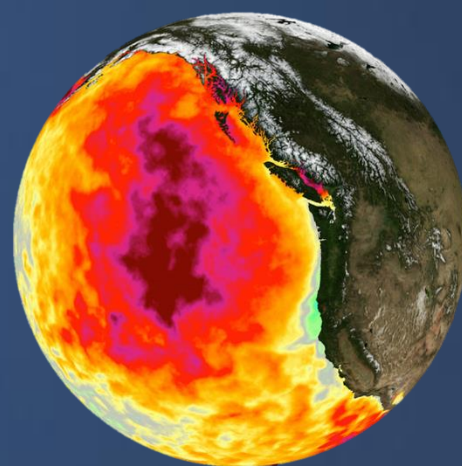
Assessment and management frameworks of the Pacific Salmon Treaty and their robustness to environmental change



Summary report prepared by:
Standing Committee on Scientific Cooperation

Prepared for:
Pacific Salmon Commission, Vancouver, British Columbia

May 2023

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Executive summary

Background

The assessment and management frameworks that underpin the Pacific Salmon Treaty (PST) are vulnerable to the challenges posed by climate change. In recent Panel/Technical Committee work plans, members have sought greater PSC attention to the risks, uncertainties, and actions required in the face of climate change. There are also certain chapter mandates to consider such change in assessment and management frameworks. In light of this, Commissioners tasked the PSC Standing Committee on Scientific Cooperation (CSC) to:

- summarize the current assessment and management frameworks of the PST;
- identify commonalities and differences in the assessment and management approaches used across chapters and the unique as well as the common challenges they face; and
- catalogue the extent to which individual chapters incorporate environmental information, account for changes in productivity, and account for and convey uncertainty.

Trends in PST salmon stocks over time

The salmon stocks covered by the PST have seen substantial variation in aggregate run size since the treaty was ratified in 1985. In general, total returns have declined over time. These declines have been most pronounced in Yukon Chinook, Transboundary Rivers (TBR) Chinook, Skeena sockeye, southern Coho, and Fraser sockeye. Across all stocks, average returns from 2009-2021 were ~45% lower than in the first decade of the Treaty (1985-1995). Several stocks have reported record low abundances in recent years (e.g., Yukon Chinook and chum in 2021, Fraser sockeye in 2019 and 2020, southern chum in 2019). However, unexpectedly large returns have also occurred (Skeena sockeye in 2022). Sharp reductions in harvests have been concurrent with declines in total returns. Accordingly, record low catches and harvest rates have occurred for many chapters in recent years. In contrast, declines in spawner abundance have been more modest.

PST fisheries management and assessment frameworks

Management objectives are well defined for all stocks covered by the PST. These objectives include managing for spawner abundances and/or harvest or exploitation rates. In addition, measures for harvest sharing and, in a few cases, sharing of enhanced salmon production are specified. Core elements of the assessment frameworks used to estimate stock abundance include pre-season forecasts of run-size and, in the majority of cases, in-season assessments based on mark-recapture, sonar and/or other enumeration methods (Figure ES1). A quarter of the management chapters have reference points in place for most stocks, with the remaining management chapters having reference points in place or under development for some, but not all, stocks. Prospective evaluation of the ability of assessment and management tools, as well as reference points, to meet management objectives (e.g., through simulation testing and Management Strategy Evaluation) has been used to inform assessment and management of Fraser sockeye, and identified as a priority in several other chapters (Yukon Chinook, Skeena sockeye, Fraser pinks).

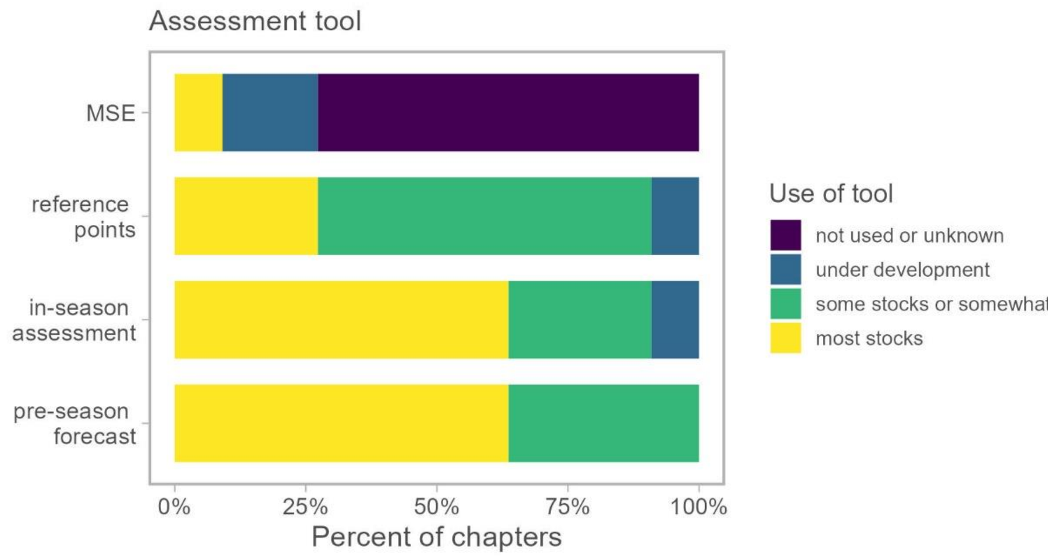

Figure ES1. *Percentage of PST chapters that use different assessment and management tools. MSE stands for Management Strategy Evaluation.*

Assessment and Management Challenges

Some of the biggest fishery management challenges under the PST are linked to declines in the abundance and productivity, inadequacies in stock and fishery assessment programs, lack of measures to consider and account for uncertainty, and unanticipated variability in environmental conditions. These declines in abundance are often linked to decreases in marine survival, increased predation, and/or changes in freshwater habitat conditions that may impact freshwater survival either as pre-smolt or adult pre-spawn mortality, all of which present challenges to pre- and in-season forecasting (Figure ES2). Depressed abundance may also exacerbate the risks posed by mixed-stock fisheries to at-risk populations. Environmentally driven changes in the distribution of salmon at sea, and the timing and location of returns, also create challenges for understanding vulnerability to fisheries and predicting run-size in-season. Lastly, changes in demographic characteristics (i.e., size, age, and sex) of returning adults, and their implications for reproductive potential and reference points, have also been identified as challenges for chapters that include Chinook salmon and to some extent for southern chum.

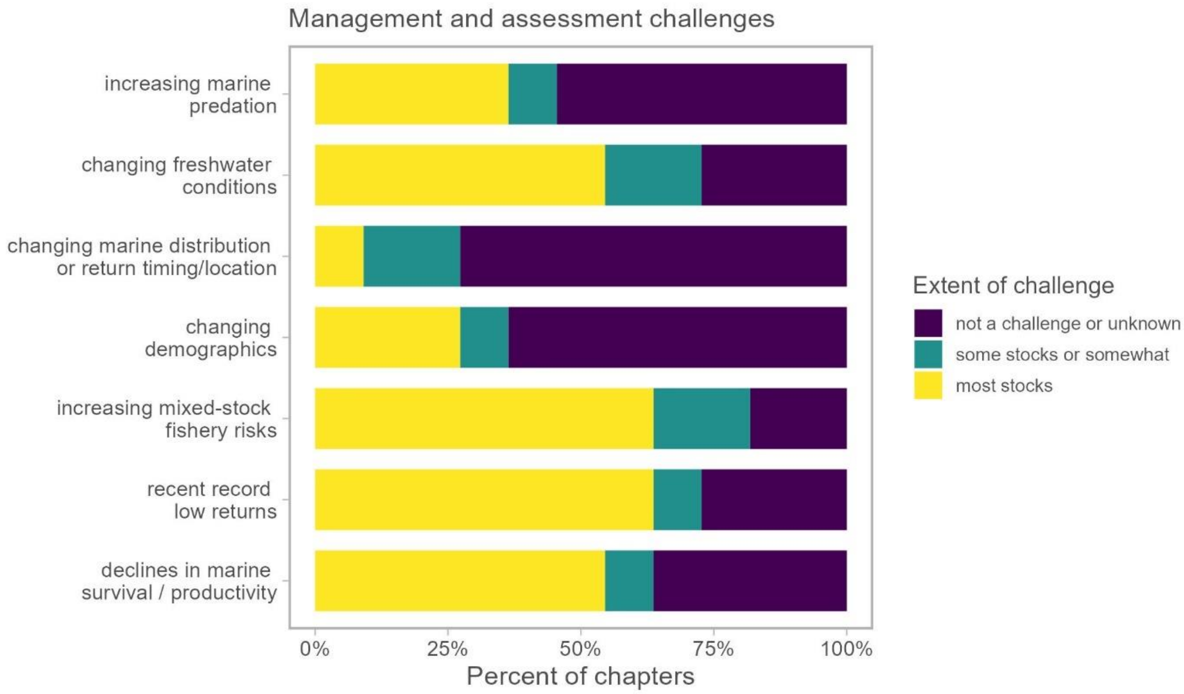

Figure ES2. *Occurrence of management and assessment challenges linked to climate change and environmental variation across PST chapters.*

Incorporating environmental information, and accounting for changes in productivity

In light of the growing evidence of climate driven impacts on fish stocks, there is increasing interest in the incorporation of environmental information into stock assessment models and accounting for environmentally driven changes in productivity in management advice. For Pacific salmon, accounting for the impact of climate driven environmental change on assessment can occur in pre-season forecasts and in-season estimation of total returns. In addition, environmental change may be incorporated into the development of reference points, escapement goals, and harvest control rules.

Across management chapters, information on the influence of environmental variability on survival and returns is most often accounted for in pre-season run size forecasts (Figure ES3). Pre-season forecasts are often qualitatively adjusted based on recent environmental conditions and/or quantitatively adjusted based on recent estimates of survival. Sibling models, that use observed abundance of younger ages of salmon to predict returns of older siblings, are also used to forecast run size in a number of chapters. Three-quarters of management chapters have at least some stocks with estimates of juvenile production which can also be used to account for freshwater survival when forecasting returns. Lastly, though uncommon, several chapters directly take time-varying productivity into account when forecasting run-size pre-season.

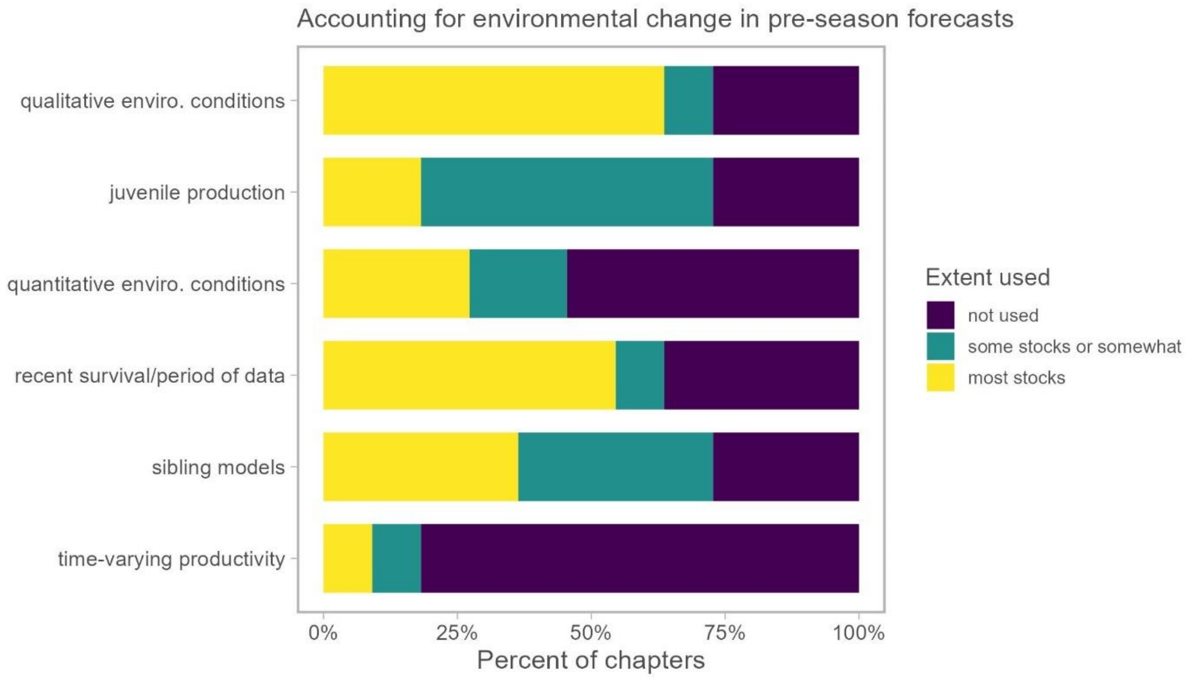

Figure ES3. *Extent to which environmental change is taken into account in pre-season forecasts across PST chapters.*

For Pacific salmon, the impact of variable environmental conditions on the accuracy of annual run size estimates can be substantially improved through in-season assessments. These in-season assessments generate relative or absolute estimates of the number of returning salmon near real-time instead of having to rely on forecasts of run size based on previous spawner or juvenile data. In-season assessments are routinely used to estimate run size for sockeye, pink, and chum salmon as well as Yukon Chinook and chum. They are also used to assess some Southern coho and most Transboundary stocks and are still being developed for the Chinook stocks covered by Chapter 3. While in-season assessments circumvent the need to account for changes in freshwater and ocean productivity by assessing the number of adult salmon returning, in some instances, there is an additional need to account for adult mortality during freshwater return migrations (e.g., due to high river temperatures or discharge) to ensure escapement goals are met. Such in-season adjustments are routinely done for Fraser River sockeye salmon. Qualitative adjustments for variation in in-river mortality due to environmental conditions are also made in several other chapters (e.g., southern chum and Yukon Chinook; Figure ES4).

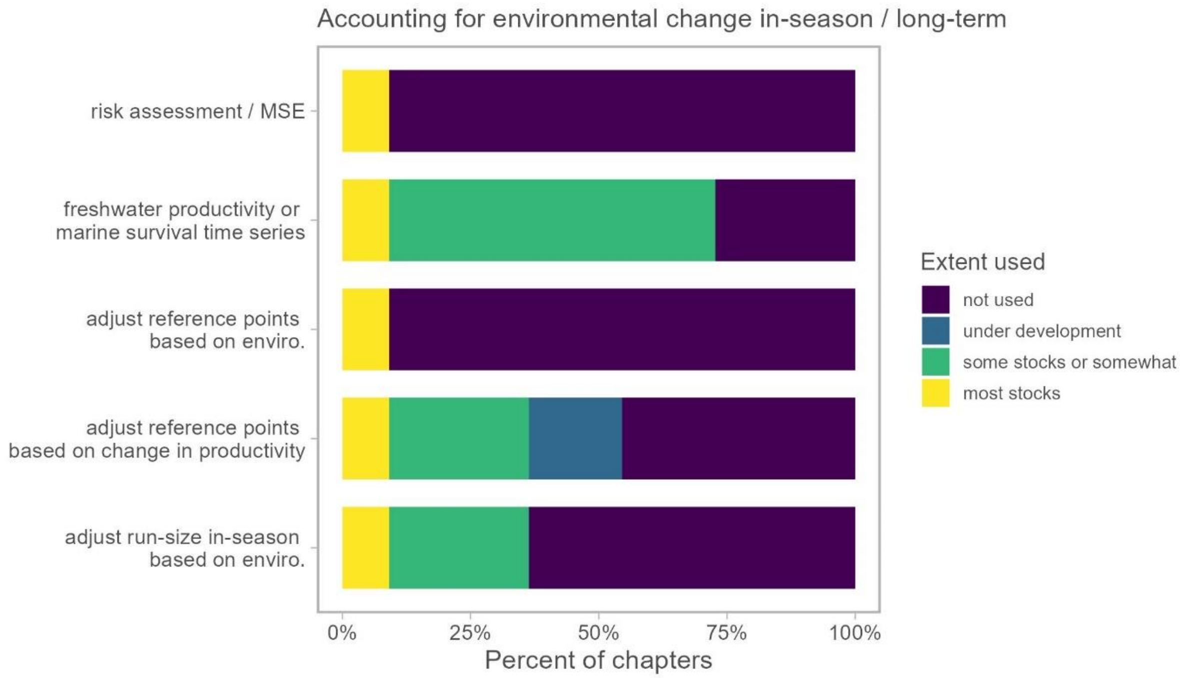

Figure ES4. *Extent to which environmental change is taken into account in-season and when estimating reference points or conducting fishery risk assessments.*

There is limited accounting for environmentally-driven changes in productivity when estimating reference points used to define management goals (Figure ES4). The use of risk assessment approaches to prospectively evaluate the appropriateness of reference points, harvest control rules, or escapement goals to meet management objectives in the face of climate change has only occurred for Fraser sockeye. However, two other chapters have identified this approach as a priority. Lastly, regular updates of references points to ensure they implicitly account for long term changes in productivity, have not occurred for most chapters.

Accounting for, and conveying, uncertainty

Uncertainty is a pervasive and well recognized aspect of fisheries management. Climate change has the potential to exacerbate it, thereby increasing the risk of failing to meet management objectives. Best practices for communicating and accounting for uncertainty include formalizing the communication of risk through procedures such as decision tables and risk matrices. These formal declarations of risk help encourage decision-making that is informed by the expected outcomes of various management strategies in the face of uncertainty. Best practices also include testing assessment and management procedures for their robustness to uncertainty, as well as harvest control rules, escapement goals, and other reference points.

Across management chapters, pre-season forecasts commonly include associated statements of uncertainty (Figure ES5). Quantitative in-season assessments of uncertainty associated with the run size and the probability of reaching escapement goals are common for at least some stocks in most chapters. Uncertainty associated with escapement goals and reference points is also accounted for, for some stocks, and in some chapters. However, uncertainty in the expected ability of escapement goals and reference points to meet management objectives in the face of climate change (i.e., quantitative evaluations of risk) is typically not accounted for. Across PST management chapters there is considerable progress that could be made to further improve the communication of, and accounting for, risk as a result of uncertainty due to climate change.

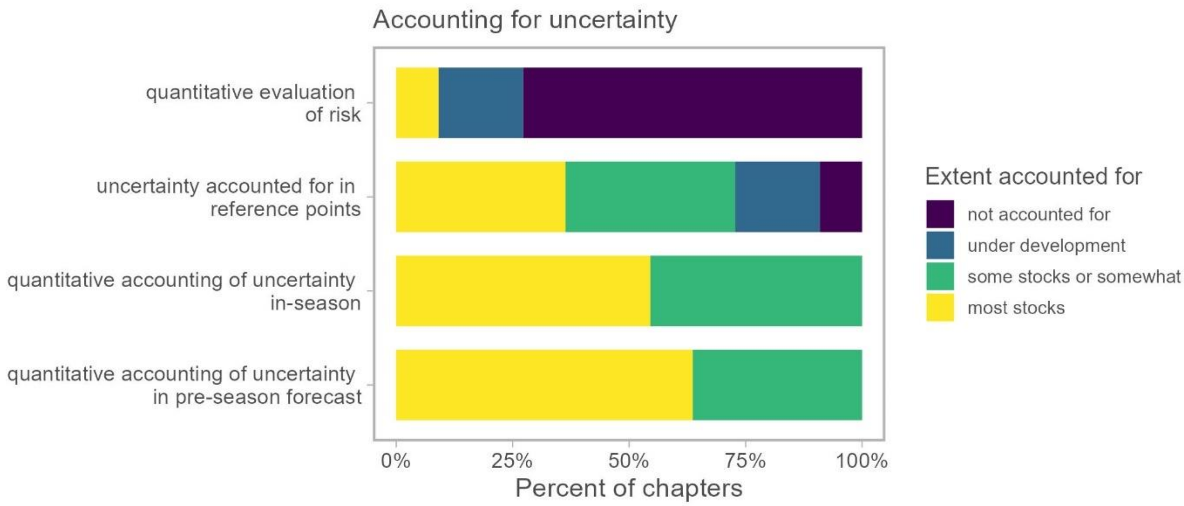

Figure ES5. *Extent to which uncertainty is accounted for across chapters.*

Conclusions and next steps

This report helps to scope the extent to which climate change and increasing environmental variation present challenges for current assessment and management under the PST. Overall the review revealed that, in comparison to other fisheries, the annual assessments of Pacific salmon across PST chapters generally attempt to account for environmental and climate-driven impacts on survival through the use of salmon-specific tools such as in-season assessments and, to a certain extent, the incorporation of environmental information in forecasts and/or reliance on sibling information. However, relationships between the environment and survival are becoming increasingly unreliable, sibling relationships are not available for all species and stocks, and not all fisheries are amenable to in-season assessments. The complexities that result from differences in salmon biology and harvest regimes mean that the value of specific approaches to accounting for environmental variation vary across management entities, species and Chapters. A key challenge moving forward is ensuring annual management goals (and associated reference points) are appropriate given climate-driven changes.

Despite these findings, this report does not make forward-looking recommendations as it is recognized that these must be developed in partnership with Panels and Technical Committees to be effectively adopted and used. It is therefore recommended that this report be followed up with a multi-year process that engages PSC Panels and Technical Committees to (a) discuss the implications of the CSC work, (b) deliberate on specific opportunities to improve the adequacy and responsiveness of PSC assessment and management frameworks to climate driven change, and (c) develop chapter-specific feedback from the PSC membership for both countries to consider and evaluate ahead of the Annex IV renegotiation in 2027-2028. ESSA Technologies (Vancouver, BC) has proposed to launch such consultations with potential financing from the Northern and Southern Funds in 2023.

Introduction

CLIMATE CHANGE AND SALMON

Climate change is rapidly creating a no-analogue future for Pacific salmon as the freshwater and marine environments they use change and are pushed outside their envelopes of historical variation. In freshwater these changes include altered precipitation regimes, reduced snowpacks, receding glaciers, more intense spring freshets and floods, prolonged droughts, reduced flows and warming waters. In the marine environment they include acidification, rapid warming of both the surface and at depth, and more frequent extremes like marine heatwaves. These changes are expected to intensify as the global climate continues to warm.

Rapid climate-driven changes in the environmental conditions salmon experience, which are overlaid on decade-to-decade variation, can have both negative and positive population-level effects as a result of shifts in abundance, distribution, and life history timing. In freshwater, extreme flood events can scour spawning and incubation habitat, while high discharge can affect juvenile foraging success and impact survival for juveniles (Neuswanger et al. 2015) and returning adults (Rand et al. 2006). Reduced flows can impact juvenile rearing and survival (Warkentin et al. 2021) and warming waters in rivers can cause thermal stress and mass mortalities in returning adults (Hinch et al. 2012, VonBiela et al. 2022) and production at juvenile life stages (Ohlberger et al. 2018). In contrast, receding glaciers are creating new salmon habitat (Pitman et al. 2021) and warming waters can change rearing lake phenology, increase food web-productivity, and freshwater juvenile salmon growth (Cline et al. 2019). In the marine environment, a warming ocean can alter salmon growth at multiple life stages (Oke et al. 2020), redistribute salmon at-sea (Abdul-Aziz 2011; Shelton et al. 2022), change return migration patterns (Hague et al. 2022), and both positively and negatively impact survival (Mueter et al. 2002; Malick 2020). All of these climate-related processes and effects can be exacerbated, and ameliorated, by anthropogenic and natural ecosystem change (Connors et al. 2020). They are also filtered by the habitats salmon use, resulting in variation in responses among species, life histories, regions, and over time (Rogers and Schindler 2011).

Climate induced changes in salmon habitat, and population level responses to them, can make the already challenging assessment and management of Pacific salmon even more difficult (Figure 1). Climate driven shifts in the distribution of salmon at sea can render assessment models based on a static assumption of distribution unreliable. Thermal stress, and indirect and direct mortality during return migrations, can impact the ability of management measures to meet spawning and harvest goals. Changes in freshwater and marine survival can undermine the reliability of models used to forecast (pre- and in-season) return abundances and prosecute fisheries. They also exacerbate fishery challenges when populations that are negatively impacted by climate change (weak stocks) co-occur with more productive populations (strong stocks) that are targeted in mixed-stock fisheries (e.g., Connors et al. 2019). The risks associated with these changes range from increased biological and conservation risks to fishery restrictions and closures with cultural, social, and economic consequences.

THE PACIFIC SALMON TREATY

The Pacific Salmon Treaty (PST), originally ratified by Canada and the United States in 1985, created a framework for both countries to work together to conserve and manage Pacific salmon. Because of their extensive marine migrations, salmon originating in the rivers of one country are often subject to the fisheries of another. A high degree of bilateral cooperation is therefore required to limit the harvest of one country's salmon by the other and appropriately share salmon available for harvest, while ensuring conservation of weaker stocks. The PST includes fifteen articles, four annexes and eight chapters (in Annex

IV, with seven specifying management regimes), covering all five species of eastern Pacific salmon and supports coordinated management of marine and selected in-river salmon fisheries from Southeast Alaska in the north through to the mid-Oregon coast in the south, as well as fisheries in the Yukon River. The overarching goals of the Treaty are to (1) prevent over-fishing and provide for "optimum" production, and (2) ensure that both countries receive benefits equal to the production of salmon originating in their waters (PST 1985s).

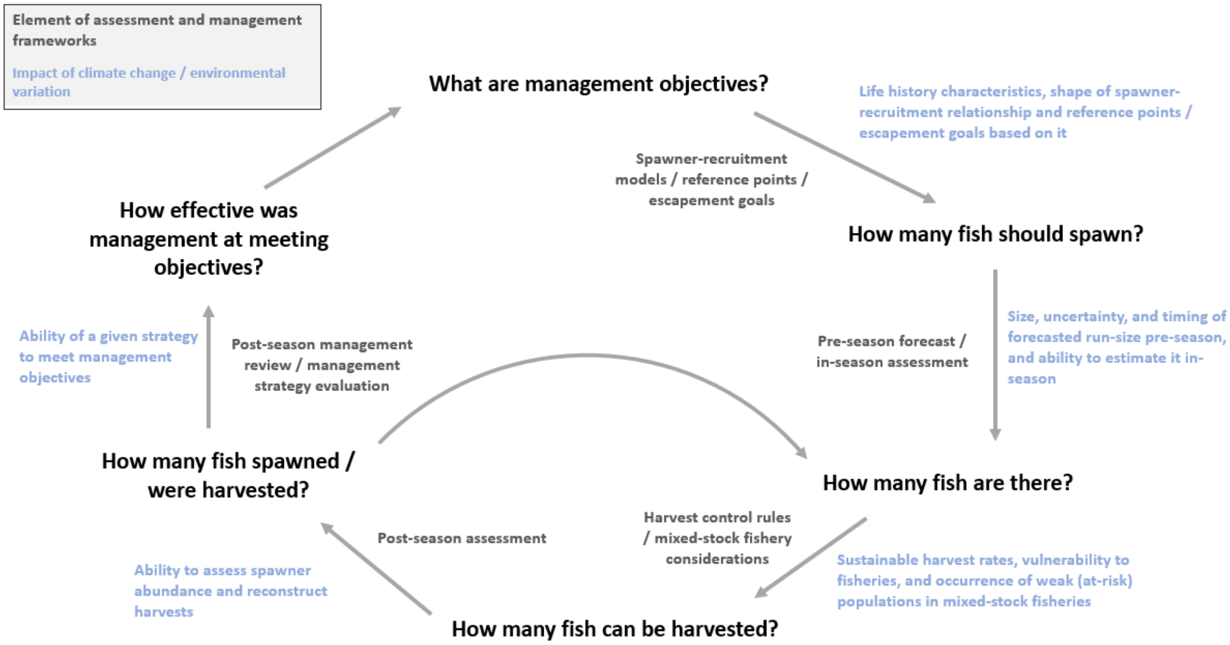

Figure 1. *Key questions that guide Pacific salmon fisheries management, elements of salmon assessment and management frameworks that help answer them (light grey text on inside of cycle) and ways in which climate change and increasing environmental variation impact them (light blue text on outside of cycle).*

The assessment and management frameworks that underpin harvest management of the PST are not immune to the challenges posed by climate change. As a result, there has been increasing recognition within the Pacific Salmon Commission (PSC), the body formed to implement the PST, of the need to ensure its assessment and management approaches are robust and resilient to both current and future climate driven change. Several PSC Technical Committees and Panels have specifically requested support to appropriately account for climate change in assessments and management.

OVERARCHING GOALS OF THIS REPORT

In response to requests by PSC Technical Committees and Panels, and in recognition of the challenges posed by climate change, the PSC Standing Committee on Scientific Cooperation (CSC) was tasked with:

- summarizing the current assessment and management frameworks of the PST (in cooperation with the PSC panels and technical committees);
- identifying commonalities and differences in the assessment and management approaches used across chapters and the unique as well as the common challenges they face; and
- cataloguing the extent to which individual chapters incorporate environmental information, account for changes in productivity, and account for and convey uncertainty.

TRENDS IN PST SALMON STOCKS OVER TIME

Among species and regions there has been substantial variation in aggregate run size and abundance indices since the PST was ratified in 1985 (Figures 2 and 3). In general, total returns (i.e., adult fish returning to the coast to spawn) of stocks with estimates of absolute abundance that are covered by the PST have declined over time, and these declines have been most pronounced in Yukon Chinook, Transboundary Rivers (TBR) Chinook, Skeena sockeye, southern coho, and Fraser sockeye (Figure 2). Across all management chapters, average returns 2009-2021, which encompasses the most recent negotiated agreement periods, have been ~45% lower than in the first decade of the Treaty (1985-1995) (Table 1). There have been reports of record low abundances for several stocks and species in recent years (e.g., Yukon Chinook and chum in 2021, Fraser sockeye in 2019 and 2020, southern chum in 2019), but also unexpectedly large returns (Skeena sockeye in 2022, not shown in Figure).

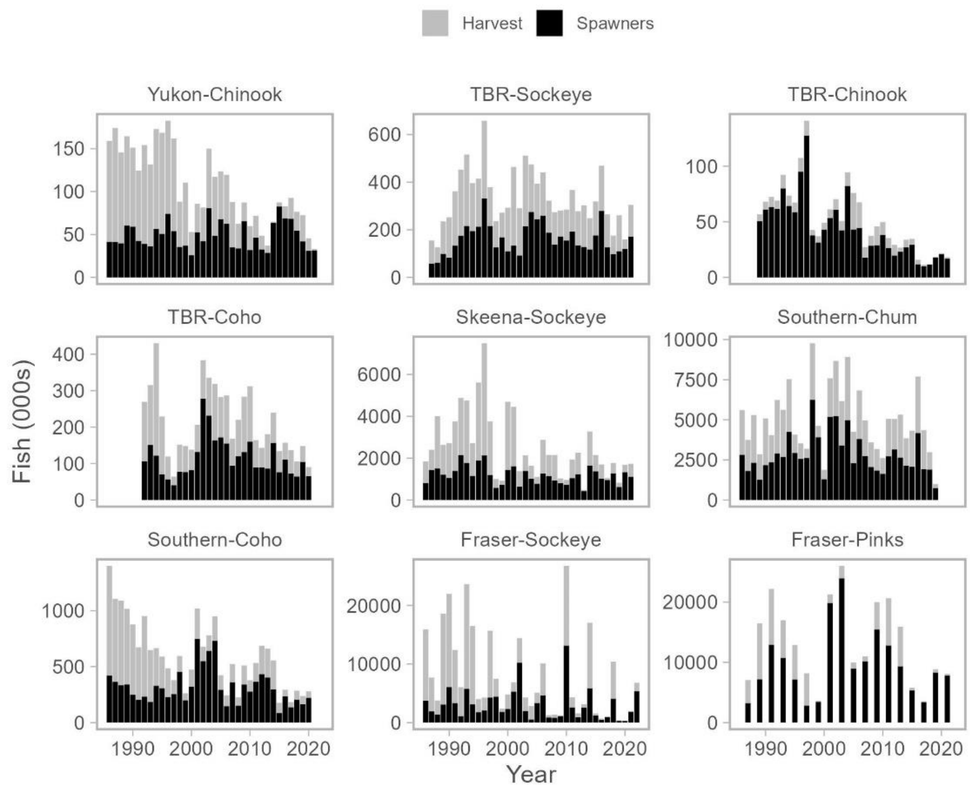

Figure 2. *Reconstructed spawner abundance and harvest for select species and regions subject to the PST from 1985 to 2022. Note that not all time-series were available through 2022 and for the Transboundary Rivers region (TBR) Taku and Stikine rivers are combined for sockeye, Taku and Alsek rivers are combined for Chinook, and Taku River is used for coho.*

Concurrent with declines in total number of returning adults, there have been sharp reductions in harvests, and harvest rates, which were as high as ~70% for Yukon Chinook and Fraser sockeye in the late 1980's and early 1990s and have averaged ~30% since 2009. In parallel with record low returns, there have been incidences of record low catches and harvest rates for stocks in many chapters in recent years. In contrast to the sharp declines in returns and harvest rates, declines in spawner abundance have been more modest (Figure 2) and have averaged ~15%, with TBR Chinook having experienced the largest declines (65%) (Table 1).

Absolute coastwide Chinook returns, and spawner abundances, are unknown, because assessment of all Chinook stocks is fiscally and logistically impractical. There are two management regimes specified for Chinook salmon in Chapter 3 of the Treaty in specific geographical regions. Within each of these regimes and regions, several types of fisheries occur. The management of fisheries in three of these regions is based on reconstructed aggregate abundance indices (of representative stock groups) relative to a base period (1979-1982), e.g., AABM regions. Across the three PST AABM regions, relative abundance since 2008 has declined by an average of ~15% compared to the late 1980s and early 1990s (Figure 3, Table 2). The remaining PST fisheries for Chinook have management objectives based on harvest rates and/or escapement goals for individual or groups of stocks.

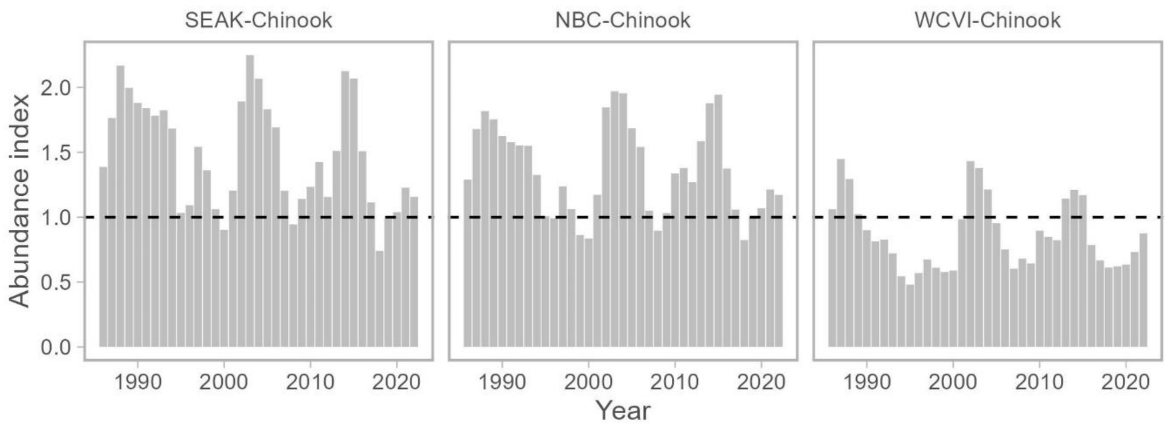

Figure 3. *Reconstructed Chinook abundance indices for the three PST Aggregate Abundance Based Management (AABM) fisheries. The indices are relative to the average of the 1979-1982 period (dashed line) and are comprised of the Model stocks in the PSC Chinook Model.*

PST fisheries management and assessment frameworks

Management of salmon fisheries requires effective long- and short-term management provisions built on stock assessment foundations, that will address issues affecting management prior to the commencement of, and during, fishing. As of the most recent PST Agreement (2019), all management chapters had strategic plans in place to carry out the terms of the Agreement, which are typically renegotiated every 10 years (Table 3). Management plans covering actions that are PST-related are developed annually for each chapter. In addition, domestic (non-PST) management plans are in place to achieve federal, state, tribal and regional objectives, e.g., by gear sector, species, harvest limits or depressed/at-risk stocks.

Management objectives under the PST include managing for spawner abundances and/or harvest or exploitation rates (Table 3). In addition, measures for harvest sharing and, in a few cases, sharing of enhanced salmon production are specified. All management chapters manage fisheries based on spawning escapement goals or ranges, except for two out of three TBR coho runs that lack escapement goals and southern coho (originating south of Cape Caution), whose fisheries are instead managed based on upper harvest rate limits. The Chinook and southern chum chapters have harvest rate obligations as well. The majority of Chapters have specified harvest sharing provisions. Chapter 1 has enhancement objectives for two of the three rivers involved. As expected, the regional (non-PST) fishery plans mandate allocations amongst domestic user groups.

All management chapters of the PST have mixed stock fisheries (Table 3). Even in-river fisheries are often mixed stock in nature. At the other end of the spectrum, all management chapters also contain localized 'terminal' fisheries that may target a single wild or hatchery stock. All management chapters except Chapter 1 and Chapter 8 contain coastal fisheries that target maturing fish on their return migrations. Chapter 3 coast wide Chinook also includes ocean and coastal fisheries targeting a mixture of mature (will spawn that year) and immature fish. In general, salmon stocks managed under the PST migrate north and west of their natal streams for their ocean residence, into the northeast Pacific Ocean. Chinook salmon reside on or near the continental shelf and have the largest number of stocks present in mixed-stock fisheries on the outer coast from Southeast Alaska to the mid-Oregon coast. All PST Chinook stocks migrate north, but some only a relatively short distance, resulting in differing stock compositions in different marine areas and associated fisheries. For the other four species, the latitude fish make landfall from offshore rearing areas, i.e., their ocean migration route to their natal stream, makes a difference in coastal stock composition and landfall varies annually for species like sockeye. For example, Fraser River sockeye salmon may landfall in southern Southeast Alaska in some years and further south in northern British Columbia in other years. These facts add complexity to managing fisheries for the different species.

The PST management frameworks are all abundance-based regimes such that harvests and harvest rates vary as a function of estimated abundance (Table 3). When abundance is higher, harvest or harvest-rates can be higher and vice-versa. Management for most species relies on annual estimates of returning abundance forecasted before, or measured during, a single fishing season through preseason and in-season assessments, respectively. Preseason forecasts are model-based projections, while in-season forecasts are based on observational data such as sonar, capture-recapture or test fishing assessments. Management for some Chinook salmon fisheries (Chapter 3) relies on relative abundance of PSC Chinook Model stocks, specific to a pre-treaty base period (1979-1982). This approach utilizes abundance data from stocks (50-60 stock groups) with adequate assessment data representative of life history types and geographic regions in the PST area, recognizing that it is logistically and financially difficult to assess more stocks.

The fisheries in all management chapters have intensive management programs in place, meaning that managers across PST regions generally have enough information to be very capable of achieving a management target, e.g., a harvest target. The initial management targets for all relevant chapters are based on pre-season forecasts of run-size (Figure 4). These forecasts may or may not be accurate postseason, and may or may not be updated in-season. Any difference between a preseason run size and associated fishing target and a postseason run size and target can be thought of as error arising from imperfect run size knowledge (i.e., process or model error), whereas management error indicates the ability to achieve a specified management target, regardless of whether the target is correct.

Not all chapters have assessment frameworks that include in-season abundance updates to fine tune the ability of managers to meet escapement and harvest objectives (Figure 4). Those presently lacking in-season assessment (for the majority of fisheries) include the Chapter 1 coho stocks (two of three), Chapter 3 Chinook, and Chapter 5 southern coho (Table 4). Note that regional (non-PST) management plans may include in-season adjustments for these stocks, especially in terminal areas. All management chapters require postseason assessment of management performance; Chapter 1 sockeye and Chinook, Chapter 2 sockeye and Chapter 3 Chinook conduct these across multiple seasons to match the multi-season requirements of that Chapter and they are also under development for southern chum.

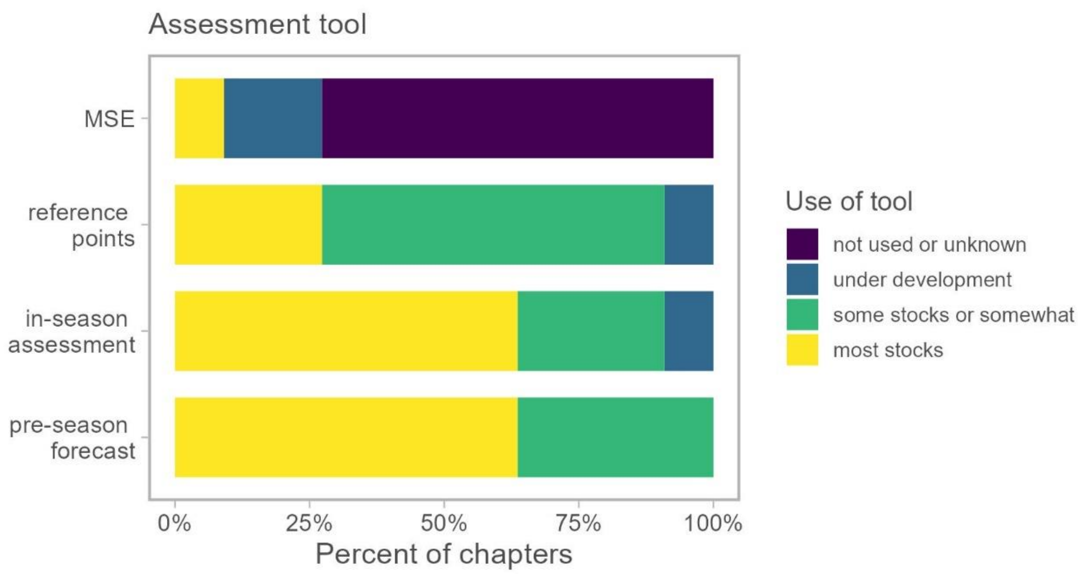

Figure 4. *Percentage of PST chapters that use different assessment and management tools. MSE stands for Management Strategy Evaluation.*

Preseason forecasts are produced for stocks managed in each chapter; however, these vary in quality and some chapters have qualitative forecasts for some stocks and quantitative forecasts for others (Figure 3; Table 4). Chapters 3 (Chinook), 5 (southern coho) and 6 (southern chum) have quantitative forecasts for selected stocks. Chapter 2 has quantitative forecasts for Nass and Skeena sockeye and Chapter 4 has the most comprehensive quantitative forecasts for Fraser sockeye and pinks. It should also be noted that forecasts are produced for all Chinook Model Stocks in Chapter 3 as inputs into the PSC Chinook Model (either by agencies or by the Model), but not for unmonitored Chinook stocks or those with incomplete data.

Most of the stocks across Chapters have upper and lower fishery reference points (Figure 4; Table 4). These reference points are based on escapement goal ranges, stock-recruit measures such as yield profiles, other analyses or regional policy. Harvest control rules (HCRs) are in place for all management chapters and most stocks therein; however, they do vary substantially in sophistication and the quantity and quality of data on which they are based. For Chapter 1 Chinook, sockeye and one coho stock, they are the upper and lower limits of the agreed escapement goal range. Reference points are under development for Chapter 2. For Chapter 3 they have been developed for many stocks, based on escapement goal ranges, a percentage of estimated S_{MSY}, an escapement floor and regional policies; they do not exist or are under development for the remainder of assessed Chinook stocks. Reference points are well developed for Fraser sockeye and partially for Fraser pinks. For southern coho (Chapter 5), management reference points (MRPs) are used to demarcate the three PST status categories of low, moderate, and abundant coho abundance. Within each exploitation rate cap for each coho MU, explicit exploitation rate limits are established for both Canada and the U.S. In Chapter 6 for southern BC chum, which are data-limited stocks, what are thought to be conservative sustainable escapement goals serve as the lower and upper fishery reference points and are defined as the 25th and 75th percentiles of the long-term escapement time series which are considered proxies for S_{MSY} based reference points. Interim goals and limits (since 2010) exist for Canadian origin Yukon Chinook and chum, based on, for chum, escapement levels thought to be near S_{MSY}. The current Yukon Chinook escapement goal is not biologically based, but is being revised based on a multi-agency effort to develop an integrated Bayesian state-space run reconstruction and spawner-recruitment model fit to all available data.

Management Strategy Evaluation (MSE), using closed-loop simulations (Punt et al. 2014) to prospectively evaluate the ability of reference points, escapement goals, and harvest control rules to meet management objectives, has been used to inform assessment and management of Fraser sockeye (Figure 4; Table 4). While MSEs have not been carried out elsewhere they have been identified as a priority in several chapters (Yukon Chinook, Skeena sockeye, Fraser pinks). We note, however, that ad hoc sensitivity tests and hundreds of model runs have been used in the past to inform assessment model performance for some chapters including Chapter 3.

Management and Assessment Challenges

One of the foremost challenges for fisheries management under the PST is declines in the abundance and productivity for many of the stocks of salmon managed under the Treaty (Figure 5; Table 5). These declines have been broadly observed in Pacific salmon (e.g., Peterman and Dorner 2021, Malick et al. 2016, Dorner et al. 2018) and have resulted in several PST stocks with record low returns in recent years (e.g., Fraser River sockeye and Yukon River Chinook). A number of environmental factors have been hypothesized to have contributed to these declines including a warming ocean, competitive interactions among salmon at sea, and increasing predation in all life stages (e.g., Cunningham et al. 2018, Nelson et al. 2019, Connors et al. 2020, Litzow et al. 2020, Crozier et al. 2021). In addition, freshwater environments have been degraded in many areas, especially in southern regions of PSC concern. Except for Chapters 1 (Transboundary Rivers) and 7 (general obligations), all chapters, have identified changes in freshwater conditions, including increasing temperatures due to climate change, as a management concern (Figure 5). Extreme alterations of freshwater environments by landslides, directly blocking fish passage, have also occurred in the Fraser and Nass and Skeena Rivers.

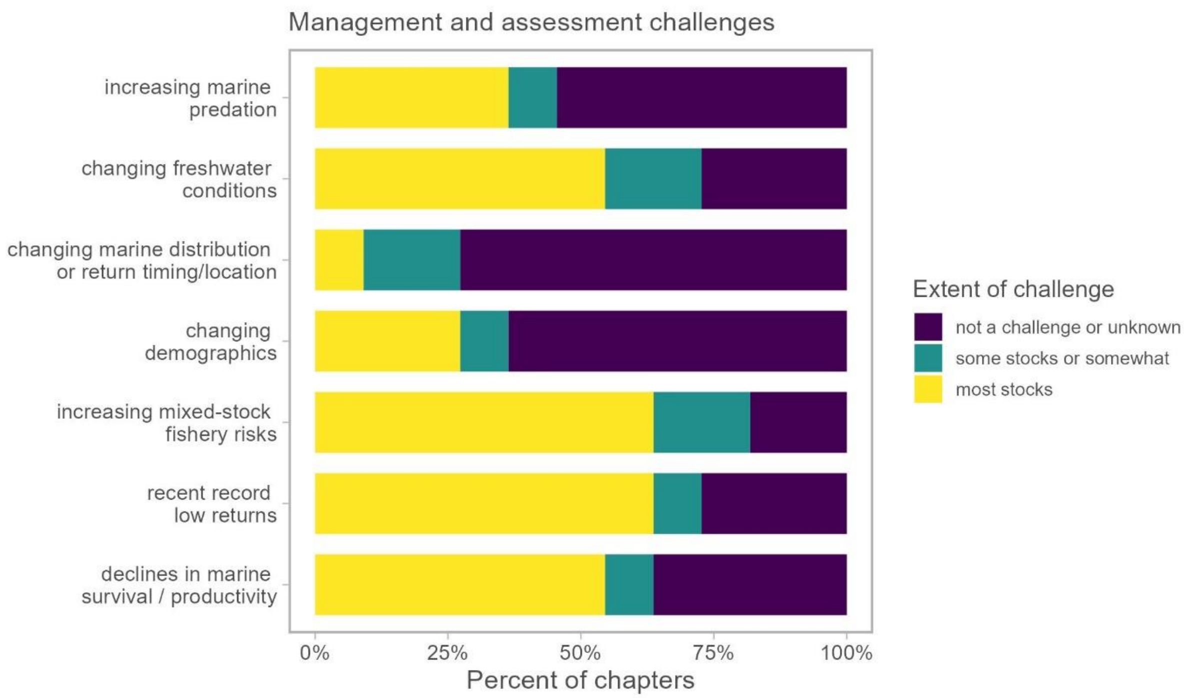

Figure 5. *Occurrence of management and assessment challenges linked to climate change and environmental variation across PST chapters.*

Declines in abundance can create numerous challenges for assessment and management including, for example, changes in the proportions of fish from different stocks and species that are vulnerable to harvest in mixed-stock fisheries, as well as overall declines in the quality of available stock assessment data. The presence of low abundance or weak (low productivity) stocks and/or other non-target species poses challenges for Nass, Skeena and Fraser River sockeye, Yukon River Chinook, southern coho and chum, and Chapter 3 Chinook fisheries management (Figure 5; Table 5). These weak stock management challenges maybe be exacerbated by lack of information on the distribution of stocks in different fishing areas and the biological status of them due to limited spawner-recruitment data or uncertainty around either pre-season or in-season assessments. Spawner-recruitment data is lacking for many pink, chum and/or coho populations. In addition, data is lacking for some Nass/Skeena sockeye populations and some Chinook populations coastwide.

Environmentally driven changes in the distribution of salmon at sea, and the timing and location of returns, create challenges for understanding vulnerability to fisheries and predicting run-size in-season (Figure 5; Table 5). In addition, changes in demographic characteristics (i.e., size, age, and sex) of returning adults, and their implications for reproductive potential and reference points, have also been identified as challenges for chapters that include Chinook salmon, as well as for some southern chum stocks.

Escapement goals are commonly used for management under the PST and most chapters have identified failure to meet escapement goals, for at least some stocks, as a management challenge (Table 5). The most common reason escapement goals have not been met is due to depressed survival and/or productivity and subsequent low returns (all chapters except Transboundary coho and sockeye, Fraser River pinks and southern coho). Overfishing has been identified as another contributor to not meeting escapement goals for some Skeena/Nass sockeye stocks, Fraser sockeye, and southern chum. High en-route losses due to warming waters during return migrations have been a persistent management challenge in Fraser sockeye and competition with abundant pink and chum salmon in the north Pacific due to ocean warming has been identified as a management challenge for meeting escapement goals for Southern chum. Incidental by-catch in other salmon or non-salmon fisheries have also been cited as posing a challenge to meeting escapement goals for some Chapter 3 Chinook stocks as well as Skeena/Nass sockeye, Fraser River sockeye, and southern chum stocks.

Incorporating environmental information, and accounting for changes in productivity

In light of the growing number of studies highlighting climate change impacts on fish stocks, there is increasing interest in the incorporation of environmental information into stock assessment models and accounting for environmentally driven changes in productivity in management advice (e.g., Pepin et al. 2022). For Pacific salmon, accounting for the impact of climate driven environmental change on assessment can occur in pre-season forecasts, and with in-season estimation of total returns. In addition, environmental change may be incorporated into the development of reference points, escapement goals, and harvest control rules. In this section we describe the extent to which information on environmental conditions or changes in productivity have been incorporated into assessments and management goals for Pacific Salmon stocks across PST chapters.

ANNUAL ASSESSMENTS

Pacific salmon have several distinct advantages compared to other fish species when it comes to accounting for environmental and climate driven impacts on survival in annual assessments. In the case of Pacific salmon, the impact of environmental variation on the accuracy of annual run size estimates can be reduced through in-season assessments (using relative or absolute estimates of the number of returning salmon instead of having to rely on forecasts of run size based on spawner or juvenile data). Across chapters, information on the influence of environmental variability on survival and returns is most often accounted for in pre-season run size forecasts (Figure 6; Table 6 and 7). In-season assessments are routinely used across PST chapters to assess sockeye, pink and chum salmon as well as Yukon Chinook and chum. They are also used to assess some of the coho and Transboundary Chinook stocks and are still being developed for the Chinook stocks covered by Chapter 3. While in-season assessments circumvent the need to account for changes in freshwater and ocean productivity by assessing the number of adult salmon returning, in some instances, there is an additional need to account for changes in adult survival during freshwater return migrations to ensure escapement goals are met. This is the case for Fraser River sockeye salmon where adverse environmental conditions in the river during their migration to the spawning grounds impact the ability to reach escapement goals. To account for this, water temperature and river discharge are used to predict in-river survival of Fraser River sockeye salmon. Similarly, high river temperatures have been hypothesized to negatively impact adult survival of southern chum and Yukon Chinook and chum in recent years and in-season management of these stocks includes a qualitative assessment of freshwater migration conditions. In some locations, in-season assessments account for changes in river discharge by using models that estimate in-season run size by stratified time periods. Reduced in-river adult survival due to adverse environmental conditions is, however, not a general occurrence or concern across other chapters and appears to be of greatest concern for those stocks that undergo the longest freshwater migrations.

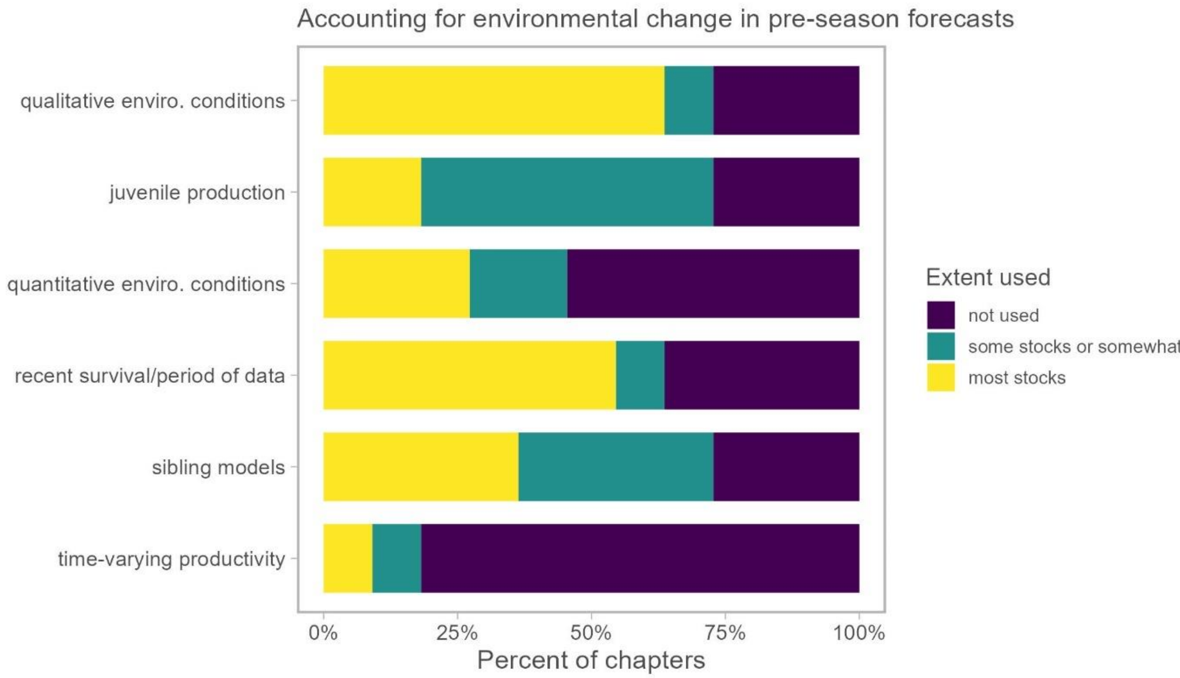

Figure 6. *Extent to which environmental change is taken into account in pre-season forecasts across PST chapters.*

Another major advantage Pacific salmon have is that it is possible to account for changes in freshwater and ocean productivity by relying on data from siblings, i.e., using the observed abundance of early maturing salmon from a given brood year to predict the abundance of their older siblings returning the following year. This approach relies on the assumption that both siblings will have experienced similar conditions and hence survival in freshwater, during their transition to sea, and in their first year or two of residence in the ocean, and that survival is high during the additional year the older siblings spend at sea. The most common way to account for changes in productivity across PST chapters is therefore through sibling models (Peterman 1982) (Figure 6, Table 7). Sibling models, however, assume limited variation in age structure, which is an assumption likely violated by climate change for some species, given recent trends towards younger ages (Ohlberger et al. 2018). Another popular forecast strategy for salmon is the use of juvenile data (Table 7), which indirectly accounts for changes in freshwater productivity, one of the main bottlenecks in terms of salmon productivity and survival. Juvenile data are used for Yukon River Chinook and Fraser River pink salmon, as well as for some of the following: Southern coho and chum, Fraser sockeye and Transboundary sockeye and coho stocks.

Sibling or juvenile data are, however, not always available or informative, and therefore other, more generic forecasting methods are relied upon, such as autoregressive methods (Table 7). These methods consider year-to-year correlations, periodicity, and trends in the data and work well for fish stocks with complex life histories and longer pre-recruitment survival windows (Haltuch et al. 2019). This method has been applied for U.S. chum stocks that rely on the estimated trend in recruits-per-spawner for their forecast method. Other chapters rely on recent survival estimates by only using recent spawner-recruitment data despite longer time series being available (Washington chum stocks and Interior Fraser coho in the southern coho chapter). In addition to the above-mentioned forecast methods, some chapters rely on average salmon returns in the last few years to produce the forecast or correct the forecast based on the average error observed in recent years (Nass and Skeena sockeye and some of the Coastwide and Transboundary Chinook stocks). Thus far, three of the chapters rely at least partially on stock-recruitment models that include a time-varying productivity (alpha) parameter – Washington chum, Fraser sockeye and selected Chapter 3 Chinook stocks, where productivity refers to the number of recruits per spawner in the absence of density dependent mortality. Even though spawner-recruitment models with time-varying productivity (Peterman et al. 2000) are common and have been explored in forecasts for some PST chapters, traditional model selection criteria usually consider these models a relatively poor fit in comparison to models that do not account for changes in productivity, given the large variability in the stock-recruitment data and the penalty for the additional parameter (Holt and Michielsens 2019).

