Juveniles than Adults
- This LF has the potential to increase in impact over time through cumulative impact of all water quality factors, such as temperature, dissolved oxygen, and ocean acidification.

LF7: Mortality or fitness reduction due to direct impacts of changes to ocean acidity. The hypothesis is that ocean acidity changes result in reduced growth, survival and/or fitness.

Figure 7.13 **Frequency distribution plots of participant scores by Limiting Factor and Life Stage for Likelihood, Impact, Future Trend, and Confidence. Review scores are based on a group consensus review of these plots. Current and Future Risks and associated frequency distribution plots and Review Scores are calculated based on risk matrices (see Methods in Main report). If n<4, then confidence=low (i.e., 1) regardless of distribution.**

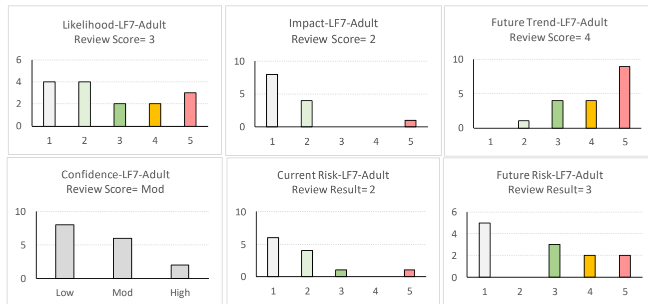


Figure 7.14 **Frequency distribution plots of participant scores by Limiting Factor and Life Stage for Likelihood, Impact, Future Trend, and Confidence. Review scores are based on a group consensus review of these plots. Current and Future Risks and associated frequency distribution plots and Review Scores are calculated based on risk matrices (see Methods in Main report). If n<4, then confidence=low (i.e. 1) regardless of distribution.**

LF 7 Comments Summary

General Summary – All Life Stages:

- Participants felt that ocean acidity likely wouldn't increase to a level that would exceed the physiological limits of salmon but may have negative impacts on the food web in the future.
- This limiting factor was challenging for participants to tease apart from other water quality limiting factors

7.2.6.2 Ranked Risks

To rank the relative risk of different LF's, results for all LFs were sorted first by Group Current Risk Review Result, then Group Future Risk Group Result, and finally by a percent current risk high score, the percentage of participants' scores that led to a current risk score of high or very high as shown (Table 7.3). Here we included statistical mean values for Future Risk (Mean FRisk) alongside the values computed as described above.

Correlations between Future Risk Scores and statistical mean Future Risk (FRisk) Scores were not significant (R^2=0.14; p=0.22) and risk categorizations using these approaches varied (Table 7.3). For example, of the seven LFs rated as Very High for Future Risk, only two of these would be Very High (i.e., 5) if we used Mean Values (LFs 4 Juv and Adult), while four would be High (i.e., 4; LF2 Juv, LF1 Juv, LF3 Juv, and LF5 Juv), and one would be Moderate (LF3 Adult). We remained most confident in the Group review group rankings, which form the basis for our analysis and discussion below.

Table 7.3 **Ranked (high to low) current and future risk rankings for limiting factors (LFs) considered during Workshop 2.**

		Group review		Participant score statistics										
Limiting Factor	**Life Stage**	Likelihood Score	Impact Score	Future Trend Score	Confidence Score 1-3	Current Risk Score 1-5	Future Risk Score 1-5	Mean FRisk Score	Reviewed Confidence	**Review Result Current Risk**	**Review Result Future Risk**	Current Risk % High	Future Risk % High	Confidence % Low
LF2 Local habitat quality	Juvenile	4	4	4	2	4	5	4	Mod	High	Very High	82%	80%	30%
LF1 Carry-over impacts	Juvenile	4	3	4	2	4	5	4	Mod	High	Very High	57%	62%	53%
LF3 Local habitat availability	Juvenile	4	3	4	2	4	5	4	Mod	High	Very High	50%	83%	50%
LF4 Local water temperature	Juvenile	4	3	5	2	4	5	5	Mod	High	Very High	47%	100%	30%
LF4 Local water temperature	Adult	4	3	5	2	4	5	5	Mod	High	Very High	39%	86%	46%
LF5 Local Dissolved oxygen	Juvenile	4	3	4	2	4	5	4	Mod	High	Very High	38%	67%	44%
LF3 Local habitat availability	Adult	3	3	5	2	3	5	3	Mod	Mod	Very High	40%	40%	46%
LF2 Local habitat quality	Adult	3	3	4	2	3	4	4	Mod	Mod	High	36%	50%	40%
LF5 Local Dissolved oxygen	Adult	3	3	4	2	3	4	4	Mod	Mod	High	25%	67%	48%
LF1 Carry-over impacts	Adult	3	3	3	2	3	3	3	Mod	Mod	Mod	36%	46%	53%
LF6 Local salinity	Juvenile	3	2	4	2	2	3	3	Mod	Low	Mod	31%	46%	53%
LF6 Local salinity	Adult	2	2	4	2	2	3	3	Mod	Low	Mod	21%	36%	53%
LF7 Ocean acidity	Juvenile	3	2	4	2	2	3	4	Mod	Low	Mod	17%	36%	67%
LF7 Ocean acidity	Adult	3	2	4	2	2	3	4	Mod	Low	Mod	8%	33%	50%

As expected, risk factors were generally rated higher for Juvenile salmon than Adults (Table 7.3). The early marine period is widely acknowledged as a period of relatively high mortality for salmon and in two systems discussed at the workshop (Sarita and Bedwell), a high proportion of naturally spawned fish smolt at very small sizes, making them vulnerable to sub-optimal early marine including estuary conditions. Future risk ratings were also generally higher than current. Again, this seems reasonable given that several of the habitat LFs examined are expected to change further with climate changes, to the detriment of many salmon.

High (current) to Very High (future) risk ratings were recorded for Juvenile WCVI Chinook for local habitat quality and availability as well as water quality related to dissolved oxygen and temperature (Table 7.3). Potential mechanisms discussed included some related to foraging theory; the combination of time spent within habitat for cover-protection versus time spent in more open water finding food results in fish being more vulnerable to predation in open water. Potential mechanisms discussed included reduced kelp forests, invasive Green Crab impacting eel grass, loss of estuary sedge grasses, and human uses such as aquaculture net pens, each of which may result in increased exposure to predation.

Adult WCVI Chinook returning to spawn also face stressors that may impact their spawning success. Workshop participants ranked water temperature as High (current) and Very High (future), while local habitat availability, quality, and dissolved Oxygen were rated as Moderate (current) and High (future) (Table 7.3).

Risk associated with changing water temperature and oxygen (LFs 4-5) increased for both Juvenile and Adult salmon in the future (Table 7.3). Participants suggested that these conditions are often set up in the inner inlets in late summer – early fall. In Alberni Inlet, the bottom fiber mat may amplify these conditions.

For Juvenile Chinook, workshop discussion focussed on the ability of these fish to avoid or escape conditions of poor water quality. The spatial distribution of Juvenile Chinook in areas and times of poor water quality was identified as a knowledge gap.

Limiting Factor 1 (carry-over effects from previous life stages) was rated high for the present and very high in the future for Juvenile salmon and moderate for both these periods for Adult salmon. Section 6a above describes how these results were interpreted considering work by others. It appears that getting a head start with rapid growth in fresh water is a major survival advantage, especially when marine productivity is low and/or competition is high. More work on carry-over effects and the importance of habitat and water quality factors is being undertaken through a "Follow the Fish" initiative begun in 2022.

Overarching discussion comments:

- Most Chinook rivers and estuaries along the WCVI have experienced significant damage. There are also some intact watersheds such as the Moyeha in Clayoquot Sound. Sampling in estuaries found Chinook smolts of similar small size (~40 mm (about 1.57 in), ~0.5g) whether from the disturbed or intact watersheds; suggesting small size may be common among WCVI rivers, perhaps resulting from changing genomics as a result of straying. Sampling in the Sarita River indicates there are some larger (70-80 mm) smolts leaving in May-June. Studies by Ruggerone et al. (2009) and Campbell and Claiborne (2016) suggest these larger smolts may comprise the majority of the Adult returns; that is, have significantly higher survival. This is a major knowledge gap. Perhaps changes in the marine survival of small smolts were a major contributor to current poor stock status?
- Hatchery smolts are similar sizes as these larger sized naturally produced smolts and most are released in May. Robertson Creek hatchery smolts survive much higher than most naturally produced smolts. A key research question is to quantify differences in survival of small vs large naturally produced smolts and reasons for differences among years.
- Participants supported the continued restoration of habitat but recognized the need for properly designed studies to evaluate the costs and benefits of restoration activities.
- There are many unknowns including movement and distribution patterns, whether young salmon are able to avoid poor habitats, and whether they move up and down in the water column to feed. These major gaps in our understanding make it difficult to confidently assess when and where major mortalities occur and should be research priorities. The 'follow the fish' program initiated in 2022 should be expanded.

7.2.7 Key Literature

Campbell, L.A., Claiborne, A.M., 2016. Successful Juvenile life history strategies in returning Adult Chinook from five Puget Sound populations. Salish Sea /Marine Survival Project 4: 2016 Annual Report.

Collicutt, B., Juanes, F., Dudas, S.E., 2019. Microplastics in Juvenile Chinook salmon and their nearshore environments on the east coast of Vancouver Island. Environmental Pollution, 244, pp.135-142. DOI: 10.10/16/j.envpol.2018.09.137.

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Ruggerone, G.T., Nielsen, J.L., Agler, B.A., 2009. Linking marine and freshwater growth in western Alaska Chinook salmon *Oncorhynchus tshawytscha*. Journal of Fish Biology, 75, pp.1287–1301.

Spanjer, A.R., Liedtke, T.L., Conn, K.E., Weiland, L.K., Black, R.W., Godfrey, N., 2020. Evidence for rapid gut clearance of microplastic polyester fibers fed to Chinook salmon: A tank study. Environmental Pollution, 265 (Part A), 115083. DOI: 10.1016/j.envpol.2020.115083.

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Trudel, M. 2023. Follow the Fish – First Marine Winter. Appendix 7.1, this publication.

7.2.8 Participants' Names and Affiliations

Name (Original Name)	Affiliation
Akash Sastri	DFO
Amber Holdsworth	DFO
Amelia Vos	Huu-ay-aht
Andrew	Unknown
Andrew Munro	ADFG
Andrew Trites	UBC
Andy Rosenberger	Independent
Angelica Pena	DFO
Arthur Bass	DFO
Barb Cannon	Creative Salmon
Bob Bocking	LGL
Brad Beaith	DFO
Byron Charlie	Ahousaht
Cameron Forbes	Recreational fisher
Cameron Freshwater	DFO
Candace Picco	Ha'oom
Cecilia Addy	City of Port Alberni
Cheryl Greengrove	UWashington
Chris Burns	LGL
Chris Neufeld	Recreational fisher
Chrissy Czembor	DFO
Christian Carson	Redd Fish
Christie Morrison	DFO
Colin Bates	Quest University
Dani Robertson	Uu-a-thluk
Danny O'Farrell	Ahousaht
Dave Rolston	Tseshaht
David Welch	Independent
Derek Price	DFO
Di Wan	DFO
Eamon Miyagi	DFO
Ed Walls	DFO
Erin Rechisky	DFO
Esther Guimond	DFO
Frank Dragon	Ka:'yu:'k't'h'/Che:k'tles7et'h'
Gideon Mordecai	UBC
Howard Stiff	DFO
iPhone	Unknown
Isobel Pearsall	Pacific Salmon Foundation
James Mortimor	DFO
Janice Valant	Cermaq
Jared Dick	Uu-a-thluk
Jeh Custerra	Friends of Clayoquot Sound
Jennifer Clark	Cascadia Seaweed
Jennifer Yakimishyn	Parks Canada
Jess Edwards	Ha'oom
Jessica Hutchinson	Redd Fish
Jim Lane	Uu-a-thluk
Jocelyn Nelson	DFO
John Candy	DFO
John Holmes	DFO
John Nelson	DFO
Jon Hunter	Commercial TROLL
Josh Temple	Coastal Restoration Society
Kent ONeill	Nootka Sound Watershed Society
Kerra Shaw	DFO
Kristi Miller-Saunders	DFO
Lal Basok	SFU
Lance Stewardson	Independent
Laura	Unknown
Laura Bianucci	DFO

Laura Sitter	DFO
Leah Sneddon	DFO
Lu Guan	DFO
Luke Swan	Ahousaht
Mack Bartlett	Cedar Coast Field Station
Mandala Smulders	Redd Fish
Mark Saunders	NPAFC IYS
Maycira Costa	UVic
Mike Wright	M.C. Wright and Associates
Miranda Smith	M.C. Wright and Associates
Monique Gillette	Ka:'yu:'k't'h'/Che:k'tles7et'h'
Nick Bohlender	DFO
Nick Brown	DFO
Parker MacCready	UWashington
Pat Deakin	City of Port Alberni
Patty Menning	DFO
Phil Edgell	Alberni Valley Enhancement Society
Pieter Van Will	DFO
Renny Talbot	DFO
Rich Pawlowicz	UBC
Roger Dunlop	Mowachaht/Muchalaht
Roland Doering	BC
Ryan Price	BC
Sam Noble	NOOTKA
Sam Starko	UVic, PSF
Sarah Rosen	Cedar Coast Field Station
Saya Masso	Tla-o-qui-aht
Terry Dorward	Tla-o-qui-aht
Tim Hawkins	West Coast Aquatic
Tom Foulds	Cermaq
Tom Therriault	DFO
Tony Farrell	UBC
Wendy Callendar	DFO
West Coast Aquatic	facilitator
Wilf Luedke	DFO
Will Duguid	UVic
Willie Mitchell	Tofino Resort and Marina

7.3 Workshop 3 – Parasites, Pathogens, Harmful Algae and Contaminants

April 5-6, 2022

7.3.1 Background

Third in the series of seven virtual workshops held during 2022 to 1) create understanding of existing knowledge on WCVI Chinook salmon and 2) investigate factors limiting their survival and productivity during their marine life stages and 3) identify knowledge gaps.

7.3.2 Objective(s)

To discuss and rank marine risk factors (LF8-11, Table 7.4) potentially limiting survival, growth and/or fitness of WCVI Chinook during four marine life stages (LS1-4):

- LS1 (first marine spring, summer and fall in estuary and nearshore marine) along WCVI
- LS2 (first marine winter along WCVI)
- LS3 (subsequent marine rearing of ages 2-4+ north of Vancouver Island ending when fish begin their homeward migration, and
- LS4 (Adult fish migrating back to the WCVI and into estuaries)

Table 7.4 Limiting Factors (LFs) Assessed During Workshop 3

LF#	Category	Limiting Factor Description
8	Contaminants	Mortality or fitness reduction due to exposure to deleterious substances or contaminants
9	Pathogens	Mortality or fitness reduction due to disease from pathogens
10	Parasites	Mortality or fitness reduction due to infection by parasites
11	Harmful Algae Blooms	Mortality or fitness reduction due to harmful algal blooms

7.3.3 Summary of Results

Of the limiting factors assessed, those relating to pathogens (LF9) and parasite infections (LF10) rated highest, with impacts of parasites principally in Juvenile Chinook life stages rather than Adults (Table 7.5). A key reason for this was that discussion of “parasites” was largely restricted to sea lice, which are macro ectoparasites known to exert strongest impacts on small Juvenile fish. However, there are a plethora of micro-parasites, including fungi and protists, that can exert impacts at all life-stages, which were assessed along with viruses and bacterial pathogens under LF9.

While current impacts for pathogens and parasites were ranked as High, they increased to Very High in future, in part because of known or suspected synergistic relationships with climate change, and elevated risks for some pathogens/parasites from spillover impacts of open-net salmon farms. Participants felt that of all the regions in BC, open-net salmon farms in WCVI sounds carry the largest potential for impact to Chinook, as Juvenile Chinook salmon spend up to a year co-habiting with high density farms, exposing wild and hatchery Chinook to various pathogens and parasites.

Models depicting pathogen hot spots throughout southern BC verify that over the fall/winter period, the WCVI sounds show an overabundance of pathogens in wild Chinook salmon compared to other regions of the coast. While farms are not the only source of pathogens, they are under human control, and their impacts can therefore be mitigated if required.

Table 7.5 Ranked (very high to low) current and future risk rankings for limiting factors (LFs) considered during Workshop 3 (see Section 6 for details)

Limiting Factor	Life Stage	Review Result Current Risk	Review Result Future Risk
LF9 disease-pathogens	LS2	High	Very High
LF10 infection-parasites	LS1	High	Very High
LF9 disease-pathogens	LS1	High	Very High
LF10 infection-parasites	LS2	High	Very High
LF8 contaminants	LS1	High	Very High
LF9 disease-pathogens	LS4	Mod	High
LF8 contaminants	LS4	Mod	High
LF8 contaminants	LS2	Mod	High
LF11 Harmful algae	LS1	Low	Mod
LF11 Harmful algae	LS2	Low	Mod
LF11 Harmful algae	LS4	Low	Mod
LF10 infection-parasites	LS4	Low	Mod

Contaminants (LF8) rated as a moderate (LS2, LS4) or high (LS1) current risk, and high (LS2, LS4) or very high (LS1) future risk. However, there was a fair degree of uncertainty in these rankings, reflected in their low confidence rating. While there was a compelling presentation on elevated contaminant concentrations from road-runoff, flame-retardant, pulp mill effluent, and agricultural pesticides within WCVI sounds, there were no data directly relating these to impacts on WCVI Chinook salmon, an area that requires further research. However, there was general agreement that impacts of contaminants were likely more important when considering cumulative impacts with other stressors, including increased susceptibility to pathogenic disease. Future studies need to consider contaminant effects in cumulative effects modeling on Chinook to provide more certainty on the intrinsic and extrinsic conditions associated with the strongest impacts, required to develop effective mitigation. Given that contaminants are largely human-derived, they are risks that can be mitigated with regulations on chemicals causing the greatest harm.

Harmful algae were given a Low current risk rating, with an increase to Moderate for future trends due to established associations with climate change and ocean acidification, although these rankings carried a Low confidence. There is good evidence that harmful algae negatively impact survival of salmon cultured in open-net farms, where fish often cannot move deep enough in the water column to escape bloom events. Many assume that wild fish will sense and avoid bloom events, but hard empirical evidence is required to verify or refute this assumption. Despite the ability to move deeper into the water column, we know that wild Chinook and sockeye salmon expose themselves for enough time to high SSTs in the summer to induce thermal stress signatures and will remain in oxygen depleted water at depth despite the availability of normoxic, cool water available at mid-depth. This is likely due to a tradeoff between optimized feeding opportunities and avoidance of predators. As such, it is possible that fish will still enter surface bloom areas to feed, but whether they remain there long enough to be impacted is unknown. This area requires more research, especially given a projected increasing risk with climate change.

7.3.4 Agenda

Day 1

8:30 am	Welcome, today's plan. Marc LaBrie, West Coast Aquatic (WCA). First Nations Opening. Larry Johnson, Nuu-chah-nulth Seafood Development Corporation (NCDS).
8:50 am	Overview of Workshops 1 & 2. Wilf Luedke, Department of Fisheries & Oceans.
9:15 am	Brief Introduction to the Workshop 3 Limiting Factors and the Scoring Process. Jessica Hutchinson, Redd Fish Restoration (RFR). Overview of the Life History Model. Wilf Luedke, DFO.
Session 1: Contaminants & Toxins Impacting WCVI Chinook	
9:45 am	Contaminant-related health risks to WCVI Chinook salmon. Peter Ross, Raincoast Conservation Foundation.
10:05 am	Surveillance of the Phytotoxin Domoic Acid in Pacific Canadian Waters: 2016 – 2021. Ian Perry, DFO.
10:25 am	Break
10:40 am	Harmful algal biotoxins in BC coastal waters. Andrew Ross, DFO.
11:00 am	Questions and Discussion
Session 2: Parasites Impacting WCVI Chinook	
11:15 am	Pathogen transmission between wild and farmed salmon in BC. Martin Krkosek, University of Toronto.
12:00 pm	Direct and indirect effects of sea lice on wild salmon. Stephanie Peacock, Pacific Salmon Foundation (PSF).
12:20 pm	Break for Lunch
1:20 pm	Juvenile salmon and sea lice monitoring in the Bedwell corridor of Clayoquot Sound Mack Bartlett, Cedar Coast Field Station Society.

1:40 pm	WCVI Juvenile Chinook Sea Lice Prevalence and Intensity 2003-2021. Lance Stewardson, Mainstream Biological Consulting Inc.
2:15 pm	DFO AMD Fish Health and Sea Lice audit data from West Coast Vancouver Island. Laura Sitter and Kerra Shaw, DFO.
3:00 pm	Afternoon Break
3:15 pm	Nootka Sound Juvenile sampling. Roger Dunlop, Mowachaht/Muchalaht.
3:35 pm	Trends in mortality of yellow fish in farmed Chinook salmon in the Clayoquot Sound, British Columbia. Derek Price, DFO.
3:55 pm	Empirical impacts of sea lice on baby salmon using hypothesis-driven physiological assessments. Tony Farrell, University of British Columbia (UBC)
4:15 pm	General discussion and input from all participants.
4:30 pm	Adjourn

Day 2

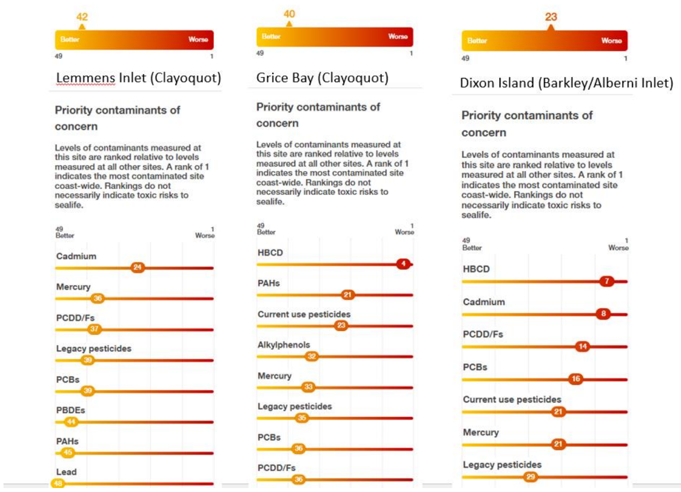
8:30 am	Overview of Day 1. Marc LaBrie, WCA
Session 3: Pathogens Impacting WCVI Chinook	
9:00 am	Empirical impacts of PRV on Juvenile salmon using hypothesis-driven physiological assessments. Tony Farrell, UBC. -> Presentation Acquired
9:20 am	Setting the stage with what we learned from SSHI, and WCVI Chinook Fit-Chips. Kristi Miller, DFO. -> Presentation Acquired
9:50 am	Farm and wild epidemiology from molecular screening. Andrew Bateman, PSF. -> Presentation Acquired
10:10 am	Linkage between PRV and jaundice/anemia disease in Chinook salmon. Emiliano Di Cicco, PSF. -> Presentation Acquired
10:30 am	Break
10:45 am	Emerging viruses in WCVI Chinook. Gideon Mordecai, UBC/PSF. -> Presentation Acquired
11:05 am	Population-level impacts of infection in wild Chinook salmon. Art Bass, UBC. -> Presentation Acquired
11:30 am	General discussion and input from all participants
12:00 pm	Lunch
1:00 pm	Introduction to the scoring procedure. Isobel Pearsall, PSF. Overview of online scoring activity. Tim Hawkins, WCA. Scoring of Limiting Factors.
4:30 pm	Adjourn

7.3.5 Presentation and Discussion Highlights

Contaminants

- **Peter Ross** – Contaminant-related health risks to WCVI Chinook Salmon
  - Local vs. Global sources of contaminants
    - Global: atmospheric pollution (metals, hydrocarbons, PCBs, etc.)
      - PCBs are polychlorinated biphenyls. Likely not immediately problematic for chinook, but they bioaccumulate to marine mammals up the food chain

PollutionTracker: WCVI sediments reveal local and global contaminants



- Industrial chemicals, pulp mill contamination, and pesticides can be attributed to local WCVI sources;
- Global (background) signals for PCBs, PBDEs and legacy pesticides) footprint;
- Natural Cd upwelling.

    - Local: chemical contaminants emanating from mostly land-based sources along WCVI
      - E.g., 6PPD-quinone, an automotive tire rubber chemical, that has been found in 80 sites around the coast, up to 5x coho natural tolerance – subject of study by Tanya Brown lab

6PPD-quinone likely cause of toxic injury and death (40-90%) of adult coho salmon returning to urban and semi-urban waterways in Puget Sound over recent decades (after ruling out dissolved oxygen, disease, copper, zinc, salt, hydrocarbons and pesticides).

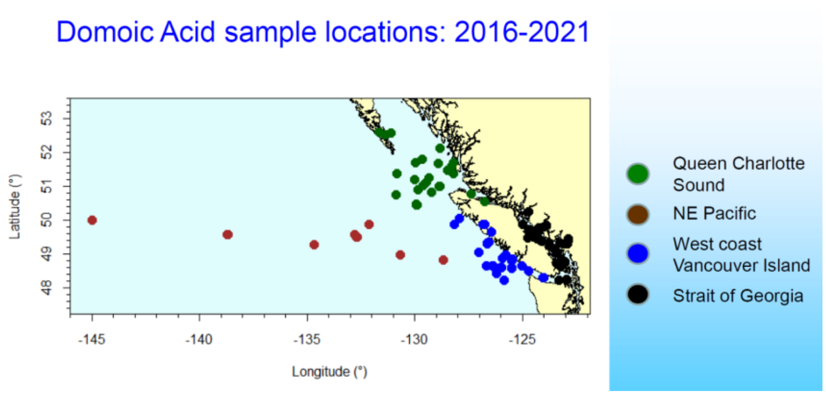
1) **Field:** Measuring automotive tire rubber-derived contaminants, including 6PPD-quinone and tire particles in road runoff and Coho and Chinook habitat in southern BC mainland (**range 2.5 to 160 ng/L**) and on Vancouver Island (**range .1 to 577 ng/L**); **LC50 for coho is 95 ng/L**. Sporadic exceedances were noted at **30%** of 13 sites.
2) **Laboratory:** Determine the mechanism of toxic action of 6PPD-quinone that is causing mortality in Coho and Chinook salmon using genomics, histopath, and whole organism endpoints.

    - Dixon Island in Barkley sound is more contaminated than in Clayoquot sound—HBCD flame retardant is a huge issue—insulation in homes, Cadmium from upwelling, PCDD/Fs, others

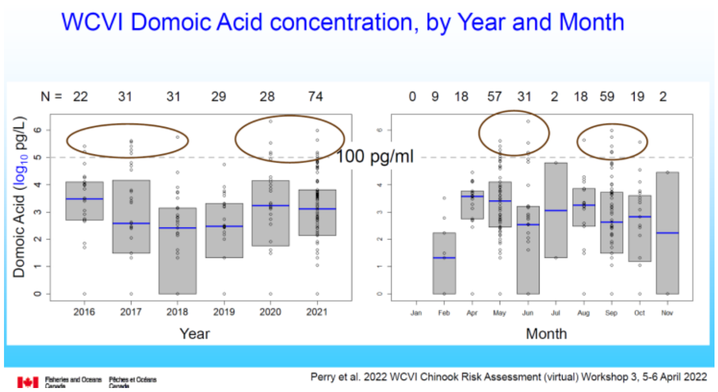
                - Effects on osmoregulation (Tierney et al 2008) is one of the acute impacts that could result directly in mortality
    - Local and global contaminants have different risks and are managed differently.
    - Contaminants can have two types of impacts to Chinook salmon
        - Acute direct impacts, causing direct mortality
        - Chronic, developmental impacts (endocrine disruption)
            - This has effects on immune, reproductive, and skeletal development – leading to stress and interacting effects with other stressors.
    - Data on contaminants and effects is limited – critical need for research
    - Abundance of evidence that contaminants can cause population level harm for /salmonids both from local and global sources
    - Q&A summary
        - Canadian legislation makes a precautionary approach to contaminants difficult, best to manage on a watershed-by-watershed basis
        - Persistent chemicals in finfish aquaculture feed can bioaccumulate

Harmful Algal Blooms

- **Ian Perry** – Surveillance of the phytotoxin domoic acid in Pacific Canadian waters
    - Domoic acid is a phytotoxin produced by *Pseudo-Nitzchia spp.* which bloom on WCVI waters
        - It is a mammalian neurotoxin, causing Amnesiac Shellfish Poisoning, can be fatal to humans.
        - Conditions for domoic acid production include presence of *Pseudo-Nitzchia spp.* and correct environmental conditions for those species to produce the toxin.

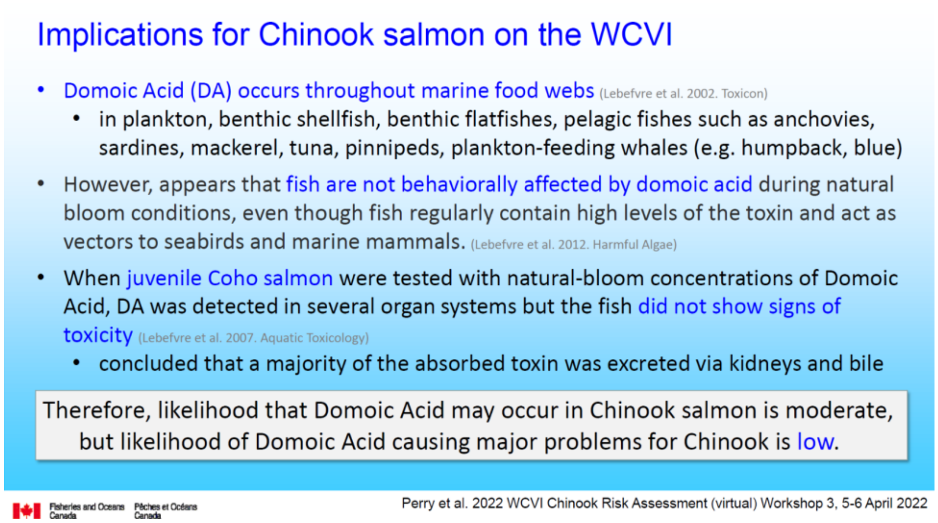


    - WCVI has relatively high detection of domoic acid on BC South Coast.
        - Spring and fall are peak concentration times – consistent with algal blooms



- Lower temperature leads to higher abundances of *Pseudo-Nitzchia spp.*
- Vertical stratification in water can lead to production of domoic acid by those diatoms
- Cooler but poorly mixed waters during phytoplankton bloom are strong conditions for production.

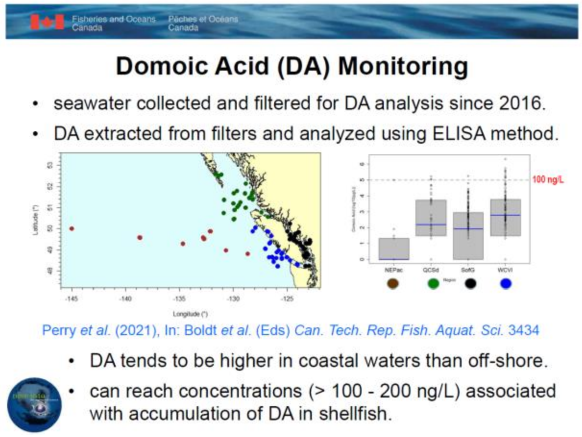
- Implications for Chinook salmon



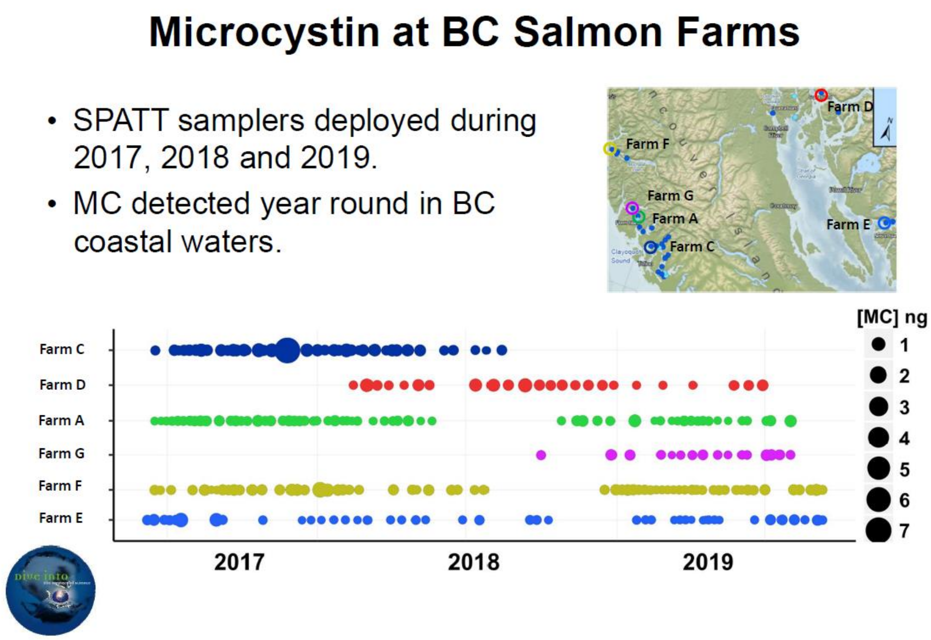
- Domoic acid bioaccumulates through food chain to Chinook salmon (Exposure rating suggestion: moderate)
- Fish regularly contain high levels of the toxin, but do not show signs of direct toxicity or resultant mortality. (Impact rating suggestion: low)
  - Significant concern as a vector to seabirds and marine mammals
  - Fish may excrete toxin through bile.

- **Andrew Ross** – Harmful Algal Biotoxins in BC Coastal Waters
  - Three types of harmful algal biotoxins
    - Domoic Acid – which produce amnesiac shellfish poisoning (ASP)
    - Saxitoxins – which produce paralytic shellfish poisoning (PSP)
    - Dinophysitoxins and Okadaic Acid– which produce diarrhetic shellfish poisoning (DSP)

- Domoic Acid

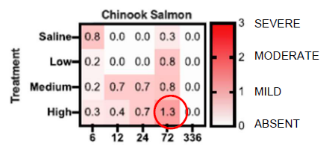


  - Pseudo-nitzchia cells at 5m produced no DA at lower salinity but increasing amounts of DA at higher salinity
  - Ocean warming may favour production of DA and/or abundance of Pseudo-nitzchia
- Microcystins are hepatotoxins implicated in net pen liver disease
  - Produced by blue-green algae (cyanobacteria), common in freshwater also found in marine



Effects of Microcystin on Chinook Salmon

- fish were orally exposed to saline (control) or *M. aeruginosa* at low, medium and high (sub-lethal) MC concentrations.
- hepatocellular hydropic degeneration (HHD) and minor gill lamellar branchitis (GLB) were observed in some fish.
- HDD was significantly affected ($p < 0.001$) by treatment and time, with histopathological features in the high treatment group differing from those in the saline group ($p < 0.05$) at 72 hours:



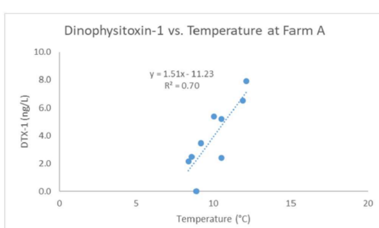
Shartau *et al.* (2022) *Journal of Fish Diseases* (DOI: 10.1111/jfd.13599)

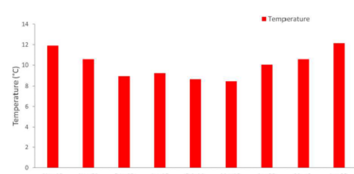
- Microcystins were found to have impacts on farmed chinook through oral exposure
    - Liver and gill damage – cumulative impacts over time
    - Farmed Chinook are canaries in the coal mine, their exposure is consistent due to their location, useful for monitoring.

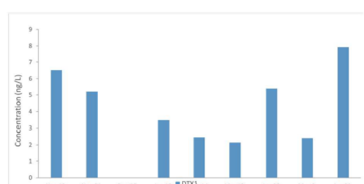
- DSP Toxin

DSP Toxins at Farm A (Clayoquot Sound)

DTX1 positively correlated with water temperature ($r^2 = 0.70$) between November 2020 and June 2021.

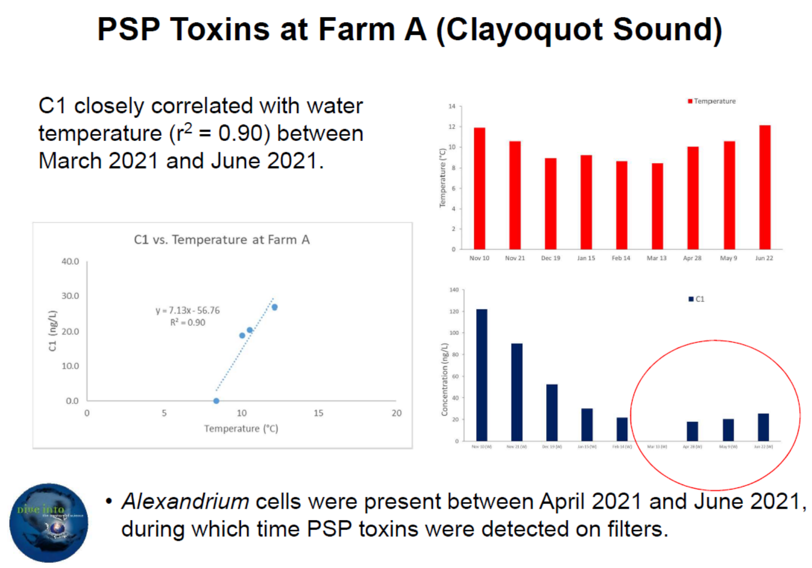






- Farm A (WCVI) is cooler than IS-2 (Salish Sea) and has a lower rate of increase of DTX with temperature (1.5 vs. 1.9 ng/L/°C).

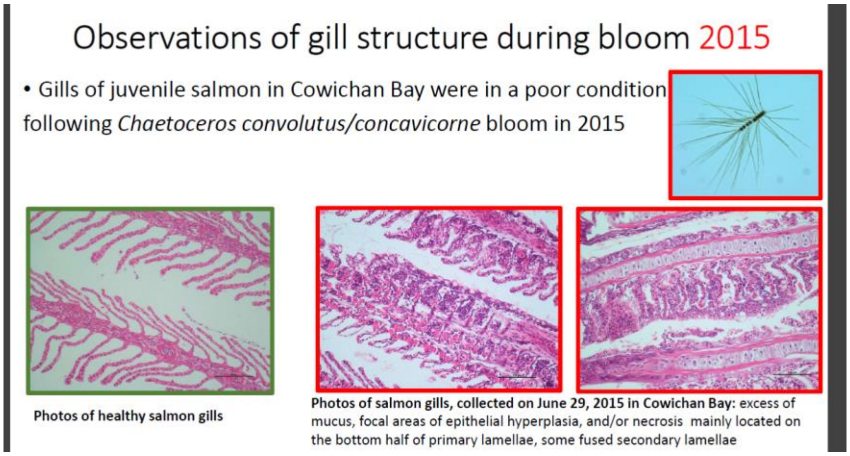
- PSP Toxins



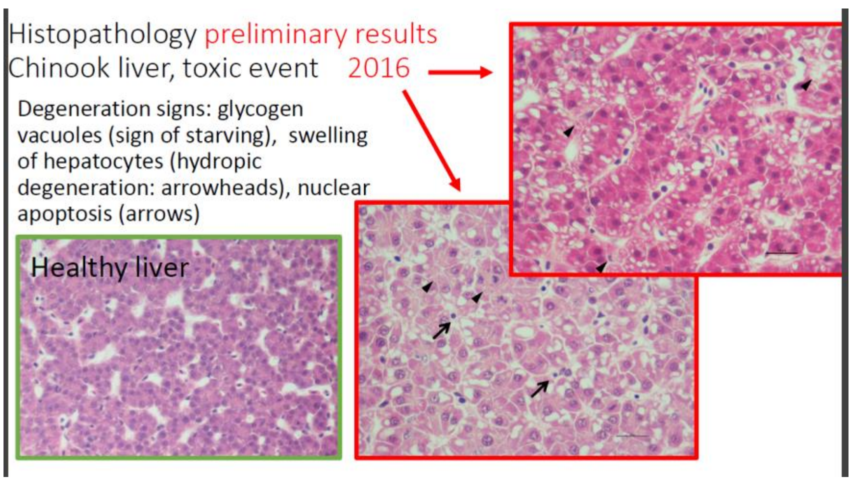
- Key Considerations
  - Harmful algae and associated biotoxins occur naturally in coastal waters worldwide and have been present historically in BC – as evidenced by records of human illness
  - Exposure to algal biotoxins can occur in fresh, brackish, and sea water – posing potential risks to salmon during multiple life stages.
  - Direct effects include damage to organs (gills, liver, gonads), sub-lethal (hormonal, reproductive) and lethal toxicity (death)
  - Indirect effects include stress, growth, survival, reproduction, changes to food web structure and environment (oxygen)
  - Toxicity and synergistic effects of these biotoxins to Chinook salmon are largely unknown
  - Exposure to high biotoxin concentration is known to cause disease in farmed salmon. There is histological evidence of exposure to microcystin in wild salmon
  - Fish have metabolic processes and physiological mechanisms that help them deal with lower-level exposure to biotoxins.
- Rating suggestion: moderate risk to WCVI CK salmon
  - The risk of exposure is likely highest during spring and fall blooms, depending on which harmful algal species are present though certain soluble PSP toxins may persist in winter.
  - Low to moderate likelihood of biotoxins causing harm to WCVI Chinook

- **Svetlana Eusenkulova** – Harmful Algal Bloom impacts to salmon
  - Harmful algal blooms (HAB) predate European colonization on WCVI.
  - HAB are a significant risk for aquaculture, shellfish, and finfish, through exposure
  - Monitoring of HAB impacts to wild salmon in Strait of Georgia

- Cowichan Juvenile chinook sampled showed significant inflammation in gills from biotoxin presence



- Cowichan chinook also showed signs of liver tissue degeneration following a toxic event



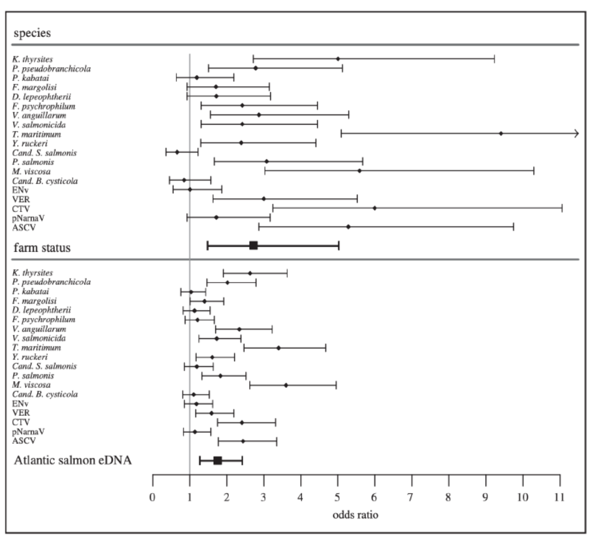
- Chinook had lower catch rates and a higher proportion of empty stomachs during HAB episodes.
- Impacts of HAB likely in reduced growth during first marine summer (Marine life phase 1) leading to subsequent winter mortality (Marine life phase 2)
- Need a better understanding of linkages between Juvenile salmon, oceanographic conditions, phytoplankton, and zooplankton

Pathogens and Parasites

- **Martin Krkosek** – Pathogen transmission between wild and farmed salmon in BC
  - Context: pathogen transmission
    - Pathogens are a natural part of salmon ecosystems

        - Salmon farms are often located in good salmon rearing or migration areas. As stationary points where infections can occur, salmon farms can be sites of disease exchange between wild and farmed fish.
            - Farmed salmon provide a domesticated host for pathogens. This:
                - Increases the intensity of infection exposure to wild salmon
                - Changes the timing to pathogen exposure of wild salmon, by being present in water year-round
                - Can alter the traits of pathogens – i.e., virulence and drug-resistance
    - eDNA monitoring of water aimed at understanding the role of aquaculture on facilitating the occurrence of pathogens
        - Tenicibaculum maritimum was most common occurring pathogen
        - Likely significant pathogen transfer between aquaculture and wild salmon.
        - We know more about parasites, less about virus, bacteria, and eukaryotic pathogens.

Effect of salmon farms on eDNA occurrence



GLMM with REs for year and species, FEs for Atlantic salmon

Occurrence is 2.72 (95% CI: 1.48, 5.02) times higher at active versus inactive sites

Shea D, Bateman A, Li S, Tabata A, Schulze A, Mordecai G, Ogston L, Volpe J, Frazer L, Connors B, Miller K, Short S, & Krkosek M., 2020. Environmental DNA (eDNA) from multiple pathogens is elevated near active Atlantic salmon farms. *Proceedings of the Royal Society B.* 287: 20202010

    - Sea Lice – Parasitic copepod
        - Three life history stages of sea lice
            - Copepodids (Juvenile – free swimming)
            - Chalimi (Juvenile – parasitic)
            - Motiles (Adults - parasitic)
        - Early marine infection by sea lice can be detrimental to marine survival

- For comparison, a Norway study showed 11.1% loss of wild Atlantic salmon recruitment through early marine sea lice infection.
- When marine rearing conditions are good, sea lice have less of an impact. When they are bad, they show more of an impact
- Demonstration of spatial dynamic of transmission along salmon migration route through study in Knight Inlet, BC
    - Infection by Juveniles early and middle migration, trails off.
    - Infection by motiles increases in abundance along migration
- When farms can treat for sea lice in a coordinated way, you see very little transmission
    - Works effectively when coordinated treatment is in winter, in advance of Juvenile outmigration
- Epizootics - the ability to fight off parasites can be overwhelmed with the extent of the time period they are exposed to sea lice for.
- Interaction between farmed and Juvenile wild salmon is a regional effect – areas where farms are concentrated
- Sea lice prevalence was very bad in the early 2000s, then Slice was developed (pesticide) which was effective, leading to several years of effective treatment
    - Since then, climate change and developed drug resistance has led to a resurgence of sea lice prevalence
- Sea lice favor conditions with higher salinity
- Challenges in extrapolation from other regions/species

Stephanie Peacock[1,2], Sean Godwin[1,3], Andrew Bateman[1,2], Martin Krkošek[1,4], Alexandra Morton[1,5] - Direct and Indirect Effects of Sea Lice on Wild Salmon
1. Salmon Coast Field Station, Simoom Sound, BC
2. Pacific Salmon Foundation, Vancouver, BC
3. Dalhousie University, Halifax, NS
4. University of Toronto, Toronto, ON
5. Raincoast Research, Sointula, BC

Open-net pen salmon farming allows for the transmission of parasites and pathogens between farmed and wild salmon. Sea lice (*Lepeoptheirus salmonis* and *Caligus clemensi*) are naturally occurring parasites of Pacific salmon that can infect and reproduce on farmed salmon. Salmon farms located in near-shore marine waters are known to facilitate the growth and spill-back of sea-louse populations to wild Juvenile salmon leaving rivers. The consequences of this elevated parasite exposure for the growth and survival of Juvenile salmon are both direct, physiological impacts of infection and indirect, or 'ecological', effects of the parasites on their hosts (Figure 7.15).

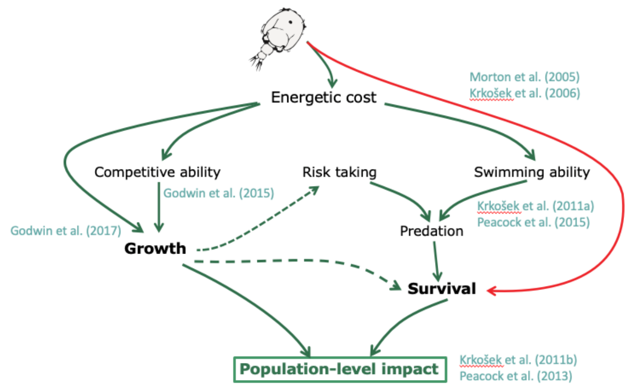


Figure 7.15. The effects of sea lice can be direct (red) or indirect via impacts on competitive ability and predator avoidance (green). The cumulative impact can lead to increases in population-level mortality. Key studies discussed here are noted in blue.

Louse attachment and feeding has a direct energetic cost to hosts and can lead to skin damage, osmoregulatory stress, and increased susceptibility to secondary infections from other parasites and pathogens. These direct effects of sea lice depend on both host size and species. Small fish (<0.3 g) are more severely affected (Brauner et al. 2009; Jones and Hargreaves 2009). Above this size threshold, pink salmon tend to mount a relatively effective immune response that makes them more resistant to infection than chum salmon (Johnson and Albright 1991). Among other species, coho appear more resistant than Chinook or Atlantic salmon (Johnson and Albright 1992) and sockeye are potentially the most susceptible (Long et al. 2019). Experiments in flow-through ocean enclosures (Morton and Routledge 2005; Krkošek et al. 2006) and laboratory settings (Jones and Hargreaves 2009; Jakob et al. 2013) have confirmed that these direct effects of sea lice lead to increased mortality of pink, chum, and sockeye salmon.

The actual impact of sea lice on wild salmon are probably much greater than the direct impacts estimated from experiments due to the ability of parasites to negatively affect their hosts' ability to forage, migrate, and avoid predation (Krkošek et al. 2011a; Figure 7.15). Juvenile sockeye salmon that are heavily infested with *C. clemensi* have lower competitive foraging ability (Godwin et al. 2015) and reduced daily body growth (Godwin et al. 2017) compared to sockeye with low parasite burdens. Perhaps because of this, infected salmon have been found to return to feeding more quickly after a simulated predation strike than uninfected conspecifics (Krkošek et al. 2011a). Swimming performance of Juvenile pink (Nendick et al. 2011) and chum (Krkošek et al. 2011a) salmon is negatively affected by a single sea louse. This impact on swimming may contribute to the reduced foraging ability, but also the ability of Juvenile salmon to avoid predation – a major source of early marine mortality. Field-based experiments have found selective predation on infected Juvenile pink and chum salmon by both coho and cutthroat trout (Krkošek et al. 2011a; Peacock et al. 2015).

At low parasite burdens, mortality from sea lice may be compensatory – changing *who* survives but not the overall proportion of the population that makes it through the early marine phase. However, modelling and statistical analyses of spawner-recruit data suggests that the parasite burdens in the Broughton Archipelago during years with active open-net salmon farms are correlated with higher population-level mortality of pink and coho salmon (Krkošek et al.

2011a, 2011b; Peacock et al. 2013). There have been studies that have not detected this effect (Marty et al. 2010; Peacock et al. 2014), perhaps due to confounding factors and high variability in salmon returns and enumeration effort, highlighting the importance of carefully designed statistical analyses across multiple regions, populations, and species.

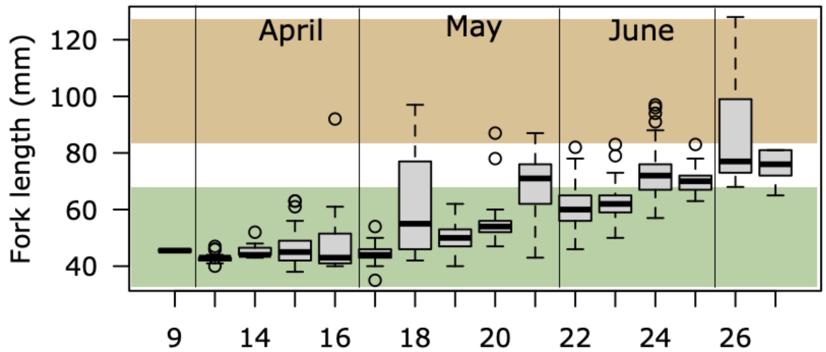


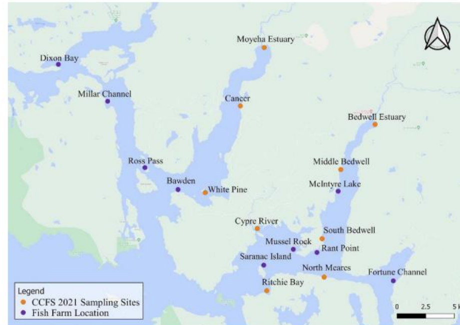
Figure 7.16. **The fork length (mm) of WCVI Chinook sampled by the Cedar Coast Field Station from 2018 - 2011. The approximate ranges in size for pink and chum salmon and sockeye salmon during this same period are noted in green and brown, respectively.**

How do these results translate to WCVI Chinook?

The demonstrated impacts of both direct and indirect effects of sea lice on host growth and survival consistently depend on the size of the host, with smaller hosts being more severely impacted. WCVI Chinook are predominantly ocean-type and enter the marine environment (and are potentially exposed to sea lice) at a relatively small size (Figure 7.16). Thus, many of the size-dependent impacts found in the aforementioned studies of other species are highly relevant to WCVI Chinook. The cumulative body of evidence from lab experiments, field experiments, observational studies, and modelling of both individual- and population-level impacts of sea lice show that parasites are a potential limiting factor.

- Q&A
    - Infection may cause slower growth or be a symptom of slower growth
    - Evidence of comparative reduced recruitment in areas with high lice prevalence

- **Mack Bartlett**
    - Chum and Chinook data – Bedwell River
        - Primary focus: beach seining in Bedwell corridor – started to track sea lice abundance on Juvenile salmon in the region in association with sea lice management failure

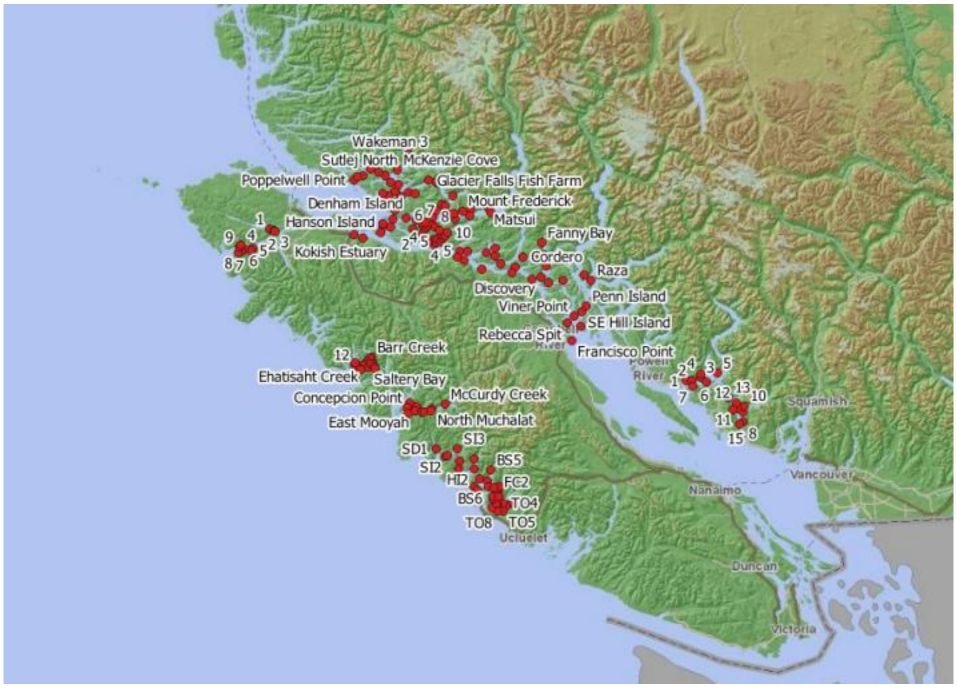


        - Micro trolling October-March, beach seining March-July
        - 56% prevalence in fish
        - Most infection is Chalimus and Copepodid
    - 2020 increase in Juvenile lice near Cypre estuary – potentially aligned with first use of Hydrolicer
        - Hydrolivrr effluent sampled showed live sea lice at all life stages
    - Conclusions on sea lice exposure

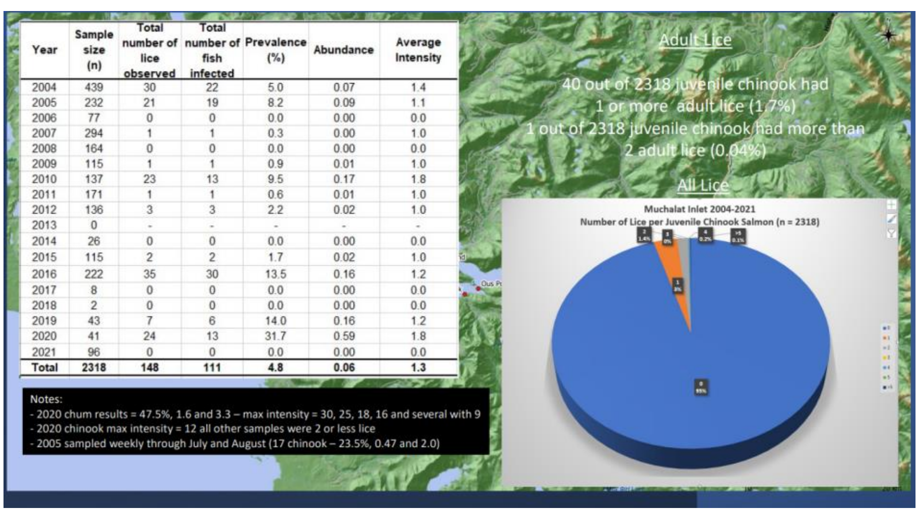
Exposure

- Juvenile chinook observed October-July annually
- High sea lice abundance on farm during sensitive outmigration window
- Relatively high sea lice abundance on both chum and chinook fry during beach seine surveys
- Management breakdown 2018 onwards
    - Slice resistance
    - Many instances over the 3 motile *L. salmonis* conditions of licence limit on farm during outmigration period
    - Mechanical delousing filtration issues

    - Q&A Summary
        - Water temperature may contribute to increased infection
- **Lance Stewardson** – WCVI Juvenile Chinook Sea Lice prevalence and intensity
    - Sea lice species dominant on WCVI seems to be caligus
    - 155 locations monitored

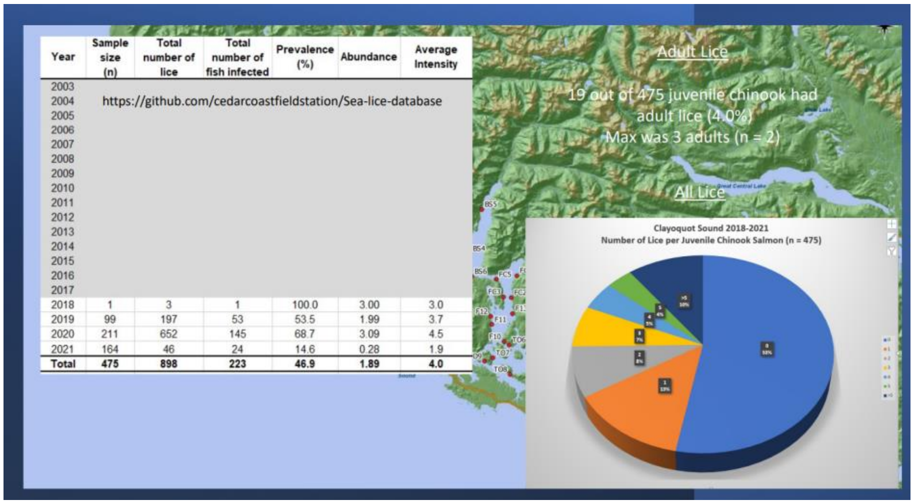


- Conclusions
  - Sea lice numbers on Juvenile salmon in 2021 were comparable to levels over the last 5 years and higher than 2008-2014 period
  - 85% of infections are Juvenile lice
  - Sampling from Quatsino, Esperanza, Muchalaht Inlet, and Clayoquot showed very few fish had sea lice infection <5% and very few of those infections were motile (Adult) lice

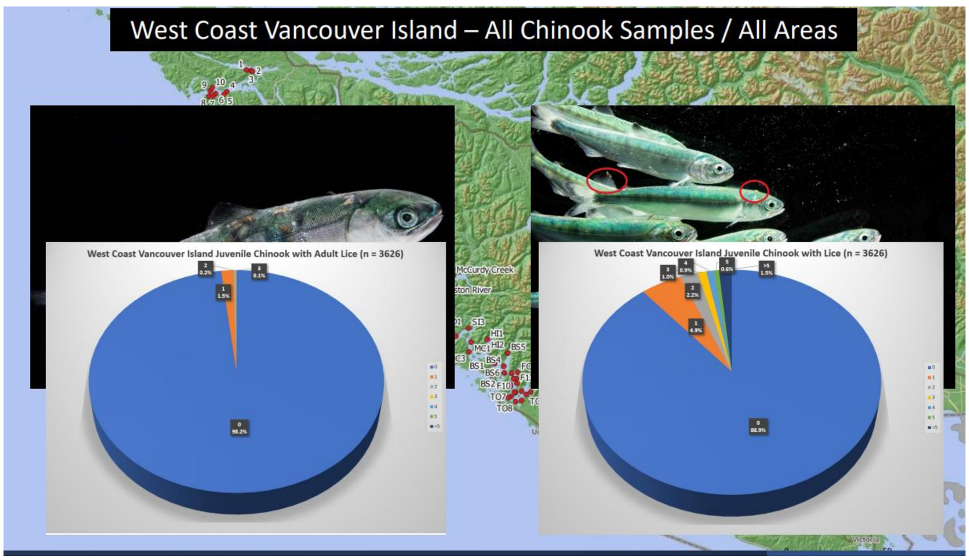


Year	Sample size (n)	Total number of lice observed	Total number of fish infected	Prevalence (%)	Abundance	Average Intensity
2004	439	30	22	5.0	0.07	1.4
2005	232	21	19	8.2	0.09	1.1
2006	77	0	0	0.0	0.00	0.0
2007	294	1	1	0.3	0.00	1.0
2008	164	0	0	0.0	0.00	0.0
2009	115	1	1	0.9	0.01	1.0
2010	137	23	13	9.5	0.17	1.8
2011	171	1	1	0.6	0.01	1.0
2012	136	3	3	2.2	0.02	1.0
2013	0	-	-	-	-	-
2014	26	0	0	0.0	0.00	0.0
2015	115	2	2	1.7	0.02	1.0
2016	222	35	30	13.5	0.16	1.2
2017	8	0	0	0.0	0.00	0.0
2018	2	0	0	0.0	0.00	0.0
2019	43	7	6	14.0	0.16	1.2
2020	41	24	13	31.7	0.59	1.8
2021	96	0	0	0.0	0.00	0.0
Total	**2318**	**148**	**111**	**4.8**	**0.06**	**1.3**

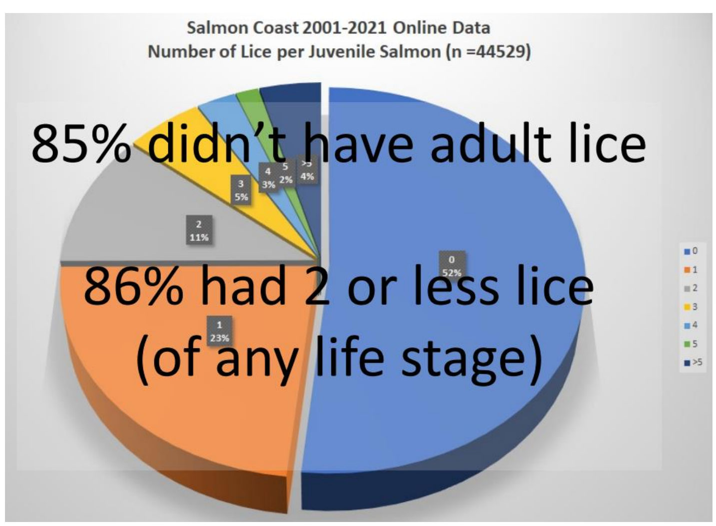
Notes:
- 2020 chum results = 47.5%, 1.6 and 3.3 – max intensity = 30, 25, 18, 16 and several with 9
- 2020 chinook max intensity = 12 all other samples were 2 or less lice
- 2005 sampled weekly through July and August (17 chinook – 23.5%, 0.47 and 2.0)



Year	Sample size (n)	Total number of lice	Total number of fish infected	Prevalence (%)	Abundance	Average Intensity
2003						
2004	https://github.com/cedarcoastfieldstation/Sea-lice-database					
2005						
2006						
2007						
2008						
2009						
2010						
2011						
2012						
2013						
2014						
2015						
2016						
2017						
2018	1	3	1	100.0	3.00	3.0
2019	99	197	53	53.5	1.99	3.7
2020	211	652	145	68.7	3.09	4.5
2021	164	46	24	14.6	0.28	1.9
Total	**475**	**898**	**223**	**46.9**	**1.89**	**4.0**



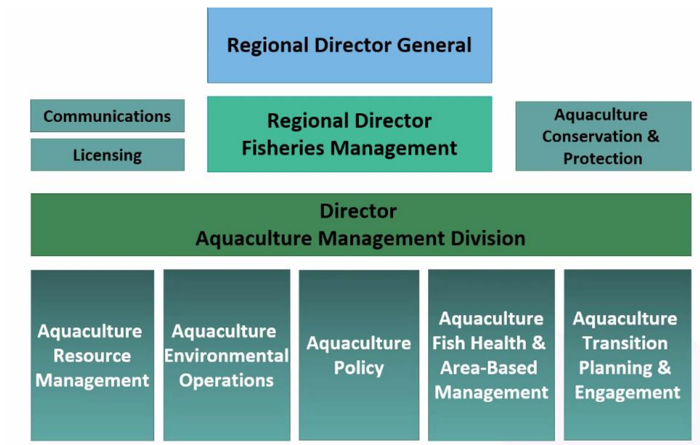
- Independent analysis of Salmon Coast Field Station



- Q&A Summary
  - 2020 was a significant year for lice impacts
  - Challenges in comparisons between different sampling procedure, challenges spotting lice sometimes
  - Temperature correlation with sea lice epizootic events

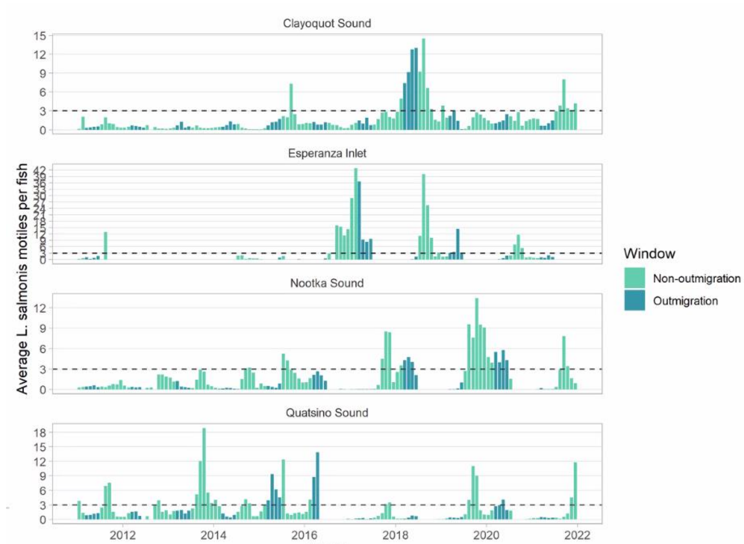
Kerra Shaw and Laura Sitter – Fish health and sea lice data from farmed Atlantic and Chinook Salmon

- Objective: Provide an overview of the BC Aquaculture Regulatory Program (BCARP) and Fish Health Audit and Intelligence Program (FHAIP) and data it collects
  - BC Aquaculture regulatory flowchart

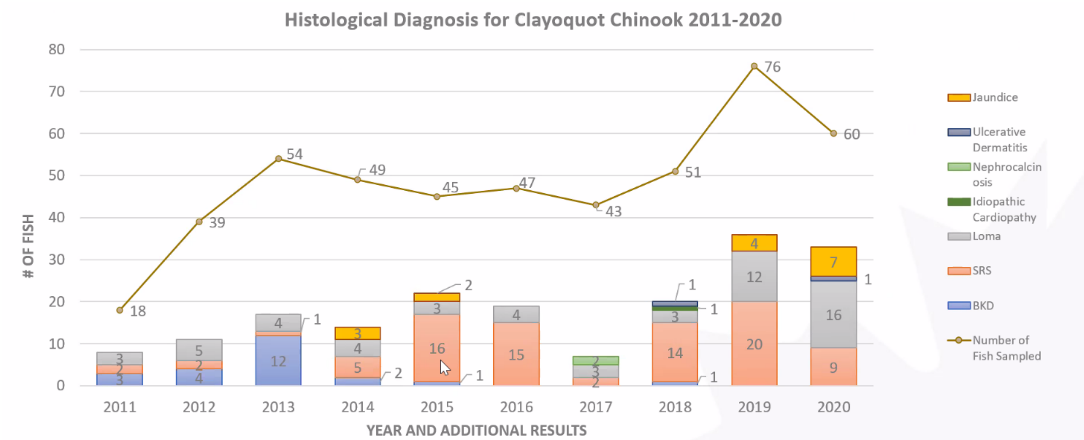


  - DFO is the lead regulator on aquaculture in BC and PEI, the provinces lead in other jurisdictions
- DFO issues licenses for marine salmon farming and monitors various activities:
  - Benthic environment for pollution
  - Habitat Assessment
  - Harvest and transfer activities
  - Sea lice on farms
- Fish Health Audit and Intelligence Program
  - DFO has a year-round team doing farmed fish health monitoring fieldwork
  - FHAIP does randomized and targeted audits of marine farms (targeted audits began in 2020)
  - The team also performs commercial salmon hatchery inspections
  - Standardized sampling at marine farms
    - 5-10 silver fish per farm collected (~840 total annually)
    - Testing of multiple (minimum 11 from each fish) tissues
    - Molecular testing conducted for:
      - *ISAv, IHNv, IPNv, SAV, VHSv, and P. salmonis*
      - Kidney sampled for bacterial isolation

- All fish health and sea lice data are publicly available at: https://open.canada.ca/en/open-data
- Sea Lice Monitoring (Atlantic salmon)
  - Sea Lice monitoring is focused on facility conditions of license
  - Data collected on average *L. Salmonis* motiles per fish



  - Chinook salmon farms in BC have different sea lice counting and reporting requirements than Atlantic salmon farms as evidence seems to indicate they are not as susceptible to sea lice infestation as Atlantic salmon
- WCVI Fish Health Events
  - Fish health event definition: suspected or active disease occurrence within an aquaculture facility that requires the involvement of a veterinarian and implementation of mitigation to reduce associated impacts and risks
  - Majority of treatments performed on Atlantic salmon is for mouth rot (caused by *Tenacibaculum maritimum and T. dicentrarchi*)
  - Majority of fish health events for Chinook salmon are bacterial kidney disease [BKD] (*Renibacterium salmoninarum*)
- WCVI Mortality Events
  - Mortality events are when 4000 kg or 2% of fish die within 24 hours; or 10000 kg or 5% of fish die over 5 consecutive days (definition was changed in July 2022 to capture significant events)
  - Mortality events must be reported to DFO within 24 hours
  - Atlantic Salmon on WCVI experience a variety of mortality events, many environmental in nature (e.g., HAB or low DO)
  - Farmed Chinook rarely experience mortality events
- WCVI Chinook Fish Health Audit Data



- Q&A Session:
  - Farms have 42 days to reduce their sea lice numbers below threshold after reporting an exceedance during the out-migration window.
  - Hydrolicer and other sea lice treatment vessels are being monitored by DFO. Mechanical sea lice treatment vessels must have filtration technology in place to prevent sea lice from re-entering the marine environment.