Across chapters, information on environmental conditions is most often accounted for in pre-season run size forecasts when using spawner-recruitment models. Spawner-recruitment models are generally used to forecast the number of adult returns under an assumption of long-term average productivity. These models therefore ignore the declines in productivity that have been observed for many of the stocks and Pacific salmon species covered by the Treaty (e.g., Peterman and Dorner 2021, Malick et al. 2016, Dorner et al. 2018). The potential bias in forecasts, when marine survival or productivity has changed and deviates substantially from their long-term average, can be reduced by including data on environmental conditions in the forecast model that are an indicator of recent recruitment success. While research suggests that including environmental data or indicators when generating annual fish stock forecasts is of limited value given the risk of spurious relationships (Basson 1999, Subbey et al. 2014), these models can capture general trends in environmental conditions and generate run size forecast time series more in line with recent productivity (Crone et al. 2019). Environmental data are routinely used as a covariate in spawner/recruitment-based forecast models for Fraser sockeye and pink salmon, as well as some of the southern chum and coho stocks and coastwide Chinook stocks (Chapter 3) (Figure 6; Table 7). Similar to forecasts that incorporate environmental information for other fish species (Marshall et al. 2019), the most common environmental indicators used to forecast salmon returns are based on the physical environment, in particular conditions at sea (Table 7). Coastal sea surface temperature and the Pacific Decadal Oscillation - an ocean basin scale index of ocean temperature, are the most common environmental indicators used across PST Chapters and are considered proxies for the biological conditions salmon experience at sea (Myers 1998). We note, however, that the meaning of ocean basin scale indexes of ocean temperature are changing, as the ocean warms, along with their relationships with salmon returns (e.g., Litzow et al. 2020). Less widely used indicators relate to species interactions, with the most common ones related to the abundance of salmon prey species in the ocean. More recently, the abundance of competing species has also been explored in some of the chapters given evidence that increased abundance of pink salmon in some years in the Pacific Ocean may be negatively impacting other salmon species (Connors et al. 2020).

FISHERIES MANAGEMENT GOALS

While accounting for environmental conditions in forecasts and in-season assessments can make meeting annual management goals in the face of a changing climate more feasible for Pacific salmon stocks compared to other fish species, the extent to which changes in productivity have been considered in the benchmarks or reference points used to define management goals has been limited (Figure 7). Across chapters, declines in abundance and increasing variability in productivity and/or marine survival have been identified as major management concerns. However, regular reviews of reference points, for example every 5 to 10 years to judge whether they implicitly account for long term changes in productivity (Silvar-Viladomiu et al. 2022), has typically not occurred for the majority of chapters. Environmentally driven changes in demographic characteristics (i.e., size, age, and sex) of returning adults, and their implications for reproductive potential and reference points (e.g., Staton et al. 2022), have also been identified as a management concern, especially for chapters that include Chinook salmon (Chapters 1, 3 and 8). However, these demographic changes have not yet been formally considered in assessment and management measures of most chapters. We do note, however, that in Chapter 3 changes in reproductive potential associated with changes in maturation rates are accounted for in Model stocks in the PSC Chinook Model which produces abundance indices and annual catch limits for the upcoming fishing season in the three AABM fisheries.

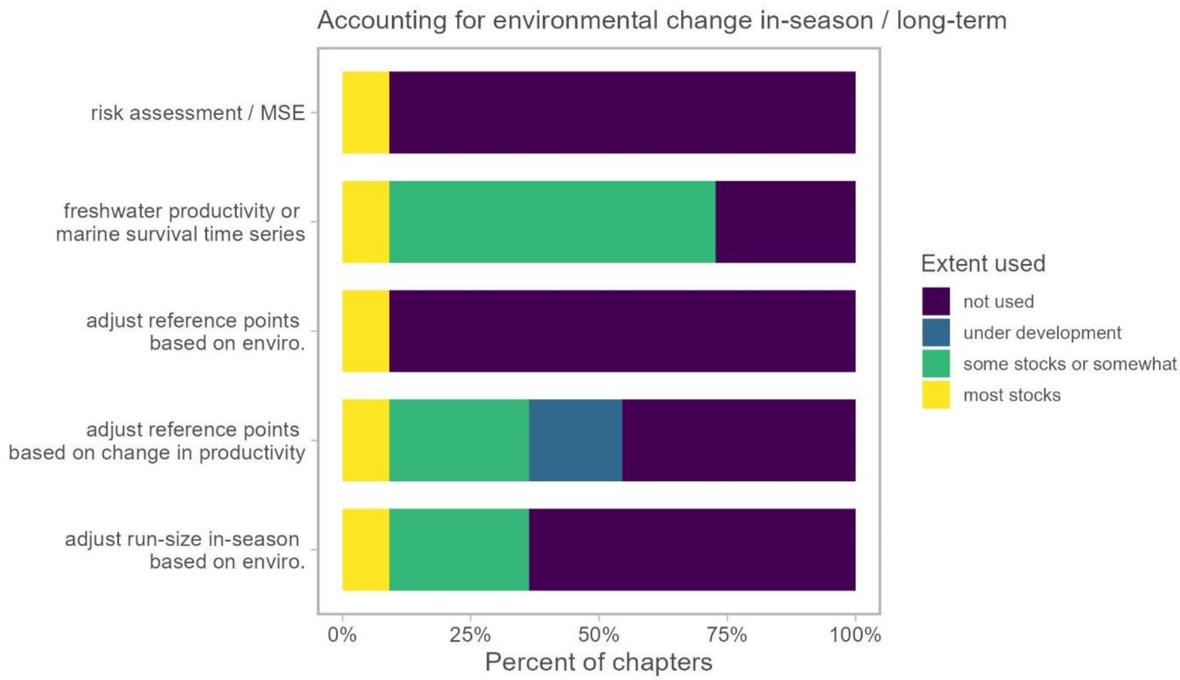

Figure 7. *Extent to which environmental change is taken into account in-season and when estimating reference points or conducting fishery risk assessments.*

Climate change impacts the ability of fisheries management strategies to achieve their goals (Punt et al. 2014, Kvamsdal et al. 2016). While accounting for trends in productivity when developing reference points ensures they reflect contemporary conditions, it does not account for increased variability from year to year in survival due to rapidly fluctuating environmental conditions. One way to account for this variation in survival is to explicitly take it into account when developing harvest control rules which determine the amount of fishing that can take place for a given stock status or abundance. For Fraser River sockeye, the harvest control rule adjusts the fishing activity based on in-season run size estimates, but instead of using fishing mortality as part of the harvest control rule, total allowable mortality (natural plus fishing mortality) is used. As a result, in years when natural mortality is expected to be large during the freshwater return migration, as predicted from observations of temperature and discharge, the total allowable catch (TAC) is reduced, while in years when environmental conditions are not a concern, the TAC can be larger. So while the harvest control rule and the escapement goals may remain the same across years, the total allowable catch is adjusted based on the environmental conditions encountered in any given year thus making fisheries management decision more likely to meet conservation objectives in the face of changing environmental conditions. Fraser River sockeye is the only PST Chapter where freshwater environmental information is explicitly incorporated into the annual management of salmon stocks through the harvest control rule.

VERIFYING CHANGES IN PRODUCTIVITY AND EVALUATING MANAGEMENT RESPONSES

When adjusting reference points and/or management goals as a result of changes in productivity, it can be helpful to understand the extent to which they are a result of changes in freshwater productivity vs. marine survival. The collection of life stage-specific abundance data for hatchery and wild smolts (or fry in the case of pink salmon) enables estimates of life stage-specific survival and the tracking of both freshwater productivity and marine survival over time. This is done to varying degrees across most chapters with the exception of most Chapter 3 Chinook stocks, one Chapter 1 coho stock and chum salmon (Chapters 6 and 8). Estimates of juvenile (fry and smolt) abundance are typically based on data collected from in-river assessment projects like fry and smolt traps, but can also be based on smolt tagging projects or juvenile marine surveys.

Management strategy performance is commonly evaluated by comparing realized escapement against escapement goals or harvest rates against harvest rate limits, either annually or across several years. This is done across all PST Chapters. While this allows for a retrospective evaluation of the performance of the annual assessment and management frameworks in place, it does not allow for prospective evaluation of the appropriateness of reference points, harvest control rules, or escapement goals to meet management objectives given long-term changes in productivity and survival. Closed loop Management Strategy Evaluation (MSE) would allow management agencies to quantitatively evaluate alternative management strategies that may be more robust to the uncertainty associated with the change and fluctuations in productivity (Punt et al. 2014). Though closed loop simulations are not very common across PST chapters (i.e., are only used for Fraser sockeye), they have been identified as a priority in several chapters (Yukon Chinook, Skeena sockeye, and Fraser pinks) (Figure 7).

Accounting for, and conveying uncertainty

Uncertainty is a pervasive and well recognized aspect of fisheries management, but if and how it is accounted for and conveyed to decision makers varies tremendously across fisheries, regions, and species. There are multiple dimensions to uncertainty in salmon assessment and management (e.g., Peterman 2004): (1) **natural variation** in both physical and biological processes; (2) uncertainty because of imperfect assessment arising from **measurement/observation error**; (3) **structural uncertainty** because of incomplete understanding of how a system functions leading to assessment model misspecification; and lastly (4) **outcome uncertainty** in how well a given management objective (e.g., an escapement goal) is achieved by a management action (e.g., total allowable catch).

Climate change has the potential to exacerbate all four forms of uncertainty. For example, climate change can increase natural variation in survival from year to year, or cause abrupt and extreme changes in it (e.g., through marine heatwaves or regime shifts). Declines in abundance can make estimates of spawner abundance and/or harvest more uncertain as fewer and fewer fish are assessed or caught in fisheries (increasing measurement and assessment uncertainty). Longstanding relationships between marine climate indices and salmon survival are breaking down as the ocean climate changes (Litzow et al. 2020), leading to increased structural uncertainty in assessments like preseason forecasts. Increased thermal stress during long freshwater migrations can increase mortality and outcome uncertainty by undermining the ability of in-river management measures (e.g., harvest restrictions) to meet biological objectives (e.g., escapement goals). Climate change and resulting deviations in 'normal' fish behavior can also impact in-season assessment. For example, high water temperatures may cause salmon to swim deeper in the water column, making them less susceptible to the traditional fishing gear used in some locations to generate indices of abundance. Such climate-induced behavioral changes may initially bias estimates of run size and, over time, lead to greater uncertainty in estimates of them.

In the face of these uncertainties several general best practices for communicating and accounting for uncertainty have emerged in the literature. These include formalizing the communication of risk through procedures such as decision tables and risk matrices to encourage decision-making that is informed by the expected outcomes of various management strategies in the face of uncertainty. They also include testing assessment and management procedures for their robustness to uncertainty, including harvest control rules, escapement goals, and other reference points to determine their robustness to key sources of uncertainty. This testing can be done with decision analyses (e.g., Pestes et al. 2008), closed-loop simulation (e.g., Collie et al. 2012, Connors et al. 2020, Freshwater et al. 2020) and the use of explicit risk evaluation frameworks such as Management Strategy Evaluation (e.g., Cunningham et al. 2019). Under the PST, there is considerable progress that could be made to further improve the communication of, and accounting for, risk. In certain chapters, there is a mandate to do exactly that.[1]

Across chapters, preseason forecasts commonly include associated statements of uncertainty which is primarily driven by natural variation (Figure 8; Table 8). The extent to which model (i.e., structural) uncertainty is accounted for differs widely with some chapters relying on two or three different models

[1] Chapter 3, paragraph 1(g): changes in ocean and freshwater conditions, stock-specific cohort survivals, stock abundances, and stock distribution are being observed. To the extent practical, the Parties shall consider these sources of uncertainty to avoid unwarranted escalation of Chinook mortalities.
Chapter 5, paragraph 7(l): The Coho Technical Committee shall undertake bilateral, technical investigations and recommend methods to address uncertainty and the impact of environmental change, for consideration by the Working Group.

while others annually evaluate a wide range of different potential forecast methods and compare results. Alternatively, some forecasts undergo bias corrections based on recent forecast errors.

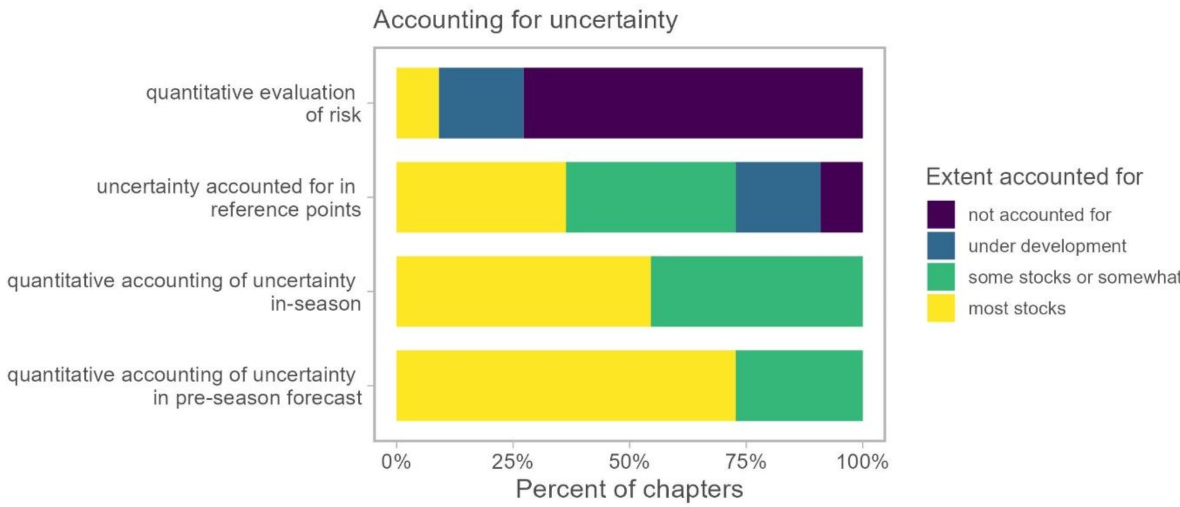

Figure 8. *Extent to which uncertainty is accounted for across chapters.*

Quantitative in-season assessments, like those for Fraser sockeye, routinely produce quantitative statements of uncertainty associated with the run size and the probability to reach escapement goals (Table 8). The timeliest in-season assessments with the lowest uncertainty generally produce the highest probability of attaining management objectives of harvest sharing and escapement objectives, notwithstanding considerations such as co-migrating species.

Uncertainty arising from natural variation and measurement error is also accounted for when deriving escapement goals and the reference points that make up harvest control rules for some chapters including Transboundary River stocks, and work is in progress to do so in Yukon Chinook, but not others like coastwide Chinook, Fraser pinks and Southern coho (Figure 8; Table 8). However, structural uncertainty and the expected ability of escapement goals and reference points to meet management objectives in the face of outcome uncertainty (e.g., climate change) is typically not accounted for. In some Transboundary River stocks the communication of risk is formalized through the use of yield and overfishing profiles (e.g., Fleischman et al. 2012) which quantify the chances of meeting both fishery and conservation objectives across a range of escapements after taking natural variation in survival and age-at-maturation, as well as measurement error, explicitly into account.

The overall performance of management measures in meeting fishery and conservation objectives is evaluated retrospectively for most chapters (Table 8), which results in a qualitative evaluation of both the biological and fishery risks associated with the management strategy that has been employed. Some chapters extended this assessment through to a qualitative evaluation of the impact of different sources of uncertainty on fisheries management performance. The use of a Management Strategy Evaluation through closed loop simulations remains, however, very uncommon having only been routinely carried out for Fraser sockeye, though several chapters have expressed interest and/or plans to use closed-loop simulations to prospectively evaluate assessment and management performance in the face of all four common forms of uncertainty (Yukon Chinook, Skeena sockeye, and Fraser pinks).

Conclusions and next steps

For Pacific salmon, accounting for the impact of climate-driven environmental change can occur in pre-season forecasts and in-season estimation of total returns, and when developing reference points, escapement goals, and harvest control rules. Across the assessment frameworks of the PST, information on the influence of environmental variability on survival and returns is most often accounted for in pre-season run size forecasts. In-season assessments, which directly reflect the influence of environmental conditions on salmon survival up until their return to terminal areas, are also used to estimate run size for a number of chapters. In contrast, there is relatively limited accounting for environmentally driven changes in productivity when estimating reference points used to define management goals. The collection of smolt (or fry) data to derive time series of freshwater productivity and marine survival can help inform the appropriateness of reference points and whether they should be adjusted following environmental changes, and these data are collected to varying degrees across most chapters. The use of risk assessment approaches to prospectively evaluate the appropriateness of reference points, harvest control rules, or escapement goals to meet management objectives in the face of climate change has also been limited, though it has been identified as a priority in some chapters. As a result, across PST chapters there is considerable progress that could be made to further improve the communication of, and accounting for, risk as a result of uncertainty due to climate change.

Overall, our review illustrates that, in comparison to other fisheries, the annual assessments of Pacific salmon across PST chapters generally attempt to account for environmental and climate-driven impacts on survival through the use of salmon-specific tools such as in-season assessments and, to a certain extent, the incorporation of environmental information in forecasts and/or reliance on sibling information. However, relationships between the environment and survival are becoming increasingly unreliable, sibling relationships are not available for all species and stocks, and not all fisheries are amenable to in-season assessments. The complexities that result from differences in salmon biology and harvest regimes mean that the value of specific approaches to accounting for environmental variation vary across species and Chapters. A key challenge moving forward is ensuring annual management goals (and associated reference points) are selected appropriately, given climate driven impacts on the growth, distribution, survival, and abundance of Pacific salmon.

Despite these findings, our report does not make forward-looking recommendations as it is recognized that these must be developed in partnership with Panels and Technical Committees to be effectively adopted and used. It is therefore recommended that this report be followed up with a multi-year process[2] that engages members of PSC Panels and Technical Committees to:

a) discuss the implications of this report;
b) deliberate on specific opportunities to improve the adequacy and responsiveness of PSC assessment and management frameworks to climate driven change; and
c) develop chapter specific feedback from the PSC membership for both parties for further consideration and evaluation ahead of the renegotiation of the next PST.

The PST is principally focused on harvest management and the assessment and management structures required to ensure obligations under the treaty are met. However, some Panels and Technical Committees have sought greater PSC attention to the risks, uncertainties, and actions required in the face of climate change. There are also certain chapter requirements to consider the uncertainties arising from changes

[2] ESSA Technologies (Vancouver, BC) has proposed to launch such consultations with potential financing from the Northern and Southern Endowment Funds in 2023.

in salmon ecology. Research shows that there are options available to the PSC, including preserving and protecting salmon population diversity and the unique adaptations that underpin it (aka “biocomplexity”), as well as the heterogenous and complex habitat landscapes and the processes that generate it (e.g., Hilborn et al. 2003, Moore and Schindler 2022). Keeping these general principals in mind as the PSC adapts its assessment and management frameworks in response to the challenges posed by climate change will help ensure the objectives of the PST are met in a rapidly changing and unpredictable future.

Overview tables

Table 1. *Average returns (adult returning salmon), spawner abundances and harvest rates in two periods as well as the percentage change between periods.*

	1985-1995 averages			2008-2021 average			% Change		
Chapter-species	**Returns**	**Spawners**	**Harvest rate**	**Returns**	**Spawners**	**Harvest rate**	**Returns**	**Spawners**	**Harvest rate**
Yukon-Chinook	154,611	46,719	0.70	66,143	49,768	0.25	-57	7	-65
TBR-Sockeye	323,311	137,149	0.58	290,015	152,295	0.46	-10	11	-21
TBR-Chinook[1]	71,289	62,765	0.12	27,134	21,668	0.17	-62	-65	43
TBR-Coho	311,067	112,377	0.64	174,754	100,892	0.41	-44	-10	-36
Skeena-Sockeye	3,464,359	1,438,844	0.59	1,602,857	1,044,907	0.30	-54	-27	-49
Southern-Chum	5,012,044	2,553,068	0.49	4,128,576	2,269,513	0.43	-18	-11	-12
Southern-Coho	901,467	296,933	0.66	398,205	263,857	0.32	-56	-11	-51
Fraser-Sockeye	13,173,013	3,137,777	0.73	6,161,645	2,911,470	0.25	-53	-7	-66
Fraser-Pinks	15,124,491	8,262,258	0.47	11,833,541	8,915,094	0.18	-22	8	-62

[1] Terminal harvest regimes for TBR (Chapter 1) Chinook did not begin until 2005.

Table 2. *Average Chinook salmon abundance index, as reconstructed by the Chinook Technical Committee, among regions and across two periods as well as the percentage change between periods.*

Region	Avg. index 1985-1995	Avg. index 2008-2021	% change in index
Southeast Alaska	1.74	1.32	-24
Northern BC	1.52	1.30	-15
West Coast Vancouver Island	0.91	0.83	-9

Table 3. *Commonalities and differences among chapters in management approaches (Legend: x = most stocks, (x) = some stocks or somewhat, blank = unknown or not used, … = under development).*

	Pacific Salmon Treaty Chapter										
	1			2	3	4		5	6	8	
	Transboundary Chinook	Transboundary Sockeye	Transboundary coho	Nass and Skeena River sockeye	Chinook All stocks	Fraser River sockeye	Fraser River pink salmon	Southern coho Selected stocks	Southern Chum All stocks	Yukon River Chinook	Yukon River Chum
Management Framework											
Management plan											
Strategic Plan	x	x	x	x	(x)	x	x	(x)	x	x	x
Annual management plan	x	x	x	x	x	x	x	x	x	x	x
Management objectives											
Achieve escapement goal or range	x	x	(x)	x	x	x	x	(x)	x	x	x
Achieve harvest rate objectives					x			x	(x)		
Specified harvest sharing	(x)	(x)	(x)	x		x	x		x	x	x
Specified enhancement objectives		(x)									
Regional (non-PST) management allocations	x	x	x	x	x	x	x	x	x	x	x
Characteristics of managed fisheries											
Mixed stock fishery(s)	(x)	(x)	(x)	x	x	x	(x)	x	x	x	x
Terminal fishery(s)	x	x	x	x	x	x	x	x	x	x	x
Coastal fishery(s)				x	x	x	x	x	x		
Ocean fishery(s)					x			x			
Management type											
Abundance based	x	x	(x)	x	x	x	x	x	x	x	x
Estimate relative abundance					x						
Estimate total abundance	x	x	(x)	x		x	x	(x)	(x)	x	x
In-season assessments & management	(x)	x	(x)	x		x	x	(x)	x	x	x
Management performance evaluation											
Annual postseason assessment	x	x	x	x	x	x	x	x	x	x	x
Multi-year assessment	x	x			x				…		

Table 4. *Commonalities and differences among chapters in assessment tools used (Legend: x = most stocks, (x) = some stocks or somewhat, blank = unknown or not used, … = under development).*

	Pacific Salmon Treaty Chapter										
	1			2	3	4		5	6	8	
	Transboundary Chinook	Transboundary Sockeye	Transboundary coho	Nass and Skeena River sockeye	Chinook All stocks	Fraser River sockeye	Fraser River pink salmon	Southern coho Selected stocks	Southern Chum All stocks	Yukon River Chinook	Yukon River chum
Preseaon forecasts											
Qualitative			(x)						(x)		
Quantitative	x	x	(x)	x	(x)	x	x	(x)	(x)	x	x
In-season assessment											
	(x)	x	(x)	x	…	x	x	(x)	x	x	x
Fishery reference points											
Lower	x	x	(x)	…	(x)	x		(x)	(x)	(x)	(x)
Upper	x	x	(x)	…	(x)	x	x	(x)	(x)	(x)	(x)
Harvest control rules											
	x	x	(x)	x	x	x	x	(x)	x	x	x
Escapement goal(s)											
	x	x	(x)	x	(x)	x	x	(x)	(x)	(x)	(x)
Management Strategy Evaluation											
Closed loop simulation				…		x	…				

Table 5. *Summary of assessment and management challenges across chapters with a particular emphasis on those related to environmental change (Legend: x = most stocks, (x) = some stocks or somewhat, blank = unknown or not used, … = under development).*

	Pacific Salmon Treaty Chapter										
	1			2	3	4		5	6	8	
	Transboundary Chinook	Transboundary Sockeye	Transboundary coho	Nass and Skeena River sockeye	Chinook All stocks	Fraser River sockeye	Fraser River pink salmon	Southern coho Selected stocks	Southern Chum All stocks	Yukon River Chinook	Yukon River chum
Abundance and survival											
Long-term decrease in abundance	x			x	x	x		x	(x)	x	
Recent record low abundance	x			x	(x)	x		x	x	x	x
Fluctuations in marine survival & productivity	(x)	(x)		x	x	x	x	x	x	x	x
Long-term decrease in marine survival/productivity	x			(x)	x	x	x	x		x	
Fisheries and mixed stock fisheries											
Long-term decrease in exploitation rate, catches	(x)			x	x	x	x	x	(x)	x	
Recent record low catches	x	x		x		x	x	x	(x)	x	x
Presence of weak (small, unproductive, at-risk) stocks/CUs				x	(x)	x		x	(x)	x	
Presence of weaker co-migrating species		x		x		x	x	x	(x)	x	x
Enhanced stocks		(x)		(x)	x			x	(x)	x	
Environmental and other changes											
Changes in species demographics	x				x				(x)	x	
Changes in marine distribution of stocks					(x)				(x)		
Changes in migratory timing of species/stocks				x					(x)		
Changes in freshwater environment conditions				x	(x)	x	x	x	(x)	x	x
Increased marine predation	x	x	x	x	(x)						
Occurrence of recent landslides that block migration				(x)		(x)	(x)				

-continued-

Table 5. *(Page 2 of 2).*

	Pacific Salmon Treaty Chapter										
	1			2	3	4		5	6	8	
	Transboundary Chinook	Transboundary Sockeye	Transboundary coho	Nass and Skeena River sockeye	Chinook All stocks	Fraser River sockeye	Fraser River pink salmon	Southern coho Selected stocks	Southern Chum All stocks	Yukon River Chinook	Yukon River chum
Assessment challenges											
Lack of stock-recruitment data			x	(x)	(x)		x	(x)	(x)	(x)	x
High uncertainty associated with preseason forecasts	(x)	(x)			x	x	x		x		
Uncertainty in-season assessments due to:	(x)	(x)	(x)	x		x	x		x	x	x
- Low returns and/or limited/no catches (low quality or no data)			(x)	(x)		(x)	x				
- Other data limitations e.g. stock/species ID resolution	(x)	(x)					x		x	x	x
- Timeliness of the data for management decisions	(x)	(x)		(x)		x	x		x	x	x
- Annual deviations from averages				x		x	x		(x)		
Outdated base calibration period given current conditions					x			x			
Lack of reference points, escapement goals or HCRs			(x)		(x)				(x)		
Lack of funding for data collection, assessments, etc.	(x)	(x)	(x)		(x)		x		x		
Management challenges											
Failure to meet escapement goals, in part due to:	(x)	(x)		(x)	(x)	(x)			(x)	(x)	(x)
- Overfishing				(x)		(x)			(x)		
- Low productivity/low returns	(x)	(x)		(x)	(x)	x			x	x	x
- High en route losses					(x)	x					
- Impact of competition in the ocean									x		
- Incidental by-catch in other fisheries				(x)	(x)	(x)			(x)		

Table 6. *Degree to which environmental information is incorporated into assessments and management advice across chapters (Legend: x = most stocks, (x) = some stocks or somewhat, blank = unknown or not used, … = under development, n/a= not applicable or not a concern, ~ = reported/evaluated but not incorporated).*

	Pacific Salmon Treaty Chapter										
	1			2	3	4		5	6	8	
	Transboundary Chinook	Transboundary Sockeye	Transboundary coho	Nass and Skeena River sockeye	Chinook All stocks	Fraser River sockeye	Fraser River pink salmon	Southern coho Selected stocks	Southern Chum All stocks	Yukon River Chinook	Yukon River chum
Management and assessment tool											
Preseason forecast											
Change in productivity accounted for	(x)	(x)	(x)	(x)	(x)	x	(x)	(x)	(x)	(x)	(x)
Environmental covariate incorporated					(x)	x	x	(x)	(x)		
In-season assessments											
Temperature/weather	n/a	n/a	n/a	n/a		x	n/a		(x)	~	~
River discharge						x	n/a		(x)	~	~
Reference Point, HCR, Escapement goal											
Change in productivity	(x)	(x)		…	(x)	x	…			~	~
Environmental covariate						x					
Validation tools											
Freshwater productivity and marine survival time series	(x)	(x)	(x)	(x)		(x)	(x)	(x)		x	
Close loop MSE simulation						x					

Table 7. *Degree to which environmental information is incorporated into preseason forecast across chapters (Legend: x = most stocks, (x) = some stocks or somewhat, blank = unknown or not used).*

	Pacific Salmon Treaty Chapter										
	1			2	3	4		5	6	8	
	Transboundary Chinook	Transboundary Sockeye	Transboundary coho	Nass and Skeena River sockeye	Chinook All stocks	Fraser River sockeye	Fraser River pink salmon	Southern coho Selected stocks	Southern Chum All stocks	Yukon River Chinook	Yukon River chum
Incorporating environmental data											
Qualitative											
Expert-based					(x)	x	x	x	x	x	x
Evaluation of ocean conditions						x	x	x	x	x	x
Evaluation of freshwater conditions						x	x	x	x	x	x
Quantitative (covariates)											
Environmental indicators:											
Ocean indicators					(x)	x	x	x	(x)		
Region scale indicators					(x)	x	x	x	(x)		
Local scale indicators					(x)	x	x	x			
Example indicators:											
North Pacific Gyre Oscillation (NPGO)					(x)			x	(x)		
Pacific Decadal Oscillation (PDO)					(x)	x	x	x	(x)		
River discharge						x	x	x			
Sea surface temperature (SST)					(x)	x	x	x	(x)		
Sea surface salinity (SSS)					(x)		x	x			
Copepod Biomass/composition								x			
Chlorophyll								x			

-continued-

Table 7. *(Page 2 of 2).*

	Pacific Salmon Treaty Chapter										
	1			2	3	4		5	6	8	
	Transboundary Chinook	Transboundary Sockeye	Transboundary coho	Nass and Skeena River sockeye	Chinook All stocks	Fraser River sockeye	Fraser River pink salmon	Southern coho Selected stocks	Southern Chum All stocks	Yukon River Chinook	Yukon River chum
Incorporating change in productivity											
Qualitative											
Expert-based					(x)	x	x		x		
Quantitative											
Time-varying productivity					(x)	x					
Autoregressive marine survival					(x)				(x)		
Recent marine survival		(x)			(x)	x		(x)			
Using recent years of data	(x)			x	x				(x)		
Bias corrections based on recent error	x	x									(x)
Fry /smolt data (acct. for freshwater prod.)		(x)	(x)	(x)		(x)	x	(x)	(x)	x	
Sibling models (acct. for ocean prod.)	x	(x)		x	(x)	x		(x)		x	(x)

Table 8. *Extent to which uncertainty is accounted for in management advice, by management tool (Legend: x = most stocks, (x) = some stocks or somewhat, blank = unknown or not used, … = under development).*

	Pacific Salmon Treaty Chapter										
	1			2	3	4		5	6	8	
	Transboundary Chinook	Transboundary Sockeye	Transboundary coho	Nass and Skeena River sockeye	Chinook All stocks	Fraser River sockeye	Fraser River pink salmon	Southern coho Selected stocks	Southern Chum All stocks	Yukon River Chinook	Yukon River chum
Preseaon forecasts											
Qualitative statement of uncertainty provided								(x)	(x)		
Quantitative expression of uncertainty provided	(x)	(x)	(x)	x	(x)	x	x	(x)		x	x
Model uncertainty evaluated/accounted for				x	x	x	x	x	(x)	x	x
In-season assessment											
Qualitative statement of uncertainty provided								(x)			
Quantitative expression of uncertainty provided	(x)	(x)	(x)	x	(x)	x	x	(x)	x	x	x
Fishery reference points, harvest control rules, escapement goals											
Uncertainty accounted for	x	x	(x)	…	(x)	x		…	(x)	(x)	(x)
Management Strategy Evaluation											
Qualitative evaluation of the impact of sources of uncertainties on management					x			x	x	(x)	(x)
Qualitative evaluation of risk through evaluation of historical performance	x	x	(x)	x	x	x	x	x	x	x	x
Quantitative evaluation of risk through closed loop simulations:				…		x	…				
Accounts for alternative biological assumptions				…		x	…				
Accounts for different hypotheses of future states of nature				…		x	…				

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Glossary

AABM – Aggregate Abundance Based Management

AC – Allowable Catch

ACL – Annual Catch Limit

ADF&G – Alaska Department of Fish and Game

AI – Abundance Index

B.C. - British Columbia

BY – Brood Year

ChumGEM – Chum Genetic and Environmental Management Model

CBC – Central British Columbia

CI – Confidence Interval

CNR – Chinook Non-retention

COSEWIC – Committee on the Status of Endangered Wildlife in Canada

CPUE – Catch per Unit Effort

CR – Chinook Retention

CSC – Standing Committee on Scientific Cooperation

CTC – Chinook Technical Committee

CU – Conservation Unit, a group of wild salmon sufficiently isolated from other groups that, if extirpated, is very unlikely to re-establish naturally within an acceptable time frame, such as a human lifetime or a specified number of salmon generations.

CWT – Coded Wire Tag

CY – Calendar Year

CYER – Calendar Year Exploitation Rate

DBE - Differences Between Estimates - Difference between estimates of spawning escapement and potential spawning escapement for Fraser River sockeye salmon.

Diversion Rates – Generally refers to the proportion of the Fraser River sockeye run that returns via Johnstone Strait (northerly) or St of Juan de Fuca (southerly). The diversion rate determines the relative susceptibility of the run to fisheries conducted in northern and southern areas.

DFO – Fisheries and Oceans Canada

Domestic Allocation Goals – Predetermined rules to allocate harvest among domestic groups.

DU - Designatable Unit – Stock grouping based on established taxonomy, genetic distinction, range disjunction or bio-geographic distinction.

Enhancement – Hatchery-reared contribution to a salmon stock.

EO – Economic Opportunity fishery

ER – Exploitation Rate

ERA – Exploitation Rate Analysis.

ESA – U.S. Endangered Species Act

Escapement Goals – A numerical target for the number of fish desired to reach spawning grounds

Exploitation Rates – The proportion of a fish stock or population removed by fishing across all gear sectors.

FRAM – Fisheries Regulation Assessment Model

FRP – Fraser River Panel

FSC – Food, Social and Ceremonial

GAM – Generalized Additive Model

Gear Sector – Fisheries sector determined by regulation, fishing method and gear type.

GSI – Genetic Stock Identification

GU – Genetic Unit

Harvest control rules (HCR) – Operational component of a harvest strategy that conveys the pre-agreed rules that determine how much fishing can take place.

Harvest sharing rules – Management tool used to allocate harvest among user groups

Hydroacoustic Data – An index of abundance produced by acoustic equipment at a fixed site, generally of adult fish migrating upriver.

IFMP – Integrated Fisheries Management Plan

IM – Incidental Mortality.

In-season Assessments – Assessments to inform fisheries management in real time throughout the fishing season.

ISBM – Individual Stock Based Management

ISC – Inside Southern Chum

ISU – In-season update model

ITQ – Individual Transferable Quota

Joint TBR Panel – Transboundary River Panel Chapter 1 of the PST.

LAER - Low Abundance Exploitation Rate - The purpose of managing a sockeye management group in a LAER situation is to permit by-catch of that stock group in fisheries directed at other management groups or species with available surpluses.

LAT – Low Abundance Threshold

LFRP – Lower Fishery Reference Point – DFO fishery decision making tool that marks the boundary below which there is a high probability of serious harm to a stock.

LOAF – List of Agreed Fisheries of the U.S. North of Cape Falcon process.

LRF – Limit Reference Point

MA – Management Adjustments – Additional fish added to an escapement target for the purpose of increasing the likelihood of achieving the escapement target.

MFMT – Maximum Fishing Mortality Threshold

MP – Management Plan – The plan developed for the management of the fisheries, by the appropriate regulatory authority.

MR – Mark-recapture – Method used to estimate stock sizes through the capture and marking of part of the population and subsequent recapture. Also referred to as capture-recapture.

MSA – Mixed stock analysis

MSE – Management Strategy Evaluation - Simulation tool that allows evaluation of the effectiveness of different harvest strategies to reach the specified management objectives.

MSH – Maximum Sustainable Harvest

MSY – Maximum Sustainable Yield – The maximum number of salmon that can be harvested from a stock in the long-term under equilibrium conditions.

MTs – Management Tools – Different tools that can be used to regulate fisheries, habitat or hatchery production.

MU – Management Unit – A group of stocks that are assessed and/or managed in the same way.

NEF – PSC Northern Boundary and Transboundary Rivers Restoration and Enhancement Fund (the Northern Fund)

NMSY – Spawning abundance associated with MSY.

NPGO – North Pacific Gyre Oscillation, a climate pattern used as an index to measure changes in ocean currents and circulation patterns.

Pacific Salmon Treaty (PST) Chapters – Parts of the Treaty in Annex IV that set out the specific conservation and harvest sharing agreements between Canada and the U.S. for different species, stocks and fisheries.

PFMA – Pacific Fishery Management Area

PDO – Pacific Decadal Oscillation, a recurring atmosphere-ocean climate pattern centered over the Pacific Ocean basin, consisting of a warm and cool phase.

PPD – Prior Probability Distributions – Expresses the knowledge about a quantity of interest prior to taking additional evidence into account e.g., the preseason forecast can be used as prior probability distribution used in in-season assessments.

Preseason Forecast – A numerical prediction of the number of fish returning in a given year by stock and/or geographic region.

Productivity – Typically considered the number of adult recruits produced per spawner.

Reference points – A basis for evaluating the status of a stock and change associated management actions.

PFMC – Pacific Fisheries Management Council

R&E – Yukon River Panel Restoration and Enhancement Fund

R&M – Yukon River Salmon Research and Management Assistance Fund

SARA – Canadian Species At Risk Act

SCMP – Southern Coho Management Plan

SEAK – Southeast Alaska

SEF – PSC Southern Boundary Restoration and Enhancement Fund (the Southern Fund)

SEG – Sustainable Escapement Goal approach, which uses the long-term escapement time series to set fisheries reference points.

SET – Spawning Escapement Target - Fisheries management goal defined in terms of number of spawners instead of number of salmon escaping marine fisheries.

Sibling models – Model that implicitly account for recent environmental conditions by using observed survival of younger ages of salmon from a given brood year to predict the abundance of their older siblings returning the following year

Spawning Areas – Salmon spawning grounds.

SST – Sea Surface Temperature

Stock Identification – Refers to the ability to identify a specific stock (or stock group) in a fishery, test Fishery, etc., whether by genetic methods, CWTs, scale pattern analysis or other techniques.

Strategic Plan – Long term management and assessment plan.

TAC – Total Allowable Catch

TAM cap – Maximum amount of Total Allowable Mortality. Includes harvest and incidental fishing mortality (Chinook) and may include natural mortality as well (Fraser sockeye).

TAM rule – Total Allowable Mortality rule - For each Fraser sockeye management group at different run sizes, Canada's Spawning Escapement Plan specifies the total allowable mortality from all sources, including fishery removals (catch) and en route mortality (represented by the Management Adjustment).

TC – Technical Committee

Terminal Area – Area in or near natal salmon streams.

TF – Test Fishing – A fishery conducted by management agencies to determine the abundance and/or stock composition of returning adult salmon. A TF may be done using non-lethal methods.

TRTC – Total return to Canada

UFRP – Upper Fishery Reference Point - DFO fishery decision making tool that marks the boundary below which harvest must be progressively reduced in order to avoid serious harm to a stock.

USFWS – U.S. Fish and Wildlife Service

WCVI – West Coast Vancouver Island

YRP – Yukon River Panel

Assessment and management frameworks of the Pacific Salmon Treaty and their robustness to environmental change

Appendix: Chapter-specific information

PST Chapter 1: Transboundary Taku River Salmon Stocks

1. Introduction

Chapter 1 of the Pacific Salmon Treaty applies to Transboundary River stocks. The assessment and management of Chinook, sockeye and coho stocks within the different Transboundary River systems (Taku, Alsek, Stikine) are documented separately in this report given the differences in management and assessment.

Within the Taku River, the total terminal Chinook salmon runs over the past 10 years, have averaged just over 17,000 large fish (> 659 mm mid-eye to fork length) and have ranged from 7,300 fish in 2018 to 27,300 fish in 2014 (Figure 1)[1]. This 10-year average is a little less than half of the long-term average (1995-2020) of 39,000 fish. This does not include the smaller age-.1 and -.2 'jacks' which are males and generally average about 10,000 fish annually. All known Chinook salmon spawning occurs in the Canadian portion of the Taku River drainage. Within the drainage there are distinct early, middle, and late run timing fish which utilize distinct tributaries, but do not appear to differ in productivity.

For sockeye, the total terminal runs to the Taku River over the past 10 years (2011-2020) have averaged about 153,500 adults and have ranged from 102,000 fish in 2014 to 221,000 fish in 2016 (Figure 2)[1]. The 10-year average is about 16,000 fish under the long-term average of 169,900 fish (1984-2020). Note that the time series presented here is the most up to date, after revisions to correct historically overestimated escapement estimates; these will not match escapement estimates in Transboundary Technical Committee reports prior to 2020 such as TCTR 19-2[2]. Most sockeye salmon returning to the Taku River drainage spawn in the Canadian portion with 10% or less spawning in the U.S. portion. The spawners include both lake and river populations.

Terminal coho salmon runs to the Taku River over the past 10 years have averaged about 119,000 adults and have ranged from 71,000 fish in 2020 to 190,000 fish in 2014 (Figure 3)[1]. The long-term average for this data set begins in 1992 and runs have averaged about 168,000 adults, about 49,000 fish more than during the recent decade. On average, about 21% of coho salmon spawning occurs in the U.S. portion of the Taku River drainage[3]. Spawning occurs in a diversity of aquatic habitat (lake beaches and tributaries, rivers, streams, mainstem upwelling areas and side sloughs). Coho salmon rearing areas are also very diverse amongst riverine, lake and slough habitat; utilization varies seasonally, and rearing is generally concentrated in the lower 40 miles of the river.

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[1] PSC and Joint Transboundary Technical Committee. 2022. Final Estimates of Transboundary River Salmon Production, Harvest and Escapement and a Review of Joint Enhancement Activities in 2020. PSC Report TCTR (22)-01.

[2] PSC and Joint Transboundary Technical Committee. 2019. Final Estimates of Transboundary River Salmon Production, Harvest and Escapement and a Review of Joint Enhancement Activities in 2017. PSC Report TCTR (19)-02.

[3] Eiler, J.H., Masuda, M.M. and Carlson, H.R. 1993. Stock composition, timing and movement patterns of adult coho salmon in the Taku River drainage, 1992. National Marine Fisheries Service Technical Report, Juneau.

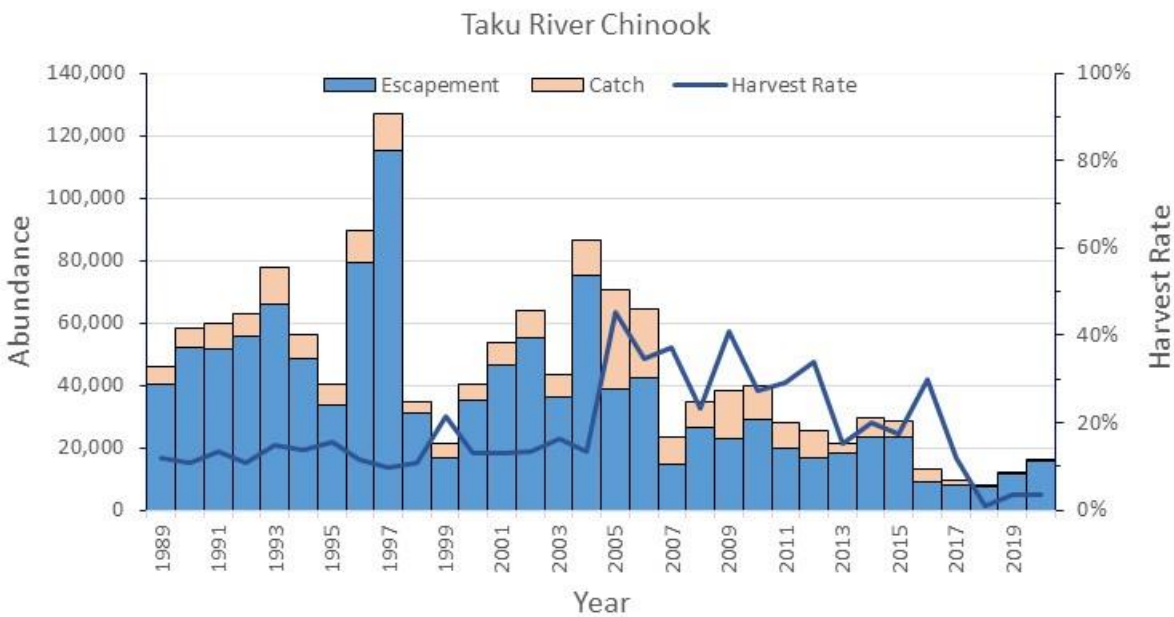

Figure 1. *Escapement, catch and harvest rate of the terminal run of Chinook salmon returning to the Taku River since 1989. Data source: TCTR 2022*[1]

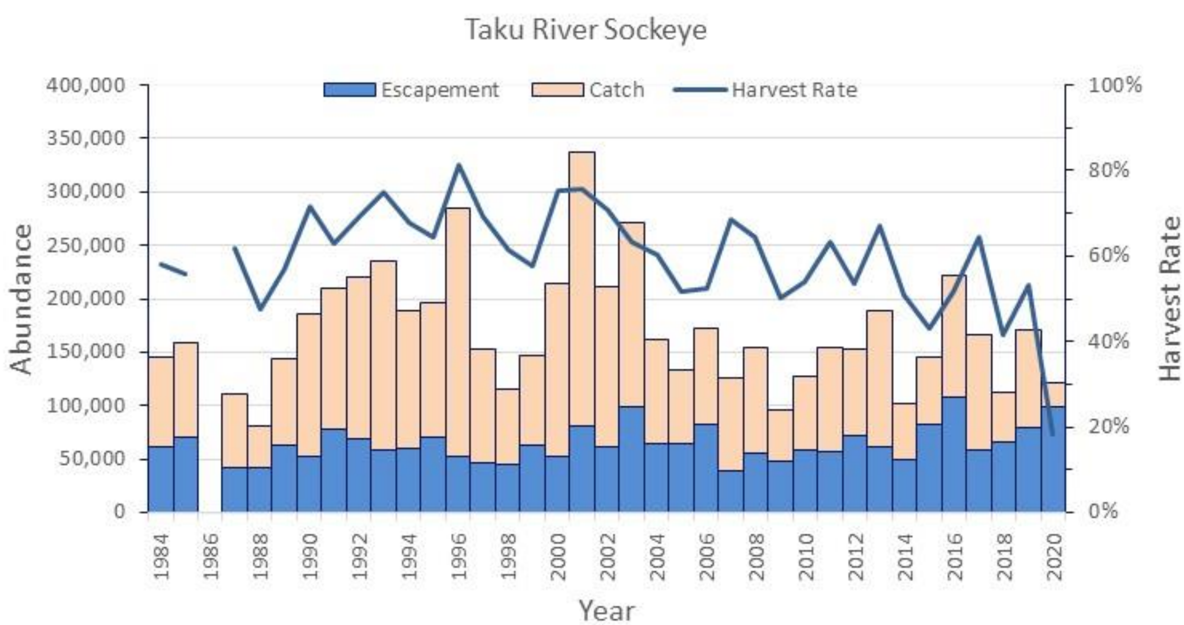

Figure 2. *Escapement, catch and harvest rate of the terminal run of sockeye salmon returning to the Taku River since 1984. Data for 1985 is not available. Data source TCTR 2022*[1]

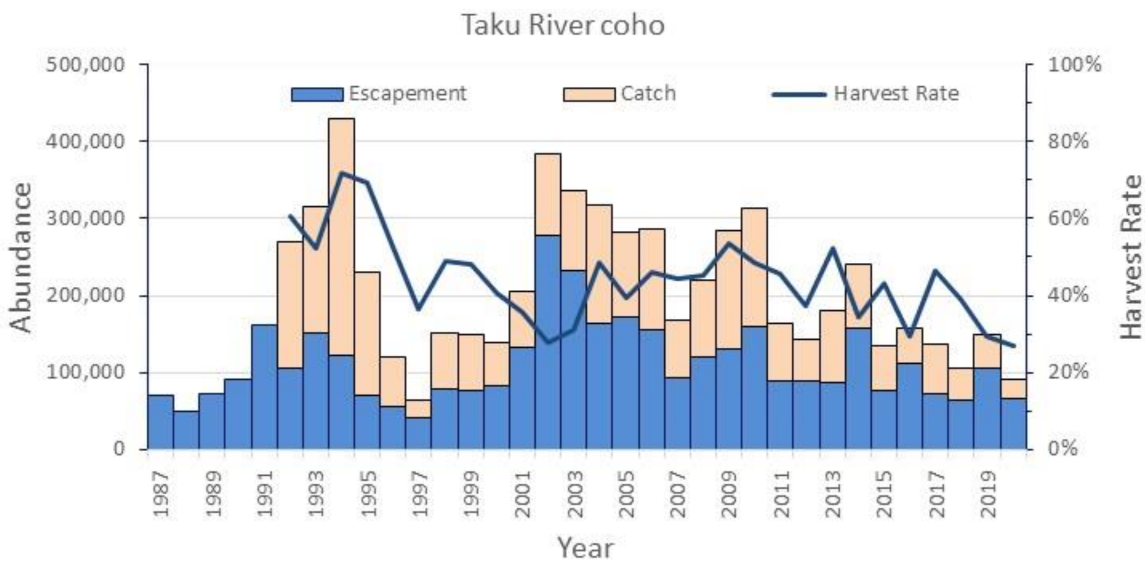

Figure 3. *Escapement, catch and harvest rate of coho salmon returning to the Taku River since 1992. Escapement is presented for 1987-1991; harvest enumeration began in 1992. TCTR 2022*[1]

2. Fisheries

The Taku River terminal run area specified in Annex IV, Chapter 1 of the PST Agreement consists of marine waters in Alaska District 111 (near Juneau in waters inside of Admiralty Island), plus the freshwater reaches within the Taku River drainage[4].

In the U.S., Taku Chinook, sockeye and coho salmon are caught in mixed stock fisheries in Alaska District 111, in commercial drift gillnet and sport hook and line fisheries. Canadian fisheries harvest Taku-origin salmon. Stock identification and harvest in mixed stock Taku fisheries are estimated by genetic stock identification methods (Chinook and sockeye), otolith banding (sockeye) and analysis of wild-stock and hatchery coded-wire tags (Chinook and coho).

Fisheries directed at Taku Chinook, sockeye and coho may have by-catch of pink salmon, steelhead and chum.

GEAR SECTORS

U.S.:

- Alaska District 111 drift gillnet (marine),
- Alaska District 111 sport hook and line (marine),
- In-river personal use,
- Alaska commercial troll,

Canada:

- In-river First Nations,
- In-river commercial gillnet, and
- In-river sport.

[4] PSC. 2020. Treaty between the government of Canada and the government of the United States of America concerning Pacific salmon. PSC, Vancouver.

INTERCEPTION OR HARVEST BY FISHERIES OUTSIDE DISTRICT 111 TERMINAL AREAS

Taku River Chinook salmon are harvested in the Southeast Alaska (SEAK) commercial troll fishery in late winter and spring and in the SEAK sport fishery (managed under Chapter 3), if open. Harvests are estimated from recovery of wild-stock coded-wire tags (CWTs). In response to poor production in the recent 4 years, the winter troll fishery has ended a month early (March 15) and the spring troll and sport fisheries have been curtailed. Taku coho salmon are harvested in the SEAK troll and sport fisheries and harvest contributions are estimated from CWT recoveries. Taku River sockeye salmon are intercepted to a minor degree in net fisheries in Lynn Canal, and Chatham and Icy Straits, if open.

FISHERY CHALLENGES

Coordinating management amongst domestic gear sectors in the U.S. (ADF&G), in Canada (DFO and Taku River Tlingit First Nation (TRTFN)), and internationally (ADF&G and DFO), is a cooperative effort that requires consistent dialogue and timely exchange of assessment data.

3. Management

The management of Taku River Chinook, sockeye and coho is the responsibility of the U.S. (ADF&G) and Canada (DFO). A strategic plan has been developed by the Transboundary Panel and Technical Committee in 2019[5]. Annual management plans are assembled and agreed to each year by the Transboundary Technical Committee and Transboundary Panel, e.g. (TCTR 2020)[6].

The management objectives for Taku River salmon runs are to: (1) achieve spawning escapement goals by species (Chinook, sockeye, coho); (2) achieve targets for international sharing of the TAC as defined in the 2019 PST Agreement (Chapter 1, Annex IV); (3) achieve sockeye salmon enhancement objectives defined in the treaty, and (4) achieve domestic allocation goals within each country. In addition, fisheries management considers the management objectives for other nearby salmon stocks.

Taku River Chinook, sockeye and coho salmon runs consist of multiple aggregates of substocks that are spread spatially and temporally throughout the drainage. Management of the Taku River Chinook, sockeye and coho salmon runs is done with an intensive in-season abundance-based approach and structured to harvest in proportion to the abundance of early, middle, and late run segments of each species each year, based on historical timing. Productivity among substocks and run segments is generally similar. ADF&G, DFO and TRTFN all contribute to the assessment framework to provide the critical numerical and biological advice to managers in both countries.

MANAGEMENT CHALLENGES

Marine survival has decreased for Chinook salmon in recent years and run sizes in some years have dropped to levels not seen since the 1970s. Marine survival has decreased 50%, on average, over the past 14 brood years (this includes adult returns through 2020, brood year 2014), compared to estimates earlier in the time series (Figure 4). Note that smolt abundance increased in the middle of this period. This downward trend in marine survival has reduced abundance; all fisheries that harvest Taku River Chinook salmon have been severely limited or closed for four years (2017-2020). The sockeye and coho salmon

[5] Pacific Salmon Commission Joint Transboundary Technical Committee (TCTR). 2019. Transboundary Panel Strategic Salmon Plan Report developed by the Joint TBR Panel and Technical Committee; Report TCTR (19)-04. Vancouver BC.
[6] Pacific Salmon Commission Joint Transboundary Technical Committee (TCTR). 2022. Salmon Management and Enhancement Plans for the Stikine, Taku and Alsek Rivers, 2022. Joint Transboundary Technical Committee Report TCTR (22)-02. Vancouver BC.

fisheries (U.S. and Canadian gillnet, U.S. troll and sport) have not been impacted to the same degree but the sockeye salmon fisheries have experienced reduced time and area in openings in recent years due to decreased abundance of co-migrating Chinook salmon. Recent abundances of sockeye and coho salmon are well within ranges of abundances observed historically (past 60 years). Unlike Chinook salmon, coho salmon marine survival estimates show no apparent trends and remained on average near 10% (Figure 5) since 1992.

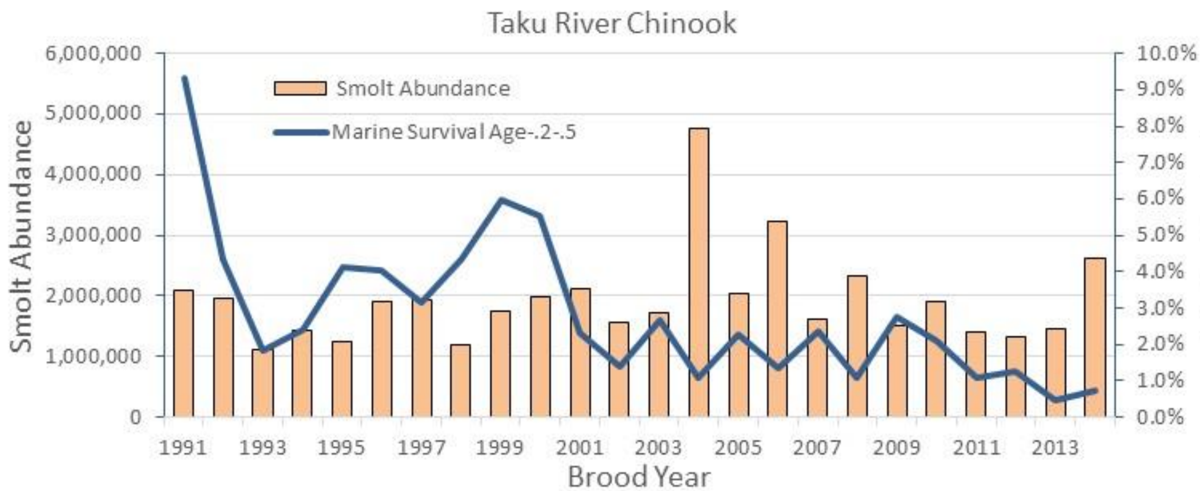

Figure 4. *Estimated smolt abundance and marine survival of Chinook salmon originating from the Taku River drainage in brood years 1991 to 2014 (current through 6-year-old return in 2020). Data source: Jeff Williams, Edgar Jones, ADF&G, Douglas, AK.*

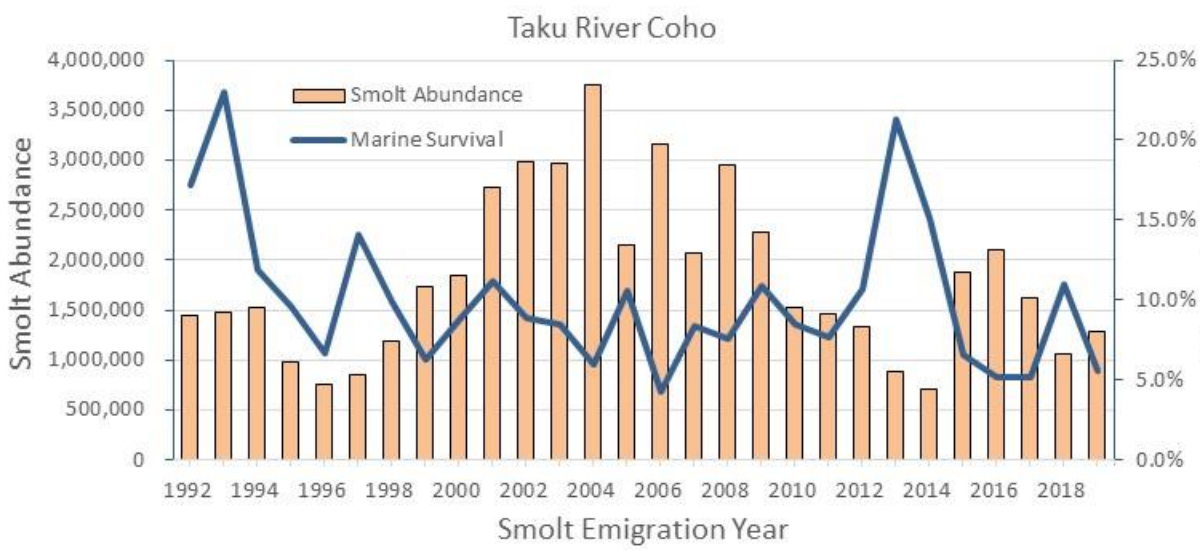

Figure 5. *Estimated smolt abundance and marine survival of coho salmon originating from the Taku River drainage in calendar years 1992 to 2019, e.g., the smolt abundance in 2019 is paired with marine survival in 2020. Data source: Jeff Williams, Edgar Jones, ADF&G, Douglas, AK.*

Recent telemetry studies (see assessment section) have identified a management concern regarding predation by marine mammals in the terminal area, particularly near the river mouth and the lower 15 miles (24 kilometres) of the river. The abundance of marine mammals, which are protected under the U.S. Endangered Species Act, is increasing in Southeast Alaska, among other places. In Taku Inlet and the lower

Taku River, increases in predatory marine mammals presumably results in increased mortality of Taku River salmon stocks.