Roger Dunlop – Nootka Sound Juvenile Sampling

- Reduced fjord freshwater surface flow leads to increased sea surface salinity and reduce headward circulation in summer – historic freshwater influence that has served to stave off sea lice parasitism is waning
- 2021 and 2020 sampling was conducted in Muchalaht Inlet and the Esparanza side of Nootka Island with shallow nets, mostly caught chum Juveniles – sampled offshore and downstream of farm sites
  - 403 chum collected May 5, 2021. Collection in 2020 as well
  - Significant negative relationship between prevalence, intensity, and SE of Intensity and distance from active farms
- Conclusion: Esperanza farms impact chum salmon in Nootka sound via Tahsis narrows
  - Evidence that treatment (hydrolicer) is not working
- Q&A Session Summary:
  - Concern re: Mainstream Biological sampling not being far enough downstream from farm sites is why MMFN chose downstream sites.
  - Chinook thought to live deeper than chum – which is why purse seines may work better

Tony Farrell – Empirical impacts of sea lice on baby salmon using hypothesis-driven physiological assessments

- Limited data quantity and quality make reliable risk predictions difficult
- Lice susceptibility of salmon is very size dependent
  - Lice susceptibility: Atlantic > sockeye > chum > Chinook > pink > coho
- There are some reliable data on pink salmon that can perhaps be extrapolated from

- Lab study conducted on a fallow MOWI farm with pink salmon
    - Four hypotheses
        - H1: lice lesions create an excessive salt body burden in the fish
        - H2: Lice attachment decreases swimming speed
        - H3: H1 and H2 impacts are lice-stage dependent, problems increase with growth of lice
        - H4: H1 and H2 are dose-dependent (increase with number of lice per fish)
    - Tested both Broughton Archipelago ocean-caught, infected pink salmon, and naïve Glendale River-caught pink salmon
    - Complications when experiment translated to reality
        - Lice migrate vertically at night
        - Fish of all ages shed lice, especially if exposed to freshwater (i.e., salinity is key variable in shedding lice)
    - Results:
        - No significant effect of 1 louse on pink salmon
        - Physical abrasion on fish to create holes in skin did not cause osmotic stress; reject H1
        - Experimental support for H2 and H3
        - No evidence for H4
        - Shedding of lice observed and significant, made experiment challenging
    - Conclusions
        - Ocean-caught, infected pink salmon (~0.7 g) – hypotheses were rejected. No effect on swimming speed or whole-body salt concentration
        - Naïve river-caught fish (0.3-0.7 g):
            - No increase in salt load with scalpel-generated 'big holes'
            - Support for a louse stage-dependent & intensity-dependent increase in whole body salt concentration
            - Support for a louse stage-dependent, but not an intensity-dependent decrease in max swimming speed
            - But shedding of lice meant lice load at time of test was lower than the initial intensity for every experimental fish. Lice shedding is not a novel observation for *L. salmonis* in a laboratory experiment
            - Lice-infected pink salmon grew for almost 1 month with up to 3 lice
    - No control mortality; 25 lice-infected dead fish (5.8%), but 17 from the 4-20 lice/fish infection group
    - Summary thoughts:
        - Must recognize that size matters when setting thresholds for lice

      - Must recognize that infectious copopedids grow while the salmon is growing
      - Depressing to see 'obvious' physiological hypotheses rejected
      - Depressing to have 'controlled' experiments confounded by louse shedding not being highlighted in earlier literature
      - Most baby salmon sampled in the Broughton (DFO & other data) & Discovery Islands (Hakai data) have no louse or one louse on them.
      - Worry about 2 lice or more on the smallest salmon; tolerance of higher loads improves with growth? (See Hvas & Bui, J Exp Biol 2002)
      - New questions to entertain:
        - Do lice target salmon with poor NKA (smoltification) development on sea entry?
        - Is 1 louse per Juvenile salmon an Evolutionary Stable Strategy?
- Q&A Session Summary:
  - Handling affects osmoregulation
  - Lice shedding when exposed to lice once, fish shed lice, with continued exposures to new infections, Juvenile salmon can get overwhelmed.

Derek Price – Trends in mortality of yellow fish in farmed Chinook salmon in Clayoquot Sound, BC

- Yellow discoloration in dead fish naturally occurs in farmed and wild Pacific salmon
- Non-specific clinical sign, also known as jaundice, described in several Pacific salmon including Coho and Chinook.
- Objective: to describe epidemiological aspects and the factors driving the onset and magnitude of mortality of yellow fish.
- Study on farmed Chinook mortality from Creative Salmon
  - over 16,000 records from 216 pens from six farms between 2005 and 2017
- Bulk of mortality occurs in winter months during lower temperatures
- Salinity is a driving factor for onset of Jaundice
- Contribution:
  - Yellow fish made up a low proportion of mortality – 2.3% of mortality, 0.3% of stocked fish
  - Mortality during winter months and cooler water and lower salinity increased the hazard for the onset of mortality
  - Summer stocked fish experienced greater and earlier mortality
  - Onset of mortality in fall-stocked fish occurs in their second winter. Losses are smaller
  - A summer at sea may be necessary for mortality to occur.
  - Summer and fall-entry farms are in proximity, but magnitude of mortality in fall farms is not affected by summer-entry stocks.
- Q&A Session Summary
  - Same disease that causes Jaundice likely has other clinical symptoms

        - Kristi Miller lab have published peer-reviewed evidence overwinter jaundice can be caused by PRV; early lesions on the pathway to jaundice have been recapitulated in lab challenges with PRV and observed in wild Chinook infected with high PRV loads
        - Dr. Miller noted in the Q&A that limiting analysis of this disease merely to the clinical sign of yellow fish would only capture a limited proportion of affected fish, as this is an end stage of the disease. A more appropriate analysis would include the pathological lesions that lead to yellowing, which may only happen in extreme cases. Hence, he should consider that the mortality levels derived from his study are likely to be underestimated.
        - No alternate causes identified
    - PRV is not included in regular fish health audit

Day 2

Tony Farrell: Empirical impacts of PRV on Juvenile salmon using hypothesis-driven physiological assessments

- Experimental work has not been done to assess the degree of PRV impact to Chinook salmon
    - May be able to extrapolate from some impact data for Sockeye salmon smolts
- PRV in Atlantic, farmed salmon
    - PRV infects naïve Atlantic salmon within 6 months of introduction into sea pens
    - Up to 90%+ of Atlantic salmon are infected by PRV before harvest
    - No supplemental mortality caused by PRV over baseline
    - Shedding of PRV from farmed salmon poses a clear risk of infecting and impacting wild Pacific salmon if a) they migrate past salmon farms & b) PRV infection impairs their performance
- Testing in Fraser sockeye revealed no PRV in marine and spawning area sampled fish, but high prevalence of PRV Boston Bar and Bridge Creek samples
- Hypothesis: PRV damage to red blood cells (RBC) or cardiac functions will lower maximum respiratory performance in sockeye salmon
    - 3-day respirometry trial showed that fish only take a couple hours to recover from stress
    - No significant difference between control and PRV infected fish in swimming performance, survival, and hematocrit post-respirometry trial
    - Therefore: no support for above hypothesis (but see Q&A below)
- In comparison, IHNv quickly killed ~30% of sockeye salmon
    - Survivors resolved the infection and had no meaningful respiratory impairment
- Conclusion: So, what might be happening after a PRV infection?
    - Sockeye successfully fought the PRV infection & its replication; cleared some of the infected RBCs

- Then existed in a carrier state that did not have a biologically meaningful impact on their respiratory performance
    - Fully understanding the risk of a PRV infection to Juvenile chinook salmon will require controlled experiments well beyond the present ones on other salmon species. Such work will need to consider costs and benefits given the absence of major cardiorespiratory impacts on Juvenile sockeye and Atlantic salmon smolts.
- Q&A Session:
    - Caution in extrapolation of results from one species to another.
    - Lysis may occur from PRV infection (destruction of RBCs)
        - Tony's take: if lysis were occurring outside of the spleen, you would see red coloration of blood, which you don't.
    - Hematocrit doesn't vary much between 4-15 degrees C, experiment at 11 degrees C
    - Note that there were two commentaries and one erratum published in response to statistical issues in this study that should be considered when weighing the "minimal impact" assertion by the authors:
        - Mordecai, G., Bass, A.L., Routledge, R., Di Cicco, E., Teffer, A., Deeg, C., Bateman, A.W. and Miller, K.M., 2023. Assessing the role of Piscine orthoreovirus in disease and the associated risk for wild Pacific salmon. *BMC biology*, *21*(1), p.114.
        - Nakagawa, S. and Lagisz, M., 2023. Next steps after airing disagreement on a scientific issue with policy implications: a meta-analysis, multi-lab replication and adversarial collaboration. *BMC biology*, *21*(1), p.116.
        - The erratum published as a result of these commentaries included new statistical analyses that identified significant transient consequences to oxygen transport and exhaustive chase recovery associated with PRV infection

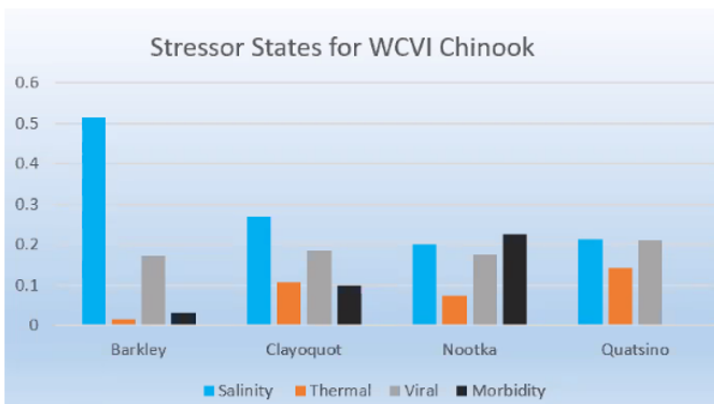
Kristi Miller – Setting the stage with what we learned from SSHI and WCVI Chinook Fit-Chips

Is infectious disease an important factor in the marine mortality of Juvenile salmon?

- Overview of Strategic Salmon Health Initiative
    - Major objective: understand the role of infectious disease in salmon declines.
    - Primarily focused on salmon in their natural environment
- Challenges with understanding disease impacts on wild populations
    - High but unobservable mortality
    - Complex life history of salmon
    - Cumulative impacts with stress and predation
    - Acute vs. chronic infections vs. carrier states
    - Traditional diagnostic approaches are not sufficiently sensitive
    - Laboratory studies do not emulate the complexity of natural systems

- Sub-lethal effects of infection may be more detrimental in the wild than in cultured fish
- Predator Removal of Diseased Fish
  - Predators preying on low condition fish may reduce densities of infected fish
  - Predators may pick off fish at early states of disease development
  - Require highly sensitive technology to study disease processes in wild salmon
- Agent, host, and environment interrelate to produce disease (or not)
- Laboratory- vs. Field-based studies have different strengths and weaknesses
  - SSHI field-based studies focus on
    - Salmon in their natural environments
    - Use of epidemiological modelling to assess:
      - Ecological drivers of infection
      - Routes of transmission
      - Population-level impacts
      - Individual-level impacts
  - Field-based studies require a weight of evidence approach to assess cause and effect
- SSHI program assessed
  - Wild and hatchery-enhance Pacific salmon, Farmed Atlantic and Chinook salmon, studied in natural systems
  - Monitored 58 infectious agents
  - Juvenile salmon sampled 2007-2018, from freshwater smolts to first 10 months of ocean residence (2000 km of migration)
  - Adult salmon research looks at interplay between infection and stress (thermal/handling) on pre-mature mortality
  - Established linkages with physiology – molecular, blood biomarkers, cellular
  - Established linkages with survival using telemetry with nonlethal gill biopsy.
    - Acoustic tracking studies in freshwater- and marine-tagged Juveniles and Adults identifies agents and host genes associated with migratory loss
  - Tools:
    - High throughput pathogen monitoring
    - Molecular monitoring for stress and disease – Fit-chips
    - High throughput sequencing for viral discovery
    - Visual tools for pathogen localization
    - Epidemiological modelling over a decade of complex pathogen data to establish population-level impacts, infection hot-spots, ecological drivers, and transmission pathways
  - Stress-challenge holding studies
    - Identify molecular biomarkers predictive of specific stress and infection responses (for Fit-Chips) and impacts of single and cumulative stressors on survival

- SSHI Findings to-date
    - Synergistic role of stress and disease undermine survival
    - Predation risk is enhanced by pathogen infections
    - Pathogen infection is contributing to annual variations in Juvenile salmon in the marine environment, an effect that can be even greater than SST, a well-established risk to survival
    - Pathogenic risks are experienced differently in hatchery and wild salmon
    - Some pathogens highly associated with open-net salmon aquaculture are spilled over into the environment and pose transmission risks to wild salmon (PRV and Tenacibaculum spp particularly)
    - Infectious disease is an important factor contributing to individual condition and survival
        - Chinook salmon may be particularly vulnerable given their nearshore life history
        - Risk associated with aquaculture-wild transmission are likely greatest where wild populations co-exist with farms through multiple seasons, as has been demonstrated in the life history of WCVI Chinook.
- Preliminary Fit-Chip analysis of microtrolling data - stressor states over winter

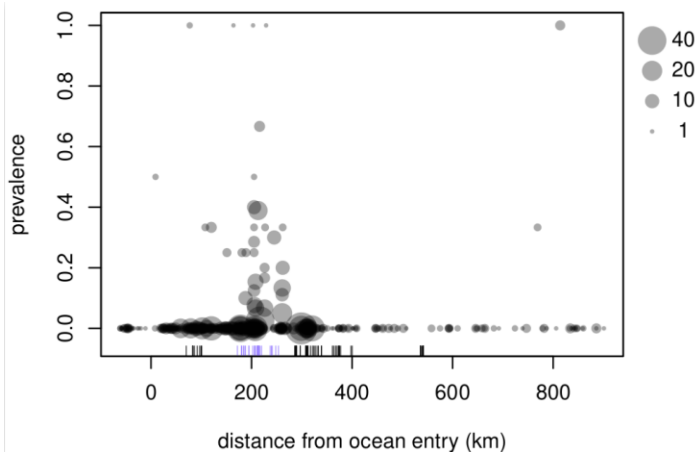


    - Salmon Fit-Chips identify fish responding to specific stressors based on co-expression of curated biomarker panels—thermal and salinity (osmotic) stress, viral disease and morbidity are four of the panels tested on WCVI Chinook
    - High salinity stress in Barkley Sound - may be from elevated pollution (see Peter Ross talk)
    - Low thermal stress throughout from sampling in winter
    - Morbidity is estimated via a biomarker panel that indicates imminent natural death (within 48 hours), and was highest in Nootka Sound (need to ensure these fish were, in fact, sampled soon after capture, and live)
    - It will be important to carry out similar analyses over the spring/summer period
- Q&A Summary
    - It would be possible to use Parentage Based Tagging data to track who survives or not with infection at a group level

- Differences between hatchery and wild fish:
  - Hatchery fish tend to move to deeper waters more quickly than wild fish, potentially leading earlier exposure to disease agents associated with marine fish, but less exposure to estuarine-transmitted pathogens.

Andrew Bateman – Farm and wild epidemiology from molecular screening

- Longitudinal Farm studies: Findings from two key pathogens that show mounting evidence of enhanced transmission risk to wild salmon
  - Piscine orthoreovirus (PRV)
    - Prevalence of infection in aquaculture environment ramps up to near 100% in first year
    - PRV shedding is observed in the water column around farms based on eDNA
  - *Tenacibaculum maritimum*
    - Most commonly found bacterial pathogen related to Atlantic salmon farms
      - Cosmopolitan marine bacterium which causes tenacibaculosis
      - *Tenacibaculum* is responsible for 'mouth rot' (ulcerative stomatitis) in BC Atlantic salmon farms – can produce high mortality rates on farms unless treated with antibiotics, which can occur over several months
      - Elevated *T. maratimum* DNA in dead/dying fish
      - *T. maritimum* is the pathogen showing the strongest evidence of enhanced shedding around active salmon farms
    - Tenacibaculosis in Pacific Salmon
      - In Pacific salmon, gill lesions and skin/fin ulcerations are more common.
      - Significant mortality in Chinook salmon reported in AK, California, and Chile
      - Strongly disagree with recent CSAS findings, which suggested minimal risk to Fraser River sockeye salmon and have been used erroneously to suggest minimal risk to all Pacific salmon—this is not scientifically defensible given strong international evidence to the contrary.
    - In Fraser River sockeye salmon, empirically fitted models capture the observed peak in detection of *T. maritimum* around Discovery Islands.
      - Study used well-established epidemiological models similar to some used in Covid 19 modelling ("susceptible/exposed/infectious" models)
      - Spike in infection seen near Discovery Island salmon farms (in both data and models), implicating those farms as a key source of infection.



- *Tenacibaculum maritimum* detections in wild sampled Fraser River sockeye salmon post-smolts. Rug represents salmon farm locations (purple = Discovery Islands farms). Point size indicates number of fish screened in each sampling event.

- Substantial inter-annual variation: high detection in 2015; future studies need more sampling north of farms.
- A couple samples near Haida Gwaii that showed high tenacibaculum infection; unclear if these are fish with continued infection or new infections.

- Conclusions
  - Limitations: For agents that primarily infect skin/gill tissue, it is difficult to distinguish exposure from infection, although agent load may offer some clues. When sampling fish over time/space, it is difficult to distinguish mortality from recovery, although acoustic tracking studies may provide some insight
  - New Information: Mouth rot can also be caused by two other species of *Tenacibaculum* that we did not study: *T. dicentrarchi* and *T. finmarkense.* A recent study from our team detected all three *Tenacibaculum* species in Adult and sub-Adult WCVI Chinook salmon that developed tenacibacuosis in a holding study at Bamfield Marine Sciences Centre; *T. dicentrarchi* was the agent with highest levels in ulcerative wounds. Disease challenge studies are now underway to contrast susceptibility to infection and disease of Chinook, coho, sockeye and chum salmon to *T. maritimum* and *T. dicentrarchi*.
- Q&A Summary
  - *T. maratimum* may persist on farms after fallowing
  - Questions about mechanics of models in many ways
  - Challenge in extrapolating impact from exposure

Emiliano Di Cicco – Linkage between PRV and jaundice/anemia disease in Chinook salmon

- Piscine Orthoreovirus (PRV)

- Discovered in Norway in 2010. Infects salmonids in both freshwater and saltwater.
    - Primary target is red blood cells
    - 3 strains globally, all proven to be causes of diseases. One strain in BC.
- Limitations of lab trials that have taken place in BC and Washington
    - Sample size issues, inadequate study design to assess pathological effects, misdirected endpoint – clinical signs including mortality (generally not demonstrated in PRV challenges anywhere)) vs. recapitulation of pathology (worldwide standard).
    - Significant results have been overlooked or dismissed
    - Failure to situate lab challenge results in an ecological framework
    - Virus infection in one species doesn't predict the outcome in another species (e.g., using sockeye in place of Chinook).
- Growing body of evidence of PRV as a causative agent of diseases from lab- and field-based studies worldwide.
- PRV-related diseases in Pacific Salmon worldwide
    - PRV related diseases tend to occur in colder months
    - PRV infects red blood cells
    - Heart problems, anemia, jaundice, liver failure, and kidney failure
    - PRV exposure can reduce hematocrit and hemoglobin concentration
- Jaundice/Anemia in Chinook Salmon
    - PRV infects red blood cells
    - Chinook salmon appear to be more sensitive to PRV infection and replication than Atlantic salmon – massive lysis of red blood cells
        - This leads to anemia and toxic levels of hemoglobin in the blood
    - PRV can cause liver and kidney failure in Pacific salmon (demonstrated worldwide)
    - PRV has been localized (using molecular probes) to areas where cell damage occurs
- Conclusions
    - PRV is a pathogenic agent that can infect Pacific Salmon – particularly seems to affect
      Chinook and coho
    - Lesions related to excess of hemoglobin manifest in fish with infected with PRV, including but not limited to jaundice
    - Evidence of PRV-related pathology in lab trials and field study (including wild salmon)
    - PRV is highly prevalent on salmon farms, which can act as a reservoir and as an amplification source of the virus to the surrounding environment.
    - Wild Juvenile chinook spending the first year in the areas around salmon farms are most prone to PRV infection and lesions – significant risk.

- Broughton Archipelago Transition Initiative
  - Organization designed to help monitoring of fish farm operations
  - Advanced techniques can help industry address fish health outbreaks before they occur in the majority of the population
  - Can help inform optimized fallowing period
  - Can help with the Indigenous Monitoring and Inspection Plan (IMIP) for First Nations
- Q&A Summary
  - Farmed Chinook may experience less PRV-related mortality than wild due to exposure to fewer life stressors
  - Some have questioned link between Anemia and Jaundice—anemia occurs as the result of lysis of infected red blood cells, jaundice is caused by toxic levels of heme, the breakdown product of hemoglobin, which can result in kidney/liver failure. These mechanisms have been demonstrated in Pacific Salmon.

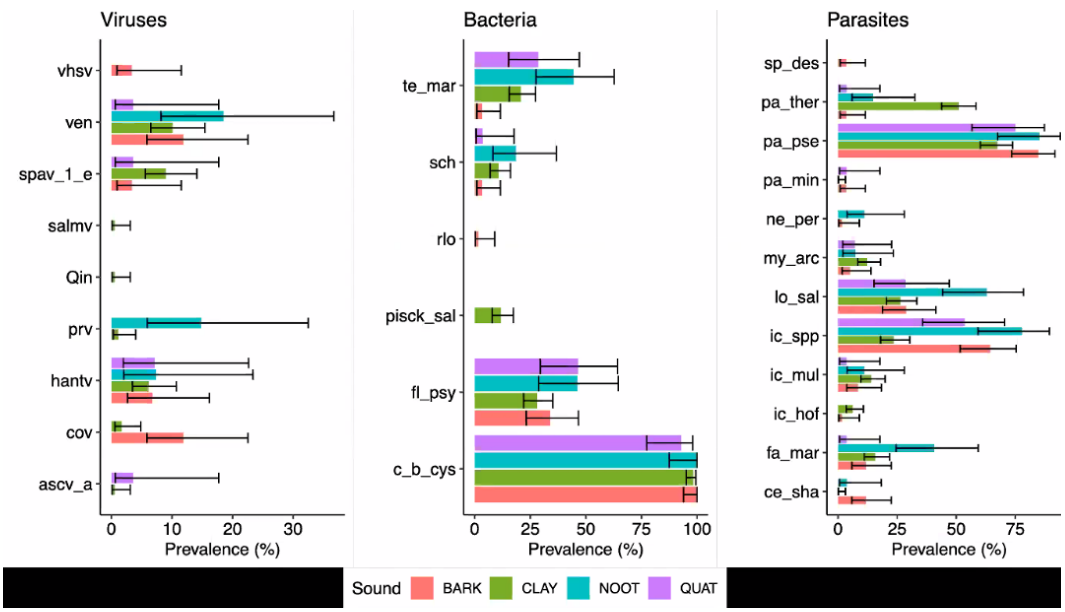
Gideon Mordecai – Emerging viruses in WCVI Chinook

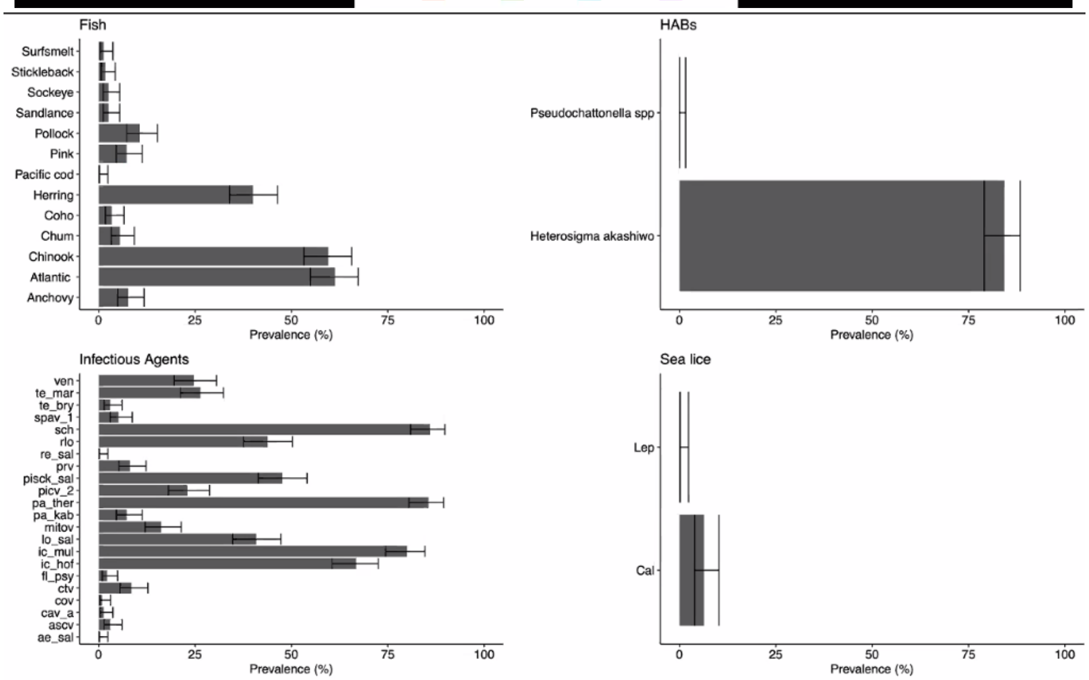
- Virus discovery
  - Focus on Pacific salmon Nidovirus
    - First corona-like virus in fish, proposed to be in the coronaviridae family. Affects gill tissue, potential to impact smoltification and saltwater adaptation. Prevalence in farmed and hatchery Chinook
    - Associated with salmon enhancement hatcheries
  - Could viruses like this one influence the poor returns of hatchery fish?
    - Virus is highly prevalent during smolt development in freshwater. Detected shortly post-release and all but disappears in the month following ocean entry
- Role of aquaculture in the introduction and spread of fish viruses
  - Transmission of pathogens and parasites is very relevant to a risk assessment process.
  - Agents that are amplified in culture carry the opportunity for mitigation of risk if well understood. We have a responsibility as scientists to probe all potential risks, perhaps most importantly those humans may affect.
- Viruses leave a genetic fingerprint
  - They employed molecular surveillance to explore epidemiological relationships, similar to what has been done to identify transmission pathways for Sars-Cov2.
- PRV case study
  - PRV-1 (an RNA virus) is ubiquitous on Atlantic salmon farms.
  - RNA viruses have high mutation rates, therefore viral genome sequencing can be used to trace the transmission paths of different viral lineages.
  - At a global scale, the lineage of PRV in the North East Pacific (a version of the "PRV-1" strain) originates from the Northern Atlantic. PRV was likely first introduced through aquaculture Atlantic salmon introductions from Norway. A

second introduction has also been documented, linked to movement of Icelandic Atlantic salmon eggs.

- In terms of local transmission, two lines of evidence strongly suggest transmission of PRV-1 between farmed and wild salmon:
  - PRV-1 infection in BC Juvenile free-ranging Chinook salmon declined with distance from active salmon farms.
  - Genomic data show that farmed and wild salmon share multiple viral variants

- Molecular pathogen screening - Preliminary microtrolling results





- Q&A Summary

- Stan Proboszcz: I've heard from DFO that PRV is endemic to the region, but you are saying it was introduced. Can someone from DFO comment?
    - Gideon, to define the word endemic – In epidemiology it is a situation in which the prevalence of an infectious agent is stable over a long period of time (as opposed to an epidemic which is growing). In ecology, endemic means an organism native to an area.
- No tools to manage/reduce PRV. Vaccine reduces symptoms but not infection itself
    - Kristi – no known prophylactic measures. But if the risk is with farmed salmon and we are going to have open-net farmed salmon, the only way to *reduce* the impact would be to go to a full-blown area-based management approach. If you get PRV out of the freshwater, if you fallow all farms in the sound for a solid period to reduce farm-to-farm transmission of agents, you could reduce the prevalence. This is still not as effective as removing farms from the sounds, but at least it is a step. Semi-closed farms do not protect against viral spillover.
- How does RAMS deal with cumulative effects and interactive effects?

Art Bass – Population-level impacts of infection in wild Chinook salmon

- Are any infectious agents negatively associated with salmon marine survival?
    - How are marine survival studies conducted?
        - Observational
        - Experimental manipulations
    - SSHI looks at correlation with infectious agent, mortality, and environmental factors. Study design to look at which infectious agents were most correlated with reduced marine survival
        - Showed PRV, T*enacibaculum maritimum*, and *Loma salmonae* (infects gills) had the strongest correlation with poor survival in Chinook salmon
        - Robertson Creek CWT population had one of the strongest negative associations for PRV and *Loma salmonae*
- WCVI Data
    - WCVI Chinook have a higher prevalence of PRV than the rest of coast wide SSHI data. Mostly in sounds north of Barkley
    - High instances of *T. maritimum* in WCVI
    - *Loma salmonae* is more prevalent in sounds than offshore, seen throughout WCVI
- How are pathogens going to change in the future?
    - Evidence for change in *Tenacibaculum maritimum* and *Loma salmonae*
    - Other pathogens negatively associated with survival in Chinook, like *Ichthyophthirius multifiliis* (a freshwater parasite that causes white spot disease impacting Juvenile and Adult salmon) are known to increase in prevalence with warming.

  - Pacific salmon nidovirus appears to be amplified in hatcheries, which could increase prevalence into the future if not mitigated, although associations with disease have yet to be established experimentally
  - Novel, exploratory analysis reveal the potential for population-level impacts on survival and condition
- Conclusions
  - Data are primarily for marine life history phase 2
  - Suggested Scoring:
    - Spatial: Medium (30-40% of habitat)
    - Temporal: Medium (3-4x per decade), varies by sound/inlet climate change could lead to high
    - Impact: Moderate/Major (21-30%)
      - Causality and precise estimate of impact could be determined with experimental release.
    - Confidence: disagreements between experts, Moderate?
      - Data exist with gaps
- Q&A Summary
  - Questions about positive associations of infectious agents with survival in the model
    - May have to do with assumptions like survivor bias
  - Salinity is the most important interactive environmental stressor associated with probability of infection

7.3.6 Workshop Synthesis

7.3.6.1 Distribution Plots and Comment Summaries

Four marine life history stages (LS) were considered:

LS1 (first marine spring, summer and fall in estuary and nearshore marine) along WCVI

LS2, first marine winter along WCVI)

LS3 (subsequent marine rearing of ages 2-4+ north of Vancouver Island ending when fish begin their homeward migration, and

LS4 (Adult fish migrating back to the WCVI and into estuaries)

Distribution plots follow sequentially for Life Stages 1, 2 and 4 starting with LF8 (LS3 was not considered to be relevant and was not assessed). Although risk was assessed for both naturally produced Chinook and those of hatchery-origin, we do not present the latter since there was agreement that effects on hatchery fish would either be lowest, or not important to this discussion. Numbers of individuals who did not rate a particular LF were recorded. Workshop participants were encouraged to input comments as they evaluated each relevant LF and LS; summaries are provided below.

Workshop results were tabulated and basic statistics (e.g., mean, median, mode, range, and standard deviation) computed for each LF and LS. These statistics were frequently inadequate due to small sample sizes and skewed statistical distributions. To help interpret these frequency distributions, a small team met during March 2023 and developed single consensus Review Scores for each of Likelihood, Impact, Future Trend, and Confidence. A brief comparison between consensus Review and Mean Scores follows in 6.b.

Here we briefly describe the distribution results for only the first example (LF8, Figure 7.17, LS1). The same approach was used for all LFs. Refer to the Methods Section in the main report (i.e., before Appendices) for more detailed methods description.

Each LF and LS has six distribution plots (e.g., Figure 7.17):

Likelihood, Impact, and Future Trend (top row).

Participant's Confidence in their scoring, Current Risk, and Future Risk (over the next 30 years; 2nd row).

The plots in the first row and the left-hand plot in the second row of Figure 7.17 display score distributions as well as consensus Group Scores; i.e., Review Scores for Likelihood (upper left plot) was 4, Impact (upper middle plot) was 3, Future Trend (upper right plot) was 4, and Confidence (lower left-hand plot) was 2 (Moderate).

Risk matrices were applied to determine Current and Future Risk distributions and single risk category review results based on the scores for Impact, Likelihood and Current Impact, Future Trend respectively. For details, see the text in the main RAMS methods section earlier in this report.

LF8: Mortality or fitness reduction due to exposure to deleterious substances or contaminants. The hypothesis is that contaminants result in reduced growth, survival and/or fitness.

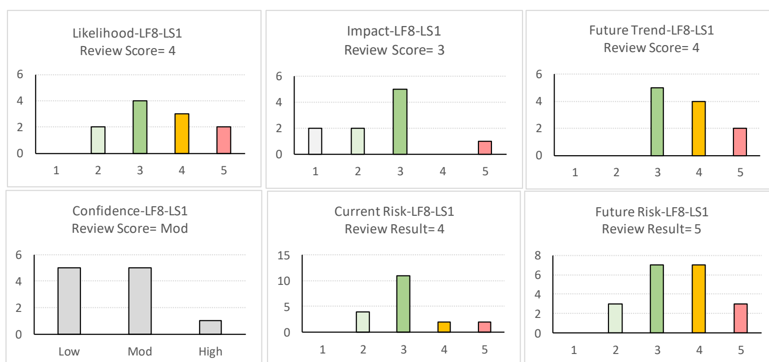


Figure 7.17 **Frequency distribution plots of participant scores by Limiting Factor and Life Stage for Likelihood, Impact, Future Trend, and Confidence. Review scores are based on a group consensus review of these plots. Current and Future Risks and associated frequency distribution plots and Review Scores are calculated based on risk matrices (see Methods in Main report). If n<4, then confidence=low (i.e., 1) regardless of distribution.**

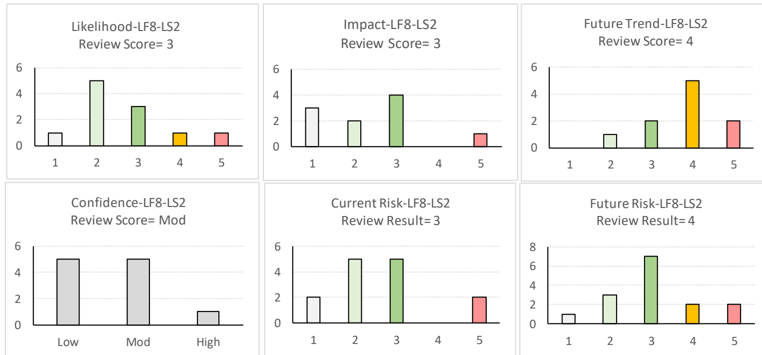


Figure 7.18 **Frequency distribution plots of participant scores by Limiting Factor and Life Stage for Likelihood, Impact, Future Trend, and Confidence. Review scores are based on a group consensus review of these plots. Current and Future Risks and associated frequency distribution plots and Review Scores are calculated based on risk matrices (see Methods in Main report). If n<4, then confidence=low (i.e., 1) regardless of distribution.**

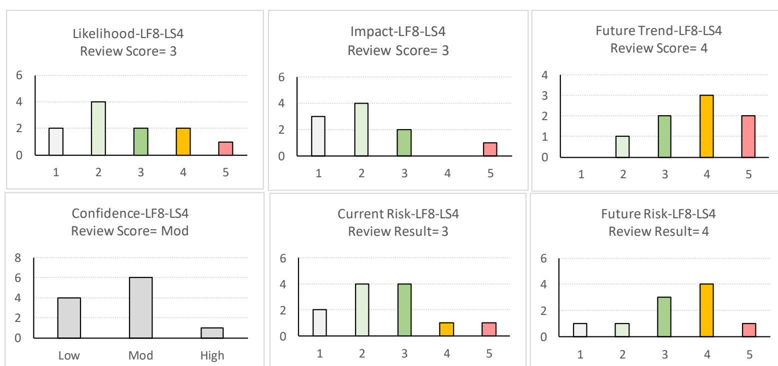


Figure 7.19 **Frequency distribution plots of participant scores by Limiting Factor and Life Stage for Likelihood, Impact, Future Trend, and Confidence. Review scores are based on a group consensus review of these plots. Current and Future Risks and associated frequency distribution plots and Review Scores are calculated based on risk matrices (see Methods in Main report). If n<4, then confidence=low (i.e., 1) regardless of distribution.**

LF 8 –Detailed Survey Comments:

LS1 and LS2 General Summary:

- Contaminants likely have a cumulative impact with other stressors on salmon fitness in future stages of life. Many contaminants can impair immunity, increasing vulnerability to diseases caused by pathogens or parasites
- LS2 seen as less high risk than LS1, but still a risk of cumulative impacts, and contaminants absorbed at sea
- Uncertainties around how many and what contaminants are in the marine environment impacting fish. Don't have great information about spills or run off, and specific impacts on Chinook salmon.

- Most contaminants are chronic rather than toxic--so greatest impacts may be on later life-stages

LS 4 General Summary:

- More likely chronic impacts of contaminants at this stage - cumulative contaminants in the body impact ability to manage other stressors as salmon migrate to spawning areas, such a temperature and DO.

LF 8 Basic Survey Comments (For all life stages):

- Life Phase 1 and 2 when salmon are most at risk from contaminants, but they bioaccumulate over their life

Knowledge Gaps

- Knowledge gap about what contaminants are entering the water, where they are entering, and how much they are being absorbed by salmon.
- How do contaminants impact survival and fitness at mature life stages? Are impacts largely cumulative or synergistic with other factors, especially infectious disease?
- Information on contaminants specifically for WCVI, and impacts on Chinook salmon.
- Concern chemical pollutants from salmon farms are an increasing risk.
- Road runoff/tire pollution data was particularly concerning-but is this more of a FW impact? Possibly carryover impact (data gap), but most important to study this factor cumulatively with other health metrics, so an integrated program with shared fish would be beneficial

Options for Mitigation

- Develop further regulations around contaminants being used that end up in the marine environment and may impact salmon

LF9. Mortality or fitness reduction due to disease from pathogens

Figure 7.20 **Frequency distribution plots of participant scores by Limiting Factor and Life Stage for Likelihood, Impact, Future Trend, and Confidence. Review scores are based on a group consensus review of these plots. Current and Future Risks and associated frequency distribution plots and Review Scores are calculated based on risk matrices (see Methods in Main report). If n<4, then confidence=low (i.e., 1) regardless of distribution.**

Figure 7.21 **Frequency distribution plots of participant scores by Limiting Factor and Life Stage for Likelihood, Impact, Future Trend, and Confidence. Review scores are based on a group consensus review of these plots. Current and Future Risks and associated frequency distribution plots and Review Scores are calculated based on risk matrices (see Methods in Main report). If n<4, then confidence=low (i.e., 1) regardless of distribution.**

Figure 7.22 **Frequency distribution plots of participant scores by Limiting Factor and Life Stage for Likelihood, Impact, Future Trend, and Confidence. Review scores are based on a group consensus review of these plots. Current and Future Risks and associated frequency distribution plots and Review Scores are calculated based on risk matrices (see Methods in Main report). If n<4, then confidence=low (i.e., //1) regardless of distribution.**

LF 9 – Detailed Survey Comments

LS1 General Summary:

- Concern about compounding effect of temperature increase, parasites, contaminants etc. on the impact of pathogens on fish health. Understanding these relationships is the greatest gap we need to fill.
- For example, a recent study on a gill parasite, *Paranucleospora theridion* (aka *Desmozoan lepthioptherii*) that was found to be negatively associated with Chinook survival over the first summer at sea, showed that disease development was positively correlated with temperature and negatively with dissolve oxygen in Atlantic salmon, suggesting that environmental conditions are highly relevant to impact (Simon Jones, DFO, presented at Fish Health workshop).
- Concern about impact of increasing water temperature on pathogen spread

- Having fitness be compromised by a pathogen, even marginally, seen as increasing chance of mortality a lot, especially through predation
- Concern about amplification of pathogen risks due to spillover from farms and aquaculture processing plants. This is a manageable risk but has to be recognized as such to be appropriately managed.
- Cumulative effects of co-infection with multiple pathogens are highly likely. SSHI introduced combined metrics of pathogen richness and load and showed that these overall infection metrics were strongly negatively correlated with the condition and survival of Chinook salmon.

Full assessments of synergistic effects of specific combinations of pathogen infection have not been properly assessed by DFO.

LS2 General Summary:

- Comments are much the same as for LS1.
- Concern about cumulative impacts of increased water temperature, contaminants, prey limitations, smaller fish, and pathogens on Chinook survival
- Pathogens in WCVI Sounds are statistically higher than in other areas along the coast, particularly in the fall.
- At the LS2 stage, Chinook residing in WCVI Sounds north of Barclay may experience the highest impacts from pathogens spilled over from farms, as they will co-habit the environments where farms are localized.

LS4 General Summary:

- Concern about cumulative impact of increased water temperature on exposure to pathogens and fish migrate back into sounds. Also, cumulative impact of decreased physical fitness as Adults get ready to spawn increasing chance of pathogen infection.
- New Bamfield holding study demonstrating tenacibaculosis outbreak of fish caught and handled by sport fishing gear also points to concern of enhanced disease impacts exacerbated by catch release fisheries. Minimization of handling is particularly important, both to reduce stress but also to reduce scale loss and wounding, which can increase opportunistic infections.
- While Adult salmon are generally seen as less high-risk life stage than Juvenile stages, there is less available research on Adult salmon, hence a lower confidence in this assessment. Most studies on pathogen infection impacts on Adult salmon have taken place in rivers, rather than on the marine approaches to natal rivers. That catch-release or catch-escapement may increase incidence of stress and wounding should be considered as a possible confounding factor that may increase risk of infectious disease. Moreover, high density farms are known to spill over pathogens, including opportunistic bacteria and fungi that carry potential to infect fish that have lost scales or been wounded from fisheries release, that could increase these risks.

LF 9 – Basic Survey Comments:
Reasons for Risk

- LS1 is likely the highest risk life stage, given the highly stressful transition between freshwater and marine entry, and the small size of LS1 fish.
- Cumulative impacts of climate-induced stressors such as elevated temperature and low DO are also most likely to affect LS1 Chinook. However, cumulative impacts that include predation and prey resources are not specific to LS 1.
- There are some overwinter diseases, like jaundice/anemia--associated with PRV infection, that may disproportionately impact LS 2 fish over winter, and there is good evidence that WCVI Chinook may be particularly vulnerable.
- Also potential for high impact at migration back to freshwater to spawn. This has not received as much study in WCVI Chinook.

Knowledge Gaps

- General uncertainty about the cumulative impacts of pathogens with other stressors, and the impact of pathogens on total survival and productivity.
- It's challenging not knowing the magnitude of natural loss outside of the study timeframes. Lab studies are considered to be fairly solid, but only if they are designed with enough power. Unfortunately, it is very hard to recapitulate in the laboratory the full range of conditions fish face in the natural environment that contribute to disease development and impact. Too often laboratory studies use death as the main indictor of disease impact, and suggest anything less than death is minimally impactful, or even avirulent. Physiological compromise is a better measure, but not always easy to recapitulate in the lab (e.g. PRV studies have failed to recapitulate the intensity of disease manifestation and impact that occurs in the field).

Options for Mitigation

- Continued research to better understand pathogens – where they are occurring, how they're impacting fitness etc. will help identify whether there are human influenced transmission risks that can be mitigated.
- Implement regulations or safety mechanisms to limit pathogen transfer at Juvenile life stages as fish pass through high-risk areas.
- DFO as a department needs to be specifically focused on protecting Wild Salmon, an important resource for all Canadians
- **LF10. Mortality or fitness reduction due to infection by parasites--** Note that the talks and discussion around this factor were strictly focused on sea lice parasites, which have received considerable research concerning risks posed by high density farm spillover. Fungal and Protozoan microparasite impacts were covered under "pathogens".

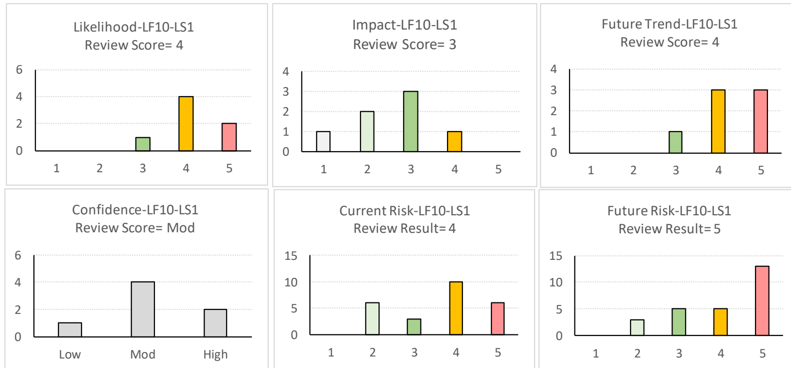


Figure 7.23 **Frequency distribution plots of participant scores by Limiting Factor and Life Stage for Likelihood, Impact, Future Trend, and Confidence. Review scores are based on a group consensus review of these plots. Current and Future Risks and associated frequency distribution plots and Review Scores are calculated based on risk matrices (see Methods in Main report). If n<4, then confidence=low (i.e., 1) regardless of distribution.**

Figure 7.24 **Frequency distribution plots of participant scores by Limiting Factor and Life Stage for Likelihood, Impact, Future Trend, and Confidence. Review scores are based on a group consensus review of these plots. Current and Future Risks and associated frequency distribution plots and Review Scores are calculated based on risk matrices (see Methods in Main report). If n<4, then confidence=low (i.e., 1) regardless of distribution.**

Figure 7.25 **Frequency distribution plots of participant scores by Limiting Factor and Life Stage for Likelihood, Impact, Future Trend, and Confidence. Review scores are based on a group consensus review of these plots. Current and Future Risks and associated frequency distribution plots and Review Scores are calculated based on risk matrices (see Methods in Main report). If n<4, then confidence=low (i.e., 1) regardless of distribution.**

LF 10 –Detailed Survey Comments:

LS1 General Summary:

- Most participants were concerned about cumulative, compounding impact of increased temperature, exposure to contaminants and pathogens, on top of sea lice parasites to impact Chinook survival.

LS2 General Summary:

- Concern around cumulative impacts of climate change, pathogens, weather variability etc. combined with sea lice parasite impacts of chinook fitness and survival.

LS4 General Summary:

- Under extreme physiological stress (e.g., very high temperatures, repeated handling in catch/release fisheries) it is possible that effects of high louse loads could increase but these scenarios are already so stressful to Adult fish it's unclear how large of an impact on survival there would be
- Impact on Adults is expected to be low, but we do not really understand the secondary effects of wounding from louse infection, which could increase risks of opportunistic fungal and bacterial infections.

LF 10 – Basic Survey Comments:

Reasons for High Risk:

General Summary:

- Comments on this topic seem to be the most polarized – some feel like any increase in sea lice is drastically impacting chinook survival, others feel that data shows that sea lice are not having a long-term impact on chinook survival, and that infection rates in Sounds in fairly low. Most of the disagreement comes between researchers, veterinarians and staff affiliated with the aquaculture industry and ecologists more concerned with wild fish health.

- Generally, everyone recognizes that sea lice will have a larger impact on Juvenile chinook fitness than larger fish.

Knowledge Gaps:

- Most participants believe that there is quite a bit of information and data on sea lice parasites and Chinook salmon. The disagreement between experts is on whether the current data shows that current parasite levels are having a negative impact on chinook survival.

Options for Mitigation:

- A group of participants feel strongly about the removal of net pen fish farms and are unlikely to be convinced that farms are having a minimal impact on sea lice abundance in wild salmon. On the other hand, industry affiliated proponents are equally unmoving on the view that there is minimal risk or impact of louse infection from farmed to wild Chinook salmon.
- There was, however, general consensus on needing to keep sea lice levels as low as possible – different mitigation options based on perspective of the experts. These include – new methods to disrupt transmission pathways, removing open pen fish farms, and policy pressure to keep lice levels low on farms.
- There was some concern expressed on the impacts of hydrolicer treatments, which have become the industry standard for lice removal given increased drug resistance to emamectin benzoate. While industry and DFO have suggested this was an "environmentally friendly" solution to reduce sea lice abundance on farms, there are not sufficient data to show that all life stages are killed, and filtration of the effluent, only recently required, does not capture the Juvenile life stages. Moreover, there was concern expressed over the lack of treatment to kill bacterial or fungal pathogen that would be contained in the mucous and scales washed off of the fish, which can spill back over to wild fish. This is an area that requires careful study to ensure this treatment option is not enhancing risks of transmission of other pathogens to wild salmon.

LF11. Mortality or fitness reduction due to harmful algal blooms

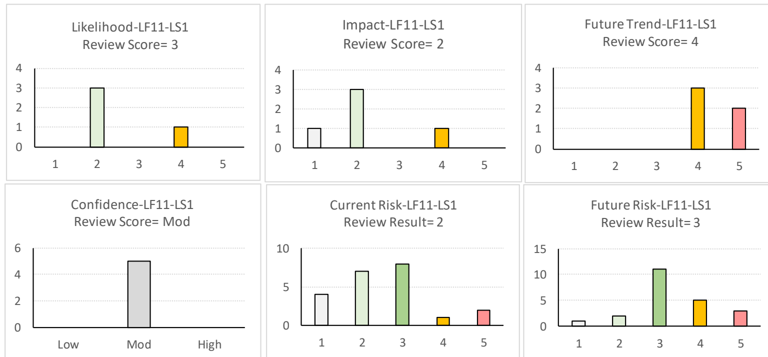


Figure 7.26 **Frequency distribution plots of participant scores by Limiting Factor and Life Stage for Likelihood, Impact, Future Trend, and Confidence. Review scores are based on a group consensus review of these plots. Current and Future Risks and associated frequency distribution plots and Review Scores are calculated based on risk matrices (see Methods in Main report). If n<4, then confidence=low (i.e., 1) regardless of distribution.**

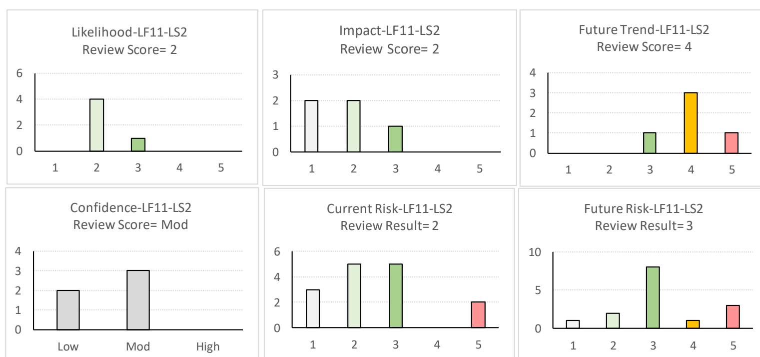


Figure 7.27 **Frequency distribution plots of participant scores by Limiting Factor and Life Stage for Likelihood, Impact, Future Trend, and Confidence. Review scores are based on a group consensus review of these plots. Current and Future Risks and associated frequency distribution plots and Review Scores are calculated based on risk matrices (see Methods in Main report). If n<4, then confidence=low (i.e., 1) regardless of distribution.**

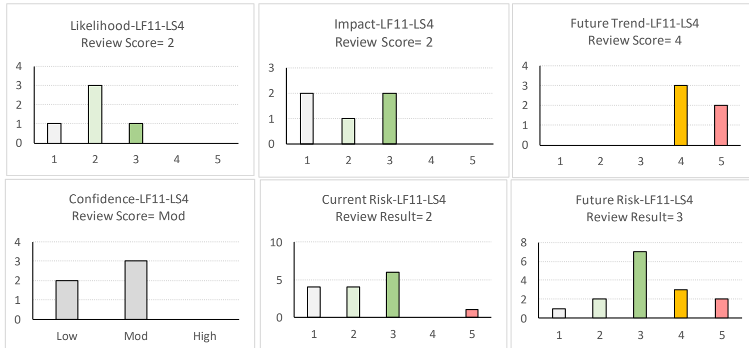


Figure 7.28 **Frequency distribution plots of participant scores by Limiting Factor and Life Stage for Likelihood, Impact, Future Trend, and Confidence. Review scores are based on a group consensus review of these plots. Current and Future Risks and associated frequency distribution plots and Review Scores are calculated based on risk matrices (see Methods in Main report). If n<4, then confidence=low (i.e., 1) regardless of distribution.**

LF 11 –Detailed Survey Comments:

LS1 General Summary:

- Most participants commented about how algal blooms are closely tied to climate change and increasing water temperature.
- Blooms will potentially have impacts on prey quality, food webs, growth, fitness, visibility for predation and habitat quality

LS2 – General Summary:

- Weather variability (increased river discharge, stress from oxygen or temperature or salinity change) due to climate change. Large scale changes like stream changes, logging, and environmental regulations around discharge could also impact. Essentially anything that results in changing water quality or eutrophication. The research needs here are likely different and more likely should be focused on the behavioral evasion of HABs and/or their toxins and the potential for bioaccumulation in feedstuffs.

LS4 – General Summary:

- Drought in summer affecting surface salinity combined with precipitation can trigger blooms. The presence of fish farm excretory products can fuel local events. Ubiquitous spores in sediments wait for the perfect conditions of salinity, temperature, and nutrient levels to bloom.

LF 11 – Basic Survey Comments:

Reasons for Risk:

- Algal blooms are seen as a lower likelihood, but very high impact events
- Generally seen that algal blooms will have the highest impact on LS1.

Knowledge Gaps:

- What are the mediating factors that affect the lethality of HABs for Chinook salmon? I.e., how do HABs interact with oceanographic conditions and prey availability to impact survival? How do salmon avoid negative impacts of HABs through changes in their behavior (i.e., what is their capacity to adapt and cope)?

- We need to better understand the relationships between environmental conditions (e.g., temperature, salinity, dissolved oxygen, pCO2, nutrients) and the production of biotoxins by harmful algal species, as well as the sub-lethal effects (growth, development, reproduction) that result from chronic exposure of (WCVI) Chinook salmon to environmentally relevant concentrations of these toxins during different life-stages.

Options for Mitigation:

General Summary:

- Seen as challenging to mitigate, as highly related to increasing temperature of the ocean
- Try to mitigate the introduction of substances that increase/produce HAB's into the marine environment. Some HAB species may be enhanced with organic loading from farms and processing plants.

7.3.6.2 Ranked Risks

To rank the relative risk of different LF's, results for all LFs were sorted first by Group Current Risk Review Result, then Group Future Risk Group Result, and finally by a percent current risk high score, the percentage of participants' scores that led to a current risk score of high or very high as shown (Table 7.6). Here we included statistical mean values for Future Risk alongside the values computed as described above (Mean FRisk where 5=very high, 4=high, 3=moderate, 2=low and 1=very low) alongside the values computed as described above.

To evaluate the appropriateness of Group consensus Review Scores, we correlated these for Future Risk with statistical mean Future Risk Scores and also compared how risk was categorized using these two approaches. Correlations were not significant (R^2=0.14; p=0.22) and risk categorizations using these approaches varied (Table 7.6). Five LFs were rated as Very High and three as High for Future Risk; using the Mean Future Risk scores, each of these would have been High (i.e., 4). We remained most confident in the Group review group rankings, which form the basis for our analysis and discussion below.

Table 7.6 Ranked (very high to low) current and future risk rankings for limiting factors (LFs) considered during Workshop 3.

		Group review		Participant score statistics											
Limiting Factor	Life Stage	Likelihood Score	Impact Score	Future Trend Score	Confidence Score 1-3	Current Risk Score 1-5	Future Risk Score 1-5	Mean FRisk Score	Reviewed Confidence	Review Result Current Risk	Review Result Future Risk	# people who did not	Current Risk % High	Future Risk % High	Confidence % Low
LF9 disease-pathogens	LS2	4	3	4	2	4	5	4	Mod	High	Very High	4	64%	63%	36%
LF10 infection-parasites	LS1	4	3	4	2	4	5	4	Mod	High	Very High	1	64%	69%	14%
LF9 disease-pathogens	LS1	4	3	4	2	4	5	4	Mod	High	Very High	3	62%	68%	27%
LF10 infection-parasites	LS2	4	3	4	2	4	5	4	Mod	High	Very High	7	44%	72%	14%
LF8 contaminants	LS1	4	3	4	2	4	5	4	Mod	High	Very High	6	21%	50%	45%
LF9 disease-pathogens	LS4	3	3	4	2	3	4	4	Mod	Mod	High	17	42%	58%	55%
LF8 contaminants	LS4	3	3	4	2	3	4	4	Mod	Mod	High	13	17%	50%	36%
LF8 contaminants	LS2	3	3	4	2	3	4	4	Mod	Mod	High	12	14%	27%	45%
LF11 Harmful algae	LS1	3	2	4	2	2	3	4	Mod	Low	Mod	2	14%	36%	0%
LF11 Harmful algae	LS2	2	2	4	2	2	3	4	Mod	Low	Mod	9	13%	27%	40%
LF11 Harmful algae	LS4	2	2	4	2	2	3	4	Mod	Low	Mod	9	7%	33%	40%
LF10 infection-parasites	LS4	3	1	4	2	2	3	3	Mod	Low	Mod	17	0%	38%	43%

For most of the limiting factors, we base much of our understanding upon studies performed outside of the WCVI Sounds, often even in Pacific salmon species other than

Chinook. Hence in future research, it will be important to specifically address these risks within Chinook populations using the Sounds.

LF9 and LF10 on pathogen and parasite risks were both rated overall as High current risks and Very High future risks. The Very High ranking stems from both established relationships with climate change (most notably temperature) and anticipated increasing anthropogenic perturbations to salmon habitats. While our scientific understanding of these risks still contains many gaps, these two risk factors have been better studied than contaminants (LF8) and harmful algae (LF11), especially pertaining to salmon in the ocean.

A surge in research into the role of infective health on survival of wild salmon was triggered in response to the notable gap in our knowledge on disease risks to Fraser River sockeye salmon identified in the Cohen Commission of Inquiry Report and Recommendations (Cohen 2012). However, the studies that ensued were not limited to sockeye salmon, with many focused on Chinook (see LF9 references below). This research identified detections of infective agents in BC wild salmon (Bass et al. 2017; Tucker et al. 2018; Thakur et al. 2018;) and farmed salmon (Laurin et al. 2019; Bateman et al. 2021) never previously surveyed in the Pacific Northwest, uncovered previously uncharacterized viruses infecting Chinook salmon (Mordecai et al 2019) and farmed salmon (2018), geographical hotspots of infection by agents in wild salmon (Bass et al. 2023), agents associated with physiological impacts on Chinook (Bass et al. 2023) and farmed (Di Cicco et al. 2018, 2019) salmon, agents associations between abundance and relative weight—a metric of salmon condition—in Chinook and coho salmon (Bass et al. 2022), and agents with prevalence levels associated with wild salmon survival—based on data from tracking and holding studies (Miller et al. 2014; Teffer et al. 2017,2018, 2019; Bass et al. 2019; Chapman et al. 2020), predation studies (Miller et al. 2014; Furey et al. 2021) and stock recruitment models based on 10 years of data on Juvenile outmigrants (Bass et al. 2022), and agents for which risks of infection are positively associated by exposure to open net salmon farms (Shea et al. 2020; Mordecai et al. 2021; Bateman et al. 2022). This research also developed a new molecular tool to non-lethally recognize fish in a viral disease state (Miller et al. 2017; Di Cicco et al. 2018). There were also several disease challenge studies investigating disease-causing potential of PRV in Pacific and farmed Atlantic salmon (Garver et al. 2018, Polinsky et al. 2019, 2021, 2022 [but see correction in 2023 and Mordecai et al. 2023]). These early studies largely focused on demonstrated mortality and/or outward clinical signs of disease as the endpoint to demonstrate disease, rather than the standard practice of showing recapitulation of disease pathology, and interpreted their findings as evidence of limited virulence of the BC variant of PRV. More recent work by this group that more fully evaluated pathology did, however, demonstrate a cause and effect relationship with the disease HSMI in farmed Atlantic salmon, and found that disease response was more a function of the genetic background of the host population than the presumed virulence of the PRV variant (Polinsky et al., presentation at the 62nd Western Fish Disease Workshop, June 2023).

It is important to recognize that many endemic pathogens and parasites are a natural component of salmon ecosystems, and for agents present for 100’s of years, the co-evolution of pathogens and hosts will often create a homeostasis whereby population-level impacts of infection will be minimized. However, shifting environmental conditions can disrupt the adaptive equilibrium between pathogens and their hosts, increasing the potential for population-level impacts even from endemic agents of disease. This includes the enhanced risks of infection when pathogens are concentrated where high density salmon culture occurs, and where offal from salmon processing plants is released untreated back into the marine environment. These risks are highly controllable if there is will by regulators to do so and this very fact is the reason that pathogen and parasite impacts were so polarizing in the workshop, which included participants from industry, academics, government, First Nations, and eNGOs.

It was recognized by all participants that climate change will continue to impact the future risks of pathogens and disease, and while human mediated, this will be a very difficult factor to manage on the short term. However, understanding the cumulative and synergistic relationships between environmental variation due to climate change and pathogen/parasite infection dynamics, and their resultant direct and indirect effects on Chinook salmon hosts, will be crucial to the identification of factors that can be effectively mitigated to increase survival of wild salmon.