On December 24, 2020, there was a large landslide in the lower mainstem area of the Taku River just above the area known as 'Yellow Bluff', approximately 15 miles (24 kilometres) upstream of the international border. This mass wasting event originating on a peak on the south side of the river produced a 2.9 magnitude earthquake whose seismic signature indicated it was due to the landslide. The slide dropped a large portion of the peak and the resultant debris flow of rock, soil and organic debris covered most of the mile-wide valley floor. It is unknown if this slide will affect salmon behaviour or salmon habitat, and the assessment and management frameworks utilized to manage the salmon resources of the Taku River.

4. Assessments

The assessment of Taku River Chinook, sockeye and coho salmon includes the use of annual pre-season forecasts, in-season assessments, and coded-wire tagging (for wild Chinook and coho salmon) as well as the use of management tools such as reference points, harvest control rules, and escapement goals.

PRESEASON FORECAST

The staff managing Taku River salmon rely on preseason forecasts of run size for the assessment and management of Taku River Chinook, sockeye and coho salmon stocks until in-season estimates of abundance are available.

The preseason forecasts for Chinook salmon rely on sibling models. Despite more than forty years of data being available, the TBR TC has used only the last 9 brood years for the forecast for about a decade, due to demographic changes such as maturation rates. In addition, the brood-year forecast is adjusted (downwards at present) for the 5-year average model error. In order for directed commercial fisheries in U.S. and Canada to be prosecuted based on the preseason forecast, the forecast must meet or exceed 31,900 large fish. This is the sum of the management objective (25,500) + maximum base level catches (5,000) + 1,400 potential assessment. The 5,000 base is the historical incidental harvests in the directed sockeye fisheries in Canada and the U.S.: 1,500 CDN + 3,500 U.S.; the 1,400 fish could occur in a mortality based commercial assessment fishery[4].

The preseason forecast for the terminal run of Taku River sockeye salmon is based on a stock-recruitment model that is adjusted using the 5-year model error (5.5%). The forecast must be above the management objective of 58,000 wild fish for the initial season openings to occur.

The preseason forecast for the total run of Taku River coho salmon is generated using a model that relies on the relationship between CPUE of smolts tagged the previous spring and total adult run estimates the following year, using data from 1997 onward. The terminal run is estimated after applying an average non-terminal marine harvest rate of 23% (for average commercial troll and sport harvest rates). The terminal run forecast must be above 75,000 fish, the management objective + 5,000 fish, or the fishery will remain restricted until in-season estimates produce in-season forecasts above this level[6].

These three different forecasts are all inputs into the fisheries planning model wherein the initial openings for each parties' fisheries are set for each species, ranging from no opening to a 'standard' opening. If there are no initial fishery openings in-river, an alternative assessment fishery or test fishery may be triggered which may be non-lethal.

After the first two to six weeks of the season, once in-season estimates produced by the intensive in-season assessment program are reliable, these estimates usually replace the preseason forecasts for fishery management purposes.

IN-SEASON ASSESSMENTS

An intensive in-season assessment program for managing the Taku River terminal salmon runs consists of several components. In-river abundance and escapement are estimated through a cooperative capture-recapture program operated in-river. Two fishwheels operate in U.S. waters to capture and allow marking and sampling of adults. A few kilometers upriver in Canada, marked fish are recaptured in commercial and assessment fisheries. Abundance is estimated by species, and staff from both countries consult and agree on weekly in-season run estimates and projections for the terminal run. Run timing is evaluated throughout the season and catch sampling for stock identification are performed weekly. In-season estimates of terminal run abundance are produced weekly by adding the estimated in-river component from the capture-recapture program to the harvest in U.S. terminal fisheries, and projecting the sum by historical run timing for the species.

In the U.S. terminal marine fisheries, Taku River Chinook salmon harvests are estimated weekly using CWT methodology with final post-season estimates based on genetic stock identification techniques. Sockeye salmon are separated into wild and enhanced components using otolith stock identification analyses. In-season otolith analyses describe the numbers of wild and enhanced Taku River sockeye salmon as well as U.S. domestically enhanced sockeye salmon stocks with the final post-season estimates based on genetic stock identification techniques. Stock identification of Taku River coho salmon is accomplished using CWT methodology. In-season data is shared as outlined in Chapter 1 of the PST and harvest sharing is done according to the explicit tables in Chapter 1 of the 2019 PST Agreement.

CODED-WIRE TAGGING OF WILD CHINOOK AND COHO SALMON

An important component of the assessment and management frameworks for the Taku River are the CWT projects for Chinook and coho salmon. These projects provide the basis to estimate smolt abundance, marine survival, total harvest, total production, calendar year harvest rate, and brood year exploitation rates for these two species. These programs provide data on the status of the wild stocks; one of six wild Chinook salmon stocks and one of less than 10 wild coho salmon stocks where such programs exist coastwide. All other 'CWT Indicator Stocks' use hatchery surrogates to estimate harvest, distribution, exploitation and maturation rates.

The CWT program is a joint effort between ADF&G, DFO and TRTFN. Each spring, crews capture Taku River wild Chinook and coho smolts with beach seines and minnow traps, transport them to a central processing location where fish are marked with ad clips, tagged with CWTs and sampled for age and length. Returning adults harvested in SEAK waters are sampled by ADF&G in all commercial and sport fisheries and recovered CWTs are processed and reported by the ADF&G Mark, Tag and Age Lab. All CWTs recovered in Canada are processed by the DFO CWT Lab in Nanaimo, BC. Harvests outside the terminal area in the U.S. are estimated by sampling statistics and expansion of CWT recoveries[7].

[7] Bernard, D.R. and Clark, J.E. 1996. Estimating salmon harvest with coded-wire tags. Canadian J. Fisheries and Aquatic Sciences 53: 2323-2332.

REFERENCE POINTS, HARVEST CONTROL RULES AND ESCAPEMENT GOALS

The management of Taku River Chinook, sockeye and coho salmon relies on the application of Total Allowable Catch (TAC), harvest control rules, harvest sharing rules and escapement goals by species[4]; all are specified in Chapter 1 of the 2019 Agreement. The TAC and harvest sharing is determined by the terminal run level, the available surplus to escapement needs and management objectives. There are also base level Chinook salmon catches included for each fishery that harvests Chinook salmon incidentally (averages prior to the 2005 agreement were used), which are included in provisions of Chapters 1. Base level catches in Alaska District 111 gillnet and sport also count towards the SEAK Treaty Catch, under provisions of Chapter 3 (Chinook).

The harvest control rules for Taku River Chinook, sockeye and coho salmon are defined by lower and upper fishery reference points, based upon escapement goal ranges for each of the three species[6]. When the projected in-season run size estimate is below the lower fishery reference point (the lower end of the escapement goal range), no directed fisheries are allowed by either party; some incidental harvest, during fisheries directed at other co-migrating stocks occurs and is accounted for under mechanisms outlined in the Treaty. If the in-season run size is within or above the range, fishery openings are structured according to harvest sharing agreements.

Time series of high-quality production data are used to generate escapement goals with ranges that sustain the stocks while also permitting harvest for each species. Though production data is examined to assess escapement goals, revisions to these goals are generally made only every ten years. The current escapement goal range for Chinook salmon is 19,000 to 36,000 large fish (>659 mm MEF), with a management objective of 25,500 fish, which was revised in 2010[8]. This is the fifth revision since 1981. Taku River sockeye salmon have an escapement goal range of 40,000 to 75,000 fish with a management objective of 58,000 fish, representing the midpoint of the escapement goal range for this stock, which was revised in 2020[9]. Taku River coho salmon have an escapement goal range of 50,000 to 90,000 fish with a management objective of 70,000 fish, representing N_{MSY} for this stock (Pestal and Johnston 2015)[10] which was established in 2015.

MANAGEMENT STRATEGY EVALUATION

The TBR TC and Panel evaluate the fisheries management performance annually for each species as directed by Paragraph of Chapter 1. Current management regimes are examined and, as required, recommendations are provided as to how they may be better suited to achieving escapement goals, harvest sharing, and other objectives. To date, no simulation modeling efforts have been implemented for management strategy evaluation.

DATA LIMITATIONS

Direct estimates of total escapement of the three species began in 1975 for Chinook, 1982 for sockeye, and 1983 for coho salmon. In-river fisheries have been enumerated and sampled since 1979. Alaska District 111 commercial and sport harvests have been enumerated since 1960 and sampled for age, size, and stock identification since 1981. Wild Chinook and coho salmon smolt have been captured, tagged with

[8] McPherson, S.A., Jones III, E.L., Fleischman, S.J. and Boyce, I.M.. 2010. Optimal Production of Chinook Salmon from the Taku River Through the 2001 Year Class. Alaska Department of Fish and Game, Fishery Manuscript Series No. 10-03, Anchorage.
[9] Miller, S.E., and Pestal, G. 2020. Estimates of a Biologically-Based Spawning Goal and Management Benchmarks for the Canadian-Origin Taku River Sockeye Salmon Stock Aggregate. DFO Can. Sci. Advis. Sec. Res. Doc. 2020/nnn. vii + 74 p.
[10] Pestal, G. and Johnston, S. 2015. Estimates of a Biologically-Based Spawning Goal and Biological Benchmarks for the Canadian-Origin Taku River Coho Stock Aggregate. DFO Can. Sci. Advis. Sec. Res. Doc. 2015/048. ix + 114 p

CWTs and released each spring since 1991 in the mainstem of the lower Taku River[8]. This joint stock assessment program has resulted in a long and precise time series of estimates of escapement and subsequent smolt and total adult production, marine survival, and stock-recruit data. Radio telemetry studies have been used to estimate spawning distribution, to produce or verify escapement estimates, and more recently to correct in-river and spawning abundance estimates of sockeye salmon affecting the time series of production data and requiring revision of the escapement objectives. Additional periodic telemetry studies will be needed to assess factors affecting escapement estimates for all three species. The bilateral assessment program is cost effective because it spans these three species; however, future funding is required to maintain the current data collection, assessment, and management programs.

ASSESSMENT CHALLENGES

The in-season assessment of Taku River Chinook, sockeye and coho salmon provides precise, timely, and accurate information for fishery management purposes. However, recent telemetry studies have identified a management concern regarding increased predation by marine mammals in the terminal area. This is also an assessment concern because these studies have shown that after tagging, a portion of the fish swim downriver through an area having a high abundance of seals. These fish are then subject to added mortality which violates a key model assumption that tagged and untagged fish behave the same, and results in overestimates of abundance. The current assessment program accounts for these issues using the information gained from the detailed radio telemetry studies, further improving the accuracy of the abundance estimates.

INFORMATION CONVEYED TO MANAGERS/DECISION MAKERS

Pre-season forecasts are provided by December 1 annually for Chinook salmon and by mid-February for sockeye and coho salmon, and are used by managers to plan for and start the fishing season. All fishery, escapement, and in-river data from in-season assessments are provided to managers weekly throughout the fishing season. In-season management coordination between U.S. and Canadian fishery managers involves weekly communication between designated members or alternates. Canadian and U.S. fishery managers conduct data exchanges by telephone and/or email on Wednesday afternoon or Thursday morning of each week during the fishing season. At that time, current harvest statistics and stock assessment data including capture-recapture data will be updated, exchanged, and reviewed. Fishing plans for the next week for each country will be discussed at this time. It is anticipated that additional communications will be required each week. Weekly decision deadlines will be a) for District 111, 11:00 a.m., Thursday, and b) for the Canadian Taku River fishery, 10:00 a.m., Friday[6].

5. Incorporating environmental data and accounting for changes in productivity

Environmental data are not used directly to generate preseason forecasts of run size; however, the sibling model used to forecast Chinook salmon production uses a more recent timeseries of brood year information and both Chinook and sockeye salmon forecasting models use the 5-year error rate to produce less biased forecasts. These adjustments inherently help to capture the changes in marine survival and production without the need to include any environmental covariates in modeling. A smolt-based forecast model is used for coho salmon which accounts for any freshwater environmental changes; however, it does not account for any marine environmental effects and operates off an assumed recent 10-year average marine survival rate.

In-season, environmental data are not used to predict the number of returning Chinook, sockeye and coho salmon; the program relies on the capture-recapture and radio telemetry program to estimate abundance and timing. The watershed is almost entirely pristine and water temperatures in-river (glacial fed in part) have not been a factor for pre-spawn mortality. Intensive in-season management on the Taku River is risk adverse and does not require incorporation of additional environmental variates.

Environmental data have not been used to derive reference points, harvest control rules or escapement goals but escapement goals reviews include tests for, and accommodations of, changes in productivity and are therefore, implicitly incorporated. Yield profiles are also used as guidance in this process.

While no simulation modeling efforts have been implemented for management strategy evaluation, the Panel and TC are committed to improving the abundance-based regime on the Taku, as detailed in the TBR Strategic Plan[5].

6. Accounting for and conveying uncertainty

The preseason forecast models for the three species all produce point estimates with associated uncertainty. Fishery management decisions using preseason forecasts for all three species are done with a great deal of caution building in the uncertainty associated with forecasting.

The in-season run size by species is a time-density model and confidence intervals are produced each week, or more often. Individual and cumulative weekly estimates are all produced with their respective error and confidence intervals.

Escapement goals are produced with point estimates and ranges, often from state-space spawner-recruitment analyses that explicitly account for, and propagate, uncertainty due to both observation error and process variation. The point estimates have estimates of uncertainty (SEs, etc.) while the upper and lower ranges for the escapement goal are constructed from expected harvest profiles that will produce a high likelihood of harvest.

The TBR TC continually evaluates the performance of the bilateral fishery management approaches and provides the Panel with recommendations regarding improvements to the strategies on an annual basis.

7. Ability to reach management objectives

The assessment and management frameworks for the Taku River Chinook, sockeye and coho salmon terminal runs operate using an abundance-based approach with intensive in-season management. It is risk adverse due to the availability of timely and precise data, the terminal nature of the fisheries and the low interception rates in non-terminal fisheries. The abundance-based approach has precluded the harvest of most Chinook salmon in recent years; it has maximized escapements even though escapement and management objectives have not always been met. Generally speaking, fishery managers consistently meet the objectives of the chapter using the current assessment and management approaches.

8. Planned assessment changes to account for climate change

ADF&G and DFO have committed to reviewing the current assessment and management frameworks and to making the necessary improvements (see recent strategic plan[5]). In addition, both parties will carefully assess the changes and uncertainty associated with the December 24, 2020, rockslide impact, per recent discussions. It is uncertain whether additional support would be required for this latter work.

PST Chapter 1: Transboundary Alsek River Salmon Stocks

1. Introduction

Chapter 1 of the Pacific Salmon Treaty applies to Transboundary River stocks. The assessment and management of Chinook, sockeye and coho stocks within the different Transboundary River systems (Taku, Alsek, Stikine) are documented separately in this report given the differences in management and assessment.

Within the Alsek River, all Chinook stocks are aggregated into one Chinook Conservation Unit (CU) even though spawning sites are located throughout the drainage. The Klukshu River is the largest Chinook producing tributary of the Tatshenshini River within the Alsek River drainage. The Chinook run generally enters the river in early May, peaks in June and the run is done in the lower river by early July. For sockeye, one river-type and three lake-type sockeye CUs have been identified for the Alsek River[1]. The early Klukshu River sockeye run that peaks in mid-July is dominated by river-type fish while the more abundant later run that peaks in early-to-mid September is dominated by lake-type fish.

Terminal Chinook salmon runs to the Alsek River over the past 10 years (2012-2021) have averaged about 4,700 fish and have ranged from 1,900 fish in 2017 to 6,500 fish in 2019 (Figure 1)[2]. This 10-year average is 51% of the long-term average of 9,300 fish (1976-2021). Chinook salmon spawning occurs in the Canadian portions of the Alsek River drainage. Within the drainage there are two large tributaries, the Alsek which is blocked to anadromy by a major velocity barrier roughly 130 km upstream from the Canadian/U.S. border and the Tatshenshini. Most spawning for Chinook, sockeye and coho salmon occurs in the Tatshenshini drainage in Canada, but some spawning does occur in Alaska in the lower drainage. The Klukshu River Chinook stocks contribute on average 25% of the Alsek River drainage-wide run[3].

Terminal sockeye salmon runs to the Alsek River have averaged about 87,000 adults. Run sizes have ranged from 16,000 fish in 2020 to 122,000 fish in 2014 (Figure 2). Run reconstruction of the total terminal run started in 2000. A longer-term monitoring program has however been in place on the Klukshu River since 1976, which accounts, on average, for 23% of the drainage's total run size[4]. Runs to the Klukshu over the past 10 years are 73% of the long-term average (Figure 3). Figure 3 was included because the time series of sockeye escapements in Figure 2, though it reflects improvements in stock assessment, is too short to judge abundance trends.

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[1] Fisheries and Oceans Canada. 2021. Transboundary Rivers Salmon Integrated Fisheries Management Plan 2021/22. 21-2057: xxviii + 216 p.

[2] Pacific Salmon Commission Joint Transboundary Technical Committee (TCTR). 2022. Final estimates of Transboundary River salmon production, harvest and escapement and a review of joint enhancement activities in 2020. Joint Transboundary Technical Committee Report TCTR (22)-01. Vancouver BC.

[3] Bernard, D. R. and Jones III, E. L. 2010. Optimum escapement goals for Chinook salmon in the transboundary Alsek River. Alaska Department of Fish and Game, Fishery Manuscript Series No. 10-02, Anchorage.

[4] Eggers, D.M., and Bernard, D.R. 2011. Run reconstruction and escapement goals for Alsek River sockeye salmon. Alaska Department of Fish and Game, Fishery Manuscript Series No. 11-01, Anchorage.

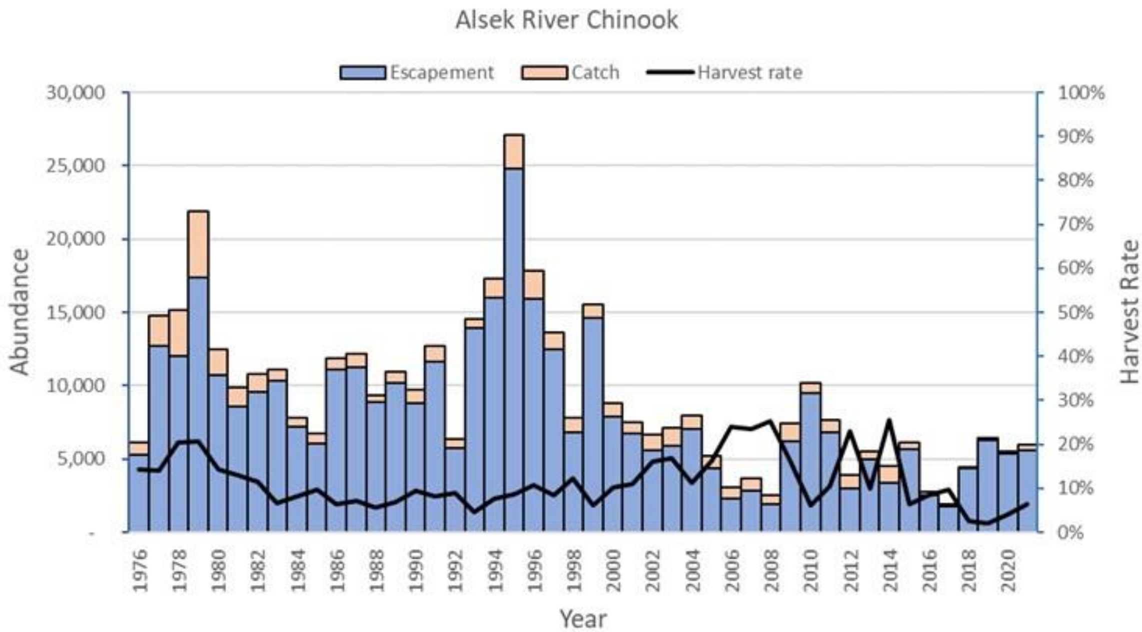

Figure 1. *Escapement, catch and harvest rate of the terminal run of Chinook salmon returning to the Alsek River since 1976. Data source: TCTR 2022[2].*

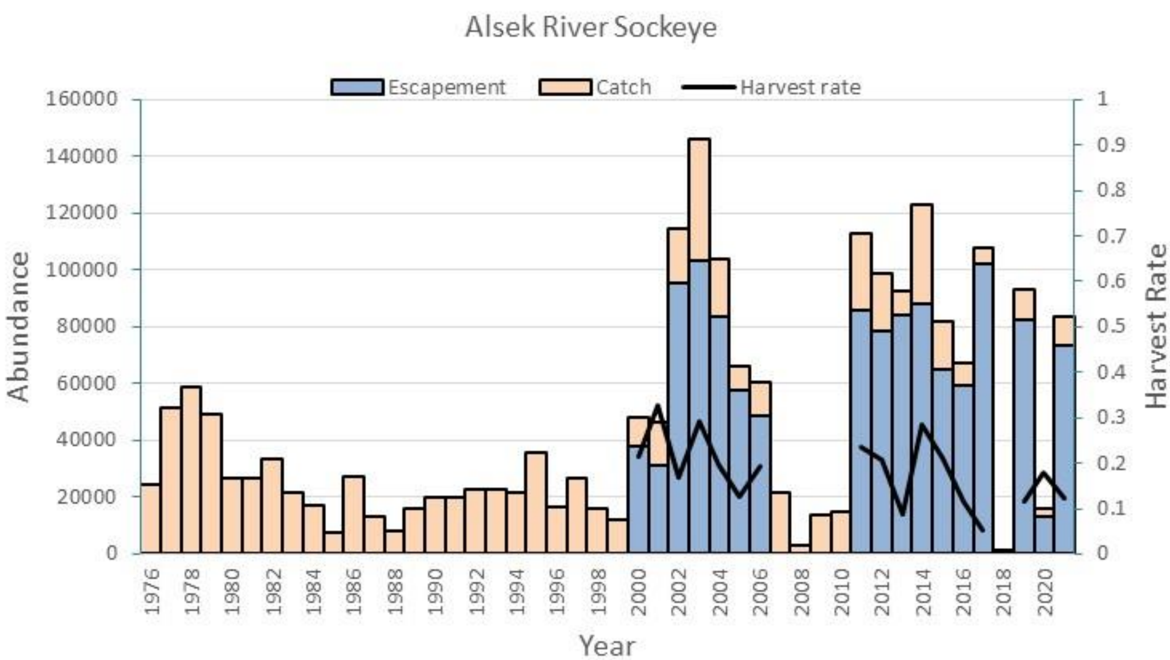

Figure 2. *Escapement, catch and harvest rate of the terminal run of sockeye salmon returning to the Alsek River since 2000, with total catch since 1976. Data source: TCTR 2022[2]. Note, no total escapement estimates exist prior to 2000 and for 2007-2010 and 2018.*

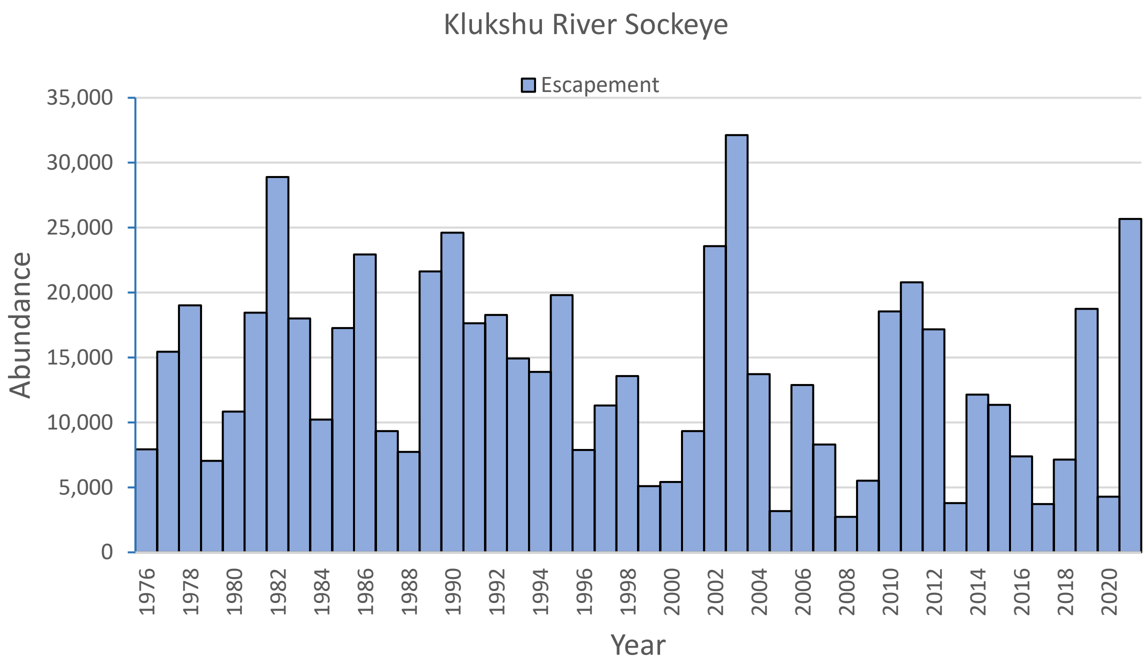

Figure 3. *Escapement of Klukshu River sockeye salmon since assessment began in 1976, accounting on average for 23% of the total Alsek run size. Data source: TCTR 2022[2].*

2. Fisheries

The Alsek River terminal run area specified in Chapter 1 of the 2019 PST Agreement consists of estuarine waters in the Alsek River in Alaska, plus the Canadian reaches of the drainage[5]. The principal U.S. fishery that targets Alsek River stocks is a commercial set gillnet fishery that operates in Dry Bay, from the Gulf of Alaska to approximately 20 km up the Alsek River. A small subsistence fishery also operates in Dry Bay. The principal Canadian fisheries occur in the upper Tatshenshini River drainage, a traditional First Nations (FN) fishery and a hook and line recreational (sport) fishery. At present, approximately 100 to 150 members of the Champagne Aishihik First Nations (CAFN) harvest salmon via traditional and non-traditional methods (gaffs, traps, rod and reel, nets, weir), primarily in the Klukshu River, and to a lesser extent, in Village Creek, Blanchard River, and Goat Creek. Recreational fisheries take place primarily on the Tatshenshini River in the Dalton Post area and on the Takhanne and Blanchard rivers. Fisheries directed at Alsek Chinook, sockeye and coho salmon may have by-catch of pink salmon, steelhead and chum.

GEAR SECTORS

U.S.:

- Alaska District-subdistrict 182-30 set gillnet, and
- Alaska District-subdistrict 182-30 subsistence.

Canada:

- In-river First Nations (Champagne Aishihik), and
- In-river sport.

[5] PSC. 2020. Treaty between the government of Canada and the government of the United States of America concerning Pacific salmon. PSC, Vancouver.

INTERCEPTION OR HARVEST BY FISHERIES OUTSIDE IN-RIVER TERMINAL AREAS

Alsek River Chinook salmon are not harvested in the Southeast Alaska (SEAK) commercial, sport or subsistence fisheries south of the Alsek River, based on both coded-wire tag (CWT) and genetic stock identification analyses conducted since the 1970s[6]. Instead, these Chinook salmon rear to the north and west of the Alsek River in the Gulf of Alaska and Bering Sea, where minor numbers of these fish may be intercepted in U.S. federal groundfish fisheries, Alaska commercial net and sport fisheries around Kodiak Island, the Alaskan Peninsula and Prince William Sound. Alsek River sockeye salmon may be intercepted to a minor degree in Alaskan net fisheries in Prince William Sound and perhaps in other sub-districts in the Yakutat area – Situk, Lost, Akwe and Italio rivers.

FISHERY CHALLENGES

Coordinating management amongst domestic gear sectors in the U.S. (ADF&G), in Canada (DFO and Champagne Aishihik First Nation), and internationally (ADF&G and DFO), is a cooperative effort that requires consistent dialogue and timely exchange of in-season assessment data. Poor marine survival of Chinook in the past decade and sockeye in some years, as well as predation by pinnipeds have presented challenges to managers.

3. Management

The management of Alsek River Chinook, sockeye and coho is the responsibility of the U.S. (ADF&G) and Canada (DFO). A strategic plan was developed by the Transboundary Panel and Technical Committee in 2019[7]. Detailed annual management plans are assembled and agreed to prior to April each year by the Transboundary Technical Committee and Transboundary Panel, following harvest sharing provisions in the PST[8]. All provisions and exchanges of stock assessment and other management information, and their schedules, are agreed to preseason.

The management objectives for Alsek River salmon runs are to: (1) achieve spawning escapement goals by species (Chinook and sockeye); (2) achieve targets for international sharing of the TAC as defined in the 2019 PST Agreement (Chapter 1); and (3) achieve domestic allocation goals within each country.

Fishery management measures in place for salmon originating from the Canadian portion of the Alsek River watershed are described in Annex IV, Chapter 1 of the PST[5]. These arrangements include directed fisheries for sockeye salmon, continuation of a U.S. subsistence fishery on Chinook, sockeye, and coho salmon stocks within the U.S. section of the Alsek River and continuation of coho salmon harvest shares.

Management of the Alsek River Chinook and sockeye salmon runs is done with an abundance-based approach that relies on preseason forecasts and different in-season models for the lower (U.S.) and upper river fisheries. The lower river fishery, germane to the entire Alsek salmon runs, has no directed Chinook fishery. The lower river U.S. gillnet sockeye fishery relies on harvest CPUE data compared to historical averages to gauge run strength and inform managers.

In-season, sockeye abundance is estimated at various upstream locations (Klukshu River, Village Creek, Blanchard River) and the upriver projection from them provides timely in-season information for

[6] McPherson, S.A., Etherton, P. and Clark, J.H. 1998. Biological escapement goal for Klukshu River chinook salmon. Alaska Department of Fish and Game, Fishery Manuscript No. 98-2, Anchorage.
[7] Pacific Salmon Commission Joint Transboundary Technical Committee (TCTR). 2019. Transboundary Panel Strategic Salmon Plan Report developed by the Joint TBR Panel and Technical Committee; Report TCTR (19)-4. Vancouver BC.
[8] Pacific Salmon Commission Joint Transboundary Technical Committee (TCTR). 2022. Salmon Management and Enhancement Plans for the Stikine, Taku and Alsek Rivers, 2022. Joint Transboundary Technical Committee Report TCTR (22)-02. Vancouver BC.

management of these upriver stocks. This information is relayed to Alaskan managers as it becomes available from DFO and CAFN. In recognition of the data delay and to provide Canada access to early-run stocks, the initial U.S. fisheries openings (4 or more), starting the first week of June, are required to be conservative in duration compared to historical openings.

An improved abundance-based management regime for Alsek Chinook and sockeye is planned, that has more accurate in-season information for fisheries management[7]. Assessment programs could be developed to support an in-season abundance-based regime with timely assessment information available to all managers. This could for example be achieved through reimplementation of a mark-recapture program, or through a non-lethal test fishery with genetic stock identification.

Alsek River Chinook and sockeye salmon runs consist of several sub-stocks that are spread somewhat spatially and temporally throughout the anadromous portion of the drainage. U.S. management is structured to harvest in proportion to the abundance of different run segments of each species each year, and the Canadian fisheries harvest stocks only in the upper Tatshenshini River and are managed to achieve escapement goals. In recent years, harvest by sub-stock for Chinook and sockeye runs is estimated by genetic stock identification methods from samples taken systematically in the U.S. commercial fishery. Total catch contributions by stock are available postseason. Overall, there is one Conservation Unit (CU) recognized each for Chinook and coho and four for sockeye salmon.

MANAGEMENT CHALLENGES

Abundance-based management is lacking timely in-season abundance by stock group for the lower river for Chinook and sockeye salmon.

Survival and productivity of Alsek Chinook has decreased over the past 14 years and, based on coded-wire tag studies on the Taku, Stikine, Chilkat and Unuk wild Chinook stocks, believed to be caused primarily by declines in marine survival. Chinook salmon terminal runs in recent years are at record lows since modern records started in 1976 (Figure 1).

The uncertainty around the preseason forecasts for Chinook and sockeye has been relatively high over the past 6 years, averaging 43% and up to 36%, respectively. To clarify, these are the average of the annual forecast minus the observed terminal run, divided by the forecast.

A management concern has been identified regarding predation by marine mammals significantly increasing in the past two or three decades. Recent telemetry studies, abundance studies, and observations by users and professional staff have supported this conclusion in waters of Southeast Alaska, especially in the terminal area and lower stretches of the Alsek River. The abundance of marine mammals, which are protected under the U.S. Endangered Species Act, has increased substantially in Southeast Alaska and other coastal areas to the south and north.

4. Assessments

The assessment of Alsek River Chinook and sockeye salmon includes the use of annual pre-season forecasts, and limited in-season assessments, as well as the use of management tools such as reference points, harvest control rules, and escapement goals.

PRESEASON FORECAST

The staff managing Alsek River salmon rely on preseason forecasts of run size for the assessment and management of Chinook and sockeye salmon stocks, which are developed bilaterally by February 1 of each year. Quantitative forecasts are germane to the Klukshu stocks of Chinook and sockeye salmon. A stock-recruitment model is used to generate the forecast based on 27 years of Klukshu Chinook production data adjusted (downwards or upwards) using the recent 5-year average model error (43%, all negative residuals). On average, the Klukshu River Chinook salmon stock comprises 25% of the Alsek River drainage-wide Chinook run and this information is used to expand the preseason forecast to an Alsek River Chinook forecast[3]. Actual proportions the Klukshu River contributes to the total run size varies substantially from year to year (14 to 33% when estimated using mark-recapture and GSI data[1]).

For sockeye salmon, the forecast is based on a stock recruit model based using 27 years of Klukshu sockeye salmon production data adjusted (downwards or upwards) using the recent 5-year average model error (1% through 2022, though it was 36% for 2021). Based on mark-recapture study results (2000–2004) and run size estimates using GSI (2005–2006, 2011), the Klukshu sockeye stock comprises approximately 23% of the Alsek River drainage-wide sockeye salmon run and this information is used to expand the Klukshu forecast to an Alsek River sockeye forecast. The uncertainty around these preseason forecasts is high due to the variability in marine survival and makes them somewhat inferior for management purposes.

IN-SEASON ASSESSMENTS

There is little in-season abundance information available to inform US fisheries management as most stock assessment data are gathered in headwaters. For Chinook there is no directed fishery in the U.S and no associated assessments, except postseason. The assessment for sockeye is based on the relationship between in-river CPUE, both cumulative and weekly, compared to historical average catches in the U.S. commercial fishery. This quantitative assessment of present CPUE (fishery performance) to historical (weekly and cumulatively) estimates allows managers to qualitatively assess the strength of the run for the entire Alsek drainage. This information may or may not reflect the in-river run size in the upriver tributaries where the Canadian fisheries occur, because of variable spawning stock distribution. The directed U.S. sockeye fishery opens during the peak of Chinook salmon returns to the Alsek River. Peak timing appears to be during the first two weeks of June based on tagging data (1998–2004) and Chinook salmon test fishery data (2005–2008, 2011 and 2012). Chinook salmon tagging studies conducted from 1998 through 2004 indicated that approximately 14% to 32% of Chinook salmon passing through Dry Bay are bound for the Klukshu River drainage. These data are some of the building blocks for future refining of in-season assessments.

Upriver in Canada, Chinook and sockeye salmon are enumerated at the Klukshu River using video technology operated by DFO and CAFN. Nesketahin Lake sockeye salmon and Blanchard River large Chinook salmon are also enumerated. In-season Canadian assessments focus primarily on the projections of abundance of salmon based on these daily counts, expanded by historical and/or in-season timing data[1]. The resulting estimates are used to inform in-season Canadian management actions on these stocks, which represent a variable proportion of drainage-wide escapements of Alsek River salmon. This information is relayed to U.S. managers as soon as available, but is not timely for in-season management decisions. Postseason data are required to inform individual stock contributions and to estimate Alsek River drainage-wide salmon abundances and escapements for both Chinook and sockeye runs[8].

REFERENCE POINTS, HARVEST CONTROL RULES AND ESCAPEMENT GOALS

The management of Alsek River Chinook and sockeye salmon relies on the application of harvest control rules to determine allowable fishing opportunity and to achieve escapement goals by species in the Klukshu River and by run segment for sockeye, until in-season assessment tools are improved[7]. The U.S. commercial fishery in-season management decisions are made by comparing present to historical fishery performance to qualitatively assess run strength. In Canada, next to conservation, the priority in management will be to provide for basic food, social and ceremonial needs of the CAFN. Basic Needs Allocation (BNA) obligations are 200 Chinook and 3,000 sockeye salmon, as documented in the CAFN final land claim agreement. Restrictions in the FN fishery will be considered if the projected Klukshu River counts are below 800 Chinook salmon, 1,500 early sockeye and/or 7,500 total sockeye salmon. Decisions to implement restrictions will take into account management actions taken to conserve stocks in both the Canadian recreational fishery and the U.S. Dry Bay fishery.

The harvest control rules for Alsek River Chinook and sockeye salmon are defined by lower and upper fishery reference points, based upon escapement goal ranges at Klukshu River for each of the two species. For Chinook, there is no directed fishery in the U.S. For sockeye, the U.S. fisheries are conservative (i.e., 1 – 2 days/week) through about the first month of the season, to allow both Chinook and early-run sockeye to pass upriver. For sockeye in Canada, when the projected in-season run size estimate is below the lower fishery reference point (the lower end of the escapement goal range), the recreational fishery will be essentially closed and may be considered in the CAFN fishery. If the projected in-season run size is within or above the range, fishery openings are structured according to agreed openings per consultation; this cannot occur early in-season (June 1 to early July), as insufficient in-season data are available to provide an in-season run size update.

Based on spawner-recruitment analysis, Alsek River Chinook salmon have an escapement goal range of 3,500 to 5,300 fish with a management objective of 4,700 fish, which is the spawner abundance associated with maximum long-term sustainable yield (S_{MSY}). This corresponds to a Klukshu River goal range of 800 to 1,200 fish with a management objective of 1,000 fish[3]. No fishing or very limited fishing will occur unless 800 Klukshu (3,500 Alsek) Chinook salmon are projected to escape.

Based on spawner-recruitment analysis, Alsek River sockeye salmon have an escapement goal range of 24,000 to 33,500 fish with a management objective of 29,700 fish (S_{MSY}). This corresponds to a Klukshu River goal range of 7,500 to 11,000 fish with a management objective of 9,700 fish[4]. No fishing or very limited fishing will occur unless 7,500 total and 1,500 early-run Klukshu (24,000 Alsek) Chinook salmon are projected to escape.

The in-season application of the harvest control rules allows managing Canadian fisheries. Results of management of the U.S. fisheries through harvest control rules is not known until postseason analysis of numeric and stock identification assessment data is complete. Harvest of Chinook in the U.S. set gillnet fishery also counts towards the SEAK Treaty Catch, under provisions of Chapter 3 (Chinook).

There are additional Pacific Salmon Treaty (PST) Chapter 1 multi-year requirements that can come into play regarding harvest rules. If the lower end of escapement goal range(s) is not met for three consecutive years, the Panel and TC will review the overall management regime and recommend adjustments commencing the following year to better address conservation requirements.

MANAGEMENT STRATEGY EVALUATION

The Transboundary (TBR) Technical Committee (TTC) and Panel evaluate fisheries management performance annually for each species as in Chapter 1 of the PST, which is presented to the TBR Panel by February 1 annually. Current management regimes are examined and, as required, recommendations are provided as to how they may be better suited to achieving escapement goals, harvest sharing, and other objectives. To date, there have been no simulation modeling efforts undertaken (closed loop or other) to evaluate the ability of alternative management procedures (e.g., in-season assessment, escapement goals and harvest control rules) to meet fishery and conservation objectives in the system.

DATA LIMITATIONS

Estimates of total escapement data back to 1976 for Chinook and 2000 for sockeye in the Alsek drainage; escapement enumerations to the Klukshu River began in 1976 for both species. Harvests have been enumerated since 1976 in Canada and 1961 in Alaska. Capture-recapture, radio-telemetry and stock-identification studies coupled with Klukshu abundance have made these drainage-wide estimates available in a limited number of years since 1998. The Chinook tagging program was terminated in 2004.

In-season estimates and run-projections are needed and planned for Alsek Chinook and sockeye salmon, to improve management for both species. This will allow more timely conservation and harvest measures and associated control rules to be implemented. Additionally, the present preseason forecasts are usually inaccurate (error rates of 25% and 51%, consistently under-forecasting) and are only germane to the Klukshu River, not the entire drainage.

The bilateral assessment program is cost effective because it spans three species; however, future funding is required to maintain and improve the current data collection, assessment, and management programs.

ASSESSMENT CHALLENGES

Recent survivals of Chinook and sockeye have been very variable, creating substantial challenges to forecast run size estimates[1].

INFORMATION CONVEYED TO MANAGERS/DECISION MAKERS

Pre-season forecasts are provided by December 1 annually, for Chinook salmon and by February 1 for sockeye salmon, to managers and are incorporated into the bilateral TBR management plan by April prior to each fishing season[8]. All fishery harvest, escapement, and in-river data from in-season assessments are provided to managers weekly throughout the fishing season as they become available. In-season management coordination between U.S. and Canadian fishery managers involves weekly communication between designated members or alternates. Canadian and U.S. fishery managers conduct data and management exchanges by telephone weekly.

5. Incorporating environmental data and accounting for changes in productivity

Environmental data are not used directly to generate preseason forecasts of run size. However, a stock-recruit model is used for forecasting run sizes of both Chinook and sockeye salmon. Resulting estimates are adjusted downwards by the recent five-year model error rate, as preseason forecasts are generally over-forecasting observed run sizes. These adjustments inherently help to capture the declining trend in marine survival and production without explicitly including environmental covariates in the analysis.

Environmental data are not used to estimate, in-season, the number of returning Chinook and sockeye salmon. The watershed is almost entirely pristine and high water temperatures in-river (glacial fed in part) have not been a factor for pre-spawn mortality.

Escapement goals reviews include changes in productivity and are therefore interannual and longer-term changes in survival are implicitly accounted for. In addition to tests and correction for non-stationarity, autocorrelation, etc., yield profiles are also used as guidance in this process.

While no simulation modeling efforts have been implemented for management strategy evaluation, the Panel and TC are committed to improving the abundance-based regime on the Alsek River, as detailed in the TBR Strategic Plan[7].

6. Accounting for and conveying uncertainty

The preseason forecast models for Chinook and sockeye all produce point estimates with associated uncertainty and 5-year error rates ((forecast – observed)/forecast). Fishery management decisions using preseason forecasts for these species are done with a lot of caution because of the present uncertainty associated with them.

The in-season run size by species are time-density models for Chinook and sockeye, but only at the Klukshu River which represents, on average, 25% and 23% respectively of the total Alsek abundance.

Escapement goals are produced with point estimates, ranges and standard errors[4] using state-space age structured spawner-recruitment models that explicitly account for uncertainty in estimates of spawning escapement, harvest and age composition. Optimum yield profiles and overfishing profiles are used to estimate the lower and upper ranges of the escapement goal, ranges that would produce sustained yields of > 90% of optimum. The probability profiles integrate over all of the uncertainty in true spawner abundance, intrinsic productivity and stock carrying capacity.

7. Ability to reach management objectives

The current assessment approach of the Alsek River Chinook and sockeye terminal salmon run reaches management objectives to a moderate extend, by relying on an abundance-based approach with available in-season management information. The terminal nature of the fisheries and the low interception rates in non-terminal fisheries are points in favor of management. The abundance-based approach has precluded the harvest of most Chinook and sockeye salmon in the past five years due to low returns of Chinook and Klukshu sockeye, poor forecast performance and untimely in-season information for drainage-wide abundance. The limited management objectives for coho salmon continue to be met annually. In general, managers generally meet the conservation objectives of the chapter; however, the TBR Panel and TC are committed to improving the abundance-based schema for Chinook and sockeye in the Alsek River.

8. Planned assessment changes to account for climate change

ADF&G, DFO and CAFN have committed to reviewing the current assessment and management frameworks to make the necessary improvements for timelier in-season assessments for more effective abundance-based management (see recent strategic plan referenced above[7]). The plans to improve the in-season assessments will make the frameworks more risk adverse to changes due to the environment or other factors affecting salmon production.

PST Chapter 1: Transboundary Stikine River Salmon Stocks

1. Introduction

Chapter 1 of the Pacific Salmon Treaty applies to Transboundary River stocks. The assessment and management of Chinook, sockeye and coho stocks within the different Transboundary River systems (Taku, Alsek, Stikine) are documented separately in this report given the differences in management and assessment.

The Stikine River in Southeast Alaska and northwestern British Columbia is considered a major producer of Chinook salmon. From 2011–2020, terminal Chinook salmon runs to the Stikine River have averaged just over 18,500 large fish (> 659 mm mid-eye to fork length) and have ranged from 8,000 fish in 2017 to 30,000 fish in 2012 (Figure 1)[1]. In contrast, runs were much larger from 2002–2010 averaging 48,000 fish. In the last 5 years, runs of Stikine Chinook salmon have been below the escapement goal target of 17,400 large Chinook salmon despite management measures to reduce catch[2]. These run estimates do not include the smaller age-.1 and -.2 jacks which are almost all males and annually contribute 5,000–10,000 fish to the run (Richards et al. 2012[3]). Chinook salmon spawning occurs both in the Canadian and U.S. portions of the Stikine River. Within the drainage there are distinct early, middle, and late run timing stocks which utilize different tributaries, but do not appear to differ in productivity (Pahlke and Etherton 1999[4]; Richards et al. 2008[5]).

Terminal run sizes for Stikine River sockeye salmon over the last 10 years (2011-2020) have averaged approximately 131,000 fish[1]. Run sizes have ranged from 38,000 fish in 2020 to 248,000 fish in 2016 (Figure 2). The average for the same 10-year span is about 14% below the long-term average of 152,000 fish (1979 – 2020) and 33% below the average of the previous 10-year period (2001–2010). In 2020, runs of Stikine sockeye salmon were substantially below escapement goal targets. Most sockeye salmon returning to the Stikine River spawn in the Canadian portion of the drainage with a much smaller portion of the returns spawning in the U.S. The spawners include both lake- and river-type populations.

Annual runs were enhanced by sockeye salmon originating from Tahltan Lake broodstock subsequently released into the Tahltan and Tuya Lake systems. Sockeye salmon enhancement efforts on Tuya Lake began with brood year 1991 an ended with the release of brood year 2013 fry in the spring of 2014. On average, the Tuya enhancement – project produced 36,500 sockeye salmon annually by brood year, with

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[1] Pacific Salmon Commission Joint Transboundary Technical Committee (TCTR). 2022. Final estimates of transboundary river salmon production, catch and escapement and a review of joint enhancement activities in 2020. Joint Transboundary Technical Committee Report TCTR (22)-01. Vancouver BC.

[2] Salomone, P.G., Courtney, K., Hagerman, G.T., Fowler, P.A. and Richards, P.J. 2022. Stikine River and Andrew Creek Chinook salmon stock status and action plan, 2021. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report No. 1J22-15, Douglas AK.

[3] Richards, P.J., Pahlke, K.A. and Etherton, P. 2012. Abundance of the Chinook salmon escapement in the Stikine River 2006-2008. Alaska Department of Fish and Game, Fishery Data Series No. 12-15, Anchorage.

[4] Pahlke, K. A. and Etherton, P. 1999. Abundance and distribution of the chinook salmon escapement on the Stikine River, 1997. Alaska Department of Fish and Game, Fishery Data Series No. 99-6, Anchorage.

[5] Richards, P. J., Pahlke, K.A., Der Hovanisian, J.A., Weller, J.L. and Etherton, P. 2008. Abundance and distribution of the Chinook salmon escapement on the Stikine River in 2005, and production of fish from brood year 1998. Alaska Department of Fish and Game, Fishery Data Series No. 08-33 Anchorage.

the last contribution to the Stikine River harvest occurring in 2019. While not the sole reason, discontinuation of the Tuya enhancement program was a contributing factor in declining Stikine River sockeye salmon harvests. The Tahltan Lake enhancement program is ongoing and continues to contribute sockeye salmon to the annual Stikine sockeye run.

The Stikine River supports a substantial population of coho salmon with spawning and rearing habitat in both the U.S. and Canadian reaches of the drainage. Limited aerial survey index data suggests the Stikine River coho salmon run has declined since 2002[6]; however, the Stikine River coho salmon stock assessment program lacks several components and drainage-wide escapement estimates do not exist at this time.

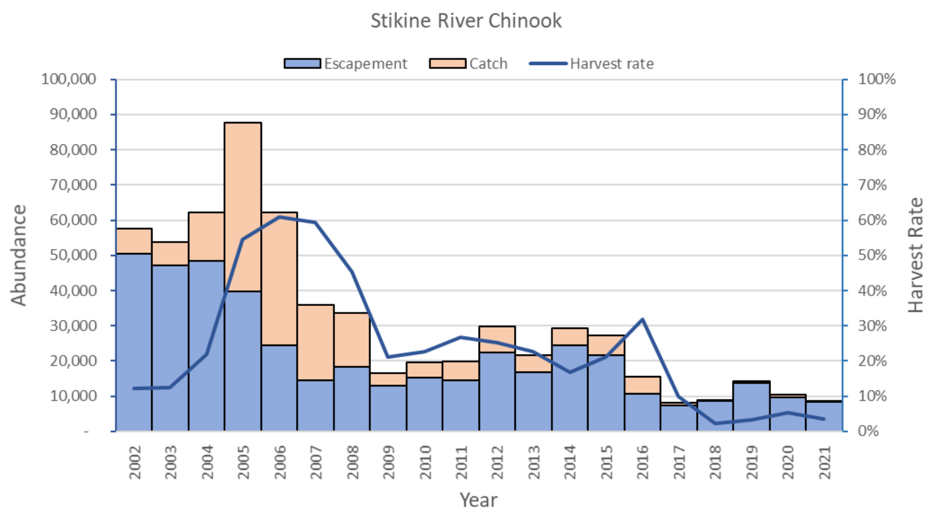

Figure 1. *Escapement, catch and harvest rate of the terminal run of Chinook salmon returning to the Stikine River since 2002[1].*

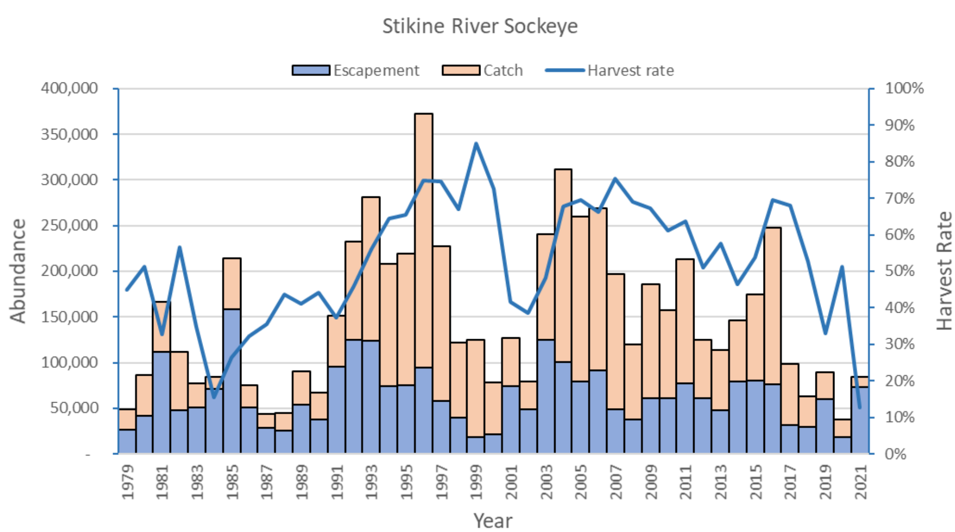

Figure 2. *Escapement, catch and harvest rate of the terminal run of sockeye salmon returning to the Stikine River since 1979[1].*

[6] Fisheries and Oceans Canada. 2021. Transboundary Rivers Salmon Integrated Fisheries Management Plan 2021/22. 21-2057: xxviii + 216 p.

2. Fisheries

The Stikine River terminal run fishing areas specified in Chapter 1 of the 2019 PST Agreement consist of marine waters in Alaska District 108 (inner channels near Wrangell and Petersburg), District 106 specifically for sockeye, and the freshwater reaches within the Stikine River drainage[7].

U.S. fisheries for Stikine Chinook, sockeye and coho salmon operate in the terminal areas of Districts 106 and 108, are managed under the PST and harvest a mix of salmon stocks in these areas. Canadian fisheries operate on the Stikine River above the U.S./Canada border, and they harvest Stikine-origin salmon. In years of high Stikine-origin Chinook salmon abundance, directed Chinook salmon fisheries in District 108 and inriver can occur but otherwise these fish are caught incidentally during traditional sockeye fisheries, annually. Fisheries directed at Stikine Chinook, sockeye and coho may have by-catch of pink salmon, steelhead, and chum salmon.

TERMINAL GEAR SECTORS

U.S.:

- Alaska District 108 commercial drift gillnet (marine),
- Alaska District 108 sport hook and line (marine),
- Alaska District 106 commercial drift gillnet sockeye salmon (marine),
- Inriver subsistence, and
- Alaska District 108 commercial troll (marine).

Canada:

- Inriver First Nations,
- Inriver commercial gillnet, and
- Inriver sport (recreational).

INTERCEPTION OR CATCH BY FISHERIES OUTSIDE ALASKA DISTRICT 108 AND 106 (SOCKEYE SALMON) AND INRIVER TERMINAL AREAS

Stikine River Chinook salmon are normally caught co-mingling with other Chinook salmon stocks in late winter and spring in the Southeast Alaska (SEAK) commercial troll fishery and, if open, in the SEAK sport fishery (both managed under Chapter 3 of the PST). Catch is estimated from the recovery of wild-stock coded-wire tags (CWTs). In response to poor Stikine River Chinook production over the most recent 5-year period, the winter troll fishery has ended 6 weeks early (March 15), spring troll fisheries have been curtailed and most inside sport fisheries have been until mid-June. Stikine River coho salmon are primarily caught, as per normal, in the northern and central SEAK troll and sport fisheries and catch contributions are estimated from CWT recoveries according to methods in Bernard and Clark (1996[8]). Stikine River sockeye salmon are caught incidentally in non-terminal pink and chum salmon fisheries.

[7] PSC. 2020. Treaty between the government of Canada and the government of the United States of America concerning Pacific salmon. PSC, Vancouver. https://www.psc.org/publications/pacific-salmon-treaty

[8] Bernard, D.R., and Clark, J.E. 1996. Estimating salmon catch with coded-wire tags. Canadian J. Fisheries and Aquatic Sciences2323-2332.

CATCHES AND HARVEST RATES

At the end of the 1990s, Chinook salmon stocks had rebounded from overfishing and low survival rates in the 1970s[9]. As a result, the PST agreement of 2005–2008 approved directed harvests of wild Chinook salmon returning to the Stikine River, thereby re-establishing District 108 and Stikine River fisheries. Initially harvests were high (Figure 1), followed by a steep decline in abundance and harvest after 2008. The PST allows directed commercial fisheries based on preseason forecasts only if the terminal run of large (greater than 660 mm MEF) Chinook salmon is projected to exceed 28,100 large fish (e.g., the mid-point of the escapement goal range of 21,000 fish plus the average traditional base level catches seen between 1985 and 2003 of 5,700 fish plus an allowance for an assessment/test fishery of 1,400 fish). Once in-season estimates are available, the terminal run must exceed 24,500 large fish (e.g., the MSY point goal of 17,400 fish plus the base level catches and the assessment/test fishery allowance). From 2005–2008, a period of high productivity, combined U.S. and Canadian harvests ranged from 15,000 to 48,000 large fish; however, from 2009–2021, a period with low productivity, combined harvests ranged from 200 to 7,500 large Chinook salmon.

Prior to 2019, harvest rates of Stikine River sockeye salmon regularly exceeded 50%, but since have declined and in 2021 were the lowest since 1979. Combined U.S. and Canadian harvests of sockeye salmon have ranged between approximately 10,000 (in 2021) to 280,000 (in 1996) which included fish from the Tuya Lake sockeye salmon enhancement program (1995 – 2019).

FISHERY CHALLENGES

Coordinating management amongst domestic gear sectors in the U.S. (Alaska Department of Fish and Game; ADF&G), in Canada (Fisheries and Oceans Canada; DFO and Tahltan First Nations, TFN), and internationally (ADF&G and DFO), is a cooperative effort that requires consistent dialogue and timely exchange of in-season assessment data. Poor marine survival of Chinook salmon in the past decade and sockeye salmon in some years, as well as other environmental factors (i.e., predation by pinnipeds, variable inriver water conditions, forest fires, etc.) have presented challenges to managers.

3. Management

The management of Stikine River Chinook, sockeye and coho is the responsibility of the U.S. (ADF&G) and Canada (DFO). A strategic plan has been developed by the Transboundary Panel and Technical Committee in 2019[10]. The Transboundary Technical Committee and Panel assemble and agree on detailed annual management plans by 15 April each year, following harvest sharing provisions in the PST[11]. All provisions and exchanges of stock assessment and other management information, and their schedules, are agreed to preseason.

The management objectives for Stikine River salmon runs are to: (1) achieve spawning escapement goals by species (Chinook and sockeye salmon); (2) achieve targets for international sharing of the total allowable catch (TAC as defined in the 2019 PST Agreement (Chapter 1); (3) achieve sockeye salmon

[9] Bernard, D.B., McPherson, S.A., Pahlke, K. and Etherton, P. 2000. Optimal production of Chinook salmon from the Stikine River. Alaska Department of Fish and Game, Sport fish Division, Fishery Manuscript No. 00-01, Anchorage.

[10] Pacific Salmon Commission Joint Transboundary Technical Committee (TCTR). 2019. Transboundary Panel Strategic Salmon Plan Report developed by the Joint TBR Panel and Technical Committee; Report TCTR (19)-4. Vancouver BC.

[11] Pacific Salmon Commission Joint Transboundary Technical Committee (TCTR). 2022. Salmon Management and Enhancement Plans for the Stikine, Taku and Alsek Rivers, 2022. Joint Transboundary Technical Committee Report TCTR (22)-02. Vancouver BC.

enhancement objectives defined in the PST, and (4) achieve domestic allocation goals within each country. Management objectives for coho salmon are expected to be developed after 2024. In addition, U.S. fisheries management considers the management objectives for other nearby salmon stocks.

Stikine River Chinook, sockeye and coho salmon runs consist of multiple aggregates of sub-stocks that are spread somewhat spatially and temporally throughout the anadromous portion of the drainage. Management decisions are structured to catch in proportion to the abundance of different run segments of each species annually. Approximately 70% of the Stikine River is inaccessible to salmon due to velocity barriers, with salmon access mainly restricted to the lower 30% of the drainage. In comparison to similar glacial systems with few velocity blocks such as the Taku River to the north and the Skeena River in British Columbia, the Stikine River supports fewer sub-stocks of each species. Stock identification and catch is estimated by genetic stock Identification methods (Chinook and sockeye salmon), otolith thermal marking of hatchery-produced sockeye salmon, scale patterns (sockeye) and analysis of wild-stock and hatchery coded-wire tags (Chinook and coho salmon).

Stikine River sockeye salmon are characterized for research, management, and monitoring purposes, and are subdivided into three stock groups: 1) wild Tahltan stock, which are those fish originating from naturally spawning sockeye salmon in Tahltan Lake; 2) enhanced Tahltan stock, which are those fish originating from broodstock collected at Tahltan Lake and subsequently back-planted as fry into Tahltan Lake; 3) mainstem stock, which are all other natural sockeye salmon populations in the Stikine River, including some minor lake-type populations (i.e., Chutine Lake). Starting in 1995 through 2019, Tuya Lake enhanced sockeye salmon were produced to increase U.S. and Canadian harvest of Stikine River origin sockeye salmon.

Fishing management measures in place for salmon originating from the Canadian portion of the Stikine River are provided in Annex IV, Chapter 1 of the PST[7]. These arrangements include directed fisheries for Chinook and sockeye salmon; continuation of a U.S. subsistence fishery on Chinook, sockeye, and coho salmon stocks within the U.S. section of the Stikine River; continuation of coho salmon harvest shares; and a sockeye salmon harvest sharing arrangement based on the continuation of the sockeye salmon enhancement program.

Management of the Stikine River Chinook and sockeye salmon runs is accomplished through an intensive in-season abundance-based approach. ADF&G, DFO and TFN all contribute to the assessment framework to provide the critical numerical and biological information to managers in both countries. An abundance-based management framework for Stikine River coho salmon is planned[10]. In the interim, the U.S. management intent is to pass enough fish upriver to support a Canadian in-river harvest of 5,000 coho salmon. Assessment programs need to be further developed before a biologically based escapement goal can be established. By 2024, the Parties are required to review the progress on this obligation.

The in-season management of Stikine River Chinook salmon initially relies on a preseason forecast and an in-season run size model (Stikine Chinook Management Model, SCMM). Initial management of Stikine River sockeye salmon relies on a preseason forecast and an in-season run size models (Stikine Management Model (SMM) and Stikine Fisheries Management Model (SFMM)).

MANAGEMENT CHALLENGES

Recently, marine survival has decreased for Chinook salmon and run sizes in some years have dropped to levels not seen since the 1970s. From 2011–2021, marine survival decreased 50%, compared to estimates earlier in the time series (1998–2003 brood years, Figure 3). The Little Tahltan River, a major tributary of the Stikine River that has served as an abundance index since 1975, exhibited a period of productivity below replacement for returns from 2007 to 2012[12].

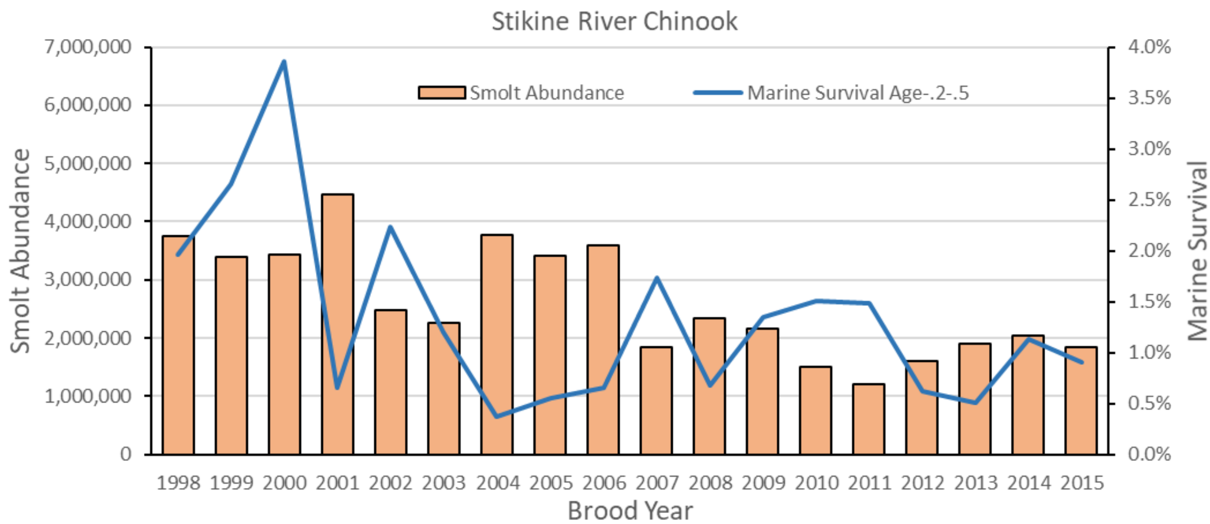

Figure 3. *Estimated smolt abundance and marine survival of Chinook salmon originating from the Stikine River in brood years 1998 to 2015 (current through 6-year-old return in 2021)[1].*

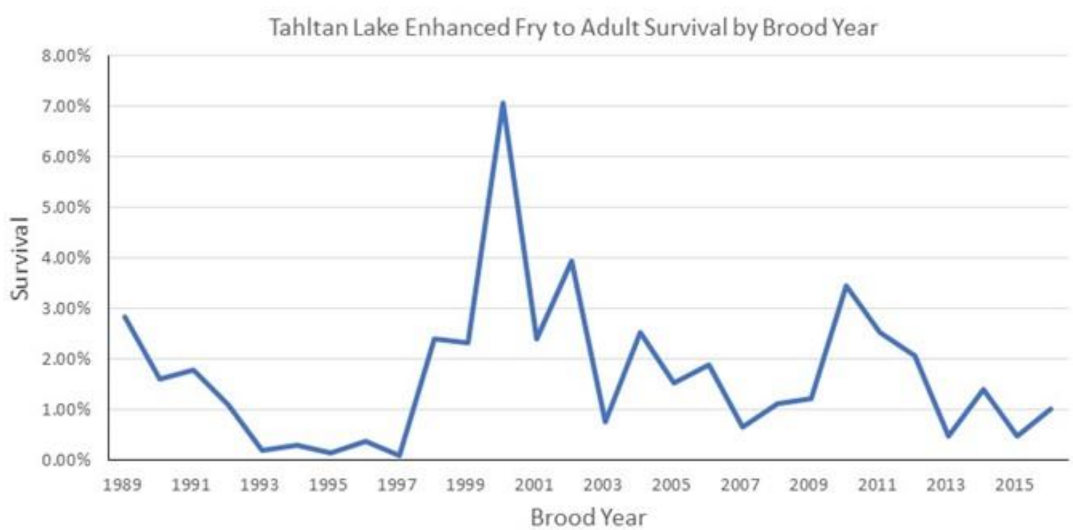

Figure 4. *Estimated survival of sockeye salmon originating from Tahltan Lake in smolt years 1989 to 2016 brood years (current through 5-year-old return in 2021). Data source: TCTR 2022[1].*

This downward trend in Chinook salmon survival has been the main cause of reduced abundance; all fisheries that harvest Stikine River Chinook salmon have been severely limited or closed for five years (2017–2021). The terminal sockeye and coho salmon fisheries in the U.S. and Canada have not been impacted to the same degree but the sockeye salmon fisheries have experienced reduced fishing opportunities (time and area openings) and lower harvests in recent years due to reduced survival of

[12] DFO. 2016. Exploration of data and methods for developing estimates of a biologically based spawning goal and biological benchmarks for Little Tahltan Chinook (Stikine River drainage). CSAS Science Advisory Report 2016/006.

sockeye salmon and decreased abundance of co-migrating Chinook salmon. Recent abundances of sockeye salmon are well within ranges observed historically (since 1979) but generally, abundance has been below historical averages in the last 10 years. Coho salmon stock assessment is limited to aerial survey counts, but it appears that escapements in Canada may have declined since 2002.

Predation, both of adult salmon and migrating smolts, may have impacted recent declining trends in abundance. Recent telemetry studies, abundance studies, and observations by users and professional staff have identified predation by marine mammals in waters of Southeast Alaska as a major management concern. The predation occurs in the terminal area and lower river, not only of the Stikine River, but also of the Taku and Alsek Rivers (included in Chapter 1 of the PST) and most medium and large river systems in the region. The abundance of marine mammals, which are protected under the U.S. Endangered Species Act, has increased substantially in Southeast Alaska and other coastal areas. In addition, predation on out-migrating smolt is a concern. Humpback whale populations have increased 15-fold (1,500 to about 25,000) since the mid-1970s and are known to predate on salmon smolts.

4. Assessments

The assessment of Stikine River Chinook, sockeye and coho salmon includes the use of annual pre-season forecasts (excluding for coho given the lack of escapement and survival data), in-season assessments, and coded-wire tagging (for wild Chinook and coho salmon) as well as the use of management tools such as reference points, harvest control rules, and escapement goals.

PRESEASON FORECAST

The staff managing Stikine River salmon rely on preseason forecasts of run size for the assessment and management of Chinook and sockeye salmon stocks until in-season estimates of abundance become available. Preseason forecasts are developed by February 1 each year.

The preseason forecasts for Chinook salmon rely on a sibling model adjusted downward for the 5-year average model error, as the model has tended to overestimate the run size in recent years. Sibling return data has indicated that the productivity is well below average in recent years.

The preseason forecast for the terminal run of Stikine River sockeye salmon is based on the sum of forecasts for the Tahltan Lake stock and all mainstem stocks combined. The Tahltan Lake forecast is based on a smolt model which uses the 3-year average age specific marine survival rate in combination with the number of smolts that emigrated from Tahltan Lake two and three years previous. The smolt forecast has been more accurate than the sibling forecast in recent years due to low return numbers and limited age sampling opportunities. The Stikine River mainstem sockeye salmon forecast is based on a stock-recruitment model that is adjusted by the average model error over the past 5 years. In the past, a sibling model, based on the relationships between sibling 4- and 5-year-old fish performed better than other models. However, because of limited fishing opportunities for mainstem stocks in 2019 – 2021, it was not possible to reliably determine the abundance of specific age classes and as a result it was not reasonable to use the sibling model for 2021 and 2022 forecasts.

Despite the annual aerial survey, Stikine River coho salmon lacks reliable escapement and marine survival data. Therefore, no forecasts are produced for coho salmon[6].

The Chinook and sockeye salmon forecasts are used to set the initial openings for each parties' fisheries by species, ranging from no opening to a 'standard' opening[11]. For directed Chinook salmon commercial fisheries in U.S. and Canada to be prosecuted based on the preseason forecast, the forecast must meet or exceed 24,600 large fish, which is based on the escapement goal plus catch associated with assessment fisheries plus U.S and Canadian base level catches (catch in fisheries directed at other species). For sockeye salmon, the forecast must indicate a TAC for the Tahltan and mainstem components for the initial season openings to occur.

IN-SEASON ASSESSMENTS

If there are no initial fishery openings in-river based on Chinook and sockeye salmon forecasts failing to reach the management objectives, an alternative assessment fishery may be triggered (which may be non-lethal). After the first two to four weeks of the season, in-season run size estimates replace the preseason forecasts once they are produced by the in-season assessment programs.

The in-season assessment program for managing the Stikine River terminal Chinook and sockeye salmon runs consists of several components, which are inputs into the in-season Stikine Chinook Management Model (SCMM) for Chinook and Stikine Management Model (SMM) and Stikine Fisheries Management Model (SFMM) for sockeye salmon[13]. The SCMM model uses Kakwan catch-per-unit-effort (CPUE) data as well as mark–recapture estimates expanded by historical timing data to estimate run size. The weekly mark–recapture estimates are obtained through a cooperative capture–recapture program operated inriver starting in late May/ early June. Two drift gillnet crews operate in U.S. waters in-river to capture adults and mark, sample, and release fish. Marked fish are recaptured upriver in commercial and/or assessment fisheries and spawning ground sampling events. In the U.S. terminal marine fisheries in District 108 and 106 (sockeye salmon), Stikine River Chinook salmon catch is estimated weekly using CWT methodology with final postseason estimates based on genetic stock identification techniques. Postseason, Stikine River sockeye salmon catch is estimated using matched otolith, scale, and genetic samples.

The Stikine Management Model (historical-SMM) has been the primary in-season forecast model since it developed was in the late 1980s (TRTC 1988[14]). The SMM model is based on lower river cumulative CPUE and historical run timing of Stikine River stocks. To predict the terminal run size, the projected in-river run is added to the projected total season harvest of Stikine River sockeye salmon in the Districts 106 and 108 fisheries. In 2015, the Stikine Forecast Management Model was created improve the SMM allowing for earlier in-season predictions of inriver and terminal run models using second order polynomial regression models (Miller and Bednarski 2017[13]). Models 1–4 are terminal run size models based on U.S. commercial fisheries data and Models 5–7 are inriver run size models based on the Canadian lower river commercial fishery. The additional model choices have been helpful, since in-season data has been limited, due to recent fishery closures. All models provide projections of the Stikine River, Tahltan, and mainstem stocks. The in-season run size estimates are updated weekly through SW 33 when U.S. fisheries transition to pink salmon management.

[13] Miller, S.E. and Bednarski, J.A. 2017. Stikine Sockeye salmon management model: improving management uncertainty. Pacific Salmon Comm. Tech. Rep. No. 38: 31 p.
[14] Transboundary Technical Committee Report: TCTR (88)-2, Salmon Management Plan for the Transboundary Rivers, 1988.

Model inputs include fishery harvest and effort information as well as stock specific information. In-season otolith samples are collected from the fisheries weekly and sent to the ADF&G Mark Tag and Age Lab for processing. All the fisheries use otolith information to separate wild and enhanced Tahltan Lake sockeye salmon. For Canadian lower in-river commercial and test fisheries egg diameter information is used to estimate Tahltan and mainstem harvest. For U.S. commercial fisheries all wild Tahltan and mainstem in-season projections are based on historical stock composition analysis. However, it should be noted that all these techniques rely heavily on information gained from commercial harvest. If no commercial fishing is anticipated an in-river assessment fishery may be implemented. The assessment fishery may be lethal or non-lethal depending on severity of run shortfalls.

CODED-WIRE-TAGGING OF WILD CHINOOK AND COHO SALMON SMOLT; AND TAHLTAN SOCKEYE SALMON SMOLT ENUMERATION

An important component of the assessment and management frameworks for the Stikine River is the CWT project for Chinook salmon and the Tahltan Lake smolt enumeration project for sockeye salmon, which are joint efforts between ADF&G, DFO and TFN. For Chinook salmon, these projects provide the basis to estimate smolt abundance, marine survival, total catch, total production, calendar year harvest rate, and brood year exploitation rates. It is an explicit goal in the strategic plan to develop these same estimates for Stikine River coho salmon, as coho (and Chinook) salmon smolt have been marked with CWTs for about 20 years. The wild Chinook and coho salmon stocks tagged (as smolt) in the Stikine River are respectively one of six wild Chinook salmon stocks and one of less than 10 wild coho salmon stocks coastwide with a CWT program. As part of the CWT program, each spring, crews capture Stikine River wild Chinook and coho salmon smolts with beach seines and minnow traps, then transport them to a tagging site where they are tagged and released. Returning Chinook and coho salmon adults caught in SEAK waters are sampled by ADF&G in all commercial and sport fisheries and recovered CWTs are processed and reported by the ADF&G Mark, Tag and Age Lab. All CWTs recovered in Canada are processed by the DFO CWT Lab in Nanaimo, BC.

Estimates of sockeye salmon smolt outmigrating from Tahltan Lake have been made since 1984, which provide a method for estimating marine survival of adults. The estimates are derived from a smolt enumeration weir and resulting data helps develop annual estimates of outmigrating sockeye salmon smolts from Tahltan Lake and includes both wild and enhanced fish.

REFERENCE POINTS, HARVEST CONTROL RULES AND ESCAPEMENT GOALS

The management of Stikine River Chinook and sockeye salmon relies on the application of harvest control rules to determine TAC, harvest sharing rules and escapement goals by species[7]; all are specified in Chapter 1 of the 2019 Agreement and annual management plans[8]. The TAC and harvest sharing is determined by the terminal run size, the available surplus to escapement needs and management objectives. The TAC also includes base level Chinook salmon catches for each fishery that catches Chinook salmon incidentally (averages prior to the 2005 agreement were used), which are included in provisions of Chapter 1. Base level catches (BLCs) in Alaska District 108 drift gillnet, sport and troll fisheries also count towards the SEAK all-gear catch limit, under provisions of Chapter 3 (Chinook).

The harvest control rules for Stikine River Chinook and sockeye salmon are defined by lower and upper fishery reference points, based on escapement goal ranges for each species, and a defined management objective[11]. When the projected in-season run size estimate is below the management objective, then no directed fisheries are allowed by either party. Some incidental catch can occur during fisheries directed at other co-migrating stocks and that is accounted for under mechanisms outlined in the PST. If directed fisheries are allowed, fishery openings are structured according to catch sharing agreements. Early in the run, the projected run size is based on the preseason forecast until sufficient data are available in-season to produce reliable estimates.

The escapement goals for Chinook and sockeye salmon are based on time series of high-quality production data with ranges that sustain the stocks long-term while also permitting catch for Chinook and sockeye salmon. The current escapement goal range for Chinook salmon is 14,000 to 28,000 large fish, with a management objective of 17,500 fish (representing S_{MSY}) which was revised in 2000[9]. This is the third escapement goal revision since 1981. This represents a drainage-wide goal and is subject to periodic review by the Transboundary Technical Committee. Corresponding escapement goal ranges for counts through the weir on the Little Tahltan River are 2,700 to 5,300 fish with a management objective of 3,300 fish. Based on the average from 2010-2021, Little Tahltan River Chinook salmon represent 6% (range: 1–17%) of the total spawning population[6].

For Stikine sockeye salmon, the Transboundary Technical Committee established in 1993 the management objective of 24,000 fish (escapement goal range 18,000 – 30,000 fish) for Tahltan Lake sockeye salmon which considers 20,000 naturally spawning fish and up to 4,000 fish needed for broodstock objectives of the Canada/U.S. Stikine River enhancement program[11].As well as the management objective of 30,000 fish (escapement goal range 20,000 – 40,000 fish) mainstem sockeye salmon. It would be prudent to revisit the goals for sockeye salmon using the extensive spawner-recruit data that has accumulated over the past three decades, which would allow for more recent production dynamics to be considered when determining a sustainable escapement goal. Currently, the escapement goals and management objectives for Stikine River sockeye salmon are under review.

Management objectives have not been established for Stikine River coho salmon. Assessment projects are in the developmental phase and are scheduled to be implemented sometime after 2023.

For directed Chinook or sockeye salmon commercial fisheries in U.S. and Canada to be prosecuted, the in-season run size must exceed the management objectives. The TAC for Chinook salmon is defined by the terminal run minus the escapement goal/management objective, the catch from the assessment fishery, and the U.S. and Canadian base level catches (BLC). For Chinook salmon, the catch assigned to the assessment fishery depends on the need (up to 1,400 large Chinook salmon) while the BLCs for the U.S. and Canada are 3,400 and 2,300 large Chinook salmon respectively. These BLCs are based on average historical incidental catches in directed sockeye salmon fisheries in the U.S. and Canada. Of the available TAC, 50% is allocated to each country. If the preseason forecast for Chinook salmon exceeds 30,000 Chinook salmon, harvest share adjustments may be made.

For sockeye salmon, the primary management objective is to reach the escapement goal for both the Tahltan Lake and mainstem sockeye salmon stocks. TAC levels for U.S. and Canadian fisheries are derived through SFMM or the SMM, based respectively on pre-season or in-season run size estimates. The models use the escapement goals in combination with run size estimates and the harvest sharing provisions in the PST to determine the TAC for each country. Based on average run timing estimate (1986–2011) and corresponding average CPUE levels of each fishery, the models estimate the weekly TAC and fishing effort for managers. The Transboundary Technical Committee prepares a Stikine Enhancement Production Plan (SEPP) annually, that is reviewed, revised, and approved by the Transboundary Panel. Since the loss of

Tuya Lake production in 2014, the plan aims to produce 65,000 adult enhanced sockeye salmon from direct release in Tahltan Lake. The harvest rate share is 53% U.S. and 47% Canada from 2019 through 2023 but is adjusted depending on the sockeye salmon return and failure of the Parties to implement the SEPP as outlined in the PST, with a goal of producing 100,000 enhanced sockeye salmon[11]. For 2024-2025, the harvest rate share is 57.5% U.S. and 42.5% Canada.

For coho salmon, U.S. fisheries management aims to ensure sufficient coho salmon enter the Canadian section of the Stikine River to allow for an annual Canadian catch of 5,000 coho salmon in a Canadian fishery directed at coho salmon.

MANAGEMENT STRATEGY EVALUATION

The Transboundary Technical Committee and Panel evaluate the fisheries management performance annually for each species as directed by Paragraph 4 of Chapter 1. Current management regimes are examined and as required, recommendations are provided as to how they may be better suited to achieving escapement goals, harvest sharing, and other objectives. To date, there has been no simulation modeling efforts to evaluate the ability of alternative management procedures (e.g., in-season assessment, escapement goals and harvest control rules) to meet fishery and conservation objectives in the system.

DATA LIMITATIONS

Direct estimates of total escapement began in 1996 for Chinook salmon and 1979 for sockeye salmon; total escapement has not been estimated for coho salmon, but index counts in six tributaries have been conducted with reasonable consistency since 1985. In recent years, limited aerial surveys have been conducted once annually. In-river fisheries have been enumerated and sampled since 1979. Alaska District 106 and 108 harvests in commercial fisheries have been enumerated since 1960 and sampled for age, size, and stock identification since 1981, the sport fishery since the 1980s. Wild Chinook and coho salmon smolt have been captured, tagged with CWTs, and released each spring since 2000 in the mainstem of the lower Stikine River. This joint stock assessment program has resulted in a long and precise time series of estimates of escapement and subsequent smolt and total adult production, marine survival, and stock-recruit data for Chinook and sockeye salmon. Data are limited for coho salmon because the total escapement is not enumerated, and/or sampled for age structure and CWT and adipose-clipped rate; thereby eliminating the ability to estimate production, harvest rates, survival, etc. Radio telemetry studies have been used to estimate spawning distribution for Chinook, sockeye, and coho salmon, and to produce or verify escapement estimates for Chinook and sockeye salmon. There has been a marked change in the distribution of Chinook salmon spawning, primarily a reduction into the Little Tahltan River. Additional periodic telemetry studies will be needed to assess factors affecting escapement estimates for all three species. The bilateral assessment program is cost effective because it spans two species and is planned for three species; however, future funding is required to maintain and improve the current data collection, assessment, and management programs.

ASSESSMENT CHALLENGES

The in-season assessment of Stikine River Chinook and sockeye salmon can provide precise, timely, and accurate information for Canadian fishery management; however, for U.S. fisheries which take place below the in-river assessment program and primarily in marine waters, inherently the information is less timely for management.

Low survival is producing low returns recently, which present challenges in estimating inriver run size for Chinook and sockeye salmon. Fewer fish are available to mark, recover and sample in assessment activities, reducing the precision of population estimates. Recent restrictions in sockeye salmon commercial fisheries in both the U.S. and Canada has reduced the availability of harvest and effort data used to estimate abundance in-season (SMM and SFMM). In both cases, in-season assessments are of little utility for in-season management for either country.

INFORMATION CONVEYED TO MANAGERS/DECISION MAKERS

Pre-season forecasts are provided by December 1 annually for Chinook salmon and by February 1 for sockeye salmon and are used by managers to plan for and start the fishing season. All fisheries harvest, escapement, and run projections from in-season assessments/models are provided to managers weekly throughout the fishing season. In-season management coordination between U.S. and Canadian fishery managers involves weekly communication between designated members or alternates. Canadian and U.S. fishery managers conduct data exchanges by telephone and/or email on Wednesday afternoon or Thursday morning of each week during the fishing season. Fishing plans for the next week for each country will be discussed at this time.

5. Incorporating environmental data and accounting for changes in productivity

Environmental data are not used directly to generate preseason forecasts of run size; however, environmental influence on survival is indirectly accounted for by the sibling model used to forecast Chinook and sockeye salmon. The Chinook forecast uses a more recent timeseries of brood year information while both Chinook and sockeye salmon forecasting models use the 5-year error rate to produce less biased forecasts. These adjustments inherently help to capture the changes in marine survival and production without inputting any environmental covariates directly into modeling. A smolt-based forecast model for Tahltan Lake stock is used for sockeye salmon which accounts for any freshwater environmental changes; however, it does not explicitly account for any marine environmental effects affecting survival and operates off a recent average marine survival rate.

Environmental data are not used to estimate, in-season, the number of returning Chinook and sockeye salmon; the in-season management models rely on the capture-recapture and CPUE for Chinook salmon and the Tahltan weir and terminal catch data to estimate in-river abundance and timing. These are coupled with timely accounting and analysis of stock ID data from all the terminal fisheries to make the total projections each week. All are input into the management models that predict run size. The watershed is almost entirely pristine and water temperatures in-river (glacial fed in part) have not been a factor for pre-spawn mortality, etc. In-season management on the Stikine River is risk adverse and does not require incorporation of additional environmental variables.

Escapement goals reviews (by ADF&G and DFO) usually evaluate and, if needed, incorporate changes in productivity and therefore interannual and longer-term changes in survival are implicitly incorporated. In addition to tests and correction for non-stationarity, autocorrelation, etc., yield profiles are also used as guidance in this process. This was done for the present Stikine River Chinook salmon goal in 2000, but not for the present two Stikine River sockeye salmon goals (Tahltan Lake and Stikine River mainstem). These are dated and we suggest that revisions in the future evaluate and incorporate changes in productivity and use other contemporary techniques[15] such as yield profiles as guidance in this process[16]. As noted, the Stikine River sockeye salmon escapement goals and management objectives are currently under review with a 2023 fishing season implementation date anticipated.

The Transboundary River Panel and Transboundary Technical Committee are committed to improving the abundance-based regime on the Stikine River, as detailed in the Transboundary River Strategic Plan[10]. However, closed-loop simulation evaluations of the current abundance-based regime (e.g., Management Strategy Evaluation) have not been undertaken.

6. Accounting for and conveying uncertainty

The preseason forecast model for Chinook salmon produces a point estimate with associated confidence intervals; no measure of uncertainty is associated with the sockeye forecast. Fishery management decisions using preseason forecasts for these species are done with an abundance of caution because of the present uncertainty associated with forecasting. Preseason forecasts serve as starting points for early season management actions.

The in-season run size by species are time-density models for Chinook and sockeye salmon; confidence intervals are produced each week, or more often. Individual and cumulative weekly estimates are all produced with their respective error and confidence intervals. It is the intent to develop the same for coho salmon in the future.

Escapement goals are produced with point estimates and ranges. The Chinook salmon goal was produced with more rigor than the sockeye salmon goal and range and did incorporate measurement error into the spawner-recruit analysis for escapements, catch and age structure[9]. The point estimate for Chinook salmon has an estimate of uncertainty (SEs, etc.) while the upper and lower ranges for the escapement goal are constructed from expected catch profiles that will produce a high likelihood (> 90%) of MSY. Revisions to escapement goals in the future should be done via state-space age structured spawner-recruitment models that explicitly account for uncertainty in estimates of spawning escapement, catch and age composition[15].

The Transboundary Technical Committee continually evaluates the annual performance of the bilateral fishery management approaches and provides the Transboundary Panel with performance summaries and recommendations regarding improvements to the strategies on an annual basis. However, closed-loop simulation evaluations of the current abundance-based regime (e.g., Management Strategy Evaluation) have not been undertaken.

7. Ability to reach management objectives

The assessment and management of the Stikine River Chinook and sockeye salmon terminal runs uses an abundance-based approach with intensive in-season management. It is risk adverse due to the availability of timely and precise data, the terminal nature of the fisheries and the low interception rates in non-

[15] Fleischman, S.J., Der Hovanisian, J.A. and McPherson, S.A. 2011. Escapement goals for Chinook salmon in the Blossom and Keta rivers. Alaska Department of Fish and Game, Fishery Manuscript No. 11-05, Anchorage.
[16] Bernard, D. R., and Jones III, E.L. 2010. Optimum escapement goals for Chinook salmon in the transboundary Alsek River. Alaska Department of Fish and Game, Fishery Manuscript Series No. 10-02, Anchorage.

terminal fisheries. The abundance-based approach has precluded the catch of most Chinook salmon in the past five years and has maximized escapements even though escapement and management objectives have not always been met. Most directed sockeye salmon fisheries on Stikine River stocks have been closed or severely limited the past 2 years. Management objectives for coho salmon continue to be met annually. In general, fishery managers consistently meet the objectives of the chapter using the current assessment, modeling, and management approaches.

8. Planned assessment changes to account for climate change

ADF&G, DFO and TFN have committed to reviewing the current assessment and management frameworks and to making the necessary improvements (see recent strategic plan[10]). There are plans to develop an abundance-based management regime for Stikine River coho salmon, which will require the assessment and management components in place for Chinook and sockeye salmon, including estimation of total escapement, in-season abundance, harvest sharing, management modeling and appropriate funding.

PST Chapter 2: Skeena and Nass River sockeye salmon[1]

1. Introduction

Chapter 2 of the Pacific Salmon Treaty applies to Skeena and Nass River sockeye salmon. The Skeena River contains 31 lake-type and two river-type sockeye Conservation Units (CUs)[2]. Babine Lake now accounts for more then 90%of the total Skeena sockeye production in some years due to the enhanced production in the tributary spawning channels and flow-controlled river sections at Fulton River and Pinkut Creek. The remainder of Skeena sockeye stocks vary in size and productivity but in general can not withstand the same exploitation rate as the more productive enhanced Babine stocks[3]. The Nass River contains eight lake-type sockeye CUs and two river-type[4] CUs and returns are dominated by sockeye from Meziadin Lake. While Meziadin Lake has been responsible for approximately 75% of the long-term average sockeye production in the Nass watershed, its annual contribution varies considerably[5].

Over the past 10 years, total sockeye salmon returns to Skeena and Nass Rivers combined have ranged from close to 1.0 million in 2013 to 3.8 million in 2014[6,7]. The majority of these sockeye salmon were produced by the Skeena River. Sockeye salmon runs to the Skeena River in the last 10 years (2011–2020) ranged from approximately 0.5 million in 2013 to 3.3 million in 2014. In recent years, runs to the Skeena River have become more uncertain with greater variability among the individual stock components[5]. Preliminary estimates for 2022 indicated a run size of 4.3 million[8]. There are multiple Skeena River stocks of particular conservation concern including Lakelse, Nanika-Morice, Kitwanga and the Babine River component of Babine sockeye. Sockeye salmon runs to the Nass River over the same period (2011–2020) ranged from 295,000 in 2020 to 869,000 in 2015. Four of the five smallest runs to the Nass River since 1992 have been observed in the last 5 years. Recent runs to Meziadin have been below the target escapement of 160,000. The Kwinageese River sockeye salmon within the Nass River watershed was severely impacted by a rockslide since 2009 but run sizes have started to improve since 2011 following site specific habitat remediation and annual timing and targeted Canadian fishery management closures to protect the stock. Preliminary estimates for 2021 and 2022 indicated Nass River run size estimates of 412,000 and 487,000 respectively[9].

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[1] This Chapter of the treaty also covers other stocks and species not covered in this report including Southeast Alaska pink salmon which are intercepted in Canadian fisheries.
[2] Holtby, L.B., and Ciruna, K.A. 2007. Conservation Units for Pacific Salmon under the Wild Salmon Policy. DFO Canadian Science Advisory Secretariat Research Document 2007/070: 358.
[3] DFO 2003. Skeena River sockeye salmon (update). DFO. Can. Sci. Advis. Sec. Stock Status Rep. 2003/047.
[4] Beacham, T.D. and Wood, C.C. 1999. Application of microsatellite DNA variation to estimation of stock composition and escapement of Nass River Sockeye Salmon (*Oncorhynchus nerka*). Canadian Journal of Fisheries and Aquatic Sciences 56:297–310.
[5] DFO. 2020. Integrated Fisheries Management Plan June 1, 2020 - May 31, 2021. Salmon Southern BC. Fisheries and Oceans Canada.
[6] PSC and Joint Northern Boundary Technical Committee. 2020. U.S./Canada Northern Boundary Area 2018 salmon fisheries management report and 2019 preliminary expectations. PSC Report TCNB (20)-1.
[7] Nisga'a Fisheries and Wildlife. 2020. Nisga'a Fisheries weekly update 2020 – 10 September 2020.
[8] DFO. 2022. North Coast Salmon Update #13 – 20 September, 2022. Fisheries and Oceans Canada.
[9] Nisga'a Fisheries and Wildlife 2022. 2022 Nass River salmon stock assessment update – Monday, 19 September.

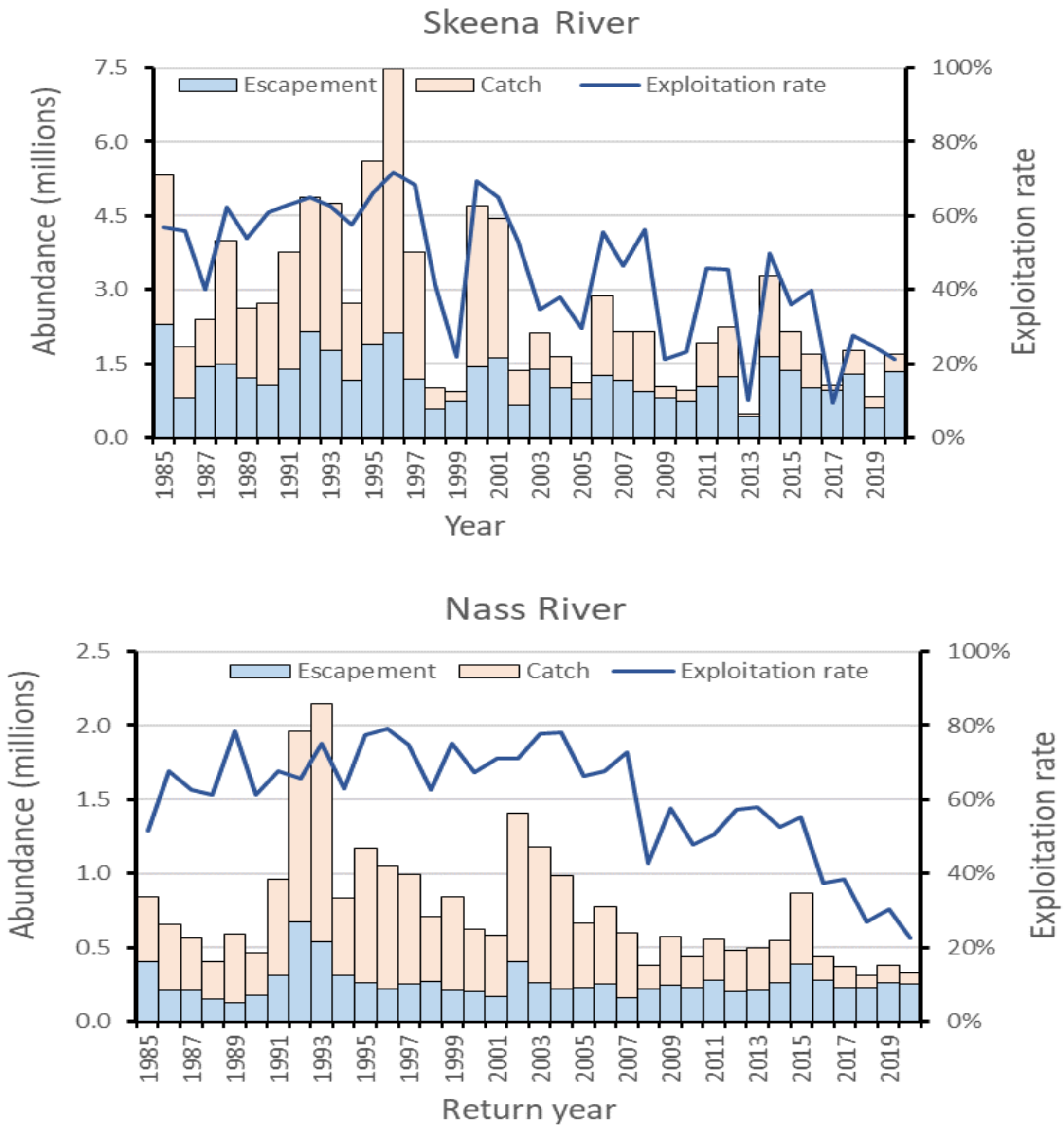

Figure 1. *Escapement, catch, and total exploitation rate from both Canada and the U.S. of sockeye salmon in the Skeena and Nass Rivers since 1985.*

2. Fisheries

The total catch of Skeena and Nass sockeye salmon has primarily been fish produced by the enhanced production facilities in Babine Lake since inception of the spawning channel flow-control structures associated with the Babine Lake Development Project (BLDP) enhancement facility were built starting in the 1970s. The increased production of Skeena sockeye resulted in increases in overall catches in both U.S. and Canadian fisheries. The negotiations of annexes to the 1985 Pacific Salmon Treaty (PST)[10] were

[10] Wood, C.C. 2001. Managing biodiversity in Pacific salmon: the evolution of Skeena River sockeye salmon fishery in British Columbia. B. Harvey and D. Duthie (eds.). Proceedings of the International Conference Blue Millennium: Managing Global Fisheries for Biodiversity. Victoria, B.C. June 25-27 2001. 64 pp. United Nations Environment Program.

intended to address high interception of Canadian-origin sockeye salmon in U.S. waters. Overall (U.S. and Canadian combined) exploitation rates of Skeena River sockeye salmon have declined, with average estimates decreasing from around 60% (1985-1997), to 43% (1998-2012), to 27% in recent years (2013-2020) (Figure 1). In addition to exploitation rates being lower, they have also been more variable in recent years in response to lower and more variable runs and concerns about catches of non-Babine stocks. Similar to Skeena River sockeye salmon, the catch and exploitation rates for Nass sockeye salmon show a strong declining trend, with average exploitation rates decreasing from about 70% (1985-2007), to 53% (2008-2015), to 34% in recent years (2016-2020) (Figure 1).

GEAR SECTORS

U.S.:

- Alaska District 104 purse seine fishery (primarily targeting U.S. Alaska pink salmon)
- Alaska District 101 drift gillnet fishery (primarily targeting sockeye, chum, pink, and coho salmon)

Canada:

- Area 3-5 gillnet (primarily targets sockeye and pink salmon), openings based on in-season abundance at Nass fishwheels and Tyee.
- Area 4 seine (primarily targets sockeye and pink salmon), openings based on in-season abundance at Tyee.
- First Nations food, social and ceremonial fisheries (FSC) gillnet, seine, fishwheels, dipnet, traps
- Escapement surplus to the spawning requirement fisheries (ESSR) – Terminal fisheries targeting enhanced sockeye salmon returning to the Pinkut Creek and Fulton River spawning channels.
- Demonstration Fisheries – Small, targeted marine and in-river First Nations economic opportunity fisheries which occur in years of high abundance for Skeena and Nass sockeye and pink salmon.
- Nisga'a Treaty Fishery – Marine and in-river fisheries, using a variety of gear types.
- Recreational fisheries – Marine and in-river recreational fisheries, primarily targeting chinook and coho salmon. Sockeye openings and retention limited based on in-season abundance past Tyee and Meziadin fishway.

HARVEST BY OTHER FISHERIES

Most of the U.S. harvest of Skeena and Nass River sockeye salmon takes place in District 104 purse seine and District 101 drift gillnet fisheries, but other fisheries that harvest these two sockeye salmon runs include Alaska Districts 101, 102, and 103 purse seine, and District 106 drift gillnet.

In Canada, sockeye retention in Area 1 Troll (primarily targeting pink, chinook, and coho salmon) occurs based on in-season abundance past Tyee and interception of sockeye in this fishery is low. In Area 3 seine (primarily targeting pink, and chum salmon) sockeye retention depends on in-season abundance at the Nass fishwheels and Tyee.

FISHERY CHALLENGES

In Canadian fisheries, Nass River sockeye salmon stocks are impacted by directed commercial fisheries and incidentally in fisheries directed at more abundant Skeena River sockeye salmon. To protect weaker Nass stocks such as Kwinageese sockeye salmon, Canadian fisheries closures are implemented for periods of the season. The ability to minimize exploitation rates on weaker stocks to meet conservation goals under the Wild Salmon Policy by responding to changes in run timing of the different component stocks however remains a challenge. In addition, variable productivity shifts through time of Nass aggregate and component stocks present a challenge to in-season modelling to prevent overfishing and to ensure optimum production. Terminal fisheries enable harvest of the more abundant stocks. Skeena River sockeye salmon stocks experience similar management issues to salmon stocks in the Nass River: variability timing of component stocks relative to the aggregate and shifts in productivity. Survival rates of Skeena and Nass River sockeye salmon have likely also been negatively impacted by increases in marine mammal populations.

Recent declines in abundance compared to the high sockeye salmon productivity period of the 1980s and 1990s have caused concern in Canada about the impact of the District 104 catches on Skeena and Nass River sockeye salmon, both in terms of abundance as well as in terms of later timing of the run. Alaska harvest rates on Skeena River sockeye salmon have averaged 8% in the District 104 fishery from 2011 to 2021 (range = 1%–17%), and 12% (range 2%-27%) for all Alaska fisheries in keeping with the intent of Chapter 2 as a compromise between allowing Nass and Skeena River sockeye stocks to pass through Alaska fisheries while allowing Alaska to fish based on domestic pink salmon abundance. However, Alaska District 104 fishermen are concerned about treaty restrictions curtailing opportunities to fish early-run pink salmon, especially when Alaska does not believe that historically low returns of Skeena and Nass sockeye salmon are the result of Alaska harvest rates[11]. Restrictions to the District 104 purse seine fishery due to Canadian sockeye salmon concerns about higher exploitation rates for Skeena sockeye in recent years may contribute to escapements well above management targets for pink salmon in some early-run pink salmon stocks along the mainland of Southern Southeast Alaska. This is particularly concerning in years of high pink salmon abundance or when these stocks arrive earlier than average. Conversely, when run timing for Skeena sockeye is later than average, as has occurred in six of the last seven years, they may experience higher exploitation rates in Alaska fisheries; however, the two Parties disagree on the extent to which Alaska harvest rates on Skeena sockeye are positively correlated with later runs[12]

Harvest rates in the District 101 drift gillnet fishery have dropped to low levels over the most recent decade (2011–2020), averaging just 5% of the total Nass River sockeye salmon run.

3. Management

Canadian Strategic plans for Skeena and Nass River sockeye are described by the Wild salmon policy[13] (protect salmon diversity and manage salmon populations to the CU level), the Pacific Salmon Strategy initiative[14] (management of commercial fisheries to limit the interception and exploitation on stocks of concern) and Bill C-68[15], fish stock provisions (section 6.1-6.3 and subsection 43(1)b.1., aim to maintain major fish stock level diversity and generate rebuilding plans for stocks declined below a critical abundance threshold). Annual Skeena and Nass River sockeye management plans are documented in the

[11] Piston, A. W. 2021. District 104 purse seine fishery harvest pattern analysis. Pacific Salmon Commission, Technical Report No.44: 127 p.
[12] Chapter 2 Northern Boundary Area Review of Performance. A joint analysis by the bilateral CAN/U.S. Northern Panel and Northern Boundary Technical Committee. February 16, 2023
[13] DFO. 2005. Canada's policy for conservation of wild Pacific salmon. Fisheries and Oceans Canada, Vancouver, B.C.
[14] Pacific Salmon Strategy Initiative (dfo-mpo.gc.ca), https://www.dfo-mpo.gc.ca/campaign-campagne/pss-ssp/index-eng.html
[15] Bill C-68. June 21, 2019. https://www.parl.ca/DocumentViewer/en/42-1/bill/c-68/royal-assent

Annual Integrated Fisheries Management Plan[5], the Southeast Alaska purse seine management plan[16], and the drift gillnet management plan[17].

Under Chapter 2 of the PST, the primary fisheries management objective for both Skeena and Nass sockeye salmon s to meet their combined spawning escapement needs, followed by sustainable harvest of the surplus fish. The PST agreement allows the District 104 purse seine fishery to harvest 2.45% of the AAH (Annual Allowable Harvest) of Skeena and Nass sockeye salmon prior to statistical week 31. For the District 101 drift gillnet fishery, the annual catch share of Nass River sockeye salmon is 13.8% of the AAH[18].

Additional domestic Canadian management objectives for Skeena River sockeye salmon are to maintain sustainable sockeye salmon stocks consistent with the Wild Salmon Policy[13] and to support constitutionally protected First Nation Food, Social, and Ceremonial (FSC), commercial, and recreational harvests. Additional domestic Canadian management objectives for Nass River sockeye are to maintain sustainable sockeye salmon stocks that will meet the Wild Salmon Policy objective of maintaining CU-level diversity, support FSC, Nisga'a Treaty fishery, commercial, and recreational harvests. The Nass River management objectives aim to reduce the harvest of weak stocks such as Kwinageese until improvements towards sustainable abundance levels are observed. Overall spawning escapement targets apply to the entire Nass aggregate. Management measures are in place to reduce impacts on stocks of concern, such as temporal closures when weak stocks are at peak run timing through fishery harvest areas.

Management objectives for Nass and Skeena River sockeye salmon are established by Canada, while the implementation of the Treaty provisions is overseen by the Northern Panel and performance is evaluated by the Northern Boundary Technical Committee of the PSC (Chapter 2, Paragraph 3(a)) and management agencies for both countries. The assessment of Nass River sockeye salmon is provided by the Nisga'a-Canada-BC Joint Fisheries Management Committee. Skeena and Nass River sockeye salmon are managed as an aggregate in the mixed stock fisheries in U.S. and Canadian marine waters. Once their migration routes diverge, they are managed separately.

MANAGEMENT CHALLENGES

The primary management challenge for fisheries harvesting Skeena and Nass River sockeye salmon under the PST is making correct early season management decisions based on preseason forecasts and limited in-season information. In the first weeks of the fisheries, in-season forecasts may be unreliable and it may not be immediately obvious if the preseason forecast is inline with actual run sizes. Management decisions made in early weeks of the fishery could potentially result in lost harvest opportunities if decisions are made that are too conservative or result in harvesting above the AAH if openings are too liberal in relation to actual salmon abundance.

Canadian domestic policies, such as the Wild Salmon Policy, present additional management challenges in directed Canadian fisheries. Aggregated sockeye salmon runs to the Skeena and Nass rivers contain

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[16] Thynes T., A. Dupuis, D. Harris, B. Meredith, A. Piston, and. P. Salomone. 2020. 2020 Southeast Alaska purse seine fishery management plan. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report No. 1J20-07, Douglas.

[17] Thynes, T., N. Zeiser, S. Forbes, T. Kowalske, B. Meredith, and A. Dupuis. 2020. 2020 Southeast Alaska drift gillnet Fishery Management Plan. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report No. 1J20-08, Douglas.

[18] PSC. 2020. Treaty between the government of Canada and the government of the United States of America concerning Pacific salmon. PSC, Vancouver.

numerous genetically distinct smaller populations. Many of these populations are data limited, making it difficult to assess their status and evaluate the impact of fisheries management measures on their status. Balancing the harvest of larger, more productive and/or enhanced stocks while reducing the risk of overharvesting less productive wild sockeye salmon and other species of concern that co-migrate with them is also a challenge.

A review is currently underway to identify management actions to support conservation of Skeena and Nass River sockeye salmon, to evaluate the consistency of the management actions with the PST obligations of Chapter 2, and outline, if feasible, the benefits of the management actions for the stocks[18]. According to the Treaty, this review will be completed by January 2023.

4. Assessments

The assessment of Skeena and Nass River sockeye includes the use of annual pre-season forecasts and in-season assessments, as well as the use of management tools such as reference points, harvest control rules, and escapement goals. A Management Strategy Evaluation (MSE) through closed loop simulations, has been recommended by an independent reviewer but implementation will depend on time and resources.

PRESEASON FORECAST

Run size forecasts are an important part of the early season management process of Skeena and Nass River sockeye salmon. The preseason forecast of the total returns to both systems is generated ahead of the fishing season and is used for planning purposes and to indicate fishing expectations until more reliable in-season forecasts are available[19]. Historically , 3 different models have been used to produce the forecast: average return forecast based on the last 5 return years, a Ricker stock recruitment model that relies on smolt data to forecast age 4_2s and 5_2s, and a sibling age-class model[20] that relies on the relationship between returns of younger returning sockeye (age 3_2 and age 4_2) and their older siblings from the same brood year (age 4_2 and age 5_2). The performance of these 3 models has been evaluated retrospectively[19]. Since the Babine smolt program ceased operation in 2002, the 5-year-average and the sibling models have been used to forecast total sockeye salmon returns to both the Skeena and the Nass River. Which model to select for either river's forecast depends on the year and any noted concerns with the available data used to generate the run size estimates. For the Nass River, forecasts based on different models may be combined. For example, the 2019 forecast for Nass River was based on a sibling regression forecast, but the 2020 forecast was based on a combination of the sibling model and mean returns. While the uncertainty around the forecast is conveyed probabilistically, the 50% probability (p50) of the forecast is used to make management decisions.

IN-SEASON ASSESSMENTS

In-season forecasts are updated weekly (or more frequently) during the fishing season, are based on actual return data, and are used for management of fisheries.

[19] Cox-Rogers, S. 2004. Pre-season 2003 stock size forecasts for Skeena River and Nass River sockeye salmon. DFO Can. Sci. Advis. Sec. Res. Doc. 2004/020.
[20] Bocking, R.C. and Peterman, R.M. 1988. Preseason forecasts of sockeye salmon (Oncorhynchus *nerka*): Comparison of methods and economic considerations. Can. J. Fish. Aquat. Sci. 45:1346-1354.

In-season forecasts for Skeena River sockeye salmon are generated from a variety of different data, including commercial catch and effort data in specific fishing areas and an index of abundance from test fishing[21]. The Tyee Test fishery is the main in-season stock assessment tool which allows estimation of daily and cumulative in-season escapement for Skeena River sockeye salmon based on the CPUE data after calibration using the Babine fence count data[22] from previous years. The total return to Canada is forecasted by expanding the escapement to date based on the long-term average percentage of escapement to date from previous years. Adding Canadian marine catches to the escapement estimates allows forecasts of the total return to Canada for Skeena River sockeye salmon.

Similar to the assessment of Skeena River sockeye salmon, the assessment of Nass River sockeye salmon is based on a variety of data[23]. The Gitwinksihlkw fish wheels are currently the main tool used for in-season assessment. IPrior to 1992, a test fishery at Monkey Dump was used for in-season assessment. The fish wheel program provides a catch index for salmon and also facilitates tagging of Nass River salmon. Mark and recapture estimates are generated from tag recoveries at the Grease Harbour fishwheels located 16 km upstream of the Gitwinksihlkw fish wheels, and at the Meziadin fishway. The combination of the historical catch index and the in-season mark–recapture information enables estimation of the run size to date to the Gitwinksihlkw fish wheel. Two different methods are used to generate a forecast of the total abundance of sockeye returning to the Gitwinksihlkw fish wheel: a mean run timing model that relies on the proportion of the run observed to date, and a linear regression based on historical estimates of the current abundance to date to the final total abundance estimate. Escapement is calculated by subtracting upstream catches from this forecasted abundance estimate, which can be compared against the escapement goal. The total run size is calculated by adding the seaward catches to the abundance at the Gitwinksihlkw fish wheel site. The seaward catches are predicted by relying on historical information: the mean harvest of sockeye salmon and the proportion of Nass stocks in the catch.

REFERENCE POINTS, HARVEST CONTROL RULES AND ESCAPEMENT GOALS

Since the inception of the PST, sockeye salmon escapement goals of 200,000 for the Nass River and 900,000 for the Skeena River have been used to calculate the AAH. In Alaska District 104, the escapement goal used for AAH calculations and management of the fisheries is based on the combined escapement goals for Skeena and Nass River sockeye salmon (1,100,000 fish). In the District 101 fishery, only the 200,000 Nass River escapement goal is used for the AAH calculation. The AAH of Skeena and Nass River sockeye salmon in U.S. Alaska area fisheries is calculated annually based on the total run of adult sockeye salmon in that year, less the escapement target, or the actual escapement (combined Nass and Skeena for District 104), whichever is less. An evaluation of the existing aggregate escapement goals is currently under review as a task in the 2019 Pacific Salmon Treaty Agreement (Annex IV).

Stock and aggregate-level biological benchmarks for Skeena and Nass sockeye salmon are currently being reviewed[24]. These consider stock-specific diversity, spawning channel capacity as well as time-varying productivity. For wild Skeena River sockeye salmon stocks, the interim lower biological benchmark is

[21] Cox-Rogers, S. 1997. Inseason forecasting of Skeena River sockeye run-size using Bayesian probability theory. Can. Manuscr. Rep. Fish. Aquat. Sci. 2412: 43 p.

[22] Cox-Rogers, S. and Jantz, L. 1993. Recent trends in the catchability of sockeye salmon in the Skeena gillnet test fishery and impacts on escapement estimation. Can. Manuscr. Rep. Fish. Aquat. Sci. 2219: 19p.

[23] Nisga'a Fisheries and Wildlife 2020. Nass River salmon stock assessment update – Thursday, 17 September.

[24] Pestal, G. and Carr-Harris, C. Biological benchmarks and building blocks for developing aggregate-level management targets for Skeena and Nass Sockeye Salmon (*Oncorhynchus nerka*). CSAP Working Paper 2018SAL05.

240,000 (40% SMSY)[5]. A harvest control rule (HCR) is used to manage Canadian domestic commercial fisheries in the Skeena River. The HCR specifies a limit reference point (LRP) below which productivity is sufficiently impaired to cause serious harm to the resource but above the level where extinction risk is a concern. The commercial harvest rates on Skeena River sockeye salmon are based on an abundance-based formula that considers the forecasted aggregate abundance of Skeena River sockeye salmon to Canada. The recreational fishery on the Skeena River is managed to an actual escapement of sockeye salmon past the Tyee test fishery of 800,000.

MANAGEMENT STRATEGY EVALUATION

A MSE allows scientists, managers, and stakeholders to use simulation modelling to evaluate the effectiveness of alternative management approaches for meeting management objectives. A risk assessment model developed for Skeena River sockeye salmon[25] utilises a similar approach to assess the risk of escapement declines under continued patterns of high fisheries exploitation. It is, however, unclear to what extent this model has influenced changes to management tools such as the escapement goal. A MSE approach has not been used recently to evaluate the current management approach for Skeena and Nass River sockeye salmon, however, the review of aggregate escapement goals that is currently underway is being informed by simulation modelling that evaluates the ability of alternative escapement goals to meet both conservation and harvest objectives in the system. There have been simulation evaluation processes developed in recent years[26] for some of these stocks but thus far their results have not been integrated in the management process.