Contaminants (LF8) rated as a moderate (LS2, LS4) or high (LS1) current risk, and high (LS2, LS4) or very high (LS1) future risk. However, there was a fair degree of uncertainty in these rankings, reflected in their low confidence rating. While there was a compelling presentation on elevated contaminant concentrations from road-runoff, flame-retardant, pulp mill effluent, and agricultural pesticides within WCVI sounds, there were no data directly relating these to impacts on WCVI Chinook salmon, an area that requires further research. However, there was general agreement that impacts of contaminants were likely more important when considering cumulative impacts with other stressors, including increased susceptibility to pathogenic disease. Future studies need to consider contaminant effects in cumulative effects modeling on Chinook to provide more certainty on the intrinsic and extrinsic conditions associated with the strongest impacts, required to develop effective mitigation. Given that contaminants are largely human-derived, they are risks that can be mitigated with regulations on chemicals causing the greatest harm.

Harmful algae were given a Low current risk rating, with an increase to Moderate for future trends due to established associations with climate change and ocean acidification, although these rankings carried a Low confidence. There is good evidence that harmful algae negatively impact survival of salmon cultured in open-net farms, where fish often cannot move deep enough in the water column to escape bloom events. Many assume that wild fish will sense and avoid bloom events, but hard empirical evidence is required to verify or refute this assumption. Despite the ability to move deeper into the water column, we know that wild Chinook and sockeye salmon expose themselves for enough time to high SSTs in the summer to induce thermal stress signatures and will remain in oxygen depleted water at depth despite the availability of normoxic, cool water available at mid-depth. This is likely due to a tradeoff between optimized feeding opportunities and avoidance of predators. As such, it is possible that fish will still enter surface bloom areas to feed, but whether they remain there long enough to be impacted is unknown. This area requires more research, especially given a projected increasing risk with climate change.

7.3.7 Key Literature[3]

LF9 - Pathogens:

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7.3.8 Participants' Names and Affiliations

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7.4 Workshop 4 – Nutrition and Changes in Prey Quality, Availability, Timing and Composition

May 3-4, 2022

7.4.1 Background

The fourth of seven workshops intended to 1) create understanding of existing knowledge on WCVI Chinook salmon and 2) investigate factors limiting their survival and productivity during their marine life stages and 3) identify knowledge gaps.

7.4.2 Objective(s)

To discuss and rank the potential risk factors (Table 7.7) of food availability, quality and timing on the survival and fitness of WCVI Chinook salmon during their marine life history.

Table 7.7 Limiting factors (LFs) assessed during Workshop 4.

LF	Category	Limiting Factor Description
12	Nutritional Quality	Mortality or fitness reduction due to the quality of available prey
13	Prey Availability	Mortality or fitness reduction due to limited abundance of prey
14	Timing	Mortality or fitness reduction due to phenological mismatch
15	Competition	Mortality or fitness reduction due to intra-specific competition for prey

7.4.3 Summary of Results

Table 7.8 Ranked (high to low) current and future risk rankings for limiting factors (LFs) considered during Workshop 4 (see Section 6 for details).

Limiting Factor	Life Stage	Review Result Current Risk	Review Result Future Risk
LF13 Prey abundance	LS3	High	Very High
LF13 Prey abundance	LS1	High	Very High
LF12 Prey quality	LS2	High	Very High
LF12 Prey quality	LS1	High	Very High
LF15 Intra-specific competition	LS1	High	Very High
LF14 Mis-match with prey	LS1	High	Very High
LF13 Prey abundance	LS4	High	High
LF15 Intra-specific competition	LS2	High	High
LF13 Prey abundance	LS2	Mod	High
LF12 Prey quality	LS3	Mod	High
LF14 Mis-match with prey	LS3	Mod	Mod
LF14 Mis-match with prey	LS2	Mod	Mod
LF15 Intra-specific competition	LS3	Low	Mod
LF12 Prey quality	LS4	Low	Low
LF15 Intra-specific competition	LS4	Low	Low
LF14 Mis-match with prey	LS4	Low	Low

The limiting factors related to nutrition, change in prey quality, availability, timing and composition for both current and future risks were generally rated higher for Juveniles relative to sub-Adult and Adult salmon (Table 7.8). These ratings align with expectations of high mortality during the early marine period, material presented during this workshop (Section 5), and other workshops. Most nutrition limiting factors rated as high (mostly for Juvenile life stages) for current risk were rated as very high for future risk. However, the high current risk ratings for 'Intra-specific competition [LF15]' for first marine winter and 'Prey abundance [LF 13] for the Adult life stage both retained high future risk ratings.

Low risk scores for both current and future risks were given to Adult stages for 'Prey Quality [LF12]', 'Mis-match with prey' [LF14] and 'Intra-specific competition'[LF15]. Those moderate and low current risk scores that did change increased from current low and moderate to moderate and high future risk ratings and were associated with Juvenile (LS1, LS2) and sub-Adult (LS3) life stages. Note, for the Marine Risk Assessment, life stages are defined in Section 2.1, and again briefly here as: LS1) represent the first ocean summer as Juveniles; LS2) the first ocean winter as Juveniles; LS3) sub-Adult to Adult rearing; and LS4) mature Adult migration to natal stream.

For Juveniles, limiting factors, 'Prey quality', and 'Intra-specific competition' were both rated high for current risk during the first marine summer through winter (LS1 and LS2). However, the current risk rating for 'Prey Abundance' [LF13] was High for first Juvenile summer and moderate for winter. The limiting factor, 'Mis-match with prey' was rated as High for summer and Moderate current risk for Juveniles during their first winter. Future risk for 'Mis-match with prey' was rated as Very High for early Juveniles, consistent with predicted variability of Chinook outmigration timing /duration. Most current risks rated High were Very High for future risk given reasonable expectations for the increased future variability of prey availability, quality, composition, and timing. Only limiting factors 'Prey abundance' for Adults and 'Intra-specific competition' for winter Juveniles retained a High rating for both current and future risks.

For Adults, risk and future risk were rated as Moderate and Low, reflecting increased survival with life stage, reduced feeding, and limited knowledge (and moderate confidence ratings) of how variable prey availability, quality, and timing, influence Adult survival. Limiting factor 15, 'Competition' addressed the influence of the intraspecific competition which was rated with a high current risk (very high future risk).

7.4.4 Agenda

Day 1

9: 00 am	Welcome, the WCVI RAMS process, review, code of conduct, products & goals. Today's plan. Marc LaBrie, WCA
9:15 am	Overview of Chinook Life History. Wilf Luedke, DFO
9:30 am	Brief Introduction to the Workshop 4 Limiting Factors and the Scoring Process. Jessica Hutchinson, Redd Fish
9:45 am	Juvenile Chinook Diet off the WCVI. Jackie King, DFO
10:15 am	Break

10:30 am	Feeding related aspects of the early marine biology of Juvenile hatchery and wild Chinook salmon in Barkley Sound. Ron Tanasichuk, DFO Emeritus
11:10 am	Factors driving and implications of variation in feeding ecology of WCVI Chinook. Eric Hertz, PSF
11:40 am	DFO Zooplankton monitoring programs: West Coast of Vancouver Island. Akash Sastri, Ian Perry, Moira Galbraith, Kelly Young, John Nelson, DFO
12:05 pm	Biomass and distribution of WCVI herring. Jaclyn Cleary, DFO
12:00 pm	Lunch
1:30 pm	Herring-Juvenile salmon interactions. Will Duguid, UVic and PSF
2:00 pm	Regional variation in food quality and Chinook nutritional health in BC. Brian Hunt, Jacob Lerner, Dilan Sunthareswaran, UBC
2:30 pm	Changing outmigration phenology and phenological mismatch in Juvenile salmon. Sam Wilson, SFU
3:00 pm	Break
3:15 pm	Marine distribution and feeding of immature and mature WCVI Chinook and other salmon. Jim Irvine, DFO
3:50 pm	Do pink and chum salmon affect WCVI Chinook via reduced food availability and quality? Jim Irvine, DFO; Greg Ruggerone, NRC; Brendan Connors, DFO
4:20 pm	General discussion
4:30 pm	Adjourn

Day 2

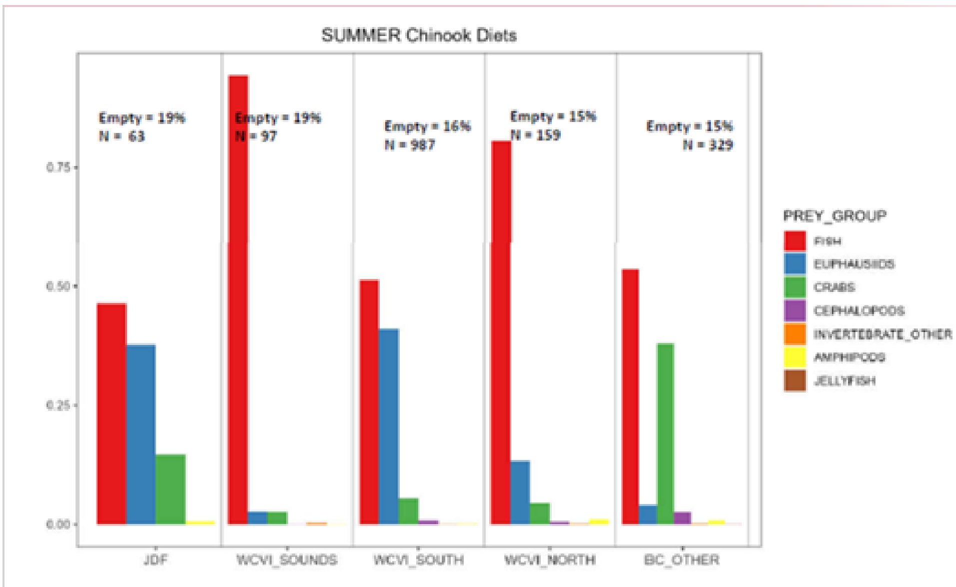
9:00 am	Overview of Day 1 – Jim Irvine and Marc LaBrie
9:15 am	Limiting Factor Scoring - Isobel Pearsall and Overview of online scoring activity. Tim Hawkins, WCA.
9:45 am	Discussion about the Limiting Factors presented during Day 1- should any be added? Discussion of key knowledge gaps, other information sources, immediate research priorities, potential actions, and scoring of limiting factors
10:30 am	Break
10:45 am	Continue discussion and scoring long form with group and Risk Rating Committee
12:00 pm	Lunch
1:00 pm	Organizing committee debrief

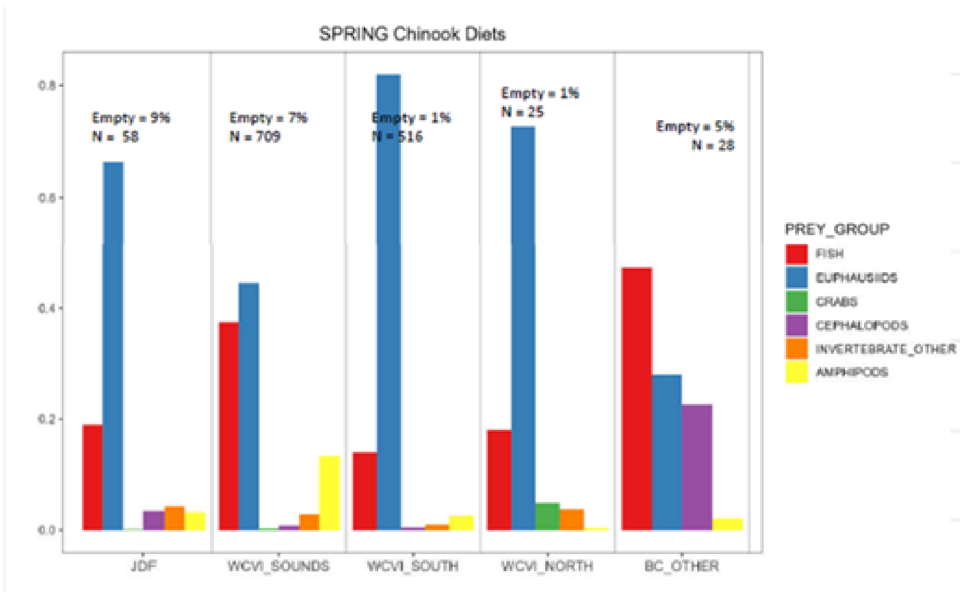
7.4.5 Presentation and Discussion Highlights

a) Juvenile Chinook Diet off the WCVI. Jackie King, DFO

- Summary of long-term (1998-2021) WCVI midwater trawl surveys which explicitly addressed LF#12 (Nutritional quality) and LF#13 (Prey availability). Major question(s): how does Juvenile Chinook diet and condition vary between their first marine summer, fall, winter and spring, and also across years, and regions?

- Diet composition (% of total stomach content volume) varies across with seasons with forage fish and euphausiids dominating in all seasons and regions for most years. Forage fish dominate stomach contents summer through winter with seasonally varying composition; whereas euphausiids dominate stomach contents in the spring.





- Juvenile hinook are mostly found in the sounds during the summer and spread out to also occupy the shelf during fall through winter where overall condition tends to be better. Interannual signals manifest during the fall and some periods (i.e. 2007-2010) recognized for poor condition.

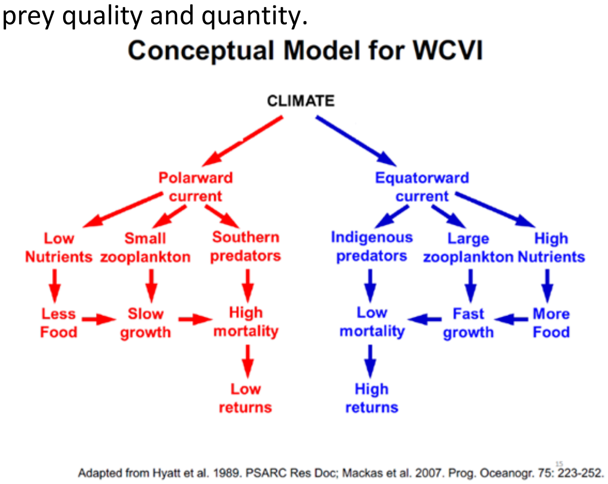
b) Feeding related aspects of the early marine biology of Juvenile hatchery and wild Chinook salmon in Barkley Sound. Ron Tanasichuk, DFO Emeritus

- Summary of intensive, 259, beach and purse-seining study during May-July 2000 and May-August 2001 in Barkley Sound to learn about migration, timing, distribution, and diet of Juvenile Chinook, coho, sockeye, and chum salmon. This presentation specifically addressed LF#13 (Prey availability), LF#14 (Timing) and LF#15 (Competition).

- In terms of timing, greatest Juvenile chinook abundance in Barkley Sound followed the other species indicating little opportunity for competition during first ocean summer. Timing of both wild and hatchery Juvenile chinook was similar.
- Juvenile chinook feeding was largely non-selective, however, life history analysis indicated that returns of Robertson Creek hatchery Chinook was: age-determined (inherited effects); predator (Mackerel, Sea-lions) effects, and the availability of the euphausiid, *Thysanossa spinifera*.

c) Factors driving and implications of variation in feeding ecology of WCVI Chinook. Eric Hertz, PSF

- Addressed the 'missing middle' between physics and fish. Summary of the relationships between climate variability, broad-scale sea-surface temperatures, copepod community structure and variability of trophic positions (estimated via stable isotopes) for zooplankton and salmon along WCVI (Hertz et al. 2016). This presentation explicitly addressed LF#12 (Nutritional quality) and LF#13 (Prey availability).
- Clear ontogenetic shift in diet composition with increasing dominance of fish in diet relative to euphausiids, amphipods and decapod larvae.
- Models relating climate indices, to varying oceanographic conditions and copepod community structure predicted survival of Chinook smolts by looking at their δ13C value in the fall.
- Demonstrates how large-scale climate variability can affect the survival of fish by mediating prey quality and quantity.



- Experimental studies of growth across temperatures for animals offered differing quantities and qualities of prey found that both prey quality and prey quantity have a greater effect than temperature.

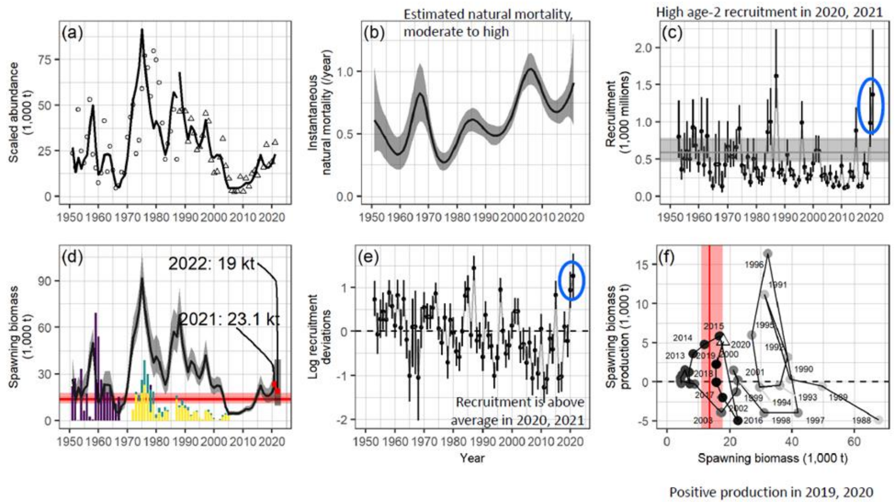
d) DFO Zooplankton monitoring programs: West Coast of Vancouver Island. Akash Sastri et al. DFO

- Summary of long-term zooplankton and oceanographic monitoring along WCVI. This presentation directly addresses LF#12 (Nutritional quality) and LF#13 (Prey availability) on annual time scales with a focus copepod and euphausiid assemblages on the shelf.
- Climate forcing i.e. warm vs. cool oceanographic regimes along WCVI covaries with annual deviation of zooplankton biomass from long-term average. 'Cool' years associated with greater than average biomass of large, lipid rich copepods and lower than average biomass of small, lipid-poor, copepods with a southerly geographic affinity. 'Warm' years are characterized by the opposite pattern.
- Zooplankton community production rates and phytoplankton to zooplankton ecological efficiency covary with zooplankton community composition and broad-scale temperature variation along the WCVI.
- Pre-2010: Temporal patterns of Juvenile coho survival (return to smolt ratios) for southern WCVI, Oregon, and Washington were positively associated with positive biomass of large, 'cool water' copepods, and negatively associated with positive biomass of small, 'warm water' copepod indicator species. Co-variation of both quantity and quality of food with temperature and Juvenile salmon survival.
- Strong association between SST, SSS, total zooplankton biomass and Juvenile chinook survival in the Strait of Georgia.

e) Biomass and distribution of WCVI herring. Jaclyn Cleary, DFO

- The presentation addresses LF#12 (Nutritional quality), LF#13 (Prey availability); and LF#14 (Timing) by summarizing timing and spatial patterns of life history events (i.e. annual timing and location of herring spawning events), and the long-term variation of biomass and size at age of Pacific herring stocks.
- DFO uses a combination of tagging, genetic analysis, local knowledge and field observations to track spatial distributions and migration patterns.
- Herring stock structure varies by spawn timing. Key WCVI spawning areas are: Barkly Sound (SA 23); Hesquiaht Harbour and Clayoquot Sound (SA 24); and Esperanza Inlet/Nuchatlitz Inlet (SA 25)
- Spawn index and catch have been low relative to long-term observations since 2000 (2005 SA 25) with a recent four-fold increase for 2021.
- Biomass, recruitment, and size at age
    - WCVI: post-2005 biomass is stable and slowly rebuilding (modelled and raw estimates)
    - Similar temporal pattern for WCVI spawning biomass which has been at or slightly above the limit point reference since 2010.

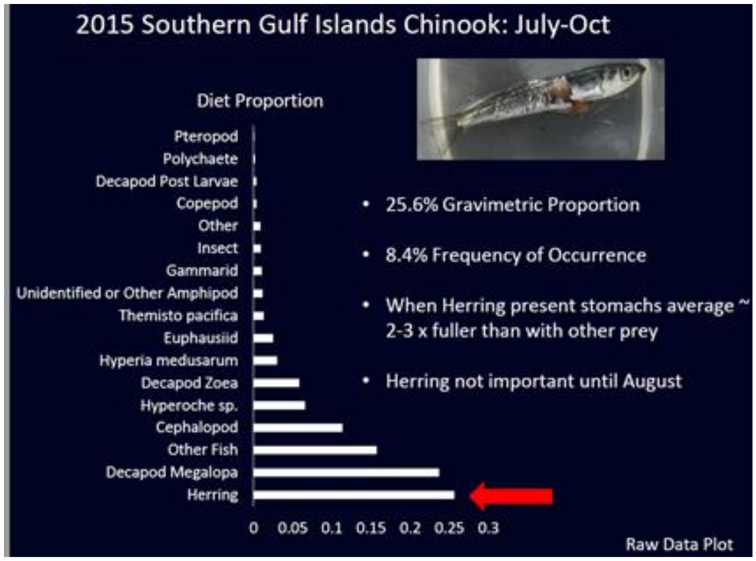
WCVI Biomass and recruitment



- Outstanding questions about WCVI herring stocks:
    - What drives changes in migratory patterns?
    - What drives changes in spawn timing/ spawn distribution?
    - What proportion of summer herring biomass on WCVI is from SOG stock?
    - What is the biomass by age class for summer herring on WCVI?

f) Juvenile Chinook salmon and herring in the Canadian Salish Sea. Will Duguid, UVic and PSF

- Summary of prey availability (LF#13) and timing (LF#14) as factors limiting survival and early marine growth rate of Juvenile Chinook in the Salish Sea and with potential application to WCVI. The presentation framed the importance of survival on early marine growth rate and early marine growth rate on piscivory (Juvenile salmon interactions-herring) in the context of four related hypotheses.
- Age-0 herring have been historically dominant in the diets of Juvenile Chinook salmon in the Salish Sea, and this has been associated with enhanced growth rates relative to more recent periods (2010-2013, 2015-2017) when herring is apparently less important in Cowichan Chinook diets until late summer. Why? Predator-prey size ratios may be limiting the ability of Juvenile Chinook Salmon to transition to piscivory in the Salish Sea. The importance of this phenomenon may differ by year and by stock.



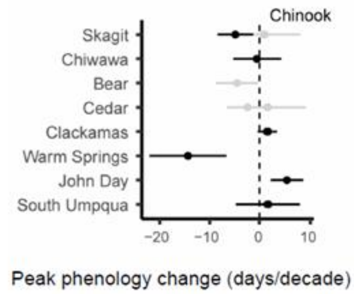
- Are trends in the relative size of first ocean year Chinook and age -0 herring, predator-prey ratios, related to changes in herring population diversity and phenology? Several factors such as collapse of late spawning herring populations (smaller in late summer), changes in temporal spawning diversity, ocean temperature, and abundance may contribute recent changes to size and availability of age-0 herring to Juvenile Chinook.
- Is early growth of Chinooks salmon (prior to piscivory) also impacted by predator/prey size ratios?
- Marine growth (and the potential to transition to piscivory) is likely related to prior growth which could in turn be related to environmental factors such as habitat quality or other intrinsic factors. For instance, wild Cowichan Chinook salmon which would subsequently become piscivorous were growing faster in freshwater (and may have entered the ocean later)
- How important is being unable to eat age 0 herring when other summer food disappears? Herring are the dominant fish prey during the first winter and predator-prey ratio may still be important for fitness i.e. greater tendency for larger Chinook to contain herring in diet in SGI. Similar patterns are apparent from first two years of WCVI microtrolling program.

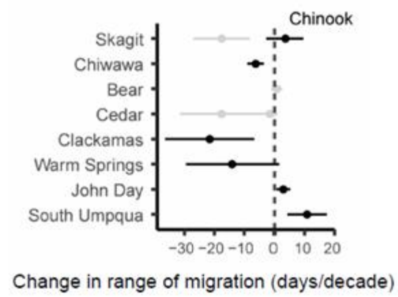
g) Changing outmigration phenology and phenological mismatch in Juvenile salmon. Sam Wilson, SFU

- Broad-scale summary of long-term changes to climate-related timing of smolt out-migration for 66 populations of six salmon species from Northern California to Alaska. Used a state-space model to predict peak and changes to peak timing across years.
- The presentation addresses LF#14 (Timing), asking: 1) is the frequency of phenological mismatches is increasing?; and 2) is phenological mismatch impacts survival and population abundance?

Question 1: Is climate change shifting Juvenile salmon phenologies?

- Examined within-species diversity in phenological shifts for 10 Chinook salmon populations and found: 1) peak timing for 5 populations is getting earlier and 5 leaving later; and 2) 6 of 10 Chinook salmon pops getting wider, 4 getting narrower





  - Species are shifting phenologies at different rates
  - High variability in population phenological shifts within species
  - Possibly leading to future mismatches

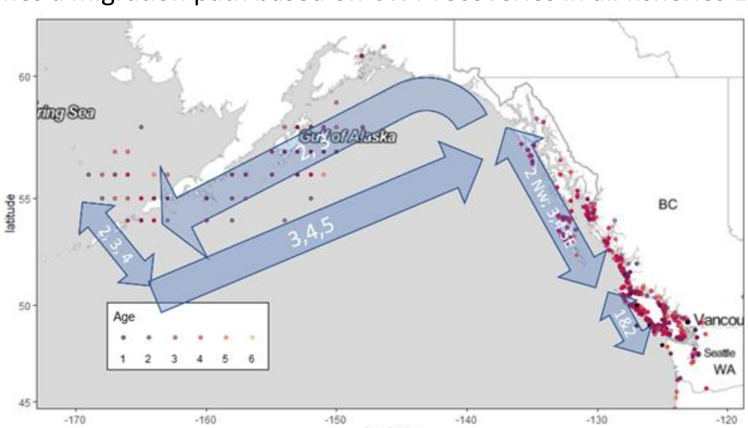
<u>Question 2:</u> Does this change impact survival?

- Steelhead trout study (Wilson et al. 2021) found that larger fish and years with earlier peak timing of northern copepod, prey, biomass (Peterson, Fisher NOAA) had better survival
  - Larger fish have higher survival, independent of ocean conditions
  - Earlier coldwater zooplankton peak correlates with higher marine survival (annual mismatch)
  - Optimal outmigration date varied annually, with marine and freshwater conditions
- Conclusions
  - Shifting phenology could mean increased exposure to phenological mismatches
  - Mismatches can impact population abundance
  - Body condition could impact sensitivity to mismatch
  - Conditions faced in freshwater impact size and condition of fish upon ocean entrance and can impact marine survival (a.k.a. Carryover effects)

h) Marine distribution and feeding of immature and mature WCVI Chinook and other salmon. Jim Irvine, DFO

- This presentation addressed LF#14 (Timing) and LF#15 (Competition) and focused attention on distribution of WCVI Chinook during life history phases 3 and 4 that encompasses the poorly understood period following the first marine winter through return to freshwater (multiple years).

- Since few Chinook were caught as part of pan-Pacific International surveys (net avoidance?), our best understanding of distribution comes from returns of coded-wire tags (cwts) recovered during fisheries Since these are entirely from WCVI hatcheries, primarily from Robertson Creek, it is not possible to known how representative these data are of other WCVI populations. How does distribution vary seasonally and between subAdult and Adults? Adult (maturing) fish are widely distributed from Vancouver Island to Alaska in all seasons; Sub-Adults are off WCVI in spring, by summer distribution extends to Haida Gwaii, and during fall and winter widely distributed.
- How does distribution vary during climate regimes? Pre-1979; 1979-1990; 1990-2000; 2001-present. Few samples pre-1979; modest catches near panhandle Gulf of Alaska post 1979, no obvious shifts between regimes.
- Summary:
    - Marine distributions of Chinook, chum and pink salmon overlap throughout the North Pacific including Gulf of Alaska
    - CWT fishery data are consistent with a movement north of some sub-Adult salmon in their 2nd marine summer; by fall of 2nd marine year, some have gone beyond the panhandle and into Bering Sea
    - CWT data also suggest some WCVI Chinook spend their entire marine life history near WCVI including the Salish Sea
    - Adults (mature fish) are widely distributed in all seasons
    - Small catches in Puget Sound and off Columbia hard to explain (strays?)
- However, cannot conclude that WCVI Chinook are shore-oriented during Phase 3 since CWT fisheries tend to be near-shore, so the following is proposed as marine distribution routes of subAdult and mature (ages 2,3,4,5) WCVI Chinook, which assumes a migration path based on CWT recoveries in all fisheries 1975-2021.



- Two new questions: (assuming WCVI Chinook spend parts of their marine lives in offshore waters):

1. How much overlap in feeding is there among salmon species?
    - Significant overlap (small squid and fish). As well, there may be effects on Chinook if large numbers of pink (and chum) reduce zooplankton numbers and thereby reduce the availability and quality of higher trophic level critters consumed by Chinook.

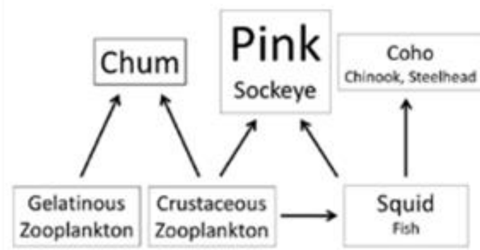
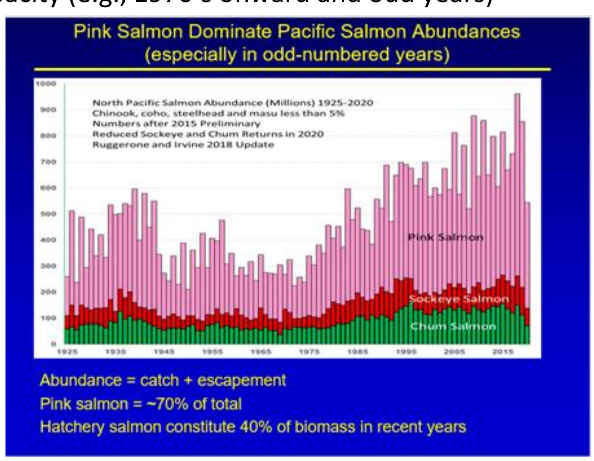


Fig. 1. Primary trophic connections between zooplankton and six species of maturing salmon in offshore waters of the Gulf of Alaska (modified from Aydin 2000).
Figure from Shaul & Geiger 2016

2. Do large numbers of competing salmon suppress prey of WCVI Chinook and thereby influence their growth and survival?
    - Focus of tenth presentation, Irvine et al. summarized below.

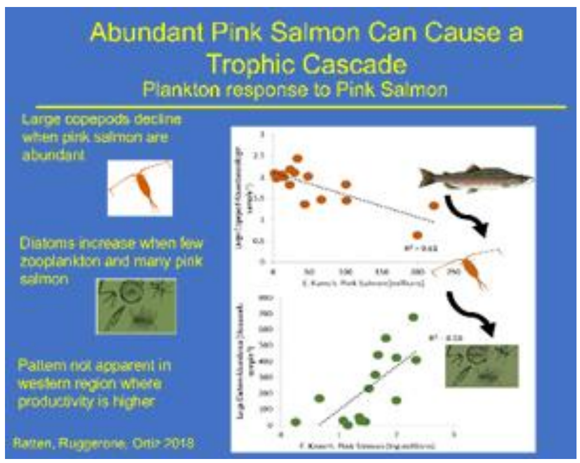
i) Do pink and chum salmon affect WCVI Chinook via reduced food availability and quality? Jim Irvine, DFO; Greg Ruggerone, NRC; Brendan Connors, DFO

- This presentation addressed whether or not LF#15, Competition, can impact chinook salmon survival or abundance. Life phases 3 and 4, with the most overlap with other salmon species (Pink and Chum) were the focus.
- Two processes potentially leading to reduced salmon growth/survival:
    - Constant numbers of salmon entering the ocean but carrying capacity is reduced
    - Number of salmon entering the ocean increases and exceeds carrying capacity (e.g., 1970's onward and odd years)



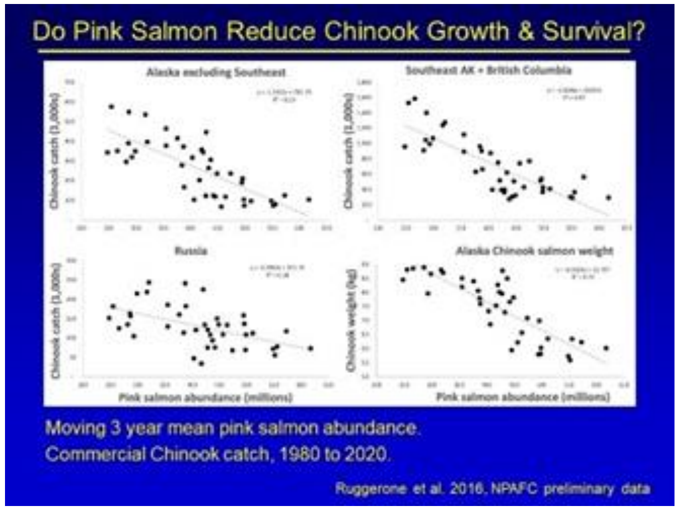
- Total salmon abundance in recent years is about 2.6X that in 1960—1975. Bottom-up processes, such as greater plankton production associated with the warming ocean since the 1977 ocean regime shift, have likely contributed to this great abundance. NB the combined abundance of Chinook, Coho, and Steelhead is less than 3% of the total catch biomass.

- <u>Do Pink Salmon Cause a Trophic Cascade?</u>
    - Zooplankton abundance (using Continuous Plankton Recorder time series) declined with increasing pink salmon abundance in Eastern Kamchatka (Batten, Ruggerone, Ortiz 2018)
    - In contrast, phytoplankton abundance (primary food of herbivorous zooplankton) increased with more pink salmon.
    - This trophic cascade was not detected in the western region where plankton productivity is higher and the biennial pattern of pink salmon is likely weaker.
    - Ruggerone and Connors 2015 found length of Fraser Sockeye spawners (across stocks) is negatively related to ink abundance



- <u>Salmon compete for a common pool of limited resources</u>
    - Pink, hum and sockeye are primarily planktivores but in their 2nd year, pink salmon often eat small squid and fish (as do Chinook)
    - Pink salmon-caused trophic cascades can affect plankton, sockeye and other salmon species. There is also evidence of effects on birds and killer whales
    - Effects of pink salmon competition can be examined because of strong odd-even year pattern in abundance e.g. Davis et al. 2005, Ruggerone and Nielson 2004, Ruggerone and Connors 2015, Cline et al. 2019
- <u>Do Pink Salmon Reduce Chinook Growth, Survival, and Abundance?</u>
    - Pink salmon much more abundant in Bering Sea in odd years
    - Chinook feed at a higher trophic level, but considerable diet overlap: Squid & Fish
    - Odd years in the Bering Sea (1991-2000): a) 56% decline Chinook stomach fullness; and 68% less squid & fish in Chinook (Davis 2003. Ruggerone et al. 2003, 2016)

- Chinook size and abundance are declining throughout their range and the commercial catch in Alaska, British Columbia, and Russia has declined with increasing pink salmon abundance over the past 41 years.
- Chinook abundance depressed throughout Alaska & BC, long-term decline in size at age & age at maturation (Lewis et al. 2015; Ohlberger et al. 2018, Cunningham et al. 2018, Oke et al. 2020)



- <u>Bristol Bay Sockeye Scale Growth relative to growth in year before & after</u>
  - For all 5 Bristol Bay stocks and during both 2nd and 3rd years at sea, growth is reduced during odd relative to adjacent even years.
  - Similar results for Fraser Sockeye and other populations and species
- **Summary**
  - Pink salmon-caused trophic cascades appear to reduce size and numbers of copepods
  - Reduced Sockeye growth during odd vs. even years (need to look at WCVI Chinook!)
  - Tendency for reduced WCVI Chinook smolt-age 2 survival with increasing numbers of pink salmon, presumably by reduced prey abundance and/or quality
  - Need better time series of WCVI wild chinook abundance, size and survival
- **Conclusions**
  - To better understand factors restricting growth and survival of WCVI Chinook, we need to consider the potential effects of a limited pool of resources (i.e., food)
  - Pink salmon-caused trophic cascades can affect plankton, Sockeye and apparently WCVI Chinook salmon
  - The hypothesis that abundant pink salmon results in reduced growth (and survival) via reduced prey abundance and quality for WCVI Chinook should be tested by:
    - Analysis of time series of marine growth patterns for WCVI Chinook

- Reconstruction of time series of abundance and sizes of natural spawning WCVI Chinook

7.4.6 Workshop Synthesis

Four marine life history life stages (LSs) were considered:

LS1 (first marine spring, summer and fall in estuary and nearshore marine) along WCVI

LS2, first marine winter along WCVI)

LS3 (subsequent marine rearing of ages 2-4+ north of Vancouver Island ending when fish begin their homeward migration, and

LS4 (Adult fish migrating back to the WCVI and into estuaries)

Day 1 started with overviews of Chinook life history and the risk assessment methodology for salmon (RAMS), presented by Wilf Luedke and Jessica Hutchinson, respectively. Presentations and discussion specific to one or more of LF's #12-15 made up the rest of the day. On Day 2, scoring across each life phase for each LF was solicited from presenters and the other workshop attendees in order to develop risk ratings in the context of the RAMS.

LF12, Nutritional Quality: Mortality or fitness reduction due to the quality of available prey. The hypothesis is that reduced prey nutritional quality results in reduced growth, survival and/or fitness. Some possible mechanisms presented and discussed in this workshop included variation in size, lipids, phytoplankton and zooplankton production, temperature, salmon food-webs, and carrying capacity.

LF13, Prey Availability: Mortality or fitness reduction due to limited abundance of prey due to reduced prey quantity or availability and resulting in reduced growth, survival and/or fitness. Discussion of possible mechanisms included (similar to LF12) limiting prey availability were zooplankton production, temperature, salmon food-webs, and carrying capacity.

LF14, Timing: Mortality or fitness reduction due to phenological mismatch. The hypothesis for this limiting factor is that outmigration timing of Chinook may not align with optimal timing forprey availability (match-mismatch), resulting in reduced growth, survival, and/or fitness. Possible timing mechanisms include phenological mismatch, mismatch of timing, prey quality and quantity, timing of herring, zooplankton availability, and temperature and climate change.

LF15, Competition: Mortality or fitness reduction due to intra-specific competition for prey due to increased competition associated with total hatchery production, wild-wild competition, and carrying capacity.

7.4.6.1 Distribution Plots and Comment Summaries

Distribution plots follow sequentially for Life Stages 1-4 starting with LF12. For the Marine Risk Assessment, life stages are defined as: LS1) represent the first ocean summer as Juveniles; LS2) the first ocean winter as Juveniles; LS3) sub-Adult to Adult rearing; and LS4) mature Adult migration to natal stream. Although risk was assessed for both naturally produced Chinook and those of hatchery-origin, we do not present the latter since there was agreement that effects on hatchery fish would either be lowest, or not important to this discussion.

Numbers of individuals who did not rate a particular LF were recorded. Workshop participants were encouraged to input comments as they evaluated each relevant LF and LS; summaries are provided below.

Workshop results were tabulated and basic statistics (e.g., mean, median, mode, range and standard deviation) computed for each LF and LS. These statistics were frequently inadequate due to small sample sizes and skewed statistical distributions. To help interpret these frequency distributions, a small team met during March 2023 and developed single consensus Review Scores for each of Likelihood, Impact, Future Trend, and Confidence. A brief comparison between consensus Review and Mean Scores follows in 6.b.

Here we briefly describe the distribution results for only the first example (LF12, Figure 7.29, LS1). The same approach was used for all LFs. Refer to the Methods Section in the main report (i.e., before Appendices) for more detailed descriptions.

Each LF and LS has six distribution plots (e.g., Figure 7.29):

- Likelihood, Impact, and Future Trend (top row).
- Participant's Confidence in their scoring, Current Risk, and Future Risk (over the next 30 years (2nd row).

The plots in the first row and the left-hand plot in the second row of Figure 7.29 display score distributions as well as consensus Group Scores; i.e., Review Scores for Likelihood (upper left plot) was 4, Impact (upper middle plot) was 4, Future Trend (upper right plot) was 4, and Confidence (lower left-hand plot) was 2 (Moderate).

Risk matrices were applied to determine Current and Future Risk distributions and single risk category review results based on the scores for Impact, Likelihood and Current Impact, Future Trend respectively. For details, see the text in the main RAMS methods section earlier in this report.

LF12: Mortality or fitness reduction due to the quality of available prey

LF 12 LS 1 Individual Score Distributions:

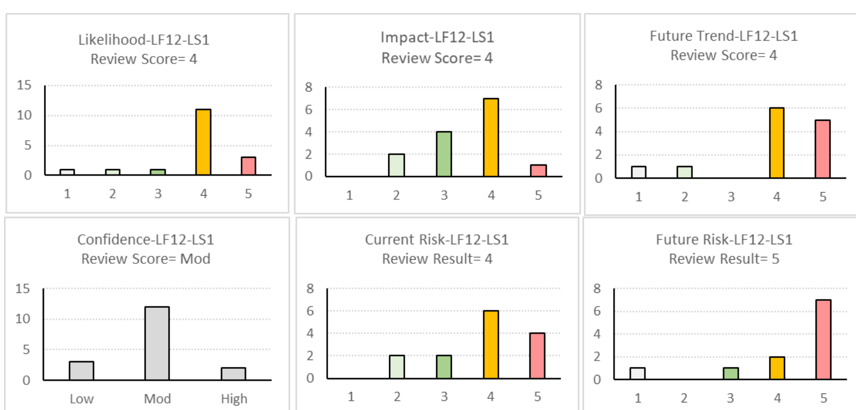


Figure 7.29 **Frequency distribution plots of participant scores for Limiting Factor 12 and Life Stage 1 for Likelihood, Impact, Future Trend, and Confidence. Review scores are based on a group consensus review of these plots. Current and Future Risks and associated frequency distribution plots and Review Scores are calculated based on risk matrices (see Methods in Main report). If n<4, then confidence=low (i.e., 1) regardless of distribution.**

LS1 General Summary:

- Participants believe that temperature changes will have the highest impact on prey quality available to Chinook salmon and that there needs to be a better understanding of temporal changes over time in food quality, including information on herring, sand lance, myctophids. This would provide more information about how Chinook survival may be impacted by bottom-up factors.
- Changes to prey quality may also be compounded by factors, such as stress, disease, parasites and how it affects ability to forage.
- Participants commented on the relationship between fish size and condition entering the marine environment, and their ability to compete for and consume high quality prey. Freshwater habitat can influence the condition of fish as they go to sea, affecting their vulnerability to poor food quality. Skinny fish require good food immediately to thrive.
- Concern about the impact competition with hatchery fish is having on the early life stage wild chinook.

LF 12 LS 2 Individuals Score Distributions:

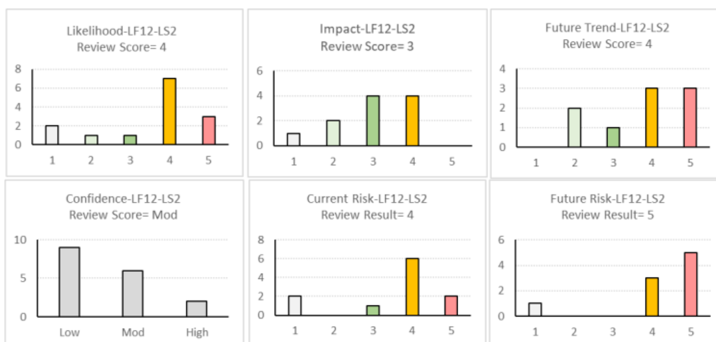


Figure 7.30 **Frequency distribution plots of participant scores for Limiting Factor 12 and Life Stage 2 for Likelihood, Impact, Future Trend, and Confidence. Review scores are based on a group consensus review of these plots. Current and Future Risks and associated frequency distribution plots and Review Scores are calculated based on risk matrices (see Methods in Main report). If n<4, then confidence=low (i.e., 1) regardless of distribution.**

LS2 General Summary:

- The impact of prey quality on this life stage is likely strongly connected to growth during the previous life stage. Participants commented on some theories that suggest the ability of fish to successfully overwinter is based on how much they have grown during spring, summer, and fall.
- Sensitivity to prey quality and availability likely depends on fish condition, so starting the winter in poor condition due to disease, lice, or poor summer feed will exacerbate any problems.
- This period of the life history is seen as a large data gap, as it has very little research completed on it, and at least in the Salish Sea this life stage might be one of the most crucial periods.

- Nutritional quality of prey forms a basis for the health of the fish. It may not be an ultimate factor but can change the susceptibility of the fish to other factors.

LF 12 LS 3 – Individual Score Distributions

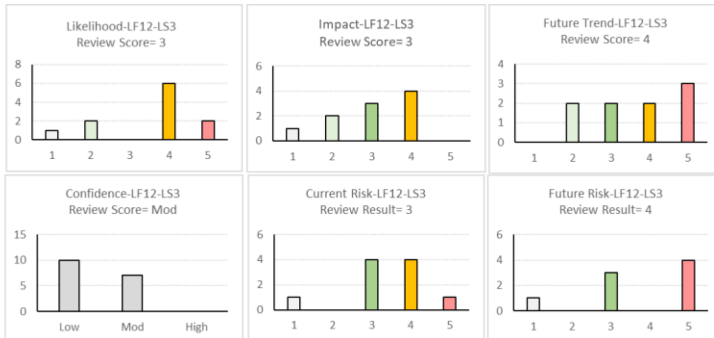


Figure 7.31 **Frequency distribution plots of participant scores for Limiting Factor 12 and Life Stage 3 for Likelihood, Impact, Future Trend, and Confidence. Review scores are based on a group consensus review of these plots. Current and Future Risks and associated frequency distribution plots and Review Scores are calculated based on risk matrices (see Methods in Main report). If n<4, then confidence=low (i.e., 1) regardless of distribution.**

LS3 – General Summary:

- We do not know where the fish are, and little information was presented on diets or prey quality for this life stage. Perhaps we could learn more at an additional workshop focused on Phase 3?
- LF 12 would be influenced by changes to the physical characteristics of the water column. Impacts causing changes to the water column, like climate change, impacts the timing of food availability. Continued competition with hatchery Juveniles for food. Fisheries for pelagic fish and euphausiids. Herring stocks on the WCVI have been depressed for decades.
- This stage seems to feed more on small fishes and euphausiids. Variability will therefore depend on how these various prey populations grow and interact with the entire WCVI and NE Pacific ecosystems.
- There is essentially no research at this life stage, but there is also no evidence that this life stage is as critical as the first year [LS1 and LS2] at sea in terms of returns.
- Larger-scale oceanographic patterns are probably more important for this life stage.

LF 12 LS 4 – Individual Score Distributions

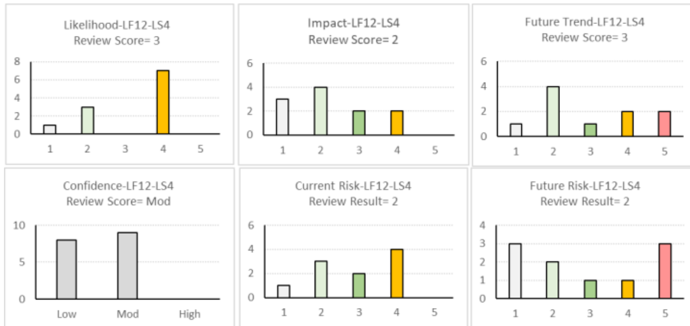


Figure 7.32 **Frequency distribution plots of participant scores for Limiting Factor 12 and Life Stage 4 for Likelihood, Impact, Future Trend, and Confidence. Review scores are based on a group consensus review of these plots. Current and Future Risks and associated frequency distribution plots and Review Scores are calculated based on risk matrices (see Methods in Main report). If n<4, then confidence=low (i.e., 1) regardless of distribution.**

LS4 – General Summary:

- Lowest risk life stage, as fish will not be feeding much as they [return to spawning streams].
- We did not hear much about this life stage and their diet or prey choices so hard to score this one.
- These fish will primarily be feeding on other fish. It is unclear how much feeding Chinook are doing during their homeward migrations plus they will have somatic reserves, so aspects relating to feeding may not be as important for this stage as for first year fish. Predation and/or fishing may be more important.
- I don't see this as an important factor as feeding is reduced during the return migration.
- If harvest of feed fish eaten by Chinook are managed for availability, then the Adult chinook should be OK health wise.
- This is not the critical life stage for WCVI Chinook, and as these fish reduce feeding as they become mature, the quality of available prey is not as critical as the environmental stressors they may encounter in the marine and freshwater ecosystems.
- Forage fish, especially herring abundances would affect this life history stage.

LF13: Mortality or fitness reduction due to limited abundance of prey

LF 13 LS 1 Individual Scoring Distribution

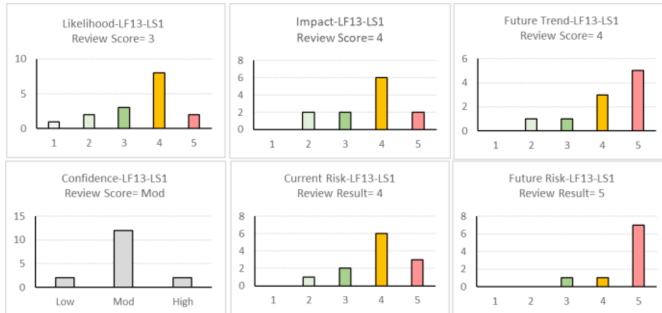


Figure 7.33 Frequency distribution plots of participant scores for Limiting Factor 13 and Life Stage 1 for Likelihood, Impact, Future Trend, and Confidence. Review scores are based on a group consensus review of these plots. Current and Future Risks and associated frequency distribution plots and Review Scores are calculated based on risk matrices (see Methods in Main report). If n<4, then confidence=low (i.e., 1) regardless of distribution.

LS1 Comments General Summary:

- Many participant comments about how prey quality and quantity are inseparable, and that they gave similar scores for each. If preferred prey is unavailable fish will find some food, but it may be lower quality. Hard to determine if it is the low quality of what they eat or the lack of availability of the higher quality prey that leads them to eat it.
- Climate change likely exacerbates availability and quality issues with lower trophic organisms, creating a cascade of nutritional and physiological fitness impacts as one moves up the web.
- Evidence presented indicated a wide variety of prey, opportunistic. Quality is more important as lipid etc. content varies by prey type. There are not many empty stomachs.

LF 13 LS 2 Individual Scoring Distributions

Figure 7.34 Frequency distribution plots of participant scores for Limiting Factor 13 and Life Stage 2 for Likelihood, Impact, Future Trend, and Confidence. Review scores are based on a group consensus review of these plots. Current and Future Risks and associated frequency distribution plots and Review Scores are calculated based on risk matrices (see Methods in Main report). If n<4, then confidence=low (i.e., 1) regardless of distribution.

LF 13 LS 2 – Commentary:

LS2 Comments General Summary:

- As for LF 12, participants feel that there is an interaction between what happens to fish during LS1 and their likelihood of surviving at LS2. If fish are small and stressed from LS1, they will be less likely to survive LS2.
- As for LF 12, participants felt that LS2 (first winter) had little information on food availability and that future research was needed, building upon work summarized by Jackie King.
- Genomic analysis of Chinook, sockeye and coho salmon during their first year in the ocean does not suggest that salmon are generally food limited over winter. In fact, metabolic signatures indicating reduced feeding are strongest in the spring, shortly after fish enter the ocean, and when they may be putting more energy into adapting to a new salinity environment. Metabolic signatures in later summer, fall, and winter do not shift appreciably.
- Some participants felt that fish that have survived to each successive life history stage likely have an increased probability of survival based on fitness so while the overall risk might remain stable, an individual's risk might decrease. However, accumulation of stress and an increased dependency on prey that may be declining in quality could be an additive risk. For example, survivors will be exposed to long term (climate-related) Future Risk that differs from risks within a salmon cohort.

LF 13 LS 3 Individual Scoring Distributions

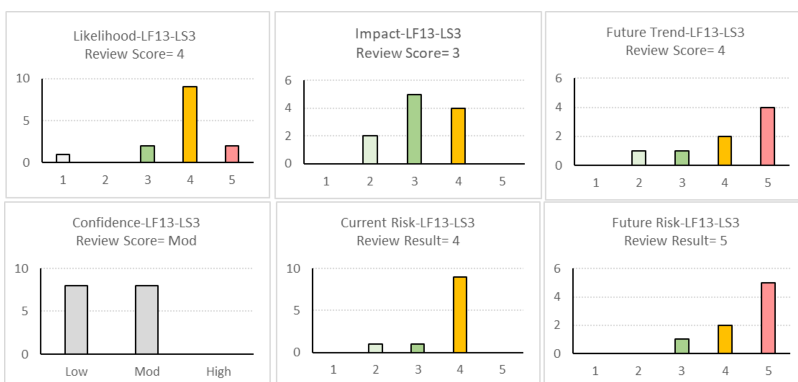


Figure 7.35 **Frequency distribution plots of participant scores 13 Limiting Factor and Life Stage 3 for Likelihood, Impact, Future Trend, and Confidence. Review scores are based on a group consensus review of these plots. Current and Future Risks and associated frequency distribution plots and Review Scores are calculated based on risk matrices (see Methods in Main report). If n<4, then confidence=low (i.e., 1) regardless of distribution.**

LF 13 LS 3 – Commentary:

LS3 Comments General Summary:

- Some participants described possible interaction with other salmon during this life stage, e.g. ink Salmon. Belief that enhancement of species like pink and chum salmon is leading to "over-grazing" of the planktonic "field" in such a way that limits larger bodied salmon by impacting their prey species; a cascade effect.

- This life stage is seen as a critical area for future research, as it seems like an area that we could do something about. E.g., by negotiating with other nations to reduce production of competing species.
- Similar to the earlier life stage, comments about how the complexity of things only increases along the timeline. The risk of a greater biomass of smaller bodied salmon being supplemented into a more stressed ecosystem may be compounding issues with a naturally cyclical pattern.
- Recommendation to start getting weight by size, or girth, or some morphometric measure of mass to track how fish weight at size is changing over time.
- Possibility that hatchery production is exasperating decreasing size and younger age of maturity. “Hatcheries provide optimal incubation and rearing environments for salmon, and it has been thought that there may be a genetic trigger to return to the natal environment as soon as possible to take advantage of optimal conditions before they change. The hatchery environment may promote a shorter life cycle that is reducing the opportunity for salmon to capitalize on naturally available prey. That said, there is evidence from studies that there is a trend towards decreasing body size and age at return in many unenhanced systems as well, but that they are accelerated on enhanced and deforested waterways. So, is there any probability that phenological mismatches are being exacerbated by hatchery derived decreasing size and, if so, are there management changes that we can consider in the hatchery system, such as better timing of releases to match natural prey availability while still being mindful of hatchery and wild fish interactions?”

LF 13 LS 4 Individual Scoring Distribution

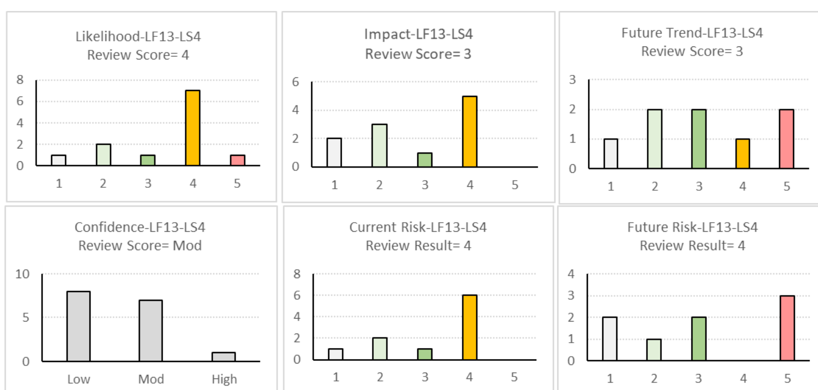


Figure 7.36 - **Frequency distribution plots of participant scores by Limiting Factor 13 and Life Stage 4 for Likelihood, Impact, Future Trend, and Confidence. Review scores are based on a group consensus review of these plots. Current and Future Risks and associate frequency distribution plots and Review Scores are calculated based on risk matrices (see Methods in Main report). If n<4, then confidence=low (i.e., 1) regardless of distribution.**

LF 13 LS 4 – Commentary:

- The pink/ Chinook interaction is interesting to note. There seemed to be a relationship but the R2 value was fairly low.

- Fish need food to fuel their return migrations but have somatic reserves to help bridge periods of low available food.
- As for LF 12 I don't see this as a priority given the limited feeding of maturing Adults.
- Ditto previous answer concerning quality of prey. Environmental factors will be more important than prey quantity at this life stage in my opinion.
- Large-scale oceanographic patterns affect this life stage.
- Current fisheries don't seem to be well considered from a wholistic perspective. We have different management teams for different species because it is functionally easier to manage them (from a human perspective) as discrete boxes. But they aren't discrete. Herring seems to be a strong example of this. Herring stocks have started to rebound in some places and (I think) that it is partly to do with fishery changes in some areas and with other measures elsewhere (spawning surface protection on creosote pilings in Howe Sound for example). Adult Chinook salmon feed on herring, but if we neglect to manage the herring fishery from a larger food web standpoint then we cause harm that may not be immediately visible.
- The obvious mechanism to allow more fish to return to the rivers to spawn is to reduce fishing pressures substantially. Every fish that ends up in a boat is a dead fish.... Every fish that isn't removed for fishing purposes has at least a chance of success.
- Terminal area environmental conditions appear to affect mature chinook behavior e.g. low DO and high temperatures may affect availability or ability to find prey.
- Not sure this is a worthwhile thing to explore. There seems to be various food sources for Adult migrating Chinook returning to the WCVI. We could look at terminal exploitation in sport with respect to rockfish blooms? Are there responses we can track? I don't think we track enough in the escapement to correlate to such food variation.

LF14: Mortality or fitness reduction due to phenological mismatch

LF 14 LS 1 Individuals Score Distributions

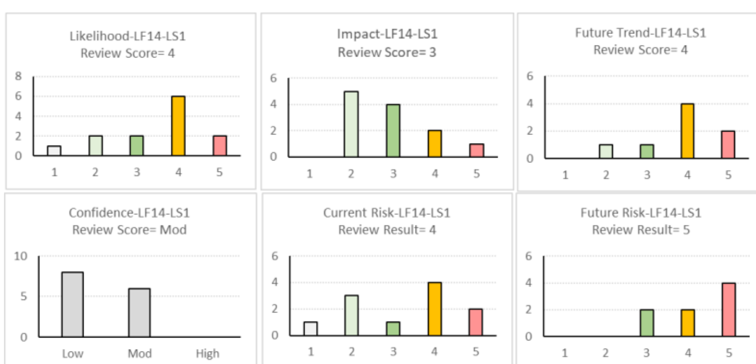


Figure 7.37 **Frequency distribution plots of participant scores for Limiting Factor 14 and Life Stage 1 for Likelihood, Impact, Future Trend, and Confidence. Review scores are based on a group consensus review of these plots. Current and Future Risks and associated frequency distribution plots and Review Scores are calculated based on risk matrices (see Methods in Main report). If n<4, then confidence=low (i.e., 1) regardless of distribution.**

LS1 Comments General Summary:

- What we heard from Sam [Wilson] is that while there is a general trend in earlier timing of smolt outmigrants across salmon species and occurring over a broad geographic range, it appears that spring blooms may also be occurring earlier, so the salmon may be more or less matching the timing of prey availability. While data for Chinook were not great, only one population showed a mismatch--was that about 10%? I think it will be important to track this over longer timeframes, but I was not convinced that this was a critical issue.
- Overall participants viewed this as a lower risk than LF 12 and LF 13 and felt that the data presented during the workshop did not appear to show high amounts of risk to Chinook.
- Recognition that this could become an issue in the future as climate change exacerbates large weather events and ocean warming.

LF 14 LS 2 Individual Scoring Distributions:

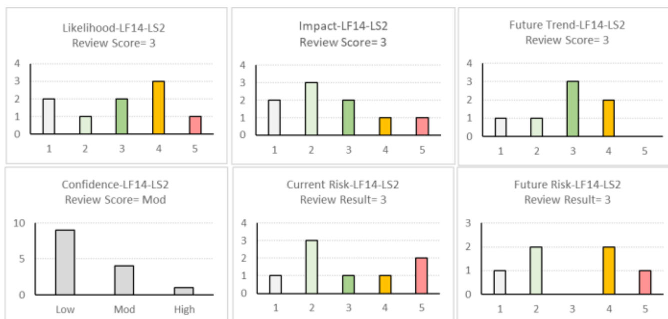


Figure 7.38 **Frequency distribution plots of participant scores by Limiting Factor 14 and Life Stage 2 for Likelihood, Impact, Future Trend, and Confidence. Review scores are based on a group consensus review of these plots. Current and Future Risks and associated frequency distribution plots and Review Scores are calculated based on risk matrices (see Methods in Main report). If n<4, then confidence=low (i.e., 1) regardless of distribution.**

LS2 Comments General Summary:

- The timing of prey availability over winter is likely less of an issue than for other factors, since winter is generally a low production period.
- Need to think about carry over effects between summer leading into winter, goth for the fish and their winter prey.
- If there is an effect of timing, it would occur soon after ocean entry, and not later in life.

LF 14 LS 3 Individuals Scoring Distributions

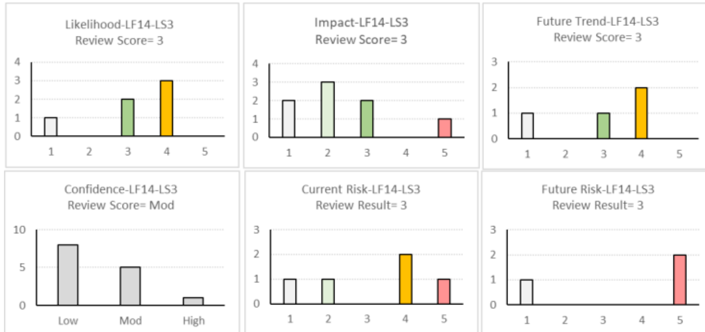


Figure 7.39 **Frequency distribution plots of participant scores by Limiting Factor 14 and Life Stage 3 for Likelihood, Impact, Future Trend, and Confidence. Review scores are based on a group consensus review of these plots. Current and Future Risks and associated frequency distribution plots and Review Scores are calculated based on risk matrices (see Methods in Main report). If n<4, then confidence=low (i.e., 1) regardless of distribution.**

LS3 Comments General Summary:

- Timing of forage fish production may be spread more widely through spring and summer, and perhaps provide a buffer to the impacts of variations in timing of individual forage fish prey species.

LF 14 LS 4 Individual Scoring Distributions

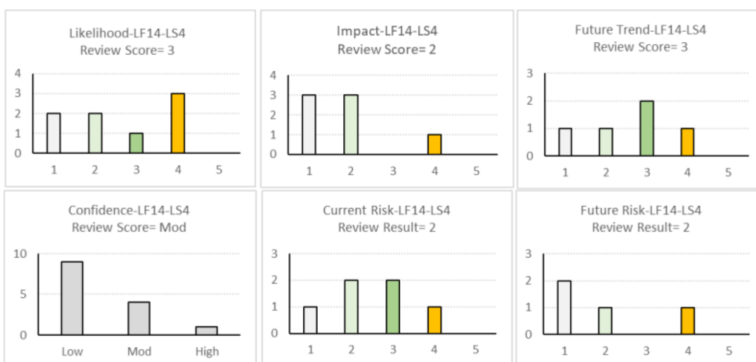


Figure 7.40 **Frequency distribution plots of participant scores by Limiting Factor 14 and Life Stage 4 for Likelihood, Impact, Future Trend, and Confidence. Review scores are based on a group consensus review of these plots. Current and Future Risks and associate frequency distribution plots and Review Scores are calculated based on risk matrices (see Methods in Main report). If n<4, then confidence=low (i.e., 1) regardless of distribution.**

LS4 Comments General Summary:

- This life stage was ranked as the lowest risk, as fish at this stage will have sufficient somatic reserves to bridge over low prey, and there is generally little feeding during the return to spawn.

LF15: Mortality or fitness reduction due to intra-specific competition for prey

LF 15 LS 1 Individual Score Distributions

Figure 7.41 **Frequency distribution plots of participant scores by Limiting Factor 15 and Life Stage 1 for Likelihood, Impact, Future Trend, and Confidence. Review scores are based on a group consensus review of these plots. Current and Future Risks and associate frequency distribution plots and Review Scores are calculated based on risk matrices (see Methods in Main report). If n<4, then confidence=low (i.e., 1) regardless of distribution.**

LS1 Comments General Summary:

- Many participants feel like competition between hatchery [and wild] fish is a potential risk, as well as competition with other fish species, or other salmon species.
- Impact of this LF is probably highly related to the previous LF's, such as quality and quantity of prey.
- We must again add to the conversation on S1 (1 yr smolts) verses S0 (migrate to sea during first year) type fish, without this, we will not be able to manage the fish in their entirety. In general, S1 will perform better in the first summer than S0's, but this participant argues that by ignoring this life history type, we are jeopardizing the best management of the WCVI Chinook. S0 smolts are a vital component of WCVI wild Chinook populations.

LF 15 LS 2 Individual Scoring Distribution

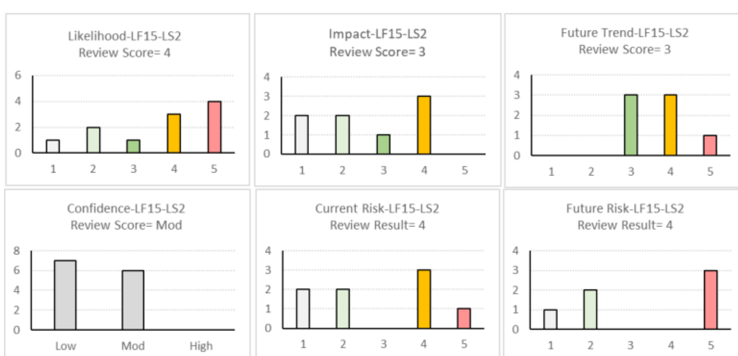


Figure 7.42 **Frequency distribution plots of participant scores for Limiting Factor and Life Stage 2 for Likelihood, Impact, Future Trend, and Confidence. Review scores are based on a group consensus review of these plots. Current and Future Risks and associated frequency distribution plots and Review Scores are calculated based on risk matrices (see Methods in Main report). If n<4, then confidence=low (i.e., 1) regardless of distribution.**

LS2 Comments General Summary:

- Suspect that competition is less of a factor in the first winter, but we have little data bearing on this.
- Connected to all other limiting factors in this section of workshops.