Independent reviewers for the current Skeena and Nass sockeye escapement goal review, and the Technical Working Group tasked with the development of updated escapement goals have recommended that the current management approach be evaluated using a MSE as part of the Nass and Skeena River escapement goal review, but this management tool is currently not yet used.

DATA LIMITATIONS

One of the main constraints in the assessment of Skeena and Nass sockeye salmon is the limited available data for several of the CUs. During previous evaluations of benchmarks for Skeena River sockeye salmon stocks, 14 CUs were considered data deficient[27].

ASSESSMENT CHALLENGES

Current in-season assessments rely heavily on historical estimates of escapement, catch, run size, and timing to date to forecast total escapement, catch, and run size. This might lead to underestimating the larger runs with later than average run timing or overestimating the size of runs that return early. Due to the inability to reliably predict things such as changes in productivity and run timing, the best management approach will likely remain one that is flexible to changing conditions and able to adapt in-season, until such a time that forecasting complex environmental and biological processes greatly improves.

[25] Cox-Rogers, S., Hume, J.M.B., Shortreed, K.S. and Spilsted, B. 2010. A risk assessment model for Skeena River sockeye salmon. Can. Manuscr. Rep. Fish. Aquat. Sci. 2920: viii + 60 p.

[26] Hawkshaw. M.A. 2018. Evaluating the impacts of current and alternative harvest strategies on salmon populations and fishing fleets using the Skeena River as a case Study. UBC, Vancouver.

[27] Korman, J. and English, K. 2013. Benchmark analysis for Pacific Salmon conservation units in the Skeena Watershed. PSF, Vancouver.

The accuracy of in-season assessment methods for Skeena River sockeye depends to a large extent on the precision and accuracy of the escapement estimates derived from the Tyee test fishery. There is considerable variability in the catchability coefficient for this test fishery which may result in biased index values in a given year. Even with high quality data, annual run timing deviations from average are the single largest source of uncertainty in in-season projections until more than half the run has been accounted for in catch and escapement. This is true for all salmon systems, even Bristol Bay, where ADF&G has over 60 years of high-quality catch and escapement data. The largest in-season run strength errors are always associated with abnormally early or late runs. Uncertainty in run-timing and catchability for both Nass and Skeena River sockeye are incorporated into probabilistic estimates, or ranges which are regularly provided to managers in-season.

INFORMATION CONVEYED TO MANAGERS/DECISION MAKERS

Pre-season forecasts of run size and AAH are provided annually by May 1, prior to the season. In-season, all parties involved in the in-season management of Skeena and Nass River sockeye exchange assessment and management information weekly, or more often if required. This information includes, but is not limited to catch data, CPUE data from test fisheries, escapement to date, and total run size estimates.

5. Incorporating environmental data

The models currently used for the forecast, the average 5-year return and the sibling model, do not explicitly incorporate environmental covariates. The forecast based on average returns using the last 5 years however implicitly accounts for recent environmental changes but does not account for annual changes. The sibling model accounts for shared environmental conditions experienced by fish that migrate to sea in the same year but does not account for environmental changes during the last year the sockeye salmon spend in the ocean.

Environmental data are not incorporated in the in-season assessment of the spawning escapement. While studies on other sockeye salmon stocks have indicated that performance and survival are negatively impacted when water temperatures exceed the optimal thermal range[28], this has not yet been confirmed for Skeena and Nass River sockeye salmon and has not been incorporated in the in-season assessment of escapement. Water temperatures are however routinely reported among the in-season assessment data.

The appropriateness of the aggregate escapement goals is currently under review as part of the 2019 Pacific Salmon Treaty Agreement, but the plans mentioned in the Treaty do not indicate that the impact of climate change will be explicitly or implicitly accounted for or that environmental covariates will be incorporated.

6. Accounting for changes in productivity

The models used for the forecast all indirectly account for changes in productivity. The forecast, based on average returns using the last 5 years, implicitly accounts for recent productivity changes but does not

[28] Martins, E., Hinch, S.G., Patterson, D.A, Hague, M.J., Cooke, S.J., Miller, K.M., Robichaud, D., English, K.K. and Farrel, A.P. 2012. High river temperature reduces survival of sockeye salmon (*Onchorhynchus nerka*) approaching spawning grounds and exacerbates female morality. Can. J. Fish. Aquat. Sci. 69: 330-342.

account for annual changes. The sibling model accounts for changes in productivity throughout the life history except for the final year at sea.

The appropriateness of the aggregate escapement goals is currently under review as part of the 2019 Pacific Salmon Treaty Agreement. This review is explicitly considering if, where, and how management reference points, aggregate harvest control rules, and escapement goals should be adjusted to account for changes in productivity at the Conservation Unit scale.

7. Accounting for and conveying uncertainty

The uncertainty associated with the preseason forecast is estimated by assuming that errors in the forecasted (log-transformed) run size are normally distributed. The uncertainty around the forecast is conveyed by communicating the different percentiles associated with it. The median (50%) estimate is used for management purposes and assumes a 50% chance that the actual run size will exceed this forecast. The other percentiles of the forecast are provided for risk assessment purposes. For example, the 90% forecast indicates that the actual run size might exceed this forecasted estimate 9 out of 10 times. Model uncertainty is taken into account by running more than one model to generate the forecast, i.e., the average returns based on the past 5 years and the sibling model[19].

The uncertainty around the in-season run sizes for Skeena and Nass River sockeye are expressed in term of 80 or 95% confidence intervals.

The appropriateness of the aggregate escapement goals is currently under review as part of the 2019 Pacific Salmon Treaty Agreement and uncertainty in the aggregate goals will be addressed. The escapement goals will be based on maximum sustained yield (MSY) and have biological benchmarks that are consistent with DFO's Precautionary Approach and Wild Salmon Policy.

8. Ability to reach management objectives

The use of an in-season assessment approach for Skeena and Nass River sockeye salmon circumvents, to a great extent, the need to account for environmental and productivity changes. When using an in-season assessment and management approach, there is however a risk early in the season that managers will not realise that the run is earlier and smaller than expected. This may result in overfishing until sufficient in-season data have been collected to identify that the run is smaller than expected. The use of a preseason forecast could provide a warning, assuming these forecasts are able to accurately predict when run sizes will be smaller. The current methods for the preseason forecast successfully incorporate general indications of changes in productivity and climate change. However, the current forecast methodology would not be able to predict low run sizes when environmental conditions dramatically deteriorate during the sockeye's last year in the ocean. For example, if a strong negative event occurs in the last year at sea (e.g., marine heat wave), this will substantially impact the marine survival of returning salmon without having impacted younger siblings in the same way and this would lead to an overestimation of the run size using the current forecast methods. Another weakness of the current management approach is that the effectiveness of the escapement goals has not been tested under assumptions of declining productivity and climate change. Changes in productivity through time will be evaluated as part of the escapement goal review and will presumably be part of the MSE.

9. Planned assessment changes to account for climate change

Canada is planning to complete a comprehensive escapement goal analysis for Skeena and Nass River sockeye salmon prior to the 2024 season. This analysis will be peer-reviewed by two independent contractors before submitting it to the Northern Boundary Technical Committee and Northern Panel for further review. This work was identified as a priority in the recent renegotiations of Chapter 2 (Annex IV) of the Pacific Salmon Treaty[18]. Contributions for both wild and enhanced sockeye salmon will be considered in the analysis.

There are no plans to explicitly evaluate the performance of assessment and management strategies that account for environmental changes. The current management system accounts for a changing environment through its flexibility. The intensive abundance-based in-season assessment and management framework employed for these two sockeye salmon runs will almost always capture changes in abundance during the season, whether caused by climate or other causes.

PST Chapter 3: Chinook Salmon

1. Introduction

The Chinook stocks managed under the Pacific Salmon Treaty (PST) originate from Cape Suckling, the most northern point of land in Southeast Alaska, to the Elk River on the Southern Oregon coast. There are many stocks that contribute to the coastwide Chinook abundance in these areas. For the assessment and management of these stocks, the Pacific Salmon Commission's (PSC) Chinook Technical Committee (CTC) relies on two types of indicator stocks, escapement and exploitation rate indicator stocks. The intent of the indicator stock program is to represent patterns of production from geographic areas and life histories along with sufficient data quality. The use of indicator stocks enables the calculation and generation of population statistics for a portion of the total coastal Chinook production, which is the majority of total production based on the CTC's investigations. Data from the indicator stocks or stock aggregates provide inputs to the Exploitation Rate Analysis (ERA) and PSC Chinook Model which allows the CTC to determine relative abundance consistently over time. Indicator stocks can be wild, hatchery, or aggregate stocks. Hatchery stocks serve as surrogates for similar natural-origin stocks by providing CWT data to estimate exploitation, marine survival rate, and other stock parameters, and as model indicator stocks.

Of the natural stocks, 52 stocks or aggregates are used by the CTC as escapement indicator stocks, covering Southeast Alaska, Transboundary Rivers, Northern/Central British Columbia, Vancouver Island, the Fraser River, the Strait of Georgia, Puget Sound, the Washington Coast, the Columbia River, and the Oregon Coast[1]. Of the 52 escapement indicators, 37 are listed in Attachment I of Chapter 3 of the PST Agreement, including 22 with escapement goals[2], which are used for specific purposes outlined in the PST Agreement. Escapement data from these stocks enables the CTC to assess the escapement status of Chinook stocks, both individually and by geographic area of origin.

There are 53 natural or hatchery stocks or aggregates that have sufficient escapement and CWT data to serve as exploitation rate indicator stocks (***Figure 1***)[3]. These are used in the annual exploitation rate analysis (ERA) by the CTC to calculate exploitation rates (brood year and calendar year) and other statistics such as the distribution of mortalities across fisheries including incidental mortalities, cohort sizes, early marine survival rates, and maturation rates. Most CWT data used in the ERA comes from hatchery fish, but there are seven stocks that use wild-stock CWT data: Chilkat, Taku, Stikine and Unuk rivers in Southeast Alaska, Queets River on the North Washington Coast, Lewis River in the Lower Columbia River, and Hanford Reach in the Upper Columbia River.

A total of 41 model stocks (representing single stocks or stock aggregates of wild and hatchery fish) are used in annually calibrating the PSC Chinook Model. The calibration produces abundance time series relative to abundances during the period 1979 to 1982 (known as the base period) as well as abundance predictions for the upcoming fishing season[4].

[1] CTC. 2021. Annual report of catch and escapement for 2020. Pacific Salmon Commission, Report TCCHINOOK (20)–3. Vancouver, BC.

[2] Pacific Salmon Commission 2020. Treaty between the Government of Canada and the Government of the United States of America concerning Pacific Salmon (2019-2028, Annex IV). PSC, Vancouver.

[3] CTC. 2021. 2020 Exploitation Rate Analysis. Pacific Salmon Commission Report TCCHINOOK (21)-5. Vancouver, BC.

[4] CTC. 2021. 2020 PSC Chinook Model Calibration. Pacific Salmon Commission Report TCCHINOOK (21)-4. Vancouver, BC.

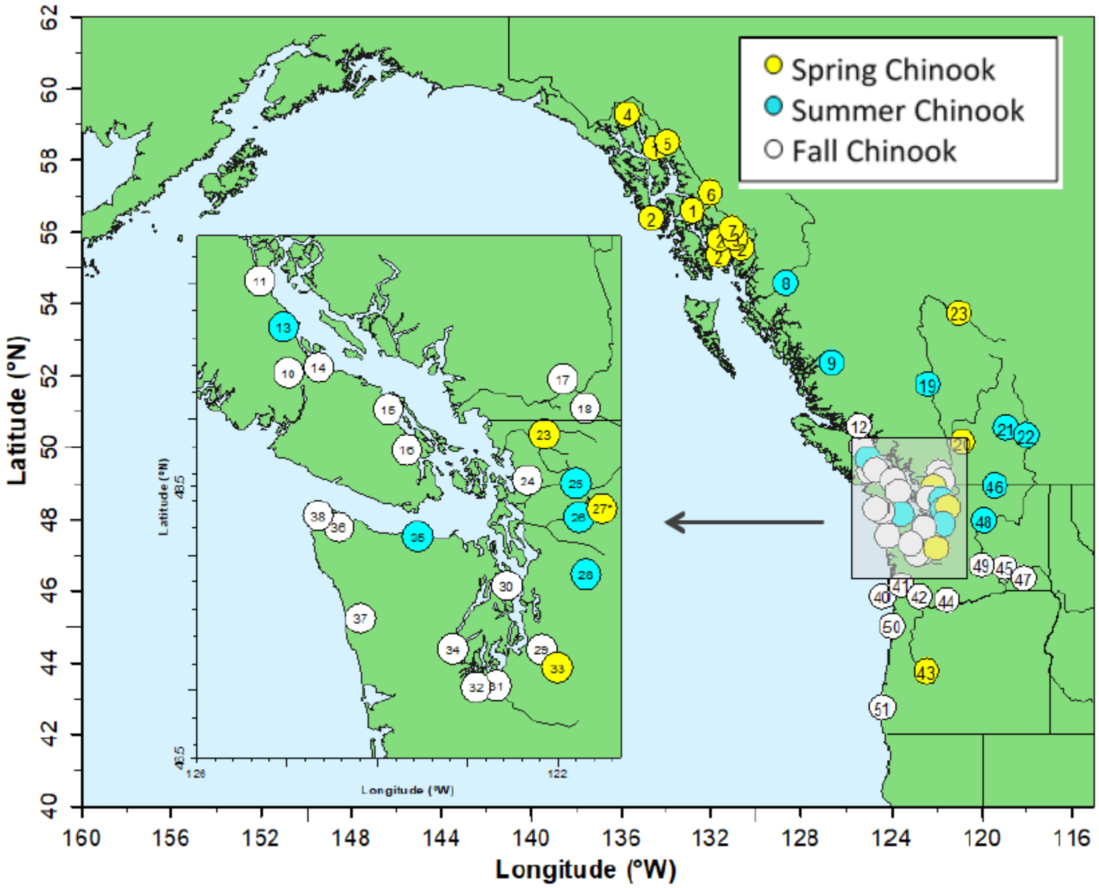

Figure 1. *Geographical locations of current Chinook exploitation rate indicator stocks. A full list of the stock names associated with each number can be found in the CTC report documenting the exploitation rate analysis[3]. Appendix A of CTC 2021 also lists the relationship between exploitation rate indicator stocks, escapement indicator stocks, and model stocks in the Pacific Salmon Treaty.*

MIXED STOCKS

There is considerable variation in the life history of PST managed Chinook salmon which produces mixed-stock migrations through coastal fishing zones. Freshwater rearing ranges from weeks to over a year; populations that smolt within weeks or months of emergence are referred to as 'ocean type' and those that smolt at least one year after emergence are 'stream type'. Ocean distribution and migration patterns vary widely. Additionally, return timing varies, with four general run types: spring-run fish returning March-May, summer-run fish returning in June and July, fall-run fish returning August-November, and winter-run fish returning from December-February. It is assumed that most run types are distributed along the continental shelf of North America during ocean residence and are classified as either far north migrating (rearing in northern BC – Alaskan waters) or southernly distributed (rearing off the West Coast of Vancouver Island and Strait of Georgia waters). Stocks with either of these ocean distributions may be vulnerable to fishing for several years, from age 2 up to age 6. In contrast, many of the 'spring' run timing Chinook stocks have a more offshore migration (though many don't) and marine distribution and so are usually only vulnerable for short periods (1–3 months) when mature fish pass into coastal or terminal waters as they return to their natal streams. The variable life history components and wide ocean distribution of this species complicates stock assessment and management. The coastal fishing zones all contain a mixture of immature and mature (that will spawn that year) fish.

Stock composition is estimated using a combination of CWT and genetic information. The following examples of stock composition from AABM fisheries illustrate the mixed-stock nature and distribution patterns of Chinook stocks. By definition, the 'Aggregate Abundance Based Management' (AABM) fisheries are managed as mixed-stock fisheries (further explanations of Chinook fisheries can be found in the Fisheries section below). There are 3 AABM fisheries defined in Chapter 3: Southeast Alaska (SEAK); Northern BC (NBC) and West Coast Vancouver Island (WCVI). Both U.S. and Canadian stocks are caught in each fishery area. Stock composition varies by time and area among AABM fisheries[4]. The majority of the Southeast Alaska AABM catch is typically comprised of six large stock groups (which consist of scores of individual wild and hatchery stocks): Columbia River Brights, Oregon Coast, Washington Coast, West Coast Vancouver Island, Fraser Summer Ocean-type, Southeast Alaska and Transboundary Rivers. This stock composition is quite different from the stock composition in the WCVI AABM fishery, which is typically dominated by five composite stock groups: Columbia River Summer and Fall stocks, Puget Sound, West Coast Vancouver Island, and Fraser Fall. Note that just two of the five stock groups commonly occur in both the Southeast Alaska and WCVI AABM fisheries. The third example is the 'Individual Stock Based Management' (ISBM) troll fishery off the Washington and northern Oregon coast, which harvests predominantly U.S. and some Canadian stocks. The landed catches in this fishery, on average, are mostly lower Columbia River Tule (about 75%) and Fraser Fall (about 15%), with small contributions of Columbia River Brights and Puget Sound and even smaller contributions of Columbia Spring (Willamette)/Summers and Oregon Coast stock groups.

These stock composition patterns in the Chinook fisheries illustrate the general migratory trends of stock groups within the PST area. Oregon and Washington coastal, Columbia River Brights, Fraser Summer Ocean-type, West Coast Vancouver Island and Northern Coast BC stocks all migrate north at least as far as Southeast Alaska. Lower Columbia River Tules, Puget Sound, Fraser Fall, and Georgia Strait stocks do not migrate north past Central BC.

RANGE OF ADULT RUN SIZES IN THE LAST 10 YEARS

Escapement time series can be found in CTC 2021[1], as provided by agencies. The actual total abundance of Chinook salmon over the broad geographic area covered under the PST is not known because not all stocks have enumeration assessment programs. However, the CTC does estimate the relative abundance of Chinook salmon for key indicator stocks and stock groups in each of the three AABM fisheries (***Figure 2***): Southeast Alaska (SEAK); Northern BC (NBC) and West Coast Vancouver Island (WCVI). These annual 'abundance indices' or AIs represent aggregated (mixed-stock) abundances relative to a 1979–1982 average (termed the base period[5]) and are derived for the AABM fisheries using the PSC Chinook Model and data from escapements, fishery catches, and the CWT results from the ERA. Below we address relative abundance patterns for AABM fisheries; the PST does not deal with ISBM fisheries in the same manner, and ISBM fisheries (as well as AABM fisheries) are discussed in the Fisheries section below.

[5] The base period is a negotiated time period that represents a time when there was a period of high CWT releases, recoveries, and sufficient information to derive key management targets. The base period years were before implementation of the Pacific Salmon Treaty in 1985.

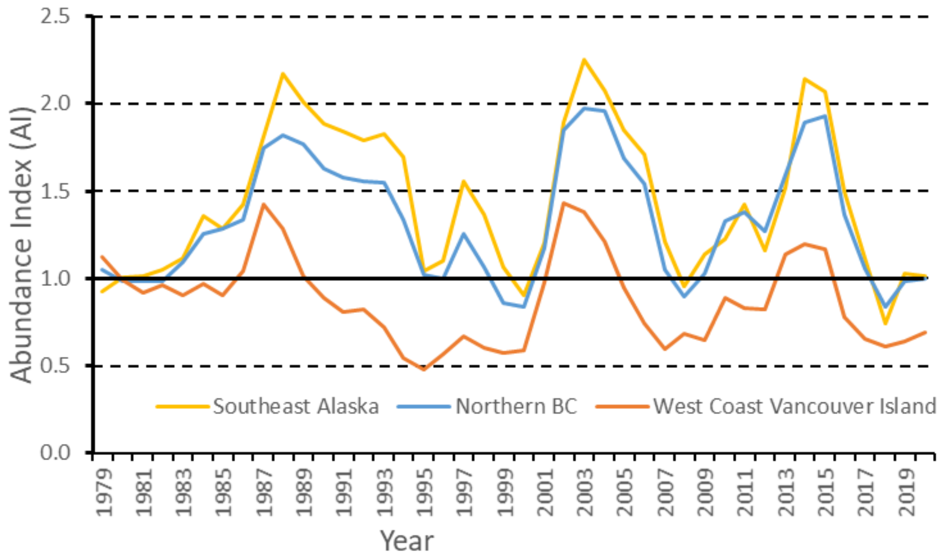

Figure 2. *Abundance Indices (AIs) for Southeast Alaska (SEAK), Northern BC (NBC) and West Coast Vancouver Island (WCVI) AABM fisheries for 1979-2020[4]. Note that the annual AIs are relative to the average of the 1979–1982 base period (e.g., an AI of 1.5 in a given year indicates abundance is on average 50% higher than during the base period or at 150%).*

During the recent 10-year period of 2011–2020, the estimated abundance relative to the base period average abundance in the SEAK fishery has ranged from 74% to 214% and averaged 137%. The trend in the Northern BC fishery is similar, with a range from 84% to 193%, and an average of 133%. In the West Coast Vancouver Island AABM fishery, the relative abundance in the recent 10 years is less, ranging from 61% to 120%, and averaging 85% of the base-period average. The stock composition of catches in Southeast Alaska and Northern BC AABM fisheries is similar and both fisheries harvest stocks that have increased, on average, with abundance indices in 2019 and 2020 matching the base period. The relative abundance of stocks caught in the WCVI fishery have, on average, decreased to levels below the base period.

It is important to point out the AIs for AABM fisheries represent, by definition, aggregate abundance. Recent run sizes vary among the multiple management units that contribute to each AABM fishery. In some years, for example, AIs may be driven by a few dominant stocks (driver stocks) while the abundance of other stocks is low (and vice versa).

2. Fisheries

Chinook fisheries under PST management fall into two classifications: the 'Aggregate Abundance Based Management' (AABM) fisheries and the 'Individual Stock Based Management' (ISBM) fisheries[2]. An AABM regime constrains catches or total mortality in fisheries to a numerical limit derived from a pre-season forecast of abundance, while an ISBM regime constrains the annual fisheries impacts on a naturally spawning Chinook stock or stock group by limiting the calendar year exploitation rate. The latter applies to all stocks that are not meeting bilaterally agreed-biologically-based management objectives, or that do not have these objectives.

The U.S. AABM fishery occurs in Southeast Alaska coastal and terminal waters. The two Canadian AABM fisheries occur in ocean waters offshore of Northern BC (commercial troll and Haida Gwaii recreational hook and line) and West Coast Vancouver Island (commercial and First Nations troll and recreational hook and line). Canadian ISBM fisheries are all fisheries in Canada that harvest Chinook and are not included in the two Canadian AABM fisheries and include First Nations, seine, gillnet and recreational hook and line gear sectors. U.S. ISBM Chinook fisheries are most of the fisheries in Washington, Oregon and Idaho that harvest Chinook salmon, whether in marine, estuarine or freshwater areas. ***Figure 3*** shows the Chinook harvests and incidental fishing mortalities as reported for the U.S. and Canadian AABM and ISBM fisheries over the past 46 years. Incidental fishing mortalities are a combination of drop-off and other mortality of both legal and sub-legal-size fish, estimated both in Chinook non-retention (CNR) and retention fisheries.

Bycatch of sockeye, pink, chum, coho, and steelhead can occur in nearly all directed and non-directed Chinook fisheries.

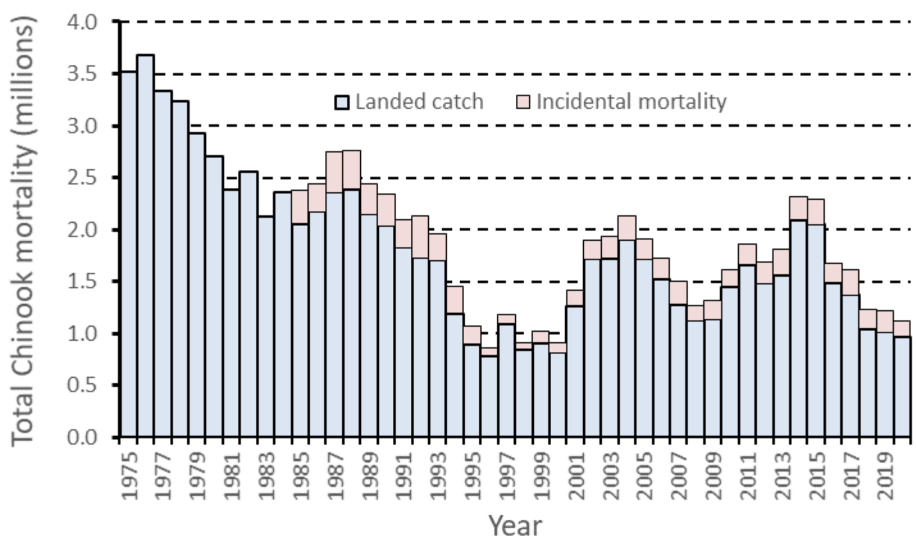

Figure 3. *Estimates of landed catch (1975–2020) and incidental mortality (1985–2020) for U.S. and Canada AABM and ISBM fisheries.*

GEAR SECTORS

U.S.:

- Commercial Troll
- Recreational Hook and Line
- Tribal (variable gear)
- Commercial Purse Seine
- Commercial Drift and Set Gillnet

Canada:

- Commercial Troll
- Recreational Hook & Line
- First Nation (variable gear – generally hook & line)
- First Nations food, social and ceremonial fisheries (FSC)
- Commercial Gillnet
- Commercial Seine

INTERCEPTION BY OTHER FISHERIES

Chinook are harvested in many geographic locations and gear sectors in directed fisheries in the PST area. Chinook are harvested incidental to the harvest of sockeye, pink, chum, and coho or other fish species fisheries. Incidental harvest may reach limits whereby Chinook are required to be released, for example if the fishery is in a Chinook non-retention area, or the Chinook caught incidentally are of sub-legal size. The mortality associated with these releases are reported in terms of incidental mortality (Figure 3) and can be an important contribution to total fishing-related mortality.

There are also interceptions of Chinook outside of the PST area. For example, incidental harvest of Chinook salmon occurs in the federally managed Alaskan pollock and non-pollock trawl (cod, rockfish, and flatfish) fisheries in the Gulf of Alaska (GOA) and the Bering Sea/Aleutian Island areas. These ocean groundfish fisheries have a hard cap (called a prohibited species cap) on the take of any size Chinook and chum salmon and fishery observers are mandatory[6]. In the Bering Sea/Aleutian Islands fishery, harvests have averaged about 19,000 Chinook per year from 2011–2019[7]. Genetic stock identification of systematic and representative samples taken from the Bering Sea pollock trawl fishery in 2012–2019 showed that majority (55%) of the sample and bycatch of Chinook are from western Alaska, North Alaska Peninsula, and Yukon River stocks, 25% from Canada and 14% from the Southern U.S., on average[7,8]. CWT sampling from 2011–2020 in the Bering Sea/Aleutian Islands groundfish fisheries harvested CWT Chinook originating from British Columbia (36%), Washington (32%), Oregon (21%), and Alaska (9%)[9]. Harvests in the GOA pollock fishery in 2012–2019 have averaged about 14,500 Chinook per year, and genetic analysis estimates are 40% Southern U.S., 39% Canada, and 14% coastal Southeast Alaska, in stock percentages. CWT sampling from 2012–2020 in the GOA groundfish fisheries indicates CWT Chinook salmon harvested originated from Southeast Alaska (24%), British Columbia (26%), Washington (27%), and Oregon (23%)[9]. The bycatch of Chinook in the Alaska trawl fisheries is primarily of non-mature fish and the harvest reported above are not adjusted for adult equivalents as in the PST fisheries, though an estimate of adult equivalent harvest for western Alaska exists[10].

Some coastal Alaskan salmon fisheries outside PST jurisdiction (e.g., west of Cape Suckling) harvest small numbers of Chinook originating from Canada and the Southern U.S in addition to harvesting Alaskan stocks. These include some commercial and sport fisheries west of Cape Suckling, including near Kodiak Island, the Alaska Peninsula, and Cook Inlet.

Chinook bycatch in U.S. west coast hake fisheries varies substantially between years. For the period 2002 to 2018, the Chinook bycatch was largest in 2014 (about 14,000) and averaged about 5,000 annually[11].

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[6] NMFS Bering/Aleutian/GOA groundfish caps. https://www.fisheries.noaa.gov/alaska/bycatch/chinook-salmon-bycatch-management-alaska

[7] Guthrie III, C.M., Nguyen, H.T. Karpan, K., Watson, J.T. and Larson, W.A. 2021. Genetic stock composition analysis of Chinook salmon (*Oncorhynchus tshawytscha*) bycatch samples from the 2019 Bering Sea trawl pollock trawl fishery. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-418, 33 p.

[8] Guthrie III, C.M., Nguyen, H.T. and Guyon, J.R. 2014. Genetic stock composition analysis of Chinook salmon bycatch samples from the 2012 Bering Sea and Gulf of Alaska trawl fisheries. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-270, 33 p.

[9] NMFS. 2020 Annual report of the Alaska groundfish fisheries Chinook salmon coded-wire tag and recovery data for Endangered Species Act consultation. https://www.fisheries.noaa.gov/resource/document/annual-report-alaska-groundfish-fisheries-chinook-salmon-coded-wire-tag-and

[10] Ianelli, J. N. and Stram.D.L. 2015. Estimating impacts of the pollock fishery bycatch on western Alaska Chinook salmon. ICES Journal of Marine Science, 72(4): 1159-1172.

[11] Richerson, K., Somers, K. A., Jannot, J. E., Tuttle, V., Riley, N. B. and McVeigh, J. 2019. Observed and Estimated Bycatch of Salmon in U.S. West Coast Fisheries, 2002–18. U.S. Department of Commerce, NOAA Data Report NMFS-NWFSC-DR-2019-02.

Similarly, Chinook is also incidentally harvested in Canadian groundfish fisheries (e.g., hake), though the magnitude of incidental harvest of Chinook in Canadian groundfish fisheries is currently unknown.

FISHERY CHALLENGES

The complexity of migrations and the mixing of mature and immature fish, along with incidental harvest of Chinook in fisheries for other species can present challenges. Management and assessment challenges are covered below. Environmental variation could contribute to non-stationarity for ocean distribution patterns for particular stocks.

3. Management

Management of Chinook salmon is carried out by the regional management entities, including ADF&G (all waters inside the three-mile Alaska state waters line) and NMFS (coastal waters between 3 and 200 miles) in Southeast Alaska, DFO in Canada, WDFW, ODFW and IDFG and the PNW Treaty Tribes in the states of Washington, Oregon, and Idaho.

There is not a single strategic plan for Chinook salmon in the PST area; however, there is strategic plan language in Chapter 3. In addition, there are regional instruments that are applicable, such as the Wild Salmon Policy[12] in Canada, the Sustainable Salmon Policy[13] in Alaska, the U.S. Endangered Species Act (ESA[14]) and the Species at Risk Act (SARA[15]) in Canada. All of these instruments are strategic to maintaining sustainable salmon resources.

One of the goals of PST Chapter 3 is to achieve sustained ocean and terminal fisheries that do not jeopardize long term viability of wild Chinook populations. The overall objective of the PST Chinook management regime is to prevent overfishing and provide for optimum production. Presently, Chinook are managed under the PST using a comprehensive and coordinated management program that uses an abundance-based framework to manage all Chinook fisheries that are subject to Chapter 3. Management goals of Chapter 3 of the PST overlay with the numerous regional management entities in the U.S. and Canada (see 4b and 4e below). Most gear types can also harvest other salmon species in AABM and ISBM fishing areas either concurrently with Chinook or through specific openings directed at different species. Chinook interceptions and landings during these openings are managed in an effort to ensure annual AABM catch limits and ISBM harvest rate metrics are not exceeded and escapement goals are attained.

Chapter 3 of the PST is an area coast-wide management plan with guidelines for the fisheries and subareas involved. In Southeast Alaska there is one annual catch limit that is divided into five gear sectors based on regulations and management plans for each passed by the Alaska Board of Fisheries[16]. These plans must meet PST requirements as well as Alaska's Sustainable Salmon Policy, Escapement Goal Policy, and the U.S. ESA requirements. This type of tiered management takes place in Canada and the Southern U.S. as well. For example, in Canada, harvest plans for the Northern BC and West Coast Vancouver Island AABM

[12] DFO. 2005. Canada's policy for conservation of wild Pacific salmon. Fisheries and Oceans Canada, Vancouver, B.C.

[13] Policy for the management of sustainable salmon fisheries. Alaska Statute 5 AAC 39.222. http://www.adfg.alaska.gov/static/regulations/regprocess/fisheriesboard/pdfs/2016-2017/jointcommittee/5aac39.pdf

[14] United States. 1983. The Endangered Species Act as amended by Public Law 97-304 (the Endangered Species Act amendments of 1982). Washington, U.S. G.P.O.

[15] Species at Risk Act (SARA). 2002. C-29. An Act respecting the protection of wildlife species at risk in Canada. https://laws-lois.justice.gc.ca/eng/acts/s-15.3/FullText.html.

[16] Commercial salmon management plans, Southeast Alaska. https://www.adfg.alaska.gov/index.cfm?adfg=commercialbyareasoutheast.salmon_managementplans

fisheries are described in the annual Northern BC and Southern BC Integrated Fisheries Management Plans (IFMPs), respectively. Southern US fisheries are managed and evaluated by the Pacific Fishery Management Council (PFMC) in association with the National Oceanic and Atmospheric Administration-Fisheries (NOAA-F). Multiple types of regional management measures, including catch limits, time and area closures, bag limits, size limits, gear restrictions, etc., are used to ensure that catch does not exceed the AABM annual catch limits (ACLs) and that ISBM obligations are met. These management measures vary by fishery sector and are influenced by other factors, such as allocation priority or domestic conservation concerns for salmon (and non-salmonid) species.

There are no explicit management units defined for Chinook stocks in Chapter 3. Instead, the PST/PSC processes use indicator stocks for the assessment and management of Chinook stocks which include both naturally produced (wild) and hatchery stocks: 52 escapement indicator stocks, 53 exploitation rate indicator stocks (Figure 1) and 41 model stocks. Domestically, additional management units are often defined for regional management purposes.

CHANGES TO THE CHINOOK MANAGEMENT FRAMEWORK

Since the original PST agreement in 1985, there have been several changes in the Chinook management framework. The first iteration consisted of four AABM-type 'ceiling' fisheries; the remainder of fisheries were more terminal 'pass-through' fisheries. The ceiling fisheries had individual catch limits (the same each year), set at levels thought to rebuild natural-origin stocks to historic levels over a 15-year rebuilding period using interim escapement goals. The pass-through fisheries were intended to structure harvest such that a portion of the Chinook saved by reductions in AABM harvests would theoretically accrue to escapement of fish to the spawning grounds. This approach failed to account for annual fluctuations in marine survival and abundance, which were found to vary more than previously known.

In the 1999 Agreement, an abundance-based approach was implemented to account for interannual variability in abundance[17]. This agreement contained the first 'Table 1' for Chapter 3, with allowable catches associated with different levels of abundance indices (AIs), unique to each of the three AABM fisheries – Southeast Alaska troll, net and sport fisheries, northern BC troll and outside sport fisheries, and West Coast Vancouver Island troll and outside sport fisheries. Negotiations between Canada and the U.S. focused on the catch limits for each AI, which resulted in derived harvest rate limits.

ISBM fisheries were to be managed such that harvest rates were held to 63.5% (Canada) or 60% (U.S.) of the base period average, or the 1991–1996 average, whichever was lower (the more restrictive of the two obligations would be recommended to meet escapement goals). This was termed the ISBM Index and was calculated for each stock by country, for specified escapement indicator stocks. Note that the ISBM Index limit did not apply to stocks that met or exceeded their agreed escapement goal. In 1998, the CTC was instructed by the Commission to establish maximum sustainable yield (MSY) or other biologically-based escapement goals for the PSC escapement indicator stocks[18].

This regime remained in place in the 2009 Agreement, except that allowable catches in Southeast Alaska and West Coast Vancouver Island AABM fisheries were reduced by 15% and 30% after negotiation,

[17] Pacific Salmon Commission. 2000. Pacific Salmon Treaty 1999, revised annexes, memorandum of understanding (1985), exchange of notes. PSC, Vancouver.
[18] CTC. 1998. Committee response to questions from the PSC commissioners regarding the U.S. and Canadian proposals for abundance-based regimes for Chinook fisheries, Report TCCHINOOK (98)–1. Vancouver, BC

respectively, to form a revised Table 1[19]. Agreed escapement goals had been established for 15 escapement indicator stocks by 1999 and were documented along with methods and alternatives for establishing those goals[20].

The 2019 Agreement retains a similar abundance-based regime for all fisheries but with reduced catches in Table 1 relative to the 2009 Agreement for the Southeast Alaska AABM fishery (reduced between 7.5% and 1.5%), and the West Coast Vancouver Island fishery (reduced between 12.5% and 2.4%), while northern BC catches remained unchanged. Annual catch limits for the SEAK AABM fishery now are estimated using catch per unit effort data from the Winter Troll fishery and translated to AIs. Additionally, the ISBM fisheries may move to a revised ISBM index by 2023, which is a calendar-year exploitation rate (CYER) as opposed to the former brood-year based metric used during the 1999 and 2009 Agreements.

MANAGEMENT CHALLENGES

Based on abundance indices (***Figure 2***), abundances have fluctuated substantially since 1979, but the overall long-term average has been stable in northern fisheries, but recently decreasing in most fisheries. This could be due to a variety of catch reduction measures taken by agencies and prescribed in the PST (***Figure 3***), as the overall marine survival of Chinook has generally decreased (***Figure 4***). Presently, the abundance of Chinook is at the lower end of the historical range (mid-1970s to present). From a management perspective, the current problem of low abundance and low marine survival are compounded with a trend towards smaller, younger fish[21,22] and less-than-perfect forecast performance[23], a lack of comprehensive in-season control rules and a management model predicated on indices that are tied to a base period (1979–1982) that is of dubious informative value in forward facing management decisions.

[19] Pacific Salmon Commission 2009. Pacific Salmon Treaty including Yukon River agreement, revisions to January 1, 2009, memorandum of understanding (1985), exchanges of notes – 1985, 1999, 2002, 2005 & 2008. PSC, Vancouver.

[20] CTC. 1999. Maximum Sustained Yield or Biologically Based Escapement Goals for Selected Chinook Salmon Stocks Used by the Pacific Salmon Commission's Chinook Technical Committee for Escapement Assessment. Report TCCHINOOK (99)–3. Vancouver, BC.

[21] Ohlberger, J., Ward, E.J., Schindler, D.E. and Lewis, B., 2018. Demographic changes in Chinook salmon across the Northeast Pacific Ocean. Fish and Fisheries, 19(3), pp.533-546.

[22] Oke, K.B., Cunningham, C.J., Westley, P.A.H. et al. 2020. Recent declines in salmon body size impact ecosystems and fisheries. Nature Communications: 11, 4155.

[23] Peterman, R.M., Beamesderfer, R. and Bue, B. 2016. Review of methods for forecasting Chinook salmon abundance in the Pacific Salmon Treaty Areas. Report to the Pacific Salmon Commission, Vancouver.

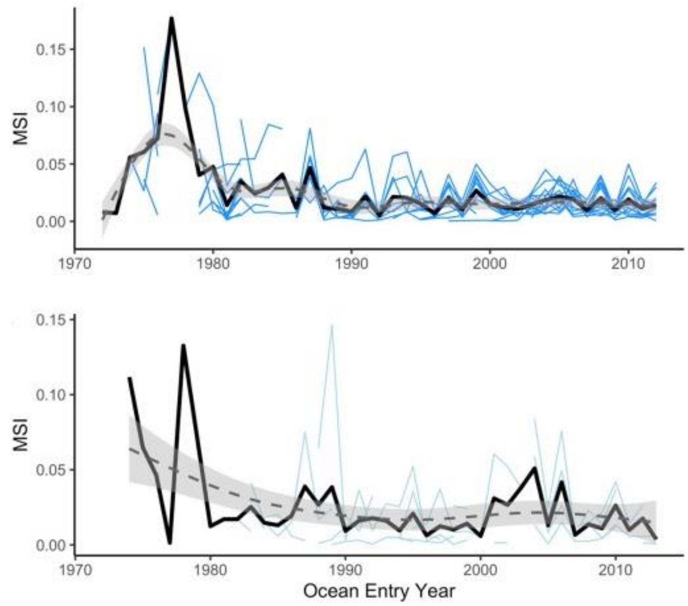

Figure 4. *Marine Survival Index for sub-yearling Chinook salmon (top panel) and yearling Chinook salmon (bottom panel) in the Salish Sea from mid-1970s to 2010s[24]. Thick solid black line represents mean for a given year with individual stocks represented by the thin colored lines. The dashed black line represents a smoothed trend line.*

Management is often challenged by the difference between pre-season forecasts and post-season estimates of abundance. Under the 2019 Agreement, AABM manages target catch limits based on the pre-season AI or SEAK Winter Troll CPUE during the fishing season. Additionally, there are provisions that apply when catches exceed post-season limits by more than 10% AIs for two consecutive years. The post-season AIs are not estimated until the following April when the next PSC Chinook Model calibration results are released. Post-season data for ISBM fisheries and the stocks for which ER (e.g., CYER) metrics are used comes available at the same time. Note that the CYER metric does not apply if the escapement goal is reached.

One management concern is balancing the harvest of larger, more productive and/or enhanced stocks while reducing the risk of overharvesting less productive, co-migrating wild Chinook stocks and other species of concern. Chinook salmon are also often harvested incidentally by fisheries targeting large populations of other salmon species. Non-retention of Chinook salmon is often employed, along with area closures, to reduce incidental harvest. This requires estimation of incidental mortality, often through expensive programs which must be run for many years in order to extrapolate to years without direct estimation programs[25]. Fisheries closures have occurred during specific windows of time to reduce the harvest when weak or specific stocks listed under the SARA or ESA are present.

[24] Sobocinski, K.L., Greene, C.M., Anderson, J.H., Kendall, N.W., Schmidt, M.W., Zimmerman, M.S., Kemp, I.M., Kim, S. and Ruff, C.P. 2021. A hypothesis-driven statistical approach for identifying ecosystem indicators of coho and Chinook salmon marine survival. Ecological Indicators: 124.

[25] CTC. 2004. Estimation and application of incidental fishing mortality in Chinook salmon management under the 1999 Agreement to the Pacific Salmon Treaty. Pacific Salmon Commission Joint Chinook Technical Report TCCHINOOK 04-01. Vancouver, BC.

4. Assessments

An extensive coastwide assessment framework is operated by the parties to inform management. The PST specifies that management agencies maintain a viable coded wire tag (CWT) system. CWT recoveries in fisheries and escapements provide critical data to complete analyses for Chinook salmon, including annual tasks done by the CTC such as the exploitation rate and cohort analyses, and the PSC Chinook Model calibration, as well as long-term data sets for forecasts, escapement goals, and management performance evaluation[26]. Other components of annual assessments include: pre-season forecasts provided by agency staff, in-season catches, in-season sampling of CWTs, in-season genetic stock identification (GSI) analyses for domestic fisheries management, other biological sampling (e.g., scales, length), post-season final escapement numbers, post-season catches, post-season CWT analyses, and post-season GSI analyses.

Annually, the CTC completes a series of assessments to inform implementation of the management framework. In particular, the CTC completes a cohort analysis using CWT data to estimate stock-specific parameters such as calendar and brood year exploitation rates (CYER and BYER), marine survival rates, maturation rates, for all exploitation rate indicator stocks. Output from the cohort analysis is one of the inputs into the PSC Chinook Model and the calibration of this model is completed annually by April 1[4]. This model is an age-structured coast-wide (PST area) production model used to estimate and forecast stock abundance indices (AIs) in AABM fishing areas. It incorporates multiple sources of information from 41 Model stocks and from the cohort analysis through an iterative algorithm to estimate abundance in the coming fishing season relative to a 1979–1982 base period. For ISBM fisheries, the CTC has recently been tasked to report CYER metrics described in paragraphs 5(a) of Chapter 3 (2019 Agreement)[2]. Specifically, the CTC is tasked with using the best available post-season data and analysis to calculate the CYER (moving 3-year average) after each fishing season and report to the Commission.

PRE-SEASON FORECAST

Pre-season forecasts of run size or escapement are integral to the present management framework for Chinook salmon. There are currently 41 model stocks (wild and hatchery) represented within the PSC Chinook Model from which relative abundance is forecasted in the PST fisheries. The relative abundance is used to set annual catch limits in the three AABM fisheries (via the predicted abundance indices and corresponding annual catch limits as documented in Table 1[2]), and is used in the extensive planning process for the ISBM fisheries in both countries.

Management agencies use external models to provide pre-season forecasts to the CTC for 36 out of the 41 model stocks, including stocks that contribute a large proportion of all the Chinook salmon harvested in an AABM fishery. These external models feed into the PSC Chinook model. For the remaining 5 stocks, the PSC Chinook Model generates the pre-season forecast[4], as the agencies do not produce forecasts for them.

For the stocks with run size forecasts, different approaches are used to generate these predictions: sibling regression models, average return rate models, and several other models which are available in the CTC software program ForecastR[4]. The sibling regression models rely on the relationship between abundance of younger returning salmon of age *a* and their older siblings (age *a* +1) in the following year, while the

[26] PSC Joint CWT Implementation Team. 2015. Five-year Synthesis Report of the PSC Coded Wire Tag (CWT) Implementation Program. PSC Technical Report 33.

average return rate models rely on the average returns of adult Chinook from smolts. The ForecastR program[27] generates age-specific or total forecast of escapement or terminal run using a variety of generic models: sibling regression models with the ability to include environmental covariates, time series models such as auto-regressive integrated moving average model (ARIMA), an exponential smoothing model, naïve models based on the preceding year, three years or five years in the time series and mechanistic models such as average return rate models. In addition to generating a forecast, ForecastR also allows comparison of different forecasts based on selected model performance metrics and generates both a point estimate for the forecast as well as a confidence interval. ForecastR has been used to produce agency forecasts for Canadian and Oregon model stocks since 2016[4]. An overview of the forecast methods used for each of the model stocks can be found in Appendix H2 of the calibration report[4].

Pre-season forecasts are also supplied to the Pacific Fishery Management Council for incorporation into the Fisheries Regulation Assessment Model (FRAM)[28]. The FRAM model is used to predict exploitation rates and the impact of fisheries (including Southeast Alaska and NBC) on coho and wild Chinook stocks originating from north-central Oregon coast, Columbia River, Puget Sound, and Southern British Columbia.

IN-SEASON ASSESSMENTS

In-season forecasts are updated by agencies for domestic in-season management. In the Southeast Alaska/Transboundary River region, in-season forecasts of total return of Chinook are estimated weekly for the Situk, Taku and Stikine rivers. Catch of Chinook in ISBM fisheries managed on the Columbia, Fraser, Oregon coast and other rivers are adjusted as in-season abundance information becomes available.

A new addition to Chapter 3 in the 2019 PST Agreement is that the pre-season Southeast Alaska AABM harvest limit is set to the appropriate catch tier using in-season CPUE information from the Winter Troll fishery. This modification was motivated by performance concerns of the PSC Chinook Model, i.e., pre-season AI forecasts were significantly different from post-season AIs.

REFERENCE POINTS, HARVEST CONTROL RULES AND ESCAPEMENT GOALS

Fisheries are managed for sustainability and to meet escapement goals. Under the PST, AABM fisheries have obligations to stay within annual catch limits, while ISBM fisheries have obligations to stay within exploitation rate limits/ISBM index bounds and to meet escapement goals.

AABM fisheries are managed through the catch limits in Tables 1 and 2, which can be converted to describe a variable harvest rate strategy, i.e., a harvest control rule (***Figure 5***). The allowable harvest rate index on the aggregate abundance of mixed stocks contributing to each AABM fishery increases with the abundance index (AI), specific to the fishery. For each AI, there is a corresponding harvest rate index from the allowable annual catch limit negotiated in Table 1 of Chapter 3 of the PST. Operationally, when the in-season catch reaches the pre-season annual catch limit, Chinook retention is stopped. As mentioned above, Chinook retention, or fishing periods, may be closed for other reasons, short of the annual catch limit. Note that there is no 'lower reference point' for AABM fisheries, below which only incidental harvest, directed at co-migrating stocks, is permitted.

[27] Vélez-Espino, L.A., Parken, C.K., Clemons, E.R., Peterson, R., Ryding, K., Folkes, M., and Pestal, G. 2019. ForecastR: tools to automate forecasting procedures for salmonid terminal run and escapement. SEF report. PSC, Vancouver, BC.
[28] Rankis, A., LaVoy, L., Packer, J., Clemons, E., Conrad, R., Simmons, C.D., Sharma, R., Grover, A. and Yuen, H. 2006. Fishery Regulation Assessment Model (FRAM): Technical documentation for coho and Chinook. 64 p.

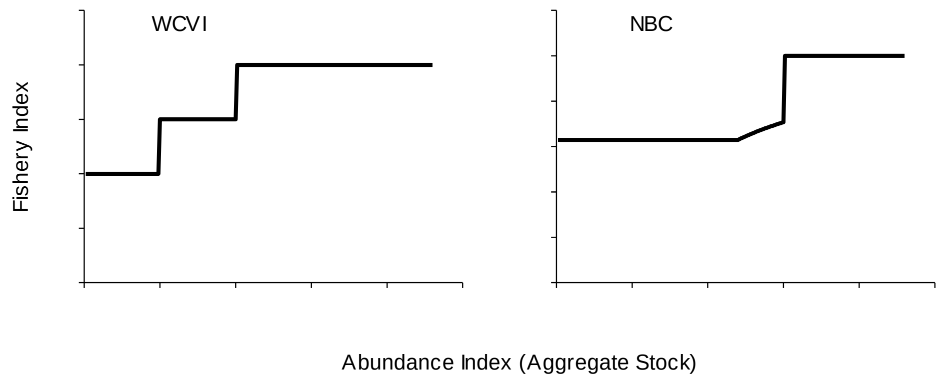

Figure 5. *Harvest control rules for the West Coast Vancouver Island and Northern BC AABM fisheries.*

ISBM fisheries are managed through a fixed stock-specific exploitation rate strategy for multiple indicator stocks. For stocks that are not meeting their management objective or do not have an objective defined, the Calendar Year Exploitation Rate (CYER) is limited according to Attachment I of Chapter 3 of the PST.

Escapement goals have been accepted by the CTC for 22 of the 52 escapement indicator stocks at present. The CTC notes that analyses for multiple stocks are pending. Bilaterally accepted escapement goals generally are those expected to produce MSY or close to it. Most are expressed as a single point, some are a range around S_{MSY}. Additional escapement benchmarks may exist regionally: in Canada, a reference point of 0.85 S_{MSY} (number of spawners producing MSY) is an abundance-based benchmark for the Wild Salmon Policy. In the U.S., further escapement or exploitation requirements may be imposed as a condition of the U.S. ESA, which presently includes Puget Sound as well as some Columbia River stocks.

MANAGEMENT STRATEGY EVALUATION

A Management Strategy Evaluation (MSE) is a systematic and transparent process that uses simulation modelling to evaluate the effectiveness of existing or alternative management approaches for meeting management objectives given uncertain information.

The PST Chinook management framework has undergone periodic evaluations and changes since the first PST was implemented in 1985. The second negotiation produced the 1999 Agreement, and an abundance-based approach was implemented for Chinook, whereby the three current AABM fisheries were allowed an annual harvest limit based on the relative abundance of an aggregate of stocks, i.e., Table 1. This aggregate abundance-based management (AABM) approach involved extensive model development. Despite this work, no formal MSE for AABM or ISBM fishery management has been conducted because the CTC identified that the Data Generation Model needed to be developed in order to be able to evaluate management strategies and other important analytical techniques and metrics (e.g., ISBM metrics).

DATA LIMITATIONS

Assessments and evaluations of Chinook salmon can be limited by data deficiencies or gaps for stocks or fisheries. In aggregate, the majority of the Chinook escapement in the PST area is believed to be enumerated, but there are many wild Chinook stocks that are not enumerated, most of which are believed to be less abundant stocks. In addition, 30 of the 52 escapement indicator stocks lack escapement goals. Note that several analyses to develop escapement goals are pending completion. Stocks presently without escapement goals are monitored for abundance trends.

The types of data lacking for naturally produced or hatchery stocks may include: accurate escapement enumeration, age and size data, CWT data, maturation and survival rates, and associated time series of stock recruit data. Data deficiencies for fisheries include: no harvest enumeration, no CWT data or other biological data sampling (GSI, scales, length, parasites, etc.), low CWT sampling rates, no direct harvest estimation, or data sharing from nearby fisheries[29]. A thorough review of the CWT program was recently completed by the CWT Improvement Team[26]. In addition, the 2019 Agreement includes creation of the coded-wire tag and recovery (CWT&R) improvement program to improve the many CWT-based analyses completed by the CTC and the Selective Fisheries Evaluation Committee (SFEC); and the Catch and Escapement Indicator Improvement (CEII) programs (Chapter 3, paragraphs 2c-d).

Data limitations can include the incorporation of uncertainty into assessments and how risk is managed in the implementation of a harvest strategy[30]. Known data limitations may be negatively impacting performance of assessment models (e.g., due to biased parameter assumptions), but a comprehensive assessment of the potential consequences of these data limitations has not been carried out.

ASSESSMENT CHALLENGES

Assessment gaps and challenges exist for many wild Chinook salmon stocks, the majority of which are not enumerated or biologically sampled or may have low quality enumeration and biological sampling programs. Other assessment challenges include: the logistics of enumerating and sampling in all locations, consistency in relative escapement estimates across geographic locales, consistency in enumeration and biological sampling of harvested Chinook, sampling for CWTs to measure exploitation and maturation rates, constraints in model structure, the loss of institutional knowledge, and the staff capacity of all agencies involved. In addition, several aspects of pre-season forecast improvements were noted to be of potential benefit in the 2016 external review of the CTC assessment program[23].

INFORMATION CONVEYED TO MANAGERS/DECISION MAKERS

The CTC produces technical reports which detail stock-specific escapement and results of the cohort analysis and model calibration. These annual reports provide managers and investigators with a host of information, including summaries of stock status and fishery evaluations. The catch and escapement report[1] includes catches, escapements, catch and escapement performance by geographic region, annual rate of change, a synoptic evaluation of exploitation rates, etc. The exploitation rate analysis report[3] includes historical time series of exploitation rates, survival metrics, maturation rates, etc. The exploitation rate analysis report also includes CYER estimates that describe the performance of ISBM

[29] Pacific Salmon Commission Calendar Year Exploitation Rate Working Group. 2021. A Review of Indirect Methods Used in Estimation of Chinook Salmon Exploitation Rates and Recommendations for Improvement. Pacific Salmon Comm. Tech. Rep. No. 46: 50 p.

[30] Pacific Salmon Commission Sentinel Stocks Committee. 2018. Pacific Salmon Commission Sentinel Stocks Committee Final Report 2009-2014. Pacific Salmon Comm. Tech. Rep. No. 39: 167 p.

fisheries in terms of the obligations set out in Chapter 3. The PSC Chinook Model calibration report[4] covers all major aspects of the annual model calibration, past performance relative to catches and AIs, etc. The annual calibration of the PSC Chinook Model forecasts AABM fishery-specific AIs which are used to determine annual catch limits (i.e., as described Table 1, Chapter 3), and also provides the first post-season AI for the previous season. This information is presented by memo to the Commissioners each April. Post-season estimates of AIs are used to report performance of the CTC model with respect to forecast accuracy.

5. Incorporating environmental data

The external pre-season forecasts used as inputs into the PSC Chinook Model are supplied by various agencies/entities. The external forecasts use various methods and/or models and most do not use environmental covariates directly. The ForecastR program can include up to three interacting environmental covariates, but the user has to provide these data themselves; these time series are not automatically provided in the program[27]. The pre-season AI forecasts generated by algorithms in the PSC Chinook Model calibration process do not use environmental data.

NOAA's Fisheries stoplight chart is used qualitatively as a tool by managers to guide their understanding of how the salmon might have fared in the open ocean[31], but is not used by the CTC in producing AIs or CYERs and it has not been evaluated by the CTC for its potential value to improve the performance of forecasts.

The in-season assessments for Chinook do not use direct input of environmental data.

Environmental data have not been explicitly integrated in the methods for most stocks to derive reference points, harvest control rules, or escapement goals. However, some escapement goals implicitly account for natural variation in population processes that are driven by environmental variation (e.g., optimal yield probability profiles). Several stocks have escapement goals that rely on a smolt to age-2 CWT survival covariate (e.g., Harrison, Cowichan), and other stocks have estimates of S_{MSY} from stock-recruitment models that have river flow as a covariate (e.g., Skagit and Nicola).

6. Accounting for changes in productivity

Model supplied Chinook forecasts do not account for changes in productivity. Changes in productivity (caused by changes in environmental factors, maturity and growth rates, smolt to age-2 survival rates, etc.) are more variable than prior to 2000. Because of this, agency and PSC Chinook Model pre-season forecasts are not able to account for rapid changes in productivity for many stocks[32]. The PSC Chinook Model also produces an environmental variable scalar that accounts for deviations in the stock-recruitment relationship. This environmental variable scalar also accounts for errors in other inputs such as maturation rates, harvest rate indices, and variations in the errors with escapement and fishery catch

[31] Harvey, C.J., Garfield, N., Williams, G.D. et al. 2021. Ecosystem status report of the California current for 2020-21: a summary of ecosystem indicators compiled by the California current integrated ecosystem assessment team (CCIEA). NOAA Technical Memorandum NMFS-NWFSC-170.

[32] Tompkins, A., G. Brown, and M. Thiess. 2011. Temporal Patterns in Productivity of North American Sockeye and Chinook Salmon. NPAFC Doc. 1356. 4 pp. Fisheries and Oceans Canada.

data, and absorbs the differences between observed and Model-generated escapement for all Model stocks during the Model calibration process.

In-season assessments to adjust harvest of Chinook likely do not need productivity co-variates, unless a factor is needed to account for freshwater mortality prior to spawning. Freshwater abundance forecasts, for both spawning and rearing stages could benefit from accurately predicted productivity factors or scalars, particularly in regions where freshwater temperatures have increased, or river flows have decreased.

AABM allowable harvests in Table 1 have been adjusted downwards twice in response to decreased abundance of some stocks, e.g., Puget Sound. Few escapement goals have been adjusted following examinations of the time series of stock-recruit data for changes in productivity (non-stationarity and autocorrelation) and adjusted when needed, e.g., Blossom and Keta rivers were removed as escapement indicators following stock-recruit examinations[33].

7. Accounting for and conveying uncertainty

Confidence intervals for pre-season forecasts of Southeast Alaska and Transboundary River Chinook stocks, and for forecasts produced by ForecastR for Canadian and Oregon Chinook stocks are supplied to both managers and the CTC. No measures of forecast uncertainty are included in the calibration of the PSC Chinook Model. Estimates of uncertainty are not accounted for in either the input nor output of the current configuration of the Chinook model. Uncertainty is not estimated for pre-season AIs for the three AABM fisheries, or ISBM CYER indexes, from the PSC Chinook Model or otherwise due to the deterministic nature of the Model. However, the CTC has reported on the retrospective performance of the Chinook model forecasts relative to the first post-season AI. The CTC has plans to improve the model's performance and it has recently changed to an improved version of the model.

The uncertainty around the in-season index of abundance for Southeast Alaska (all-gear) is provided to domestic ADFG managers. The uncertainty around in-season run size assessments of the Transboundary River Chinook runs (Taku and Stikine) is also provided to the co-managers weekly. In-season run size estimates are developed for the Fraser Spring-run Age 1.3 and the Summer-run Age 1.3 stock groups within the Fraser River as part of the domestic in-season fisheries management process, but these are not involved in the PST management. In-season assessment in the Columbia River are provided through fish counts at dams.

Most escapement goals agreed to by the CTC have precision estimates (standard errors or confidence intervals), but these are not part of annual PSC or FRAM modeling. AIs and associated harvests limits (annual catch limits) in AABM fisheries have no measures of uncertainty reported for them nor do reference points and harvest control rules for AABM and ISBM fisheries.

8. Ability to reach management objectives

The present management regime for Chinook in the PST area has an aggregate abundance-based component and an individual stock-based management component. Performance measures include:

[33] Fleischman, S.J., Der Hovanisian, J.A. and McPherson, S.A. 2011. Escapement goals for Chinook salmon in the Blossom and Keta rivers. Alaska Department of Fish and Game, Fishery Manuscript No. 11-05, Anchorage.

1) Staying within harvest limits in Table 1 and Table 2 in each of the three AABM fisheries (SEAK, NBC and WCVI) defined by the pre-season AI for WCVI and NBC fisheries and the in-season winter troll CPUE index for SEAK;
2) Staying within the incidental mortality limits in each of the three AABM fisheries;
3) Staying below calendar year exploitation rate limits for ISBM fisheries' indices; and
4) Achievement of agreed management objectives as a component of ISBM obligations.

The regime could use improvement to meet these performance measures, especially with regard to environmental and productivity changes. Over the past 3 years (2018–2020) 72% of the escapement indicator stocks with bilaterally established goals have met or exceeded targets[1]. In 2020, 4 of the 22 escapement indicator stocks with management objectives were below 85% of their escapement goals (Unuk in Southeast Alaska, Taku and Stikine, both Transboundary Rivers, Harrison in the Fraser River)[1]. An improvement of estimation of the abundance indices (AIs) to decrease the difference between pre-season and post-season estimates (Figure 6) would be beneficial. ISBM fisheries would equally benefit from improved forecast ability, whether in terms of pre-season or in-season metrics.

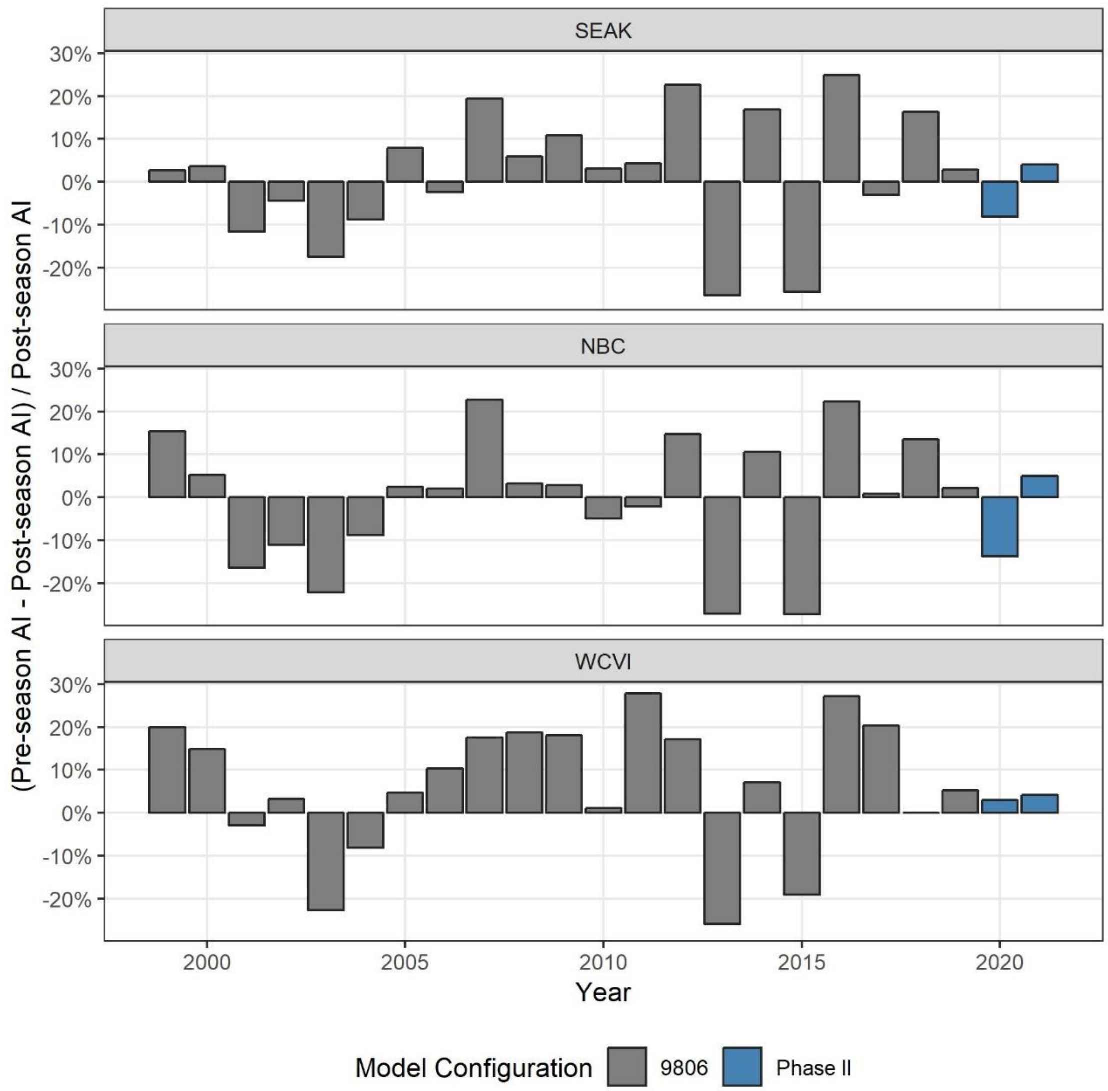

Figure 6. *Deviation between pre- and post-season abundance indices (AIs) for the three aggregate abundance-based management (AABM) fisheries, 1999–2021. Deviations are calculated as: (pre-season AI - post-season AI) / post-season AI*[34]*.*

Note: There was no CTC consensus on the 2015 and 2016 model calibrations (CLB 1503 and 1601). Outputs from CLB 1503 was used by the Commission to configure AABM fisheries in 2015. Abundances indices for AABM fisheries generated from CLB 1601 were accepted by the Commission. Values for the 2014 and 2015 post-season AIs are from CLB 1601 and values for the 2015 pre-season AI is from CLB 1503.

Note: With the implementation of the Phase II model configuration beginning with the 2020 pre-season, the 2019 post-season AIs are based on CLB 2000-9806, which was conducted using the 9806 model configuration. The 2020 pre-season AIs in this figure are from CLB 2003, which is a corrected version of CLB 2002, the 2020 model calibration that was used for pre-season planning.

Note: Beginning in 2019, the SEAK AABM fishery transitioned to a CPUE index for management in place of the AI.

[34] CTC. 2022. 2021 PSC Chinook Model Calibration. Pacific Salmon Commission Report TCCHINOOK (22)-XX. Vancouver, BC.

9. Planned assessment changes to account for climate change

There are no immediate plans for the CTC to explicitly evaluate the performance of assessment and management strategies that account for environmental changes. However, the CTC has formed a workgroup tasked with configuring a new or revised model. This will likely include features that include environmental change and will likely result in changes in the management framework(s) for many, if not all Chapter 3 Chinook fisheries.

More bilaterally accepted escapement goals are needed. Those that currently exist would benefit from reassessment due to changes in maturation, size and fecundity observed coastwide in recent years. Many of the escapement indicator stocks (30 out of 52 stocks) do not have goals, but many could be produced given recent improvements from the Sentinel Stocks initiative[30] and the new Catch and Escapement Improvement Initiative (CEII) which has helped to produce the information necessary to develop escapement goals.

In the last three annual workplans, the CTC specifically requested help in dealing with the issue of wide fluctuations in environmental conditions, and the associated difficulties it presents in producing reasonably accurate pre-season forecasts. Pre-season forecast improvements would seem the ideal place to address this issue; however, past experience has shown that isolating environmental co-variates that provide meaningful improvement for management is often very difficult and relationships are not consistent nor informative over time.

PST Chapter 4: Fraser River sockeye salmon

1. Introduction

Chapter 4 of the Pacific Salmon Treaty applies to Fraser River sockeye and pink salmon which are documented separately in this report given their differences in management and assessment. Fraser River sockeye consists of 32 Conservation Units (CUs; potentially up to 24)[1] and in the last 10 years, adult run size estimates have ranged from 291,000 in 2020 versus 28 million in 2010 (Figure 1).

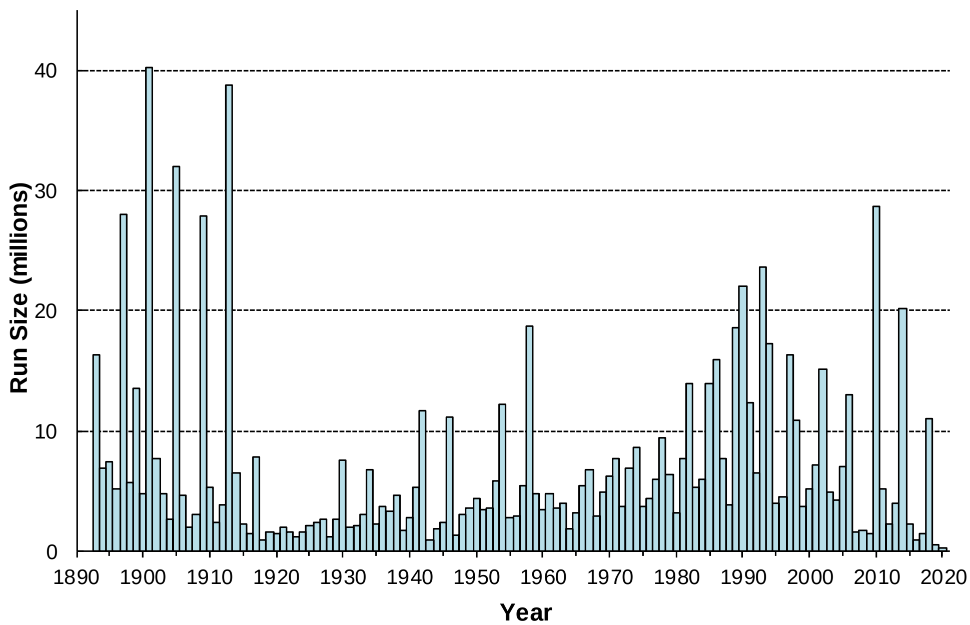

Figure 1. *Total sockeye returns to the Fraser River since 1893.*

2. Fisheries

From 1960 to 1980, exploitation rates of Fraser River sockeye salmon fisheries were relatively high (averaging 75%) and supported by higher productivity compared to recent years. It should be noted that prior to 1992, en route losses were not included in the total run size estimates, which may account for a positive bias in exploitation rates prior to 1992[2]. Despite this bias, overall catches were high and on average exceeded 10 million sockeye between 1985 and 1994. Since the mid-1990s, exploitation rates have been on a declining trend, with the exception of the exploitation rates on the dominant cycle line. This in general coincided with a decreasing trend in productivity and abundances. In some of the recent years, catches have been limited to test fishing catches used to assess the run and bycatch in fisheries

[1] Grant, S.C.H., Holt, C.A., Pestal, G., Davis, B.M., and MacDonald, B.L. 2020. The 2017 Fraser Sockeye Salmon (*Oncorhynchus nerka*) Integrated Biological Status Re-Assessments Under the Wild Salmon Policy Using Standardized Metrics and Expert Judgment. DFO Can. Sci. Advis. Sec. Res. Doc. 2020/038.

[2] English, K.K., Edgell, T.C., Bocking, R.C., Link, M.R. and Raborn, S.W. Fraser River sockeye fisheries and fisheries management and comparison with Bristol Bay sockeye fisheries. LGL Ltd. Cohen Commission Tech. Rept. 7: 190p. Vancouver, BC.

directed at other stocks or species, and exploitation rates have been lower than 5%. Fisheries directed at Fraser River sockeye, may have by-catch of Chinook, pink, chum, coho and steelhead.

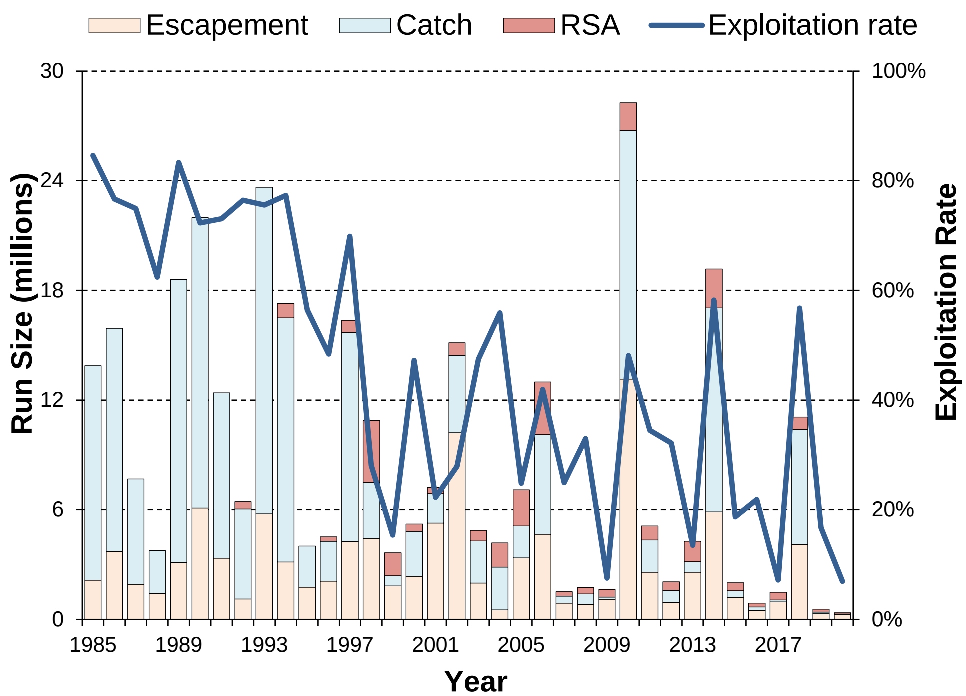

Figure 2. *Fraser River sockeye run size and exploitation rates since 1985. In addition to including escapement and catch estimates, the total run estimates also include a Run size Adjustment (RSA) to account for en route mortality and biases in spawner and catch estimates. Fisheries catches that are not genetically identified have not been included.*

GEAR SECTORS

US:

- Treaty Tribal purse seine fishery
- Treaty Tribal gillnet fishery
- Treaty Tribal reefnet fishery
- All Citizen purse seine fishery
- All Citizen gillnet fishery
- All Citizen reefnet fishery

Canada:

- FSC and First Nation Economic Opportunity and Demonstration fisheries
- Area B purse seine fishery
- Area D and E gillnet fishery
- Area G and H troll fishery
- Recreational fisheries in South Coast waters and the Fraser River

INTERCEPTION BY OTHER FISHERIES

In some years, District 104 (Alaska) catches a substantial proportion of the total Fraser River sockeye run while in other years there is no interception at all. For example, preliminary estimates in 2019 indicated

77,000 Fraser River sockeye were caught in District 104 while the total number of sockeye returning to the Fraser River in 2019 was 493,000. In 2010, the total Fraser River run size was the largest in the last 50 years, and one of the largest on record, but it is estimated that no Fraser River sockeye were caught in District 104. In Canada, the Area A purse seine fishery, Area C gillnet fishery and Area F troll fishery have on occasion captured very low numbers of Fraser sockeye.

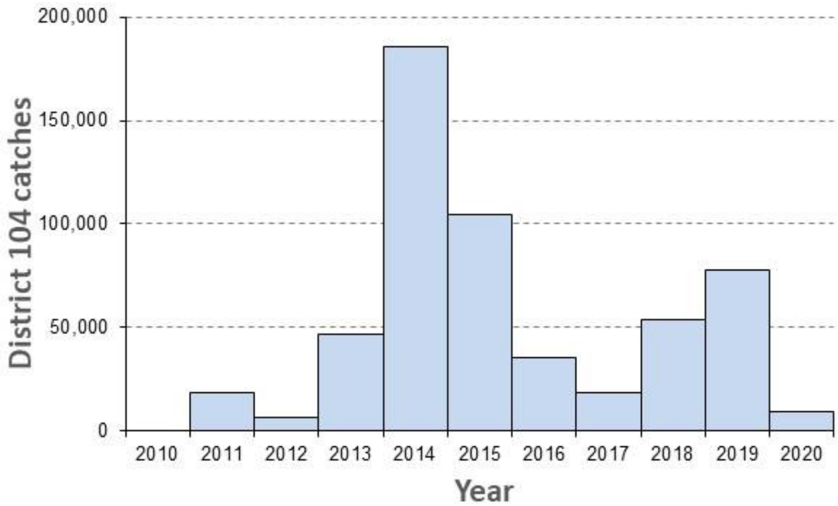

Figure 3. *District 104 purse seine catches of Fraser River sockeye salmon since 2010.*

FISHERY CHALLENGES

There is a high degree of overlap in return timing between management groups, therefore all Fraser River sockeye stocks are caught in mixed stock fisheries, with the exception of terminal FSC fisheries, and access to the fish and the Total Allowable Catch (TAC) is limited by low abundances of co-migrating management groups or stocks of concern.

3. Management

Strategic plans for the management of Fraser River sockeye are documented by the Wild Salmon Policy[3], while annual management plans are documented in the Annual Integrated Fisheries Management Plan[4]. The management of Fraser River sockeye salmon is the responsibility of the Fraser River Panel (Panel waters) and Fisheries and Oceans Canada (DFO) (non-Panel waters). Fraser River sockeye salmon are managed as 4 management units: Early Stuart, Early Summer run, Summer run, and Late run.

The management objectives for Fraser River sockeye are to: (1) achieve spawning escapement goals by stock or stock grouping; (2) achieve targets for international sharing of the TAC as defined in the Treaty; and (3) achieve domestic allocation goals within each country. In addition, fisheries management needs to ensure that the conservation needs and management requirements for other salmon species (e.g., pink and coho salmon) and other sockeye stocks are taken into account.

[3] DFO. 2005. Canada's policy for conservation of wild Pacific salmon. Fisheries and Oceans Canada, Vancouver, B.C.

[4] DFO. 2020. Integrated Fisheries Management Plan June 1, 2020 - May 31, 2021. Salmon Southern BC. Fisheries and Oceans Canada.

MANAGEMENT CHALLENGES

Survival rates for Fraser River sockeye have been declining for the last 25 years. Returns in 2009 at the time were the lowest on record (1.6 million). The implied low survival caused Canada to establish the Cohen Commission of Inquiry into the decline of sockeye salmon in the Fraser River[5]. The Cohen Commission concluded that there was no single cause that could explain the decline but that there were numerous stressors that may have negatively impacted these stocks and that similar patterns of declining productivity had been observed at larger, regional spatial scales. The report of the Cohen Commission contained 75 recommendations. Despite the progress made on the implementation of these recommendations[6], returns have continued to decline. In 2019, the lowest survival rate to date was observed.

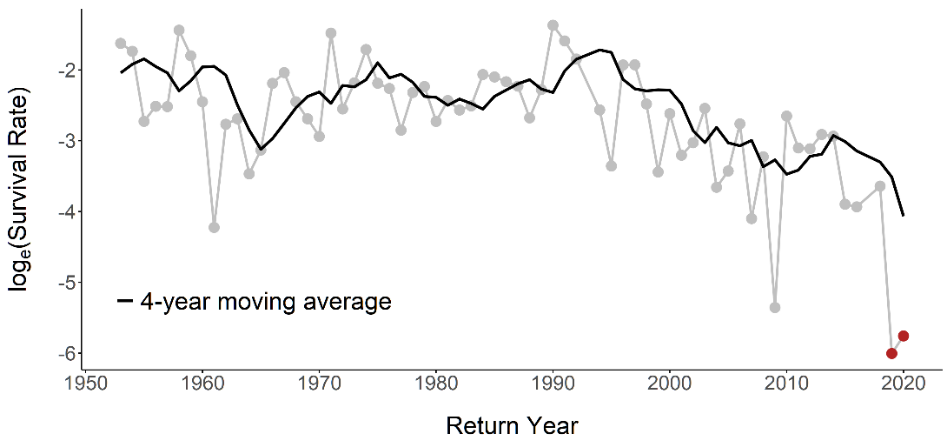

Figure 4. *Chilko survival rates since 1952 with 2019 and 2020 emphasized in red.*

All Fraser River sockeye stocks are caught in mixed stock fisheries and are managed in four Management Units (MUs: Early Stuart, Early Summer run, Summer run and Late run, Table 1). The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) identified 24 Designatable Units (DUs), which align exactly with the 24 Conservation Units (CUs) within the Fraser River. Fisheries directed at Fraser River sockeye occur within and outside of Fraser Panel Area waters. Management tools are applied to management groups, meaning that reference points, escapement goals, and harvest control rules are derived for individual stocks but when used for harvest management purposes, they are combined by management groups. Currently, COSEWIC has assessed 8 CUs as endangered (Early Stuart, Bowron, Taseko, Late Stuart, Quesnel, Portage, Weaver, and Cultus) and 2 as threatened (North Barriere and Widgeon)[7]. These CUs have all shown substantial declines in productivity[8]. Because more productive stocks within management groups tend to influence the management group-specific reference points, escapement goals, and harvest control rules, the endangered and threatened stocks within a management unit may experience fishery exploitation rates that are too high based on the stock-specific

[5] The Cohen Commission of Inquiry into the decline of Sockeye salmon in the Fraser River (Canada). 2012. The uncertain future of Fraser River sockeye salmon. Minister of Public Works and Government Services Canada.
[6] https://www.dfo-mpo.gc.ca/cohen/report-rapport-eng.htm
[7] COSEWIC. 2017. COSEWIC assessment and status report on the Sockeye Salmon *Oncorhynchus nerka,* 24 Designatable Units in the Fraser River Drainage Basin, in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. xli + 179 pp.
[8] DFO. 2020. Recovery Potential Assessment for Fraser River Sockeye Salmon (*Oncorhynchus nerka*) – Nine Designatable Units – Part 1: Probability of Achieving Recovery Targets. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2020/012.

estimates of productivity, despite the management units themselves being harvested appropriately. In addition to declines in productivity, some of the stocks have also seen substantial en route losses associated with increased river temperatures, high discharge levels, or early upstream migration (in the case of Late run stocks). Beginning in 2019 a rockslide upstream of Lillooet at Big Bar has significantly impacted the survival of Early Stuart, Bowron, Taseko sockeye stocks and to a lesser extent Nadina and Summer run stocks. In some years, these en route losses have been substantial, making it impossible to reach escapement goals, even in the absence of fishing. The table below provides an overview of some of the major challenges that have been identified for the CUs in the different management units.

Table 1. *Overview of the different Fraser River sockeye management units, the status of their stocks according to COSEWIC[7], hatchery enhancement and major challenges identified.*

Management Unit	Stock status	Hatchery enhancement	Major challenges
Early Stuart	Endangered	Yes	- En route losses - Declining productivity - Big Bar rockslide
Early Summer run	1 CU endangered 1 CU threatened 2 CU special concern 6 CUs not at risk	2 CUs (Bowron, Taseko)	- Declining productivity - En route losses - Mixed stock fisheries - Big Bar rockslide
Summer run	3 CUs endangered 1 CU threatened 1 CU special concern 2 CUs not at risk	No	- Declining productivity - Mixed stock fisheries
Late run	3 CUs endangered 2 CU special concern 1 CU not at risk	1 CU (Cultus)	- En route losses - Declining productivity - Declining freshwater productivity (Cultus) - Mixed stock fisheries

4. Assessments

The assessment of Fraser River sockeye includes the use of annual pre-season forecasts and in-season assessments, as well as the use of management tools such as reference points, harvest control rules, escapement goals and a management Strategy Evaluation (MSE) through closed loop simulations.

PRESEASON FORECAST

The Fraser River Panel relies on preseason forecasts of run size[9], run timing[10], diversion rates[10], and expected Management Adjustments (MAs)[11] for the assessment and management of Fraser River sockeye stocks. These different forecasts are all inputs into the fisheries planning model that allows exploration of the extent and timing of fishing opportunities given different assumptions about run size, timing and diversion rate. The forecasts are also used as inputs into the in-season run size models in the form of prior probability distributions[12]. Early in the season, these forecasts play a larger role in the assessments and fisheries management advice than later in the season when more in-season information will have accumulated and the peak migration date has been observed in the catch-per-unit-effort (CPUE) and hydroacoustic data. In addition, early in the season, prior to in-season run size estimates being available, evaluations of catch proposals made by each country are based on a criteria for fishing decisions table which compares preseason expectations of abundance, timing, and stock identification from the fisheries planning model with in-season observations to trigger the opening of low impact fisheries. The impact of the forecasts on assessments and fisheries decisions diminishes as more in-season information about the run becomes available.

IN-SEASON ASSESSMENTS

Fraser River in-season daily abundance estimates, based on hydroacoustic data, are collected at Mission. Abundance estimates by management groups (Early Stuart, Early Summer run, Summer run, and Late run), as well as for some individual stocks (Chilko, Quesnel, etc.) are derived through the application of genetic stock identification methods. Marine daily abundance estimates en route to the Fraser River are based on test fishing CPUE data collected in marine areas in combination with historical and in-season catchability estimates. These in-season projections can be verified 6 days later at Mission for most stocks. For Harrison and Late run stocks, total abundances can only be verified at the end of the season because a proportion of these stocks may delay their upstream migration by remaining in the Strait of Georgia. In-season run-size forecasts are derived using a Bayesian time–density model fitted to a combination of CPUE data collected by marine test fisheries and reconstructed daily marine abundance estimates derived based on a combination of hydroacoustic data at Mission and seaward catches[12].

REFERENCE POINTS, HARVEST CONTROL RULES AND ESCAPEMENT GOALS:

The management of Fraser River sockeye salmon relies on the application of the Total Allowable Mortality (TAM) rule as the harvest control rule[4], defined by a Lower Fishery Reference Point, an Upper Fishery Reference Point, a TAM cap, and a Low Abundance Exploitation Rate (LAER). When the in-season run size is below the Lower Fishery Reference Point, no directed fisheries are allowed; only incidental harvest, directed at co-migrating stocks, is permitted. This incidental harvest needs to remain below the Low Abundance Exploitation Rate. In cases where the in-season run-size estimate falls between the Lower and

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[9] Grant, S.C.H., Michielsens, C.G.J., Porszt, E.J., & Cass, A. 2010. Pre-season run size forecasts for Fraser River Sockeye salmon in 2010. DFO Can. Sci. Advis. Sec. Res. Doc. 2010/042.

[10] Folkes, M.J.P., Thomson, R.E., and Hourston, R.A.S. 2018. Evaluating Models to Forecast Return Timing and Diversion Rate of Fraser Sockeye Salmon. DFO Can. Sci. Advis. Sec. Res. Doc. 2017/021. vi + 220 p.

[11] MacDonald, J.S., Patterson, D.A., Hague, M.J. & Guthrie I.C. (2010) Modeling the Influence of Environmental Factors on Spawning Migration Mortality for Sockeye Salmon Fisheries Management in the Fraser River, British Columbia. Transactions of the American Fisheries Society 139:768-782.

[12] Michielsens, C.G.J. and Cave, J.D. 2019. In-season assessment and management of salmon stocks using a Bayesian time–density model. Can. J. Fish. Aquat. Sci. 76: 1073-1085.

the Upper Fishery Reference Point, the TAM rate ranges between the LAER and the TAM cap depending on run size. Above the Upper Fishery Reference Point, the TAM rate remains fixed at the TAM cap. The projected MA is subtracted from the TAM to calculate the final allowable exploitation rate calculation[4]. Between the Lower and Upper Fishery Reference Points, a fixed escapement target, equal to the Lower Fishery Reference Point, is assumed. These Lower and Upper Fishery Reference Points are derived through the Fraser River Sockeye Spawning Initiative (FRSSI), a management strategy evaluation process that quantitatively evaluates the long-term (12 generation / 48 year) performance of different escapement strategies under a wide range of alternative biological assumptions and future states of nature while qualitatively taking into account social and economic considerations[13].

The escapement goals or targets for Fraser River sockeye salmon are derived in-season through the application of the TAM rules and are dependent on the in-season run-size estimates. In addition, an adjusted Spawning Escapement Target (SET) will also incorporate the Management Adjustment (MA) based on the predicted difference between the number of sockeye entering the Fraser River and the number enumerated at the spawning grounds.

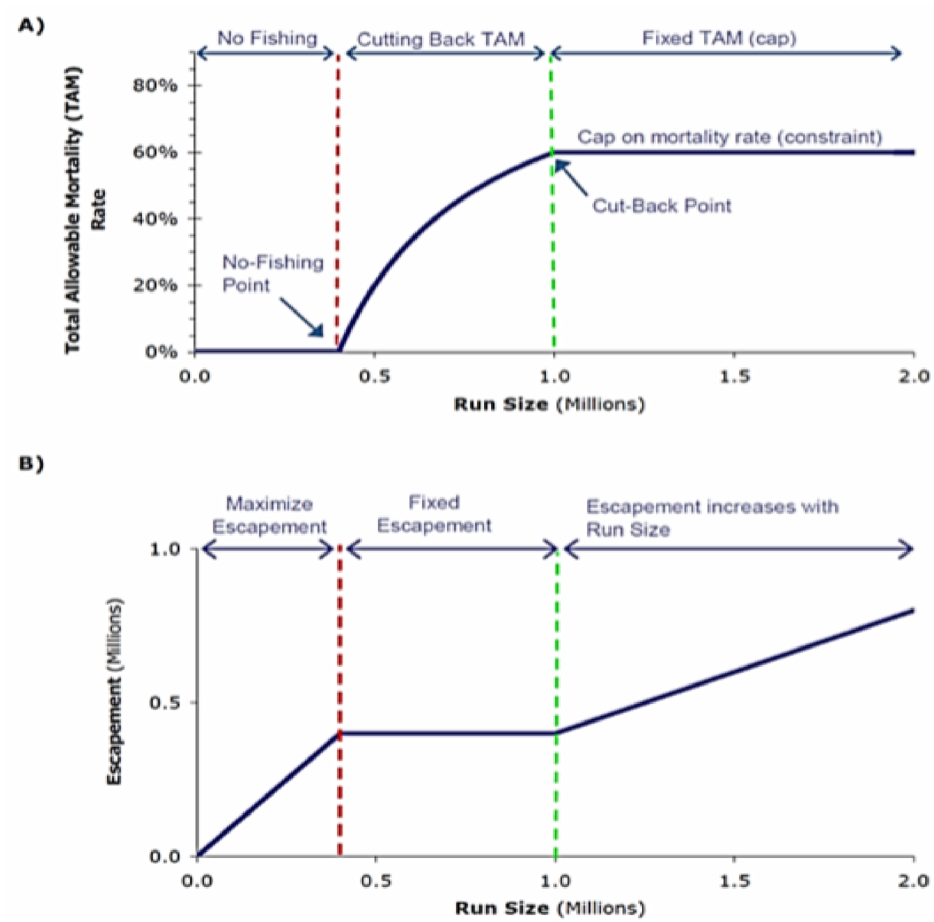

Figure 5: *Total Allowable Mortality rule for Fraser River sockeye salmon*

[13] Chaput, G., Cass, A., Grant, S., Huang, A.-M., and Veinott, G. 2013. Considerations for defining reference points for semelparous species, with emphasis on anadromous salmonid species including iteroparous salmonids. DFO Can. Sci. Advis. Sec. Res. Doc. 2012/146. v + 48 p.

MANAGEMENT STRATEGY EVALUATION

The Fraser River Sockeye Spawning Initiative (FRSSI) model is used to evaluate the long-term performance of different TAM rules under a wide range of alternative biological assumptions and hypothesized future states of nature[13]. The FRSSI model has been used to assess the TAM rule and derive the Lower and Upper Fishery Reference Points since 2006. The FRSSI participant process qualitatively incorporates social and economic considerations.

DATA LIMITATIONS

The cyclic nature of several Fraser River sockeye stocks requires either more complex spawner-recruitment models (e.g., using Larkin models that account for delayed density dependence) or the use of one out of every four years of data. Both methods require a lot of data. The former due to the fact that more complex models are fitted to the data, requiring more parameters to be estimated, and the latter by severely reducing the number of years of data that can be used (one out of every four years).

In 2019 there was a rockslide in the Fraser River at Big Bar[14]. It impacted all sockeye salmon stocks with spawning grounds above Big Bar, which can range from 50% to 80% of the total run depending on the year. The rockslide created a physical barrier that impeded upstream migration, especially early in the season when water velocity was too high to allow natural migration past the slide. As discharge levels decreased over the summer and water levels declined, an increasing proportion of the run was able to make it past the slide naturally. Big Bar and the discharge levels at Big Bar are another environmental factor that impacts the likelihood of spawners making it to the spawning grounds under certain discharge conditions. As such, the impact of Big Bar should be taken into account in the prediction of the Management Adjustments (MAs) during high discharge periods when discharge passage thresholds are exceeded. To incorporate this impact quantitatively will be challenging as the number of observations is very limited (2 years thus far) and the data collected in 2019 are no longer valid given the substantial mitigation work done after the 2019 season which included breaking up and removing rocks to improve natural fish passage. In addition, incorporating observations qualitatively in MA estimates will be challenging as observations at Big Bar will be too late to impact fisheries management decisions in marine areas given that it takes sockeye salmon about 17 days to migrate from the marine test fishing areas to Big Bar. Predicting MA estimates, however, is only a concern if run sizes are sufficiently large to support fisheries. In 2019 and 2020, the run sizes of Fraser River sockeye salmon were too small to support fisheries as the escapement goals equalled the run sizes. Therefore, there was no need to formally include the impact of Big Bar into MA estimates. This may not be the case in future years.

ASSESSMENT CHALLENGES

The in-season assessment of Fraser River sockeye salmon provides excellent information for management purposes but is costly and time-consuming. The strongly cyclic nature of some of the Fraser River sockeye stocks complicates assessment. Because trends in changing abundances are not always very apparent for cyclic stocks, data may need to be split out by cycle line, thereby quartering the length of the data sets. In addition, models suitable for cyclic stocks are often more complex (e.g., Larkin models). The Late-run management group and other delaying stocks (e.g., Harrison) present challenges for in-season

[14] Murphy, I., S. Johnson, and T. Hatfield. 2020. Big Bar Landslide Southern Endowment Fund Science Workshop Summary. Consultant's report prepared for Pacific Salmon Commission and Fisheries and Oceans Canada by Ecofish Research Ltd, June 22, 2020.

assessments due to their increased time spent in the marine areas, once they've passed by the marine test fisheries, but prior to entering the Fraser River.

INFORMATION CONVEYED TO MANAGERS/DECISION MAKERS

Preseason, the Fraser River Panel requires preseason forecasts of run size, timing, diversion rate, and expected Management Adjustments (MAs). They also receive the results of the fisheries planning model that explores the extent and timing of fishing opportunities given different assumptions about run size, timing, and diversion rate.

In-season, the Fraser River Panel receives a twice-weekly update of the in-season run size and timing by management unit, and the overall diversion rate. In addition, the Panel receives updates of the catches to date by fishery, the test fishing catches, hydroacoustic abundance estimates at Mission and Qualark, the latest stock identification results in different areas, observed and predicted estimates of temperatures at Qualark and discharge at Hope, observed temperatures and deviations from average throughout the watershed, model predictions of the Management Adjustments (MAs), observations from throughout the watershed and from the spawning grounds, daily migration information for various stocks, predictions of the abundances en route to Mission, run size and timing estimates for specific assessment groups (determined by the resolution of the GSI data as well as their relative abundance), and comparisons of the observed versus expected abundances and stock identification.

Once the Fraser River Panel decides to officially adopt the in-season run sizes and Management Adjustments, it is provided with updated TAC estimates and remaining balances after the removal of catches-to-date. Technical staff will also evaluate fisheries opening proposals to assess if these are consistent with the remaining TAC.

5. Incorporating environmental data

Environmental data are used quantitatively to generate preseason forecasts of run size, timing, diversion rate- and Management Adjustments (MA). The suite of run-size forecast models includes several models with environmental covariates. These variables include mean winter (November-March) indices from the Pacific Decadal Oscillation (PDO), mean spring-summer (April-July) sea surface temperatures collected at Entrance or Pine Island, and Fraser River peak and mean discharge from April to June measured in Hope[9]. Similarly, the suite of timing and migration route models include several environmental covariables[10], including three El Niño indices (Oceanic Niño Index (ONI), Southern Oscillation Index (SOI), and the Bivariate ENSO Timeseries (BEST)), Fraser River discharge, relative sea level, sea surface temperature (in the open ocean and near-shore), sea surface salinity, wind stress, ocean current velocity (from both the NEPSTAR (North East Pacific Salmon Tracking and Research) ocean model and the OSCAR (Ocean Surface Current Analysis Real-time) data series), and earth magnetic field estimates (intensity and inclination). The preseason forecast of the Management Adjustment is based on models that include Fraser River temperature and discharge forecasts, provided by DFO's Environmental Watch group[11], and period of delay in the Strait of Georgia (Late run MU only).

In addition to the use of quantitative environmental information, the run-size forecast has relied on qualitative environmental information through the supplement to the run-size forecast[15]. Participants to the annual workshop compiled and integrated environmental data and observations across the life cycle of the salmon returning in the year that was being forecasted and provided advice regarding the expected survival. While the quantitative run-size forecast produces forecasts based on long-term trends and relationships, the supplemental information qualified if the survival should be expected to be below or above average based on recent salmon and ecosystem information. The information from this expert-based process was presented annually to the Fraser River Panel and it was up to the Panel to determine to what extent to use it when making management decisions. This expert-based process replaced the indicator approach of ocean conditions[16] that had been used until 2009, but which was discontinued following the failure to provide indications of the low returns that year. In recent years the supplemental process has been discontinued, but the run size forecast still highlights additional environmental information that is not necessarily accounted for in the quantitative forecasts but may impact salmon survival, such as the Big Bar rockslide and Fraser Valley flooding.

In-season, environmental data are used to predict the number of returning sockeye expected to make it to the spawning ground, i.e., the potential spawning escapement. These are estimated based on the sockeye abundances estimated at Mission, reduced by the upstream catches and the predicted Management Adjustment which takes environmental conditions into account. From a management point of view, the prediction of the potential spawning escapement is important because the comparison with Spawning Escapement Targets (SETs) will determine the available TAC. Management Adjustments are adopted by the Fraser River Panel based on predicted differences between the projected and the observed spawning escapement. These Differences Between Estimates (DBEs) can be predicted using both quantitative or qualitative methods. Quantitatively, in-season (DBEs) are predicted for all stocks except Late run stocks using Fraser River forecasts of temperature at Qualark and discharge at Hope[11]. For Late run stocks the DBEs are predicted using a regression model that relates the migration delay into the Fraser River to historical DBE estimates. In addition, the Fraser River Panel also uses environmental information qualitatively to inform the Panel's choice of MAs, e.g., temperatures in other parts of the watershed, discharge levels at the Big Bar slide, flooding, and significant rain or drought events. This also gets combined with other qualitative biological observations such as shifts in migration behaviour and observations on salmon condition and mortality.

Environmental data are incorporated in the in-season application of the TAM rule and setting escapement goals. In order to calculate TACs and allowable exploitation rates, the TAM rule incorporates an estimate of the Management Adjustment. Depending on whether the Fraser Panel adopted a Management Adjustment based on the historical median value, MA model output or in-season observations, environmental data will be incorporated quantitatively or qualitatively.

Environmental data are somewhat incorporated in the FRSSI model that is used to derive the reference points. The FRSSI model includes different Management Adjustment scenarios among the wide range of alternative scenarios, but thus far, these scenarios have been based on past observations (since 2001). In

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[15] MacDonald, B.L., Grant, S.C.H., Wilson, N., Patterson, D.A., Robinson, K.A., Boldt, J.L., King, J. Anderson, E., Decker, S., Leaf, B., Pon, L., Xu, Y., Davis, B., & Selbie, D.T. 2020. State of the Salmon: Informing the survival of Fraser Sockeye returning in 2020 through life cycle observations. Can. Tech. Rep. Fish. Aquat. Sci. 3398: v + 76 p.

[16] DFO, 2009. Pre-season run size forecasts for Fraser River sockeye and pink salmon in 2009. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2009/022.

addition, the largest uncertainty associated with MAs is currently the assumptions regarding future Big Bar landslide impacts during high discharge events. No further qualitative integration of environmental data has been done.

For the management strategy evaluation, the impact of increasing water temperatures and discharge is taken into account quantitatively by including different Management Adjustment scenarios among the wide range of alternative scenarios, but thus far, these scenarios have been primarily based on past observations (since 2001). No further qualitative integration of environmental data has been done.

6. Accounting for changes in productivity

Changes in productively have been quantitatively incorporated into the forecast from 2010 onward in various ways. In 2010[17] and 2011[18], different forecasts had been produced based on different assumptions about changes in productivity in the forecast year, i.e., long-term average productivity and recent productivity (last 8 years). From 2011 to 2019, changes in productivity had also been taken into account through the application of a spawner-recruitment model that explicitly modelled change in productivity over time using a Kalman Filter[19]. For years with extremely low productivity e.g. 2009[17] and 2019[4], the best performing models for the preseason forecast of 5-year-olds in the following year were sibling models that included the low recruits per effective female for the 4-year-olds from the same brood year as a predictor variable.

Productivity has also been taken into account qualitatively in the run size forecast statement by indicating that the forecasted distributions represent the full range of historical productivity estimates while recent productivity has been below average[20]. Therefore, actual returns may be closer to estimates that are lower than the 50% probability level of the forecast, e.g., the 25% probability level of the forecast was recommended for planning purposes in 2017. This information is communicated to the Fraser River Panel and it is up to the Panel to determine to what extent to use it when making management decisions.

The impacts of changes in productivity have been quantitatively included in the scenarios used to derive the reference points and harvest control rules. Due to concerns about the potential impacts of increased variability and observed trends in productivity that accompanies climate change, DFO is reviewing the robustness of the current and alternative harvest control rules. This is occurring within the FRSSI model by testing the harvest control rules against alternative future productivity patterns to identify harvest control rules that produce undesirable outcomes. To date, productivity changes have not been incorporated in the in-season derivation of the escapement goal, nor has qualitative integration been done.

Changes in productivity have been somewhat incorporated in the Management Strategy Evaluation. Due to concerns about the potential impacts of increases in variability and observed trends in productivity that

[17] DFO, 2010. Pre-season run size forecasts for Fraser River Sockeye salmon in 2010. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2010/031.
[18] DFO. 2012. Pre-season run size forecasts for Fraser River Sockeye & Pink Salmon in 2011. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2011/052.
[19] Peterman, R.M., and Dorner, B. 2012. A widespread decrease in productivity of sockeye salmon (Oncorhynchus nerka) populations in western North America. Can. J. Fish. Aquat. Sci. 69(8): 1255–1260.
[20] DFO. 2017. Pre-season run size forecasts for Fraser River Sockeye (Oncorhynchus nerka) and Pink (*O. gorbuscha*) salmon in 2017. DFO Can. Sci. Advis. Sec. Sci. Resp. 2017/016.

accompanies climate change, DFO is reviewing the robustness of the current and alternative harvest control rules. This is occurring quantitatively within the FRSSI model by testing the harvest control rules against alternative future productivity patterns to identify harvest control rules that produce undesirable outcomes. Initial work on these improvements began in 2019 and will be ongoing in 2021[4]. No qualitative integration has been done.

7. Accounting for and conveying uncertainty

The preseason forecast models use Bayesian estimation methods, and the uncertainty in the forecast results is expressed in terms of a probability distribution for the following percentiles: 10%, 25%, 50%, 75%, and 90%[9]. The median forecast (50th percentile, or p50) represents an equal chance (i.e., a one in two chance) that the return will fall either above or below the forecast value for each stock. In comparison, there is a one in four chance that the actual number of returning sockeye salmon will fall at or below the forecast associated with the 25th percentile (p25 probability level). Within the current forecast methodology, for those models that do not incorporate environmental covariates, the p50 forecast assumes long-term average productivity will be maintained, the p10 and p25 forecasts assume below-average productivity, while the p75 and p90 forecasts assume above-average productivity.

The in-season run size model is a Bayesian time-density model, and the resulting run-size estimates are conveyed in terms of the median and the 95% probability interval.

Uncertainty has not been explicitly accounted for in terms of the reference points, harvest control rule and escapement goals.

For the Management Strategy Evaluation, the FRSSI model allows scientists, managers, and stakeholder to evaluate the long-term performance of different management strategies under a wide range of alternative biological assumptions and hypotheses about future states of nature[13]. DFO is gradually allowing for more uncertainty in the future states of nature by incorporating productivity changes as well as the uncertainty associated with the Big Bar rockslide impact. DFO is expected to complete this work in time for the 2022 Fraser Sockeye season.

8. Ability to reach management objectives

The assessment of Fraser River sockeye salmon incorporates environmental data to a large extent, accounts for changes in productivity, and conveys the uncertainty associated with estimates. Despite this, Fraser River sockeye have experienced abundance declines since the implementation of the original PST in 1985, especially for some smaller stocks. The current management of Fraser River sockeye is done by management group: Early Stuart, Early Summer run, Summer run, and Late run. These management groups consist of 24 Conservation Units (CUs). Management tools are however applied to management groups, meaning that reference points, escapement goals, and harvest control rules are derived for individual stocks but when used, they are combined by management groups. Over the last few years, there has been an overall decline in the productivity and abundance of all the Fraser stocks which has been linked to environmental changes[8]. Currently, the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) has assessed 8 CUs as endangered and 2 as threatened (Table 1)[7]. These CUs have all shown substantial declines in productivity[8]. Because more productive stocks within management groups tend to influence the management group specific reference points, escapement goals, and harvest control rules, the endangered and threatened stocks within a management unit may experience fishery exploitation rates that are too high based on the stock specific estimates, despite the management units themselves being harvested appropriately.

9. Planned assessment changes to account for climate change

DFO is currently reviewing the robustness of the current and alternative harvest control rules to the potential impacts of increases in the variability and observed trends in productivity that accompanies climate change. In addition, DFO is gradually allowing for more uncertainty in the future states of nature by incorporation the uncertainty associated with the Big Bar rockslide impact. Initial work began in 2019 and DFO is expected to complete this work in time for the 2022 Fraser Sockeye season. No additional support would be required for this work.

PST Chapter 4: Fraser River pink salmon

1. Introduction

Chapter 4 of the Pacific Salmon Treaty applies to Fraser River sockeye and pink salmon which are documented separately in this report given their differences in management and assessment.

Fraser River pink salmon stocks can be categorised in terms of early and late run stocks[1]. The early run includes stocks from the lower Fraser mainstem, the Thompson River and the Seton Creek areas. The Late run contains Harrison and Chilliwack-Vedder stocks. Fraser River pink salmon are also produced in four spawning channels, contributing about 5% to the annual return[2]. Even though there is genetic variability among the pink salmon stocks within the Fraser River, they are all considered part of the same conservation unit and managed as one management unit[3]. In marine areas, however, the Fraser River pink salmon stocks comigrate with other pink salmon stocks, i.e., Canadian South Coast stocks and Washington State stocks.

Total run size in the last 10 years has ranged from 3.5 million in 2017 to more than 20 million in 2009. Fraser River pink salmon spawn in odd years only (pink salmon spawners are virtually absent from the Fraser River in even years). Methods to estimate the spawner component of the run size have changed substantially over the years, resulting in various levels of uncertainty associated with the estimates. From 1957 to 1991, spawner estimates were based on stream specific spawner estimates, from 1993 to 2001, estimates were derived through a system-wide mark-recapture program in the Lower Fraser, from 2003 to 2007, estimates were based on marine test fishery data and, since 2009, estimates have relied on the hydroacoustic data collected at Mission.

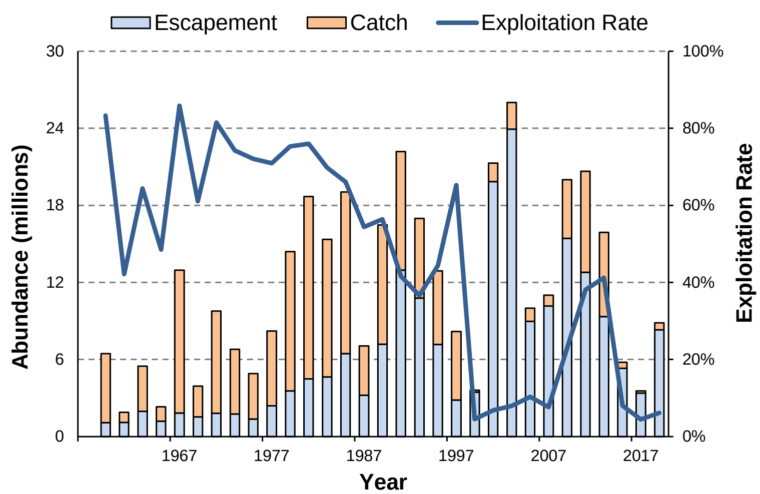

Figure 1. *Total pink salmon run size and exploitation rate to the Fraser River since 1959. The run size is defined by the escapement plus catch. Note that abundances on even years are negligible.*

[1] DFO. 1998. Fraser River salmon summary. Fraser River Action Plan, Fisheries Management Group. Vancouver, B.C. 16p.
[2] Riddell, B.E. and R.J. Beamish. 2003. Distribution and Monitoring of Pink Salmon (*Oncorhynchus gorbuscha*) in British Columbia, Canada. (NPAFC Doc. 707). 33p. Science Branch, Pacific Region, Department of Fisheries and Oceans, Canada.
[3] Holtby, L.B. and Ciruna, K.A. 2007. Conservation units for Pacific salmon under the Wild Salmon Policy. CSAS Research Document: 2007/070

2. Fisheries

Fraser River pink salmon have traditionally been harvested as by-catch in fisheries directed towards Fraser River sockeye salmon. Starting in 1999, concerns over the status of Late run sockeye and Interior Fraser coho salmon led to harvest restrictions across all salmon species during the migration of these sockeye stocks. In addition, low prices of pink salmon in combination with high fuel costs decreased the interest for later-timed fisheries solely targeting pink salmon[4]. This resulted in a dramatic decrease in pink salmon harvests from 1999 to 2007. From 2009 to 2013, reduced sockeye harvest opportunities in combination with improved pink salmon prices increased the desire for later-timed salmon fisheries directed at pink salmon. Further increases in conservation concerns for Late run sockeye resulted in an increased focus on the non-retention of sockeye in pink-directed fisheries and the reporting of fishing-induced mortality or release mortality, i.e., the number of sockeye expected to die due to the stress of capture and handling prior to release. Fishing-induced mortalities for released sockeye are not counted against the Total Allowable Catch (TAC) for sockeye but are incorporated into estimates of total exploitation rate. Since 2015, pink salmon catches have been substantially lower due to lower pink salmon run sizes, limited available TAC and in-season uncertainty regarding the run size and subsequent TAC. Fisheries directed at Fraser River pink salmon, may have by-catch of sockeye, Chinook, chum, coho, and steelhead.

GEAR SECTORS

US:

- Treaty Tribal purse seine fishery
- Treaty Tribal gillnet fishery
- All Citizen purse seine fishery
- All Citizen gillnet fishery
- All Citizen reefnet fishery
- Recreational fisheries

Canada:

- FSC and First Nations Demonstration and Economic Opportunity fisheries
- Area B purse seine fishery
- Area D and E gillnet fishery
- Area G and H troll fishery
- Recreational fisheries

INTERCEPTION BY OTHER FISHERIES

In marine areas, catch of pink salmon can only be attributed to the Fraser River if the catch occurs in terminal areas and through the application of stock identification methods. The proportion of Fraser River pink salmon in fisheries directed at pink salmon in Southern BC and Washington State are evaluated through stock identification methods. Previous studies indicated that pink salmon are also intercepted by other fisheries but stock identification is not part of the regular assessment of these catches and, as a result, catches of Fraser River pink salmon catches are not reported for these fisheries. Reported Fraser

[4] Grant, S.C.H., Townsend, M., White, B. and Lapointe, M. 2014. Fraser River pink salmon (*Oncorhynchus gorbuscha*) data review: inputs for biological status and escapement goals. Final project report to Southern Boundary restoration and enhancement fund. Vancouver.

River pink salmon catches caught north of Cape Caution have been estimated to make up less than 10% of the total Fraser River pink salmon catches[5].

FISHERY CHALLENGES

Because the migration timing of Fraser River pink salmon overlaps with Fraser River sockeye salmon stocks with later timing, such as Late run stocks as well as Interior Fraser coho, access to pink salmon TAC is limited by low abundances of and conservation concerns for these comigrating salmon stocks. In addition, Fraser River pink salmon run size and associated TAC have been more challenging to estimate in-season than for Fraser River sockeye salmon, partly because pink salmon have a longer and more variable migration and there are no in-season updates to catchability.

3. Management

The management of Fraser River sockeye salmon is the responsibility of the Fraser River Panel (Panel waters) and Fisheries and Oceans Canada (DFO) (non-Panel waters). Fraser River pink salmon is managed as one management unit. Strategic plans for the management of Fraser River sockeye are documented by the Wild salmon policy[6], while annual management plans are documented in the Annual Integrated Fisheries Management Plan[7].

The management objectives for Fraser River pink salmon are: (1) to achieve the spawning escapement goal; (2) to achieve targets for international sharing of the TAC as defined in the Treaty; and (3) to achieve domestic allocation goals within each country. In addition, fisheries management needs to ensure that the conservation needs and management requirements for other salmon species (e.g., sockeye and coho salmon) are taken into account.

MANAGEMENT CHALLENGES

Since 1999, conservation concerns for Fraser River sockeye salmon have restricted fisheries access to Fraser River pink salmon. Since 2015, there has been a substantial drop in the abundance of Fraser River pink salmon and, as a result, fishing opportunities for pink salmon decreased further. Similar to Fraser River sockeye salmon, there seems to be a declining trend in marine survival for Fraser River pink salmon (Figure 2). Additional conservation concerns for Interior Fraser coho and lower Strait of Georgia Chinook further reduced access to Fraser River pink salmon[8].

[5] Shaklee, J.B., Beacham, T.D., Seeb, L. and White, B.A. 1999. Managing fisheries using genetic data: case studies from four species of Pacific salmon. Fisheries Research, 43: 45-78.
[6] DFO. 2005. Canada's policy for conservation of wild Pacific salmon. Fisheries and Oceans Canada, Vancouver, B.C.
[7] DFO. 2020. Integrated Fisheries Management Plan June 1, 2020 - May 31, 2021. Salmon Southern BC. Fisheries and Oceans Canada.
[8] Grant, S. and G. Pestal. 2009. Certification Unit Profile: Fraser River Pink Salmon. Can. Man. Rep. Fish. Aquat. Sci. 2875: vii + 36p.

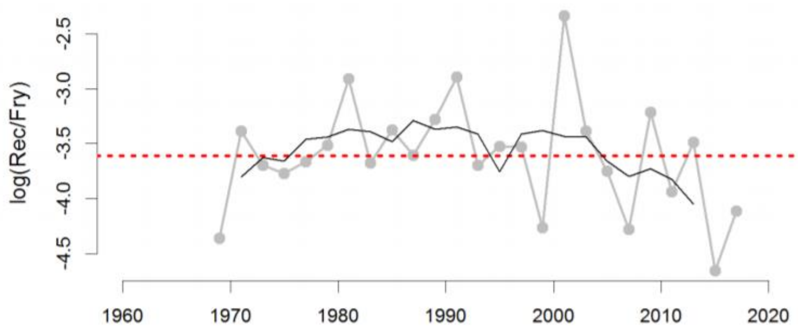

Figure 2. *Estimated fry to adult survival rates for Fraser River pink salmon[9]. Dashed red line: long term average survival rate since 1969. Solid black line: 4-year moving average.*

4. Assessments

Fraser River pink salmon assessments are only performed on odd years as abundances on even years are extremely low. Assessments include the use of annual pre-season forecasts and in-season assessments, as well as the use of long-term planning tools such as reference points, harvest control rules, escapement goals. No management Strategy Evaluation (MSE) through closed loop simulations has been executed for Fraser River pink salmon.