LF 15 LS 3 Individual Scoring Distribution

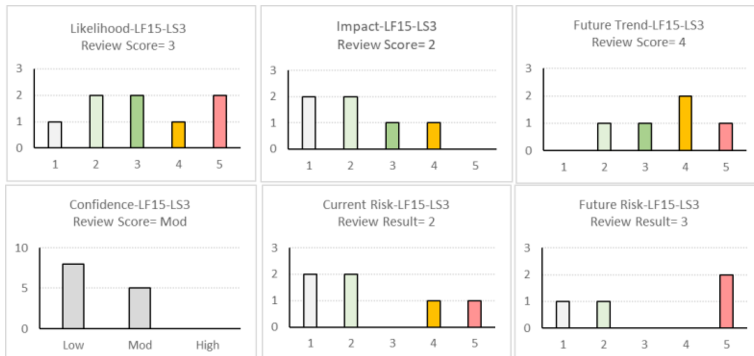


Figure 7.43 **Frequency distribution plots of participant scores for Limiting Factor and Life Stage 3 for Likelihood, Impact, Future Trend, and Confidence. Review scores are based on a group consensus review of these plots. Current and Future Risks and associated frequency distribution plots and Review Scores are calculated based on risk matrices (see Methods in Main report). If n<4, then confidence=low (i.e., 1) regardless of distribution.**

LS3 Comments General Summary:

- The ocean environment is always in flux. The only thing we can do is ensure enough chinook are surviving the first 90 days in the ocean and this would ensure Adult returns increase.
- We know next to nothing about this. At this stage competition would involve stocks from other regions, with the potential that the productivity of the stocks and the extent of hatchery releases could change profoundly through time.
- See two presentations summarized above that consider LS3.

LF 15 LS 4 Individual Scoring Distribution

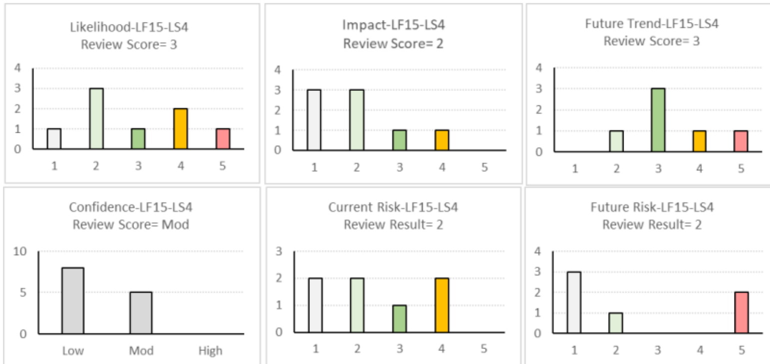


Figure 7.44 **Frequency distribution plots of participant scores for Limiting Factor 15 and Life Stage4 for Likelihood, Impact, Future Trend, and Confidence. Review scores are based on a group consensus review of these plots. Current and Future Risks and associated frequency distribution plots and Review Scores are calculated based on risk matrices (see Methods in Main report). If n<4, then confidence=low (i.e., 1) regardless of distribution.**

LF 15 LS 4 – Commentary:

LS4 Comments General Summary:

- Participants view this LS as the lowest risk, with larger fish being less affected by food availability.
- Belief that research into interaction with pink salmon should be investigated further.

Additional Comments Reflecting Consensus :

LF12: Nutritional Quality

- … it was only recently established that WCVI Chinook are remaining in the sounds for up to the first year of marine life; very little study has actually been undertaken in the sounds themselves, so this remains data poor… needs to be some focus on food availability where fish are rearing
- Sensitivity to prey quality and availability likely depends on fish condition, so starting the winter in poor condition due to disease, lice, or poor summer feed will exacerbate any problems.
- Nutritional quality of prey forms a basis for the health of the fish. It may not be an ultimate factor but can change to susceptibility of the fish to other factors.
- Some theories suggest the ability of fish to successfully overwinter is based on how much they have grown during spring, summer, and fall. Winter zooplankton and forage fish prey fields are often low during the winter, and so this may be less important than for Stage 1 fish.
- The role of diet or any other factor limiting growth and survival in the overwinter period [LS2] is much less studied in general than factors impacting salmon in their first summer, although there are considerable numbers of papers that hypothesize this is a critical period. I would support more research to contrast the quality of prey being consumed in fish within sounds with that experienced by fish caught on the shelf and moving between sounds.

- This stage [LS3] seems to feed more on small fishes + euphausiids, Variability will therefore depend on how these various prey populations grow and interact with the entire WCVI + NE Pacific ecosystem.
- We have very little knowledge about what these fish are doing during this stage [LS3] or the role of prey quality at the subAdult stage on population productivity. However, starvation seems unlikely.
- Assuming the Adults are feeding less, depending on where they are in their migration, this LF might have less of an impact at this stage of life

LF13: Prey Availability

- I think this is inseparable from prey quality and I am essentially answering the same. If preferred prey is unavailable fish will find some food, but it may be lower quality. So, it is a chicken and egg question, is it the low quality of what they eat or the lack of availability of the higher quality prey that leads them to eat it.
- Evidence presented indicated a wide variety of prey, opportunistic. Quality is more important as lipid etc. content varies by prey type. Not many empty stomachs. Good hunters. ocean acidification may be a big confounding factor? AND many other environmental factors which could stress fish and reduce ability to hunt and grow and avoid predators. Link to previous workshops.
- Some have hypothesized that food availability during the overwinter period is limiting, but few ships are out sampling salmon during this time, which is the only reason I ranked this of higher priority for future research. Note that our genomic analysis of Chinook, sockeye and coho salmon during their first year in the ocean does not suggest that salmon are generally food limited over winter. In fact, metabolic signatures indicating reduced feeding are strongest in the spring, shortly after fish enter the ocean, and when they may be putting more energy into adapting to a new salinity environment. Metabolic signatures in later summer, fall, and winter do not shift appreciably.
- I think this links in closely to the previous stage in that the environmental factors that impact low trophic prey also have cumulative effects on the next level and that, as the salmon grow and seek larger prey, those too will see fitness and survival impacts related to the abundance and quality of the organisms that they feed upon.
- I think those fish that have survived to each successive life history stage likely has an increased probability of survival based on fitness so while the overall risk might remain stable, the individual risk might decrease. However, accumulation of stresses and an increased dependency on prey that may be declining in quality could be an additive risk. I'm not sure which way to look at it.
- This life stage [LS3] is moving to piscivory, therefore the susceptibility of this stage to variations in food quantity will be a combination of variations in zooplankton and forage fishes. We know more about zooplankton than we do about the key forage fish species, therefore information is somewhat limited.

- Environmental factors will be more important than prey quantity at this life stage [LS4] in my opinion.
- Terminal area environmental conditions appear to affect mature chinook behavior. e.g. low DO and high temps may affect availability or ability to find prey.

LF14: Timing

- Although we have good data now for the timing and spatial distribution of Sarita Chinook in the estuary, we do not have sufficient data on the distribution over time and space of prey in the estuary. Data on both nearshore marine residency of Juvenile Sarita Chinook and nearshore marine prey items is also lacking.
- What we heard from Sam [Wilson] is that while there is a general trend in earlier timing of smolt outmigrants across salmon species and occurring over a broad geographic range, it appears that spring blooms may also be occurring earlier, so the salmon may be more or less matching the timing of prey availability. While data for Chinook were not great, only one population showed a mismatch--was that about 10%? I think it will be important to track this over longer timeframes, but I was not convinced that this was a critical issue.
- We know some things about how timing of prey production in spring varies, in particular for zooplankton. Timing of forage fish production may be spread more widely through spring and summer, and perhaps provide a buffer to the impacts of variations in timing of individual forage fish prey species.
- LS4: I suspect that fish at this stage have sufficient somatic reserves to allow them to bridge over periods of low prey; Little feeding during return; Changes in environmental conditions and subsequent prey availability over large geographic ocean areas affects this stage.

LF15: Competition

- The impact of this factor on this life stage is based on the presence (or not) and the timing (match of mismatch) of other salmon species. Knowledge on when and where Juvenile salmon [LS1, LS2] species mix is probably reasonably well known, but how they partition the prey field (i.e. what they each feed on) and its variability in space and time is less well-known.
- Ocean conditions will always change and cold verses warm water conditions that are the drivers for feed type and abundance that chinooks [LS2] are dependent on. We know one form of feed humans can assist in is herring numbers and to expand the spatial distribution. Herring spawn would most likely have been reduced in areas from harvest. If herring can be identified to greatly improve the overall well being of Chinook then this should be a priority management tool to use, that us as humans, can control.
- I suspect that competition is less of a factor in the first winter [LS2], but we have little data bearing on this; same as spring-summer life phase. continuation of micro trolling and ancillary analysis will cover this.

- We know next to nothing about this. At this stage [LS3] competition would involve stocks from other regions, with the potential that the productivity of the stocks and the extent of hatchery releases could change profoundly through time.
- LS4: I think the question of interactions with pink salmon needs to be investigated further; the main mortality occurs in the first 90 days of ocean entry. The larger fish are lesser affected by food availability as they will survive and during shortages, if this occurs, simply the maturation rate will be delayed or sizes at maturation be smaller; terminal area environmental conditions appear to affect mature chinook behavior. e.g., low DO and high temps may affect availability or ability to find prey; not sure this is a worthwhile thing to explore. There seems to be various food sources for Adult migrating chinook returning to the WCVI. We could look at terminal ER in sport wrt years with many young rockfish? Are there responses we can track? I don't think we track enough in the escapement to correlate to such food variation.

7.4.6.2 Ranked Risks

To rank the relative risk of different LF's, results for all LFs were sorted first by Current Risk Review Result, then Future Risk Group Result, and finally by a percent current risk high score, the percentage of participants' scores that led to a current risk score of high or very high as shown (Table 7.9). Here we included statistical mean values for Future Risk alongside the values computed as described above.

Correlations between Future Risk Scores and statistical mean Future Risk Scores were significant (R^2=0.52; p=0.002) although risk categorizations using these approaches varied. Of the six LFs rated as Very High using the Group Review rankings (top six results rows in Table 7.9), only one (LF13 prey abundance, LS1) was rated Very High using mean values; the remainder were rated High. Of the four LFs rated High for Future Risk, there was agreement using the Mean Future Risk scores in two cases (LF13, LS1; LF15, LS2), while LF13, LS4 was rated Moderate and LF13, LS2 as High (i.e., 4). We remained most confident in the Group review group rankings, which form the basis for our analysis and discussion below.

Table 7.9 Ranked (high to low) current and future risk rankings for limiting factors (LFs) considered during Workshop 4.

		Group review		Participant score statistics											
Limiting Factor	**Life Stage**	Likelihood Score	Impact Score	Future Trend Score	Confidence Score 1-3	Current Risk Score 1-5	Future Risk Score 1-5	Mean FRisk Score	Reviewed Confidence	**Review Result Current Risk**	**Review Result Future Risk**	# people who did not score	Current Risk % High	Future Risk % High	Confidence % Low
LF13 Prey abundance	LS3	4	3	4	2	4	5	4	Mod	High	Very High	6	82%	88%	50%
LF13 Prey abundance	LS1	3	4	4	2	4	5	5	Mod	High	Very High	5	75%	89%	13%
LF12 Prey quality	LS2	4	3	4	2	4	5	4	Mod	High	Very High	6	73%	89%	53%
LF12 Prey quality	LS1	4	4	4	2	4	5	4	Mod	High	Very High	4	71%	82%	18%
LF15 Intra-specific competiti	LS1	4	3	4	2	4	5	4	Mod	High	Very High	4	56%	60%	54%
LF14 Mis-match with prey	LS1	4	3	4	2	4	5	4	Mod	High	Very High	4	55%	75%	57%
LF13 Prey abundance	LS4	4	3	3	2	4	4	3	Mod	High	High	7	60%	38%	50%
LF15 Intra-specific competiti	LS2	4	3	3	2	4	4	4	Mod	High	High	5	50%	50%	54%
LF13 Prey abundance	LS2	3	3	4	2	3	4	5	Mod	Mod	High	5	67%	80%	25%
LF12 Prey quality	LS3	3	3	4	2	3	4	4	Mod	Mod	High	7	50%	50%	59%
LF14 Mis-match with prey	LS3	3	3	3	2	3	3	4	Mod	Mod	Mod	10	60%	67%	57%
LF14 Mis-match with prey	LS2	3	3	3	2	3	3	3	Mod	Mod	Mod	7	38%	50%	64%
LF15 Intra-specific competiti	LS3	3	2	4	2	2	3	3	Mod	Low	Mod	7	33%	50%	62%
LF12 Prey quality	LS4	3	2	3	2	2	2	3	Mod	Low	Low	7	40%	40%	47%
LF15 Intra-specific competiti	LS4	3	2	3	2	2	2	3	Mod	Low	Low	6	29%	33%	62%
LF14 Mis-match with prey	LS4	3	2	3	2	2	2	2	Mod	Low	Low	9	17%	25%	64%

Both current and future risks were generally rated higher for Juvenile relative to sub-Adult and Adult salmon life stage with respect to limiting factors: nutrition, change in prey quality, availability, timing and composition for (Table 7.9). These ratings align with expectations of high mortality during the early marine period, material presented during this workshop (Section 5), and other workshops. Multiple participant comments reference greater sensitivity of Juvenile fitness/survival to variation of prey availability/quality relative to the Adult life stage characterized by reduced feeding. Participant comments also note that little is known about the impacts of prey availability and composition for sub-Adult Chinook, highlighting the need for additional study. Most nutrition limiting factors rated as high (mostly for Juvenile life stages) for current risk were rated as very high for future risk. However, the high current risk ratings for 'Intra-specific competition [LF15]' for first marine winter and 'Prey abundance [LF 13] for the Adult life stage both retained high future risk ratings.

Risk scores rating low for both current and future risks were given to Adult stages for 'Prey Quality [LF12]', 'Mis-match with prey' [LF14] and 'Intra-specific competition'[LF15]. Those moderate and low current risk scores which did change increased from current low and moderate to moderate and high future risk ratings and were associated with Juvenile and sub-Adult life stages. Confidence scores were moderate (2 relative to 1-3 scale) for all life-stage specific limiting factors. Correspondence between the mean future risk scores and reviewed future risk ratings was good with differences always equal to one. Mean future risk scores were generally lower than reviewed future risk scores rated high or very high, and typically equal to or greater than moderate and low reviewed future risk scores.

For Juveniles, limiting factors, 'Prey quality', and 'Intra-specific competition' were both rated high for current risk during the first marine summer through winter (LS1 and LS2, see also

King and Hertz presentations addressing seasonal patterns of prey quality, composition and abundance for these stages). However, the current risk rating for 'Prey Abundance' [LF13] was high for first Juvenile summer and moderate for winter, in recognition of the low prey availability during winter and probable effects of summer body size (as presented by Duguid) carrying over to survival during the first winter. The limiting factor, 'Mis-match with prey' was rated as high for summer and moderate current risk for Juveniles during their first winter. Future risk for 'Mis-match with prey' was rated as very high for early Juveniles, consistent with increased modeled and observed shifts of Chinook outmigration timing and duration presented by Wilson. Most current risks rated high were rated as very high for future risk given reported given reasonable expectations for the increased future variability of prey availability, quality, composition, and timing. Only limiting factors 'Prey abundance' for Adults and 'Intra-specific competition' for winter Juveniles retained a high rating for both current and future risks. The limiting factor, 'Mis-match with prey' was rated as high for summer and moderate current risk for Juveniles during their first winter. Future risk for 'Mis-match with prey' was rated as very high for early Juveniles, consistent with increased modeled and observed shifts of Chinook outmigration timing and duration presented by Wilson. Most current risks rated high were rated as very high for future risk given reported given reasonable expectations for the increased future variability of prey availability, quality, composition, and timing. Only limiting factors 'Prey abundance' for Adults and 'Intra-specific competition' for winter Juveniles retained a high rating for both current and future risks.

For Adults, risk and future risk were rated as moderate and low, reflecting increased survival with life stage, reduced feeding, and limited knowledge (and moderate confidence ratings) of how variable prey availability, quality, and timing, influence Adult survival. Of note is an apparent discrepancy between the mean risk score (3), participant comments (suggesting low risk) and reviewed risk ratings (high for both current and future) for Adult stage Chinook and the 'Prey abundance' limiting factor 13. However, this was one of the LF-specific life stages with fewer participant scores. Limiting factor 15, 'Competition' addressed the influence of the intraspecific competition which was rated with a high current risk (very high future risk) and was addressed in part for Juveniles by Tanasichuk's presentation on hatchery and wild fish diets which indicated similar timing for both hatchery and wild Juvenile Chinook sampled in Barkley Sound. Ratings for this limiting factor did not explicitly address inter-specific competition. For Juvenile salmon in Barkley Sound, Tanasichuk's sampling indicated little opportunity for competition between Juvenile Chinook and other species since Chinook were the last to enter the sound. Irvine et al.'s presentations addressed the role of inter-specific competition for sub-Adults and Adults and focussed on multiple lines of evidence indicating both competition and food-web effects of both interannual variability of pink salmon and the long-term increase of pink and chum salmon and in the northern part of Chinook migration routes.

In summary, both current and future risk ratings identify Juvenile life stage (LS1 and LS2; first spring through winter) fitness and survival as most sensitive to variation in nutritional quality, prey availability, timing and competition. Indirect assessments such as total zooplankton production and ecological efficiency are useful as they influence prey quantity and quality for all life stages (both directly and indirectly). An ecosystem scale perspective is important when considering ‘cool’ vs. ‘warm’ regimes. Carryover effects from the spring-summer such on overall health, parasite load, and body size, may be just as important as prey availability/quality during the winter when productivity is at its seasonal low. The focus of most presentations and comments from participants highlight the relative absence of information and need for focussed study on feeding and nutrition for subAdult (LS3) animals. Risk rating and consensus for the Adult life stage was that environmental factors (treated in other workshops) may be more important than nutrition and prey for this life stage since feeding is reduced and survival/fitness advantages due to positive prey conditions are accrued during early life stages.

7.4.7 Key Literature[4]

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7.4.8 Participants' Names and Affiliations

Name	Affiliation
Akash Sastri	DFO
Andrew Jackson	Tla-o-qui-aht First Nation
Andrew Munro	ADFG
Ashley Popovich	Catalyst Paper
Barb Cannon	Creative Salmon
Brad Beaith	DFO
Bob Bocking	LGL
Brendan Zoehner	DFO
Cameron Freshwater	DFO
Candace Picco	Ha'oom
Carol Schmitt	Omega Pacific Hatchery
Cecilia Addy	Port Alberni Port Alberni
Christian Carson	Redd Fish
Christie Morrison	DFO
Christopher Burns	LGL
Chrys Neville	DFO
Dani Robertson	Uu-a-thluk
Dave Burt	Independent
Dave Rolston	Tseshaht First Nation

Derek Price	**DFO**
Di Wan	**DFO**
Dianna McHugh	**DFO**
Dilan Sunthareswaran	**UBC**
Eamon Miyagi	**DFO**
Ed Walls	**DFO**
Eric Hertz	**SFU**
Erin Rechisky	**DFO**
Esther Guimond	**DFO**
Graham Murrell	**Hupacasath First Nation**
Ian Perry	**DFO**
Isobel Pearsall	**PSF**
James Mortimor	**DFO**
Jackie King	**DFO**
Jaclyn Cleary	**DFO**
Jacob Lerner	**UBC**
Jared Dick	**Uu-a-thluk**
Jeh Custerra	**Friends of Clayoquot Sound**
Jennifer Boldt	**DFO**
Jess Edwards	**Ha'oom**
Jessica Hutchinson	**Redd Fish**
Jessy Bokvist	**DFO**
Jim Irvine	**DFO**
John Candy	**DFO**
John Holmes	**DFO**
Jon Hunter	**Area G Troll**
Josh Temple	**Coastal Restoration Society**
Kael Klein	**DFO**
Kaylyn Kwasnecha	**Redd Fish**
Kelly Young	
Kiana Matwichuk	**DFO**
Kristi Miller-Saunders	**DFO**
Leah Sneddon	**DFO**
Levana Mastrangelo	**Yuułuʔiłatḥ Government**
Marc LaBrie	**WCA**
Matt Clarke	**DFO**
Michael Thom	**DFO**
Moira Galbraith	**DFO**
Monique Dragon-Gillette	**Ka:'yu:'k't'/Che:k:tles7et'h' First Nation**
Nick Brown	**DFO**
Paige Ackerman	**DFO**
Patrick James	**Mowachaht Muchalaht First Nation**
Penny Cote	**ACRD**

Peter Mackenzie	Cermaq
Phil Edgell	Alberni Valley Enhancement Society
Ron Tanasichuk	Independent
Sam	
Sarah Fowler	Tahsis
Sonia Batten	Marine Biological Association
Spencer Russell	VIU
Suzanne Earle	DFO
Svetlana Eusenkulova	PSF
Tim Hawkins	WCA
Timothy Healey	DFO
Tom Balfour	Redd Fish
Wilf Luedke	DFO
Will Duguid	PSF

7.5 Workshop 5 – Predation

May 24 – 25, 2022

7.5.1 Background

Fifth in the series of seven virtual workshops during 2022 to 1) create understanding of existing knowledge on WCVI Chinook salmon and 2) investigate factors limiting their survival and productivity during their marine life stages and 3) identify knowledge gaps.

7.5.2 Objective(s)

To assess and rank marine risk factors (LF16-19, Table 7.10) potentially limiting survival, growth and/or fitness of natural-origin WCVI Chinook during four marine life stages (LS1-4):

LS1 (first marine spring, summer and fall in estuary and nearshore marine) along WCVI
LS2 (first marine winter along WCVI)
LS3 (subsequent multi-year marine rearing of ages 2-4 north of Vancouver Island ending when fish begin their homeward migration, and
LS4 (Adult fish migrating back to the WCVI and into estuaries.

Table 7.10 Limiting Factors Assessed in WCVI Marine Risk Assessment Workshop 5

LF	Category	Limiting Factor Description
16	Predation	Survival, growth and/or fitness reduction due to elevated predation levels by marine mammals
17	Predation	Survival, growth and/ fitness reduction due to elevated predation levels by birds
18	Predation	Survival, growth, and/fitness reduction due to elevated predation levels by fish
19	Predation	Survival, growth and/ fitness reduction due to novel predators shifting or expanding their range

7.5.3 Summary of Results

The fifth WCVI Marine Risk Assessment workshop, “Predation Affecting WCVI Chinook” was convened May 24-25, 2022. The primary objective of the workshop was to assess how four Limiting Factors (LF): *Predation by marine mammals* (LF16); *Predation by birds* (LF17); *Predation by fish* (LF18); and *Predation by novel predators* (LF19); influence survival, mortality and/or fitness reduction of WCVI Chinook across 4 marine life phases (LS1-4,Table 7.10).

The first day started with an overview of Chinook life history and the risk assessment methodology for salmon (RAMS). Presentations and discussion specific to one or more of the limiting factors made up the rest of the day. The second day consisted of a discussion on the presentations and information shared on the previous day and an overview of the detailed scoring surveys. Presenters and other workshop attendees were invited to fill out an online survey with their risk rankings in order to develop an overall risk rating in the context of the RAMS. Unfortunately, relatively low numbers of participants completed the survey, making the validity of the results questionable.

Following completion of the workshop, a small group met to review the distribution of scores from all participants who scored limiting factors individually and assign a risk ranking for each limiting factor. Detailed results for each limiting factor are provided in Section 6, and a summary of the group results is provided below (Table 7.11).

Table 7.11 **Ranked (very high to very low) current and future risk rankings for limiting factors (LFs) considered during Workshop 5 (see Section 6 for details).**

Limiting Factor	Life Stage	Review Result Current Risk	Review Result Future Risk
LF16 Predation marine mammals	LS4	High	High
LF18 Predation by fish	LS1	High	High
LF16 Predation marine mammals	LS3	High	High
LF17 Predation by birds	LS1	High	High
LF18 Predation by fish	LS2	High	Mod
LF16 Predation marine mammals	LS2	Mod	Mod
LF16 Predation marine mammals	LS1	Mod	Mod
LF18 Predation by fish	LS3	Mod	Very Low
LF19 Predation by novel predators	LS1	Low	Low
LF17 Predation by birds	LS3	Low	Very Low
LF17 Predation by birds	LS2	Very Low	Very Low
LF17 Predation by birds	LS4	Very Low	Very Low
LF18 Predation by fish	LS4	Very Low	Very Low
LF19 Predation by novel predators	LS2	Very Low	Very Low
LF19 Predation by novel predators	LS3	Very Low	Very Low
LF19 Predation by novel predators	LS4	Very Low	Very Low

Workshop presentations and discussions demonstrated that predator-prey relationships are complex. Predation varies spatially and temporally, and more data are often needed to adequately represent when and where Chinook are being consumed. Predation can affect Chinook salmon populations through direct consumption and can also influence population demographics through size-selective predation on larger fish resulting in decreases in size and age at maturity.

A high risk from predation by marine mammals was identified for returning Adult (LS4) and sub-Adult (LS3) WCVI Chinook, both now and in the future. Some differences in predation risks were noted among marine mammals. For example, coastal predators and terminal predators would have different influences on the four Chinook life stages. Coastal predators, such as Steller sea lions and Resident Killer Whales, are expected to consume mainly larger fish; therefore, sub-Adult and Adult life stages would be more vulnerable to predation by these species. Harbour seals are primarily terminal predators that target pre-spawning Adults as they return to estuaries and rivers. Smaller chinook runs would be more vulnerable to this type of predation, especially if barriers and low water levels slow their migration. The risk from harbour seal predation on Juvenile Chinook is moderate; however, there may be specific locations where seals learn to feed on concentrations of out-migrating Juveniles resulting in a high risk for those populations.

Risk of predation by fish ranged from a high risk for the early marine stage LS1 to very low for the final life stage LS4. In fact, predation risk from birds, novel predators and other fish was very low. Other fish species, such as hake, mackerel, and salmon sharks are known to consume salmon although the magnitude of impact of this type of predation for LS2 and LS3 is uncertain.

A high risk from predation by birds was identified for LS1. Herons have been shown to be important predators on out-migrating smolts; small smolts appear to be most susceptible. Risks from bird predation in estuaries may increase during low flows. Risks to subsequent life stages was generally very low, presumably in part due to Chinook being larger.

Predation risk from novel predators was low or very low across all life stages under both current and future conditions. Limited data were available to assess this limiting factor; however, it was not identified as a high priority for further research.

Several areas of uncertainty and knowledge gaps were identified in the workshop. Knowledge gaps for the highest risk limiting factors need to prioritized.

7.5.4 Agenda

Day 1

9:00 am	Welcome, the WCVI RAMS process, products & goals. Today's plan. Marc LaBrie, WCA
9:20 am	Overview of Workshop2 #1, 2, 3,4. Wilf Luedke, DFO
9:40 am	Brief Introduction to the Workshop 5 Limiting Factors and the Scoring Process. Jessica Hutchinson and Christian Carson, Redd Fish. Overview of the Life History Model. Wilf Luedke, DFO
10:00 am	Cowichan Chinook survival studies: preliminary results and application to WCVI rebuilding. Kevin Pellett, DFO
10:30 am	Break
10:45 am	Wading to strike: herons as the unsuspected salmon smolt predator. Zac Sherker, UBC
11:15 am	Seabird diets. Mark Maftei, Raincoast Education
11:40 am	Predation-related aspects of the early marine biology of Juvenile hatchery Chinook salmon in Barkley Sound/West Coast Vancouver Island. Ron Tanasichuk, DFO Emeritus
12:15 pm	Lunch
1:15 pm	Summary of Pinniped Population Trends and Diets on WCVI. Sheena Majewski and Strahan Tucker, DFO
1:45 pm	Assessing the Influence of Anthropogenic and Environmental Conditions on Chinook Survival. Jamieson Atkinson, BCCF

2:15 pm	WCVI Chinook affecting Predation (it's all about perspective!): Southern Resident Killer Whale habitat preference and foraging areas in the Salish Sea and Swiftsure Bank area. Sheila Thornton and Scott Toews, DFO Science
2:45 pm	Steller Sea Lions: An Important but Unrecognized Salmon Predator. Peter Olesiuk, Pacific Eco-Tech Environmental Research (DFO Retired)
3:15 pm	Break
3:30 pm	Using ecosystem modelling to assess marine mammal predation impacts on Chinook salmon. Fanny Couture, UBC
4:00 pm	General discussion
4:30 pm	Adjourn

Day 2

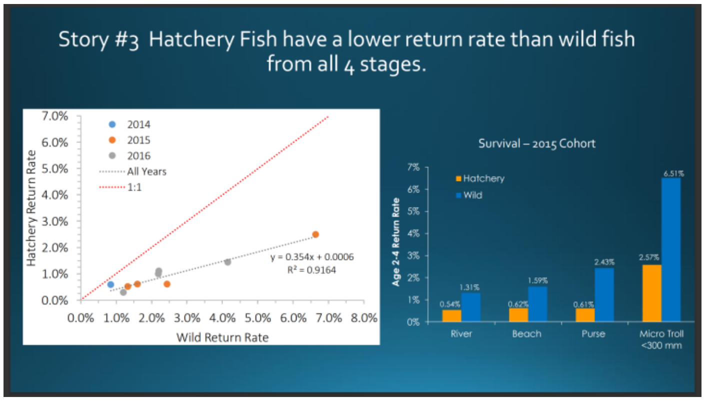
9:00 am	Overview of Day 1. Discussion about the Limiting Factors presented during Day 1- should any be added? Discussion of key knowledge gaps, other information sources, immediate research priorities, potential actions, and scoring of limiting factors. Wilf Luedke, DFO and Marc LaBrie, WCA
9:45 am	Limiting Factor Scoring / Overview of online scoring activity. Tim Hawkins, WCA
10:15 am	Begin scoring
10:45 am	Break
11:00 am	Wading to strike: herons as the unsuspected salmon smolt predator. Zac Sherker, UBC
11:15 am	Continue discussion
12:00 pm	Ajourn

7.5.5 Presentation and Discussion Highlights

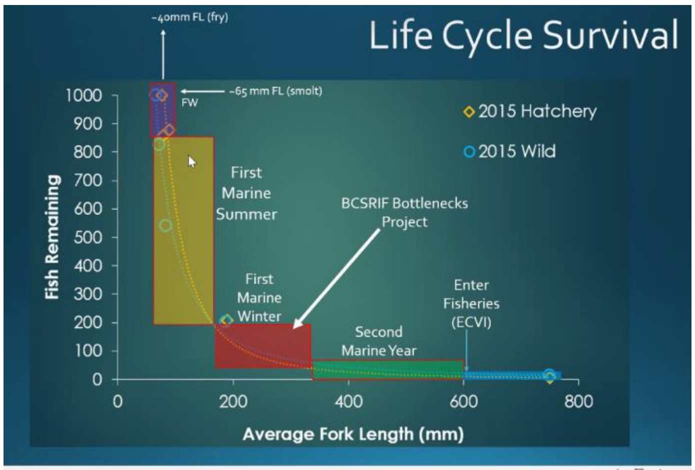
Cowichan River Chinook Survival Studies: Preliminary Results and Application to WCVI Rebuilding

Presenter: Kevin Pellet – South Coast Stock Assessment Biologist (DFO)

- Cowichan Chinook marine survival project applied PIT tags over 4 years (2014-2017) at 4 distinct stages of Chinook life cycle (River, Beach, Purse, Microtroll) to assess survival in wild and hatchery fish
- Evidence of poor freshwater survival
- Small wild fish observed to stay longer in freshwater compared to large wild fish.
- Hatchery fish left the system the fastest
- Hatchery fish had a lower return rate than wild fish in all 4 life stages



- Life Cycle survival model may be relevant to WCVI
- Greatest mortality occurs in the first marine summer
- Mortality in first winter is poorly understood and not often studied



- Predation was observed by trout, mergansers, raccoons, river otters, herons
- Some PIT tags found at seal haul outs indicating some predation by Harbour seals

Q&A Summary

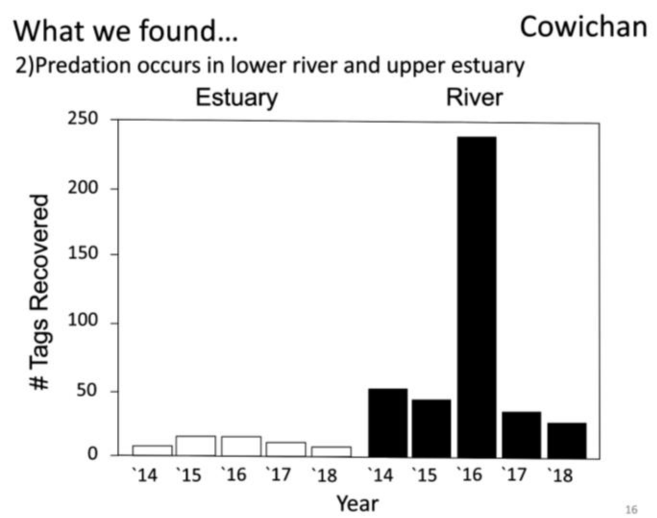
- Tom Balfour – pit tag study on Toquaht found that the releases closest to the ocean had the highest mortality rate
  - Kevin – could be a sampling error with too many fish crossing at once – tag collisions
  - Tom – could also be specific to treacherous canyon on lower Toquaht
- Candace Picco – do you have a mortality estimate for the tagging process?
  - Kevin – yes and no. For hatchery fish, we have an estimate of 5% or less initially, then down to 1% for the tagging process. One study showed that wild fish had high mortality with trapping for studying survival rates, so no assessment on wild mortality with tagging.
- David Welch – there are some really interesting PIT tagging studies around BC, it would be interesting to do a meta-analysis for perspective.
  - Also provided a distinction between mortality and survival and provided some suggestions about additional analysis of data.

- Andrew Trites – Cowichan is our best dataset on predation.
    - History of Cowichan system – historically a major chinook production system – big decline in early 2000s, low in 2009. Now seeing large (20-50k) returns. Was hatchery dominated return, now a wild dominated return.
- Peter Olesiuk – question about seal scat analysis – in Cowichan log boom
    - Kevin – potential underestimation of seal mortality in winter with scat analysis due to sampling constraints
    - Peter - May be some additional data from Austen Thomas's work to explore more detailed analysis of composition from harbour seal scat using DNA analysis

Wading to strike: Pacific Great Blue Herons as the unsuspected salmon smolt predator

Presenter: Zachary Sherker – PhD Student Pacific Salmon Ecology and Conservation Lab (UBC)

- PIT tag study to look at salmon predation in the Cowichan
- Lots of mortality observed in freshwater stage
- Tags were being taken out of the system – missing tags associated with Heron predation
- 600 pit tags observed in Cowichan heronry
- More predation observed in river compared to estuary
- Higher predation in low flow years



- Different heron predation strategies on different systems
    - In Cowichan, the herons wait at the tide line on the river. In Capilano, the Stanley Park heronry shows predation throughout the estuary area.
    - Smaller fish are more heavily preyed upon
    - Predation occurs during chick rearing (late May through late July, peak in early June)
- It is likely that herons are consistent predators on out-migrating salmon smolts. In low flow years, that predation can be even higher.
- Smaller smolts are more susceptible to heron predation.

Q&A Summary

- What else do heron eat?
    - Sculpin, perch, etc. other fish.
- Is there a preference by species for heron predation?
    - Seemed like similar predation rates between Chinook and Coho
    - Hatchery fish may be more susceptible to predation because they are not as good at avoiding predation

<u>Rhinoceros Auklets as Predators of Salmon</u>

Presenter: Mark Maftei (Raincoast Education Society)

- Rhinoceros auklets are indicators of ocean conditions
- Auklets do not prefer to feed on salmon and demonstrate strong preference for herring and sand lance
    - But some years, they eat a lot of salmon for lack of other food.
    - All other species of salmon are eaten, almost no chinook are ever seen predated by auklets – mostly pink, sockeye, chum
- Observed that auklets predate on salmon that are weaker/struggling
- Bottom line: Rhinoceros auklets do not eat chinook salmon up and down the coast.

Q&A Summary

- Andrew Trites – is there data on what rhino auklets feed themselves rather than what they feed their young?
    - Mark: may be different due to soft bodied fish being less durable to bring back to young.
- Were any other seabird species sampled?
    - Mark: only other possible species would be Tufted puffins or Murres but no data to answer question definitively.

<u>Predation-related aspects of the early marine biology of Juvenile hatchery Chinook salmon in Barkley Sound/West Coast Vancouver Island</u>

Presenter: Ron Tanasichuk (DFO Emeritus)

- Looked at migration timing and early marine distribution of Juvenile chinook salmon in Barkley Sound
    - Juvenile Chinook are in Alberni Inlet/Barkley Sound from June through August
    - Most natural-origin Juvenile Chinook salmon were collected in nearshore waters and hatchery Juveniles occurred away from shore
- Distribution and abundance of known predators
    - Pacific mackerel – evidence of predation on hatchery produced smolts
    - Steller sea lions feed on Chinook but no evidence of Juvenile Chinook predation
        - Sea lion abundance increasing since 1980s
- Analysis on effect of predation on total return of Robertson Creek Hatchery Chinook
    - Analysis tested effects of hatchery rearing, prey biomass, and predator abundance

    - Predation by mackerel and sea lions was found to explain the variation in age-specific return of Robertson Creek Hatchery Chinook
    - Sea lion predation had twice the effect that mackerel predation did on return

Q&A Summary

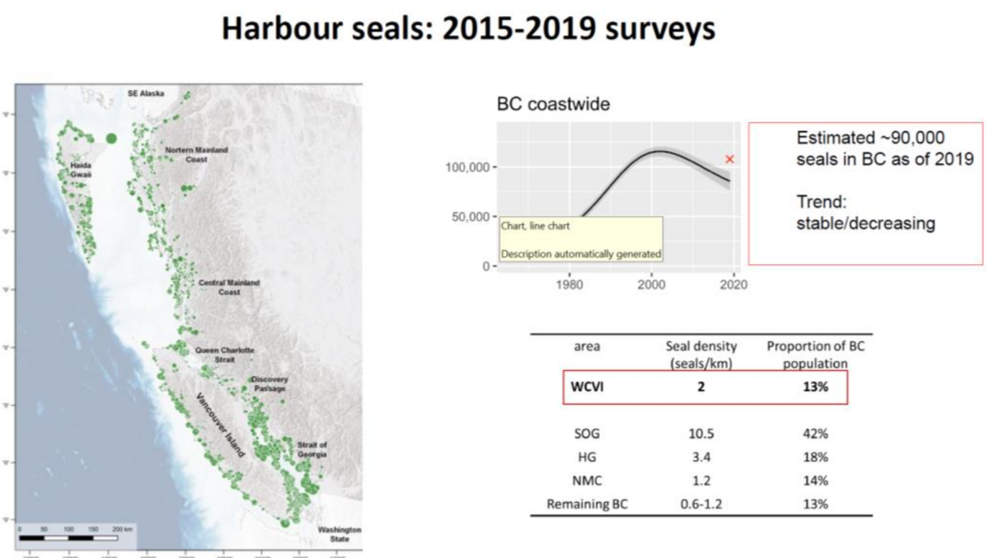
- Andrew Trites: Are you assuming the Steller sea lions are eating Juvenile salmon?
    - Ron – Yes
    - Andrew – How do you define the size of Juvenile salmon?
    - Ron- at the most 10 cm long
    - Andrew – no direct evidence that Steller Sea lions are eating Juvenile fish based on dentition and animal size. Doesn't line up with them having an impact on Juvenile fish but they do consume Adults.
    - Ron – quite a concentration of Sea Lions along the coast. May need some additional work to confirm whether Juveniles are being consumed
- Peter Olesiuk: Juveniles may actually be larger in size by the time they migrate up the coast
    - Some evidence in the scat data of 20 cm chinook that are also Juvenile, but it is a small part of the diet.
    - Because of the high abundance of Sea Lions this could still be a potential source of impact
    - Ron – some tools available to explore this further
    - Peter – DNA barcoding is useful for species composition information but in order to get size information you need to rely on bones. Bones from small fish are observed in scat – reference Austen Thomas' work
    - Ron – some opportunities for additional follow up work to resolve some uncertainties
- Andrew Trites: don't know much about the diet of other fish. Mackerel predation information is important to consider as well as predation by other fish
    - Ron – agree that this is a data gap

Summary of Pinniped Population Trends and Diets on WCVI

Presenter: Sheena Majewski – Pinniped Research Program (DFO)

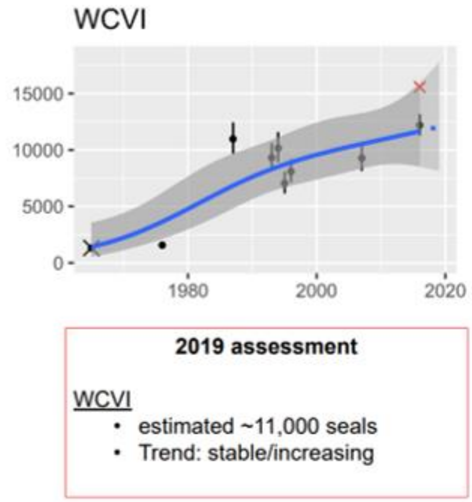
- Study focused on Steller Sea lion, California sea lion, and harbour seal
    - DNA analysis of scat
    - Abundance estimates
- Steller Sea Lions
    - BC population is part of Eastern Stock – California to Gulf of Alaska
    - Breeding season surveys conducted since 1971 (June 27-July 9)
    - Increase in number of rookery sites and year-round haul out sites
    - The growth in pup production appears to be slowing
    - Total summer 2017 abundance of approx. 43k. No significant change from previous assessment
    - Winter survey in 2017 estimated 53k

  - Seasonal shifts in distribution
    - Summer aggregation at rookeries, mostly north of Vancouver Island and up to PR.
    - Highly mobile throughout their range
  - Large rookery at Scott Island Rookery
    - Most pups in BC are born here.
- California Sea Lions
  - Breeding in California, not BC. But part of the population overwinters in BC waters.
  - Fall/winter overlap with Steller Sea Lion, especially outside of Clayoquot Sound and Barkley Sound and down to Race Rocks
  - California sea lion males arriving earlier, staying later. Numbers overwintering increasing and range expanding
- Pacific harbour seals
  - Estimated ~90k seals in BC as of 2019.
  - Strait of Georgia has by far the highest density, 40% of total
  - Trend: stable/decreasing



area	Seal density (seals/km)	Proportion of BC population
WCVI	2	13%
SOG	10.5	42%
HG	3.4	18%
NMC	1.2	14%
Remaining BC	0.6-1.2	13%

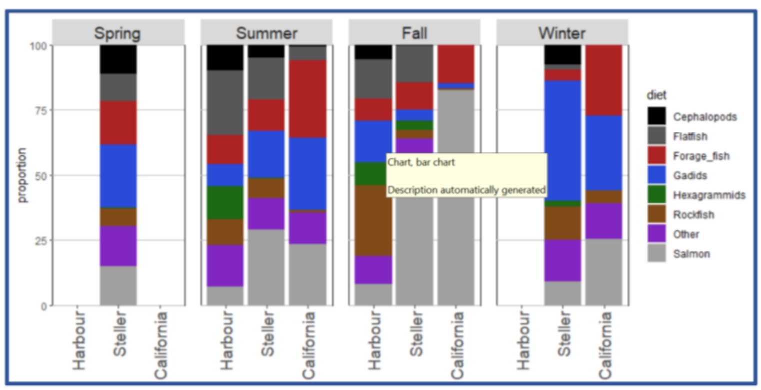
  - Population on WCVI is stable/increasing



- Good data for Barkley Sound, more limited for other areas

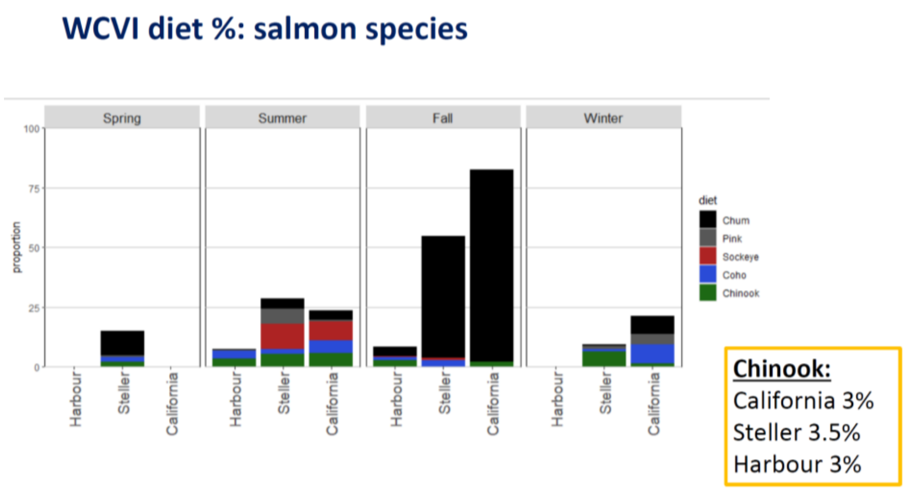
- Pinniped diet – current focus on scat-based methods
- Comparison of diets between SoG, WCVI, and Broughton

WCVI diet %: DNA scats



- **Seasonal variation**
- **Harbour seal: most diverse, ~8% salmon**
- **Steller sea lion: herring and hake, ~25% salmon**
- **California sea lion: herring and hake, ~40% salmon**

  - Harbour seals have a diverse diet, 8% salmon
  - Steller sea lions eat mostly herring, hake, and salmon – 25% salmon
  - California sea lions have the least diverse diet, eating mostly herring, hake, and salmon – 40% salmon (3% chinook)



- Most salmon eaten across pinnipeds is chum salmon, 3% of salmon eaten by each species are CK.

- Important inter-annual differences but sample sizes are limited
- Size of fish consumed is assessed through hard part analysis
    - likely majority over 30cm – mostly older age classes (sea lions and seals)
- Need to be cautious about extrapolating assumptions about data from a limited sample size
- Estuary use
    - Only about 5% of seals are thought to reside within Estuaries
    - Diets vary greatly between individuals

Q&A Summary

- Dave Rolston – Is DFO able census all estuaries and rivers?
    - Sheena – yes, low densities of seals during August sampling period which may not be the most abundant time period and they may redistribute at other times of year.
- Were seal scats from estuary and river seals combined or analyzed separately?
    - Sheena – looked for haul out near river estuaries and assumed they would be foraging in the estuaries but can't determine where seals were feeding.
- Candace - How does the percentage of fish in the diet translate to biomass?
    - Sheena – not able to address this in their work
- Peter Olesiuk – to convert abundance to biomass you can calculate this.
    - For estuary counts - suggests that seals can be counted sleeping on ocean floor in estuary – need to develop search image for this
    - Problem of not being able to collect scat in estuaries – could potentially install floats to be able to monitor
- Wilf – How do we handle habituated seals?
    - Peter Olesiuk – habituated animals fed exclusively on salmon in Comox estuary
        - Different populations mix together on the log booms
        - Observational studies in the rivers are needed

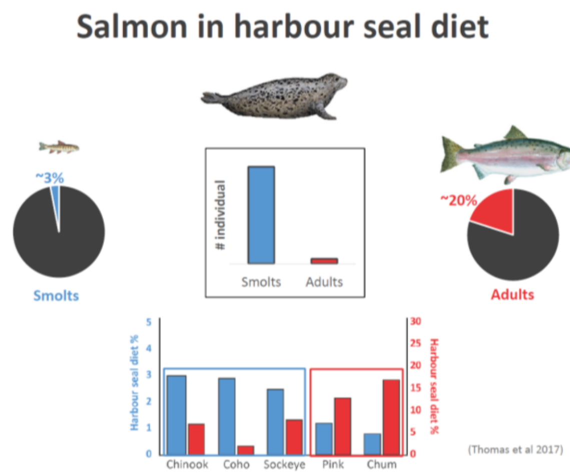
- How to remove habituated seals that learn to feed in estuaries – need to better monitor estuaries so that mitigation of effects could be targeted.

<u>Seals and Salmon</u>

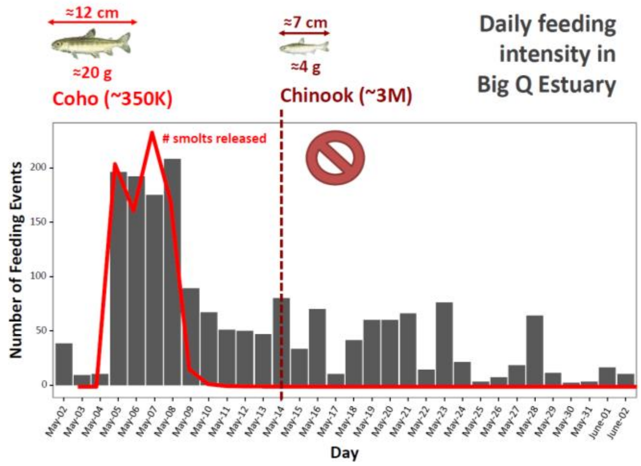
Presenter: Andrew Trites, University of British Columbia

- Discussed three key studies on seals in the Salish sea

Harbour seal diet analysis using DNA metabarcoding



  - Allows us to know which species are being consumed
  - Don't know the size of the fish
  - Hake and Herring are the dominant prey items
  - More salmon are found in estuary sites compared to non-estuary sites
  - Species composition varies across locations - need to be cautious about making comparison across a broader area
  - Chinook smolts more common in diet (~3%) and Adult Chinook less abundant compared to other salmon species
- Studied movement and behaviour of seals in Big Qualicum area
  - Some seals were observed to move to other locations
  - Different types of feeding strategies among estuary, intermediate, and non-estuary seals
  - Tight correlation in daily feeding intensity linked to release of Coho smolts from Big Q
  - No response observed in seal daily feeding with release of Chinook smolts
    - Chinook smolts were much smaller in size compared to coho and may not be worthwhile for predators at that small size



- Spike in feeding activity in estuary at sunset may reflect movement of fish or changing light conditions
- Chinook Juveniles do become part of the seal diet when they are larger in size.

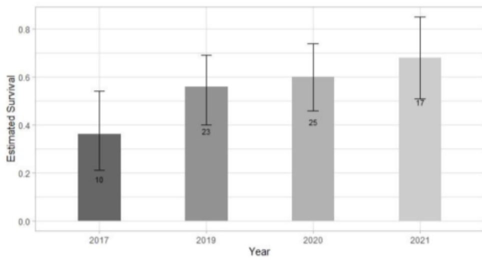
- Predation may target weaker fish with lower likelihood of survival
- Fish that stay longer in the estuary are likely to be more vulnerable to seal predation

Assessing the Influence of Anthropogenic and Environmental Conditions on Chinook Survival

Presenter: Jamieson Atkinson, BCCF

- Study funded by Cowichan Tribes to understand if log booms impact Adult Cowichan Chinook
  - Looking into mechanisms of mortality
  - When and how was mortality occurring?
  - Do log booms influence predator prey relationship?
- Multi-year study developed
  - incorporated acoustic tags and PIT tags to understand mortality
  - 2019 was a control year with no log booms due to Western Forest Service strike
- Seal survey data - difficult to get consistent counts due to DFO aerial surveys being done typically at low tide
  - Observed seals by land and boat not consistent with aerial surveys and were highly variable
  - Seal abundance assumed to be constant for all years with or without log booms
- Sampled and tagged fish across four years - removed non-Cowichan origin fish
- High survival of Chinook salmon observed in 2021 - lowest in 2017
  - River discharge and migration timing varied over the years
  - Years with high flows, fish are moving faster and spending less time in the estuary and have higher survival

Year	PIT-Tagged N =		Survival
	Deployed	Detected MN	
2017	29	10	0.34
2019	41	22	0.56
2020	42	25	0.62
2021	25	17	0.68



Log Booms Presence	Predicted Probability of Survival			P =
	Mean	Lower C.I.	Upper C.I.	
Yes	0.48	0.36	0.59	0.11
No	0.67	0.48	0.86	
Discharge (m^3/s)	Probability of Survival			P =
	Mean	Lower C.I.	Upper C.I.	
5.3	0.39	0.27	0.54	0.01
7.6	0.47	0.37	0.57	
9.9	0.54	0.46	0.63	
12	0.61	0.51	0.7	
15	0.7	0.54	0.81	

- River discharge observed to be significantly correlated to survival
- Log boom presence also appeared to be correlated to survival, but no significant relationship was observed
    - Log booms may contribute to increased predation efficiency
    - Acoustic detections suggest that predation may occur in shallow water in estuary
- Limiting factor - most likely affecting return migration to WCVI (Phase 4) also phase 1 in estuary near shore areas
- River discharge is likely the primary driver of mortality
    - Prolongs estuary and lower river staging
    - Log booms may contribute to amplified predation efficiency

Q&A Summary

- Andrew - why were log booms kept in the model when the parameter results were not significant?
    - Jamieson - log booms were the primary reason for the study and although the p-value was not significant it was felt that the potential effects may be biologically significant. The study is being continued to increase sample size and will be investigating this further
- Will - Was much sea lion predation observed?
    - Not much but sea lions typically arrive in larger numbers during the chum run

<u>WCVI Chinook affecting Predation (it's all about perspective!): Southern Resident Killer Whale habitat preference and foraging areas in the Salish Sea and Swiftsure Bank area</u>

Presenter: Sheila Thornton and Scott Toews, DFO Science

- Four different populations of Killer Whale (Resident (S and N), Bigg's (Transient), Offshore)
- Southern and Northern Residents feed mostly on salmon, some other fish species and squid
- Investigating causes of decline identified correlation of mortality indices and Chinook salmon abundance
- Threat of reduced prey availability (primarily Chinook) identified

- Other threats to recovery include acoustic and physical disturbance, contaminants, ship strikes.
- Reduction in prey available may result from:
  - Changes in abundance
  - Decrease in accessibility
- Framework approach to evaluate SRKW presence and co-occurrence of threats
  - Merged effort and sightings data to identify where the whale are found
  - Identified areas of likely forage and travel
  - Focused on foraging areas around Nitinat, Swiftsure Bank and Haro Strait
  - SRKW spending less time in Salish Sea and peaking later in the season
- Working to get a better understanding of foraging behaviour and caloric needs with current research projects
- Winter prey diet distribution identified smaller Chinook in SRKW diet
- SRKW predation impacts
  - No direct effects anticipated for Phase 1 or Phase 2 Chinook
  - Predation impacts primarily to Phase 3 (4 year old) chinook from both NRKW and SRKW
  - Effects to phase 4 SRKW predation more spatially focused from May to Oct

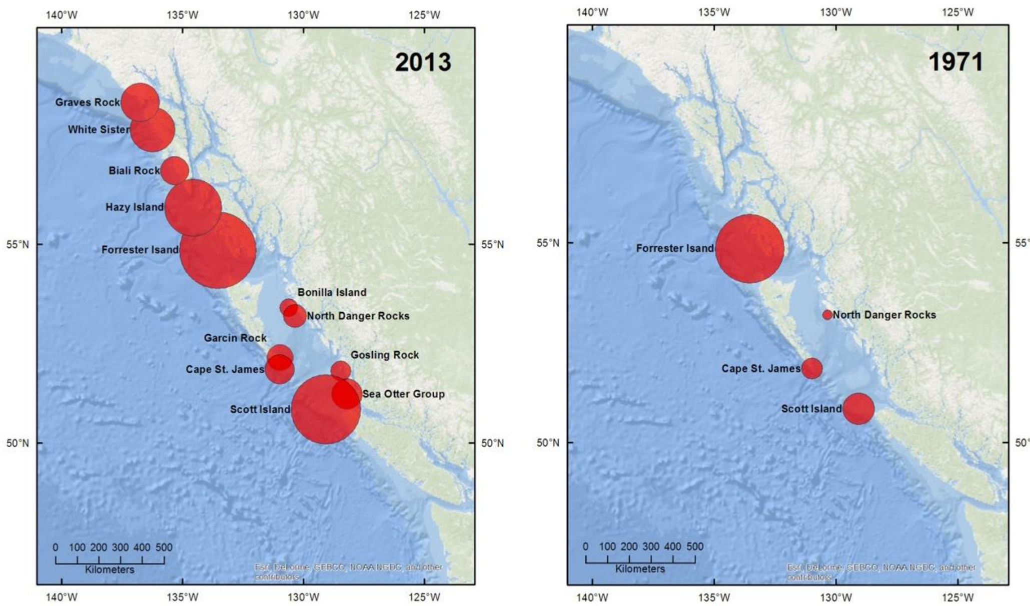
Q&A Summary

- Wilf - Surprised SRKW are not going into Barkley Sound. Is that maybe because of the sound in that area?
  - Sheila - going to spend one more summer off Nitinat but would like to focus more on Barkley Sound after that. It is likely that Robertson Creek would provide a rich foraging area in that area.
- Mark - What stocks are being intercepted in the Swiftsure area? Is it primarily Nitinat and Sooke fish or various populations?
  - Sheila - work will be focusing on prey samples to analysis for genetic and ageing. Will be developing a technique to hopefully get to stock ID by using fecal samples to help identify which stocks are being targeted. Is it representative of available prey in the area or are some groups being targeted (e.g., wild vs hatchery)?

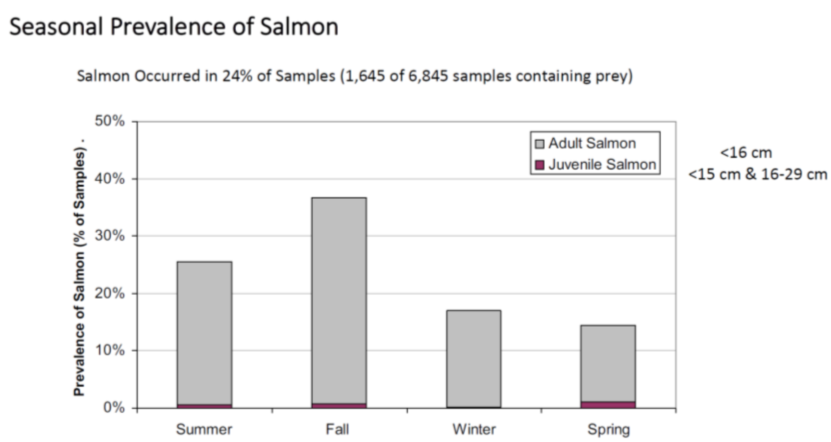
Steller Sea Lions: An Important but Unrecognized Salmon Predator

Presenter: Peter Olesiuk, Pacific Eco-Tech Environmental Research

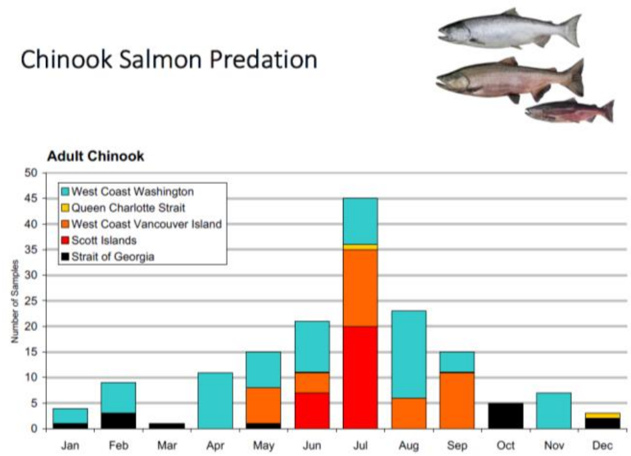
- Presenting on Steller Sea lion research in southern endowment area - focus on easter Steller sea lion population breeding sites
- An increase in the size and number of rookeries since 1960s



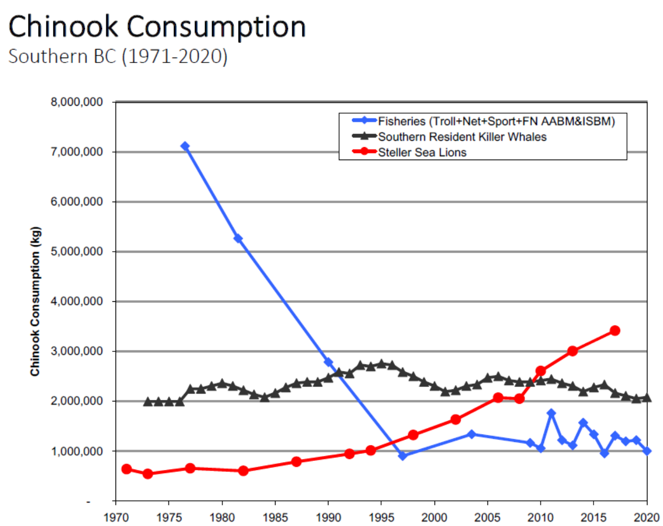
- Bioenergetic models were developed to estimated daily prey requirements (17.9kg prey per day)
- Steller sea lions are leading fish predator
  - Scat sample analysis was done to assess what they were eating
  - Salmon was fairly common part of diet (about 12 % of diet)



- Genetic analysis done to identify which species were being consumed
- Chinook displayed a broader pattern of consumption - peaking June-August but found in all months of the year



- Some indication that June-Sep capture larger fish
- Lower proportion of Chinook in high Pink salmon years
- Large number of overall salmon consumption has been observed.
- In recent years Steller sea lions seem to have largest consumption of Chinook salmon compared to Troll fishery and SRKW.



- Juvenile Chinook make up a very small proportion of the overall diet but make up a large total number of smolts – uncertain what the magnitude of this impact would be on Chinook stocks, some of which may be impacted significantly if their outmigration patter coincides with large Sea Lion numbers.
- Ecosystem Impact of Predators on Chinook
    - Steller Sea Lions have also increased in Northern BC
    - More limited samples but based on scat collection seem like similar prevalence of salmon in summer diet
    - Limited genetics data to show what species are being consumed
    - Predators may be having a big impact on Chinook with a larger impact in the north

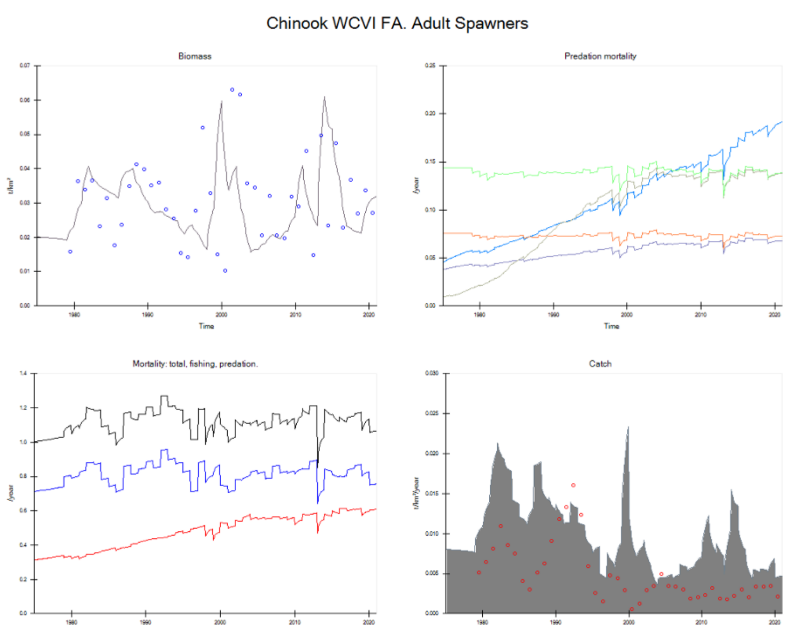
Q&A Summary

- Ron - question about what areas are included in the calculation of smolt consumption
    - Peter, although a large number of smolts are consumed, there is no stock composition data to say where the smolts are coming from. These could all be Columbia River fish. Smolts are considered to be incidental prey and make up a small proportion of the diet.
- Andrew - what is the size category of the smolt?
    - Juvenile salmon - <29cm - need to be clear about how we are defining smolt
    - Where there any differences between males and females? Was this considered in the analysis? - bioenergetics analysis could be different between males and females
        - Peter - at non-breeding sites didn't find it to make a big difference.
            - Females nursing young would have higher prey requirements
- Wilf - salmon stock and size composition data are available
    - Peter - refined estimates should be done by salmon folks

<u>Using ecosystem modelling to assess marine mammal predation impacts on Chinook salmon</u>

Presenter: Fanny Couture, PhD Candidate, University of British Columbia

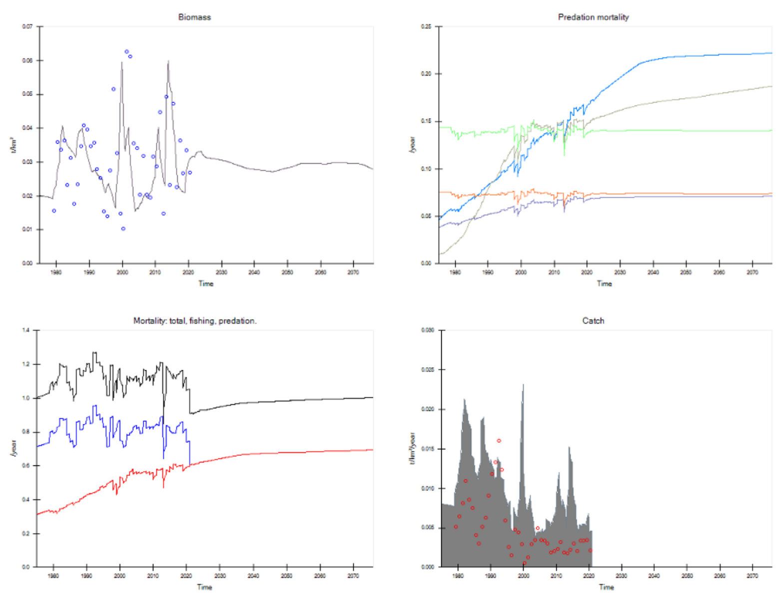
- Main objective of research is to understand how marine mammal competition for food could limit the SRKW population
    - Also estimating marine mammal predation and fisheries impact on Chinook salmon
    - Modelling done using Ecopath with Ecosim
    - Spatial extent: Dixon Entrance to central California
    - Created regional and seasonal groups for different salmon species
    - Presentation focused on smolts and Adult spawners
- WCVI Adult spawners - model predicts increased in Steller Sea lion predation mortality



Scenario 1 - Fisheries Closure from 2020

- Scenario assumes all fishing pressure stops
- Assume that the hatchery production levels would stay at about the 2020 level
- NRKW and TKW at stable levels
- Assume similar mortality for SRKW

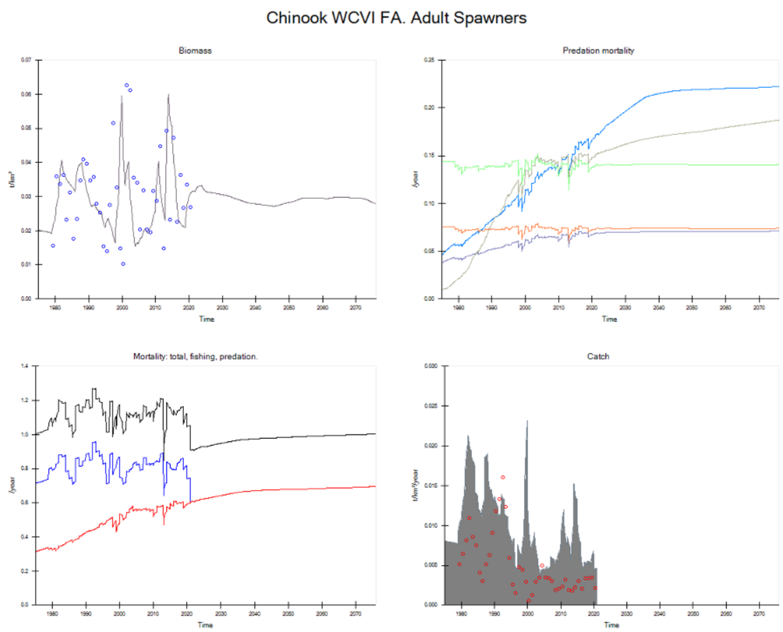
Chinook WCVI FA. Adult Spawners



- For WCVI Adults:
    - Observe continuous increase in predation mortality
    - Biomass stabilizes

Scenario 2- Pinniped population reduction after 2020

- Reducing harbour seals to 50% of pop'n size
    - predict slight increase in SRKW
- Reducing Steller sea lion to 50% of population size
    - Slight increase in FRGSPS Chinook smolts
    - Increase in biomass in FR Chinook Adults
    - WCVI Chinook biomass predicted to almost double



- For WCVI Adults:
    - Strong decrease in Steller sea lion predation mortality
    - Biomass predicted to almost double between 2020 and 2075
- Preliminary modelling results emphasize the need to consider marine mammal predation as a primary cause of mortality for Chinook salmon

Q&A Summary

- Candace - where does WCVI biomass data come from? What are the assumptions in the model
    - Fanny - from CTC data, many assumptions were not discussed - some assumptions were made related to hatchery release, also assumptions around diet for different groups - model used annual estimates and assumptions about winter diet were needed
- Wilf - Robertson Creek stock info may not be indicative of the rest of the west coast - could help provide additional info to refine the model. (e.g., exploitation rates are lower for the rest of WCVI) - Are Steller sea lions a major factor of predation for WCVI?
    - Fanny - assumed higher predation mortality than what Peter Olesiuk presented, consumption rate in model also higher, model parameters can be refined with additional information.

7.5.6 Workshop Synthesis

7.5.6.1 Distribution Plots and Comment Summaries

In workshop 5, participants were invited to score each limiting factor and provide related rationale and comments through an on-line survey, following the Risk Assessment Methods for Salmon (RAMS) methodology. The 'detailed' survey methodology included scoring for spatial and temporal exposure, biological impacts on the productivity, confidence in the scoring given the information provided and personal knowledge and experience.

Risk was assessed for both naturally produced Chinook and those of hatchery-origin, but we do not present the latter since there was agreement that effects on hatchery fish would either be lowest, or not important to this discussion. Numbers of individuals who did not rate a particular LF were recorded. Workshop participants were encouraged to input comments as they evaluated each relevant LF and LS; summaries are provided below.

Limiting factors were scored separately for the following life stages:

- Life Stage 1 (LS1) = first spring-summer-fall in the estuary and nearshore marine;
- Life Stage 2 (LS2) = winter phase along the WCVI;
- Life Stage 3 (LS3) = marine rearing of age 2-4 from Central Coast BC up along the Alaskan panhandle and into the Aleutian Islands; and
- Life Stage 4 (LS4) = Adult migration back to the WCVI and into estuaries.

Distribution plots follow sequentially for the four Life Stages starting with Limiting Factor (LF)1. Results were tabulated and basic statistics (e.g., mean, median, mode, range and standard deviation) computed for each LF and LS. Because few individual scores were available for Workshop 5, we doubted these results would be adequate. To help interpret these frequency distributions, a small team met during March 2023 and developed single consensus Review Scores for each of Likelihood, Impact, Future Trend, and Confidence for each Life Stage. A brief statistical comparison between Group consensus Review and Mean Scores follows in 6.2.

Here we briefly describe the distribution results for only the first example (Figure 7.45; LF16, LS1). The same approach was used for all LFs and LSs. Refer to the Methods Section in the main report (i.e., before Appendices) for more detailed descriptions.

Each LF and LS has six distribution plots:

- Likelihood, Impact, and Future Trend (top row).
- Participant's Confidence in their scoring, Current Risk, and Future Risk (over the next 30 years (2nd row).

The plots in the first row and the left-hand plot in the second row of Figure 7.45 display score distributions as well as consensus Group Scores; i.e., Review Scores for Likelihood (upper left plot) was 4, Impact (upper middle plot) was 2, Future Trend (upper right plot) was 3, and Confidence (lower left-hand plot) was 2 (Moderate).

Risk matrices were applied to determine Current and Future Risk distributions and single risk category review results based on the scores for Impact, Likelihood and Current Impact, Future Trend respectively. For details, see the text in the main RAMS methods section earlier in this report.

Limiting Factor 16: Mortality, growth and/or fitness reduction due to elevated predation levels by marine mammals.

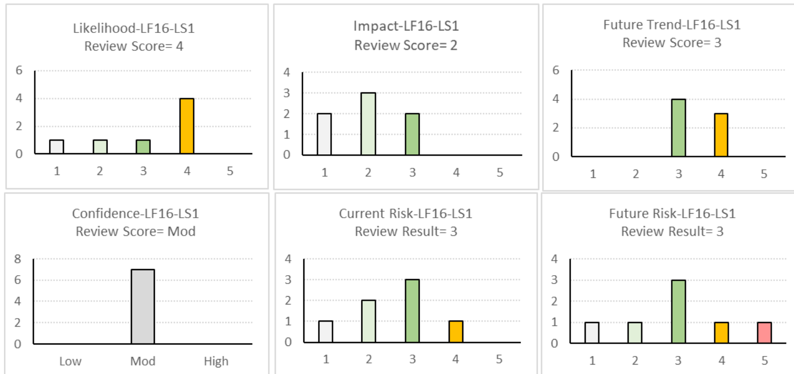


Figure 7.45 **Frequency distribution plots of participant scores by for LF16 and LS1 for Likelihood, Impact, Future Trend, and Confidence. Review scores are based on a group consensus review of these plots. Current and Future Risks and associated frequency distributi*on plots and Review Scores are calculated based on risk matrices (see Methods in Main report). If n<4, then confidence=low (i.e., 1) regardless of distribution.***

Predation risk from marine mammals at LS1 was associated primarily with predation from harbour seals. This was generally thought to be a Moderate Risk, both currently and in the future; however, in specific cases where seals learn to feed on concentrations of out-migrating Juveniles, this could have a large impact on some populations. The size and timing of ocean entry are also thought to influence the vulnerability to predation for the Juvenile life stage

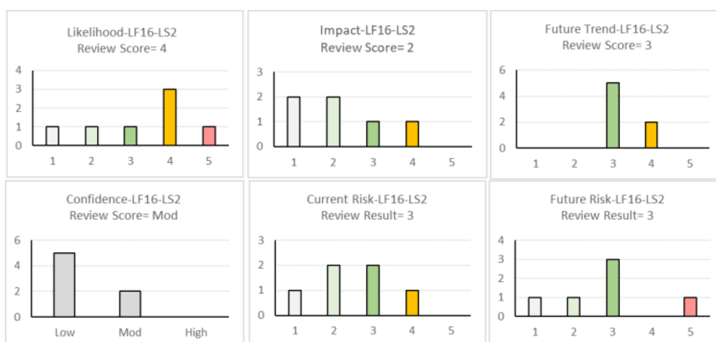


Figure 7.46 **Frequency distribution plots of participant scores for LF16 and LS2 for Likelihood, Impact, Future Trend, and Confidence. Review scores are based on a group consensus review of these plots. Current and Future Risks and associated frequency distribution plots and Review Scores are calculated based on risk matrices (see Methods in Main report). If n<4, then confidence=low (i.e., 1) regardless of distribution.**

This limiting factor rated for LS2 is a Moderate risk both now and in the future. There was a Low confidence in this ranking due to the limited data available for this life stage.

Figure 7.47 **Frequency distribution plots of participant scores for LF16 and LS3 for Likelihood, Impact, Future Trend, and Confidence. Review scores are based on a group consensus review of these plots. Current and Future Risks and associated frequency distribution plots and Review Scores are calculated based on risk matrices (see Methods in Main report). If n<4, then confidence=low (i.e., 1) regardless of distribution.**

This limiting factor rated for sub-Adults in their marine rearing phase is a high risk. With climate change the future risk is expected to remain the same and was also scored as a high future risk. There was a Moderate confidence in this ranking. Predation by Steller sea lions and killer whales were identified as sources of mortality for the sub-Adult life stage (Olesiuk pointed out that risks of predation by California sea lions may be underestimated). Predation is expected to occur in coastal waters throughout the migration route of WCVI chinook, from SE Alaska to northern and southern BC.

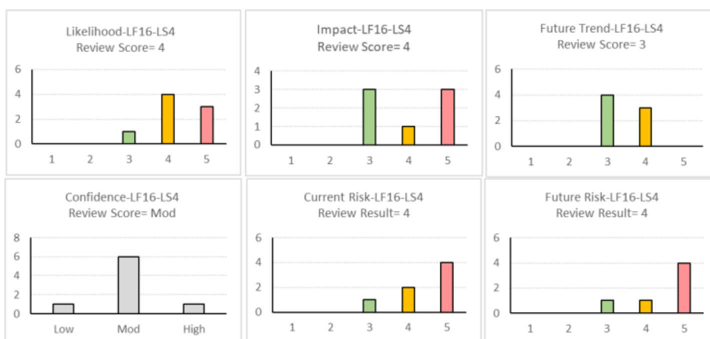


Figure 7.48 **Frequency distribution plots of participant scores for LF 16 and LS4 for Likelihood, Impact, Future Trend, and Confidence. Review scores are based on a group consensus review of these plots. Current and Future Risks and associated frequency distribution plots and Review Scores are calculated based on risk matrices (see Methods in Main report). If n<4, then confidence=low (i.e., 1) regardless of distribution.**

This limiting factor rated for Adults during their return migration phase is a High risk. With climate change the future risk may increase and was scored as at least a High future risk. There was a oderate confidence in this ranking. Most marine mammal predation by Steller sea lions and Killer Whales is expected to occur on larger sized fish making this life stage the most vulnerable to predation. Future risk may increase if pinniped populations continue to display increasing trends. Selective removal of an increasing proportion of larger Chinook might result in a decrease in the age at maturity, which would increase the magnitude of potential impact from predation by marine mammals. Some areas of uncertainty were identified, such as knowledge gaps around differences in predation rates between male and female pinnipeds and uncertainty around overwintering behaviour and distribution of both Chinook salmon and marine mammals.

LF16 comments summary:

- that changes in freshwater environmental conditions are reducing fitness of Juveniles and increasing susceptibility.
- The effect of harbour seals on Juvenile chinook (LS1) is likely low but there may be specific cases where seals learn to feed on concentrations of out-migrating Juveniles.
- Size and timing of ocean entry is also thought to influence vulnerability to predation for this life stage.
- There may be differences in predation risk among marine mammals. For example, predation from coastal predators vs terminal predators.
- Impact on specific chinook stocks is likely dependent on their migration patterns. Exposure to predators will be highest for stocks that linger in coastal waters, and lowest for stocks that quickly move offshore.
- Expected that the greatest impacts from predation would be from sea lions and Resident Killer Whales.
- More uncertainty in overwinter behaviour and distribution of both marine mammals and Chinook salmon.
- Seals that "learn" or "habituate" to feed on vulnerable pre-spawning chinook could have an impact. As seal populations recovered, there is greater competition for prey and "nuisance" seals appear to have become more dependent. This issue cannot be addressed by seal surveys and scat analyses but will require observations of seal foraging behaviour in estuaries and rivers when Chinook are spawning.
- Harbour seals are mainly a terminal predator that take pre-spawning Adults mainly as they concentrate in estuaries and rivers. Smaller chinook runs would be more vulnerable, especially if their migration is slowed by obstacles, low water levels, etc.
- Size-selective predation by killer whales could also be contributing to the decline in size-at-age of chinook (i.e. selective removal of an increasing proportion of larger chinook would result in progressively smaller chinook surviving).
- Predation by Steller sea lions and killer whales appears to have replaced fisheries as the leading source of mortality for WCVI Chinook. Predation occurs in coastal waters throughout the migration route of WCVI Chinook, from SE Alaska to northern and southern BC.
- Some areas of uncertainty were identified, such as knowledge gaps around differences in predation rates between male and female pinnipeds.

Limiting Factor 17: Mortality, growth and/or fitness reduction due to elevated predation levels by birds.

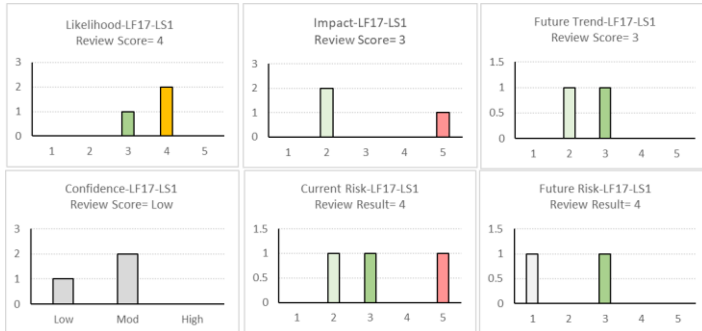


Figure 7.49 **Frequency distribution plots of participant scores for LF17 and LS1 for Likelihood, Impact, Future Trend, and Confidence. Review scores are based on a group consensus review of these plots. Current and Future Risks and associated frequency distribution plots and Review Scores are calculated based on risk matrices (see Methods in Main report). If n<4, then confidence=low (i.e., 1) regardless of distribution.**

Sample sizes were very low and as a result confidence was low. In general, small Juvenile salmon would be most susceptible to bird predation where fish-eating birds are present. Mergansers have been observed at river mouths where they may be consuming Juvenile Chinook.

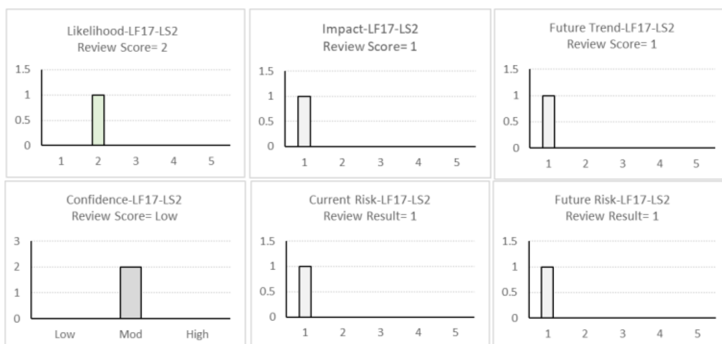


Figure 7.50 **Frequency distribution plots of participant scores for LF17 and LS2 for Likelihood, Impact, Future Trend, and Confidence. Review scores are based on a group consensus review of these plots. Current and Future Risks and associated frequency distribution plots and Review Scores are calculated based on risk matrices (see Methods in Main report). If n<4, then confidence=low (i.e., 1) regardless of distribution.**

Again, sample sizes were extremely small, resulting in a low confidence rating. Regardless, predation by birds during salmon's first marine winter is a **low risk,** both now and in the future.

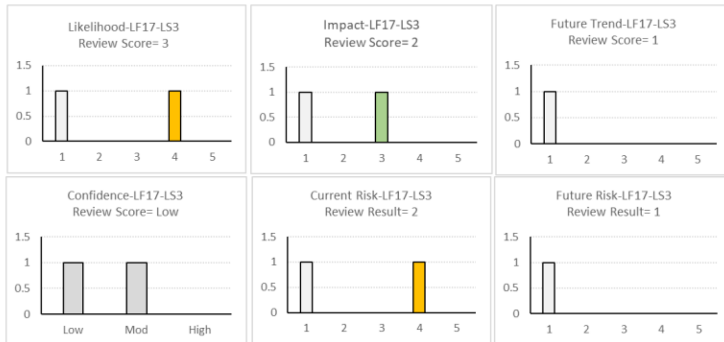


Figure 7.51 **Frequency distribution plots of participant scores for LF17 and LS3 for Likelihood, Impact, Future Trend, and Confidence. Review scores are based on a group consensus review of these plots. Current and Future Risks and associated frequency distribution plots and Review Scores are calculated based on risk matrices (see Methods in Main report). If n<4, then confidence=low (i.e., 1) regardless of distribution.**

Again, sample sizes were extremely small, resulting in a low confidence rating. Regardless, predation by birds during LS3 is Low (current) or Very Low (future).

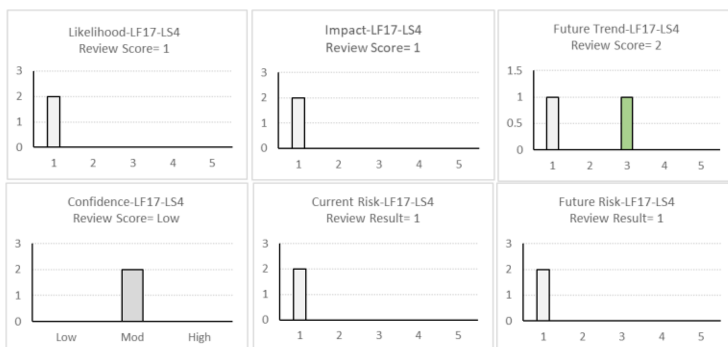


Figure 7.52 **Frequency distribution plots of participant scores for LF17 nd aLS4 for Likelihood, Impact, Future Trend, and Confidence. Review scores are based on a group consensus review of these plots. Current and Future Risks and associated frequency distribution plots and Review Scores are calculated based on risk matrices (see Methods in Main report). If n<4, then confidence=low (i.e., 1) regardless of distribution.**

Once again, sample size was extremely low (n=2), resulting in a low confidence. This limiting factor rated for Adults in their return migration phase is **very low risk,** both now and in the future. Adult Chinook are not vulnerable to bird predation due to their relatively large size.

LF17 Comment Summary

- Not many herons are present in the Somass compared to other areas of the coast.
- Smaller Juveniles would be more susceptible to predations by herons where they are present.
- Differences in predation risk would be expected among different bird species.
- Older life stages are not thought to be vulnerable to bird predation.
- Herons may be important predators on out-migrating smolts. This could be a bigger factor in low flow years.
- Merganser have recently been observed in recent years at the river mouths.

Limiting Factor 18: Mortality, growth and/or fitness reduction due to elevated predation levels by fish.

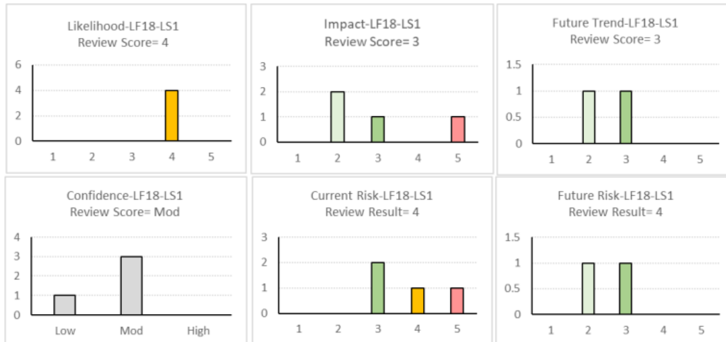


Figure 7.53 Frequency distribution plots of participant scores for LF18 and LS1 for Likelihood, Impact, Future Trend, and Confidence. Review scores are based on a group consensus review of these plots. Current and Future Risks and associated frequency distribution plots and Review Scores are calculated based on risk matrices (see Methods in Main report). If n<4, then confidence=low (i.e., 1) regardless of distribution.

This limiting factor rated for Juveniles in their first spring-summer-fall is **high risk**, both now and in the future.

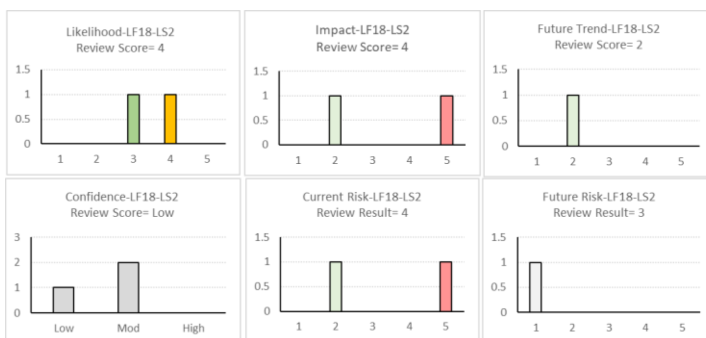


Figure 7.54 Frequency distribution plots of participant scores for LF18 and LS2 for Likelihood, Impact, Future Trend, and Confidence. Review scores are based on a group consensus review of these plots. Current and Future Risks and associated frequency distribution plots and Review Scores are calculated based on risk matrices (see Methods in Main report). If n<4, then confidence=low (i.e., 1) regardless of distribution.

Although the risk of predation by other fishes was High and Moderate for current and future respectively. In general, smaller fish are thought to be more susceptible to predation by other fish species.

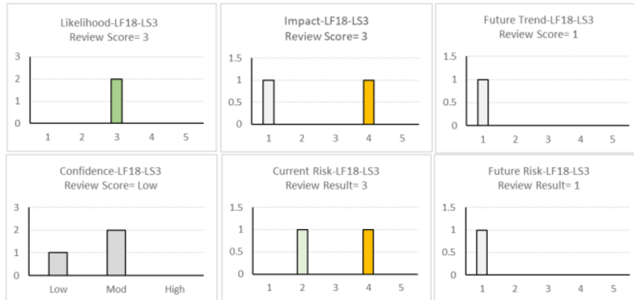


Figure 7.55 **Frequency distribution plots of participant scores by Limiting Factor and Life Stage for Likelihood, Impact, Future Trend, and Confidence. Review scores are based on a group consensus review of these plots. Current and Future Risks and associated frequency distribution plots and Review Scores are calculated based on risk matrices (see Methods in Main report). If n<4, then confidence=low (i.e., 1) regardless of distribution.**

The risk of predation by other fishes was High and Moderate for current and future respectively. In general, smaller fish are thought to be more susceptible to predation by other fish species.

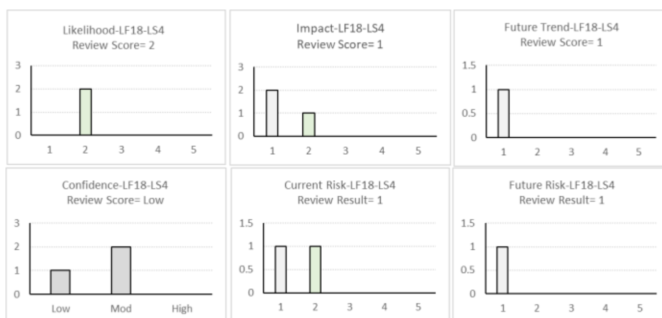


Figure 7.56 **Frequency distribution plots of participant scores for LF 18 and LS4 for Likelihood, Impact, Future Trend, and Confidence. Review scores are based on a group consensus review of these plots. Current and Future Risks and associated frequency distribution plots and Review Scores are calculated based on risk matrices (see Methods in Main report). If n<4, then confidence=low (i.e., 1) regardless of distribution.**

This limiting factor rated for Adults in their return migration phase is very low, both now and in the future. Adult Chinook salmon are not particularly vulnerable to predation by other fish species.

LF18 Comment Summary

- Episodic environmental conditions (e.g. El Niño verses La Niña climate patterns) likely influence episodic increases/decreases in certain transitory/migratory fish predators presence - such as hake and anchovies - whereas resident fish species/populations (e.g. lingcod, etc) would likely contribute low continuous background predation.
- Individual escape and rearing behaviours would likely greatly affect predation interception and success
- predatory fish learn behaviour related to food supplies; mackerel have been identified as a significant predator on net pen smolts in the Alberni. Hatchery practices may be exacerbating this.

- It appears that processes driving this stage of subAdult salmon numbers are "bottom-up" plankton processes verses top-down predator driven - especially when considering fish as predators.

Limiting Factor 19: Mortality, growth and/or fitness reduction due to elevated predation levels by novel predators.

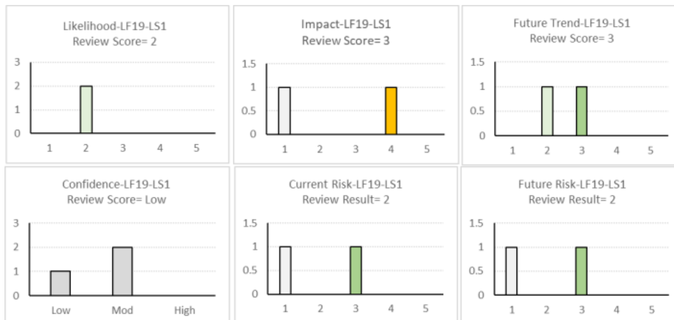


Figure 7.57 Frequency distribution plots of participant scores for LF19 and LS1 for Likelihood, Impact, Future Trend, and Confidence. Review scores are based on a group consensus review of these plots. Current and Future Risks and associated frequency distribution plots and Review Scores are calculated based on risk matrices (see Methods in Main report). If n<4, then confidence=low (i.e., 1) regardless of distribution.

This limiting factor rated for LS1 was low risk, both now and in the future.

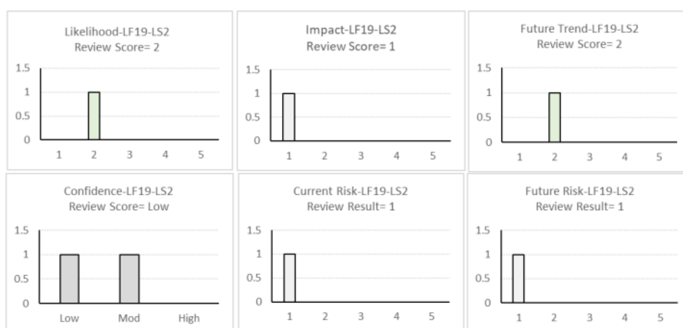


Figure 7.58 Frequency distribution plots of participant scores for LF19 and LS2 for Likelihood, Impact, Future Trend, and Confidence. Review scores are based on a group consensus review of these plots. Current and Future Risks and associated frequency distribution plots and Review Scores are calculated based on risk matrices (see Methods in Main report). If n<4, then confidence=low (i.e., 1) regardless of distribution.

This limiting factor was very low risk, both now and in the future.

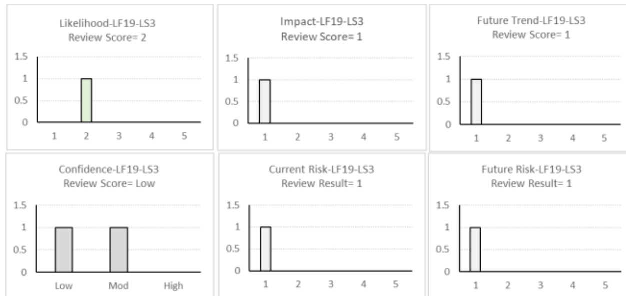


Figure 7.59 **Frequency distribution plots of participant scores for LF19 and LS3 for Likelihood, Impact, Future Trend, and Confidence. Review scores are based on a group consensus review of these plots. Current and Future Risks and associated frequency distribution plots and Review Scores are calculated based on risk matrices (see Methods in Main report). If n<4, then confidence=low (i.e., 1) regardless of distribution.**

This limiting factor was very low risk, both now and in the future.

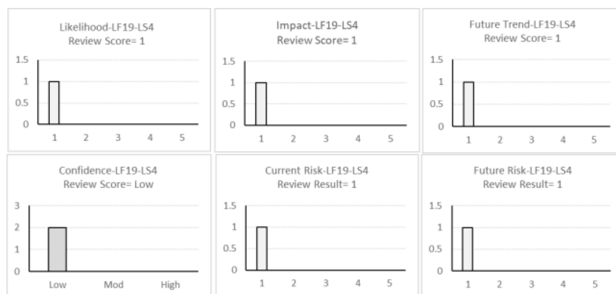


Figure 7.60 **Frequency distribution plots of participant scores for LF19 and LS3 for Likelihood, Impact, Future Trend, and Confidence. Review scores are based on a group consensus review of these plots. Current and Future Risks and associated frequency distribution plots and Review Scores are calculated based on risk matrices (see Methods in Main report). If n<4, then confidence=low (i.e., 1) regardless of distribution.**

This limiting factor was very low risk, both now and in the future.

LF19 Comment Summary

- Better distinction of novel predators needed
- Presence/absence and impact of novel predators on this life stage is probably more tied to climate - e.g., Humboldt squid
- There is potentially a data gap in this limiting factor, but it was considered to be a low priority for future research.

Uncertainties / Knowledge Gaps Identified:

- Predation by other fish species
- Outstanding question about different predation rates between male and female pinnipeds
- Better information on the size of chinook consumed by sea lions is required, and on the migration patterns of WCVI chinook.

7.5.6.2 Ranked Risks

To rank the relative risk of different LF's, results for all LFs were sorted first by Group Current Risk Review Result, then Group Future Risk Group Result, and finally by a percent current risk high score, the percentage of participants' scores that led to a current risk score of high or very high as shown (Table 7.12). Here we included statistical mean values for Future Risk (Mean FRisk where 5=very high, 4=high, 3=moderate, 2=low and 1=very low) alongside the values computed as described above.

To evaluate the appropriateness of Group consensus Review Scores, we correlated these for Future Risk with statistical mean Future Risk Scores and also compared how risk was categorized using these two approaches.

Interestingly, despite small sample sizes, correlations between Future Risk Scores and statistical Mean Future Risk (Mean FRisk) Scores were significant (R^2=0.55; p=0.001) although risk categorizations using these approaches varied (Table 7.12). For example, of the four LFs rated as High for Future Risk (i.e., 4) only one of these would be High if we used Mean Values (LF16 LS4), while one would be moderate (i.e., 3; LF16 LS3) and two would be low (i.e., LF 18 LS1 and LF17 LS1. We remained most confident in the Group review group rankings,

Table 7.12 **Ranked (high to very low) current and future risk rankings for limiting factors (LFs) considered during Workshop 5.**

		Group review score			Participant score statistics										
Limiting Factor	**Life Stage**	Likelihood Score	Impact Score	Future Trend Score	Confidence Score 1-3	Current Risk Score 1-5	Future Risk Score 1-5	Mean FRisk Score 1-5	Reviewed Confidence	**Review Result Current Risk**	**Review Result Future Risk**	# people who did not	Current Risk % High	Future Risk % High	Confidence % Low
LF16 Predation marine mammals	LS4	4	4	3	2	4	4	4	Mod	High	High	1	86%	83%	13%
LF18 Predation by fish	LS1	4	3	3	2	4	4	2	Mod	High	High	0	50%	0%	25%
LF16 Predation marine mammals	LS3	4	3	3	2	4	4	3	Mod	High	High	1	33%	40%	29%
LF17 Predation by birds	LS1	4	3	3	1	4	4	2	Low	High	High	0	33%	0%	33%
LF18 Predation by fish	LS2	4	4	2	1	4	3	1	Low	High	Mod	1	50%	0%	33%
LF16 Predation marine mammals	LS2	4	2	3	2	3	3	3	Mod	Mod	Mod	1	17%	17%	71%
LF16 Predation marine mammals	LS1	4	2	3	2	3	3	3	Mod	Mod	Mod	0	14%	29%	0%
LF18 Predation by fish	LS3	3	3	1	1	3	1	1	Low	Mod	Very Low	1	50%	0%	33%
LF19 Predation by novel predators	LS1	2	3	3	1	2	2	2	Low	Low	Low	1	0%	0%	33%
LF17 Predation by birds	LS3	3	2	1	1	2	1	1	Low	Low	Very Low	0	50%	0%	50%
LF17 Predation by birds	LS2	2	1	1	1	1	1	1	Low	Very Low	Very Low	1	0%	0%	0%
LF17 Predation by birds	LS4	1	1	2	1	1	1	2	Low	Very Low	Very Low	0	0%	0%	0%
LF18 Predation by fish	LS4	2	1	1	1	1	1	1	Low	Very Low	Very Low	1	0%	0%	33%
LF19 Predation by novel predators	LS2	2	1	2	1	1	1	1	Low	Very Low	Very Low	1	0%	0%	50%
LF19 Predation by novel predators	LS3	2	1	1	1	1	1	1	Low	Very Low	Very Low	1	0%	0%	50%
LF19 Predation by novel predators	LS4	1	1	1	1	1	1	1	Low	Very Low	Very Low	1	0%	0%	

In summary, workshop presentations and discussions demonstrated that predator-prey relationships are complex. Predation varies spatially and temporally, and more data are often needed to adequately represent when and where Chinook are being consumed. Predation can affect Chinook salmon populations through direct consumption and can also influence population demographics through size-selective predation on larger fish resulting in decreases in size and age at maturity.

A high risk from predation by marine mammals was identified for returning Adult (LS4) and sub-Adult (LS3) WCVI Chinook, both now and in the future. Some differences in predation risks were noted among marine mammals. For example, coastal predators and terminal predators would have different influences on the four Chinook life stages. Coastal predators, such as Steller sea lions and Resident Killer Whales, are expected to consume mainly larger fish; therefore, sub-Adult and Adult life stages would be more vulnerable to predation by these species. Harbour seals are primarily terminal predators that target pre-spawning Adults as they return to estuaries and rivers. Smaller chinook runs would be more vulnerable to this type of predation, especially if barriers and low water levels slow their migration. The risk from harbour seal predation on Juvenile Chinook is moderate; however, there may be specific locations where seals learn to feed on concentrations of out-migrating Juveniles resulting in a high risk for those populations.

Peter Olesiuk states that California sea lions warrant greater attention because of increasing numbers and a northward shift in distribution during the last century. Early sea lion assessments in Canada presumed the species ever ranged this far north, until Guiguet (1953) published a record of a California sea lion skull that had been found in Barkley Sound in the 1800s. A few stragglers were observed in Barkley Sound in the 1950s and 1960s, and their numbers increased, and range expanded dramatically during the 1970s and 1980s, presumably due to the recovery of breeding populations off California. Mainly subAdult and Adult males occur in BC during the non-breeding season. They are highly mobile and form large aggregations move around to take advantage of foraging opportunities, so numbers wintering in BC are highly variable and somewhat unpredictable. Nevertheless, they could potentially impact LS3 chinook wintering along WCVI (few CSL range north of Vancouver Island; however, as most don't arrive in BC until September-October, their arrival timing might miss most LS4 chinook (P. Olesiuk, pers. com.). Steller sea lions are also an increasing threat due to recent population increases.

The risk of predation by fish ranged from a high risk for the early marine stage LS1 to very low for the final life stage LS4. In fact, predation risk from birds, novel predators and other fish was very low. Other fish species, such as hake, mackerel, and salmon sharks are known to consume salmon although the magnitude of impact of this type of predation for LS2 and LS3 is uncertain.

A high risk from predation by birds was identified for LS1. Herons have been shown to be important predators on out-migrating smolts; small smolts appear to be most susceptible. Risks from bird predation in estuaries may increase during low flows. Risks to subsequent life stages were generally very low, presumably in part due to Chinook being larger.

Predation risk from novel predators was low or very low across all life stages under both current and future conditions. Limited data were available to assess this limiting factor; however, it was not identified as a high priority for further research.

Several areas of uncertainty and knowledge gaps were identified in the workshop. Knowledge gaps for the highest risk limiting factors need to be prioritized.

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7.5.8 Participants' Names and Affiliations

Participant ListName (Original Name)	Affiliation
Akash Sastri	DFO
Amelia Vos	Huu-ay-aht
Andrew Munro	ADFG
Andrew Trites	UBC

Andy Rosenberger	Independent
Brad Beaith	DFO
Cameron Freshwater	DFO
Candace Picco	Ha'oom
Chantal Nessman	DFO
Chelsea Stanley	DFO
Christian Carson	Redd Fish
Christie Morrison	DFO
Chrys Neville	DFO
Dave Burt	Independent
Dave Rolston	Tseshaht
David Welch	Independent
Derek Price	DFO
Diana McHugh	DFO
Ed Walls	DFO
Elmar Plate	LGL
Erin Rechisky	DFO
Esther Guimond	DFO
Fanny Couture	DFO
Graham Murrell	Hupačasath
Howard Stiff	DFO
Isobel Pearsall	Pacific Salmon Foundation
James Mortimor	DFO
John Candy	DFO
Jon Hunter	Commercial TROLL
Jonquil Crosby	Yuułuʔiłʔatḥ
Karen Hulshof	Unknown
Kaylyn Kwasnecha	Redd Fish
Kevin Pellett	DFO
Krista Bohlen	Parks Canada
Kristi Miller-Saunders	DFO
Lance Stewardson	Independent
Luke Swan	Ahousaht
Mark Maftei	Raincoast Education Society
Matt Clarke	DFO
Moira Galbraith	DFO
Nick Brown	DFO
Paige Ackerman	DFO
Peter McKenzie	Cermaq
Peter Olesiuk	Pacific Eco-Tech Environ. Research (DFO retired)
Rachel Saraga	DFO
Ron Tanasichuk	Independent
Sam James	PSF
Scott Toews	DFO
Sheena Majewski	DFO
Sheila Thornton	DFO
Strahan Tucker	DFO
Suzanne Earle	DFO
Tim Hawkins	West Coast Aquatic
Tim Healy	DFO
Tom Balfour	Clayoquot
Wilf Luedke	DFO
Will Duguid	UVic

7.6 Workshop 6 – Hatcheries

August 2-3, 2022

7.6.1 Background

Sixth in the series of seven virtual workshops held during 2022 to 1) create understanding of existing knowledge on WCVI Chinook salmon and 2) investigate factors limiting their survival and productivity during their marine life stages and 3) identify knowledge gaps

7.6.2 Objective(s)

To discuss and rank the impacts of hatcheries and hatchery fish potentially limiting survival, growth and/or fitness of naturally occurring WCVI Chinook salmon during their Juvenile (first summer, fall and winter) and Adult (marine rearing plus return migration) marine life history. Factors assessed were genetic and ecological as well as disease and pathogens (Table 7.13)

Table 7.13 Limiting Factors Assessed during MRA Workshop 6

LF	Category	Limiting Factor
21	Genetics	Mortality, growth and/or fitness reduction due to reductions in genetic diversity and integrity or changes in biological characteristics (fecundity, maturation rate, sex ratios, size at age, behaviour, etc.) from hatchery rearing.
23	Ecological	Mortality, growth and/or fitness reduction due to inter/intra-specific competition.
24	Ecological	Mortality, growth and/or fitness reduction due to elevated predation.
25	Disease and Pathogens	Mortality, growth and/or fitness reduction due to changes in hatchery disease patterns and/or pathogen transfer.

7.6.3 Summary and Results

During this workshop, assessment of key risks posed by hatcheries and hatchery fish on naturally occurring WCVI Chinook physiology, survival and fitness during their marine life history was carried out using the RAMS process. The hypotheses addressed were that hatchery production a) reduces overall genetic diversity and integrity, b) increases competition and/or predation, or c) increases disease, pathogen diversity or loads in naturally-produced fish, ultimately resulting in reduced growth, survival and/or fitness of wild WCVI Chinook.

Facilitated discussions resulted in consensus that there is a very high risk of hatchery rearing on growth, survival and fitness of wild WCVI Chinook due to impacts on genetic diversity and integrity and/or biological characteristics (LF21,Table 7.14). Evidence was provided to show that WCVI stocks display declining genetic diversity due to hatchery introgression into naturally-produced stocks (particularly in NWVI where there are high stray rates), and most rivers have a PNI (proportionate natural influence) less than 0.25.

Hatcheries have the potential for large magnitude ecological impacts on wild salmon populations, and these are not fully understood, nor adequately evaluated or assessed. Partial to complete diet overlap between naturally-produced and hatchery-origin Chinook occurs for at least some life stages, suggesting that competitive impacts are possible. Impacts of inter/intraspecific competition from hatchery fish was scored by consensus as a high risk that could result in reduced growth, fitness and survival of naturally occurring WCVI Chinook during early rearing in WCVI nearshore regions and Sounds, and evidence was presented on the similarity of diets between hatchery and naturally-produced fish during this period. The future risk was scored as very high because of climate change impacts on the food web and possible enhanced competitive pressures due to lower prey abundance (Table 7.14). Numerous data gaps were identified related to impacts of competition on later life stages, including by pink and chum salmon in the Gulf of Alaska, as well as the level of predation by hatchery fish on naturally-produced Chinook. Interestingly, the effect of predation on Adult chinook was scored high with low confidence while the effect and confidence for Juveniles was moderate.

Finally, the workshop examined whether hatcheries and hatchery production could result in an increased source of pathogens, increased pathogen richness, and/or pathogen transfer from hatchery to naturally-produced fish. Pathogen richness in freshwater showed few differences between hatchery and naturally-produced fish but was highly variable among stocks/years. It is possible that the higher survival of WCVI hatchery fish may be associated with high infection intensity in natural fish, the result of pathogen transfer from hatchery fish. However, many knowledge gaps exist; consequently, the limiting factors associated with impacts of pathogens were scored as moderate (Table 7.14) with low confidence.

Recommendations for improvements (i.e., increases) to PNI include a) managing hatchery production (i.e. producing the fewest fish necessary to achieve program goals and objectives), 2) removal of excess hatchery-origin Chinook from the spawning population, and 3) management of pNOB (proportion of natural-origin broodstock) and PNI in general in rivers supplemented with hatchery fish to best maintain natural-origin influence and reduce the risk of natural-origin extirpation. Pilots are underway along WCVI to address low PNI and assist with stray management: Conuma, Sarita and Burman Chinook populations are being mass marked, and Huu-ay-aht First Nation have implemented a plan to maintain hatchery production but improve PNI by selective harvest of hatchery marked Chinook in the Sarita. SEP also has implemented other measures to help reduce straying (e.g., relocating seapens closer to natal estuaries/freshwater influence, switching from seapen releases to river or lake releases, etc.) and the potential effects from straying, improve survival and reproductive fitness of hatchery Chinook and reduce ecological interactions between hatchery and naturally-produced Chinook.

Many risks remain as knowledge gaps and the need for continued and improved monitoring, open data, PNI management, assessment of interactions between naturally-produced and hatchery fish throughout their life cycle, as well as evaluation of potential for pathogen transfer between these categories of salmon were highlighted as key data needs and current knowledge gaps. Ultimately, given the potential for severe genetic and ecological risks of hatcheries, addressing these knowledge gaps is highly recommended.

Table 7.14 . Ranked (very high to very low) current and future risk rankings for limiting factors (LFs) considered during Workshop 6 (see Section 6 for details). LF23 Adults not scored.

Limiting Factor	Life Stage	Reviewed Confidence	Review Result Current Risk	Review Result Future Risk

LF20 Loss of genetic or demographic diversity	All	Mod	Very High	Very High
LF21 intra/inter specific competition	Juvenile	Low	High	Very High
LF22 predation	Adult	Low	High	High
LF21 intra/inter specific competition	Adult	Mod	Mod	Mod
LF22 predation	Juvenile	Mod	Mod	Mod
LF23 disease or pathogens from hatchery	Juvenile	Low	Mod	Mod

7.6.4 Agenda

Day 1

9:00 am	Welcome, the WCVI RAMS process, products & goals. Today's plan. Tim Hawkins, WCA and First Nations Steering Committee Rep.
9:20 am	Overview of previous workshops and objectives of Workshop 6, fisheries risks, and a review of the rebuilding process. Wilf Luedke, DFO
9:40 am	Overview of the Life History Model. Natural vs hatchery catch and returns – hatchery % smolts vs Adult returns, preliminary results from freshwater risk assessment, what we know about imprinting/homing in Chinook. Wilf Luedke, DFO
10:00 am	A review of hatchery reform science in Washington State. Joe Anderson, Washington Department of Fish & Wildlife
10:20 am	BREAK
10:35 am	The WCVI Hatchery Program: Objectives, benefits, and risk management. Dave Willis and Michael Thom, DFO SEP
11:00 am	WCVI Chinook population genetic distinctions and diversity, Ruth Withler, DFO Emeritus and Wilf Luedke, DFO
11:15 am	North Pacific hatchery production. Jim Irvine, DFO Emeritus
11:30 am	Hatchery Fish Health Management. Corino Salomi & Ian Keith, DFO
12:00 pm	Lunch
12:45 pm	Magnitude, patterns, and extent of straying from WCVI hatcheries. Jacob Weil, DFO
1:15 pm	Pathogen risks from hatcheries. Kristi Miller-Saunders, DFO
1:45 pm	Changes in biological characteristics. Andy Rosenberger, Pacific Salmon Foundation
2:15 pm	Break
2:30 pm	Do hatchery salmon in the Gulf of Alaska compete with WCVI Chinook salmon? Jim Irvine, DFO Emeritus
2:50 pm	Overview of research on Barkley Sound hatchery and naturally-produced Chinook salmon. Ron Tanasichuk, DFO Emeritus
3:20 pm	Local ecological interactions and Microtrolling preliminary findings. Jessy Bokvist, DFO
3:40 pm	Are hatchery and naturally-produced Chinook Salmon competitors and cannibals? Will Duguid, Pacific Salmon Foundation

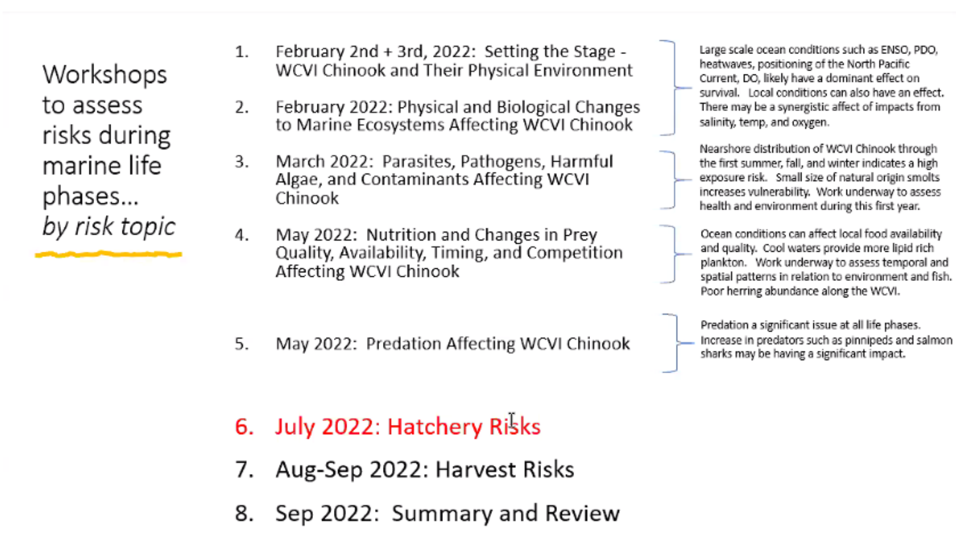
3:50 pm	Four Decades of Raising Chinook Salmon in B.C. – from Hatchery to Ocean, both naturally-produced and farmed, what we've learned on fish health and survivals and how this applies to the management of hatchery enhancement releases alongside naturally-produced populations of Chinooks. Carol Schmitt, Omega
4:15 pm	Hatchery reform: Ongoing and future implementation. Michael Thom and Dave Willis, SEP
4:45 pm	Adjourn
Day 2	
9:00 am	Overview of Day 1 – Jim Irvine and Tim Hawkins
9:15 am	Limiting Factor Scoring – Wilf Luedke, DFO Emeritus and Jessica Hutchinson, Redd Fish Restoration Society; Overview of online scoring activity. Christian Carson, Redd Fish Restoration Society
9:45 am	Discussion about the Limiting Factors presented during Day 1- should any be added? Discussion of key knowledge gaps, other information sources, immediate research priorities, potential actions, and scoring of limiting factors
10:30 am	Break
10:45 am	Continue discussion
12:00 pm	Adjourn

7.6.5 Presentation and Discussion Highlights

Day 1: August 2, 2022

Presentation 1 - Overview of previous workshops and objectives of Workshop 6, fisheries risks, and a review of the rebuilding process. Wilf Luedke, DFO

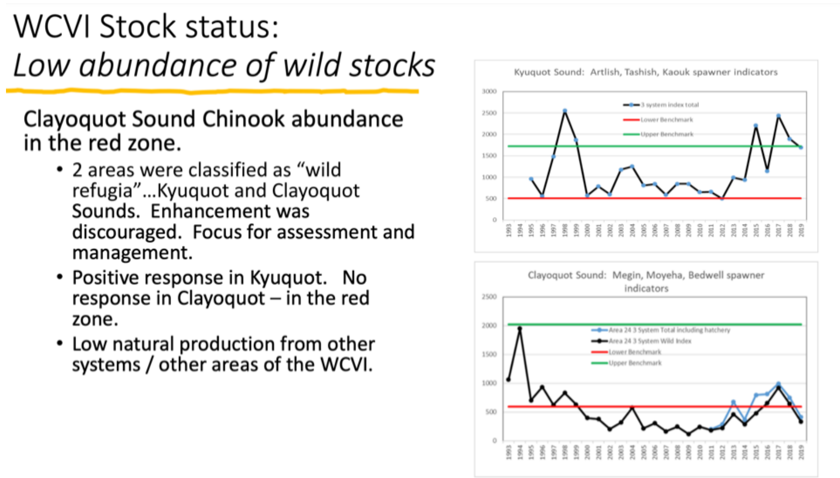
- Wilf provided an overview of scope and key highlights of the workshops carried out previously to this workshop and outlined the scope for workshop #6



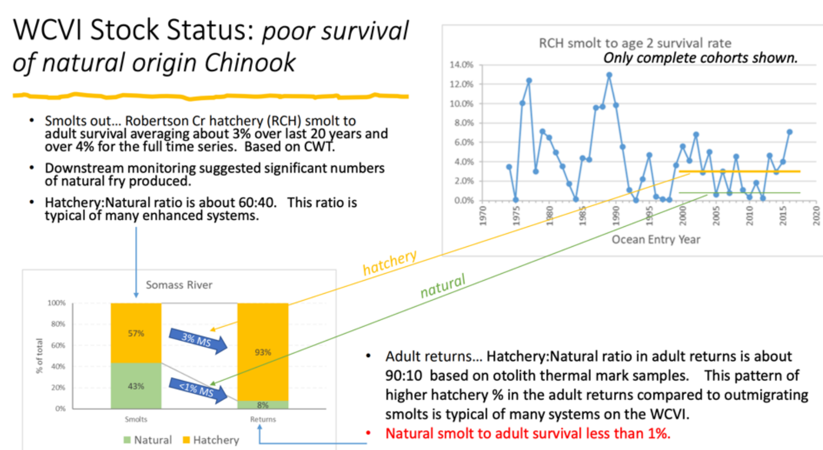
Presentation 2 - WCVI Chinook Review. Wilf Luedke, DFO

- Wilf provided data and background relevant to the Hatchery Risk Assessment.

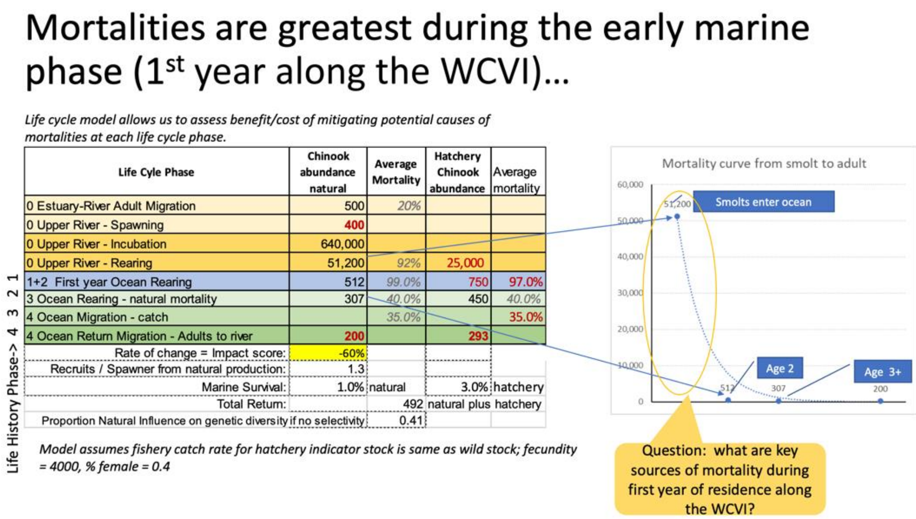
- To protect naturally-produced stocks, Kyuquot and Clayoquot have been classified as naturally-produced refugia – where enhancement has been discouraged. A positive response was noted in Kyuquot but there was no response in Clayoquot.



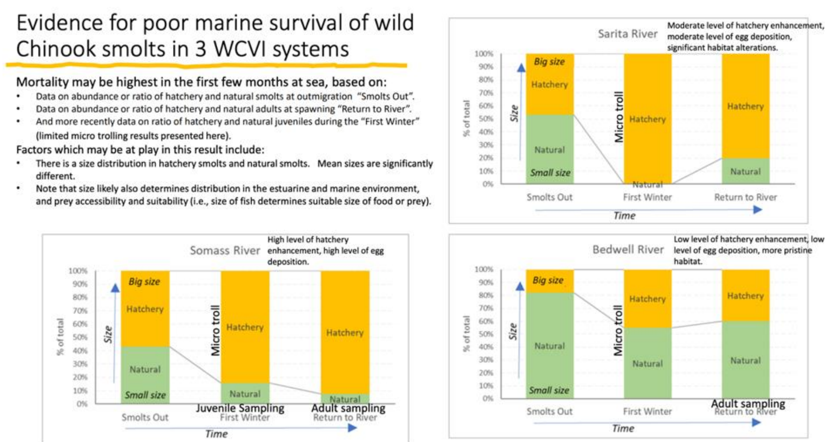
- In general, WCVI stock status shows poor survival of natural origin Chinook. RCH smolt to Adult survival ~3% while natural spawned smolt survival only ~0.5-1%



- Mortalities appear to be greatest during the early marine phase (the first year of life spent along WCVI). The basic life history model was introduced.

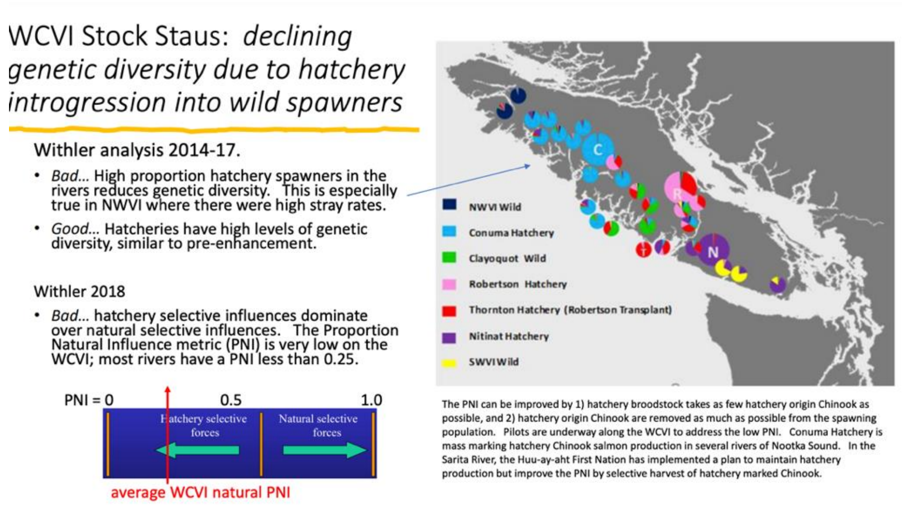


- Wilf provided information about poor marine survival of naturally-produced Chinook smolts in 3 WCVI systems, the Bedwell, Sarita and Somass. He noted that mortality for those populations may be highest in the first few months at sea based on smolt abundance data for naturally-produced and hatchery fish, abundance of spawners and microtrolling data. He noted that mean sizes of hatchery and naturally-produced fish differ substantially, which likely impacts estuarine and marine distributions as well as prey accessibility and suitability.



- In addition, hatcheries are causing reduced genetic diversity in natural spawning populations, particularly where there are high hatchery stray-in rates; however, genetic diversity within enhanced populations has been maintained (word by Ruth Withler 2014-2017)
- The PNI (proportion natural influence) < 0.25 at WCVI scale, and most rivers have a PNI less than 0.25. IT appears that hatchery selective influences dominate over natural selective influences along WCVI (Withler 2018).
- PNI can be improved if a) the hatchery broodstock takes as few hatchery-origin Chinook as possible, and 2) if hatchery origin Chinook are removed as much as possible from the

spawning population. Pilots are underway along WCVI to address low PNI. Conuma is mass marking hatchery Chinook salmon in several rivers of Nootka Sound, and Huu-ay-aht First Nation implemented a plan to maintain hatchery production but improve PNI by selective harvest of hatchery marked Chinook in the Sarita.

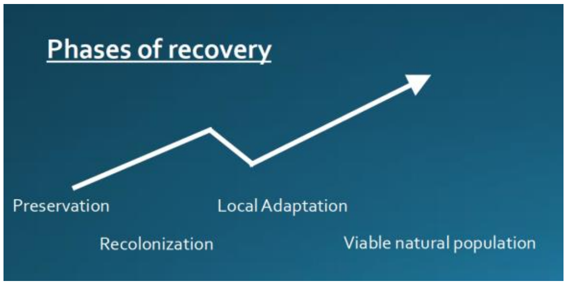


Presentation 3 - A review of hatchery reform science in Washington State. Joe Anderson, Washington Department of Fish & Wildlife

- Washington Fish & Wildlife Commission asked WDFW to review science concepts in *Hatchery and Fishery Reform Policy C-3619*, adopted in 2009. Policy C-3619 was originally adopted in November 2009 with a stated purpose to advance the conservation and recovery of naturally-produced salmon and steelhead by promoting and guiding the implementation of hatchery reform. Key questions that WDFW was asked to consider included:
    - Are WDFW's hatchery policy guidelines supported by science?
    - What have we learned in 10 years since the policy was adopted?
- Risks to be considered included fishery, ecological and genetic risks, while benefits to be considered included treaty rights, social and cultural benefits, economic and conservation.
- WDFW's Final report was completed in 2020 and can be accessed here: https://wdfw.wa.gov/fishing/management/hatcheries/hatchery-reform-policy-review with more details about the process here: https://wdfw.wa.gov/publications/02121
- Hatchery reform is a system of hatchery management that focuses on hatchery goals; and which should ultimately benefit the conservation of a natural population or promote harvest opportunities. Important questions centre on discerning which natural populations are most important for recovery of a region (ESU or Evolutionary Significant Unit). As naturally-produced populations move through phases of recovery, there are adaptive changes in reform and policy regarding the management of the population. Some key metrics used to assess hatchery impacts include:
    - pHOS: Proportion of natural spawners made up of hatchery-origin fish
    - pNOB: Proportion of hatchery broodstock made up of natural-origin fish

- There are many conservation benefits of Hatcheries, and these benefits vary by urgency of intervention. These include:
    - **Prevent extinction**. There are numerous examples of preserving a unique genetic lineage
    - **Recolonization**. There are numerous examples of increasing abundance of naturally spawning, hatchery-origin fish, but the longer-term genetic risks do need to be considered. Small-scale case studies do demonstrate the potential for low or minimal genetic risks.
    - **Increase abundance of natural-origin Adults**. Large-scale syntheses across multiple rivers find little evidence for sustained increases in natural-origin abundance. This leads to the suggestion that hatchery supplementation is akin to being stuck in "recolonization" and there is little evidence for transitioning to self-sustaining natural production.
- Meanwhile, there are fishery risks
    - Fisheries typically target abundant hatchery populations, but are limited by unintentional mortality to co-mingled natural populations
    - Mark-selective fisheries are the primary tool for limiting mortality to natural populations, *but* there are constraints to their implementation
    - Large scale hatchery production magnifies the asymmetry between lost harvest opportunities and conservation gains
- **Findings of the review** were as follows:
- Hatchery reform is just one of several factors requiring careful planning and aggressive implementation to achieve meaningful recovery of salmon populations
    - Hatchery reform was never intended or expected to achieve salmon recovery on its own
- Hatchery reform is largely aimed at reducing risk in a relative but not absolute sense
    - We know that various actions can reduce risk, but we are not sure what the degree of reduction in risk will be and what outcomes that will have on the population itself e.g. we know actions such as reducing program size or increasing pNOB will reduce risk BUT models and extensions of empirical studies lack sufficient precision to confidently, precisely predict hatchery impacts or fine-tune hatchery management
- In WDFW's hatchery system, a focus on efficiency and maximizing abundance prevents widespread implementation of risk reduction measures
    - Studies showing demographic benefits or minimal genetic risks have generally been conducted on *small-scale* conservation hatchery programs
    - However, the majority of WDFW's hatchery programs are *large-scale*, harvest programs
    - Unfortunately, many risk reduction measures are not compatible with production-oriented hatcheries

- The principles of reducing pHOS and increasing pNOB to achieve fitness gains in naturally-produced populations are well-founded, and should be fundamental goals in any hatchery reform management action
    - There is strong empirical and modeling support for the principle that hatchery and natural environments present different selection pressures
    - Measuring and controlling gene flow is essential to managing genetic risks
    - However, unequivocal, *population-scale empirical evidence for a genetic component to fitness loss remains relatively rare*
- Program size requires more careful scrutiny and scientific justification because it affects virtually every aspect of hatchery risks
    - Hatchery programs can be so large and so production oriented, that it can be difficult to reduce risks. For example, there may be relatively few naturally-produced-origin fish available and making changes to pHOS may not be the right goal in the larger scope
    - Where integrated population demographics are dominated by hatchery production, it is possible that declines in natural population abundance and fitness are unavoidable and severe in magnitude
    - There is limited evidence for ability to control pHOS by other means
    - Ecological risks and the genetic risk of homogenization also scale with program size
    - Demographic dominance of hatchery-origin fish is commonplace
    - Thus- programs of large size and a legacy of impacts require more scrutiny
- The HSRG's phased approach to recovery has strong conceptual merit, but its implementation has resulted in an absence of stricter, conservation-oriented goals for many populations
    - Four recovery phases are outlined which recognize a spectrum of conservation intervention urgency but often these recovery phases lack tangible goals



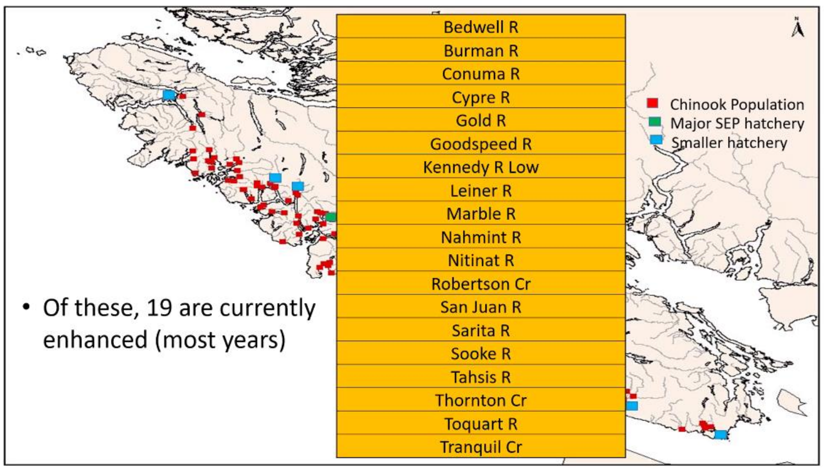
    - There are no pHOS goals for natural populations in the "preservation" or "recolonization" phases
    - Implementation frequently confounds harvest and conservation goals
    - Phase designations often lack measurable performance benchmarks
    - There is an absence of effectiveness monitoring after implementing reform
    - Hatcheries have the *potential of a large magnitude of impacts on natural populations, but those impacts are not well understood*

- Recommendation is for a stand-alone monitoring and adaptive management plan *for each hatchery program*
- The absence of a landscape-level, replicated experiments prevents empirical assessment of hatchery reform effectiveness
  - Population-scale experiments addressing conservation hatchery benefits provide some guidance but there is a strong need for population-scale experiments addressing effectiveness of hatchery reform measures and especially broodstock management at large scale harvest programs
- **Hatcheries have potential for large magnitude ecological impacts on natural populations that are not well understood, not typically evaluated and not measured**
  - There are many knowledge gaps
  - Genetic risks have dominated hatchery-naturally-produced research and hatchery reform
  - There are indications of competition and rearing capacity constraints in some large-scale assessments of ecological interactions notably in marine environments
  - Little is known regarding impacts on reduced life history diversity on hatchery-naturally-produced interactions and ecosystem stability
  - Food web impacts of pulsed hatchery releases poorly understood
  - Ecosystem services provided by salmon, such as prey for orcas, may depend on diversity, not just abundance
- **Conclusions**
- Hatchery Risk depends on hatchery management, especially program size and risk tolerance and benefits must be weighed against the risks.
  - Can certainly develop hatchery programs that have low or minimal genetic, ecological, and disease risk
  - However, the large scale of hatchery programs in Washington State limits the ability to control and understand these risks
  - Risk tolerance is a policy decision
- They recommend crafting a stand-alone monitoring and adaptive management plan for each hatchery program that quantifies both benefits and risks, and explicitly links hatchery performance metrics to potential operational changes
  - Monitoring and adaptive management are critical tools for evaluating risks and benefits
  - Considerable statewide investment in population monitoring
  - However, application of data to decision making often suffers from the absence of a clear monitoring and evaluation plan and adaptive management process
- Role of science in the decision-making process:
  - WDFW has been wrestling with this quite a bit; one area of literature is based on structured decision making. This allows for more explicit representations of the weight of all the different socio-economic, cultural, etc. factors in the overall

cost benefit analysis. Ecological aspects or genetic metrics may be large scale at the science level, but where they interweave with all the other socio-economic risks and benefits, they may be lower on the list.