PRESEASON FORECAST

The Fraser River Panel relies on preseason forecasts of run size[9], run timing[10] and diversion rate[10] for the assessment and management of Fraser River pink salmon. Prior to 2021 the preseason run size forecast models use fry abundances estimated at Mission during the downstream migration in combination with sea surface salinity data, collected at Amphitrite Point and at Race Rocks (DFO, 2007). In 2021 the fry abundance information was not available as the Mission downstream program was cancelled due to COVID 19. Alternative models were used for the 2021 forecast that relied more heavily on recent environmental conditions related to Fraser discharge and sea surface temperatures. The forecast for run timing and diversion rate rely on historic timing and diversion rate estimates. The run size, timing and diversion rate forecasts are all inputs into the fisheries planning model. This model has been developed by Pacific Salmon Commission Secretariat staff to support the Fraser River Panel with pre-season planning. More specifically it allows exploration of the extent and timing of fishing opportunities given different assumptions about run size and diversion rates as well as different assumptions about comigrating Fraser River sockeye. The forecasts are also used as inputs into the in-season run size models in the form of prior probability distributions[11]. The role of these forecasts in assessments and for fisheries management advice diminishes in-season as more information accumulates and the peak migration date has been observed in the CPUE data.

[9] Hawkshaw, M., Xu, Y., Davis, B. 2020. Pre-season run size forecast for Fraser River sockeye (*Oncorhynchus nerka*) and pink (*Oncorhynchus gorbuscha*) salmon in 2019. Can. Tech. Rep. Fish. Aquat. Sci. 3391: vi + 52 p.
[10] Folkes, M. 2019. Forecast of Fraser Pink return timing for 2019. PBS, Nanaimo.
[11] Michielsens, C.G.J. and Cave, J.D. 2019. In-season assessment and management of salmon stocks using a Bayesian time–density model. Can. J. Fish. Aquat. Sci. 76: 1073-1085.

IN-SEASON ASSESSMENTS

In-season, daily abundance estimates are based on marine catch-per-unit-effort data collected by marine test fisheries and used in combination with historical catchability estimates. Because a proportion of the run may delay its upstream migration into the Fraser River, the daily pink salmon abundance estimates collected at Mission using hydroacoustic data can not be used in-season to verify the daily marine abundance estimates as is the case for most Fraser River sockeye salmon. In season run size forecasts are derived using a Bayesian time–density model fitted to the catch-per-unit effort data collected by marine test fisheries[11].

REFERENCE POINTS, HARVEST CONTROL RULES AND ESCAPEMENT GOALS:

The current harvest control rule for Fraser River pink salmon was developed more than twenty years ago[4] and includes an escapement goal of 6 million spawners when the run size is between 7.059 and 20 million salmon[7]. The harvestable surplus is the difference between the run size and the escapement goal, and the resulting exploitation rate ranges from 15% for a run size of 7.059 million to 70% when the run size is 20 million. For run sizes less than 7.059 million, the allowable exploitation rate is the run size multiplied by 0.15/7,059,000. This will result in an exploitation rate that increases linearly from zero when the run size is 0 to 15% as the run size increases to 7.059 million. There is no Lower Fishery Reference Point defined below which no directed fisheries are allowed. The Upper Fishery Reference Point is the run size above which the allowable exploitation rate remains fixed. For Fraser River pink salmon, the allowable exploitation rate remains at 70% for run sizes in excess of 20 million, causing the escapement goal to increase as the run size increases beyond 20 million. Benchmarks related to the Wild Salmon Policy have yet to be developed for Fraser River pink salmon.

MANAGEMENT STRATEGY EVALUATION

A management strategy evaluation (MSE) to evaluate the effectiveness of the current harvest control rule for the management of Fraser River pink salmon has been requested by DFO Fisheries Management. The current plan is to expand the current Fraser River sockeye MSE process to include Fraser River pink salmon. Discussions on quantitative objectives for Fraser pinks will occur after in-person meetings resume – tentatively in 2022-23.

DATA LIMITATIONS

Declining funding for stock assessments and the lower relative importance of Fraser River pink salmon to fisheries have limited the data available for pink salmon assessment. Fisheries and Oceans Canada (DFO) stopped collecting spawning ground information for pink salmon after 2001. Since 2009, Fraser-wide spawner estimates have been derived from hydroacoustic data collected at Mission minus upstream catches. The changes to the methods to derive spawner numbers has impacted the quality of the stock-recruitment data. In 2019 there was a rockslide in the Fraser River at Big Bar[12]. Due to the lack of recent spawning ground estimates, the proportion of the Fraser River pink salmon run spawning above Big Bar impacted by the slide remains unclear, but estimates range from 5 to 30%. The fact that pink salmon arrive at Big Bar later in the season when discharge levels are lower, however, increases their chances of

[12] Murphy, I., S. Johnson, and T. Hatfield. 2020. Big Bar Landslide Southern Endowment Fund Science Workshop Summary. Consultant's report prepared for Pacific Salmon Commission and Fisheries and Oceans Canada by Ecofish Research Ltd, June 22, 2020.

successfully passing the Big Bar landslide area. In addition, pink salmon have been observed to spawn in new locations when encountering barriers en route to their spawning grounds.

ASSESSMENT CHALLENGES

Currently, the main in-season assessment tool for Fraser River pink salmon relies on test fishing CPUE data used in combination with historical catchability estimates. Unlike for sockeye salmon, the historical test fishing catchability for pink salmon cannot be updated based on in-season information due to the fact that pink salmon delay their upstream migration into the Fraser River. The larger variability among catchability estimates for pink salmon compared to sockeye exacerbates the greater uncertainty associated with the in-season run-size estimates for Fraser River pink salmon. In addition, in-season assessments are also challenging because of the large variability in migration behaviour: migration speed and timing, the proportion and amount of the run that delays upstream migration into the Fraser River and the diversion rate. Catch of pink salmon in U.S. fisheries has also been explored as a tool to assist in run size estimation with limited success. In recent years, the lower sockeye abundance on pink salmon years in combination with the low price for pink salmon has meant that the cost of the test fisheries on pink salmon years can no longer be offset by the revenue from the catch.

INFORMATION CONVEYED TO MANAGERS/DECISION MAKERS

Pre-season, the Fraser River Panel requires forecasts of run size, timing and diversion rate. The Panel also provides input into and receives the results of the fisheries planning model. The model allows exploration of the extent and timing of fishing opportunities given different assumptions about run size, timing and diversion rate as well as different levels of overlap in migration timing with Fraser River sockeye salmon.

In-season, the Fraser River Panel receives a twice weekly update of the in-season run size, the timing and the diversion rate. In addition, the Panel receives updates of catches to date by fishery, the test fishing catches, hydroacoustic abundance estimates at Mission once available, and the latest stock identification results in different marine areas.

Once the Fraser River Panel decides to officially update in-season run sizes, it is provided with updated TAC estimates and remaining balances after subtraction of catches-to-date. Technical staff also evaluate fisheries opening proposals to assess if these are consistent with the remaining TAC.

5. Incorporating environmental data

Environmental data are used quantitatively to generate preseason run size forecasts, as the suite of run size forecast models includes several models with environmental covariates. These variables include Fraser River discharge measured at Hope, Pacific Decadal Oscillation (PDO), sea surface temperatures collected at Entrance or Pine Island, and sea surface salinity[13]. In addition to the quantitative forecast, freshwater and ocean survival conditions are also evaluated to provide a qualitative estimate of expected returns to the Fraser River[14].

[13] DFO. 2021. Pre-season Run Size Forecasts for Fraser River Sockeye (Oncorhynchus nerka) and Pink *(Oncorhynchus gorbuscha*) Salmon in 2021. DFO Can. Sci. Advis. Sec. Sci. Resp. 2021/038.

[14] Davis, B., Patterson, D. and Xu, Y. 2021. Supplemental Environmental Data for 2021 returns. Presentation to the Fraser River Panel. 9 Feb 2021.

Environmental covariates have also been used to produce timing and diversion rate forecasts for Fraser River pink salmon, following similar methodology used for Fraser River sockeye[15]. These covariates include ocean currents, surface wind stress and sea surface temperature. One of the main problems with the timing and diversion rate forecasts for pink salmon is that the best predictors require data collected in July that only become available later in August when pink salmon have already started to return and in-season observations are available, allowing no opportunity to include these estimates in the preseason planning processes. For preseason planning purposes, timing[10] and diversion rate[10] forecasts have been based on medians or time-series analyses of historical estimates.

Unlike for Fraser River sockeye salmon, there is no evidence that adverse environmental conditions within the Fraser River impact the survival of pink salmon and their ability to reach the spawning grounds. The limited work done on pink salmon suggests that they have a high thermal tolerance consistent with the late-summer migration in the Fraser River[16]. However, the effects of environmental factors on pink salmon timing and migration from marine test fisheries to the Mission hydroacoustic site have not been fully explored.

Given that pink salmon are expected to be less negatively impacted than sockeye by adverse environmental conditions, environmental data have neither been incorporated to derive the reference points nor escapement goals for Fraser River pink salmon. Further, environmental data have not been incorporated in the in-season application of the harvest control rule.

6. Accounting for changes in productivity

The forecast models for Fraser River sockeye salmon do not explicitly account for changes in pink salmon productivity, but the retrospective evaluations of model performances do[13]. These retrospective analyses evaluate a wide range of forecast models, both with and without environmental covariates, to assesses their performance during the last 5 years that exhibited lower productivity in addition to their performance over a longer 15-year period. The model used to produce the forecast performs best across the two performance assessment windows. Productivity has also been incorporated qualitatively by comparing the productivity implied by the forecast with the recent productivity estimates.

Changes in productivity have not been accounted for to derive the reference points, harvest control rule or escapement goals for Fraser River Pink salmon.

7. Accounting for and conveying uncertainty

The preseason forecast models use Bayesian estimation methods and the uncertainty in the forecast results is expressed in terms of a probability distribution in terms of the following percentiles: 10%, 25%, 50%, 75%, and 90%[17]. The median forecast (50th percentile, or p50) represents an equal chance (i.e., a one in two chance) that the return will fall either above or below the forecast value for each stock. In

[15] Folkes, M.J.P., Thomson, R.E., and Hourston, R.A.S. 2018. Evaluating Models to Forecast Return Timing and Diversion Rate of Fraser Sockeye Salmon. DFO Can. Sci. Advis. Sec. Res. Doc. 2017/021. vi + 220 p.

[16] Clark, T.D., Jeffries, K.M., Hinch, S.G., and Farrell, A.P. 2011. Exceptional aerobic scope and cardiovascular performance of pink salmon (Oncorhynchus gorbuscha) may underlie resilience in a warming climate. J. Exp. Biol. 214: 3074-3081.

[17] Grant, S.C.H., Michielsens, C.G.J., Porszt, E.J., and Cass, A. 2010. Pre-season run size forecasts for Fraser River Sockeye salmon (*Oncorhynchus nerka*) in 2010. DFO Can. Sci. Advis. Sec. Res. Doc. 2010/042.

comparison, there is a one in four chance that the actual number of returning pink salmon will fall at or below the forecast associated with the 25th percentile (p25 probability level). Within the current forecast methodology, for those models that do not incorporate environmental covariates, the p50 forecast assumes long-term average productivity will be maintained, the p10 and p25 forecasts assume below average productivity, while the p75 and p90 forecasts assume above average productivity.

The primary in-season run size model is a Bayesian time-density model and the resulting run-size estimates are conveyed in terms of the median and the 95% probability interval.

The current reference points, harvest control rule and escapement goals for Fraser River pink salmon were developed more than twenty years ago and lack proper documentation of the underlying methodology, including the uncertainty around both the reference points and escapement goals.

8. Ability to reach management objectives

In general, it has been assumed that Fraser River pink salmon are resilient and can rebound from low to higher abundance in one or two generations[18]. Despite this apparent resilience, there have been indications of declining productivity of Fraser River pink salmon stocks in recent years. The current harvest control rule and escapement goal were developed at a time when Fraser River pink salmon returns were abundant, and the rules and the goal may benefit from re-examination given apparent trends in productivity and growing conservation concerns.

9. Planned assessment changes to account for climate change

There are tentative plans for an MSE for Fraser River pink salmon. The scope of the project has yet to be decided. However, given the increasing concerns around impacts of climate change and evidence of changing productivity, it is likely that these factors will be incorporated to some degree.

[18] Heard, W.R. 1991. Life history of pink salmon (Oncorhynchus gorbuscha). In Pacific salmon life histories. Edited by C. Groot and L. Margolis. UBC Press, Vancouver, B.C. pp. 121–139. doi:10.2307/1446178.

PST Chapter 5: Southern coho salmon

1. Introduction

Chapter 5 of the Pacific Salmon Treaty applies to coho salmon stocks in Washington and Southern British Columbia. The Southern Coho Agreement is focused on 12 naturally spawning Management Units (MU) containing different naturally spawning coho populations: three Southern BC Inside Management Units (Interior Fraser, Lower Fraser and Strait of Georgia), five U.S. Inside Management Units (Skagit, Stillaguamish, Snohomish, Hood Canal and Strait of Juan de Fuca), and four U.S. Outside Management Units (Quillayute, Hoh, Queets and Grays Harbor).

Between 1986 and 2009, total Southern coho run size has been declining and between 2010 and 2019 has ranged from close to 700,000 in 2012 to less than 200,000 in 2015 (Figure 1).

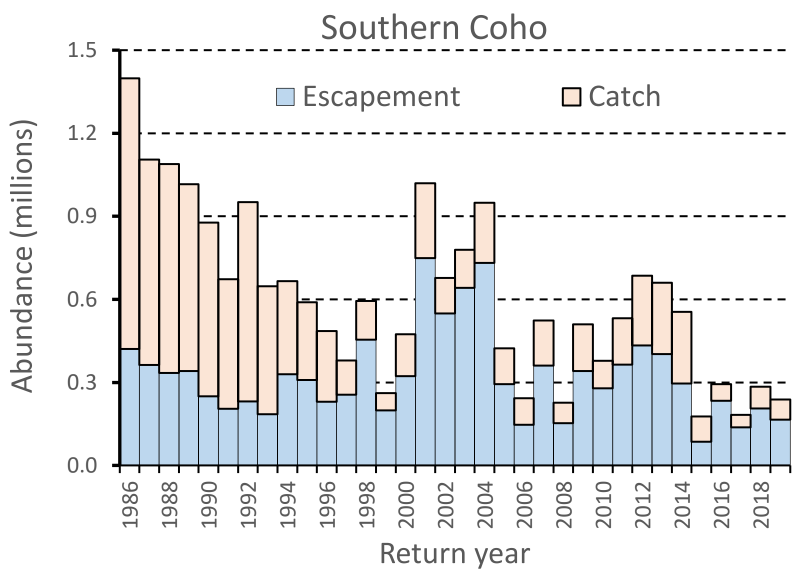

Figure 1. *Total run size of 12 naturally spawning Southern Coho Management Units (1986-2019). The run size is defined by the escapement plus catch. These totals exclude estimates for the Lower Fraser and Strait of Georgia MUs which have not been assessed in recent years.*

In 2021, of the 12 management units (MUs) assessed, four were considered low in abundance (Interior Fraser, U.S. Strait of Juan de Fuca, Quillayute, and Queets), five were moderate (Skagit, Snohomish, Hood Canal, Hoh, and Grays Harbor), and one was considered abundant (Stillaguamish), while the status of Lower Fraser and Strait of Georgia MUs have not been forecast or assessed[1], due to a lack of data to assess MU abundance status. In comparison, in 2019, five MUs were considered abundant (Grays Harbor, Queets, Quillayute, Hoh, and Stillaguamish)[2]. In addition, Interior Fraser coho has been assessed as Threatened by Committee on Status of Wildlife in Canada (COSEWIC) and is currently under consideration

[1] Pacific Fishery Management Council. 2021. Preseason Report III: Council Adopted Management Measures and Environmental Assessment Part 3 for 2021 Ocean Salmon Fishery Regulations: RIN 0648- BJ97. (Document prepared for the Council and its advisory entities.) Pacific Fishery Management Council, 7700 NE Ambassador Place, Suite 101, Portland, Oregon 97220-1384.
[2] Pacific Salmon Commission 2020. Thirty-fifth annual report 2019/2020. PSC, Vancouver, 215p.

for listing under the Species at Risk Act (SARA)[3]. While not recently assessed, the total abundance of Lower Fraser coho modelled in FRAM (Fishery Regulatory Assessment Model) for the 2004–2010 period ranged from 67,000 in 2004 to 3,000 in 2008 while the modelled abundance of Strait of Georgia coho during the same period ranged from 306,000 in 2004 to 15,000 in 2008.

2. Fisheries

The decline in natural coho abundance caused the PSC in 2002 to adopt a management plan for coho salmon directed at the conservation of the coho MUs in Southern British Columbia and Washington based on abundance status and escapement goals. The Southern Coho Management Plan (SCMP) aimed to constrain the exploitation rates on individual MUs in order to achieve long-term Maximum Sustainable Harvests (MSH) and protect diversity. These constraints are implemented by specifying exploitation rate limits for the individual MUs dependent on annual abundance status. The total allowable fisheries exploitation rate for an MU depends on the categorical abundance status of that MU: low abundance (total exploitation rate less than 20%), moderate (total exploitation rate between 20 to 40%), and abundant (total exploitation rate greater than 40%). The exploitation rates of the individual MUs differ and in general, exploitation rates in recent years have been higher than average for Hood Canal, Quillayute, and Hoh and lower than 20% for Interior Fraser coho. Continued concerns about the low abundance status of Interior Fraser coho resulted in the requirement that U.S. fisheries not exceed a 10% exploitation rate for the Interior Fraser MU since abundance-based management was initiated[1].

Fisheries directed at Southern coho salmon may have bycatch of Chinook, sockeye, pink, chum and steelhead.

GEAR SECTORS

U.S. Ocean Fisheries:

- Non-Tribal Troll fisheries
- Tribal Troll fisheries
- Ocean Sport fisheries
- All-species sports fisheries in Columbia Ocean Area, Westport, La Push, and Neah Bay, Washington

U.S. Inside Fisheries:

- Washington Coastal Rivers Tribal and non-Tribal net and sport fisheries
- Columbia River Tribal and non-Tribal net and sport fisheries
- Strait of Juan de Fuca Sport fisheries
- Strait of Juan de Fuca Tribal Troll (Area 4B, 5 and 6C) fisheries
- Strait of Juan de Fuca Tribal Net fisheries
- San Juan Island Net (Area 6, 7 and 7A) fisheries
- San Juan Island (Area 7) Sport fisheries
- Inside Puget Sound (Area 8-13) Sport fisheries
- Puget Sound Marine Net (Area 8-13 & 7B-D) fisheries
- Puget Sound Rivers Tribal net and non-Tribal sport fisheries

[3] Arbeider, M., Ritchie, L., Braun, D., Jenewein, B., Rickards, K., Dionne, K., Holt, C., Labelle, M., Nicklin, P., Mozin, P., Grant, P., Parken, C., and Bailey, R. 2020. Interior Fraser Coho Salmon Recovery Potential Assessment. DFO Can. Sci. Advis. Sec. Res. Doc. 2020/025. xi + 211 p.

Canada:

- WCVI FSC and Treaty troll fisheries
- Lower Fraser FSC, commercial and recreational fisheries with hook and line and net
- BC Interior FSC, commercial and recreational fisheries with hook and line and net
- Strait of Georgia FSC fisheries and Treaty Domestic fisheries, predominantly terminal fisheries
- Johnstone Strait net fisheries
- WCVI Economic Opportunity fisheries
- Offshore and nearshore integrated hook-and-line or terminal Five Nations Communal Sales fishery
- Recreational fisheries in tidal and non-tidal waters with barbless hooks on hook and line gear
- Excess Salmon-to-Spawning Requirement (ESSR) fisheries

INTERCEPTION BY OTHER FISHERIES

Coho may be encountered as bycatch in fisheries directed at other more abundant salmon species and by fisheries in other areas such as Northern BC and SE Alaska. In Canada, retention of hatchery or natural coho bycatch may be considered in First Nations FSC fisheries when coho abundances are sufficiently high but are generally not permitted in commercial and recreational fisheries that have the potential to intercept Interior Fraser coho. Mark-selective fisheries (MSF) for coho have, however, been implemented in most Southern BC recreational fisheries and some commercial fisheries, which permit retention of hatchery reared (marked) coho salmon, while reducing impacts on unmarked coho stocks. MSF restrictions are also implemented in U.S fisheries south of Cape Falcon. For the period from 2001 to 2014, 3–17% of the total Puget Sound coho catch was caught in MSF while 14–52% of the Washington Coast and 5–37% of the Columbia River region coho catch were caught in MSF[4]. Overall, bycatch of coho salmon in U.S. fisheries targeting other salmon species varies substantially from year to year but is generally an order of magnitude lower than Chinook bycatch in the same fisheries[5].

FISHERY CHALLENGES

Concerns about the low abundance status of Interior Fraser River coho has been restricting fisheries access to coho salmon, both in Canada and in the U.S. The decline of this MU started in the mid-1990s and was the result of low marine survival rates in combination with substantial fishery impacts. In 1997, Fisheries and Oceans Canada (DFO) implemented a number of fisheries management measures to reduce the harvest of this MU and in recent years, the Canadian exploitation rate target has been reduced to 3-5% (Canadian domestic objective) with an additional 10% permitted in U.S. fisheries. Despite the general reduction in exploitation rate, the abundance status of this MU has remained low, due to persistently low productivity since 1994[6,7].

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[4] Pacific Salmon Commission Selective Fishery Evaluation Committee 2021. Analysis of coho salmon double index tag (DIT) groups for brood years 1998-2011. Report SFEC (21)-1.

[5] Richerson, K., Somers, K. A., Jannot, J. E., Tuttle, V., Riley, N. B. and McVeigh, J. 2019. Observed and Estimated Bycatch of Salmon in U.S. West Coast Fisheries, 2002–18. U.S. Department of Commerce, NOAA Data Report NMFS-NWFSC-DR-2019-02.

[6] DFO. 2020. Integrated Fisheries Management Plan June 1, 2020 - May 31, 2021. Salmon Southern BC. Fisheries and Oceans Canada.

[7] Decker. A.S., Hawkshaw, M.A., Patten, B.A, Sawada, J, A.L. Jantz I. 2014. Assessment of the Interior Fraser Coho Salmon (*Oncorhynchus kisutch*) Management Unit Relative to the 2006 Conservation Strategy Recovery Objectives. DFO Can. Sci. Advis. Sec. Res. Doc. 2014/086. xi + 64 p.

In addition, fisheries access to coho catches have also been constrained by management objectives for Chinook stocks listed by the U.S. Endangered Species Act (ESA), conservation concerns and legal Treaty Indian sharing obligations in the U.S. The total exploitation rates of Canadian fisheries (especially WCVI sport and troll fisheries) have been constrained by the low abundance status of Interior Fraser Coho MU as well as by the management measures put in place since 2019 to have as many Fraser Chinook return to spawning grounds.

3. Management

Coho stocks that originate in rivers with mouths south of Cape Caution, i.e., originating in Southern BC, Washington State and Oregon, are the responsibility of the Southern Panel, except for 3 Canadian Southern coho MUs that are recognised for domestic management (Northeastern Vancouver Island and Mainland Inlets, Northwestern Vancouver Island and Southwestern Vancouver Island).

Canada's Wild Salmon Policy[8] documents the strategic plan for Canadian wild Pacific salmon but does not specifically cover coho MUs. For U.S. coho stocks, there is no strategic plan that covers all stocks. In the U.S., coho management for Puget Sound and Washington Coastal stocks are covered in regional management plans. The Pacific Fisheries Management Council operates under a Framework Management Plan and has developed rebuilding plans for the following coho MUs which have been classified as being "overfished" (failure to meet escapement objectives for three consecutive years): Strait of Juan de Fuca, Queets, and Snohomish[9].

The Pacific Salmon Treaty (PST) defines the Exploitation Rate (ER) caps and the corresponding limits on the ER for Canada and the U.S. through the PST's Southern Coho Management Plan (SCMP). Overall, the SCMP is directed at constraining total mortality fishery ERs on 12 naturally spawning Management Units: Southern BC Inside Management Units (Interior Fraser, Lower Fraser, and Strait of Georgia, which was split out into a Mainland and Vancouver Island MU prior to 2019), U.S. Inside Management Units (Skagit, Stillaguamish, Snohomish, Hood Canal, and Strait of Juan de Fuca), and U.S. Outside Management Units (Quillayute, Hoh, Queets, and Grays Harbor)[10].

The objective of the Southern Coho Management Plan (SCMP) as described in the Treaty[10] is to manage the fisheries impact on Southern coho stocks by limiting the total fishery exploitation and allow the different MUs to produce long-term Maximum Sustainable Harvest (MSH), while maintaining the genetic and ecological diversity of the individual populations. In addition, the plan is designed to improve the prospect of sustaining healthy fisheries for both parties over the long-term. The plan is also expected to be cost-effective, flexible to available technical capacity and information, provide a predictable framework for planning fisheries impacts on the spawning populations and allow for objective monitoring, evaluation and modification of the management regime.

In order to achieve this, annual exploitation rate (ER) limits or caps are established for each of the MUs based on the level of abundance and health of the natural stocks. Actual exploitation rate constraints for Canadian fisheries on U.S. coho MUs are determined by formulas that specify sharing allowable

[8] DFO. 2005. Canada's policy for conservation of wild Pacific salmon. Fisheries and Oceans Canada, Vancouver, B.C.
[9] https://www.pcouncil.org/actions/coho-salmon-rebuilding-plans/
[10] Pacific Salmon Commission 2020. Treaty between the Government of Canada and the Government of the United States of America concerning Pacific Salmon. PSC, Vancouver, 145p.

exploitation rates and a composite rule, which adjust constraints for Canadian fishery exploitation rates based on the number of U.S. MUs that fall in a given category. Exploitation rate constraints for U.S. fisheries on Canadian MUs are dependent on the status of the Interior Fraser MU until the biological status of the other Canadian MUs has been determined. Canada is currently working to develop the information base (smolt to adult survival, escapement) to support the application of the status determination method developed for the Interior Fraser coho MU to the Lower Fraser and Strait of Georgia MUs.

Each country manages the coho harvest within its ER cap through its own domestic fisheries management processes and annual fisheries plans. For Canada, the annual domestic planning process is documented in the salmon Integrated Fisheries Management Plan (IFMP)[6]. For the U.S., the North of Cape Falcon ocean salmon fishing plans are reported in Preseason Report III (Pacific Fisheries Management Council)[1]. For U.S. Inside MUs, the 2019 PST uses the exploitation rate thresholds and stepped harvest rate goals from the Comprehensive Coho Agreement and adopted as FMP conservation objectives in 2009. For U.S. Outside MUs, exploitation rate constraints represent the Maximum Fishing Mortality Threshold (MFMT)[1].

MANAGEMENT CHALLENGES

Despite the SCMP and fisheries ER constraints, overfishing still occurs. Since 2018, Queets, Snohomish, and Strait of Juan de Fuca natural coho had been classified as overfished by the Pacific Fisheries Management Council[1]. Time and area adjustments had been made to reduce exploitation on these MUs, while allowing fishing on coho MUs or other species in healthier status. These three MUs have rebuilding plans adopted by the Pacific Fisheries Management Council. All three have been rebuilt and are no longer considered overfished.

A key consideration for Canadian fisheries management is ensuring that the domestic conservation obligations are being met for Interior Fraser coho, which includes the Thompson River. Coho migration into the Fraser River, however, overlaps with the migration of Fraser River sockeye and pink salmon, and conservation concerns for Interior Fraser coho have impacted planning for Fraser fisheries. Prior to 2014, Canadian fisheries were managed so as not to exceed a 3% maximum exploitation rate. In 2014, a record forecast for Fraser sockeye salmon caused Canada to increase the exploitation rate limit on upper Fraser coho in Canadian fisheries to 16% to allow for coho impacts in sockeye-directed fisheries. This resulted in a total exploitation rate of 32% for that year. Since 2015, upper Fraser coho has been managed according to its low abundance status and while the abundance of interior Fraser coho MU is slowly increasing, it is expected to remain in low abundance status for several years going forward, resulting in a continued constraint on Canadian and Southern U.S. fisheries.

Despite declines in fisheries exploitation, coho salmon productivity in general is low, and well below the relatively high productivity observed in the 1980s (Figure 1)[3,11]. There has been a general pattern of declining smolt survival detected for coho salmon within the Salish Sea and the survival declined faster in the Strait of Georgia than in Puget Sound[12].

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[11] Sobocinski, K.L., Greene, C.M., Anderson, J.H., Kendall, N.W., Schmidt, M.W., Zimmerman, M.S., Kemp, I.M., Kim, S. and Ruff, C.P. 2021. A hypothesis-driven statistical approach for identifying ecosystem indicators of coho and Chinook salmon marine survival. Ecological Indicators: 124.

[12] Zimmerman, M., Irvine, J.R., O'Neill, M., Anderson, J.H., Greene, C.M., Weinheimer, J., Trudel, M., and Rawson, K. 2015. Spatial and temporal patterns in smolt survival of wild and hatchery coho salmon in the Salish Sea. Mar. Coast. Fish. 7, 116–134.

As noted in Section 4 below, data deficiencies are limiting management.

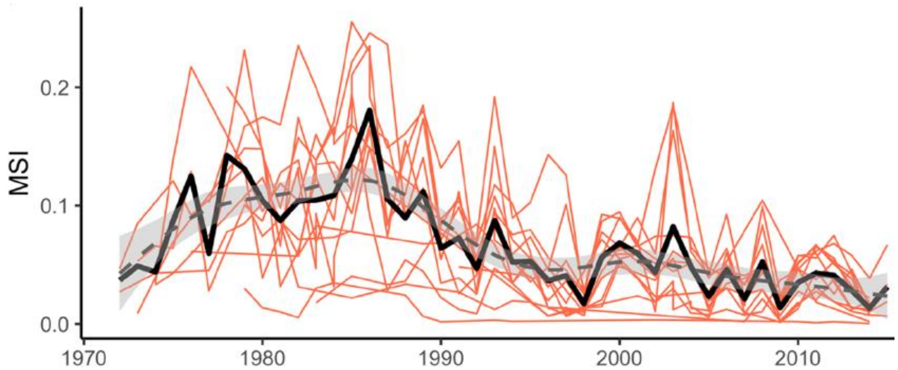

Figure 2. *Marine Survival Index (MSI) for coho salmon within the Salish Sea from mid-1970s to 2010s[11]. The thick solid black line represents the mean for a given year and individual U.S. Inside MUs are represented by the thin colored lines.*

4. Assessments

The assessment of Southern coho salmon includes, for U.S. MUs, the use of annual pre-season forecasts, in-season assessments (to a certain extent), as well as the use of management tools such as reference points, harvest control rules, and escapement goals. The necessary data to support quantitative assessments is lacking for Canadian MUs. Alternative management strategies have been evaluated qualitatively while the current strategy is assessed quantitatively.

PRESEASON FORECAST

Each year, according to the PSC Treaty, both Canada and the U.S share information on the status of each of their MUs as low, moderate, or abundant and provide any changes in the maximum, status dependent Exploitation Rate (ER) cap, along with expectations for fishery planning. According to the Treaty, this needs to be achieved by March 31 prior to the upcoming fishing season.

Over the years, a wide variety of methods have been used to derive run size forecast for the various U.S. MUs[13]. More recently, the accuracy of the run size forecasts (adult ocean recruits) have been improved by relying on smolt abundance estimates for the majority of the stocks in combination with marine survival estimates instead of escapement-based estimates[14]. Initially sibling regressions were the main tool to predict marine survival[15]. Since 2012, environmental indicators have been used as predictors of marine survival[16]. Forecasts that feed into the Fishery Regulation Assessment Model (FRAM) are adjusted to the number of age-3 fish in January of the fishing year, by applying an expansion factor of 1.23 to account for natural mortality of age-3 ocean recruits[14].

[13] Rankis, A., LaVoy, L., Packer, J., Clemons, E., Conrad, R., Simmons, C.D., Sharma, R., Grover, A. and Yuen, H. 2006. Fishery Regulation Assessment Model (FRAM): Technical documentation for coho and Chinook. 64 p.
[14] Litz, M.N.C. 2021. 2021 wild coho forecasts for Puget Sound, Washington Coast, and Lower Columbia. Washington Department of Fish and Wildlife, Fish Science Division. 55 p.
[15] Zimmerman, M.S. 2011. 2011 wild coho forecasts for Puget Sound, Washington Coast, and Lower Columbia. Washington Department of Fish and Wildlife, Olympia, Washington.
[16] Zimmerman, M.S. 2012. 2012 wild coho forecasts for Puget Sound, Washington Coast, and Lower Columbia. Washington Department of Fish and Wildlife, Olympia, Washington.

Preseason run size forecasts are not available for the Canadian MUs. In 2015, the biological status of the five Conservation Units (CUs) making up the Interior Fraser MU was assessed[17] but no status updates have been provided since then. In 2017, Canada developed a status determination method that integrates hatchery smolt-to-adult survival and escapement information[18]. Moving to a higher status requires three consecutive years of smolt-to-adult survival and spawning ground escapement meeting the ranges established for that zone. The MU is considered low in escapement at present by this method. The Lower Fraser and Strait of Georgia MUs lack the escapement data required to determine escapement-based status thresholds using the methodology adopted for Interior Fraser Coho. Exploitation rate constraints for U.S. fisheries on Canadian MUs are dependent on the status of the Interior Fraser MU until the biological status of the other Canadian MUs has been determined.

The Fisheries Regulation Assessment Model (FRAM)[13] is used to project the impact of Southern U.S. fisheries on marked and unmarked coho stocks and to predict exploitation rates in U.S. fisheries. The coho version of the model evaluates the impact of fisheries on a comprehensive set of coho stocks representing total West Coast coho production. It projects ERs of proposed fisheries and generates information for evaluation against management objectives including the PFMC Framework Plan, inter-sector allocation agreements, domestic Treaty sharing obligations, international legal obligations (e.g., exploitation rate caps) under the PST. FRAM tracks the abundance of 123 individual coho stocks as they pass through 198 different fisheries that have the potential to exploit them. Each of the groups have both marked and unmarked components to allow assessment of mark-selective fisheries regulations. The model relies predominantly on Coded Wire Tagging (CWT) information from a base period (1986-1992) to infer stock distribution and estimate contemporary exploitation rates. Within the model, natural stocks or stocks without CWT information are modelled as aggregates combined with hatchery stock with CWT information[19].

The 2019 PST requires Canada to confirm the expected impact of the planned fisheries on U.S. and Canadian MUs by June 30th annually. This task is accomplished by running FRAM using inputs from the final agreed planning run in the U.S. planning process and the information for Interior Fraser coho and scalars provided during the March 30th exchange. These results are reported in two tables showing expected ER by MU and expected ER by fishery and MU.

IN-SEASON ASSESSMENTS

According to the Treaty, the parties are not allowed to change the status of the MUs or the associated ER caps after March 31 for fishery planning purposes. For U.S. fisheries, in-season adjustments to time-area-fishery allocations for ocean fisheries are made on an impact neutral basis and updates of the status of the MUs can and have been made in response to information obtained in season, such as low returns or poor body condition. In addition, in-season information is commonly considered in terminal fishery management in the U.S.

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[17] DFO. 2015. Wild salmon policy biological status assessment for conservation units of Interior Fraser River Coho Salmon (Oncorhynchus kisutch). DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2015/022.

[18] DFO. 2018. Framework for Determination of Pacific Salmon Commission Reference Points for Status Determination and Associated Allowable Exploitation Rates for Select Canadian Southern Coho Salmon Management Units. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2018/016.

[19] Hagen-Breaux, A., Dapp, D. and Cary, J. 2019. Fishery Regulation Assessment Model (FRAM): exploitation rate investigation for the Upper Columbia River Summer Chinook stock.

REFERENCE POINTS, HARVEST CONTROL RULES AND ESCAPEMENT GOALS

The SCMP provides for the parties to exchange information on escapement goals and criteria employed to determine MU status. For Canadian MUs, management reference points (MRPs) are used to demarcate the three PST status categories of low, moderate, and abundant coho status. The status category of an MU will determine the corresponding exploitation rate (ER) caps or ceilings under the Southern Coho Management Plan (SCMP). Within each ER cap, explicit ER limits are established for both Canada and the U.S.

According to the Pacific Salmon Treaty, the parties are responsible for establishing and documenting escapement goals or exploitation rates that achieve Maximum Sustainable Harvest (MSH) for each MU.

Currently, Interior Fraser Coho is the only Canadian MU with informative escapement data for which biological abundance-based benchmarks have been established[17,20,21].

MANAGEMENT STRATEGY EVALUATION

When the last SCMP was renegotiated, the Southern Panel convened a series of workshops that allowed to evaluate alternative management scenarios by applying a structured framework for defining and describing alternative, contrasting management strategies and a process for qualitatively evaluating the strengths and weaknesses of these alternatives through facilitated deliberations[22].

The SCMP provides for Periodic Reviews of the performance of the current management strategy quantitatively. The current Periodic Review is under development with plans to release it in electronic form to facilitate access and updating.

Previously, the Coho Technical Committee implemented a management strategy evaluation when evaluating the effect of MU size for Puget Sound and Interior Fraser Coho stocks on harvest, escapement, and the fisheries management processes[23]. As part of this analysis, three different hypothetical management regimes were explored: a) each region managed as a single MU, e.g., all Puget Sound MUs lumped into a single MU, b) manage five separate MUs in all fisheries, e.g., each Interior Fraser CU would be managed as a separate MU, c) manage each region as an aggregated MU to set exploitation rate ceilings or caps, but separate MUs in domestic fisheries. The model simulated these regimes under a range of different abundance scenarios for each population within the MU, and projected the total number of coho harvested by using the Comprehensive Coho abundance breakpoints and exploitation rates for Puget Sound coho and arbitrary breakpoints and ER ceilings for the Interior Fraser CUs. The sharing formulae in the treaty were used to calculate the proportion of each unit's ER that would have been harvested in each country and examined the management process that would be required if the current MU grouping changed.

[20] DFO. 2014. Assessment of the interior Fraser River Coho Salmon Management Unit. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2014/032.

[21] Korman, J., Sawada, J., Bradford, M.J. 2019. Evaluation framework for assessing potential Pacific Salmon Commission reference points for population status and associated allowable exploitation rates for Strait of Georgia and Fraser River Coho Salmon Management Units. DFO Can. Sci. Advis. Sec. Res. Doc. 2019/001. ix + 81 p.

[22] DFO. 2018. PST Southern Coho Reference Points and Exploitation Rate Caps. Engagement Process Discussion Paper

[23] Pacific Salmon Commission Joint Coho Technical Committee. 2010. The effects of management unit (MU) size for PST coho: one vs. five MUs in Puget Sound and the Interior Fraser. Report TCCOHO (10)-1.

DATA LIMITATIONS

Two of the three Canadian MUs are data deficient, and this creates assessment challenges for fisheries planning and evaluation.

ASSESSMENT CHALLENGES

Southern coho assessments are conducted annually but are in no way timely since the data needed for these assessments (CWT) lag by two years. This means that an assessment conducted in 2022 covers the 2020 fishing season. The lag is largely related to the recovery of CWTs from U.S. fisheries. In addition, there are no in-season adjustments that can be made.

FRAM assumes natural mortality and stock distribution to be reflected by the base period selected to represent fishery and stock distribution patterns[13], which are assumptions that are unlikely to hold due to annual variability, and which may be even more tenuous under environmental change.

INFORMATION CONVEYED TO MANAGERS/DECISION MAKERS

The FRAM model predicts the impact of Southern U.S. fisheries on natural coho stocks and exploitation rates in U.S. and Canadian fisheries. The results are conveyed in terms of run sizes, exploitation rates, fisheries mortalities and escapement for the different MUs in U.S. Planning processes which conclude in April of each year. These estimates are used in the PFMC and North of Falcon annual salmon season processes. Reports include summaries of run size, catch by fishery, stock, and age as well as escapement. The model also provides detailed information regarding mark-selective fisheries for coho[13]. Canada uses information available from FRAM and a domestic planning tool.

5. Incorporating environmental data

Environmental data are used quantitatively to generate preseason run size forecasts for several U.S. coho MUs and hatchery and natural stocks[14]. A suite of “Ocean Scale,” “Region Scale,” and “Local Scale” indicators have been evaluated in terms of their ability to predict marine survival. Ocean Scale indicators have been applied to all Washington coho stocks. The selection of Region Scale indicators assumes oceanographic processes affect survival differently in the different regions and differ for U.S. Inside versus U.S. Outside MUs. Linear regression models have been used to examine the relationship between the different environmental indicators and marine survival of the different populations. A backwards stepwise regression process has been used to compare nested multiple regression models and improve the prediction of marine survival. Model evaluation statistics have been used to evaluate competing models and final predictions of marine survival have been provided in terms of a median and 95% confidence intervals.

Environmental impacts are also implicitly incorporated in the criteria used in the status determination methodology applied to Interior Fraser coho through the use of smolt-to-adult survival estimates.

6. Accounting for changes in productivity or survival

Because the forecast models rely on smolt data, juvenile survival/productivity is already accounted for in the forecast and environmental indicators are used to predict the marine survival estimates. Given that the relationship between environmental indicators and marine survival is based on historical data, this may prevent proper accounting for environmental change when relationships between environmental indicators and marine survival change or predictions fall outside of the historical range. Trends in marine survival itself have not been used for the forecast.

Changes in survival have not been accounted for when deriving reference points, harvest control rule or escapement goals for Southern coho.

There was a management evaluation workshop convened when the last SCMP was negotiated, and the impact of changes in survival were evaluated qualitatively during the workshop[22].

7. Accounting for and conveying uncertainty

The preseason run size forecast for U.S. coho MUs are conveyed in terms of medians and 95% confidence intervals. But abundance forecasts used in FRAM are point estimates and FRAM does not consider uncertainty in abundance forecasts, fishery distribution, or fishery conduct. Preseason run size forecasts are provided for Interior Fraser oho and survival scalar forecasts are used for the other Canadian MUs for preseason planning.

For preseason planning, FRAM relies on a base calibration period average fishery-time period exploitation rates using analyses of CWT recoveries from 2007 to 2013 fishing years. Because fishery harvest rates have been markedly reduced, fishing patterns are unstable, MSFs have increased and impacts caused by environmental change have become increasingly unpredictable, the uncertainty surrounding estimates of CWT ERs is too great to permit updating of the FRAM base period. Continued reliance on FRAM and assumptions of stable distribution and fishing patterns is tenuous and will be considered during efforts to improve the ability to consider and contend with environmental change.

Uncertainty has not been accounted for to derive the reference points, harvest control rule or escapement goals for Southern coho. The qualitative management evaluation workshop highlighted various sources of uncertainty impacting the management of Southern coho salmon[22].

8. Ability to reach management objectives

The main management objective for Southern coho has been to achieve long-term Maximum Sustainable Harvest (MSH) by limiting the total fishery exploitation. The decreased productivity of stocks across the different MUs will have negatively impacted the Maximum Sustainable Harvest that can be achieved. Despite declines in exploitation rates, MUs such as Interior Fraser coho remain low in status, in recent years some MUs have been overfished, and the status of other Canadian MUs is unknown. The lack of data needed to assess the status of Canadian MU's results increases the uncertainty of estimates of ERs available from Coho Technical Committee assessments.

9. Planned assessment changes to account for environmental change

The Southern Panel's annual workplans include efforts proposed to investigate development of a strategic plan for dealing with environmental change under the PST.

PST Chapter 6: Southern chum salmon

1. Introduction

Chapter 6 of the Pacific Salmon Treaty applies to chum salmon stocks in Washington and Southern British Columbia.

Chum stocks in Southern British Columbia and Washington State (Southern chum stocks) can be divided in three groups based on migration timing to the spawning grounds: Summer run (June-August), Fall run (September-November) and Winter run (December-January). While some rivers in Southern BC contain Summer-run chum stocks, only Fall run stocks are actively managed in mixed-stock fisheries. In Southern BC, impacts on summer Chum are mainly from marine bycatch in fisheries directed on other species, and any available surplus is harvested in terminal areas[1]. For assessments and management purposes, the Fall chum stocks in Southern BC are grouped into four Pacific Fishery Management Areas (PFMAs): Johnstone Strait, Strait of Georgia, Fraser River, West Coast Vancouver Island (WCVI). Johnstone Strait, Strait of Georgia and the Fraser River chum stocks are collectively described as Inside Southern Chum (ISC)[2]. In the U.S., Summer chum salmon consist of stocks from Strait of Juan de Fuca, Hood Canal and South Puget Sound. Fall chum salmon contain stocks of Willapa Bay, Grays Harbor, Strait of Juan de Fuca, Nooksack/Samish, Skagit, Stillaguamish/Snohomish, Hood Canal and South Puget Sound, while Winter chum is encountered in South Puget Sound. U.S. chum-directed fisheries in mixed-stock areas target Fall run stocks.

The total annual run size for Southern chum varies substantially from year to year. In addition, there is substantial uncertainty associated with the total run size time series and the escapement data from which they are derived. These time series are not accurate measures of absolute abundance and should therefore be considered abundance indices. Having said that, estimates of total Southern chum abundance in the last 10 years (2010-2019) have ranged from 7.7 million in 2016 to 1 million in 2019. The average run size during this period (4.2 million) was lower than in the previous 10 years (2000-2009: 5.6 million), but higher than in the 1970s (2.9 million). The 2019 run size of around 1 million was the smallest on record since 1968, and several stocks did not meet their escapement goals. Also, a number of Fall Chum hatchery programs throughout Puget Sound were not able to achieve their egg-take objectives in 2019[3].

The Fraser River supports the largest chum stock aggregate in British Columbia, while in the U.S. the Hood Canal and South Puget Sound regions provide the largest contributions to total U.S. chum abundance. Hood Canal and Strait of Juan de Fuca Summer run chum have been listed under the Endangered Species Act since 1999[3]. Combined, they are recognised as one Evolutionarily Significant Unit[4] (ESU). Other stocks of conservation concern include Winter run chum salmon from the Nisqually River in South Puget Sound and Fall chum salmon in North Puget Sound[5].

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[1] DFO. 1999. Inner South Coast Chum Salmon. Stock Status Report D6-09.

[2] Pacific Salmon Commission Joint Chum Technical Committee. 2022. 2018 post season summary report. TCCHUM (22)-01.

[3] Pacific Salmon Commission 2020. Thirty-fifth annual report 2019/2020. PSC, Vancouver, 215p.

[4] Lestelle L., Sands, N., Johnson, T. and Downen, M. 2018. Recovery goal review and updated guidance for the Hood Canal Summer chum salmon ESU. Report submitted to the Hood Canal Coordinating Council. Poulsbo, WA.

[5] Litz, M., Small, M., Addae, K., Patton, B. and Spidle, A. 2020. Report to Southern Boundary Restoration and Enhancement Fund: Puget Sound Chum salmon GSI. WDFW, Olympia.

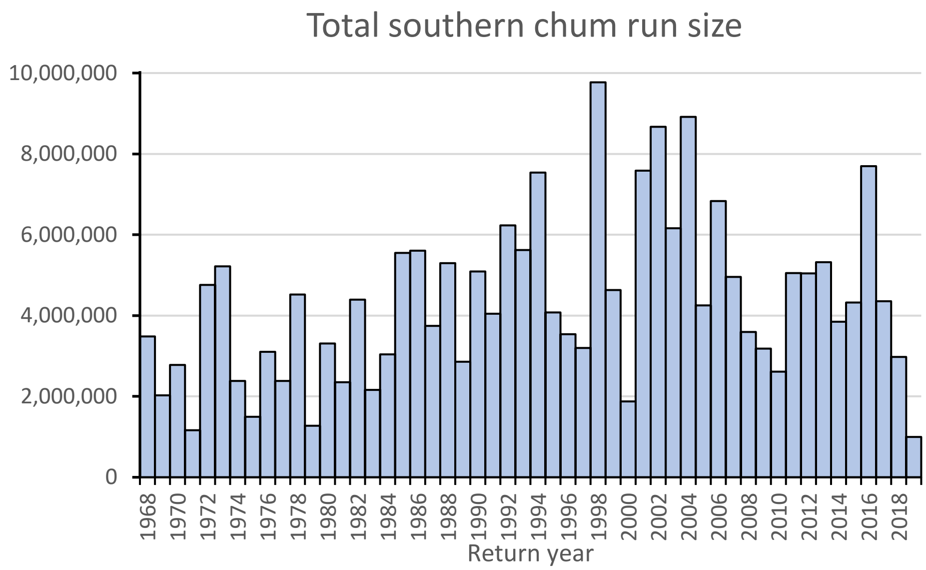

Figure 1. *Abundance index of total chum run size in Southern British Columbia and Washington State (1968-2019), excluding BC Summer run stocks*[2,6,7,8,9,10].

2. Fisheries

While the total fisheries exploitation rate of Southern chum salmon is uncertain given the uncertainty associated with the escapement and catch time series from which exploitation rates are derived, the estimated changes across years should be representative of underlying trends.

From 2010 to 2019, the average total catch of Southern chum, including hatchery-reared fish, was around 1.9 million, representing an average exploitation rate of 43%. This represents an average increase of 5% compared to the previous 10 years. Between 2009 and 2018, the average harvest rate of ISC stocks was 34%. Over the same period, the average harvest rate in Johnstone Strait fisheries was 16.35%[2], which is below the maximum allowable exploitation rate of 20% when the abundance of ISC stocks is determined to be above 1 million.

For Washington Summer chum stocks, the average harvest rate in the last 10 years has been 7% and in 2019 it was 5%[2]. The average harvest rate of Washington Fall and Winter chum stocks over the last 10 years was 64% and 24% respectively. On average ninety percent of US chum catches are taken in Puget Sound, while the Area 4B, 5, 6C and Area 7, 7A account respectively for 0.5% and 7%.

[6] Pacific Salmon Commission Joint Chum Technical Committee. 1988. Historical Canadian and United States chum salmon data report for the years prior to 1985. Report TCCHUM (88)-1.

[7] Pacific Salmon Commission Joint Chum Technical Committee. 1994. Final 1992 post season summary report. TCCHUM (94)-1.

[8] Pacific Salmon Commission Joint Chum Technical Committee. 1996. Final 1993 post season summary report. TCCHUM (96)-1.

[9] Pacific Salmon Commission Joint Chum Technical Committee. 2003. Final 1994-2001 post season summary report. TCCHUM (03)-1.

[10] Pacific Salmon Commission Joint Chum Technical Committee. 2010. 2007 post season summary report. TCCHUM (10)-1.

Fisheries directed at Fall chum salmon may have potential bycatch of Chinook, coho and steelhead. Earlier in the season (July-September), chum salmon, and especially Summer run chum, may be caught as bycatch in fisheries directed at sockeye and pink salmon[11] or Chinook and coho salmon[12].

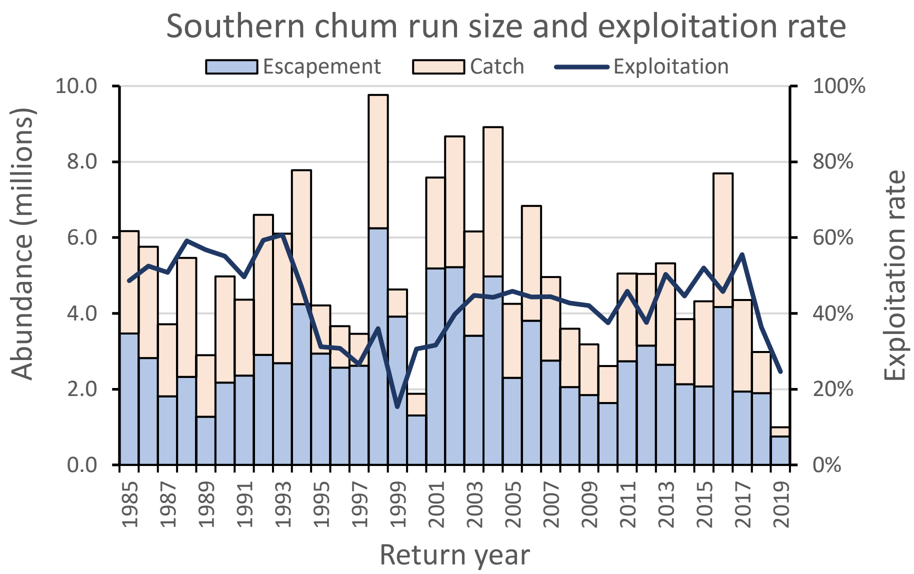

Figure 2. *Total chum escapement, catch and exploitation rates in Southern British Columbia and Washington State (1985-2019), excluding BC Summer run stocks[2,8,9,10].*

GEAR SECTORS

Canada:

- Johnstone Strait (Pacific Fisheries Management Areas or PFMAs 11-13):
  - Purse seine test fishery (Double Bay/Blinkhorn)
  - Commercial: purse seine, gillnet and troll
  - Recreational fisheries
  - First Nations fisheries
- Strait of Georgia:
  - Purse seine test fishery
  - Commercial: purse seine, gillnet and troll
  - Recreational fisheries
  - First Nations fisheries
- Fraser River (PFMA 29):
  - Gillnet test fisheries (Albion, Whonnock, Cottonwood)
  - Commercial: gillnet
  - Recreational fisheries
  - First Nations fisheries

[11] Tynan, T. 1997. Life history characterization of summer chum salmon populations in the Hood Canal and eastern Strait of Juan de Fuca regions. Tech. Rep. H97-06, 99 p. Wash. Dep. Fish and Wildlife, Olympia, WA.
[12] Tynan, T. 1992. Hood Canal early chum harvest and escapement assessment: A review of Hood Canal early chum escapements and inside Hood Canal commercial net fishery harvests (1969-91) with recommendations for short and long term management measures to assist stock rebuilding. Internal Rep., 57 p. Wash. Dep. Fish Wildlife., Olympia, WA.

- West Coast Vancouver Island (WCVI PFMAs 20-27, 121-127):
  - Commercial: purse seine, gillnet and troll
  - Hatchery directed gillnet and purse seine fishery in Nitinat (Area 21/22)
  - Limited-entry fishery in Nootka Sound (Area 25) and Kyuquot Sound (Area 26) and other terminal areas
  - First Nations FSC fisheries in all WCVI areas
  - Recreational fisheries
- Strait of Juan de Fuca fisheries (Area 20):
  - Research fisheries
  - Recreational fisheries

U.S.:

- Strait of Juan de Fuca fisheries (Areas 4B, 5, 6C):
  - Research fisheries
  - Tribal gillnet fisheries
  - Recreational fisheries
- San Juan Islands/Point Roberts fisheries (Areas 7 and 7A):
  - Tribal gillnet, purse seine and reef net fisheries
  - Non-tribal gillnet, purse seine and reef net fisheries
  - Recreational fisheries
- South Puget Sound fisheries (Areas 9, 10, 11, 13 and 13A-K)
- Hood Canal fisheries (Areas 12, 12B and 12C):
  - Tribal gillnet, purse seine and reef net fisheries
  - Non-tribal gillnet, purse seine and reef net fisheries
  - Recreational fisheries

INTERCEPTION BY OTHER FISHERIES

Chum may be encountered as bycatch in fisheries directed at other salmon species such as sockeye and pink salmon. Summer run chum salmon are the most vulnerable to interception by other fisheries given their earlier run-timing compared to Fall and Winter chum salmon.

FISHERY CHALLENGES

The main challenge with the mixed-stock fishery is there are several different chum populations, all of varying productivities, that co-migrate. The management strategy in Johnstone Strait uses a fairly conservative 20% harvest rate to help with that issue and supports more terminal harvest management. In recent years, constraints with Interior Fraser River (IFR) steelhead have further reduced the mixed-stock fishery in Area 12 and in the Fraser River. In the Fraser River, the chum-directed fisheries have been managed to reduce impacts on co-migrating IFR steelhead by adjusting the timing and duration of fisheries. Since 2019, a window closure has been applied to fisheries along the IFR steelhead migration route. This closes the commercial gillnet and seine fisheries for 42 days and FSC and commercial troll fisheries for 27 days, which greatly reduces the opportunity to harvest chum salmon during the peak of their migration.

Recent genetic stock identification (GSI) analyses in South Puget Sound have shown that a proportion of the Fall chum caught in the test fishery at Apple Cove Point, as well as the commercial harvest of Areas 10 and 11 are not local to South Puget Sound, with many originating in Hood Canal. Since the catch-per-unit-effort in these fisheries is used in in-season abundance estimation models for the South Puget Sound run, the influence of non-local stocks has the potential to inflate in-season run size estimates. The non-local contribution is variable across years, but not well-correlated to the relative abundances of the runs to Hood Canal and South Puget Sound. Alternative test fishery locations and real-time GSI analyses are currently being explored.

Fisheries directed at Fall chum salmon in the U.S. are designed to avoid Winter run chum salmon from the Nisqually River, which is a unique stock of conservation concern in South Puget Sound. Improvements in the baseline for South Puget Sound indicated that the majority of Winter run chum caught in the mixed-stock fisheries in Area 10 and 11 in Sound Puget Sound were predominantly Diru Creek hatchery chum salmon, rather than Nisqually chum salmon[5]. While the Diru Creek broodstock originated from the Nisqually River, over time the broodstock selection has resulted in earlier timing in comparison to the timing of the Nisqually River stock.

3. Management

Southern British Columbia and Washington State Chum stocks caught in mixed-stock fisheries are the responsibility of the Southern Panel, as well as regional management authorities, including DFO in Canada, and the Washington Department of Fish and Wildlife and the Northwest Treaty Tribes in the US. Management of mixed-stock fisheries in Hood Canal, South Puget Sound, as well as terminal fisheries fall outside the Treaty agreement.