Presentation 4- The WCVI Hatchery Program: Objectives, benefits, and risk management. Dave Willis and Mike Thom, DFO SEP

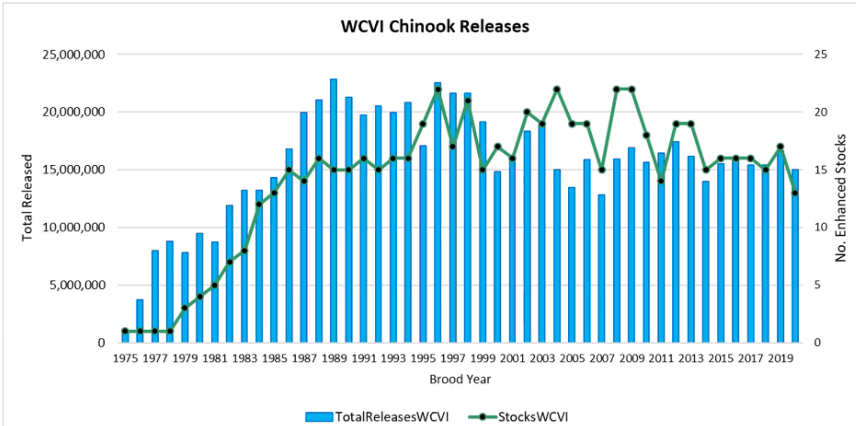
- The presenters provided an overview of WCVI Hatchery Programs. In total there are 60 unique populations on the WCVI (with some records of over 80) with the highest concentration in the big 5 Sounds. There are 19 total enhanced populations and 16 hatchery projects on WCVI (for areas 20-27), 12 of which produce Chinook. The 19 enhanced populations are listed in the slide below.



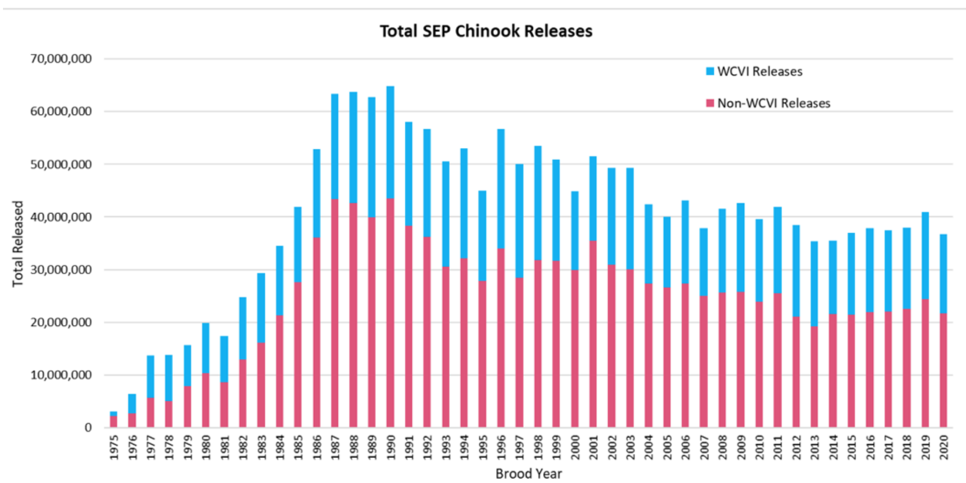
- Chinook egg targets for each WCVI hatchery projects are shown below to illustrate variance in production scale (note, some of the egg targets are comprised by multiple Chinook populations):

Project	Sum of Chinook Egg Target by Project (all stocks)
Robertson Creek	7,200,000
Nitinat	5,250,000
Conuma	3,980,000
P Hardy/Marble	1,100,000
San Juan	510,000
Thornton	350,000
Tahsis	320,000
Tofino	315,000
Tla-o-qui-aht	300,000
Sooke	250,000
Holberg	40,000
Juan de Fuca Salm Rest Soc	15,000

- Historic trends in production were discussed. There are currently around 15 million Chinook released on an annual basis across an average of 15 populations (see figure below). Releases increased during the early early days of SEP in the 70s, peak in the 80s, slowly declined since then, but has been relatively stable over the past few years. The numbers of populations enhanced also have been relatively stable in recent years.



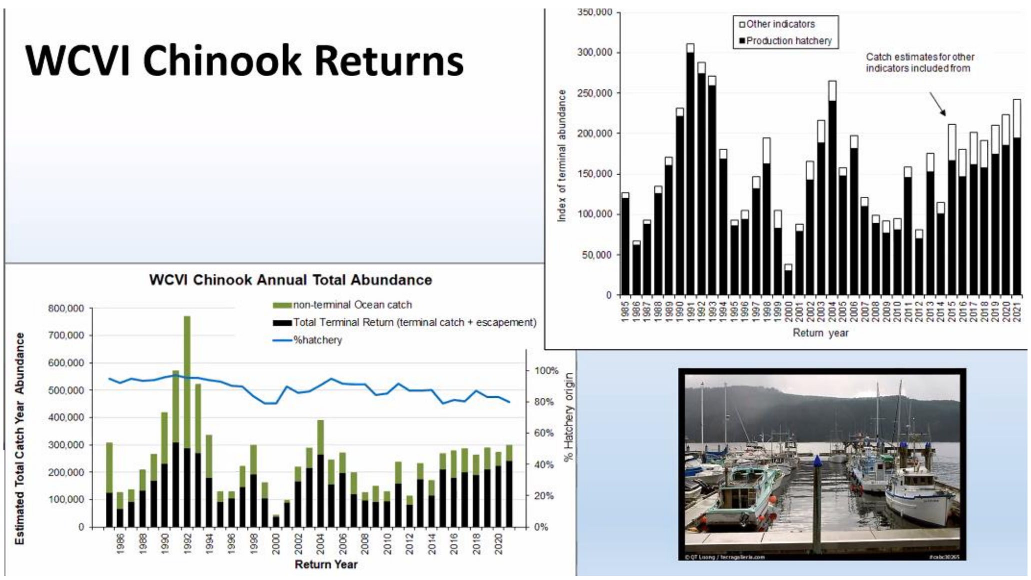
- To put WCVI production into context, see the following image which shows total Chinook production in the Pacific region. WCVI is a large component of the total production, almost 50% in some years. The bulk of non WCVI production is from ECVI. Note that these fish tend to migrate north through Queen Charlotte Strait so there is no direct interaction with WCVI Chinook until these fish are in the north.



- The objectives of hatchery production are to make more fish than would otherwise be there in the natural environment. There are specific (sometimes more than one) production objectives for each hatchery. These include production for:
    - Harvest
    - Conservation
    - Rebuilding
    - Stock Assessment
    - Stewardship & Education
- Most WCVI hatcheries production objectives are for Harvest and Rebuilding
- A production program is always the outcome of a benefit-risk analysis. In some cases such as harvest, it may be a tradeoff of naturally-produced salmon values for socio-economic benefits, however in other cases such as rebuilding and conservation

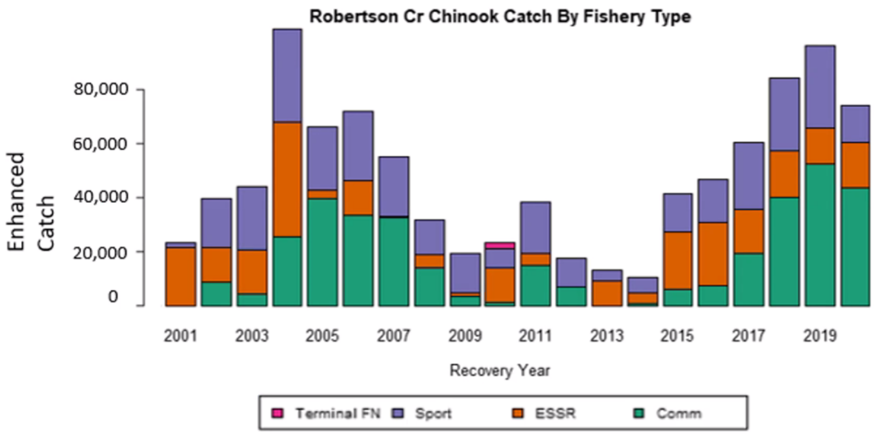
programs, there are primarily biological considerations on both sides of the risk benefit equation.

- Benefits:
    - The abundance of WCVI Chinook is dominated by hatchery production and current abundance is likely greater than in the past due to hatchery production
    - Historic equilibrium abundance was likely lower than the returns we see today. The top right chart below shows the abundances increasing in recent years from a trough around 2010, as a result of both large hatchery and the other natural and small hatchery production increasing.
    - Bottom left graphs shows that the % hatchery is slightly declining. This is likely a result of the harvest of many of these hatchery fish both in the ocean and in terminal areas.

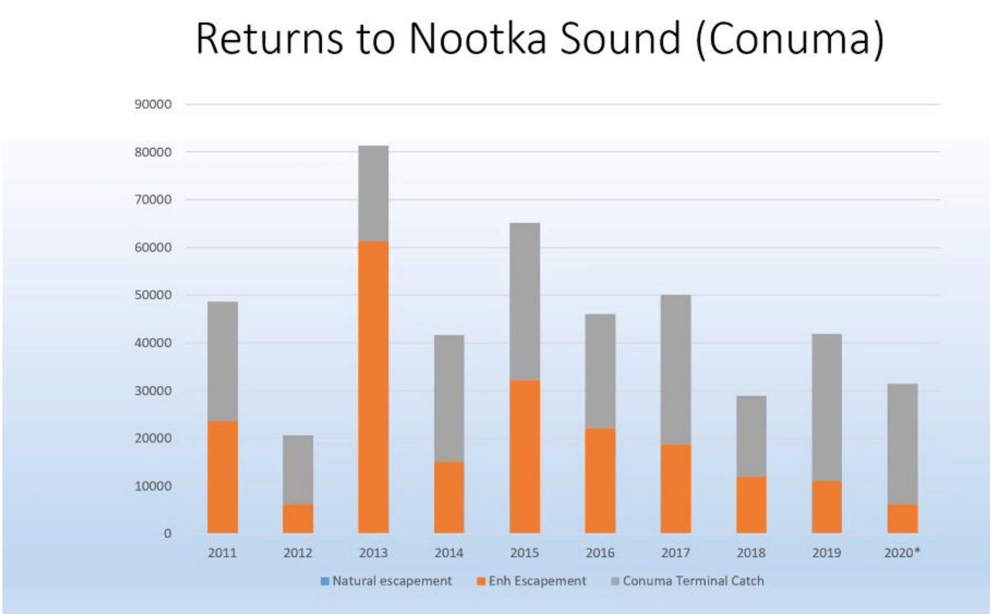


    - The bulk of production is from the three major hatcheries, which are goal oriented for harvest. Harvest is the biggest major benefit of hatcheries.
        - E.g. Robertson Creek Chinook, which supports many fisheries, both indigenous and recreational (see figure below). This figure shows the total catch of RCH hatchery fish by year (35% of this is pre-terminal, but RCH has significant terminal catch, in some years upwards of 80%). This supports multiple fisheries including major First Nation EO and FSC fisheries, treaty & rights based fisheries (Maa'nulth, 5 Nations), Area D gillnet, Area B seine, and major recreational fisheries in Alberni, Barkley etc.

Robertson Creek Chinook Harvest



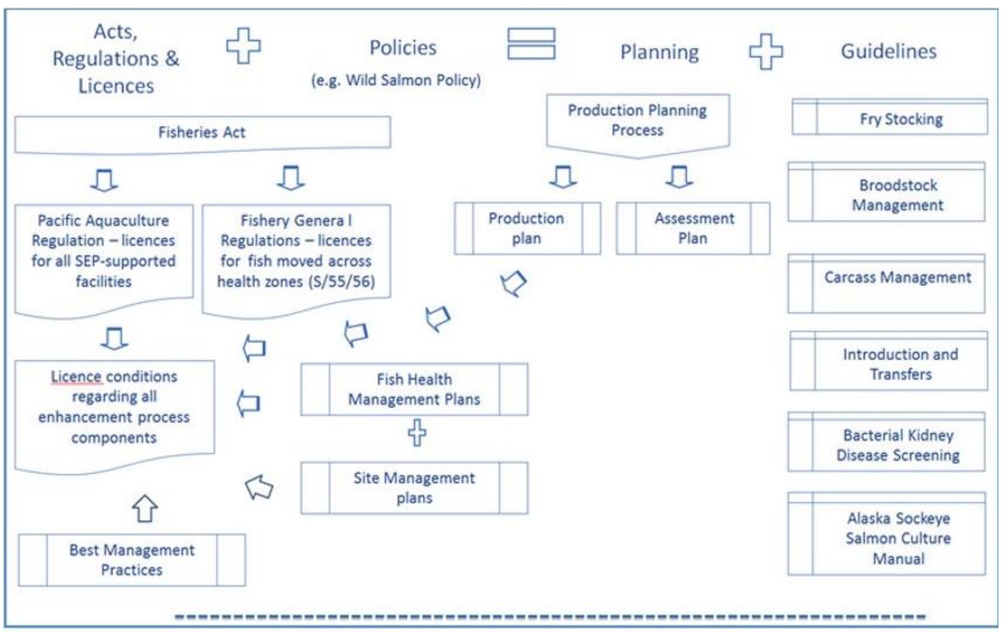
- E.g., Conuma Hatchery- Conuma is virtually all hatchery influenced with almost no natural-origin production. The figure below shows total catch of Conuma hatchery fish in Nootka Sound. 35% are taken before return back to Nootka, but the hatchery fish are also taken in many terminal fisheries (e.g., 10s of thousands harvested in FSC, Treaty, 5 Nations, commercial gillnet, and a huge recreational fishery).



- There also are several rebuilding programs across WCVI e.g., Nahmint Chinook Rebuilding
  - 50% of population is hatchery origin
  - High exploitation rate (~30%)
  - Increases in abundance by around 50% annually
  - Rebuilding has sustained the population from dropping to WSP lower benchmarks for abundance

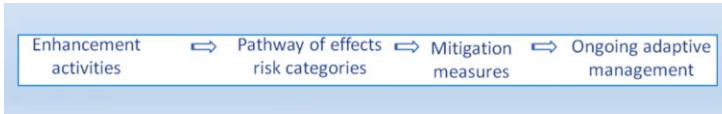
- Sarita is an example of a moderate sized program, also effective at producing returns and increasing abundance of fish which are now contributing to Barkley fisheries as well as a terminal HFN economic opportunity

- Risks: Michael Thom introduced the topic of Risk Management in SEP and described the Biological Risk Management Framework (RMF). This framework is designed to inventory and assess risk to naturally-produced salmon from enhancement and, is in part a response to the Wild Salmon Policy. Risks are examined for three main categories:
  - Genetic
  - Disease
  - Ecological
- The RMF does not assess large-scale harvest and marine carrying capacity risks, but does acknowledge them.
- The RMF discusses risk management at the salmon population level, and is intended for use as part of SEP's major operational facilities, as well as those at smaller community-based facilities. It is linked to many other policies and guidelines:



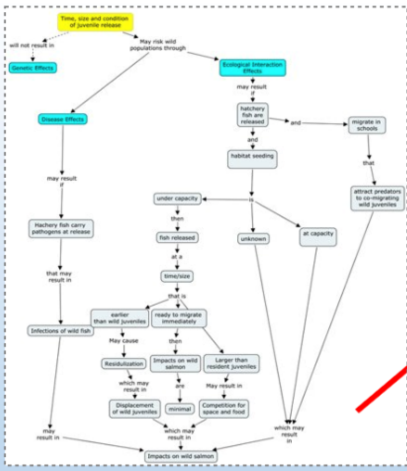
Inter-relationships between legal, policy, planning processes and guidelines that guide SEP production.

- The Risk Management Framework uses a pathway of effects (POEs) to help identify and mitigate risk. Risks for each POE are summarized by risk category and mitigation measures are subsequently put into place and implemented to reduce risk, followed by adaptive management. These mitigations are dependent on other socio-economic influences.



- Below is an example of a pathway of effect model related to some of the key aspects surrounding hatchery releases.

Risk identification, assessment, and management process – example:



POE for Release time, Size, and Condition

Enhancement Activity	Risk Category	Risk to Wild Salmon	Risk Mitigation Measures
Release time, size and condition	Genetic	Not applicable.	Not applicable.
Release time, size and condition	Disease	Hatchery fish may carry pathogen loads that could impact wild fish.	Follow FHMP protocols and comply with PAR licence conditions with respect to disease screening and treatments.
Release time, size and condition	Ecological	Juveniles released prematurely or too large may stay in freshwater to compete or predate on wild fish.	Comply with FHMP and PAR licence conditions with respect to releases. Comply with production plan for release numbers and strategies.

Here is a generalized example where risks are considered in both a mitigated or non-mitigated context. Risk can be substantially mitigated with proper implementation of best practices, modern assessment tools, and hatchery reform principles:

Risk identification, assessment, and management process:

Likelihood of risk occurrence associated with enhancement activities **with and without** mitigation

Enhancement Activity	Genetic		Disease		Ecological Interaction	
	W/Out Risk Management	W/ Risk Management	W/Out Risk Management	With Risk Management	W/Out Risk Management	W/ Risk Management
1. Adult collection, holding and sorting	H	L/M	L	L	L	L
2. Spawning practices	H	L/M	L	L	N/A	N/A
3. Adult carcass management	N/A	N/A	H	L	L	L
4. Incubation	L	L	L	L	L	L
5. Rearing	L /M	L	M	L	L	L
6. Release time, size and condition	N/A	N/A	M	L	M	L/M
7. Release location	L	L	M	L	H	L/M
8. Assessment	M	L	L	L	M	L
9. Spawning channels	L/M	L	M	L	M	L

H(igh) – very likely, M(edium) – likely, L(ow) – unlikely to occur, N/A – not applicable

- **Conclusions**

- Hatcheries play a major role in WCVI Chinook management and abundance
- WCVI hatchery programs have been extremely effective at increasing abundance to support harvest as well as to augment spawning returns
- The RMF supports structured consideration of risk for improved decision-making and risk mitigation

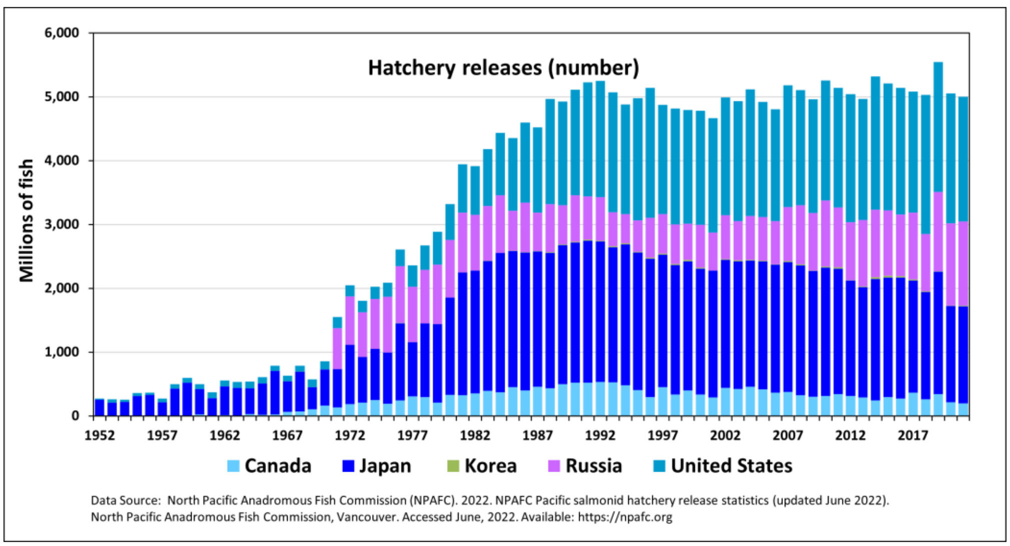
Presentation 5 - WCVI Chinook population genetic distinctions and diversity. Ruth Withler, DFO Emeritus and Wilf Luedke, DFO

- Ruth was not available

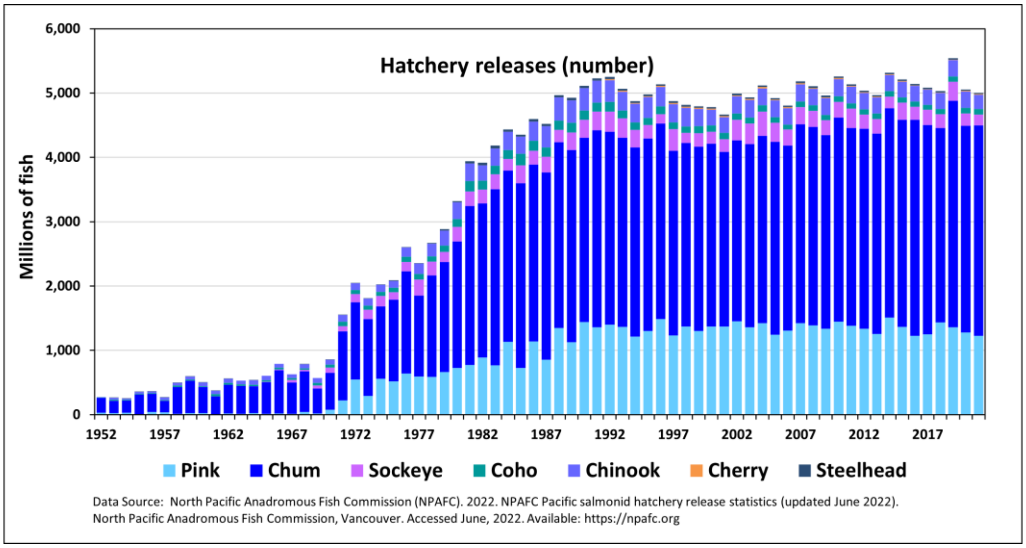
Presentation 6 - North Pacific hatchery production. Jim Irvine, DFO Emeritus

- The goals of Jim's presentation were to address the following questions:
  - How many hatchery salmon are released?
  - What proportion of returning salmon are hatchery origin?
  - Why might this be a concern for WCVI Chinook?

Jim presented the North Pacific hatchery releases by country (see figure below). Most releases are from the United States and Japan, with lower releases from Russia and very low numbers from Canada.



- When we look at releases by species (see figure below), it is apparent that the bulk of hatchery fish released are chum, followed by pink salmon, then much smaller proportions of sockeye, coho and Chinook.



- Numbers of returning Adult naturally-produced and hatchery salmon are shown in the figure below (from Ruggerone and Irvine 2018). Returns to Asia and the North Pacific are increasingly dominated by hatchery chum, while populations of pink and sockeye returning to the same regions are still primarily naturally-produced, although returns of hatchery pink salmon are increasing is North America and the North Pacific over the past 2-3 decades.

Y

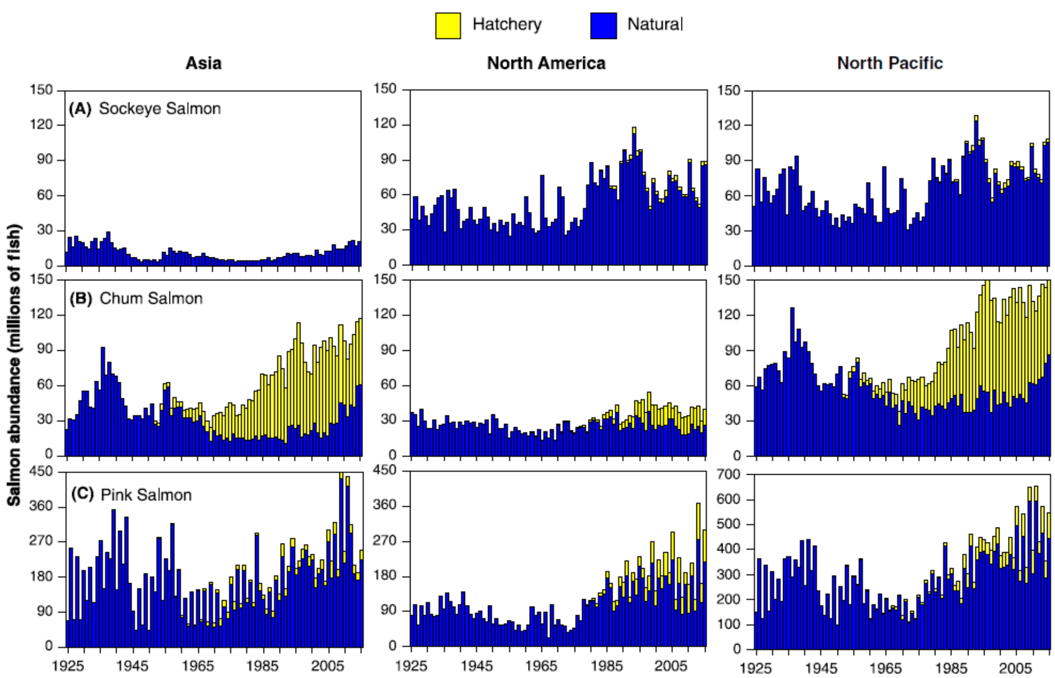
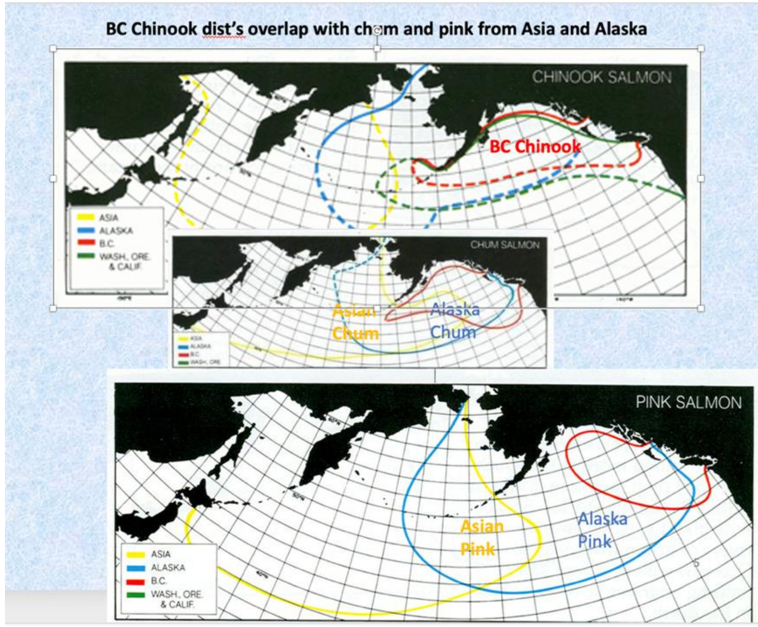


FIGURE 3. Annual abundances (catch plus number of spawners; millions of fish) of natural- and hatchery-origin (A) Sockeye Salmon, (B) Chum Salmon, and (C) Pink Salmon returning to Asia, North America, and the entire North Pacific Ocean, 1925–2015. Note that the *y*-axis scale is different for Pink Salmon.

- The distributions of BC Chinook overlap with those of both pink and chum salmon from Asia and Alaska



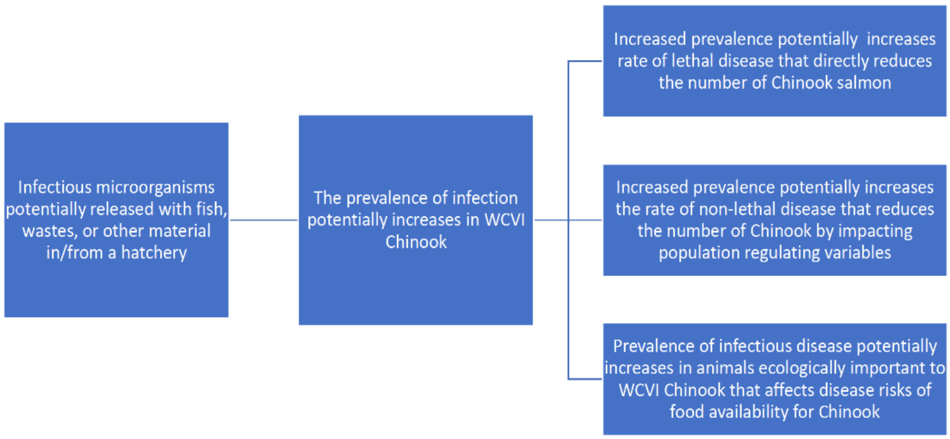
- **In conclusion,** Jim noted the following answers to the questions posed at the beginning of his presentation:
  - Qu: How many hatchery salmon are released? *Ans: ~5 billion annually (mostly pink & chum); Canada releases ~6-8%*
  - Qu: What proportion of returning salmon are of hatchery origin? Ans: *About 40% of biomass*
  - Qu: Why might this be a concern for WCVI Chinook? Ans: a) *BC Chinook distribution overlaps with chum & pink from Asia & Alaska, b) there are more salmon in the ocean (including GoA) than ever, in part, to hatchery releases from Asia and Alaska and c) when ecosystem carrying capacity is exceeded, fish growth & survival reduced. Carrying capacity may be exceeded in odd years (more pink salmon)*
  - *Qu:* Is this a problem for WCVI Chinook? Ans: *Likely, if they live off the shelf and carrying capacity is exceeded (bottom up)*

Presentation 7 - Hatchery Fish Health Management. Corino Salomi & Ian Keith, DFO

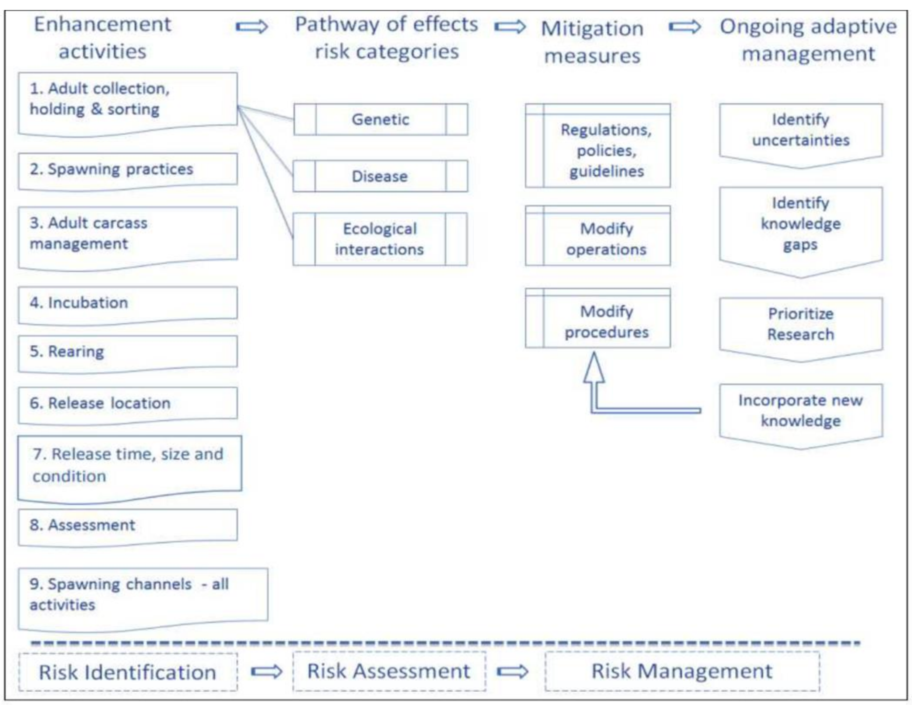
- The goal of SEP Hatchery Production is as follows:
  - Produce fish as similar as possible to natural cohorts
  - Mimic natural conditions as much as possible
  - Requires connection with natural environment while:
    - Protecting hatchery fish from pathogen transmission risks in the hatchery rearing environment
    - Protecting fish from potential downstream pathogen transmission via hatchery effluent
    - Protecting fish from potential pathogen impacts of comingling hatchery and naturally-produced fish after releaseo mimic natural environment,

whilst also preventing the transmission of pathogens and subsequently disease.

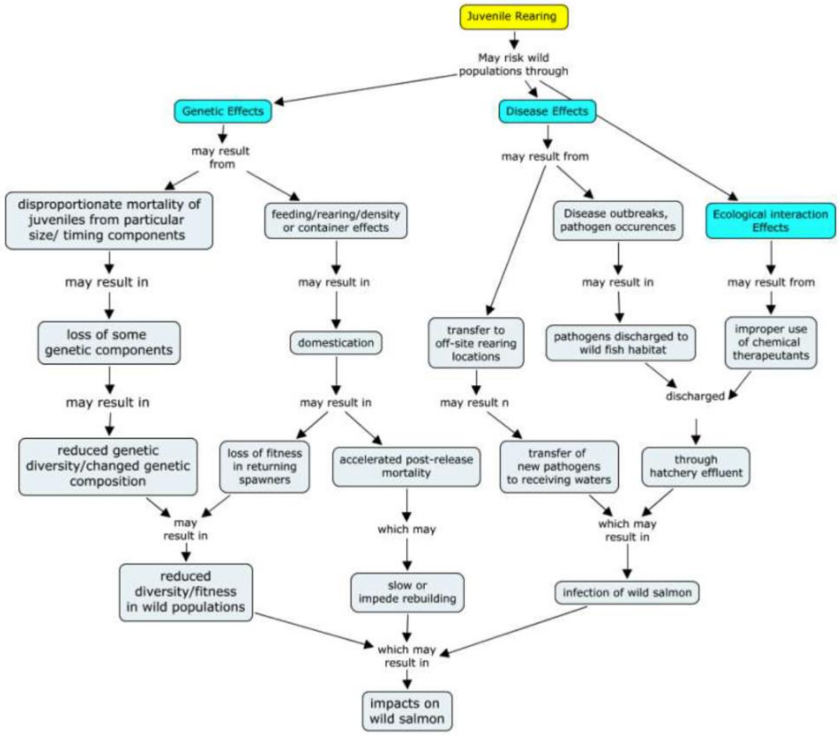
- There are several mechanisms by which hatcheries could affect diseases that could, in turn, affect the health and productivity of WCVI marine Chinook. The alteration of activities in the hatchery program, depending on the Risk Management Framework for that program, can limit the impacts of disease.



- The SEP Biological Risk Management Framework documents potential pathways of hatchery related biological risks and mitigation measures for each phase of fish culture (see image below).



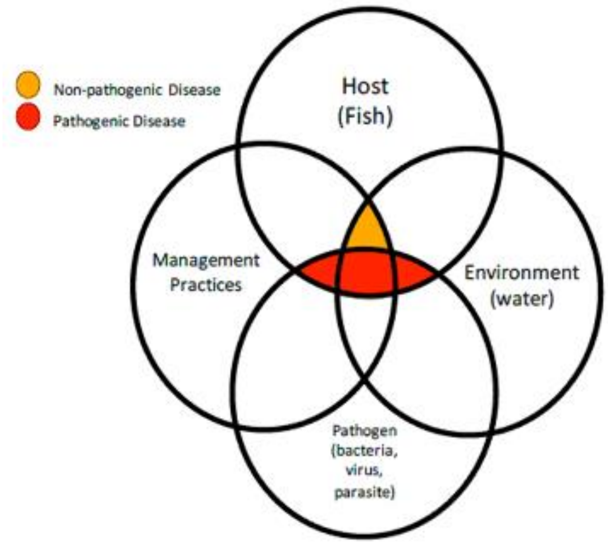
- Within each of the categories numbered on the left-hand side of the image above, there are detailed pathways of effects descriptions identifying the possible risks associated with each activity, and their possible impacts. For example, for 5. Rearing, the potential risks and impacts are as follows:



- There are a number of guidelines and regulatory tools implemented in hatcheries to address fish disease. These include:
  - Operational and Planning Guidelines such as the Production Planning Framework, Biological Risk Management Framework and Operational Guidelines
  - Pacific Aquaculture Licencing which includes Fish Health Management Plans. These outline requirements and guidelines for documenting fish health and biosecurity practices, methods to keep pathogens out and to prevent pathogen spread, fish monitoring and the need for maintaining optimum rearing environments, and veterinary oversight.
  - ITC which includes Salmon Introductions and Transfers Application and Review Process, Records reviews, veterinary oversight and Fish health attestation process.
- There is a wealth of historical fish health information in hatcheries (40 years +).
  - Fish culture always begins with disinfected eggs.
  - Most fish health events involve a narrow set of commonly present pathogens which include:
    - Bacterial
      - In Freshwater- BKD, Myxobacteria (Flavobacteria), Furunculosis
      - In Saltwater- BKD, Vibriosis
    - Parasitic
      - In Freshwater- Trichodina, Ich, Costia, Epistylus, Tetracapsuloides
    - Fungal
      - In Freshwater- Saprolegnia

- Viral
  - In Freshwater and Saltwater-IHN
- Daily observations during feeding and fish culture typically allow for quick detection and response. Many pathogens are treatable and preventable during culture using vaccination and other methods of prevention. Several programs include a marine rearing phase that includes monitoring of pathogens. These instances very rarely see outbreaks or issues related to disease.

- One of the most common diseases in BC and the most challenging is BKD (*Renibacterium salmoninarum*) which is naturally present in all salmon populations in BC and the most significant disease management challenge in fish culture. It is passed easily between fish by direct contact, feces ingestion, direct shedding in water and uptake across membranes, and also carried from parent to offspring within the egg. The fish's immune system does not recognize it as foreign resulting in the risk of later disease development. Ultimately it creates lifelong infection culminating in disease if fish are under chronic stress and can cause poor saltwater tolerance and increased risk of predation.
- BKD risk management involves annual program-wide random prevalence testing to understand historical & changing distribution patterns; targeted broodstock screening where stocks are known to have more consistent and higher detections; culling if necessary, antibiotic use and egg surface disinfection. SEP also promotes fish stress management and optimal hatchery practices to avoid disease and pre-release screening, particularly:
  - Where mortalities have typically been higher than expected
  - Where stocks have a history of BKD
  - Where a relevant stress event may have occurred during rearing
  - Antibiotics to manage low-grade hatchery infections to reduce clinical disease and transmission (but there is no cure and no vaccine)
- IHNV is a viral pathogen naturally carried by BC stocks of sockeye, and chum and Chinook are also susceptible. It can cause high mortality to Juvenile salmon and can be transmitted to Chinook through "dish-to-fish "exposure of co-migrating species or exposure to water containing sockeye salmon. Survivors may become lifelong carriers with the virus reactivating on return to FW. There is no treatment; if disease is diagnosed then the hatchery stock is destroyed. It is generally managed through:
  - Targeted screening of Chinook broodstock in sockeye systems
  - Biosecurity and fish husbandry practices
- Disease is a complicated process that is influenced by a myriad of ecological and environmental factors. *Detection of pathogens does not imply disease and subsequent risk.* All fish carry pathogens at all free-swimming stages of life but disease many only occur if the environment changes, environmental stress predisposes fish to disease of there is some environmentally induced imbalance.



- Detecting a signature of a pathogen:
  - Does not necessarily indicate that a fish is sick
  - May indicate that an immune response has been successful in clearing a pathogen from system
  - Everything harbours something and
  - A few sick fish does not mean a population is unhealthy
  - May be due to remnants picked up by sensitive tools & generating false positives
- Current disease risks are well understood, but subject to change if environmental/ anthropogenic conditions change. *Climate change acts as a potential for unpredictability in disease management from SEP.* As climate severity and variability increases, so will the potential for increased risks from diseases.
  - E.g. *Phoma*, which is a common plant fungal saprophyte/pathogen that falls onto the water surface and can be ingested by fry feeding at the surface, resulting in infection of swim bladder or gut can result in death
  - This occurrence has been historically rare but has become more frequent in recent years and SEP speculates that in years where plants are more stressed, there is more *Phoma* sp. and this results in greater exposure to young salmon and risk of developing disease.
  - This has not been established but is a scenario of how a changing environment affects the host/environment/ pathogen interaction.
- In summary, SEP has a long history of building practices to manage and mitigate health risks within the hatchery environment and a network of fish health practitioners in the Pacific Northwest helps to identify emerging issues
- Hatchery fish tend to be exposed to fewer pathogens than naturally-produced fish during rearing
- It is difficult to predict future problems due to increasing environmental variability and associated stress effects on fish

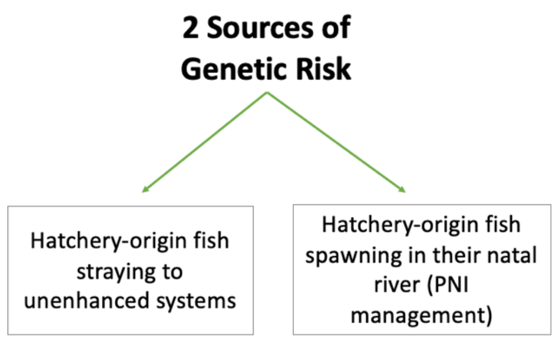
- There are not many studies or examples of disease transfer from hatchery to naturally-produced fish
- Science can help identify potential threats and there are many new tools and techniques to help improve management

Presentation 8 - Magnitude, patterns, and extent of straying from WCVI hatcheries. Jacob Weil, DFO

- The goals for Jacob's presentation were to:
    - Describe the **magnitude and extent of straying from** major and smaller facilities along WCVI for 1998-2017
    - Describe **which WCVI rivers are receiving** the bulk of these strays, in both enhanced and unenhanced rivers
    - Compare hatchery stray rates to unenhanced, 'background' stray rates
    - Discuss potential **hatchery practices** linked to **increased stray rates**
- **Homing** to the natal stream is a characteristic behaviour in salmonids to increase the likelihood of finding a mate and to maintain suitable habitat for the survival and persistence of a population. Meanwhile, **straying** to non-natal sites is a critical evolutionary feature that buffers populations against spatial and temporal variability in habitat and allows for the colonization of new habitats.
- **Natural stray rates** vary by species and life-history strategy:
    - Complex age-structures are predictive of more precise homing
    - Chinook tend to stray less and spread reproductive risk across a greater number of age-classes
    - Other species (*e.g.* pink, chum) buffer these risks by straying at higher rates when conditions are poor at natal sites
- While many studies describe straying for hatchery-origin fish, **very few studies have examined natural stray rates** in Chinook salmon. This is clearly difficult to do because most methods to determine the origin of fish rely on hatchery marking.
- However, two studies have used DNA parentage analysis and PIT-tagging in the Columbia River Basin, to find that natural straying into non-natal tributaries occurs at average rates of **3 to 4%,** within the boundaries of the watershed, with out of basin straying occurring at a rate of **less than 1%.**
    - Ford et al. (2015) used parentage analysis to observe natural-origin straying into tributaries of the Wenatchee River, WA, USA
        - Average out-of-tributary stray rates of ~4%
    - Pearsons and Connor (2020) used PIT-tag recoveries to categorize several Upper Columbia R stray rates at multiple geographic scales:
        - Out-of-tributary straying: ~3% (avg. across all rivers)
        - Out-of-basin straying: <1%
- When we compare with **hatchery-origin recoveries**, the range of values varies between **0 and 99%** depending on treatment group, however a large-scale review of all hatchery-origin straying studies found that an average of **35% of ocean-type and 3% of stream**

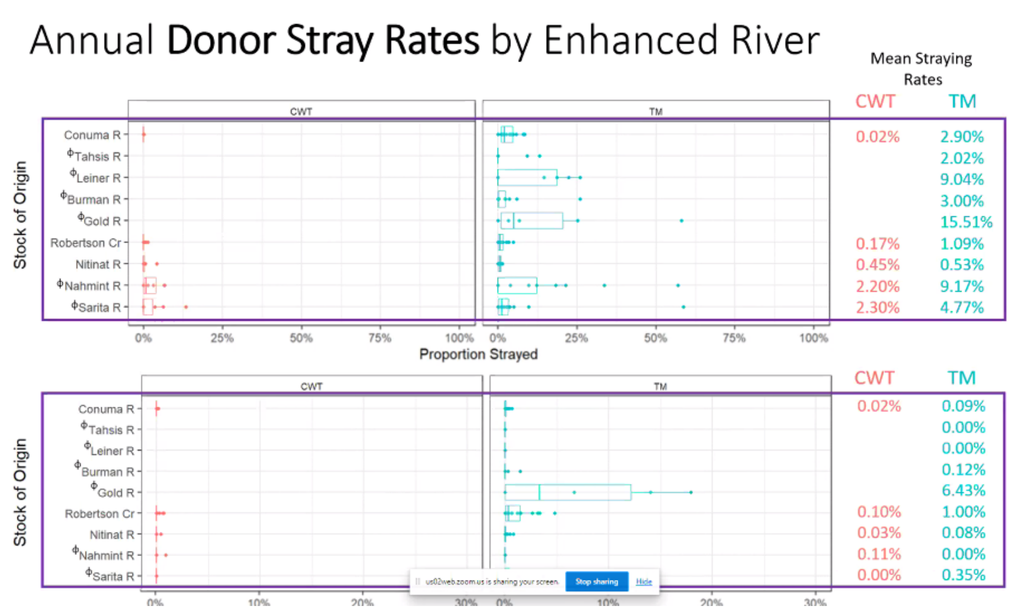
type Chinook strayed. A problem with these averages is that they represent an array of hatchery interventions including transplanting and experimental rearing treatments, which bias this average high, but still, evidence does suggest that ocean-type, hatchery-origin fish tend to stray more than their natural-origin counterparts.

- What are the *potential threats* of hatchery fish straying into natural populations?
  - Increased competition
  - Displacement of natural-origin fish
  - Outbreeding depression
  - Potential hybridization and domestication of stocks
  - Reduced productivity
- Genetic Risks
  - There are 2 sources of genetic risk:



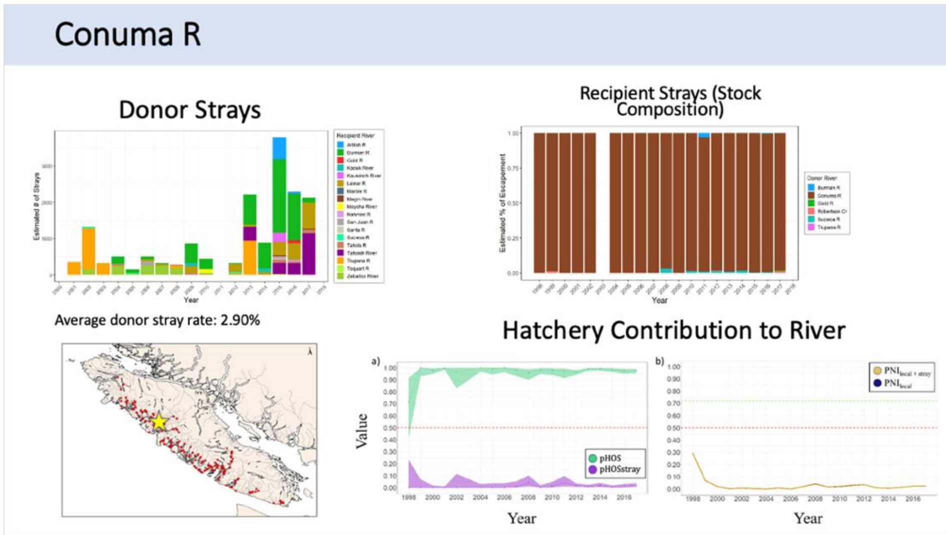
  - It is important to separate the risk of hatchery introgression in a river from two possible sources: one being hatchery fish straying into unenhanced systems, and another, being in those enhanced systems where hatchery fish are homing correctly to spawn alongside their natural-origin counterparts in their river of origin.
  - This is where we hatchery intervention and broodstock management, also called PNI management, need to be considered.
- For recipient river straying, DFO estimates several metrics to describe the hatchery composition of stocks each year. These include:
  - **pHOS** (proportion of hatchery-origin spawners): The proportion of salmon returning to a watershed of hatchery origin
  - **pHOS*local***: The proportion of hatchery origin spawners that returned to their watershed of origin (*i.e.* did not stray)
  - **pHOS*stray***: The proportion of hatchery origin spawners that originated from a watershed different from their return location (*i.e.* strayed)
  - **PNI** (proportionate natural influence): A metric calculated as pNOB/(pNOB + pHOS), ranging between 0 and 1 that indicates the relative influences of the natural and hatchery environments on a salmon population (Withler *et al.* 2018)
  - **PNI_{local}:** PNI calculation including only non-strayed fish
  - **$PNI_{local+stray}$:** PNI calculation including all fish sampled (homed and strayed fish)

- For WCVI, DFO quantified the rate and magnitude of hatchery straying primarily by analyzing returning fish for the presence of one of two types of internal, hatchery marks- thermal marks and CWT's. A greater proportion of WCVI stocks are identified by thermal mark as opposed to CWTs.
- **Results** for WCVI are as follows:
    - Overall stray rates for CWT are quite low, between 0 and 2.3%. Thermal mark data, which tends to be a better indicator of stray rate across populations, spans from around half a percent at Nitinat R, up to 15% in Gold R, which, is biased high due to a couple of outlying years with substantial straying into Area 23.
    - Most hatchery-origin populations on the west coast stray at rates closer to those found in natural-origin fish, and well below the average ocean-type stray rate of 35% found for hatchery-origin fish across studies.
    - On the scale of the conservation unit, mean stray rate drops precipitously in all populations outside the CU.
    - Substantial straying occurred in Area 23.
    - Conuma has the highest proportion of strays from any hatchery. Strays typically occur within the same CU.
    - When looking at local trends of straying within the CU, particularly the risk of specific donor-recipient relationships between nearby rivers, important patterns and potential sources of risk emerge.

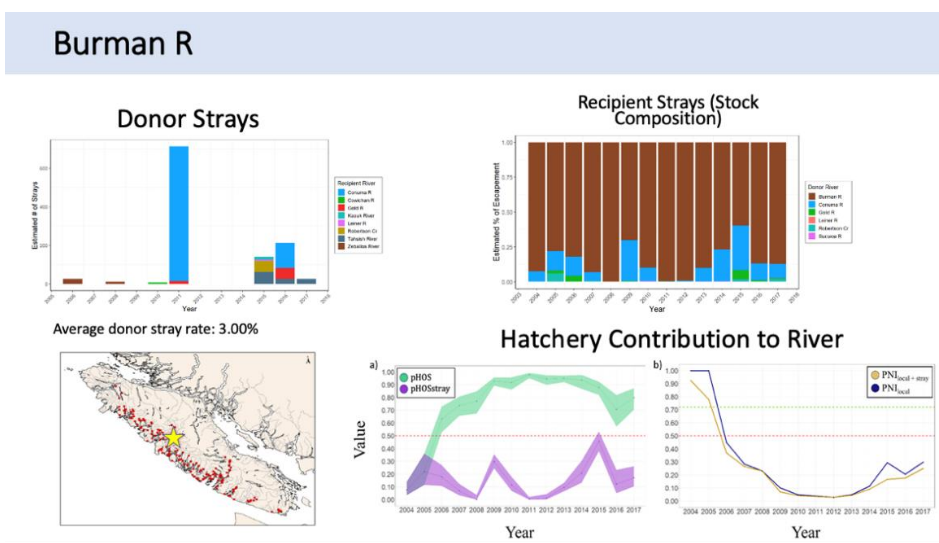


- Next, results are provided for specific systems. In each case, the figure on the left describes the **destination of strays** that originated from the river in question. The figures to the right show the **stock composition** from the recipient perspective, ie. what proportion of the escapement is comprised of which stocks, and the bottom right figures show the proportion of hatchery fish and the stray component of the escapement. PNI values on the right indicate whether the system is being influenced by primarily the hatchery or natural environment.

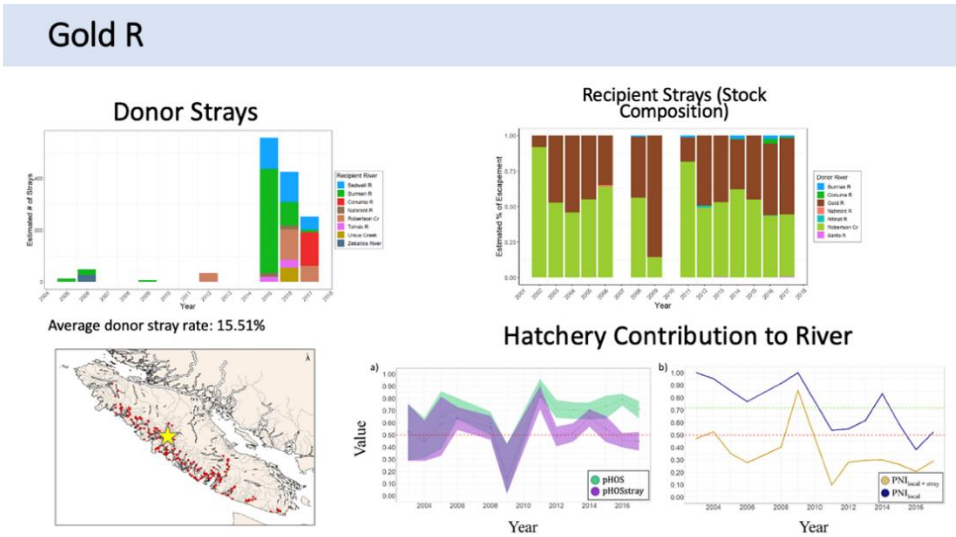
- For Conuma, a great variety of rivers receive its strays, and it produces the greatest number of strays along WCVI each year, ranging from a couple of hundred individuals to over 3800 in 2015, but most of these strays occur within the same conservation unit (Leiner, Tahsis, Sucowa, etc.). Spawners on this system are almost entirely comprised of hatchery fish, and PNI values reflect this.



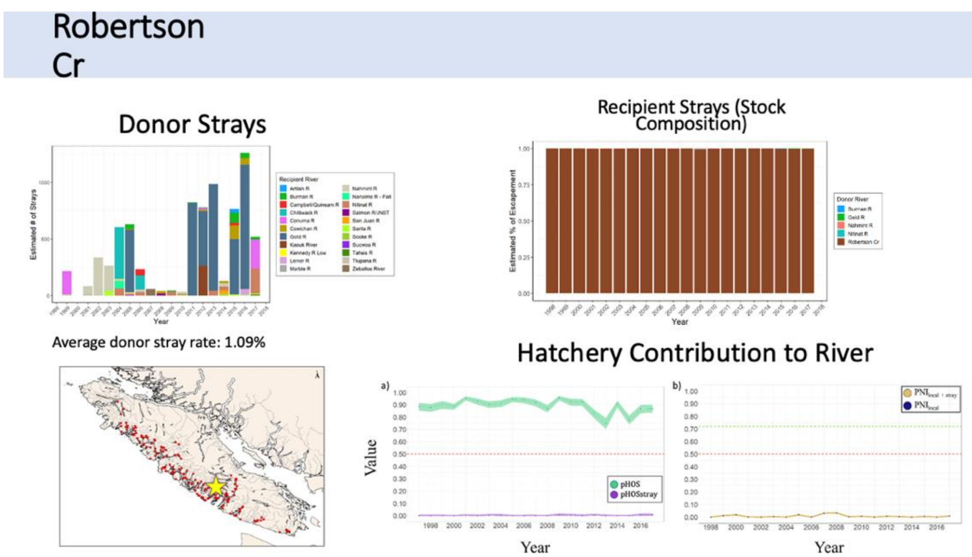
- Burman river fish stray to a few systems sporadically, but like Conuma are typically concentrated within Nootka Sd. The Burman also regularly receives Conuma strays, as well as the odd Gold R and other Nootka Sd fish. These fish do depress PNI values slightly, but the number of Burman-origin hatchery fish are of far greater contribution to the hatchery component in this river than are out-of-river strays into the system.



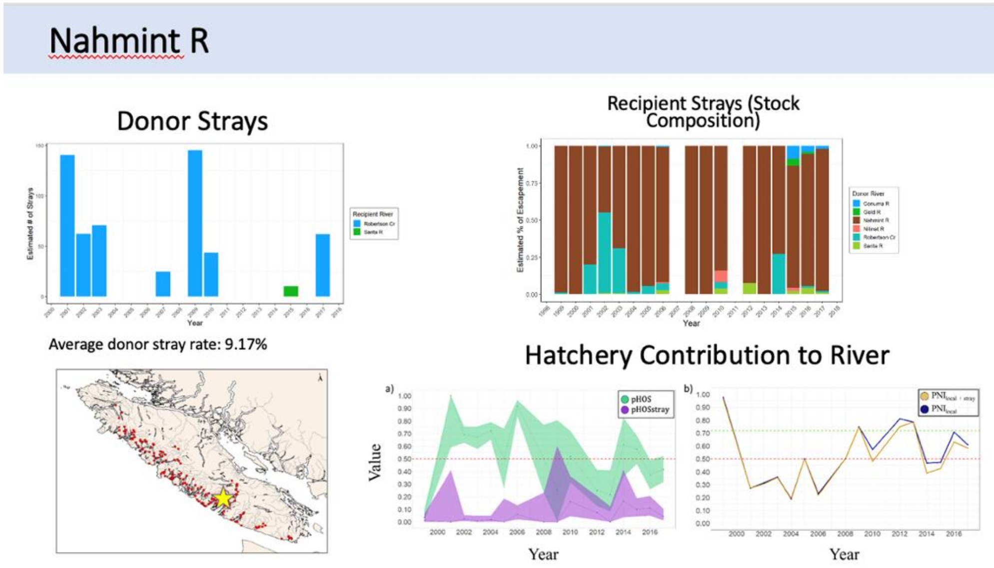
- Nearby Gold River saw minimal straying prior to 2015, but following 2015 a substantial proportion of the escapement was observed straying into nearby Burman River, regular staying into the Bedwell R began, and in 2016 and 17, a number of Gold R fish strayed into Robertson Creek. In DFO escapement records, since 2001, Robertson Creek fish have made up the majority of escapement in more than half of years. This high incidence of straying from Robertson is probably one of the most well-known cases of straying on the west coast, and it is hypothesized that between 1986 and 2015, a complete replacement of the original Gold R stock may have taken place. The strays depress PNI values well below 50% in most years, indicating a net gene flow from the hatchery environment.



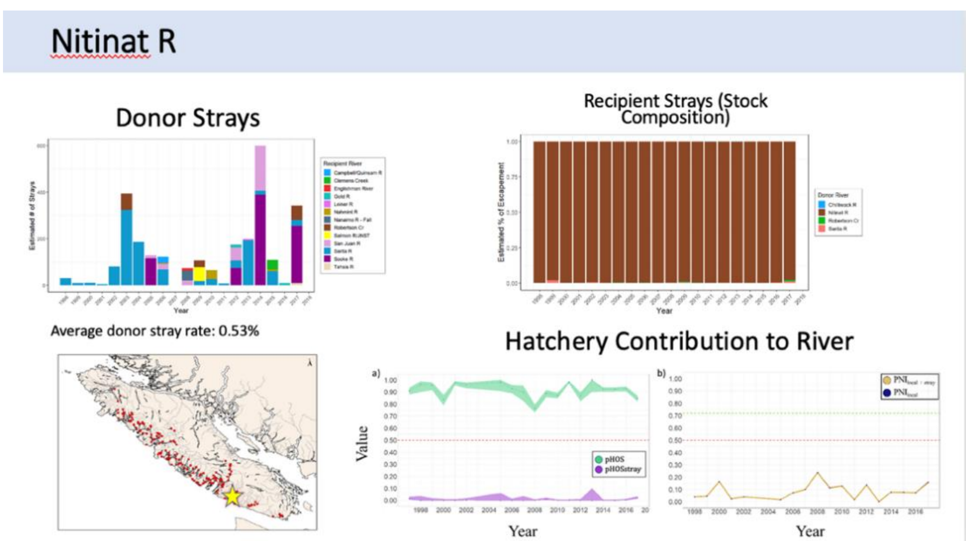
- Robertson Creek produces far fewer strays overall compared to Conuma, and most are found in Gold R. Outside of the Gold R component, straying is fairly minimal but outside of the CU straying is greater here than in the other two hatcheries.



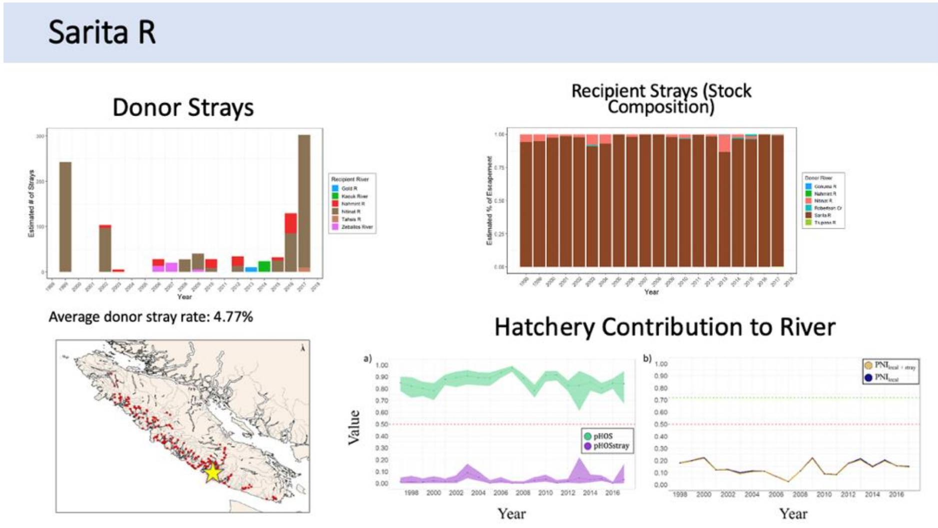
- In Nahmint River, strays are from Robertson Creek, the facility where these fish are reared, save for a few recoveries in Sarita River in 2015. Since 2009, hatchery fish have typically made up the minority of recoveries, and PNI values are typically just above the 50% mark.



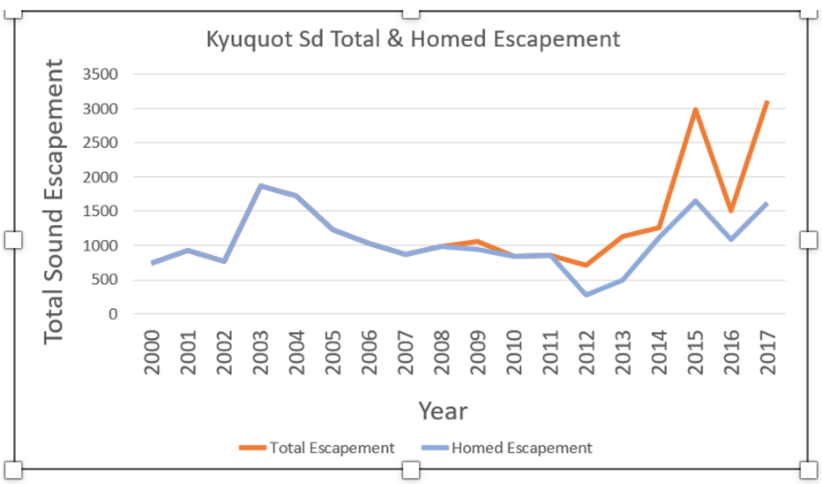
- Nitinat River has even fewer donor strays than the two large hatcheries on the west coast. The most common recipients of these strays are nearby Sarita River, as well as nearby San Juan and Sooke Rivers. These three rivers account for over 75% of the strays observed coming from Nitinat, and again display this trend of increased likelihood of observing a stray in nearby systems. Occasional, sporadic recoveries are made in other systems. As in the other two major facilities, the proportion of natural-origin Chinook in the escapement is very low and characteristic of a production facility like Nitinat.



- Sarita River fish predictably stray into the system in which they are regularly reared, Nitinat. This occurs at a relatively low level but has been high in some years. As a recipient river, Nitinat fish are regularly observed straying into the Sarita at a low level. These strays do not significantly alter the PNI of the river, however this system is already one in which hatchery origin fish make up the vast majority almost every year.



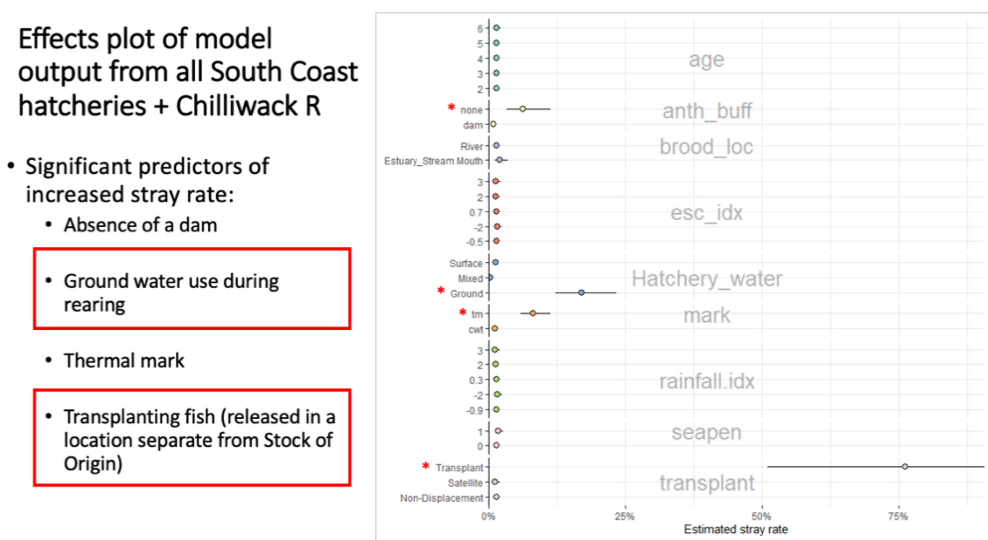
- DFO also monitors unenhanced or natural systems across WCVI including Kyuquot Sound, where escapement estimates in recent years suggest that the total return has been increasing. However, when thermal mark data revealed the origin of these fish, a substantial portion were found to be Conuma R strays. Thus, *Kyuquot Sound may be affected significantly by Conuma enhancement,* despite not having any facilities within the Sound. The risk in this case is the displacement of Kyuquot fish with a significant proportion of Conuma H stock.



- Mixed effects models have been used to predict stray rates. The factors examined included the age of returning fish, presence of a dam, where brood was collected, how many fish returned, the source of water used during rearing, which mark was applied, rainfall levels, whether the fish was reared in a seapen, and whether the individual was transplanted and released at a location different from where it was reared
- Major differences that were consistent between facilities include the presence of a dam at Robertson Creek, broodstock collection in the estuary/stream mouth in Conuma, and the different use of rearing water sources between the three hatcheries.

Factor	Nitinat R	Robertson Cr	Conuma R
Age	Categorical	Categorical	Categorical
Presence of a dam	No	Yes	No
Broodstock capture location	In-River	In-River	Estuary / Stream Mouth
Escapement index	Continuous	Continuous	Continuous
Rearing water source	Mixed (surface + ground)	Surface	Ground
Mark type	CWT and TM	CWT and TM	CWT and TM
Rainfall index	Continuous	Continuous	Continuous
Seapen	Binary	Binary	Binary
Transplant	Categorical	Categorical	Categorical

- The results of this model reveal four significant predictors for increased stray rate. Those included *the absence of a dam, the use of groundwater during rearing, thermal marking, and finally the transplanting of fish.*
- The significance of the absence of a dam may be tied to flow control or just a general increase in control over the environment that is provided by rivers with dams and thermal marking may have been significant due to a greater proportion of fish being thermally marked as opposed to coded-wire tagged.
- The interesting hatchery practice terms that were significant in the model include transplanting and ground water use, both have been well documented as contributors to increased stray rate due to their *adverse effects on imprinting* during Juvenile stages. Note that these practices are currently or have already been addressed by SEP.

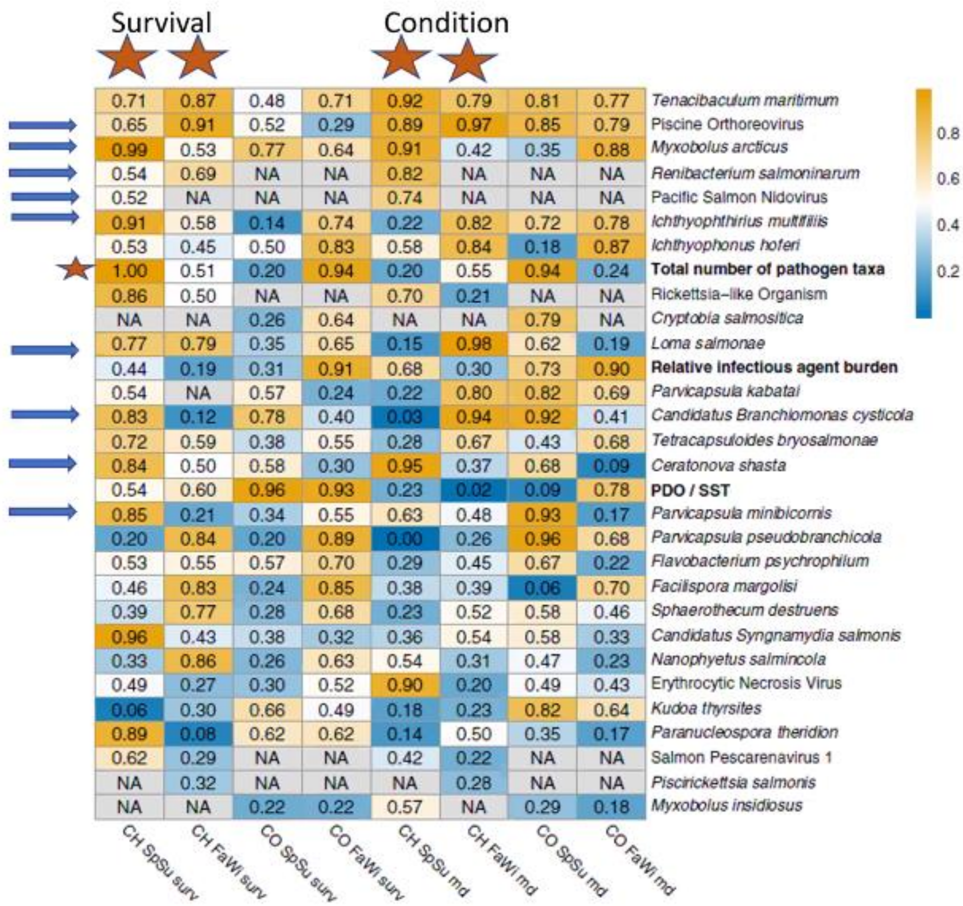


- Conclusions are as follows:
    - Most hatchery populations in SBC stray at rates similar to those found in natural-origin populations

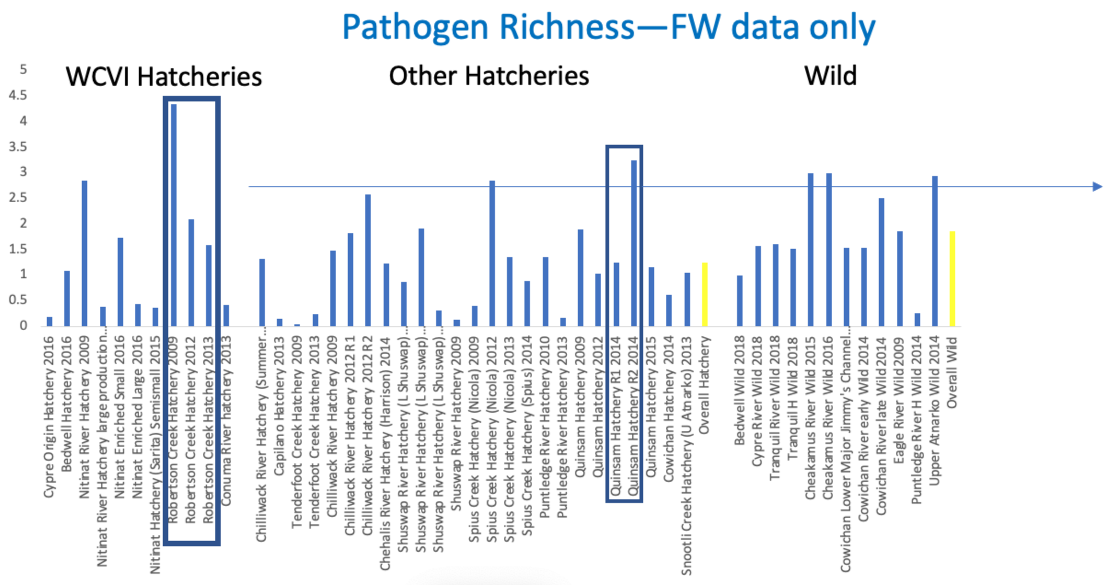
- Large production hatcheries, especially Conuma stray at low rates, but still produce a substantial number of strays each year – impacts vary depending on escapement size of recipient populations
- Rivers supplemented with the goal of avoiding natural-origin extirpation should continue managing pNOB and PNI to maintain natural-origin influence in select stocks when possible
- Hatchery practices such as transplanting, and groundwater use during rearing increase the potential for returning hatchery Chinook to stray
- The magnitude of straying to unenhanced streams varies by system - may be highest in Kyuquot Sd where a substantial number of hatchery fish may return, despite not having any enhancement in the sound.

Presentation 9 - Pathogen risks from hatcheries. Kristi Miller-Saunders, DFO

- Strategic Salmon Health Initiative (SSHI) have conducted high throughput pathogen monitoring to assess pathogen loads in Pacific salmon collected over a decade from trajectory sampling (freshwater through to the 1^{st} year of marine residence) resulting in samples of 1000s of fish of known stock origin from southern BC.
- Marine (post-release) survivorship models were based on CWT data and used pathogen profiles in saltwater only, assessing population-level survival and individual-level condition (relative weight) metrics for spring/summer and fall/winter periods (led by Art Bass)
- Pathogens included in the models were ranked by the consistency of their “impact” across Chinook and coho salmon survival and condition (note that the orange cells in the figure below show a negative associated with survival/condition)
- Data showed that pathogens which typically affected condition also affected survival.

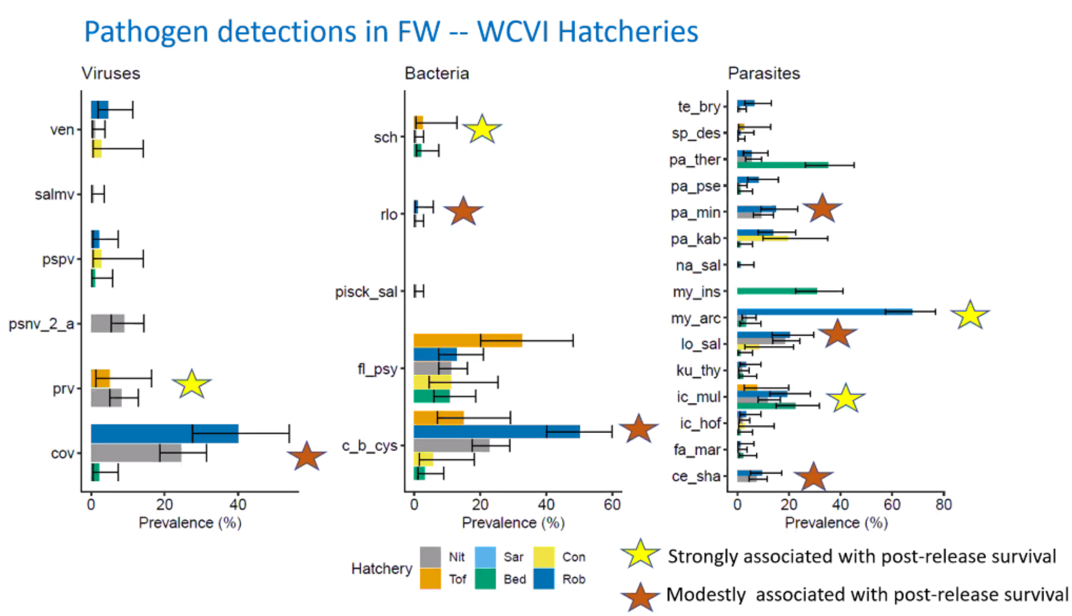


- *Pathogen richness* is a measure that reflects the diversity of pathogens within an individual and is highly associated with marine survival.
  - An examination of pathogen richness (see graph below) in freshwater showed no strong differentiation between hatchery and naturally-produced fish, but was highly variable among stocks/years
  - This was especially true in hatcheries—where averages ranged from 0.1 to 4.4 pathogens/fish
  - The highest diversity existed in Robertson Creek Hatchery fish.
- Climate change is expected to increase pathogen richness.



- Bacterial Pathogens found in Freshwater:
    - *Candidatus* Branchyomonas cysticola was the most common bacterial agent in hatchery and naturally-produced fish, but varied across stocks, it can cause gill disease in the ocean and models show that it is associated with early marine survival.
    - *Flavobacterium psychrophylum* were the second most commonly observed in hatchery and naturally-produced fish, causing coldwater disease in freshwater, but with higher prevelance in naturally-produced fish.
    - *Renibacterium salmoninarum* was only observed in hatchery fish, but not commonly. This causes BKD (but hatcheries select against females with high loads to reduce incidence) and a lower condition in the marine environment. Antibiotics can control levels in hatchery releases.
- Viral Pathogens found in Freshwater:
    - *Pacific salmon nidovirus* was the most common and is possibly associated with early marine survival. It infects gill tissue and thought to disrupt osmoregulation/ saltwater adaptation. There is a possible risk of transmission from hatchery to naturally-produced fish. This pathogen is related to the coronavirus family.
    - *Piscine orthoreovirus (*PRV) was only observed in hatchery fish in freshwater, and is associated with jaundice/anemia disease in saltwater; its' early pathology is apparent from challenge studies. It is strongly associated with poor marine survival and low condition in Chinook. Aquaculture associated transmission has been demonstrated. Aquaculture hatcheries have successfully reduced or eliminated PRV through triple disinfection of eggs.
- Parasites with no intermediate host found in Freshwater:

- *Ichthyptherius multifiliis* (Ich) is common and highly associated with marine survival in the models. It is relatively common on WCVI (H and W) and can possibly be controlled in hatcheries. Climate change increases risk.
    - *Loma salmonae* is observed across hatchery and naturally-produced fish in freshwater, can cause gill disease and is modestly associated with marine survival.
- Parasites with an immediate invertebrate host found in Freshwater:
    - Some clustering within hatcheries was found and likely a result of introduction of natural river/lake water.
    - There appears to be no fish-fish transmission, hence no threat between hatchery and naturally-produced fish, but certainly potential threats within infected stocks
    - *Ceratonova shasta* is a reportable agent of disease highly controlled in US hatchery/naturally-produced populations; it is highly thermally responsive, and climate change will thus worsen the impacts of this agent (*Parvicapsula minibicornis* is also highly correlated).
        - Carefully timing/testing of influx of natural water could reduce hatchery exposure
        - Highly associated with survival and condition in models
    - *Myxobolus arcticus* was the most prevalent, and is a brain parasite highly associated with early marine survival. This agent should be more carefully controlled, where possible; but needs more study.
- The figure below shows detections in WCV hatcheries and level of association of various pathogens with post-release survival.



- **Key points to consider include:**

- WCVI hatchery fish appear to have higher marine survival than naturally-produced and it is possibly that a slightly higher infection intensity in naturally-produced fish could contribute to this difference.
- Several well understood acute pathogens are rarely, if ever, observed; in SSHI studies, sampling did not specifically target hatchery mortalities (which may have led to more findings of these specific pathogens such as *Vibrio salmonicida, Vibrio anguilarum* (*ordalli* not assessed), *Aeromonas salmonicida*, VHSV).
- Many agents strongly associated with survival are relatively less understood in Chinook e.g. *C. B cysticola, M. arcticus*, PsNv (cov), *P. minibicornis*, sch (gill chlamydia) and require more follow-up studies. Again, pathogens associated with acute diseases may be difficult to assess in live-sampled fish.
- What is the point of mitigating infection risks in hatchery fish?
    - It can increase post-release survival; decrease annual variability
    - It can reduce the risk of transmission to naturally-produced fish (Note: thus far these risks appear considerably lower than those from Aquaculture)
- Their models did not consider proximity of sampled naturally-produced fish to hatchery effluent which could increase exposure to freshwater pathogen spillover effects from hatcheries
- They need data from seapen rearing to further evaluate pathogen impacts during very early rearing
    - e.g. whether assumed cases of vibriosis are, in fact, always Vibrio
    - Seapens allows for sampling of dying fish and provide important validation for model data
- *Pathogens transmitted in freshwater but only causing disease in saltwater are not currently recognized or specifically mitigated in hatcheries*
    - Many pathogens transmitted in freshwater have been associated with condition (potential carry-over effect) and/or survival post-release
    - A better understanding of these risks is required
        - How much is freshwater relative to saltwater transmission contributing to risk?
        - Are impacts during down-stream migration or in the ocean?
- Understudied agents require laboratory challenge studies to validate cause and effect relationships with disease
    - Pathology in natural environments has been investigated for many potentially impactful agents
- Mitigation would focus on the above listed pathogens to have the greatest impact on naturally-produced survivorship outcomes
- **In summary:**
    - WCVI hatchery fish appear to have a higher marine survival than naturally-produced
        - Likely due to higher infection intensity in naturally-produced

    - Several well understood acute pathogens are rarely, if ever, observed
    - Many agents are strongly associated with survival are less understood in Chinook
    - Point of mitigating infection risk in hatchery?
        - Increase post-release survival
    - Next steps will include using data from seapen rearing
- For the Risk Assessment of the risk posed by pathogens, the following information is useful:

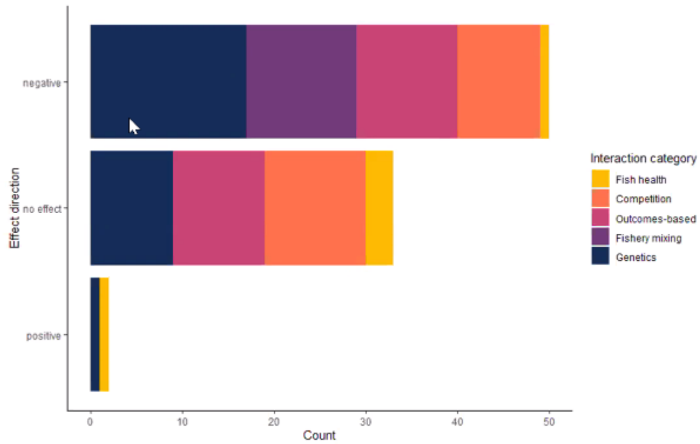
Risks posed by pathogens

- Climate change increases risk and susceptibility
    - C.b. cysticola, C. shasta, P. minibicornis, I. multifiliis demonstrated impacts of temperature
- Subclinical fish may have poor saltwater tolerance and delayed mortality
    - COV (PsNv) suspected to impact SW adaptation given localization in chloride cells and rapid loss of highly infected fish
    - Suspect some FW transmitted agents are causing disease in SW (including those with limited impacts in FW)
- Actual transmission risks to wild fish have not yet been assessed

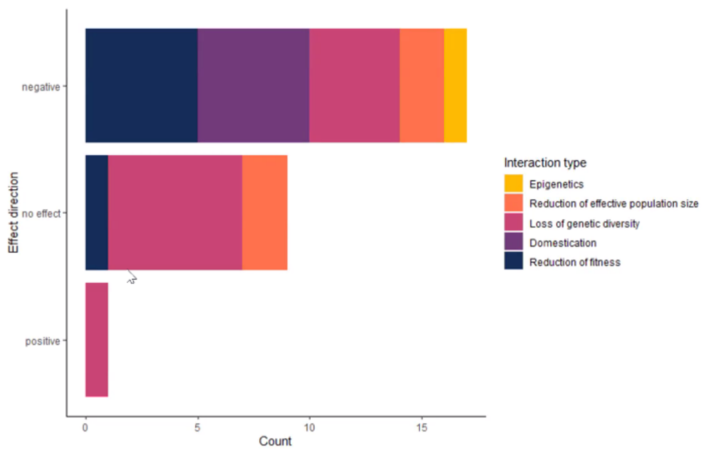
LF	Hatcheries	Hypothesis	Possible Mechanisms and Potential Metrics	Limiting Factors
3	Disease producing pathogens	Changes in hatchery disease patterns and/or pathogen transfer result in reduced growth, survival and/or fitness.	Climate change increases susceptibility of both hatchery and naturally produced fish to bacteria, viruses, fungi, and parasites normally present within a hatchery water supply. Direct or indirect/delayed fitness reduction due to the combined impacts of environmental stress and infection pressure. For example - sub-clinically infected fish may have poor saltwater tolerance and suffer delayed transition mortality, or may see increased predation due to a weakened state of fitness from chronic infection (e.g. BKD).	Pathogens can be transferred both within a hatchery and out to naturally produced fish: 1. Vertically - from female to egg before spawning, renders immune system ineffective against that pathogen (few examples - BKD) 2. Horizontally – from fish to fish via shedding into the water (most common form of transmission) Increased opportunity for horizontal transfer in a hatchery because fish are at high density and predation is restricted. Pathogens shed in hatchery effluent may increase risk of transfer to naturally produced fish. Direct or indirect/delayed mortality as a result of pathogen transfer within and/or out of the hatchery.

Presentation 10 - Changes in biological characteristics. Andy Rosenberger, Pacific Salmon Foundation

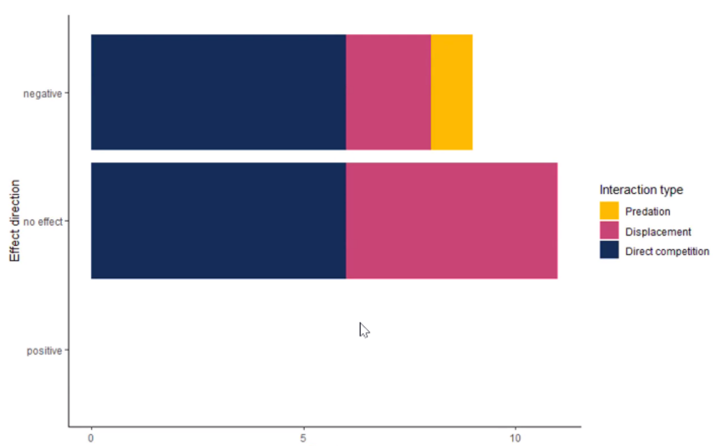
- The goal of this presentation was to provide a background on the PSF BCSRIF hatchery effectiveness review, the key components of the review and main findings to date
- The first component described were results of a review carried out to summarize the literature concerning hatchery-naturally-produced interactions. Questions addressed in this review included:
    - What are the major categories of interactions, and how do they vary geographically and across species?
    - What recommendations are made in the literature to prevent or lessen the negative consequences of these interactions?
- A systematic literature review was conducted with 108 papers finally included. Most were from the US and most considered Chinook and steelhead. Overall, studies found more negative effects of hatchery fish on naturally-produced fish than positive or no effects. Only 2 studies found a positive effect.



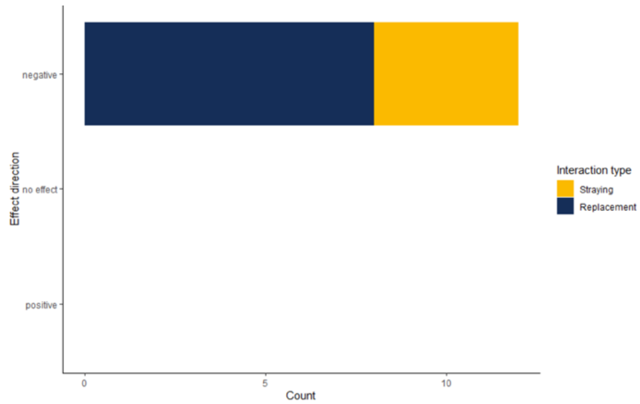
- Genetic effects included interactions resulting in impacts on epigenetics, effective population size, genetic diversity, domestication and fitness. The majority of studies showed negative effects of interactions on these outcomes.



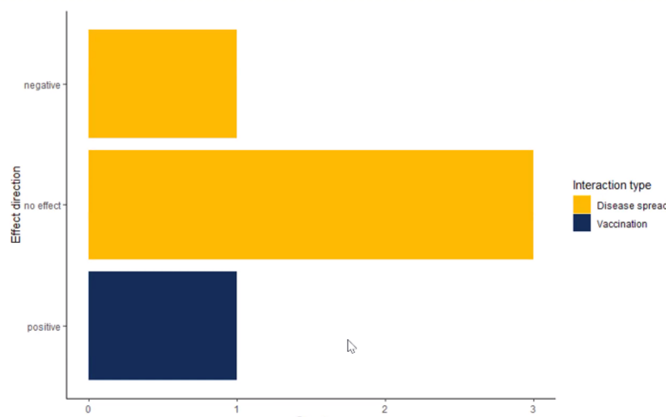
- Competitive interactions between hatchery and naturally-produced fish resulted mostly in no effects or negative effects on naturally-produced fish.



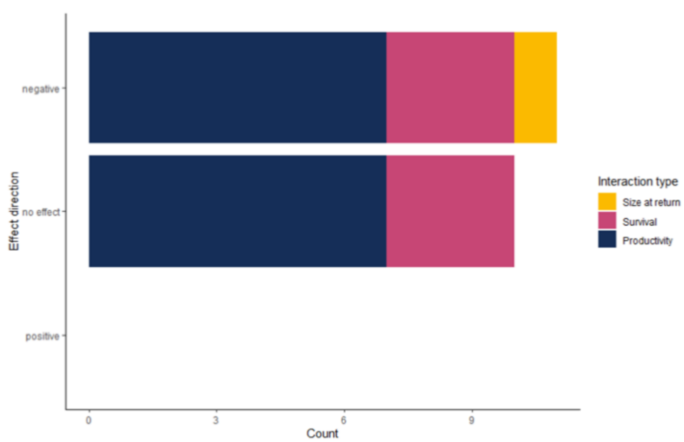
- Fishery Mixing effects included impacts of straying or displacement by hatchery fish and were all negative for naturally-produced fish.



- Studies of fish health and interactions among hatchery and naturally-produced fish showed mainly no effect with one negative and one positive for impacts to naturally-produced fish. However, sample sizes were very low.

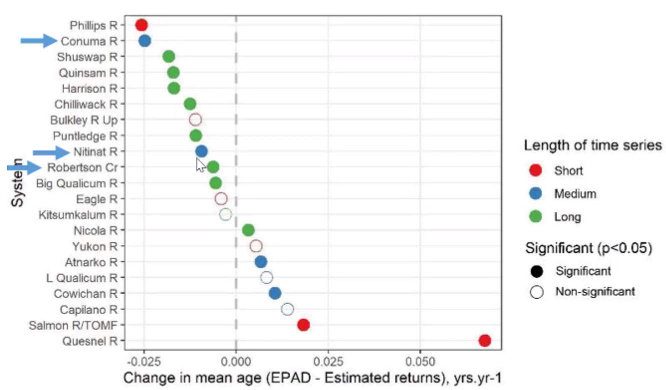


- Studies assessing outcomes of interactions have primarily shown no effect or a negative effect of hatchery fish interacting with naturally-produced fish in terms of outcomes such as survival, size at return or productivity of naturally-produced populations.

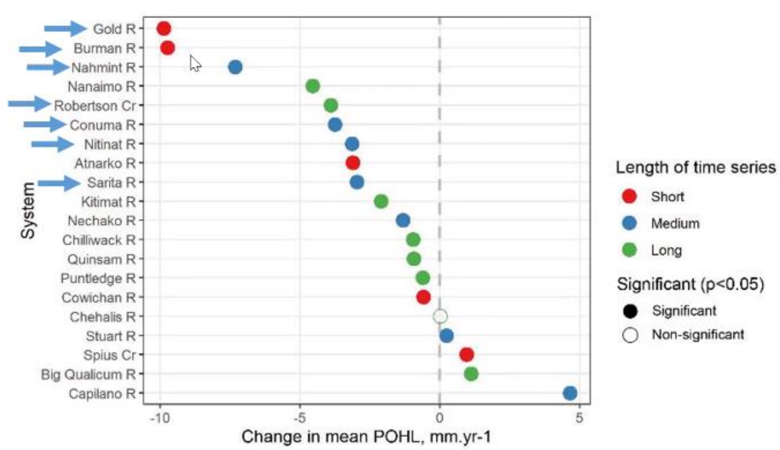


- The literature provided a number of recommendations to lessen the negative impacts of interactions between hatchery and naturally-produced fish, and these included:
  - Prevent interactions if possible, if not, mitigate them
  - Determine that expected benefits exceed potential risks

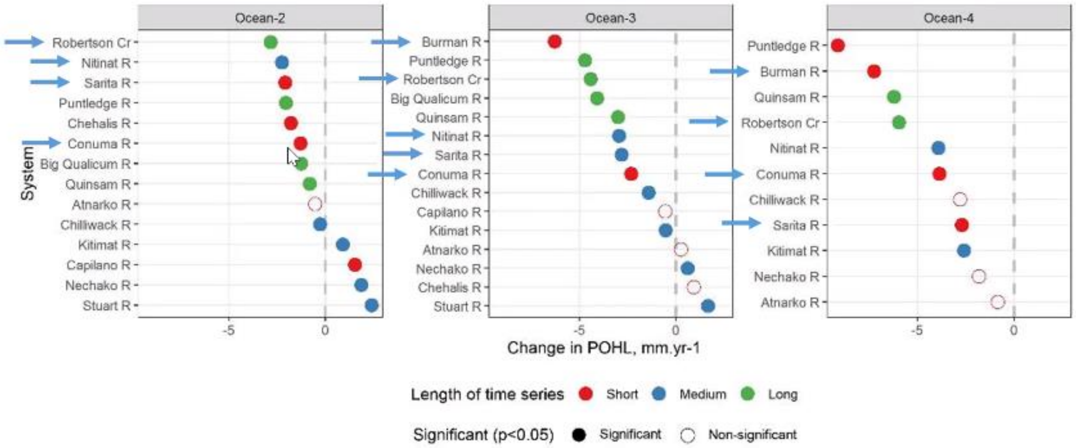
- Overall hatchery management strategy should be cautious and adaptive
    - Hatchery operations should optimize the reduction of harm to naturally-produced fish
    - Perspectives need to transcend species and borders
    - Ongoing monitoring and assessment
- The next set of studies assessed changes in biological traits associated with hatchery and naturally-produced fish. Declines in Chinook stocks have been detected across the Pacific Northwest, but the extent and causes are not well understood in BC. Some key questions are:
    - How are mean size and age changing for BC stocks and how might changes be influenced by changes in:
        - Age composition
        - Female composition
        - Size-at-age
        - Size by sex
- Overall results showed a reduction in mean age across populations for WCVI population



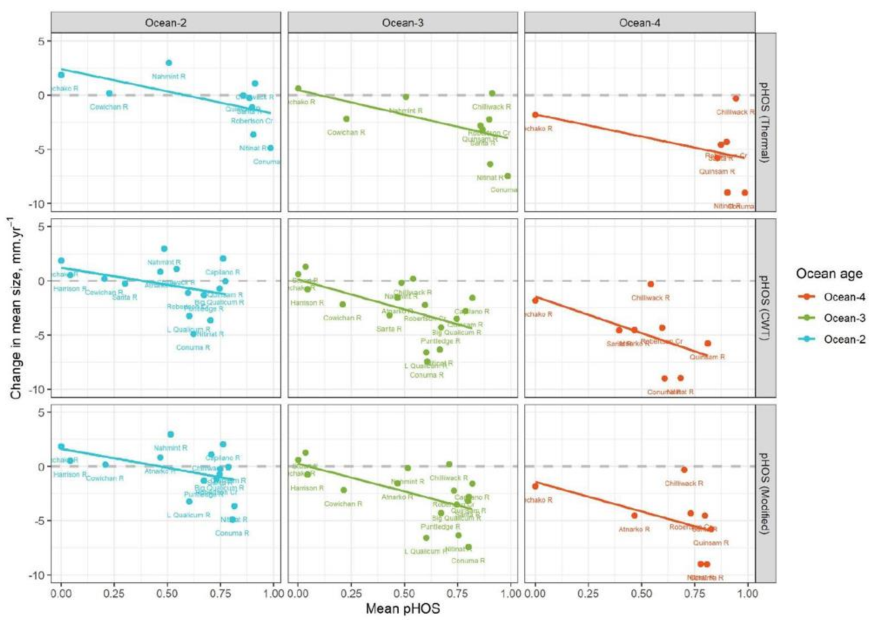
- In addition, the vast majority of WCVI stocks have shown major size reductions



- There have also been significant declines in size-at-age (POHL) across stocks in the WCVI



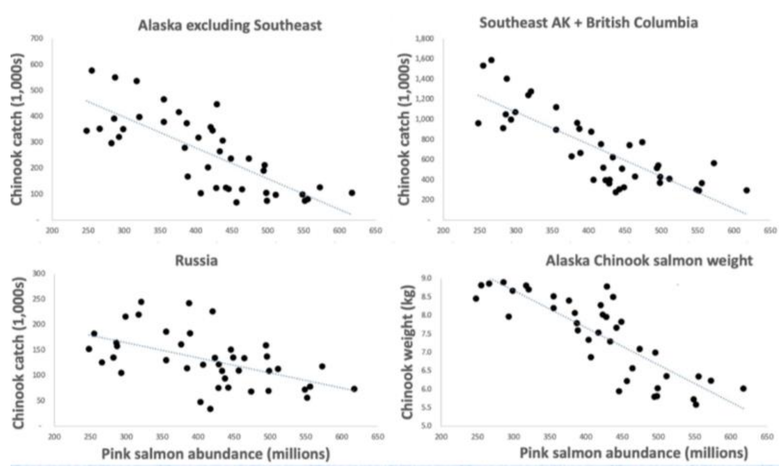
- Changes in size at age have been compared to pHOS by age class and there are some significant relationships but more work is needed.



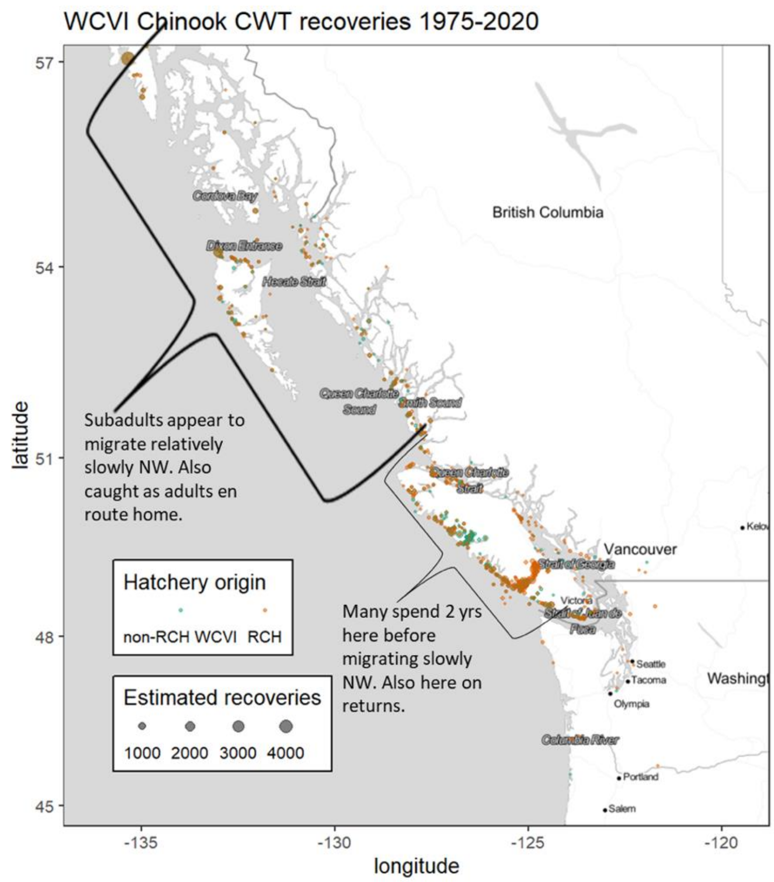
- What does this mean for hatcheries? Key findings from this component so far are that:
  - Declines in size, age and sex of Chinook populations is happening in BC
  - Biodata is largely from enhanced systems, so it is difficult to compare with naturally-produced populations
  - There is lots more to do e.g. different models that include environmental indices, regions, etc.; more historical data (pre-96) and small hatchery data to be processed
- Other components of the effectiveness review were described but results not available to date.

Presentation 11 - Do hatchery salmon in the Gulf of Alaska compete with WCVI Chinook salmon? Jim Irvine, DFO Emeritus

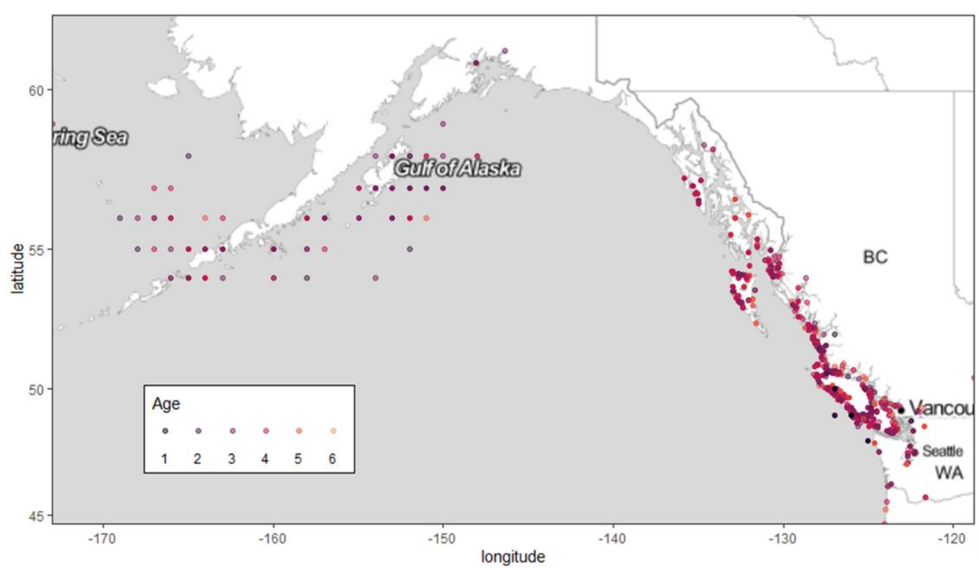
- The North Pacific ecosystem is dominated by pink and chum salmon, many of which are of hatchery origin (see earlier presentation above).
- There is significant spatial overlap by BC Chinook with chum and pink salmon from Asia and Alaska (and of course BC and southern US).
- Pink & chum are primarily planktivores but in their 2nd year, pink salmon often eat small squid and fish (as do Chinook) – which could result in direct competition.
- Pink (& chum?) salmon-related trophic cascades can affect plankton, sockeye & other salmon species. Micronekton (squid, fish, euphausiid) feeders (e.g., Chinook) are likely affected via bottom-up processes and presence of pink and chum could also result in indirect competition.
- What is the evidence for competitive interactions and their impacts?
    - Growth and abundance of various Chinook population are reduced in high productivity pink and chum years.
    - Growth and abundance for many populations of Chinook are declining and the commercial catch of Chinook salmon in Alaska, British Columbia, and Russia has declined in relation with increasing pink salmon abundance over the past 41 years. There have also been size declines (and weights for Alaska chinook).
    - There appears to be a relationship between pink salmon abundance and both commercial catch (1980-2000) and weight of Chinook (see figure below; Ruggerone et al. 2016, NPAFC preliminary data).



- Do we know if WCVI Chinook are co-mingling with pink and chum? The distribution of WCVI ocean type Chinook can be determined using either CWTs caught in fisheries or through genetic analysis of samples.
- The pattern of CWT recoveries illustrated below shows that WCVI Chinook are commonly caught along WCVI and northward along the coast, which ties with what we know about their slow NW migration as Juveniles and returns to coastal regions.



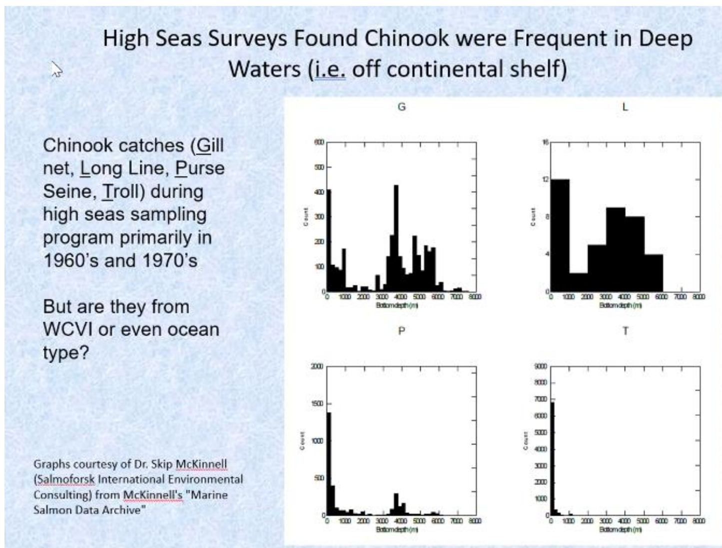
- WCVI Chinook salmon were also caught very frequently in deep waters off the continental shelf and have been captured as bycatch in Alaska groundfish (pollock) fisheries, well into Bering Sea and south of Aleutians. The figure below shows the marine catch distribution of WCVI Chinook (CWT recoveries in all fisheries 1975-2021).



- Thus, there seems to be an overlap in both WCVI Chinook and pink and chum in space and time off the continental shelf, suggesting that competitive interactions could occur.

However, the real question is whether WCVI Chinook are spending significant time off the continental shelf where they may be affected via bottom-up processes because of hatchery salmon?

- NOAA Alaskan geneticists (Pat Barrie and Wes Larson) are generating SNP based estimates of the proportion of WCVI Chinook in these Alaskan fisheries and have found that WCVI Chinook make up a small portion of catch in Bering Sea but a larger portion of catch in Gulf of Alaska (GoA). The catches in the Alaskan Pollock Fisheries are suggestive of an on-coastal distribution of WCVI Chinook. However, earlier surveys also have shown that Chinook occur in very deep waters, well off the continental shelf, but it is not clear if these catches include WCVI Chinook.



- High seas surveys have confirmed that ocean type Chinook (which the majority of WCVI Chinook are), were predominately localized off the continental shelf.
- Summary
  - Growth & abundances of various Chinook populations are reduced in years when pink & chum are abundant
  - Capture of WCVI Chinook in Alaskan pollock fisheries is suggestive of distributions off the continental shelf
  - Early high seas surveys found ocean type Chinook caught off the continental shelf where pink & chum are abundant
  - It seems likely that WCVI Chinook spend a significant portion of their lives in deeper waters of Gulf of Alaska where they probably compete with pink & chum salmon, many of hatchery origin
  - High seas competition may be influencing the survival, growth, and fitness of WCVI Chinook populations but further work needs to be done to determine the size of the effect. To test the hypothesis that competition is an important risk factor, the following are required:
    - Additional genetic analyses of fishery and research survey samples of Chinook salmon from GoA

- ▪ Assembly and interpretation of time series of annual marine growth estimates organized by ocean year for WCVI Chinook
- ▪ Verification of ageing results from high seas surveys
- ▪ Sampling in deep waters of GoA using gear suitable for capturing Chinook salmon

Presentation 12 - Overview of research on Barkley Sound hatchery and naturally-produced Chinook salmon. Ron Tanasichuk, DFO Emeritus

- Ron's work examined the effects of hatchery rearing and release practices, oceanographic parameters, and marine mammal (Stellar sea lion) and fish (Pacific mackerel) predation on annual returns of Robertson Creek Hatchery (RCH) Chinook.
    - o Data showed gradual reductions in size-at-release, no changes in rearing density and pond-specific release numbers, earlier release start dates and reductions in the size of annual total releases over the 1982-2012 time series of age 0+ smolt releases from RCH.

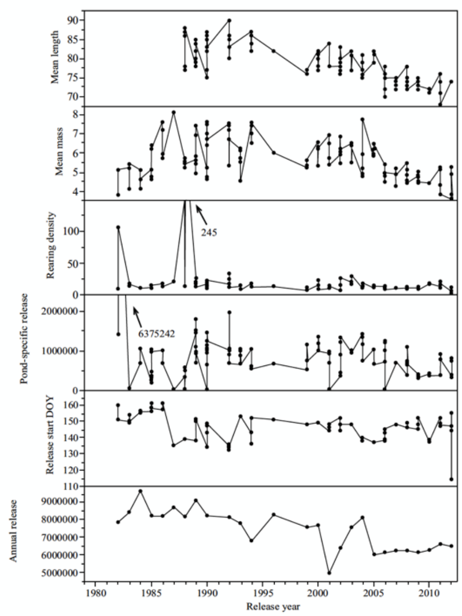


Fig. (2). Robertson Creek Hatchery chinook rearing and release history, rearing density is kg • m^{-3}.

-
    - o Results showed that return was best described age-specifically and was affected by variations in predator (Steller sea lion, Pacific mackerel) abundances. An estimated 99.8% of the chinook consumed by Stellar sea lions were Juveniles. There was no detectable effect of hatchery rearing/release practices.
- A second study described the early life history of WCVI Chinook (Barkley Sound/ Alberni Inlet) and investigated interactions between wild and hatchery Chinook
    - o Purse and beach seine catches in Alberni Inlet/Barkley Sound showed that Juvenile hatchery and naturally-produced Chinook, Juvenile hatchery and naturally-produced coho, and naturally-produced sockeye and chum occur contagiously, as species- and hatchery or wild-specific schools, and do not interact
    - o Juvenile hatchery and wild Chinook occur contagiously, i.e., in schools.

    - Overall, Juvenile hatchery and naturally-produced Chinook don't interact with Juveniles of other species or each other.
- Conclusions were as follows:
    - Variation in the return of Robertson Creek Hatchery Chinook is best described age-specifically and is affected by variations in predator (Steller sea lion, Pacific mackerel) abundances. The effect of predation overwhelmed any effect of "stock" (size-at-release, number and timing of release, rearing density).
    - There was no detectable effect of hatchery rearing/release practices on the return of Robertson Creek Hatchery Chinook.
    - Juvenile hatchery and naturally-produced Chinook occur as discrete schools in Alberni Inlet/Barkley Sound and do not interact physically.
    - There may be competition for prey between hatchery and naturally-produced Chinook Juveniles in Alberni Inlet/Barkley Sound. This could be testable (the Barkley Sound euphausiid/non-euphausiid monitoring program includes a 23-year time series (1991-2013) of Chinook prey availability and 2 years of diet data (2000-2001) and these time series have been resurrected.

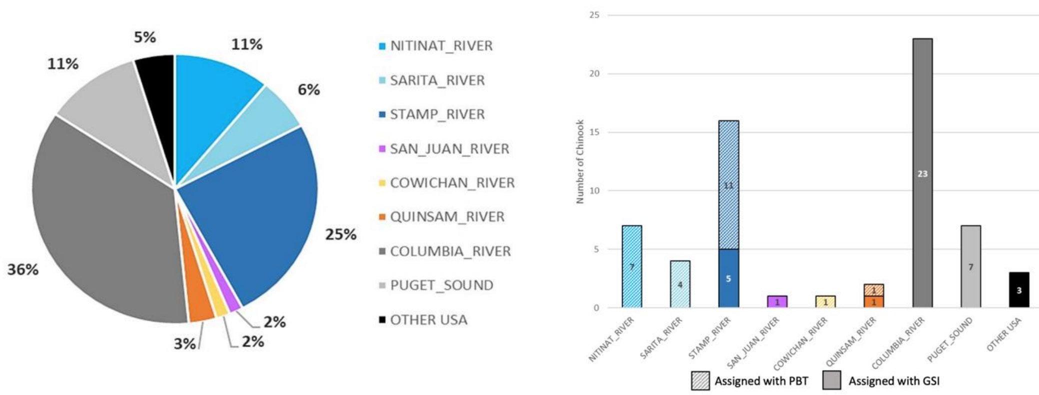
Presentation 13 - Local Ecological Interactions and Microtrolling preliminary findings. Jessy Bokvist, DFO

- Jessy described the 2020-2021 WCVI microtrolling pilot which was carried out to:
    - Inform knowledge gaps regarding WCVI Juvenile salmon distribution, health, and condition in nearshore areas within sounds.
    - Target Chinook Juveniles in their first winter at sea haphazardly throughout the sounds.
    - Collect various biological samples and data
- DNA was sampled from every Chinook to examine stock-specific spatial and temporal trends.
    - To date, preliminary stock composition results are not corrected for effort and pooled across months.
    - Stock composition was determined via parentage-based tagging (PBT) or genetic stock identification (GSI).
- Jessy provided the stock composition for microtrolling activities from each Sound (see figures below).
- Barkely Sound Chinook from microtrolling were 52% US fish, followed by Stamp R, and some Nitinat and Sarita. Canadian fish were identified as primarily hatchery fish.
- Clayoquot Sound Chinook were 61% from Stamp R, with lower proportions of Nitinat and Sarita, and very small proportions of Bedwell, lower Kennedy R and Thornton Creek. Canadian fish were identified as primarily hatchery fish.
- Nootka Sound Chinook were made up of Conuma fish, followed by Tahsis and Leiner R fish. Other Chinook originated from Stamp R and Nitinat and again were mostly hatchery fish.

- Finally, Quatsino Sound Chinook were 41% Marble R naturally-produced fish with smaller proportions of Stamp R, Conuma, Nitinat and Sarita fish.

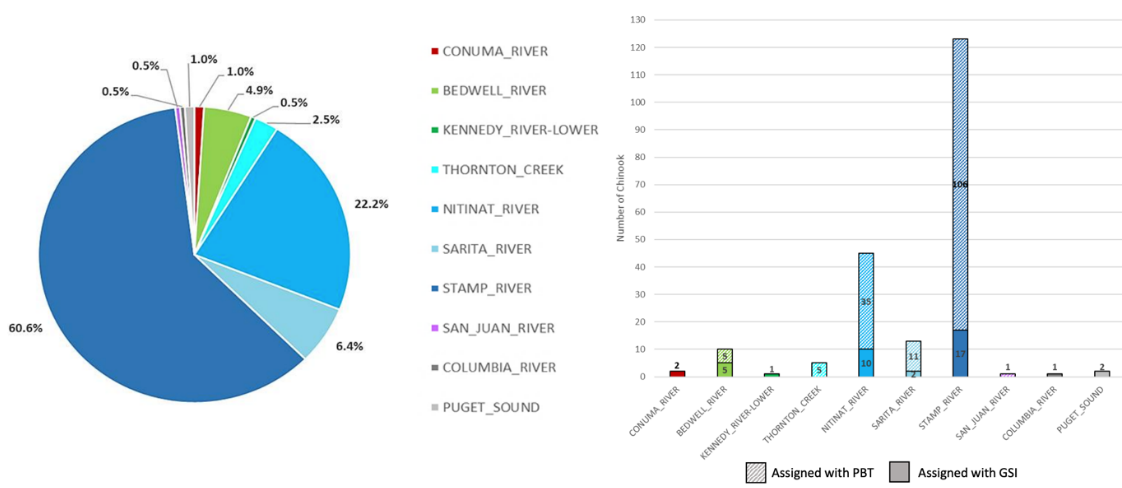
Barkley Sound Microtrolling (n=64)

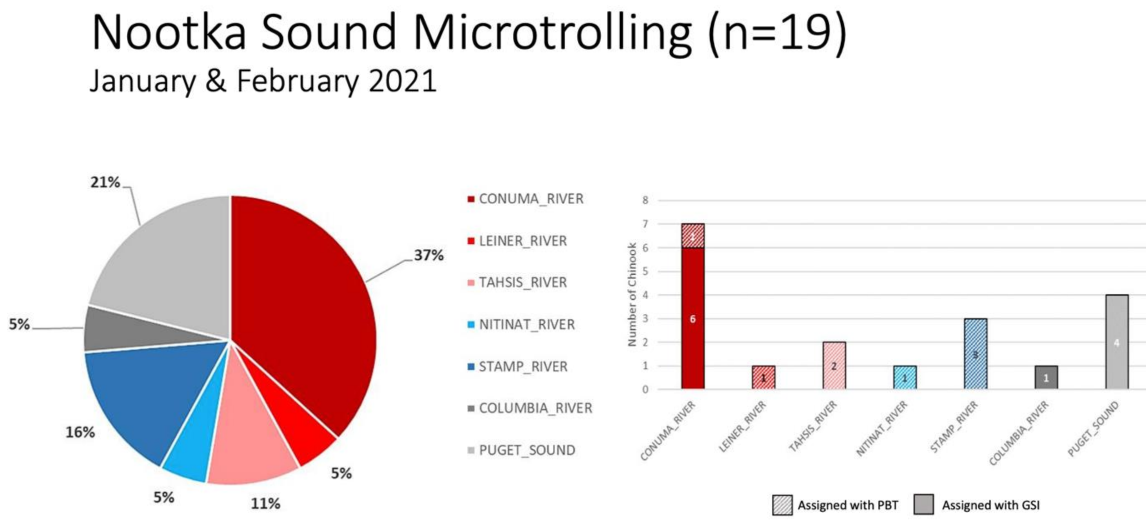
February & March 2021

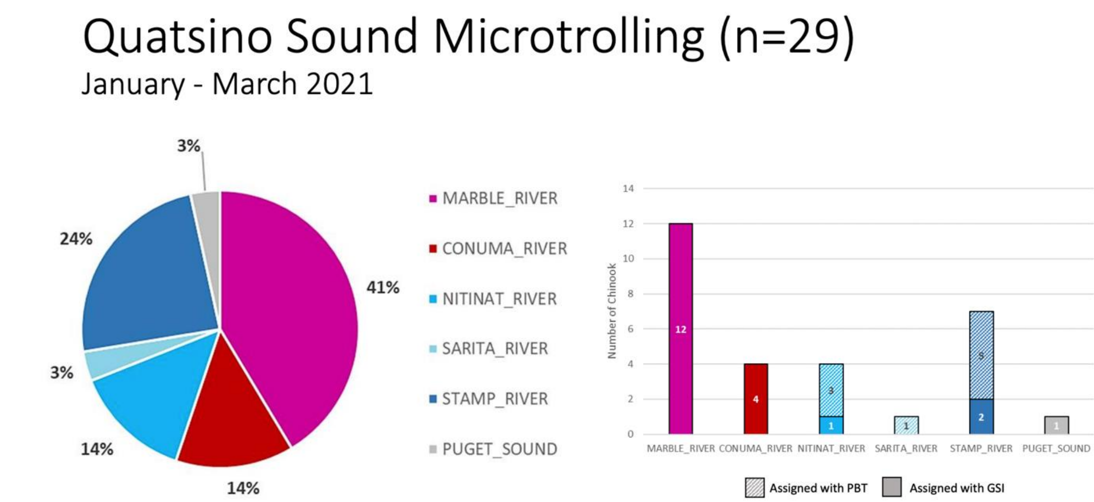


Clayoquot Sound Microtrolling (n=203)

November 2020 - March 2021



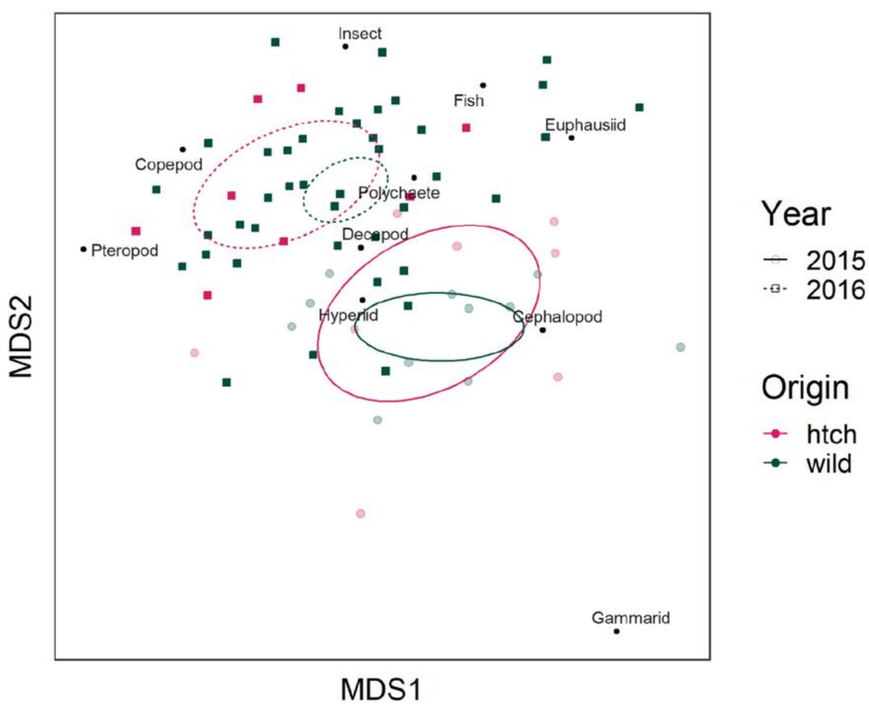




- In summary, she noted that with respect to WCVI Chinook Distribution Hypotheses:
  - Preliminary stock composition results may lend support to the hypothesis that WCVI Juvenile Chinook "sound hop" and stay nearshore during northern migration.
  - Migration may be slow and continuous throughout the winter as shown by interception of Barkley Sound Chinook present in all sounds during all months surveyed.
  - Ongoing microtrolling efforts are occurring from October 2021 through to March 2022.

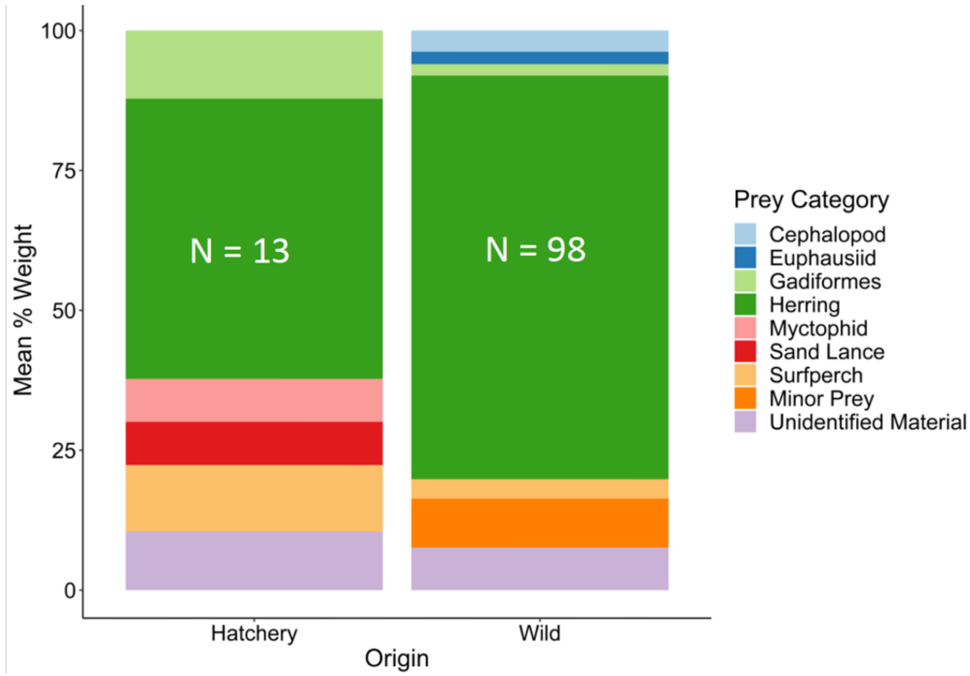
Presentation 14 - Are hatchery and naturally-produced Chinook Salmon competitors and cannibals? Will Duguid, UVic/Pacific Salmon Foundation

- Will's talk centred on the LF relating to "Hatchery production increases *competition* and/or *predation* resulting in reduced growth, survival and/or fitness". However, his data are not for WCVI specifically.
- Hatchery and naturally-produced fish cannot always be easily discerned. For example, both clip status and PBT vs GSI assignments have issues; while otoliths are not aways available to determine thermal mark presence.
- Chittenden et al. 2018 assessed hatchery and naturally-produced Chinook stomach samples from Cowichan and noted that "In this study, the clipped (hatchery) Chinook Salmon smolts were larger than the unclipped smolts, ate a more piscivorous diet, were relatively absent in the estuary, and disappeared from the study site sooner."
- Much of Will's work during the Salish Sea Marine Survival Project focussed on assessing fine scale habitat use of Cowichan River Chinook. He assessed unclipped and clipped Cowichan River origin Chinook 2015-2016, finding that diet differed by year but not by fish origin and that the size of both hatchery and naturally-produced fish was very similar over those two years.



NMDS (stress 0.25) of averaged presence (1) and absence (0) data for randomly selected roups of 9-11 fish with non-empty stomachs. Ellipses indicate 95% confidence of mean ocation.

- Since 2017 the UVic Adult Diet Program has assessed several hundred Chinook and Coho stomachs, including comparisons of naturally-produced and hatchery Adult Cowichan Chinook stomachs. The image below shows the diets for these fish.



- **Conclusions related to competition**
    - Partial to complete diet overlap between hatchery and naturally-produced fish occurs for at least some life stages
    - The importance of competition is likely influenced by the relative size and phenology of hatchery and naturally-produced fish which may vary among systems and years
    - Competition is likely only important when food resources are limiting -and the frequency of this is an outstanding question.
    - (Will's speculation, not conclusion) For Adult WCVI Chinook salmon it is likely that non-WCVI Chinook and other species are more important than WCVI Chinook as competitors
- Are Chinook Adults cannibalizing Juvenile Chinook?
    - Work done by Beauchamp and Duffy (2011) has provided some information of Chinook on Chinook predation, but sampling could be limiting (see figure below). They found that Chinook in second summer (~300 mm) eat small first summer Chinook in July. Based on bioenergetic modelling this could mean a consumption of 6% to 60% of the population. But there are no available data for April/May.

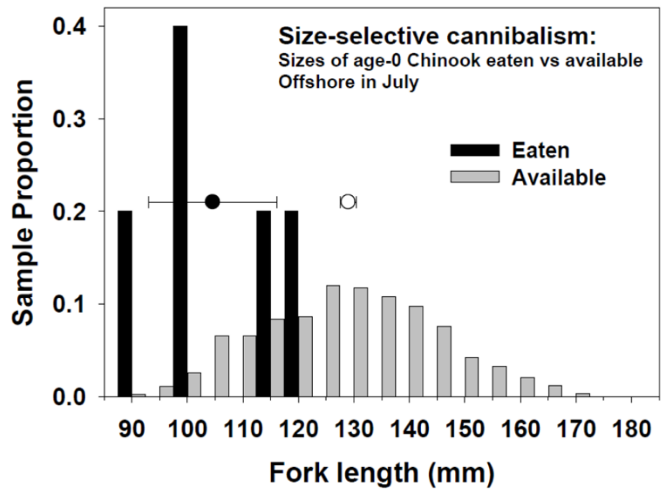


Figure 30. The size of age-0 Chinook salmon found in the stomachs of resident Chinook salmon versus the size distribution sampled offshore in the midwater rope trawl during July 2002, 2004, 2005, and 2009. These were the years when the lengths of identifiable Chinook salmon could be measured from stomach samples of predators taken concurrently with trawl samples. The circles represent the mean size (± 2 SE) of age-0 Chinook eaten (dark circles) versus those available in the trawl sample (open circles).

- Beauchamp et al. revisited this question by microtrolling between May to September in 2018 and 2019 (Report in prep.; see figure below) The found no evidence of predation on Chinook by Chinook and only one case by coho, but a lack of night sampling could introduce bias if crepuscular piscivory is occurring.

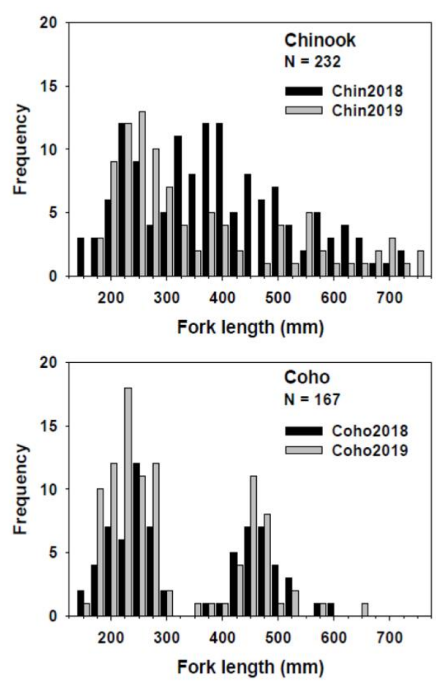


Figure 1. Fork length frequency distributions for Chinook (top panel) and Coho (bottom panel) sampled via microtrolling during May-September 2018 and 2019.

- The UVic Adult salmon diet program has also examined diets of Adult Chinook since 2017, with 3145 Chinook assessed to date showing only 3 individuals

(0.1%) consumed Juvenile salmon, while of 488 Coho, only 27 individuals (5.5%) consumed Juvenile salmon. However, most of the Juvenile salmon were not identified to species, and in total they found only 2 confirmed cases of predation on Chinook salmon.

- **Conclusions related to predation**
    - Adult and subAdult Chinook Salmon do eat first ocean year Chinook Salmon, but likely very rarely.
    - The most likely window of impact is subAdults feeding on first ocean summer fish, we have limited diet data for this period.

Presentation 15 - Four Decades of Raising Chinook Salmon in B.C. – from Hatchery to Ocean, both naturally-produced and farmed, what we've learned on fish health and survivals and how this applies to the management of hatchery enhancement releases alongside naturally-produced populations of Chinooks. Carol Schmitt, Omega Pacific Hatchery Inc.