Canada's Wild Salmon Policy[13] documents the strategic plan for Canadian wild Pacific salmon stocks. The implementation of this plan requires, among other things, identifying Conservation Units (CU) and upper and lower benchmarks to monitor the status of each CU[14,15]. In the U.S., strategic plans for the management of Southern chum salmon focus on the recovery plans associated with the federal Endangered Species Act[4].

The Pacific Salmon Treaty defines the management objectives and the harvest control rules for Southern chum stocks in the Johnstone Strait mixed-stock fishery and the Fraser River chum fishery in BC, and in Area 7 and 7A in the U.S. Canada's anticipated pre-season fisheries management plan for Southern chum fisheries, including the those mentioned in the Treaty, is documented annually in the salmon Integrated Fisheries Management Plan (IFMP)[16]. For the U.S., the North of Cape Falcon process results in a List of Agreed Fisheries (LOAF)[17], including fisheries directed at chum salmon. This LOAF represents the results of negotiations between the Washington Department of Fish and Wildlife and the Northwest Treaty Tribes during North of Falcon and Pacific Fisheries Management Council (PFMC) planning meetings.

[13] DFO. 2005. Canada's policy for conservation of wild Pacific salmon. Fisheries and Oceans Canada, Vancouver, B.C.

[14] Godbout, L., Irvine, J.R., Bailey, D., Van Will, P. & McConnell, C. (2004). Stock status of wild chum salmon (Oncorhynchus keta) returning to British Columbia's central coast and Johnstone and Georgia Straits (excluding the Fraser River). DFO Can. Sci. Adv. Secret. Res. Doc. 2004/007:45p.

[15] Holt, C.A., Davis, B., Dobson, D., Godbout, L., Luedke, W., Tadey, J., and Van Will, P. 2018. Evaluating Benchmarks of Biological Status for Data-limited Conservation Units of Pacific Salmon, Focusing on Chum Salmon in Southern BC. DFO Can. Sci. Advis. Sec. Res. Doc. 2018/011. ix + 77 p.

[16] DFO. 2020. Integrated Fisheries Management Plan June 1, 2020 - May 31, 2021. Salmon Southern BC. Fisheries and Oceans Canada.

[17] 2021-2022 co-managers' List of Agreed Fisheries (May 1, 2021 – May 14, 2022). Northwest Indian Fisheries Commission and Washington Department of Fish and Wildlife, Olympia, WA.

The Treaty does not make specific reference to chum management units but Johnstone Strait, Strait of Georgia and the Fraser River chum stocks are collectively managed as Inside Southern Chum (ISC) stocks[18]. In addition, the Treaty makes special reference to the Fraser River terminal run size.

According to the Treaty[18], Canada shall manage its fisheries in such a way as to allow rebuilding of depressed naturally spawning chum stocks and limit harvest of U.S. chum stocks. Any stock-specific surpluses identified, must be taken in terminal fisheries to minimise the impact on non-target stocks. To achieve this, specific management measures are described for the Johnstone Strait mixed-stock chum fishery, for the Fraser River chum fishery and for the fisheries directed at hatchery-reared Nitinat chum:

- If the run size of Inside Southern Chum (ISC) is less than the Critical Threshold of 1 million, Canada shall only conduct assessment and non-commercial fisheries in Johnstone Strait. If the Critical Threshold of 1 million is exceeded, Canada shall limit the Johnstone Strait exploitation rate of ISC stocks to 20%.
- If the in-season Fraser River terminal area run size is lower than 900,000, Canadian commercial chum fisheries within the Fraser River and associated marine areas (Area 29) shall be suspended. If the in-season terminal run size exceeds 900,000, Canada will set commercial Total Allowable Catch limits.
- For fisheries targeting hatchery reared Nitinat chum salmon, Canada shall minimize the harvest of non-target stocks.
- In the Area 20, Canada requires the live release of chum salmon from purse seine fishing gear from July 1 to September 15.

The treaty specifies the following for the U.S. fisheries in Areas 7 and 7A and in the Strait of Juan de Fuca (U.S. areas 4B, 5 and 6C):

- If the run size for the ISC stock group is less than the Critical Threshold of 1 million, the U.S. catch of chum salmon in Area 7 and 7A shall be limited to incidental catch in fisheries directed at other species or to minor fisheries, with total catches limited to 20,000 chum.
- If the ISC run size exceeds the Critical Threshold of 1 million, the U.S. catch in Area 7 and 7A is limited to 125,000 chum, unless the in-season run size for Fraser River chum is lower than 1,050,000 or exceeds 1.6 million. In case of the former, the U.S. catch in Area 7 and 7A is restricted to an additional 20,000 chum from the day following the date the U.S. is notified. In case of the latter, the catch ceiling is increased to 160,000 chum. Canada will provide a run size estimate of chum salmon entering the Fraser River no later than October 22 of each year.
- In addition, U.S. commercial fisheries directed at chum salmon shall not occur prior to October 10 and from July to September 15, purse seine and reef net fisheries in the Strait of Juan de Fuca and Areas 7 and 7A directed at other species require the live release of chum salmon.

[18] PSC. 2020. Treaty between the government of Canada and the government of the United States of America concerning Pacific salmon. PSC, Vancouver.

- In the Strait of Juan de Fuca (areas 4B, 5, 6C), the U.S. shall maintain and monitor the limited fishing effort on chum salmon and, to the extent practical, not increase catches of Canadian chum salmon in this fishery.

MANAGEMENT CHALLENGES

The majority of Southern chum stocks are fall timed. There are summer- and winter-timed chum stocks but these are not actively targeted in fisheries. Chum fisheries are managed to avoid these stocks, resulting in impacts to these stocks being primarily from bycatch in fisheries directed at other comigrating species[16].

In recent years, the outlook for Fraser chum salmon has been consistently average to below average and in 2019, the Fraser River chum run size in-season was estimated to be substantially below 900,000 salmon needed to allow for Canadian commercial fishing opportunities[19]. Also in 2021, preliminary run size estimates for Fraser River chum indicated the second lowest return in a decade, well below the critical threshold.

For ISC stocks, one factor contributing to low chum production in recent decades is low marine productivity[20, 21]. In addition, chum salmon appear to directly and/or indirectly compete for food in the marine environment with pink salmon[22]. Chum salmon stocks that interact with pink salmon in the marine environment seem to exhibit strong even and odd year variation in abundance, size and productivity due to ocean conditions and competition with pink salmon, which are much more abundant in odd versus even years[23].

Productivity of Washington chum salmon seems to have declined in recent years[23,21]. Individual chum stocks in North and South Puget Sound have not consistently reached escapement goals over the past 10 years. While substantial habitat restoration actions have been undertaken for the ESA-listed summer chum stocks, it is unclear to what extent they will be able to counter the effects of reduced marine survival[4].

The PST language has very explicit breakpoints that determines the management measures, but these breakpoints remain fixed and cannot be changed given the current Treaty agreement. Even if the Chum Technical Committee determines that breakpoints should be adjusted based on recent trends in productivity, there is no mechanism in the Treaty to enact it.

A primary challenge with the publication of Technical Committee annual reports for chum salmon revolves around the data needed for assessments of Southern chum. As chum salmon are the latest-returning salmon, escapement monitoring often occurs into January, which delays the final reporting until July/August. Catch estimates are also typically not finalized until the summer of the following year. In addition, results of Southern Endowment Fund projects are typically not available until the summer or fall

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[19] DFO 2019. Fisheries notices

[20] Van Will, P., Brahniuk, R., Hop Wo, L. and Pestal, G. 2009. Certification Unit Profile: Inner South Coast Chum Salmon (Excluding Fraser River). Can. Man. Rep. Fish. Aquat. Sci. 2876: vii + 63p.

[21] Malick, M.J. and Cox, S.P. 2016. Regional-Scale declines in productivity of pink and chum salmon stocks in western North America. PLoS ONE 11(1): e0146009.

[22] Ruggerone, G.T., and Nielsen, J.L. 2004. Evidence for competitive dominance of Pink salmon (*Oncorhynchus gorbuscha*) over other Salmonids in the North Pacific Ocean. Rev Fish Biol Fish 14:371-390.

[23] Litz, M.N.C., Agha, M., Dufault, A.M., Claiborne, A.M., Losee, J.P. and Anderson, A.J. 2021. Competition with odd-year pink salmon in the ocean affects natural populations of chum salmon from Washington. Mar. Ecol. Prog. Ser. 663: 179-195.

the following year. Chum Technical Committee annual reports therefore lag behind by one year in terms of the need to provide timely annual assessments. Preliminary estimates for some fisheries and escapements are usually available in January/February. While there have been recent efforts to complete analyses faster, it is likely this time lag in final reporting will always exist due to the nature of the species and associated fisheries.

4. Assessments

The assessment of Southern chum stocks includes the use of annual qualitative or quantitative pre-season forecasts and in-season assessments, as well as the use of management tools such as reference points, harvest control rules, and escapement goals.

PRESEASON FORECAST

For chum stocks in Southern BC, the practice of providing quantitative preseason forecasts has been discontinued in recent years due to insufficient years of suitable forecast data and a management approach for Southern chum designed to respond to in-season abundance estimates[24]. In addition, the survival and maturation rates for chum salmon are very variable[25,26] and the resulting forecasts are relatively inaccurate compared to pre-season forecasts for other species. Instead of relying on quantitative forecasts, fisheries managers are provided with qualitative forecasts of expected returns based on expert assessment of brood year returns, relative contributions of hatchery and wild stock components as well as freshwater and ocean survival conditions[16]. The categorical outlook produced for these stocks compares the expected spawning abundance to past years of observations. Four different outlook categories exist, as defined by the percentiles of the historical time series: well below average (category 1, <25th percentile), below average (category 2, 25-40th percentile), Near average (category 3, 40 to 60th percentile) and abundant (category 4, >60th percentile). For example, in 2020, the forecast for ISC chum stocks was classified as below average (2) while for WCVI chum it was below average to near average (2 and 3). Quantitative preseason forecasts are, however, produced for enhanced chum stocks such as chum salmon in Area 14. Chum stocks returning to Area 14 have been enhanced since the 1960s and terminal fisheries target these enhanced chum populations. The forecasts for Area 14 chum are important to guide fisheries decisions in that area and are based on brood year escapement, average survival and age composition[2]. Similarly, pre-season forecasts for the Nitinat system (predominantly enhanced) are based on brood year escapements, hatchery smolt output and estimated survival rates[16]. Forecasts are also provided from some key terminal harvest areas in the Strait of Georgia including the Nanaimo, Cowichan, Goldstream, and some key stocks in Jervis Inlet.

For Washington chum stocks, several different forecast methods have been evaluated and are applied annually[27]. For major natural Summer, Fall, and Winter run chum stock aggregates in Hood Canal and Central/South Puget Sound, a Generalized Additive Model (GAM) is used to estimate time trends in recruits/spawner. This model integrates density dependent effects with ocean indicators. For the density

[24] Grant, S. and G. Pestal. 2009. Certification Unit Profile: Fraser River Chum Salmon. Can. Man. Rep. Fish. Aquat. Sci. 2874: vii + 40p.
[25] Thorson, J.T., Jensen, O.P. and Zipkin, E.F. 2014. How variable is recruitment for exploited marine fishes? A hierarchical model for testing life history theory. Can. J. Fish. Aquat. Sci. 71: 973-983.
[26] Haeseker, S.L., Peterman, R.M., Su, Z. and Wood, C.C. 2008. Retrospective evaluation of pre-season forecasting models for sockeye and chum salmon. N. Am. J. Fish. Manag. 28(1): 12-29.
[27] Agha, M. March 2022. Personal communication.

dependent effects, both pink and chum brood year escapement are used in the model. A range of different datasets were used to train the model, including the full time series back to 1968, starting the time series after 1990, removing outliers, etc. Model performance to predict the next year's chum abundance is evaluated using a one-step-ahead approach for the most recent 5 years of return estimates and model selection is based on the lowest mean absolute percent error. Forecasts for hatchery chum and smaller stock aggregates incorporate a variety of methods, including average returns-at-age-per-pound released, fry based, ocean indicator based, or based on the average of the last 3 return years.

IN-SEASON ASSESSMENTS

Both Canadian and Washington chum stocks are assessed in-season using catch per unit effort (CPUE) data collected from test fishing as well as commercial CPUE data, when available.

In-season assessment of the run size for ISC stocks relies on CPUE data collected by the Johnstone Strait test fishery in Area 12. These time series are relied upon to produce relative abundance indices as well as estimates of migration timing (peak and spread) and stock composition estimates[16]. The test fishery data in combination with information from commercial openings are used to determine the likelihood of reaching the critical threshold levels for ISC stocks[2]. Other biological information (e.g., size, sex, age) is collected from the test fishery and commercial samples.

In-season assessments of the terminal Fraser River chum run relies on catch data collected by the Albion gillnet test fishery to estimate the run size and timing of Fraser River chum stocks. Estimates are available every other day from September 1 to October 20 and subsequently every day until November 10, then every other day until approximately November 23. A Bayesian in-season assessment model is used to estimate the terminal run size, peak migration timing, and spread of the run. The prior probability distributions for the run size, timing, spread and catchability are based on the median and CV of historical estimates and may change year to year. The distribution for catchability is not updated in-season.

In-season assessment of the strength of the chum salmon run to other areas in BC is assessed based on early catch information, visual observations at river estuaries and escapement counts[11] and allows to determine potential surpluses for fisheries.

Both the Hood Canal Fall and Puget Sound Fall chum stocks are assessed in-season using in-season update (ISU) models. The ISU model for Hood Canal relies on fishery-dependent data to estimate the total run size. More specifically, the model relies on the relationship between the cumulative CPUE of the non-Treaty purse seine fleet in Hood Canal to estimate the total run size[28]. Because fishery-dependent models are of limited use when fisheries are constrained due to conservation concerns, the in-season assessment of Hood Canal Fall Chum Salmon may incorporate fishery-independent data in the future[29]. For South Puget Sound, ISU models based on the Apple Cove Point (ACP) test fishery are used to assess the run size. This test fishery is located on the Area 9/10 border and provides weekly CPUE information from statistical week 41 to week 46. When available, alternative ISU models based on CPUE of the non-Treaty purse seine fleet in Areas 10 and 11 have also been used for in-season assessments, although recent changes in the structure of that fishery, including limited entry, have rendered these models less useful.

[28] Dufault, A. 2016. Hood Canal Escapement and Run size; Fall Chum Salmon. Washington Department of Fish & Wildlife, 600 Capitol Way N, Olympia, WA.
[29] Addae, K. 2020. Area 9 Test fishing proposal. WDFW, Olympia.

Improvements could be made to the current in-season assessments, and this has been highlighted as a need for the new (2019) Treaty implementation.

REFERENCE POINTS, HARVEST CONTROL RULES AND ESCAPEMENT GOALS

The harvest control rules for ISC stocks are well defined by the Treaty language and further details are provided by the decision guidelines in the IFMP. Overall, the exploitation rate is set at 20% across all Johnstone Strait fisheries targeting Fall run chum stocks. Of the 20%, 15% is provided for commercial fisheries and 5% is set aside for test fisheries, FSC fisheries and recreational harvest. If the ISC run size is below the critical threshold of 1 million fish, commercial fisheries are suspended and only assessment and non-commercial fisheries take place. The fixed harvest rate is implemented based on effort, time and area and assumes normal fleet participation (recent year's maximum effort or trends in effort). Fishing schedules and exact fishing dates are confirmed pre-season based on consultation with industry, First Nations and stakeholders.

Because chum stocks in Southern BC do not have reliable time series of recruit data, these stocks are considered data limited[15]. As a result, Upper and Lower Fishing reference points for ISC stocks were developed using the sustainable escapement goal (SEG) approach[30], which uses the long-term escapement time series to set fisheries reference points. Conservative sustainable escapement goals are defined as the 25th and 75th percentiles of the long-term escapement time series and are considered proxies for determining a range of escapement around S_{MSY}[31]. The Limit Reference Point for the Inside Southern Chum aggregate is 1 million[16]. ISC terminal fisheries are managed to spawning goals at a more local level than the conservation units identified under the Wild Salmon Policy.

The current in-season escapement goal for chum salmon within the Fraser River is 800,000 wild fish[24]. This estimate is based on stock-recruit analyses executed in the 1990s that estimated that on average 800,000 chum spawners are needed to maximize the sustainable yield (S_{MSY}) of Fraser River chum salmon. This escapement goal was first adopted in 1999 but the uncertainty associated with this estimate was substantial (80% confidence interval: 500,000-2.5 million).

Management of Washington Chum stocks is based on escapement goals and terminal fishing needs. Escapement goals have not been updated since the 1960s or 1970s, and doing so will require run reconstructions going back to the mid-1990s and genetic stock identification information[17]. For South Puget Sound, the co-managers have recently developed additional abundance-based reference points designed to allow more fish to reach terminal areas in low abundance years.

Escapement goals and reference points for Southern chum stocks should be revisited to confirm they are still accurate and meet management objectives.

[30] Bue, B.G. and Hasbrouck, J.J. 2001. Escapement goal review of salmon stocks of Upper Cook Inlet. Alaska Department of Fish and Game, Report to the Alaska Board of Fisheries, Anchorage.
[31] Clark, R.A., Eggers, D.M., Munro, A.R., Fleischman, S.J., Bue, B.G. and Hasbrouck, J.J. 2014. An evaluation of the percentile approach for establishing sustainable escapement goals in lieu of stock productivity information. Alaska Department of Fish and Game, Fishery Manuscript No. 14-06, Anchorage.

MANAGEMENT STRATEGY EVALUATION

Over the years, there have been different efforts (including but not limited to modelling) to assess aspects of the assessment and management framework but there has not yet been a concerted effort to conduct a Management Strategy Evaluation for Southern BC and Puget Sound chum salmon stocks.

The fixed harvest rate approach in Johnstone Strait, first initiated in 2002, has been assessed through modelling[16]. The underlying model assumptions were based on mark-recapture analyses to estimate harvest rates, fleet efficiencies, and migration rates of Chum through the mixed-stock fishing area. Based on the modelling results, it was agreed that harvest rates would be limited to a more cautious level of 20% implemented through a fixed effort approach, with two seine openings and limited gill net and troll opportunities through the month of October. While cautious in the mixed-stock areas, it was evaluated that this approach provided more stable harvest opportunities compared to the previous stepped harvest rate approach (also known as Clockwork). More specifically, it is designed to be robust in the face of the large annual variability in chum abundance, to account for differences in productivity among stocks, and to stabilise Johnstone Strait fishing opportunities[20]. The fixed harvest rate approach evaluation was not done using a closed-loop simulation.

The use of sustainable escapement goals based on percentiles of historical escapement data as biological benchmarks under Canada's Wild Salmon Policy has been evaluated by comparing them to stock-recruit based benchmarks. This evaluation has been done both through a retrospective analysis as well as through simulations under different future scenarios which included different scenarios of stock productivity and harvest[15]. Results supported the use of percentile-based benchmarks for data-limited stocks when productivity is moderate to high and harvest rates are moderate to low. The use of percentile benchmarks under low productivity scenarios required further evaluations.

For Puget Sound Chum stocks, the co-management process involves annual reassessment of the management strategy and development of a comprehensive Chum management plan is ongoing.

DATA LIMITATIONS

The ISC chum stocks are considered data-limited. While escapement data have been collected for many stocks since 1953, several of the time series are incomplete due to gaps in the data. In addition, the quality of the recruitment data is not considered reliable enough to derive stock-recruit relationships. This impacts both pre-season forecasts as well as the derivation of benchmarks based on stock-recruitment relationships[15]. In response, a run reconstruction model is being developed, ChumGEM (Chum Genetic and Environmental Management Model), currently covering 10 Fall Genetic Units (GUs) as well as chum salmon fisheries in Southern British Columbia and Puget Sound, Washington[32]. Once completed, the model is expected to produce GU-specific estimates of daily abundance, timing and exploitation rates. In addition, the model could potentially be used for management strategy evaluations (MSEs) but there is no formalised process yet to consider a traditional MSE.

One important data gap currently is the diversion rate of chum salmon through Juan de Fuca Strait compared to Johnstone Strait[17]. Until recently, in-season assessments focused on the use of CPUE from the Johnstone Strait test fishery but similar structured test fishery sampling for chum salmon had not been

[32] Li, L., Jenewein, B. and Van Will, P. 2019. Modifications to the chum genetic and environmental management model (ChumGEM), a run reconstruction model. Annual Report for the PSC Endowment Fund.

undertaken in Juan de Fuca Strait. This is currently being remedied through a multi-year project involving the operation of an additional sampling program in Juan de Fuca Strait and the collection of CPUE data and biological samples to determine stock composition, sex, age and length.

The implementation of the current management plan for Southern chum stocks requires the identification of individual stock groups, in particular ISC and Fraser chum stock. One major limitation has been the baseline to identify individual chum stocks within the catches. In the last few years, a concerted effort has been undertaken to add key chum salmon populations to the baseline, both wild and hatchery-reared, and increase the collection size for existing key populations with the aim to improve the ability to identify individual Southern chum stocks within mixed-stock fisheries.

ASSESSMENT CHALLENGES

Assessment and management of stocks at a finer stock resolution requires genetic stock identification information from commercial and test fisheries[17]. The Chum Technical Committee is in the process of updating the genetic baseline of Southern chum stocks with the goal to improve chum stock ID in mixed fisheries and to further improve the model to reconstruct chum abundance for Southern BC and Washington stocks.

INFORMATION CONVEYED TO MANAGERS/DECISION MAKERS

The implementation of the harvest control rules for Southern chum stocks requires an in-season run size estimate for ISC stocks as well as an evaluation of terminal abundance of Fraser River chum. In-season, Canada shall provide a Fraser River chum run size estimate by October 22 and will notify the U.S. of any updates to the run size estimate throughout the season. In-season run size information for ISC and Fraser chum stocks are provided to Canada's South Coast chum Advisory Committee which meets weekly in-season through conference calls.

5. Incorporating environmental data

The forecasts for Southern BC chum stocks rely on qualitative instead of quantitative methods. These forecasts consider Canadian coast-wide trends in chum returns as well as the expected impact of environmental conditions on chum survival. For example, in 2020, the outlook for Fraser River chum salmon was considered low because of the impact of the warm Pacific Ocean[16].

Coastal sea surface temperature (SST) and Pacific Decadal Oscillation (PDO) seem to explain a small proportion of the variation in total productivity of Southern chum stocks[33,34], and are the main environmental indicators used as part of the GAM models to forecast the run size of Washington chum stocks[27]. For the major components of the Fall chum run (Hood Canal, South/Central Puget Sound), average SST at Race Rocks from May till September of the outmigration years is used. For Summer run chum in South/Central Puget Sound, it is average SST in January to September at Race Rocks. For Summer run chum in Hood Canal it is based on an ensemble of multiple indicators including Pacific Decadal Oscillation (PDO) April to June and North Pacific Gyre Oscillation (NPGO) May to August.

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[33] Mueter, F.J., Pyper, B.J. and Peterman, R.M. 2005. Relationships between coastal ocean conditions and survival rates of northeast Pacific salmon at multiple lags. Trans Am Fish Soc 134:105-119.

[34] Malick, M.J., Cox, S.P., Mueter, F.J., Dorner, B. and Peterman, R.M. 2016. Effects of the North Pacific current on the productivity of 163 Pacific salmon stocks. Fisheries Oceanography 26(3): 268-281.

In-season assessments use environmental information qualitatively to inform management (e.g., low water levels or flooding results in more precautionary management), but this information is not incorporated into quantitative models. Some attempts have been made to explore correlations with environmental variables, but none have shown to be significant to date.

While environmental co-variates have been evaluated for North and Central BC Chum Salmon stocks[35], this methodology has not yet been applied to Southern BC and Puget Sound stocks, nor used to develop reference points[15]. In addition, environmental conditions during migration and spawning are not taken into account in quantitative determination of harvest control rules or escapement goals.

Changes in environmental conditions have been accounted for when evaluating different aspects of the management strategy, but a traditional quantitative MSE tool (i.e., closed-loop simulations) has not yet been used. Changes in environmental conditions could, however, potentially be explored within a MSE though ChumGEM.

6. Accounting for changes in productivity or survival

The qualitative forecast for chum stocks in Southern BC considers Canadian coast-wide trends in productivity. For example, the 2020 chum return to the Fraser River was expected to be low due to the low returns of Fraser River chum observed since 2017 which reflected below average productivity[16]. For Washington chum stocks, the GAM model accounts for non-linear trends in productivity/survival. In addition, models with and without a temporal autocorrelation structure have been evaluated[27].

Changes in productivity have been accounted for qualitatively in some in-season assessments but are not explicitly included in models.

Changes in productivity have been accounted for when evaluating the suitability of percentile-based benchmarks for data-limited Southern stocks[15]. Recommendations following this work, however, suggest that further evaluations are needed under the scenario of low productivity and/or high harvest rates, as under these conditions the percentile benchmarks may be more optimistic compared to benchmarks derived from stock-recruitment data.

Changes in productivity have been accounted for when evaluating different aspects of the management strategy, but a traditional quantitative MSE tool (i.e., closed-loop simulations) is not used.

7. Accounting for and conveying uncertainty

When uncertain about the qualitative forecast for BC chum stocks, the pre-season outlook will note more than one forecast category, e.g., average to below average returns. For Washington chum stocks, model uncertainty is accounted for by evaluating a range of different models, but the final forecast is based on the top-ranked model and the forecasts are communicated to managers in terms of point estimates.

In-season assessment of ISC and Fraser stocks indicate the probability that the run would exceed the critical thresholds. Quantitative in-season assessments of Puget Sound Fall chum abundances provide

[35] Godbout, L., Fu, C., and Irvine, J.R. 2006. Evaluation of Chum Salmon fishery performance using Ricker and Beverton–Holt stock recruitment approaches in a Bayesian framework. American Fisheries Society Symposium 49:1417-1433.

managers with both point estimates and ranges of confidence, which tend to be wide, but progressively tighten with each weekly assessment.

Uncertainty has been considered in the development of the management procedures given the data-limited nature of especially the BC chum stocks. The fixed harvest strategy of 20% in Johnstone Strait, in combination with terminal fisheries on stocks assessed in-season, limits the risk associated with this uncertainty. Similarly, the Fraser River escapement target of 800,000 has been deliberately selected to be more risk-averse[24].

Uncertainty has been explicitly accounted for in the data and population dynamics when evaluating the use of sustainable escapement goals based on percentiles of historical escapement data as biological benchmarks for data-limited stocks[15].

8. Ability to reach management objectives

Recent declines in productivity due to reduced marine survival has meant that in years like 2019 escapement goals are not being met for several Southern chum stocks, despite in-season management decisions requiring the closures of chum fisheries targeting these stocks.

9. Planned assessment and management changes to account for environmental change

In 2012, the Chum Technical Committee (Chum TC) developed a strategic plan regarding the assessment work needed to be undertaken in support of the implementation of Chapter 6 of the Treaty. This strategic plan included: 1) maintaining catch and escapement assessments conducted historically, 2) estimate stock composition and exploitation rates, 3) reviewing stock status and fisheries activities, 4) exchange information on productivity and escapement requirements, and 5) reporting on stock composition information. To implement this plan, the Chum TC submitted a series of Southern Endowment Fund (SEF) proposals. Currently, the Chum TC is in the process of renewing the strategic plan. Future plans include an evaluation of the extent that chum abundance and productivity is impacted by environmental variables and plans to request additional Southern Endowment funding. Many of the multi-year SEF projects are at or near completion as of 2023, and the SEF has indicated the intent of the funds is not for long-term funding of initiatives. The Chum TC intends to evaluate the future requirements of the work initiated through these projects, and will require discussions with the Commission about how to fund continuation of work identified as critical to successful implementation of Chapter 6.

PST Chapter 8: Yukon River Chinook and chum salmon

1. Introduction

Chapter 8 of the Pacific Salmon Treaty applies to Yukon Chinook and fall-run chum salmon originating in Canadian waters which make up approximately 41% and 25% of total Chinook and chum salmon production, respectively, from the entire Yukon River basin.

The Canadian-origin Yukon Chinook salmon stock aggregate is comprised of 10 provisional Conservation Units[1] which are in turn made up of over 100 unique spawning populations[2]. In the last 10 years, the adult run sizes of Canadian-origin Yukon Chinook ranged from 33,000 in 2021 to 97,000 in 2017[3]. The Canadian-origin Yukon fall chum salmon stock aggregate is comprised of 6 Conservation Units, not including the Fishing Branch Fall Chum, and spawning escapement in the last 10 years ranged from 23,000 in 2021 to 402,000 in 2017[3]. Note that the total run size for Canadian chum salmon is not estimated.

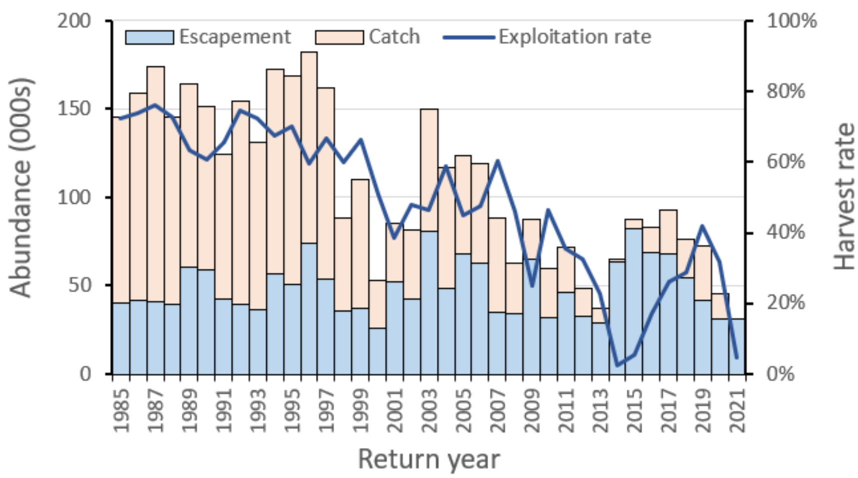

Figure 1. *Total Canadian-origin mainstem Yukon Chinook salmon spawning escapement, harvest and resulting harvest rate since 1985 to present[3].*

[1] Holtby, L.B., and Ciruna, K.A. 2007. Conservation Units for Pacific Salmon under the Wild Salmon Policy. DFO Canadian Science Advisory Secretariat Research Document 2007/070: 358.

[2] Brown, R.J., Finster, A. von, Henszey, R.J., and Eiler, J.H. 2017. Catalog of Chinook salmon spawning areas in Yukon River basin in Canada and United States. Journal of Fish and Wildlife Management 8(2): 558–586.

[3] JTC (Joint Technical Committee of the Yukon River U.S./Canada Panel). 2022. Yukon River salmon 2021 season summary and 2022 season outlook. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report No. 3A22-01, Anchorage

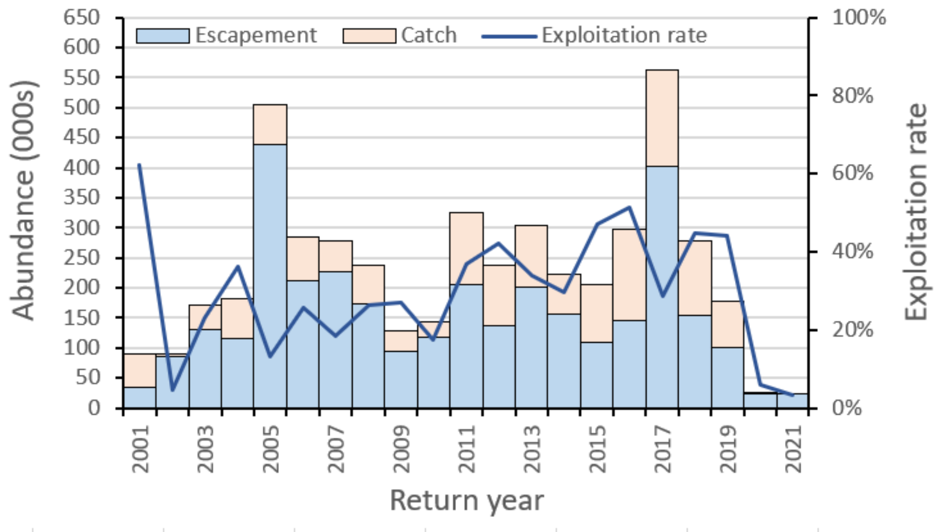

Figure 2. *Canadian-origin mainstem Yukon fall chum salmon spawning escapement, harvest and resulting harvest rate 2001 to 2021*[3].

2. Fisheries

Estimates of exploitation rates for Chinook salmon are available from 1985 to present. Over this period exploitation rates have averaged 50% and ranged from as high as 76% in the late 1980s to as low as 2% in the mid 2010s. Harvest over this same time period averaged in the 100,000s in the 1980s and 1990s, in the 50,000s in the 2000s and around 20,000 over the most recent decade (with a low of 2,300 fish in 2021). With the poor returns of Canada-origin fish in recent years and the conservative management regime, average exploitation rate of Canadian-origin Chinook salmon harvest in Alaska for the recent period of 2018–2022 has decreased to approximately 23% and was as low as 4% in 2021.

Fall chum salmon harvest in the Alaska portion of the Yukon River is difficult to assign to stock of origin and so total harvest of Canadian-origin mainstem Yukon chum salmon cannot be estimated with confidence. Estimated run sizes for the mainstem Yukon River in Canada and Fishing Branch River components include Canadian escapement plus Canadian harvests and ad hoc estimates for U.S. fall season harvests by applying 25%, to represent the Canadian mainstem component and 4% for the Fishing Branch River component.

These estimates of catch and exploitation rates do not account for incidental harvest of Chinook and chum salmon in Bering Sea/Aleutian trawl fisheries.

Canadian-origin Yukon Chinook are potential incidental in chum salmon fisheries and vice-versa.

GEAR SECTORS

U.S.:

- Alaska Yukon Coastal District and mainstem Districts 1-5 gillnet and fish wheel subsistence fishery
- Alaska Yukon recreational fishery
- Alaska Yukon Districts 1-5 gillnet and fish wheel commercial fishery

Canada:

- Mainstem Yukon River commercial gillnet fishery

- Mainstem Yukon River domestic gillnet fishery
- Mainstem Yukon River Food Social and Ceremonial gillnet fishery
- Porcupine River FSC gillnet fishery

INTERCEPTION BY OTHER FISHERIES

Yukon River salmon have the potential to be captured by fisheries that harvest mixed stocks of salmon (incidental harvest), other species of fish (as bycatch), and by illegal fishing activities (e.g., unmonitored fishing vessels in U.S. or foreign waters) throughout their oceanic distribution. Yukon River Canadian-origin salmon, are caught as bycatch in Bering Sea Aleutian Island groundfish fisheries along with other salmon stocks from Alaska, the west coast of Canada and the United States, eastern Asia, and Russia. Canadian-origin Chinook salmon comprise a relatively small percentage (2%–5%) of the total catch of Chinook salmon each year and are predominately captured as bycatch during their immature life-history stage and will spend one or more additional years in the ocean before returning to freshwater. Bycatch estimates that are adjusted for natural mortality, referred to as Adult Equivalent bycatch, suggest that on average (1994–2017) groundfish trawl fisheries harvest approximately 1% of the run, with a maximum of up to 3.1%[4].

FISHERY CHALLENGES

There is overlap in return timing between Canadian-origin and lower and middle Yukon River Chinook salmon stocks, as well as the summer chum salmon stock in Alaska. This overlap creates challenges for the management of mixed stock fisheries targeting combinations of these stocks in over 3 dozen communities in Alaska before Canadian-origin fish cross the border into Canada. The mixed-stock and broadly distributed nature of these fisheries for Chinook and fall chum salmon, coupled with the remoteness of the region, and extensive freshwater migration of Canadian stocks, make it challenging to impose gear restrictions and open and close fisheries in a manner that reduces harvest on low abundance stocks while permitting harvest on more abundant ones and ensuring sufficient Canadian-origin fish make it across the border into Canada to either be harvested in Canadian fisheries or spawn.

Fall season starts with the transition from summer to fall chum salmon components entering the river in mid-July followed by the overlapping coho salmon run that begins in August. Both summer chum and coho salmon mostly turn off into the Tanana River tributary with the remaining chum salmon stocks moving above the Tanana River confluence being primarily fall chum salmon of both U.S. and Canadian- origin. Fall chum salmon also enter the river in extreme pulses of abundance throughout the season resulting in protracted timing and without a normal distribution in the lower river thus making in-season projections more variable.

The Fishing Branch River origin fall-run chum salmon comprise a smaller component of the Yukon River drainage fall chum salmon run than the mainstem Canadian fall-run chum salmon, making it difficult to assess the run strength in-season and apply effective management actions. Genetic samples for mixed-stock analysis (MSA) are collected from chum salmon in the Lower Yukon at the mainstem sonar near Pilot Station. Fishing Branch River fall chum salmon are genetically distinct making up 2-4% of the drainage-wide fall chum salmon run, though confidence intervals are too variable to produce a reliable estimate due to the small component. Additionally, Fishing Branch River chum salmon typically arrive in each pulse

[4] Ianelli, J.N., and Stram, D.L. 2018. Chinook bycatch mortality update. Discussion paper presented to the North Pacific Fishery Management Council, April 2018

of fall chum salmon entering the river. Assessment challenges and salmon entry patterns of these stocks limit the effectiveness of management actions while fisheries are prosecuted to harvest abundant stocks in the mainstem Yukon River.

3. Management

Management of Chinook and chum salmon fisheries is the responsibility of the Alaska Department of Fish and Game (ADF&G) in Alaska and Fisheries and Oceans (DFO) in Canada. Management of Chinook salmon bycatch in Bering Sea/Aleutian trawl fisheries is the responsibility of the U.S. federal agency National Marine Fishery Service (NMFS). Alaska's strategic plan for Chinook and chum salmon is documented in its Policy for the Management of Sustainable Salmon Fisheries[5], while for Canada it is described by the Wild Salmon Policy[6]. Annual management plans for Alaska are documented in the Yukon River Drainage King Salmon Management Plan[7], the Yukon River Summer Chum Salmon Management Plan[8], and the Yukon River Drainage Fall Chum Salmon Management Plan[9] while Canada's annual management plans are described in the Annual Integrated Fisheries Management Plan[10].

Specific management objectives for Chinook or chum salmon are not detailed in Chapter 8 of the Pacific Salmon Treaty. However, in practice the overarching strategic management objective for Canadian-origin Yukon River Chinook and chum salmon are to prevent overfishing and provide for optimum production. This translates into tactical objectives that include: (1) achieve spawning escapement goals for each stock; (2) achieve targets for international sharing of the TAC as defined in the Treaty; and (3) achieve domestic allocation goals within each country.

Yukon Chinook salmon are managed as three management units: lower Yukon River, Middle Yukon River and Upper (Canadian) Yukon River. Chum salmon are managed as three management units: Canadian-origin fall-run chum salmon, Porcupine River fall-run chum salmon, and Alaskan fall-run chum salmon (Upper Yukon and Tanana River stocks).

MANAGEMENT CHALLENGES

The very large size of the Yukon River Basin (larger than 8 of the 13 Provinces or Territories in Canada and larger than all U.S. states except Alaska), declining run-sizes, concentration of the majority of fisheries in lower and middle mainstem and changing environmental conditions all contribute to management challenges. Each year, in-season run-size, by management unit and species, is first estimated at Pilot Station hydroacoustic site near the mouth of the river. Based on estimates of run size and timing, fisheries can then be opened in various sections of the river in Alaska, with subsequent passage of salmon into Canada, assessed at the hydroacoustic site at Eagle near the border with Alaska. Estimates of run-size at Pilot Station are includes uncertainties due to the detection range of the sonar that is used, and challenges associated with species apportionment. As a result, decisions to open or close fisheries upstream of Pilot

[5] Alaska Board of Fisheries. 2000. Policy for the Management of Sustainable Salmon Fisheries. 5 AAC 39.222.
[6] DFO. 2005. Canada's policy for conservation of wild Pacific salmon. Fisheries and Oceans Canada, Vancouver, B.C.
[7] Alaska Board of Fisheries. 1982. Yukon River Drainage King Salmon Management Plan. 5 AAC 05.360
[8] Alaska Board of Fisheries. 1990. Yukon River Summer Chum Salmon Management Plan. 5 AAC 05.362.
[9] Alaska Board of Fisheries, 1994. Yukon River Drainage Fall Chum Salmon Management Plan. 5 AAC 01.249
[10] DFO. 2020. Integrated Fisheries Management Plan July 1, 2020 – June 30, 2021. Yukon River, Y.T Chinook, fall chum, and coho. Fisheries and Oceans Canada.

Station are based on imperfect information and the true number of fish able to pass into Canada is not known until after all Alaskan fisheries have been prosecuted and assessment at the border occurs.

In recent years, differences in estimates of Chinook salmon between Pilot Station (198 route km, rkm) and Eagle (1941 rkm) have been relatively large (e.g., 33,000 fish in 2019) and coincided with elevated water temperatures along the migration route, physiological evidence of heat stress[11], observations of pre-spawn mortality[12]and increased level of *Ichthyophonus* disease in 2020 and 2021. These "missing" fish complicate manage decision about whether or not to open fisheries in the Alaskan portion of the river and make it more challenging to ensure border passage goals are met as declines in overall run-size occur.

4. Assessments

The assessment of Yukon River Chinook and fall chum salmon includes the use of annual pre-season forecasts, in-season assessments, as well as the use of escapement goals.

PRESEASON FORECAST

The Yukon River Joint Technical Committee develops annual preseason forecasts for both Canadian-origin Chinook and fall chum salmon. Chinook salmon are forecasted using three independent models weighted by forecast performance within an integrated Bayesian framework to derive a single probabilistic forecast of run size one year into the future[4]. The three models include a dynamic sibling model, spawner-recruitment model, and juvenile abundance model based on Northern Bering Sea surface trawl surveys. River basin wide chum salmon are forecasted using either sibling or spawner-recruitment models, and in some years, they are further adjusted based on average recent forecast performance (i.e., ratio of observed to predicted)[4]. The basin wide forecasts are then multiplied by 25% to forecast Canadian-origin chum salmon abundance based on mixed-stock genetic analyses that indicate, on average, approximately one quarter of total returning chum salmon are Canadian-origin.

IN-SEASON ASSESSMENTS

In-season daily abundance estimates are based on hydroacoustic, and drift gillnet test fishery data collected in the lower Yukon River at Pilot Station. These data are used to estimate daily fish passage, by species. Genetic mixed stock analysis is used to estimate in-season stock compositions of Chinook and chum salmon passage at the Pilot Station sonar using genotypes of samples collected from the test fishery operated for species apportionment. The mixed stock genetic analysis for Chinook salmon is done for temporal strata (approximately 2-3 weeks per strata) resulting in relative abundance and migration timing data to support in-season projections of total run size and management actions to meet border passage goals. For chum salmon, during the fall season strata are typically selected based on defining a pulse of fish (usually one per week ranging from 5-7 strata). These data provide fishery managers an important "first look" at salmon run strength and timing before those fish migrate through most Alaska fisheries.

[11] von Biela, V.R., Bowen, L., McCormick, S.D., Carey, M.P., Donnelly, D.S., Waters, S., Regish, A.M., Laske, S.M., Brown, R.J., Larson, S. and Zuray, S., 2020. Evidence of prevalent heat stress in Yukon River Chinook salmon. Canadian Journal of Fisheries and Aquatic Sciences, 77(12), pp.1878-1892.

[12] von Biela, V.R., Sergeant, C.J., Carey, M.P., Liller, Z., Russell, C., Quinn-Davidson, S., Rand, P.S., Westley, P.A. and Zimmerman, C.E., 2022. Premature mortality observations among Alaska's Pacific Salmon during record heat and drought in 2019. Fisheries, 47(4), pp.157-168.

Without these data, fishery managers would have no information about the Canadian-origin run until fish arrive at the Eagle sonar site, when most of the run has already passed through 1,900 km of fisheries.

In addition, a lower river test fishery (downstream of Pilot Station near Emmonak) is operated from May into September to assess salmon run timing and relative abundance. During the fall season, another test fishery based in Mt. Village (operated from mid-July into September) has also been used to assess run timing and relative abundance of chum and coho salmon and typically correlates better with passage at Pilot Station.

REFERENCE POINTS, HARVEST CONTROL RULES AND ESCAPEMENT GOALS:

Canadian-origin mainstem Yukon River Chinook and fall chum salmon are managed under the umbrella of the Yukon River Salmon Agreement (Chapter 8 of PST) and the Yukon River Panel meets annually to recommend escapement goals for Canadian-origin stocks to the Canadian and U.S. management agencies.

Since 2010, the Yukon River Panel has adopted an interim management escapement goal range for Chinook salmon that is not biologically based (i.e., not based on a production or population model). However, in recent years a multi-agency effort to develop an integrated Bayesian state-space run reconstruction and spawner-recruitment model fit to all available data has been undertaken[13]. The inference from this model (e.g., yield and recruitment probability profiles) has been used by the Yukon River Joint Technical Committee in 2022 to recommend a biologically-based aggregate escapement goal for the Yukon River panel to consider moving forward.

Similarly, the Yukon River Panel has adopted since 2010 an interim management escapement goal range for Canadian-origin chum salmon that is based on a historical estimate of spawners at maximum sustained yield plus or minus 20%.

MANAGEMENT STRATEGY EVALUATION

There has been no formal (i.e., undertaken by or with the Yukon River Panel or management agencies) evaluation of the long-term performance of alternative escapement goals or harvest control rules for Canadian-origin Yukon Chinook or chum salmon. However, there has been informal closed-loop simulation evaluation of Chinook salmon escapement goals[14] and chum salmon in-season management tactics[15]. A formal quantitative evaluation of the performance of alternative management strategies using closed-loop simulation as part of a Management Strategy Evaluation was recently recommended[13].

DATA LIMITATIONS

Suspected data limitation includes the influence of small-scale hatchery in Whitehorse on wild Chinook salmon assessment, uncertainty in harvest apportionment among Chinook stocks in Alaska and in harvest

[13] Connors, B.M., Bradley C.A., Cunningham C., Hamazaki T., and Liller, Z.W. 2022. Estimates of biological reference points for the Canadian-origin Yukon River mainstem Chinook salmon (*Oncorhynchus tshawytscha*) stock aggregate. DFO Can. Sci. Advis. Sec. Res. Doc. 2022/031. iv + 100 p

[14] Jones, M.L., S. Truesdell, J. Syslo, M.J. Catalano, and S. Fleischman. 2018. Developing tools to evaluate management strategies for sustainable exploitation of Yukon River Chinook Salmon. AYK-SSI Project Completion Report. 45 pp.

[15] Catalano, M.J. and Jones, M.L., 2014. A simulation-based evaluation of in-season management tactics for anadromous fisheries: accounting for risk in the Yukon River fall chum salmon fishery. *North American Journal of Fisheries Management*, *34*(6), pp.1227-1241.

estimation in both Alaska and Canada, a general lack of tributary level assessment data in Canada, and en route and pre-spawn mortality during extensive upstream adult freshwater migration.

In addition, fall chum salmon harvest in Alaska is unable to be assigned to stock of origin and so total harvest of Canadian-origin mainstem Yukon chum salmon is not estimated with confidence. To estimated run sizes for the mainstem Yukon River in Canada and Fishing Branch River components they include Canadian escapement plus Canadian harvests and application of assumptions for U.S. fall season harvests by applying 25%, to represent the Canadian mainstem component and 4% for the Fishing Branch River component.

ASSESSMENT CHALLENGES

There is a general lack of long-term and contemporary tributary level spawning ground assessment data in Canada. As a result, estimates of spawning escapement for Canadian-origin Chinook and chum salmon are based on assessments of border passage minus estimated fishery removals in Canada. These estimates assume that there is no en route or pre-spawn mortality which, with recent observations of elevated water temperatures along the migration route, heat stress[11], and pre-spawn mortality[12], is becoming an increasingly tenuous assumption, and may lead to overestimation of escapement.

Chinook and chum salmon that spawn in the Canadian portion of the Yukon River drainage are currently treated as single homogeneous population complexes. However, Yukon Chinook[3] and chum salmon spawn in hundreds of streams within the watershed. These spawning populations have likely adapted traits related to their specific spawning and rearing locations which in turn contribute to variability in intrinsic productivity and sustainable harvest rates among populations (for an example with Chinook salmon, see[16]). This heterogeneity in population productivity and size complicates management because the higher harvest rates that can be sustained by the most productive populations come at the risk of overfishing and potential extirpation of the less productive populations. In addition, an uneven distribution of these populations among watersheds may lead to uneven impacts of aggregate management across the communities that rely upon salmon for subsistence and cultural needs[17].

The age at maturity of female Chinook salmon, and to a lesser extent the proportion of females in the spawning population, have declined over time[13]. These demographic changes have likely resulted in declines in potential measures of per capita reproductive output such that for the same number of spawners, early years (1980s) produced above average total eggs or eggs mass, whereas recent years (2010s) produced below average total eggs and egg mass. Failure to account for demographic change can

[16] Connors B.M., Siegle M., Harding J., Rossi S., Staton B., Jones M., Bradford M., Brown R., Bechtol B, Doherty B., and S. Cox. In press. Chinook salmon population diversity contributes to fishery stability and tradeoffs with mixed-stock harvest in the Yukon River. Ecological Applications.

[17] Connors B.M., Staton B., Coggins L., Walters C., Jones M., Gwinn D., Catalano M. and S. Fleischman. 2020. Incorporating harvest – population diversity trade-offs into harvest policy analyses of salmon management in large river basins. Canadian Journal of Fisheries and Aquatic Sciences. 77: 1076-1089

result in biased reference points[18] and undermine management performance. Yukon chum salmon have also experienced declining size over time[19].

INFORMATION CONVEYED TO MANAGERS/DECISION MAKERS

Preseason, the Yukon River Panel and U.S. and Canadian management agencies are provided preseason forecasts of run size, by species and management group.

In-season, throughout most of the fishing season, the Yukon River Drainage Fisheries Association facilitates weekly teleconferences to provide managers, fishermen, tribal/traditional council representatives, and other stakeholders the opportunity to share information, provide input, and discuss in-season management options. During these weekly teleconferences, assessment staff of U.S. and Canadian management agencies provide in-season run assessment information from various assessment projects. During these calls U.S. and Canadian managers also relay information about management strategies and subsistence fishermen report on river conditions in their respective communities along the river.

5. Incorporating environmental data

Environmental information is not directly used to forecast run size but is indirectly incorporated into preseason forecasts of run size by either accounting for the effects of environmental conditions on survival across the full life cycle for earlier returning age classes (sibling models) or freshwater rearing and early marine life stages (juvenile model; Chinook salmon only).

In addition, in some years chum salmon forecasts are adjusted based on average recent forecast performance which is another way that recent environmental conditions, and their influence on recent survivals and returns, are indirectly accounted for.

Most environmental data are not quantitatively used in-season, but environmental conditions are monitored, and reported daily in the Yukon Daily Update email and weekly during teleconference calls. Water temperature and stream discharge information is tracked in-season and may be used to modify estimated timing of salmon arriving to upper river assessment projects. Wind patterns also affect salmon entry and magnitude of groups of fish (particularly fall chum salmon) in the Lower Yukon River. Timing and run strength information influences fishery openings and closures. At the end of the season both the U.S. and Canada provide a report on environmental conditions relevant to adult salmon migrating through Yukon River drainage. This includes examining weather records and stream discharge data in relation to historic records to identify anomalies and/or unusual events, and their implications for salmon.

Environmental data are not incorporated into reference points or escapement goals.

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[18] Staton, B.A., Catalano, M.J., Fleischman, S.J., and Ohlberger, J. 2021. Incorporating demographic information into spawner–recruit analyses alters biological reference point estimates for a western Alaska salmon population. Can. J. Fish. Aquat. Sci. 78(12): 1755–1769

[19] Oke, K.B., Cunningham, C.J., Westley, P.A.H., Baskett, M.L., Carlson, S.M., Clark, J., Hendry, A.P., Karatayev, V.A., Kendall, N.W., Kibele, J. and Kindsvater, H.K., 2020. Recent declines in salmon body size impact ecosystems and fisheries. Nature communications, 11(1), pp.1-13.

Formal closed-loop simulation evaluations of escapement goal and harvest policies (e.g., Management Strategy Evaluation) have not been undertaken, and informal ones that have occurred have not explicitly incorporated environmental data.

6. Accounting for changes in productivity

Changes in productivity are not explicitly accounted for in forecasts but are partially, and implicitly, captured on the models used to forecast run size by incorporating recent survival across the full life cycle from earlier returning age classes (sibling models) or freshwater rearing and early marine life stages (juvenile model; Chinook salmon only).

Changes in productivity are not explicitly accounted for in development of reference points and escapement goals. However, the influence of declines in female Chinook salmon age at maturity, and the proportion of females in the spawning population, both of which have likely resulted in declining reproductive potential and productivity, have been incorporated into exploratory escapement goal analysis for Canadian-origin Yukon Chinook salmon[13].

Formal closed-loop simulation evaluations of escapement goal and harvest policies (e.g., Management Strategy Evaluation) have not been undertaken in the system, and informal ones that have occurred, have not explicitly accounted for changes in productivity.

7. Accounting for and conveying uncertainty

The preseason forecast model for Chinook salmon uses Bayesian estimation methods and uncertainty in the forecast results is expressed in terms of a probability distribution for the 20th, 50th and 80th percentiles[3]. The median forecast (50th percentile) represents an equal chance (i.e., a one in two chance) that the return will fall either above or below the forecast value for each stock. In comparison, there is a one in five chance that the actual number of returning Chinook salmon will fall at or below the forecast associated with the 20th percentile.

The preseason forecasts for chum salmon relies on a Bayesian spawner-recruitment model and the forecast is expressed in terms of median and 80% probability interval.

In-season, uncertainty in run-size is estimated and conveyed. The mainstem Yukon River sonar projects operated at Pilot Station and Eagle both provide 90% confidence intervals around the daily passage estimates for Chinook and chum salmon. Genetic mixed stock analysis of chum salmon provides 95% confidence intervals around the estimated proportions by stock groups for each strata. No formal confidence intervals for fall chum salmon are included in the in-season projections but could be conveyed based on the uncertainty around the Pilot Station sonar estimates.

For Chinook salmon, a recent bilateral technical committee develop an integrated state-space run-reconstruction and age structured spawner-recruitment model is fit to data from assessment projects that estimate mainstem passage, harvests, tributary escapements, stock-proportions, and age-composition, under a single Bayesian estimation framework[13]. This approach explicitly accounts for uncertainty in estimates of spawning escapement, harvest and age composition, as well as intrinsic productivity and the carrying capacity of the stock. This uncertainty is conveyed through 95% probability intervals around reference points. In addition, yield and recruitment profiles, that integrate over these uncertainties, are used to develop escapement goal recommendation.

Formal closed-loop simulation evaluations of escapement goal and harvest policies (e.g., Management Strategy Evaluation) have not been undertaken in the system.

8. Ability to reach management objectives

Assessments of Canadian-origin Yukon Chinook and chum salmon indirectly account for some aspects of environmental and productivity changes. The management approaches in place have limited harvest of most Chinook and chum salmon in the past several years and maximized escapements even though escapement goals have not always been met. Realized escapements, however, may be lower than estimated ones in recent years due to en route losses. Reliance on genetic mixed-stock analysis (MSA) to assess the abundance of Canadian-origin Chinook and fall chum salmon stocks in the lower Yukon has improved the effectiveness of management actions to reach objectives.

Escapement levels may be lower than predicted due to pre-spawning mortality of Yukon for Chinook salmon in the Yukon River drainage. One source of mortality during in-river migration could be related the fish parasite *Ichthyophonus*. A collaborative research project, conducted by the U.S. Fish and Wildlife Service's (USFWS) Northern Alaska Fish and Wildlife Field Office and the Alaska Department of Fish and Game (ADF&G) from 2021-2023, is evaluating the prevalence and intensity of *Ichthyophonus* in Canadian-origin Chinook salmon at lower-, mid-, and upper-river sites within the U.S. section of the Yukon River. This study seeks to identify mortality trends throughout the river and in relation to various salmon demographics such as age, sex, size, and genetic stock composition. Moreover, estimates of pre-spawning mortality can be used to more accurately estimate expected escapement levels and to guide fishery management.

9. Planned assessment changes to account for climate change

In regard to yearly variation in Chinook salmon reproduction, a better understanding of the interactions among multiple pre-spawning mortality factors could provide more precise estimates of annual productivity. Beyond the influences of *Ichthyophonus*, studies evaluating the impacts of climate change, such as increasing water temperatures that cause heat stress and mortality in salmon, could provide insight on salmon migration and reproduction. With trends of warming environmental conditions, understanding the interplay among abiotic and biotic factors that hinder meeting escapement goals is crucial in developing sustainable management targets set to rebuild salmon stocks and increase salmon productivity.

Continued monitoring of environmental and productivity is important to evaluate future changes or abnormal events. The Yukon River Panel has included shifts in habitat, productivity, and other investigations of fall chum salmon as Restoration and Enhancement Fund (R&E) and Research and Management Assistance Fund (R&M) priority information needs for Canadian-origin fall chum salmon. Environmental conditions and extreme events may be considered in-season to inform management decisions regarding harvest opportunities.

Juvenile monitoring will continue to be used to help reduce the dimensionality inherent in productivity and guide pre-season assessments. Plans are in place to add a dynamic component to the juvenile Chinook salmon models to better accommodate environmental impacts on survival over time. Multiple research projects are underway to improve our understanding of how warming temperature in the northern Bering Sea is altering the early marine feeding ecology, growth, condition, and survival of Yukon River salmon. International research teams are currently conducting research on the impact of climate on the abundance, distribution, migration, and growth of salmon during the immature and maturing stages of salmon. These research initiatives will help provide a framework for understanding the impact of environmental conditions on Yukon River salmon during their marine life-history stage.