- Carol Schmitt described the history of raising Chinook salmon at Omega Pacific Hatchery Inc.
- With respect to fish hatchery operations and impacts she noted that differences exist among individual hatchery operations and that hatcheries should be assessed on an individual basis using a rating system to determine their level of risk to naturally-produced fish. She noted that a rating system would allow for better management and minimize effects on naturally-produced fish e.g.
    - Omega Pacific Hatchery - Water Source is fish & Pathogen Free, cold temperatures, Brood stock & smolts disease screened, site 37 years pathogen free, incubators low density – high flow, rearing pools no accumulation on bottom, pools/incubators 100% disinfected, water discharged via exfiltration to gravel ponds (closed system). Rating should be very low
    - Robertson Creek Hatchery **-** Water source Sockeye migration, warm temperatures, since 2014 – 2021. IHN virus has occurred in steelhead and Chinook resulting in terminations, incubators are at high density (Heath), rearing pools accumulation removed after fish released, pools unable to be disinfected, water discharge into Stamp River. During this time frame Nahmint Chinook from another watershed have continued to be brought on site resulting in some terminated due to IHN. Rating should be very high
- Carol described how disease screening of chinook broodstock for Aquaculture and Enhancement since 1985 has resulted in changes in pathogen prevalence, for example:
    - During the 1980's to 2011 Aquaculture companies received Chinook eggs (green) from federal hatcheries and Robertson Creek Hatchery was the main facility to supply eggs
    - The broodstock was screened for viruses and Bacterial Kidney Disease. However BKD prevalence in Robertson Chinook increased from 10% to 60% between 1985 to 2018. Additionally, while IHN virus was previously non-existent, there

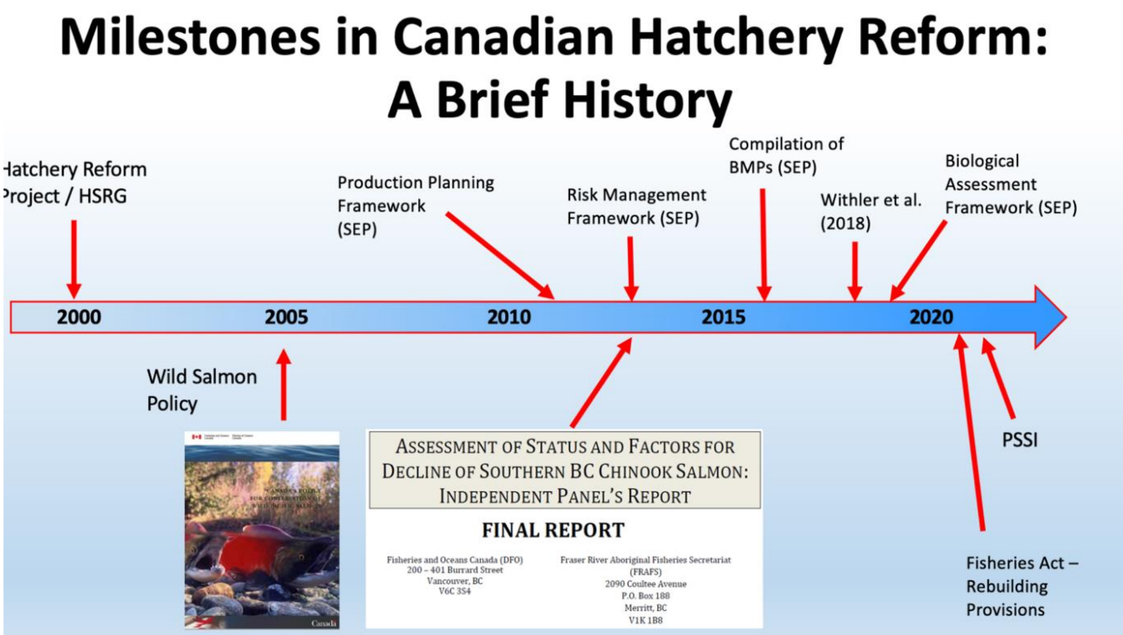
have been more positive tests in Chinook broodstock over time with infections at Robertson Hatchery in Juvenile Chinook and steelhead

- Her observations in the marine environment include:
  - During the 1980-1990's they released S0 smolts into the ocean, which were dip vaccinated for Vibriosis prior to ocean entry
  - All S0 smolt entries had Vibrio outbreaks from July lasting to December
  - After 1990 they released S1 smolts and the CASH Program documents 96% survivals for consecutive entries of Omega's S1 after 24-month ocean rearing with no apparent Vibrio outbreaks
- Given these results, Carol suggests releasing S1 smolts to help rebuild WCVI Chinook. She notes that currently DFO Hatcheries along WCVI release the majority of their Chinook as S0 smolts, but 90% mortality is reported in the first 4 months of ocean entry for S0 smolts. She believes that release of S1 enhancement smolts will increase marine survivals & re-build stocks.
  - S1 were assessed on average to have 10x greater marine survivals –so fewer smolts would be needed
  - S1 smolts migrate earlier & faster rate spending minimal time in the shoreline areas
- She also noted that:
  - Scale reading is an interpretive tool open to errors
  - Naturally-produced Chinook emergent timing is April to May at 0.45 gram so suggests that observations of 2 and 3 gram fry in streams during this time are overwintering S1
  - Hatchery smolts grow at 10x faster growth rate to that of naturally-produced due to high energy diets
  - The upper reaches of all streams on Vancouver Island are made up of S1 chinook smolts
- Key recommendations provided were as follows:
  - Fish hatchery operations are important and can effectively be used, with minimal risk to rebuild WCVI Chinook populations to self-sustaining levels.
  - To achieve this outcome –
    - Individual Hatchery Risk ratings should be established
    - Brood & Juveniles should be tested for IHN virus & BKD
    - Natural S1 smolts in a program such as Omega Hatchery be used to increase escapement to over 1,000 to initiate a stock to become self-sustaining

Presentation 16 - Hatchery reform: Ongoing and future implementation. Michael Thom and David Willis, SEP

- The objective of this presentation was to describe recent implementation of hatchery reform actions in WCVI Chinook hatchery management that is intended to reduce risks to salmon populations

- A timeline of Canadian hatchery reform is provided in the graphic below:



- As discussed by Joe Anderson, US Hatchery Reform rests on 3 main principles:
    - **Principle 1:** Develop clear, specific, quantifiable harvest and conservation goals for natural and hatchery populations within an "All H" context.
    - **Principle 2:** Design and operate hatchery programs in a scientifically defensible manner.
    - **Principle 3:** Monitor, evaluate, and adaptively manage hatchery programs
- Along WCVI, implementation of Principle 3 is ongoing and includes:
    - Increase PNI & maintain/increase genetic diversity
    - Reducing straying & the potential effects from straying
    - Improve survival and reproductive fitness of hatchery Chinook
    - Reduce ecological interactions between hatchery and naturally-produced Chinook
    - Average PNI values for WCVI systems and current trends were provided. The cursory trend analysis looked at the last two decades of available data – unless a clear trend was observable, the default was no trend (-->). Most systems have low PNI numbers.

Population	Average of PNI (Thermal)	Trend (nominal PNI)
Bedwell River	0.79	→
Burman River	0.15	↑
Conuma River	0.02	→
Gold River	0.45	→
Leiner River	0.43	→
Marble River	0.88	→
Nahmint	0.59	↑
Nitinat River	0.10	→
Robertson Cr (Stamp R)	0.06	→
San Juan River	0.58*	→
Sarita River	0.10	→
Tahsis River	0.25	↓

- Averages are taken from available data points between 2015-2020 – most programs had data points for 4+ years
- To increase PNI and maintain/increase genetic diversity, SEP implemented a number of actions including the following:
  - Implementation of the All-H Analyzer (AHA) tool that was developed by the US Hatchery Scientific Review Group
  - Mass marking pilots (Sarita, Burman, Conuma)
  - Adjusted release targets (Burman, Thornton, Gold)
- To address stray rates, SEP is implementing the following:
  - CSAS Science Advisory Report on straying (in development)
  - Mass marking (Conuma)
  - Intensive genetic broodstock screening (Nahmint, Burman)
  - Seapen removal or relocation (Thornton, Conuma, Gold)
  - Cold water attraction flows (Conuma)
- To improve survival and reproductive fitness of hatchery Chinook, SEP is implementing/considering:
  - New hatchery spawning protocols (in development via CSAS)
  - Genomic tools
  - Alternative rearing strategies
  - Nitinat semi-natural fry
  - Thornton hatchery environmental enrichment
  - Robertson Creek time and location of release
  - Nahmint Chinook subyearling/yearling releases
- To reduce ecological interactions between hatchery and naturally-produced Chinook, SEP is considering/implementing:
  - Mass marking & selective removal (Sarita)
  - Seapen rearing (Nitinat, Conuma, Robertson, Burman)
  - “Follow the Fish” studies in the early marine environment

- In conclusion there has been a great deal of new work in recent years aimed at reducing the risk of hatcheries to naturally-produced WCVI Chinook, and many further investments upcoming (particularly with PSSI) that will add more support and work in fish health and hatchery science. With the adaptive management that has been ongoing in recent years, change is apparent, but the magnitude of change and continued risks is still uncertain. SEP believes that hatcheries remain a foundational tool along with habitat and harvest actions to rebuild WCVI Chinook populations, as well as an opportunity to further reduce risks to naturally-produced WCVI Chinook.

Presentation 17 Day 2 - Hatchery Impacts on WCVI Chinook Summary. Jim Irvine, DFO Emeritus

Jim provided an overview presentation summarizing the key points from the talks on Day 1. He noted the following important messages:

- Genetic Impacts
    - WCVI stock status shows declining genetic diversity due to hatchery introgression into naturally-produced spawners - Wilf Luedke
    - Ruth Withler's analyses show that although the high proportion of hatchery spawners in WCVI rivers reduces genetic diversity (especially in NWVI where there are high stray rates), hatcheries still exhibit high levels of genetic diversity, similar to pre-enhancement - Wilf Luedke
    - However, hatchery selective influences dominate over natural selective influences PNI on the WCVI is very low- most rivers have a PNI less than 0.25 – Wilf Luedke
    - The principles of reducing pHOS and increasing pNOB to achieve fitness gains in naturally-produced fish are well founded and should be fundamental goals of any hatchery reform action - Joe Anderson
    - Risk tolerance is basically a policy issues- science is only one source of information, while other factors including economics and social science are also important – Joe Anderson
    - Studies showing demographic benefits or minimal genetic risks have generally been conducted on small-scale hatchery programs – Joe Anderson
    - Through hatchery reform and risk management, genetic risk can be reduced but Adult collection and spawning practices may be exceptions - Dave Willis and Mike Thom
    - Two sources of genetic risk include: 1. straying and 2. hatchery-origin fish spawning in-river. According to a 2014 review of all previous straying studies in the US and BC: Hatchery origin ocean-type stray rate=35%; Hatchery-origin stream-type stray rate= 3%- Jacob Weil
    - Impacts of straying may depend on size of the recipient populations; and hatchery practices such as transplanting and groundwater use increase the potential for returning hatchery Chinook to stray -Jacob Weil

    - The apparent health of Kyoquot Sound populations may simply be a result of straying – Jacob Weil
    - Found declines in age, size and size at age for WCVI hatcheries that are presumably genetically controlled- Andy Rosenberger
  - Ecological Impacts
    - Hatcheries have the potential for large magnitude ecological impacts on natural populations that are not well understood- Joe Anderson
    - SEP manages for impacts of release time and condition on naturally-produced fish, understanding that hatchery Juveniles released prematurely or too large may stay in freshwater longer, resulting in competition or predation impacts on naturally-produced fish - Dave Willis and Mike Thom
    - Competitive Impacts: growth & abundances of various Chinook populations are reduced in years when pink & chum are abundant. Pink and chum enhancement in the North Pacific represent the majority of salmon in the offshore marine area- Jim Irvine and Greg Ruggerone
    - Competitive Impacts: It seems likely that competition with hatchery salmon is an important risk factor during later marine stages for WCVI Chinook- Jim Irvine and Greg Ruggerone
    - Competitive Impacts: Chinook prey availability studies in Barkley and Clayoquot Sound will help answer questions about naturally-produced and hatchery salmon competition in nearshore environments- Ron Tanasichuk
    - Competitive Impacts: partial to complete diet overlap between naturally-produced and hatchery Chinook occurs for at least some life stages. The importance of competition is likely influenced by the relative size and phenology of hatchery and naturally-produced fish which may vary among systems and years. Competition is likely only important when food resources are limiting and the frequency of this is an outstanding question. Duguid suggests that non WCVI Chinook and other species are likely more important than WCVI Chinook as competitors – Will Duguid
    - Predation Impacts: from studies in the Salish Sea (not WCVI) it has been found that Adult and subAdult Chinook salmon do eat first ocean year Chinook salmon, but likely very rarely. The most likely impacts would be subAdults feeding of first ocean summer fish, but we have very limited diet data for this period – Will Duguid
- Pathogens & Disease:
  - Risk posed by pathogen transfer from hatchery to naturally-produced fish- climate change increases risk of transmission and susceptibility, subclinical fish may have poor saltwater tolerance and delayed mortality, but actual transmission risk to naturally-produced fish has not yet been assessed- Kristi Miller-Saunders
  - SEP has a good understanding of current disease risks and a long history of building practices to manage and mitigate these risks. In general hatchery fish

    - tend to be exposed to fewer pathogens during rearing than naturally-produced fish – Corino Salomi & Ian Keith
    - Appropriate risk management of pathogen transfer from hatchery to naturally-produced fish can reduce it to acceptable levels in most cases- Mike Thom and Dave Willis
    - Establishment of individual hatchery risk ratings and testing of brood and Juveniles for IHN and BKD are recommended – Carol Schmitt
- Risk Management:
    - SEP reports to have a good understanding of risks and a long history of building practices to manage and mitigate health risks to naturally-produced salmon- Carino Salomi and Ian Keith
    - Adaptive management has been ongoing at SEP in recent years, and while the direction of change is known, the magnitude is still uncertain - Mike Thom and Dave Willis
    - There has been a major increase in investment in hatchery science and fish health since PSSI - Mike Thom and Dave Willis
    - Hatcheries remain a foundational tool along with habitat and harvest actions to rebuild WCVI Chinook populations, as well as an opportunity to further reduce risks to WCVI Chinook - Mike Thom and Dave Willis

7.6.6 Workshop Synthesis

Scoring Methodology, RAMS and Group Assessment of LFs, and Risk Assessment at SEP

7.6.6.1 Scoring Methodology

- Scoring for each limiting factor was carried out by a facilitated discussion on Day 2 of the workshop. Group consensus scores for exposure (spatial, temporal) and impact of each limiting factor, level of confidence, and current and future trends were placed into an excel spreadsheet, resulting in immediate assessments of current and future biological risk for each limiting factor (for details, see Methods section in main body of report that precedes Appendix 7.1).
- Limiting factors were scored for the entire WCVI and for LFs 23, 24 and 25. For this workshop, naturally occurring WCVI Chinook salmon were assessed during their Juvenile (first summer, fall and winter) and Adult (marine rearing plus return migration) marine life history.

7.6.6.2 RAMS and Group Assessment of LFs

During this workshop, assessment of key risks posed by hatcheries and hatchery fish on naturally occurring WCVI Chinook physiology, survival and fitness during their marine life history was carried out using the RAMS process. Three key risks were considered; genetic, ecological and pathogens/disease. The hypotheses addressed were that hatchery production a) reduces overall genetic diversity and integrity, b) increases competition and/or predation, and/or c) increases disease, pathogen diversity or loads in naturally-produced fish, ultimately resulting in their reduced growth, survival and/or fitness.

There are 60 unique populations on the WCVI, of which 19 are enhanced through 16 hatchery projects (for areas 20-27), of which 12 produce Chinook. The objective of this hatchery production is to make more fish than would otherwise be there in the natural environment, and production objectives for WCVI hatcheries are primarily for Harvest and Rebuilding. The overall abundance of WCVI Chinook is currently dominated by hatchery production and SEP notes that current abundance is likely greater than it was in the past as a benefit of this hatchery production. WCVI hatchery fish show higher smolt to Adult survival than naturally-produced fish (~3% versus 0.5-1%), perhaps because the former are substantially larger in size.

However, it is understood that hatcheries and hatchery fish can pose risks to naturally-produced salmon. The first area of risk assessed was genetic.

LF20: Mortality, growth and/or fitness reduction due to reductions in genetic diversity and integrity or changes in biological characteristics (fecundity, maturation rate, sex ratios, size at age, behaviour, etc.) from hatchery rearing.

Evidence provided showed that WCVI naturally-produced stocks are displaying declining genetic diversity due to hatchery introgression, particularly in NWVI where there are high stray rates); most rivers have a PNI less than 0.25. Recent analysis by the Pacific Salmon Foundation has shown declines in age, size and size at age for WCVI hatchery Chinook may also be an indication of genetic impacts. On the positive side, Withler (2018) showed that within hatcheries themselves, there are still high levels of genetic diversity.

Key sources of genetic risk are straying plus hatchery fish spawning in rivers: data collated from broader regions has shown that ocean type hatchery fish tend to stray at higher rates than stream type hatchery fish (35% versus 3% respectively). However, most hatchery-origin populations on the west coast stray at rates closer to those found in natural-origin fish, and well below the average ocean-type stray rate of 35% found for hatchery-origin fish across studies. WCVI CWT-based stray rates are quite low, between 0 and 2.3%.; while thermal mark data, (which tend to be better indicators of stray rates across populations), show stray rates from around 0.5% at Nitinat River up to 15% in Gold River (which is biased high due to a couple of outlying years with substantial straying into Area 23). The large production hatchery Conuma showed the highest stray rates overall along WCVI.

The impacts of straying appear to depend on the size of the recipient populations; and hatchery practices such as transplanting and groundwater use increase the potential for returning hatchery Chinook to stray. One interesting suggestion was that the apparent resilience of the naturally-produced refuge Kyuquot populations as compared to the declining Clayoquot populations might simply be a result of high stray rates into the former systems.

Key knowledge gaps for genetic risks of hatcheries and hatchery fish include a) the level of genetic changes to natural rearing stocks in WCVI including loss of adaptive traits and incorporation of maladaptive hatchery traits, and genetic homogenization, and b) the impacts of this genetic introgression on fitness and survival. These knowledge gaps resulted in a moderate confidence applied to the risk rating

PNI can be improved if a) the hatchery broodstock takes as few hatchery origin Chinook as possible, and 2) if hatchery origin Chinook are removed as much as possible from the spawning population, and c) hatchery production is properly managed (I.e. as few fish to meet program objectives or goals) Recommendations are for management of pNOB, pHOS, and PNI in general in rivers supplemented with hatchery fish to best maintain natural-origin influence. Pilots are underway along WCVI to address low PNI. Conuma is mass marking hatchery Chinook salmon in several rivers of Nootka Sound, and Huu-ay-aht First Nation has implemented a plan to maintain hatchery production but improve PNI by selective harvest of hatchery marked Chinook in the Sarita.

LF21 Mortality, growth and/or fitness reduction due to inter/intra-specific competition

Hatcheries also have the potential for large ecological impacts on natural populations, and these are not fully understood, nor adequately evaluated or assessed. Partial to complete diet overlap between natural and hatchery Chinook occurs for at least some life stages, suggesting that competitive impacts are possible, but may only occur when food resources are limiting. Despite diet overlaps during early rearing periods in WCVI nearshore regions and Sounds, schools of hatchery and naturally-produced Chinook appear disparate and thus may not interact with one another to any great degree. It is possible that non-WCVI Chinook and other species are likely more important than WCVI Chinook as competitors. However, there is some evidence that competition with hatchery salmon may be an important risk factor during later marine stages for WCVI naturally-produced Chinook: for example, there is evidence for reductions in growth and abundance of various Chinook populations in years when pink and chum are abundant in the North Pacific. Presenters also examined the possibility that large hatchery fish may feed on smaller naturally-produced Chinook. There are no data for WCVI to address this, but studies in the Salish Sea have found that Adult and subAdult Chinook salmon do eat first ocean year Chinook salmon, if only rarely. It is possible that subAdult hatchery fish may feed on first ocean summer fish, but again, this constitutes a data gap.

Overall, LF21 was scored with a low confidence for Juvenile Chinook, given the knowledge gaps which included: extent of overlap of hatchery and naturally-produced fish; lack of knowledge of the extent of density dependent interactions along WCVI, and uncertainty about how predators respond to influxes of hatchery fish into a region and whether negative impacts to naturally-produced fish are one outcome. The highest risk was for competition between young hatchery and naturally-produced fish during early rearing along WCVI as evidence was presented on the similarity of diets between hatchery and naturally-produced fish at this time, and increasing future risks seem likely given the impacts of climate change on the food web, and enhanced competitive pressures possible because of lower prey abundance. Competitive effects later in life, including by pink and chum salmon in the Gulf of Alaska could be significant, although information specific to WCVI Chinook was lacking.

LF22 Mortality, growth and/or fitness reduction due to elevated predation

Impact was two-fold; predation directly from hatchery fish as well as elevated predation on naturally-produced fish due to increased attraction from hatchery fish influx. For sub and full Adults, some areas may be more at risk than others. For example, "Brooks Peninsula or Scott

Islands has a pinch point or bottleneck where there may be increased predation as fish move through both south and north."

LF 23 Mortality, growth and/or fitness reduction due to changes in hatchery disease patterns and/or pathogen transfer

Finally, the workshop examined whether hatcheries and hatchery production could result in an increased source of pathogens, increased pathogen richness, and/or pathogen transfer from hatchery to naturally-produced fish. An examination of pathogen richness in freshwater showed no strong differentiation between fish types but was highly variable among stocks/years. It is possible that the higher survival of WCVI hatchery fish could be associated with a higher infection intensity in naturally-produced fish. Well understood acute pathogens are rarely, if ever, observed in hatcheries, while other agents strongly associated with survival are not well understood in Chinook. However, there are concerns with both IHN and BKD within hatcheries and pathogen transfer from hatchery to naturally-produced fish is feasible. It is also known that subclinical fish may have poor water tolerance and delayed mortality and that impacts (including risk and susceptibility) will likely worsen under climate change. However, the actual transmission risk of pathogens from hatchery to naturally-produced fish has not yet been assessed.

Overall, confidence was low for scoring LF23. There was not enough information available on LF23 Adults to score risk. Attendees urged the need for future work as this is a critical data gap that needs to be looked at.

Risk Management at the Salmonid Enhancement Program (SEP)

SEP has a long history of building practices to manage and mitigate risks. For instance, many pathogens are treatable and preventable during culture using vaccination and other methods of prevention. Additionally, several programs include a marine rearing phase that includes monitoring of pathogens and rarely have these seen outbreaks or other issues related to disease.

The Biological Risk Management Framework (RMF; https://waves-vagues.dfo-mpo.gc.ca/library-bibliotheque/361269.pdf) is designed to inventory and assess risk to naturally-produced salmon from enhancement and, is in part a response to the Canada's Pacific Wild Salmon Policy (https://waves-vagues.dfo-mpo.gc.ca/library-bibliotheque/315577.pdf . Risks are examined for three main categories: genetic, disease and ecological. SEP presenters noted that risk can be substantially mitigated with proper implementation of best practices, modern assessment tools, and hatchery reform principles:

- Along WCVI, SEP has implemented plans to:
  - Increase PNI & maintain/increase genetic diversity
  - Reducing straying & the potential effects from straying
  - Improve survival and reproductive fitness of hatchery Chinook
  - Reduce ecological interactions between hatchery and naturally-produced Chinook
- To increase PNI and maintain/increase genetic diversity, SEP implemented several actions including the following:

- Implementation of the All-H Analyzer (AHA) tool that was developed by the US Hatchery Scientific Review Group
- Mass marking pilots (Sarita, Burman, Conuma)
- Adjusted release targets (Burman, Thornton, Gold)

- To address stray rates, SEP is implementing the following:
  - CSAS Science Advisory Report on straying (in development)
  - Mass marking (Conuma)
  - Intensive genetic broodstock screening (Nahmint, Burman)
  - Seapen removal or relocation (Thornton, Conuma, Gold)
  - Cold water attraction flows (Conuma)
- To improve survival and reproductive fitness of hatchery Chinook, SEP is implementing/ considering:
  - New hatchery spawning protocols (in development via CSAS)
  - Genomic tools
  - Alternative rearing strategies
  - Nitinat semi-natural fry
  - Thornton hatchery environmental enrichment
  - Robertson Creek time and location of release
  - Nahmint Chinook subyearling/yearling releases
- To reduce ecological interactions between hatchery and naturally-produced Chinook, SEP is considering/implementing:
  - Mass marking & selective removal (Sarita)
  - Seapen rearing (Nitinat, Conuma, Robertson, Burman)
  - "Follow the Fish" studies in the early marine environment

7.6.6.3 Risk Ranking

To rank the relative risk of different LF's, results for all LFs were sorted first by Current Risk Review Result, and then by Future Risk Group Result (Table 7.15).

Table 7.15 . Ranked (very high to very low) current and future risk rankings for limiting factors (LFs) considered during Workshop 6. Current risk is based on x, y coordinates of impact, likelihood while future risk is based on x, y coordinates of current risk, future trend, each determined using risk matrices described in the Methods section of the main report. LF23 Adults were not scored

Limiting Factor	Life Stage	Likeli-hood Score	Impact Score	Future Trend Score	Reviewed Confidence	Review Result Current Risk	Review Result Future Risk
LF20 Loss of genetic or demographic diversity	All	5	4	3	Mod	Very High	Very High
LF21 intra/inter specific competition	Juvenile	4	4	5	Low	High	Very High
LF22 predation	Adult	4	3	3	Low	High	High
LF21 intra/inter specific competition	Adult	3	3	3	Mod	Mod	Mod
LF22 predation	Juvenile	4	2	3	Mod	Mod	Mod

LF23 disease or pathogens from hatchery	Juvenile	4	2	3	Low	Mod	Mod

Facilitated discussions resulted in consensus that there is a very high risk of hatchery rearing on growth, survival and fitness of wild WCVI Chinook due to impacts on genetic diversity and integrity and/or biological characteristics, both now and in the future (i.e., LF20, Table 7.15). Research findings from Ruth Withler, described at the workshop, have shown that WCVI stocks are displaying declining genetic diversity due to hatchery introgression into wild stocks (particularly in NWVI where there are high stray rates), and most rivers have a low PNI (Proportionate Natural Influence).

Hatcheries also have the potential for large magnitude ecological impacts on wild salmon populations, and these are not fully understood, nor adequately evaluated or assessed. Partial to complete diet overlap between naturally-produced and hatchery-origin Chinook occurs for at least some life stages, suggesting that competitive impacts are possible. Impacts of inter/intraspecific competition from hatchery fish was scored by consensus as a high risk that could result in reduced growth, fitness and/or survival of naturally occurring WCVI Chinook during early rearing in WCVI nearshore regions and Sounds (i.e., LF21 Juvenile, Table 7.15), and evidence was presented by Ron Tanasichuk on the similarity of diets between hatchery and naturally-produced fish during this period. Future risk was scored as very high because of climate change impacts on the food web and possible enhanced competitive pressures due to lower prey abundance. Competitive effects later in life, including potentially significant effects by pink and chum salmon in the Gulf of Alaska as described by Irvine, were only moderate overall (LF21 Adult), due to agreement that competition during the homeward migration would be minor. Numerous data gaps were identified related to impacts of competition on later life stages.

Interestingly, the effect of predation on Adult Chinook (LF22 Adult) was scored high with low confidence while the effect and confidence for Juveniles (LF22 Juvenile) was moderate. The former is puzzling and may be an error. Discussion notes included the comment that “Brooks Peninsula or Scott Islands has a pinch point or bottleneck where there may be increased predation as fish move through both south and north”. Perhaps the committee was rushed and was thinking of predation from marine mammals?

Miller-Saunders concluded that while climate change increases risk of transmission and susceptibility of pathogens and disease, actual transmission risk from hatchery salmon to naturally-produced Chinook have not yet been assessed. Risk was assessed as moderate with low confidence for young Chinook (i.e., LF23 Juveniles) and there was no ability to rate risk for Adults (Table 7.15).

There has been much new work in recent years aimed at reducing the risk of hatcheries to naturally-produced WCVI Chinook, and many further investments upcoming (particularly with PSSI) that will add more support and work in fish health and hatchery science. With the adaptive management that has been ongoing in recent years, change is apparent, but the magnitude of change and continued risks is still uncertain, particularly with the ongoing and increasing impacts of climate change.

Many risks remain as knowledge gaps and the need for continued and improved monitoring, open data, PNI management, assessment of interactions between naturally-produced and hatchery fish throughout their life cycle, as well as evaluation of potential for pathogen transfer between naturally-produced and hatchery fish were highlighted as key data needs and current knowledge gaps. Ultimately, given the potential for severe genetic and ecological risks of hatcheries, addressing these knowledge gaps is highly recommended.

7.6.7 Key Literature[6]

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[6] References cited list was formatted and organized using ChatGPT (OpenAI, 2023).

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7.6.8 Participants' Names and Affiliations

There were 85 participants on Day 1 of the workshop (presentations), and 76 on Day 2 (scoring). The participants were from diverse backgrounds, with attendees from DFO Science, DFO-SEP, academia (e.g., University of Victoria), non-profits, community/science organizations and consulting firms (e.g., Pacific Salmon Foundation, Redd Fish, LGL, Coastland Research, Mainstream Biological, Kintama Research), WCVI Roundtables, West Coast Aquatic, First Nations (Ahousaht fisheries, Ha-oom, NTC). The full list of participants is provided below.

Name (Original Name)	Affiliation
Aaron Greenberg	UBC
Alyssa Nonis	DFO
Andrew	Unknown
Andrew Bateman	PSF
Andrew Munro	ADFG
Andy Rosenberger	Independent
Angus	Unknown
Ayumi Nakamura	Ahousaht
Barb Cannon	Creative Salmon
Bob Bocking	LGL
Bob Cole	Recreational fisher
Brad Beaith	DFO
Brendan Zoehner	DFO
Brock Ramshaw	DFO
Byron Charlie	Ahousaht
Cameron Freshwater	DFO
Candace Picco	Ha'oom
Carol Cross	DFO
Carol Schmitt	Independent
Carolyn Churchland	DFO
Chantal Nessman	DFO
Chris Burns	LGL
Christian Carson	Redd Fish
Colton Van Der Minne	Ha'oom
Corino Salomi	DFO
Curtis Curkan	DFO
Dave Burt	Independent
Ed Walls	DFO
Erin Rechisky	DFO
Esther Guimond	DFO
Gary Marty	BC
Gemma MacFarlane	Ahousaht
Genyffer Troina	UBC
Gideon Mordecai	UBC
Howard Stiff	DFO
Ian Keith	DFO
Jacob Weil	DFO
Jason Mahoney	DFO
JB	Unknown
Jess Edwards	Ha'oom
Jessica Hutchinson	Redd Fish
Jessy Bokvist	DFO
Jim Irvine	DFO
Joe Anderson	NOAA
John Candy	DFO
John Holmes	DFO
John Nelson	DFO
JSZCZOT	Unknown
Julian Grant	Tla-o-qui-aht
Kaylyn Kwasnecha	Redd Fish
KeithI	Unknown
Kristi Miller-Saunders	DFO
Lance Stewardson	Independent
Leah Sneddon	DFO
Levana Mastrangelo	Cermaq

Lian Kwong	DFO
Luke Swan	Ahousaht
Mack Bartlett	Cedar Coast Field Station
Mairin Deith	UBC
Michael Thom	DFO
Moira	Unknown
Monique Gillette	Ka:'yu:'k't'h'/Che:k'tles7et'h'
Paige Ackerman	DFO
Patricia Woodruff	LGL
Paul Welch	DFO
Peter McKenzie	Cermaq
Phil Edgell	Alberni Valley Enhancement Society
Pieter Van Will	DFO
Rob Brouwer	DFO
Roberto	Unknown
Ron Tanasichuk	Independent
Sabrina Crowley	Uu-a-thluk
Steve Emmonds	DFO
Suzanne Earle	DFO
Tim Hawkins	West Coast Aquatic
Tim Rundle	Creative Salmon
Tom Balfour	Clayoquot
Wendell Challenger	LGL
Wilf Luedke	DFO
Will Duguid	UVic

7.7 Workshop 7 – Harvest

September 27, 2022

7.7.1 Background

Seventh and final in the series of virtual workshops held during 2022 to 1) create understanding of existing knowledge on WCVI Chinook salmon, 2) investigate factors limiting their survival and productivity during their marine life stages, and 3) identify knowledge gaps.

7.7.2 Objective(s)

To assess and rank the potential effects of limiting factors (LFs; Table 7.16) related to marine harvest on naturally-occurring WCVI Chinook salmon.

Table 7.16 Limiting Factors (LFs) Assessed During Workshop 7.

LF	Category	Limiting Factor Description/Hypothesis
24	Harvest	Overfishing results in decline in population abundance or genetic diversity, within regulated fisheries.
25	Harvest	Overfishing results in population declines, mortality, or fitness reduction due to fishing outside of the regulations; I.e. under-reported, unreported, and illegal catch of WCVI Chinook.
26	Harvest	Changes to population demographics result in fitness reduction due to fishery selectivity-leading to changes in biological characteristics such as fecundity, maturation rate, sex ratios, and size at age.

7.7.3 Summary of Results

Pertinent background to this risk assessment workshop includes presentations summarized in Section 5 and the review provided in Section 6 that we summarize here. WCVI Chinook are far north migrating (occasionally as far as the Bering Sea but primarily in Southeast Alaskan and northern BC waters) where they rear for 1-7 years. Most will go to sea during their first year of life then mature and return to the WCVI at ages 2 (~2-3%), 3 (~20%), 4 (>50%), and 5 (~20%), although a few natural populations have small proportions maturing at ages 6 or 7. WCVI Chinook are therefore vulnerable to marine fisheries during most of their life, with many recruiting to fisheries beginning at age 3. Their 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. Female WCVI Chinook tend to mature later than males. About 85% of mature age 5+ WCVI Chinook are female compared to about 10% of mature age 3 fish.

The average annual calendar year fishery exploitation rate (CYER), including release mortality (from capture-related injuries), is about 35%. Because older fish are exposed to more fisheries over their lifetime than younger fish, and some fisheries may target larger and older fish, recent exploitation rates on large old fish have approached 50%. Removing large, predominantly female salmon is problematic in several ways—big females tend to produce more eggs and dig deep redds (nests) that provide good protection from bed scour in the rivers, a key risk factor identified in the freshwater risk assessments.

Based on the available information and knowledge of the workshop participants, the risk posed by the limiting factors in Table 7.16 was assessed (Table 7.17).

Table 7.17 **Ranked (very high to low) current and future risk rankings for harvest limiting factors (LFs) considered during Workshop 2 (see Section 6 for details) during life stage LS3= immature rearing fish in northern BC and Alaskan waters, and LS4=mature Adults migrating back to rivers of origin along the WCVI.**

Limiting Factor	Life Stage	Reviewed Confidence	Review Result Current Risk	Review Result Future Risk
LF26 Changes in demographics due to fishing	LS4	Mod	High	Very High
LF24 Overfishing	LS4	High	Mod	Mod
LF24 Overfishing	LS3	High	Low	Low
LF25 Illegal fishing	LS3	Low	Low	Low
LF25 Illegal fishing	LS4	Mod	Low	Low
LF26 Changes in demographics due to fishing	LS3	Mod	Low	Low

Fisheries-related demographic changes caused by size-selectivity in fisheries targeting mature returning Chinook (LS4) were the highest ranked risk; High during the current period, increasing to Very High in the future (Table 7.17). Demographic changes included reduced sizes and proportions of female spawners as well as their fecundity, egg size, and redd depth. In contrast, demographic changes affecting immature (LS3) fish were Low; fisheries generally do not target immature Chinook.

LF24 Overfishing in 'regulated' fisheries on mature returning Chinook was the 2nd highest risk factor (Moderate during the current and future). Although the 35% average CYER suggests that the stock is fished at a sustainable level, large and old and predominantly female salmon are harvested at high rates. WCVI Chinook fishery management includes Pacific Salmon Treaty (PST) and domestic considerations. Harvest levels were reduced by about 50% following the inception of Treaty in 1985. Actions to further reduce CYER are limited since much of the catch is taken in Alaskan waters. Additional restrictions taken in Canadian northern troll fisheries reduced catch levels below allowable levels as specified in the PST. Similar actions to reduce fishery impacts continue to be implemented along the WCVI with closures adjacent to river mouths and along the migration path as required.

The PST-defined allowable catch is based on the aggregate of hatchery and naturally-produced salmon; which can result in over-fishing on low productivity natural stocks such as occur in Clayoquot Sound. A higher risk ranking may be warranted in these specific cases. Participants agreed that efforts should be made to have the PST determine allowable catches based on numbers of non-hatchery salmon.

In contrast, workshop participants rated overfishing of immature and generally smaller WCVI Chinook as a Low Risk (LF24, LS3). CYER on ages 2, 3, and, in some years, age 4 are lower than the overall average.

LF25 Illegal or unsanctioned fishing on immature WCVI Chinook (LS3) was also Low risk, with the proviso that little is known about impacts of non-salmon fisheries such as high seas trawl fisheries targeting Pollock and Hake, among other species. Similarly, workshop participants indicated a need for better information regarding CYER impacts from non-PST Alaskan fisheries. With warming oceans, there is likely to be an increased prevalence of WCVI Chinook farther west along the Aleutian Islands and into the Bering Sea seeking cooler waters and more abundant prey. Workshop participants identified this as an important knowledge gap; more work was suggested on monitoring impacts in these fisheries, and that the PST should be acknowledging catch of Canadian Chinook in all Alaskan fisheries, not just those directly targeting salmon.

Most participants thought LF25 Illegal or unsanctioned fishing on mature Adults (LS4) was a low risk; although some participants provided knowledge at the local population / river level where these fisheries likely play a major role in stock decline. It was difficult to substantiate or quantify the level of impact suggested by these illegal or unsanctioned fishing activities.

7.7.4 Agenda

Time	**Agenda Item / Description**
8:45 am	Meeting Room open
9:00 am	Update on rebuilding plan progress and process. - Marc LaBrie (West Coast Aquatic)
9:15 am	Workshop objectives and review of limiting factors related to harvest (see Appendix 7.1 for details) - Marc LaBrie (WCA)
9:30 am	Risk assessment methodology overview, agenda review – Tim Hawkins (WCA)
9:45 am	Life History and background of WCVI Chinook - Biological context for harvest discussion. - - Wilf Luedke (Department of Fisheries and Oceans)
10:15 am	Fishery Management framework applied to WCVI Chinook High level goals of Chinook Rebuilding (WSP) Review of PST AABM and ISBM management regime Changes in allocation over time -- Wilf Luedke (DFO) Local Management in river / terminal fisheries - Kaden Snook
10:35 am	Break
10:50 am	Introduction/Overview of fishery assessment methods, management cycle and data inputs into annual planning, Key metrics such as escapement goals, ER limits, TAC in AABM. Current knowledge of fishery impacts affecting abundance – Pre-Amble to ranking LF 24 Wilf Luedke (DFO)
12:15 pm	Lunch
1:00 pm	Ranking Limiting Factor 24 - Mortality or fitness reduction due to overfishing within regulatory framework. (PST) Nick Brown (DFO)
1:30 pm	Review: Fisheries outside current management regime / regulatory framework (fisheries not regulated for WCVI Chinook). Ranking of Limiting Factor 25 - Mortality or fitness reduction due to overfishing outside PST framework, example of the Pollock Fishery in Alaska. - Jim Irvine (DFO)

2:00 pm Fisheries Impacts to Population Demographics and Ranking Limiting Factor 26 Nick Brown (DFO)

3:00 pm Break

3:15 pm Can We Improve Exploitation Rate Estimates and management – Discussion on Current and Future Tools and Trends.

3:45 pm Wrap-up Summary

4:00 pm Adjourn

7.7.5 Presentation and Discussion Highlights

Life history overview relevant to fishery exploitation—Wilf Luedke (DFO)

- WCVI Chinook originate from 60+ rivers, 3 Conservation Units, 1 stock management unit (SMU) along the WCVI.
- The total annual abundance (catch plus escapement) of WCVI Chinook is about 280,000. Most (80+%) of this total abundance is hatchery origin; returns to 3 major hatcheries including Robertson Creek Hatchery, Conuma Hatchery, Nitinat Hatchery as well as smaller hatcheries distributed along the coast. This stock abundance results in WCVI Chinook being a significant contributor to fisheries in Southeast Alaska, northern BC, and the WCVI.
- The status of WCVI Chinook is poor based on:
    - Low levels of spawners in many systems, especially in Clayoquot Sound.
    - Low genetic diversity. High hatchery levels in many systems, often over 80-90% hatchery origin resulting in a low Proportion Natural Influence (PNI) in many watersheds.
    - Low marine survival of naturally produced smolts (whether hatchery or wild spawners) relative to hatchery produced smolts.
    - Low freshwater survival of eggs and fry from natural spawners; there is a high level of habitat degradation amplified by effects of climate change.

Life History relevant to fisheries. See previous workshops for additional details.

- WCVI Chinook rear in waters off northern BC and Alaska– and so are called "far north migrants". In northern areas both rearing and mature WCVI Chinook beginning at age 2, then age 3, 4, 5 are fully vulnerable to fishing. Older age classes of mature WCVI Chinook have a higher proportion females compare to younger mature migrants (75% in age 5 but less than 10% in age 3 mature migrants). Older females have a higher fecundity compared to younger females.

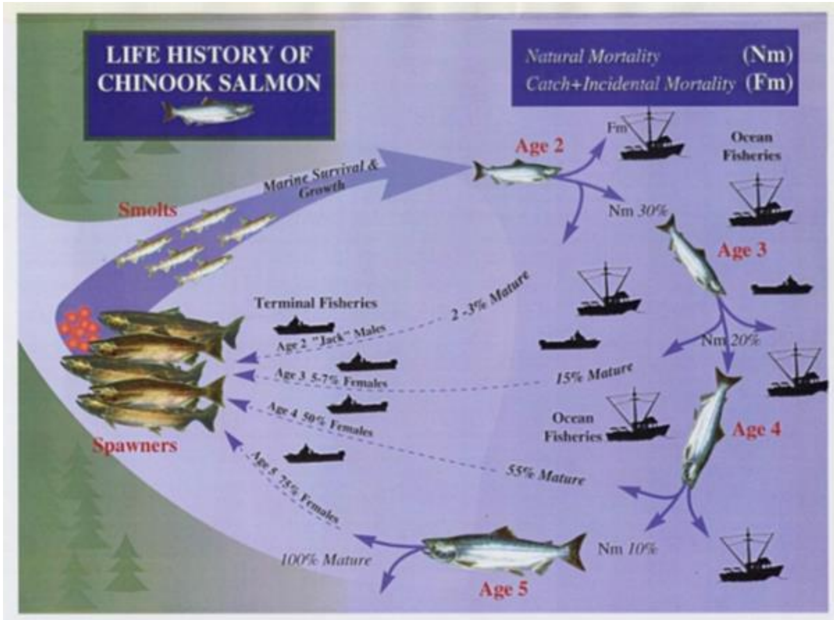

Figure 7.61 **Life history of WCVI Chinook salmon.**

- The return timing of maturing individuals from northern Pacific has a duration of about 4-5 weeks for 90% of the abundance. NWVI Chinook have an earlier timing compared to SWVI Chinook; the 50% date for NWVI is late July and late August for SWVI, based on Conuma Hatchery and Robertson Creek Hatchery CWT recoveries to Area 25 (1985-2015, see Figure 7.62). For Robertson Creek Hatchery / Stamp River Chinook the peak into the terminal area is late August (or about 1-2 weeks after Area 25 in the Figure 7.62).

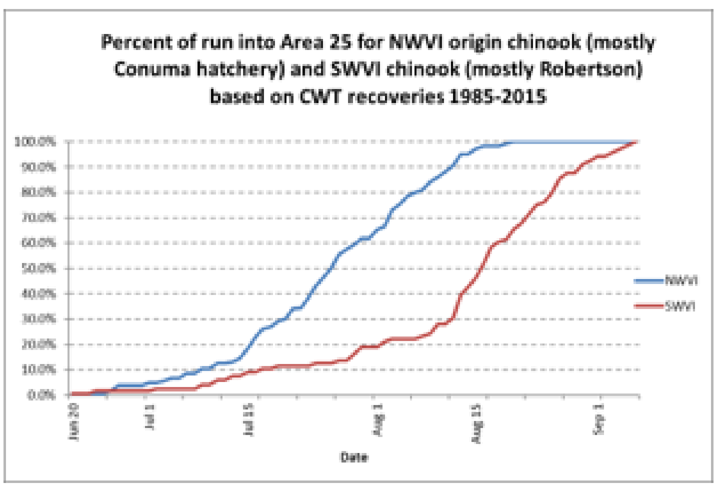

Figure 7.62 **Cumulative distribution of migration of NWVI Chinook and SWVI Chinook to the WCVI; showing the difference of 3-4 weeks between the 50% mark for these stock aggregates.**

Fishery management framework for WCVI Chinook—Wilf Luedke (DFO)

- WCVI Chinook are far north migrating, rearing in portions of the Gulf of Alaska, and so subject to harvest in Alaskan waters.

- Management therefore falls within the jurisdiction of the Pacific Salmon Commission. The management framework for coastwide Chinook is outlined in the Pacific Salmon Treaty (PST) Chinook Chapter. It includes aggregate abundance-based management (AABM) in 3 key fishing areas of Southeast Alaska, northern BC, and WCVI 'offshore' fisheries. The aggregate abundance (which defines the total allowable catch) includes all hatchery and wild Chinook stocks from Oregon to Southeast Alaska. As Chinook migrate from AABM fishing areas toward rivers of origin, management is based on Individual Stock Based Management (ISBM), where fishery impacts are managed to reduce impacts by agreed amounts by stock unit. (for a technical rationale of AABM see PSC Chinook Technical Report TCCHINOOK (11)-1, for ISBM management TCCHINIOOK (11)-4, and for annual reporting refer to annual exploitation rate analyses TCCHINOOK (23)-01. These reports are all available through the PSC.org website under Publications/Technical Committee Reports/Chinook https://www.psc.org/publications/technical-reports/technical-committee-reports/chinook/).
- Domestic management: Canada's Fisheries Management Regulatory framework is defined by legislation such as Canada's Fisheries Act, Species at Risk Act, Oceans Act. Within the Fisheries Act, the fish stock provisions outline a precautionary approach (PA) for each Stock Management Unit (SMU), see Figure 7.63. The PA has 3 zones (critical, cautious, and healthy), identified by lower and upper reference points, and harvest control rules. This PA is not yet defined for the WCVI SMU. The Species At Risk Act may also regulate fisheries, although no salmon species has yet to be listed.
    - Domestic management also includes policy considerations such as allocation, fishing practices, and other policy considerations. Specific domestic constraints within Canadian fisheries targeting WCVI Chinook have been outlined annually in the southern and northern BC Salmon IFMP. Since the collapse of WCVI Chinook in the 1990s, fishery impacts in key Canadian fisheries where WCVI Chinook are prevalent have a 10% annual exploitation rate limit. This includes Northern AABM troll and sport fisheries, and offshore WCVI AABM troll and WCVI sport fisheries. The focus of these restrictions has been the returns to Clayoquot Sound.
- The WCVI fisheries are concentrated in the approaches to the 3 major hatcheries, including Nootka Sound for Conuma Hatchery production, Barkley Sound and Alberni Inlet for Robertson Creek Hatchery production, and Nitinat gap and Lake for Nitinat Hatchery production. These areas have local management plans, developed at local round tables, provide a comprehensive abundance-based management approach, with egg targets by river.

Figure 7.63 **DFO Precautionary Approach framework , where 1=Lower Reference Point, 2= Target reference point, 3= removal rate in the healthy zone. The components of this decision framework include reference points and stock status zones as shown in the graph, harvest decision rules, and accounting for uncertainty and risk.**

Terminal and pre-terminal exploitation on WCVI Chinook in PST-regulated fisheries—Wilf Luedke and Nick Brown (DFO)

- The annual exploitation rate (ER) is generally defined as catch divided by catch plus escapement. Catch is based on the kept catch plus release mortalities during the period from October 1 to September 30. The Pacific Salmon Commission Chinook Technical Committee defines this as catch year exploitation rate (CYER).
- The recent 10-year average CYER for Robertson Creek Hatchery, based on CWT recoveries, is approximately 35%, not including catch in actively managed terminal fisheries in Barkley Sound and Alberni Inlet (dashed line in the following graph). This exploitation rate is believed to representative of Clayoquot Sound Chinook (TCChinook 22-03 at https://www.psc.org/publications/technical-reports/technical-committee-reports/chinook/). Note the reduction in CYER through time.
- Approximately 50% of the marine catch is in southeast Alaska (SEAK; blue area in following chart) with the other 50% in non-terminal Canadian troll, sport, and First Nation fisheries from northern BC to Barkley Sound (orange in the following chart). This means the CYER in BC non-terminal fisheries is averaging about 17% per year. This does not include actively managed commercial, sport, and First Nations ‘terminal’ fisheries in Barkley Sound and Alberni Inlet (shown in green in the following Figure 7.64).

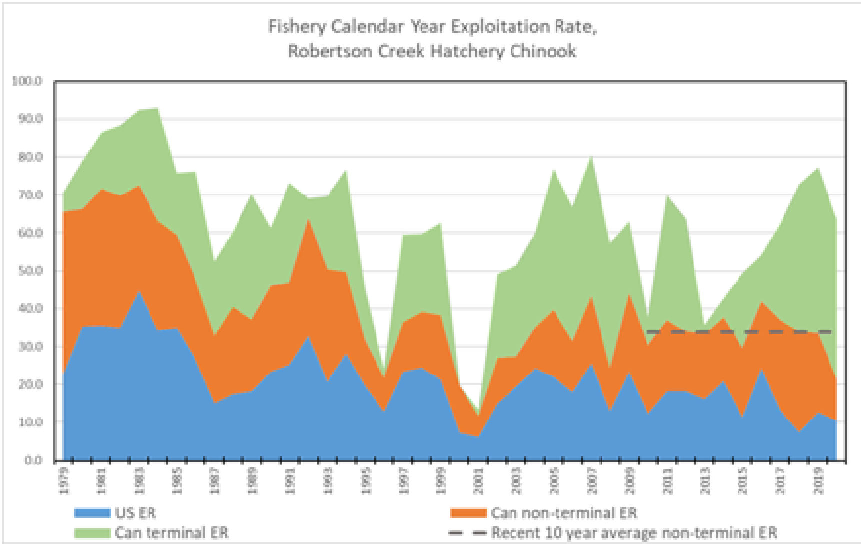

Figure 7.64 **Annual total mortality rate (including reported catch plus incidental fishing mortality) of Robertson Creek hatchery Chinook CWT. The green component is actively managed terminal exploitation, which does not affect nearby stocks such as Clayoquot Sound.**

- The sustainability of a fishery can be assessed based on a KOBE plot (see https://issuu.com/wpcouncil/docs/what_is_a_kobe_plot) using the ratio of current exploitation rate relative to the exploitation rate at Maximum Sustainable Yield (MSY) and the current spawner biomass relative to the spawner biomass to achieve MSY. For this assessment, we assumed a 50% decline in productivity from the habitat-based estimates derived using the methodology of Parken et al. 2006. The following KOBE plot shows how management of the fishery appears to be in the 'sustainable' zone in many recent years.

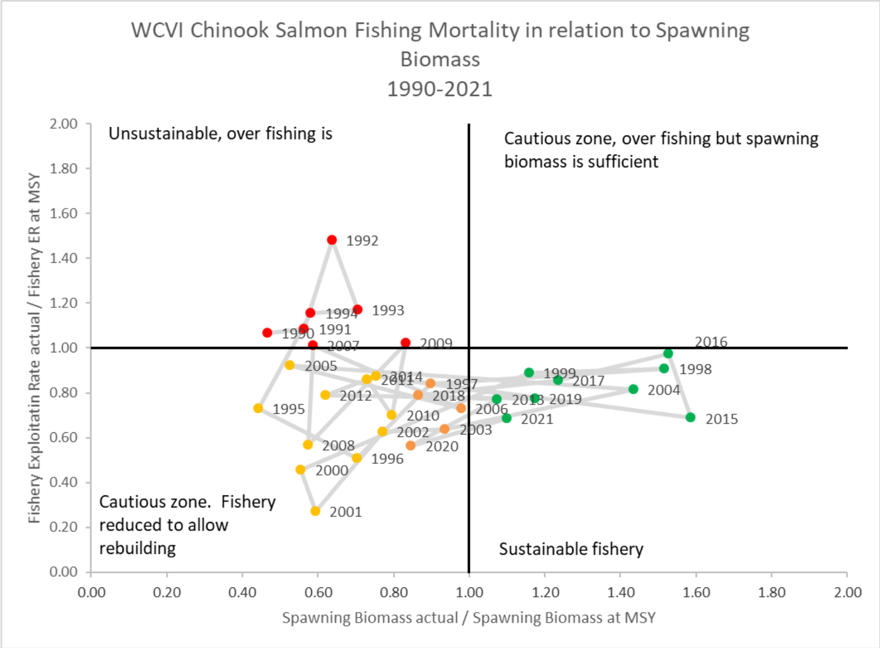

Figure 7.65 **KOBE plot for WCVI Chinook salmon from 1990 through 2021.**

- While the average exploitation rate is near 35%, the rate is not equal between age classes. Older age 4-5 fish have a higher exploitation compared to younger age 2-3 fish. Age 5 Chinook, which are mostly mature, egg-bearing females, are exploited at over 40% (range 38-80% in last 10 years), age 4 at about 30% (range 19-45% in the last 10 years), age 3 at about 10% (range 3-13% over last 10 years).

  There is no clear evidence whether this difference by age is a result of the fishery management regime (e.g. individual quota fisheries such as northern troll, or minimum vs maximum size limits in recreational fisheries), fisher behaviour (e.g. employing gear that selects for larger fish), or age-specific vulnerability (e.g. swimming speeds, vision, average swimming depth).

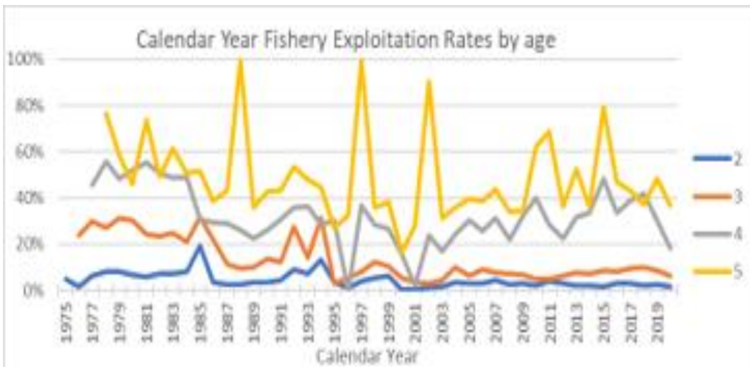

Figure 7.66 **Annual catch year exploitation rate by age for WCVI Chinook salmon, as determined by the Pacific Salmon Commission Chinook Technical committee, based Coded-Wire-Tag recoveries in total mortalities in catch plus escapement.**

Fisheries not included in the overall ER: preliminary results from Alaskan pollock fisheries—Jim Irvine (DFO)

- Chinook retained in bycatch fisheries, even those that are regulated but just outside the PST, are not included in exploitation rate estimates quoted here. WCVI Chinook have been caught in the Bering Sea although numbers are low.
- Random Chinook samples taken from catch in Alaskan walleye pollock trawl fisheries. Genotyped against SNP baseline developed by Alaskan Department of Fish & Game.
- WCVI Chinook may comprise up to 25% of salmon bycatch in Alaskan Pollock trawl fisheries in some years. This would correspond to approximately 2400 WCVI Chinook in 2020.

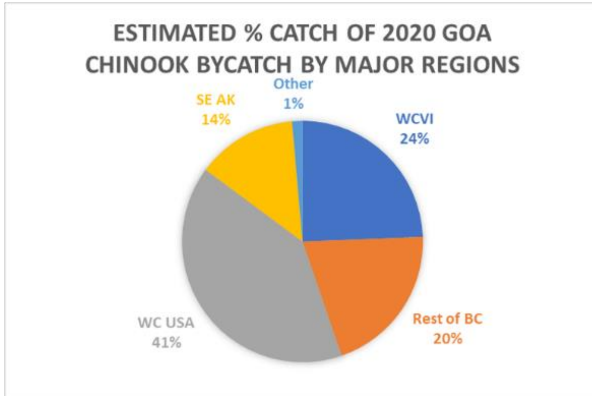

Figure 7.67 **Estimated percent stock composition of the Chinook bycatch in non-salmon trawl fisheries in the Gulf of Alaska in 2020 (results courtesy of Pat Barry, Chuck Guthrie & Wes Larson, NOAA Alaska Fisheries Science Center).**

To evaluate whether the current CTC approach to estimate exploitation for WCVI Chinook results in significant underestimates would require:

- Repeating these types of analyses for multiple fisheries and years
- Collaborating with American researchers to ensure adequate baselines (Canadian and US populations) are used

Brief synopsis of available information on WCVI Chinook demographics over recent decades—Nick Brown (DFO)

- Fisheries selectivity can affect the demographics of a stock. Here we review some specific demographics and observable changes in Robertson Creek Hatchery Chinook.
    - Maturation rates appear to be increasing in age 3 & 4 Chinook based on the PSC cohort analysis. This means fewer fish are returning as older spawners.
    - Apparent decline in size-at-age among 4- and 5-year-old Stamp River Chinook. This means the older spawners are declining in size.
    - Fecundities in Robertson Creek Hatchery Chinook appear to have declined by 6-20% from 1980s. This means fewer eggs from those spawning females. Note this decline is based on few samples with a big gap in sampling between the early 1990s and 2022. This is an identified knowledge gap requiring more intensive study on fecundities in Chinook. This change can affect spawner benchmarks and hatchery brood stock targets in future fishery planning.

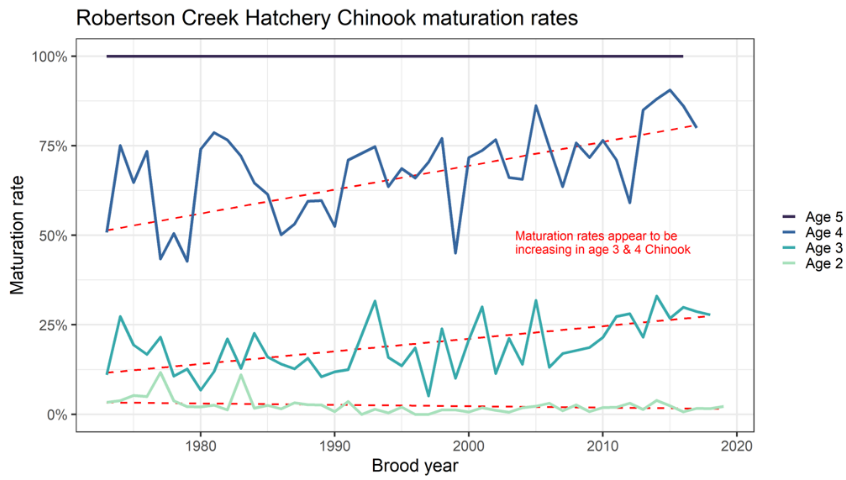

Figure 7.68 **Increasing trends in maturation rates of ages 3 and 4 Robertson Creek** Hatchery Chinook salmon.

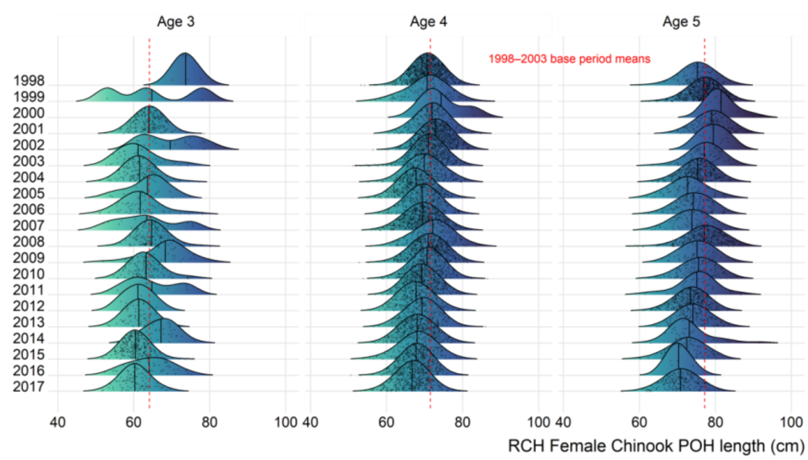

Figure 7.69 **Annual distribution and mean length of Chinook salmon returning to Robertson Creek hatchery between 1998 and 2017 showing that female age 5 fish have the highest decline in size, of nearly 10cm over the period shown.**

7.7.6 Workshop Synthesis

The workshop covered three distinct limiting factors associated with human harvest on WCVI Chinook during Life Stage (LS) 3 (marine rearing of ages 2-4+ north of Vancouver Island ending when fish begin their homeward migration, and LS4 (Adult fish migrating back to the WCVI and into estuaries).

- Limiting Factor 24—This limiting factor is defined as: overfishing results in a reduction of spawner abundance due to harvest in regulated and directed fisheries.
- Limiting Factor 25: reduction of spawner abundance due to unreported or unsanctioned harvest, non-salmon fisheries with poor understanding of by-catch impacts, and salmon fisheries outside the prevue of the Pacific Salmon Treaty.
- Limiting Factor 26: reduction in egg deposition due to demographic changes in body size and age at maturity driven by selective harvest of older, larger salmon.

Beginning at the end of age 2, WCVI Chinook salmon are subjected to directed harvest through a gauntlet of salmon fisheries spanning their entire marine migration pathway from their rearing in the ocean off northern BC and Alaska, to their natal watersheds on Vancouver Island.

Most of these fisheries are regulated under the Pacific Salmon Treaty, which stipulates Total Allowable Catch in Aggregate Abundance Based areas and exploitation rate reductions in remaining Individual Stock Based Management areas. The PST is adjusted about every 10 years. Chinook fisheries are also regulated to meet domestic Canadian legislation and policy (e.g., Fish Stock Provisions, Species at Risk, allocation policy, Wild Salmon Policy, etc.).

Exploitation rates are estimated for regulated, salmon-directed fisheries from southeast Alaska to the southern US, which include commercial net and troll, sport, and First Nation fisheries listed in annual Chinook Technical Committee reports (www.psc.org). Catch year exploitation rates (CYER) by age class are estimated annually by the Pacific Salmon Commission using Coded Wire Tag (CWT) recovery data. CYER includes total mortality from reported catch and estimates of mortality associated with releases. Sources of uncertainty include the management scale, population identification, lack of external marking, monitoring at landing sites, effort, level of harvest, area openings, bycatch regulations, release mortality.

The CYER estimate does not include catch or bycatch in salmon and non-salmon fisheries that are not regulated under the Pacific Salmon Treaty. The group learned that sampling and reporting CWT recoveries in non-salmon fisheries is not mandatory in many non-salmon fisheries.

Five presentations informed discussion of the three limiting factors related to human harvest. The discussion on each limiting factor is summarized below and the resulting risk assessment scores and ranking are in Table 7.18.

Table 7.18 Ranked (high to low) current and future risk rankings for limiting factors (LFs) considered during Workshop 7. Current risk is based on x, y coordinates of impact, likelihood while future risk is based on x, y coordinates of current risk, future trend determined using risk matrices described in the Methods section of the main report.

Limiting Factor	Life Stage	Likelihood Score	Impact Score	Future Trend Score	Confidence Score 1-3	Reviewed Confidence	Review Result Current Risk	Review Result Future Risk
LF26 Changes in demographics due to fishing	LS4	4	4	4	2	Mod	High	Very High
LF24 Overfishing	LS4	4	2	3	3	High	Mod	Mod
LF24 Overfishing	LS3	3	1	3	3	High	Low	Low
LF25 Illegal fishing	LS3	3	2	3	1	Low	Low	Low
LF25 Illegal fishing	LS4	3	2	3	2	Mod	Low	Low
LF26 Changes in demographics due to fishing	LS3	3	2	3	2	Mod	Low	Low

Discussion regarding LF24: Risk of overfishing in regulated and directed fisheries reducing spawner numbers was Moderate for Life Stage 4 (mature migrating Adults) and Low for LS3. LS3 and LS4 are distinguished by a demarcation in size at about 30 cm.

- Across all ages, the recent 10-year average annual catch year exploitation rate (CYER) has been ~35% in non-terminal fisheries, which is assumed to reflect the harvest rate on Clayoquot Sound Chinook. CYER would be lower for more northern WCVI populations (e.g. Quatsino Sound) that reach their natal rivers prior to entering WCVI Troll and WCVI AABM sport areas. A KOBE plot (Figure 7.65) indicated WCVI Chinook have generally been fished sustainably in recent years and are not causing declines in abundance. However, the following concern resulted in a higher impact score.
- The PST management framework aggregates hatchery and wild salmon in determination of allowable catch in AABM fisheries. Here we are concerned about exploitation of wild production, not the aggregate. Since naturally-produced salmon have lower survival rates than hatchery salmon, we increased the impact score from 1 to 2, resulting in a moderate risk for LF24 overfishing.
- As addressed in LF26, the CYER on the older age 4-5 is higher than for all ages combined, at about 40% average in recent years. The CYER on the younger age 2-3 is much lower, at less than 20% on average. Non-regulated fishery impacts are addressed in LF25.

Discussion regarding LF25: Risk due to reduced spawner numbers from unreported or unsanctioned harvest, non-salmon fisheries with poor understanding of by-catch impacts, and salmon fisheries outside the purview of the Pacific Salmon Treaty was Low. Additional genetic analyses are needed to verify this assessment.

- Finfish fishing closures implemented in inlets and approach areas along the WCVI have improved the enforceability of non-First Nation fisheries. Local knowledge suggests that illegal fishing is low.
- First Nations have a constitutional right to fish for food and ceremonial purposes. Given concerns about low Chinook returns, most WCVI First Nations have imposed strict limits or even closures on fishing local Chinook populations. As a result, these are thought to be a low risk for most Chinook populations.
- Much of the discussion's focus was on catches not included in the CYER estimation. The CYER estimate must be an underestimate since some WCVI Chinook are caught as by-catch. The magnitude of the bias is largely unknown due to a lack of by-catch information by stock or CWT recovery information from non-salmon fisheries such as BC and Alaskan trawl fisheries. For example, findings from preliminary genetic analyses reported at this workshop suggested that WCVI Chinook may have comprised up to 25% of salmon bycatch in Alaskan Pollock trawl fisheries in 2020 (Figure 7.67). Fortunately, Chinook bycatch in Alaskan Pollock trawl fisheries appears to have been reduced in recent years. There are similar concerns about Hake and other trawl fisheries in BC. There is increasing recognition of these concerns and consequently actions are taken to reduce and improve reporting and sampling of salmon by-catch. Although the extent of bias is not known, generally the by-catch is estimated to be small in relation to the total production. Hence the risk was assessed as Low for LF 25 although sampling including genetic analysis is required to verify this.

Discussion on LF26: reduction in egg deposition due to demographic changes in body size and age at maturity driven by selective harvest of old, large salmon. Fishing can result in changes to population demographics. E.g., temporal and/or size selectivity in fisheries can ultimately reduce the number of eggs deposited. Fitness reductions result from changes in biological characteristics such as fecundity, maturation rate, sex ratios, size at age, etc. Assessed risk is High.

- A lack of females (and egg deposition) in rivers along the WCVI is evident in the data associated with returns to major hatcheries as well as sampling and brood stock collection in smaller rivers. This results from 1) variation in cohort abundance, where ta small cohort results in few age 5 females returning compared to younger ages, and 2) differential mortality rates by age, possibly due to size-selectivity in fisheries.
- Figure 7.66 shows that the CYER by age is highest on the older (and larger and higher proportion female) Chinook. The CYER across all ages clearly underestimates the CYER on the older age 4-5 Chinook, which comprise most of the spawning females. The CWT approach to estimate CYER by age may not be sufficiently precise to identify specific fisheries and practices (such as targeting large fish). More information on potential size-selectivity in fisheries is required.
- There also was discussion on mating strategies within the WCVI hatcheries. The DFO SEP random mating protocols maintain a high level of genetic diversity but may be a key factor in declining size-at-age. Anecdotal information provided by the Tahsis Enhancement Society suggests that non-random mating in the Tahsis Hatchery program has returned significant numbers of large (>30 lbs) 'Tyee' Chinook. Information from Nitinat Hatchery suggests that rearing strategies may also result in older ages of return. This discussion was referred to Workshop 6 on Hatcheries, but a placeholder recommendation is to evaluate changes in the random mating strategy to ensure large-sized chinook return to better deal with increasing river scour of incubating eggs in the rivers.
- There is insufficient population-specific demographic data outside of Robertson Creek Hatchery returns. Changes in demographics of the hatchery production from a single hatchery may not reflect changes in natural production along the WCVI. Anecdotal information suggests declines in spawner size and numbers of female spawners. Improved sampling is suggested.

7.7.7 Key Literature[7]

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7.7.8 Participants' Names and Affiliations

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Brock Ramshaw	DFO
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Candace Picco	Ha'oom
Carol Schmitt	Independent
Christian Carson	Redd Fish
Christie Morrison	DFO
Christie Nelson	DFO
Cory Lagasse	DFO
Curtis Curkan	DFO
Dave Burt	Independent
Dave Rolston	Tseshaht
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Kadin Snook	Ha'oom
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Pieter Van Will	DFO
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Suzanne Earle	DFO
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