PSCTR.59

OVERVIEW OF PRE-SEASON, IN-SEASON AND POST-SEASON ASSESSMENT METHODS FOR FRASER RIVER SOCKEYE SALMON

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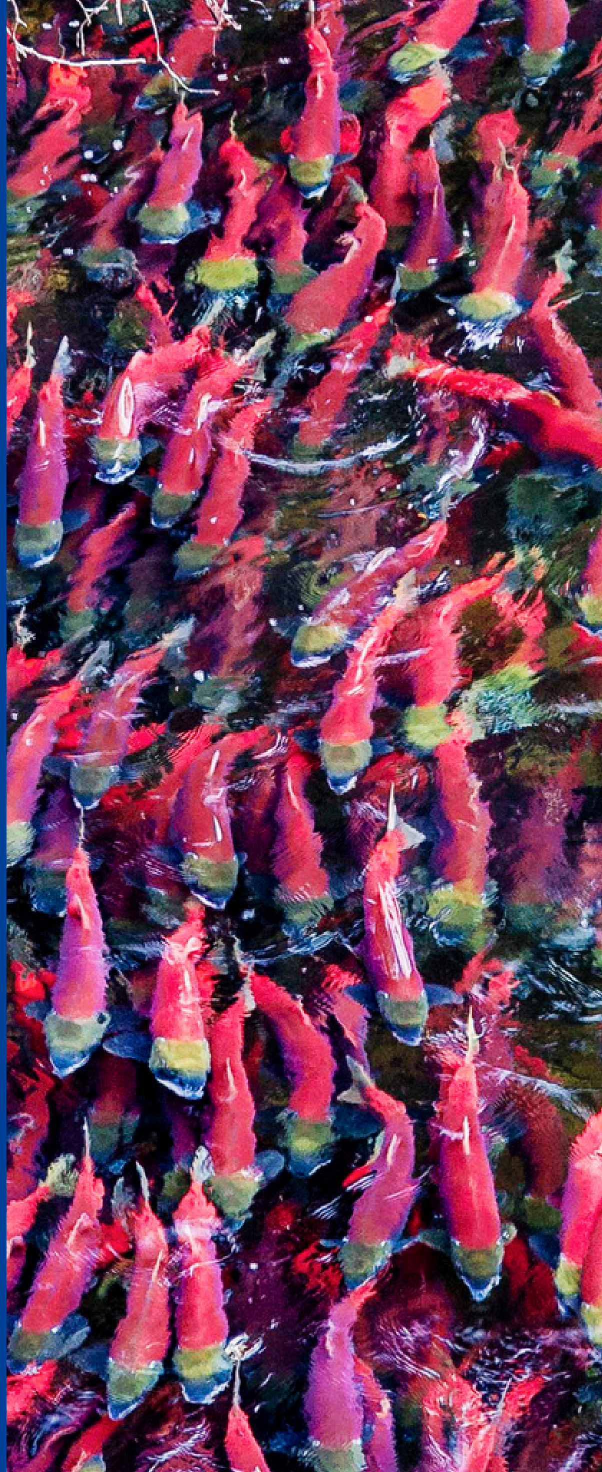
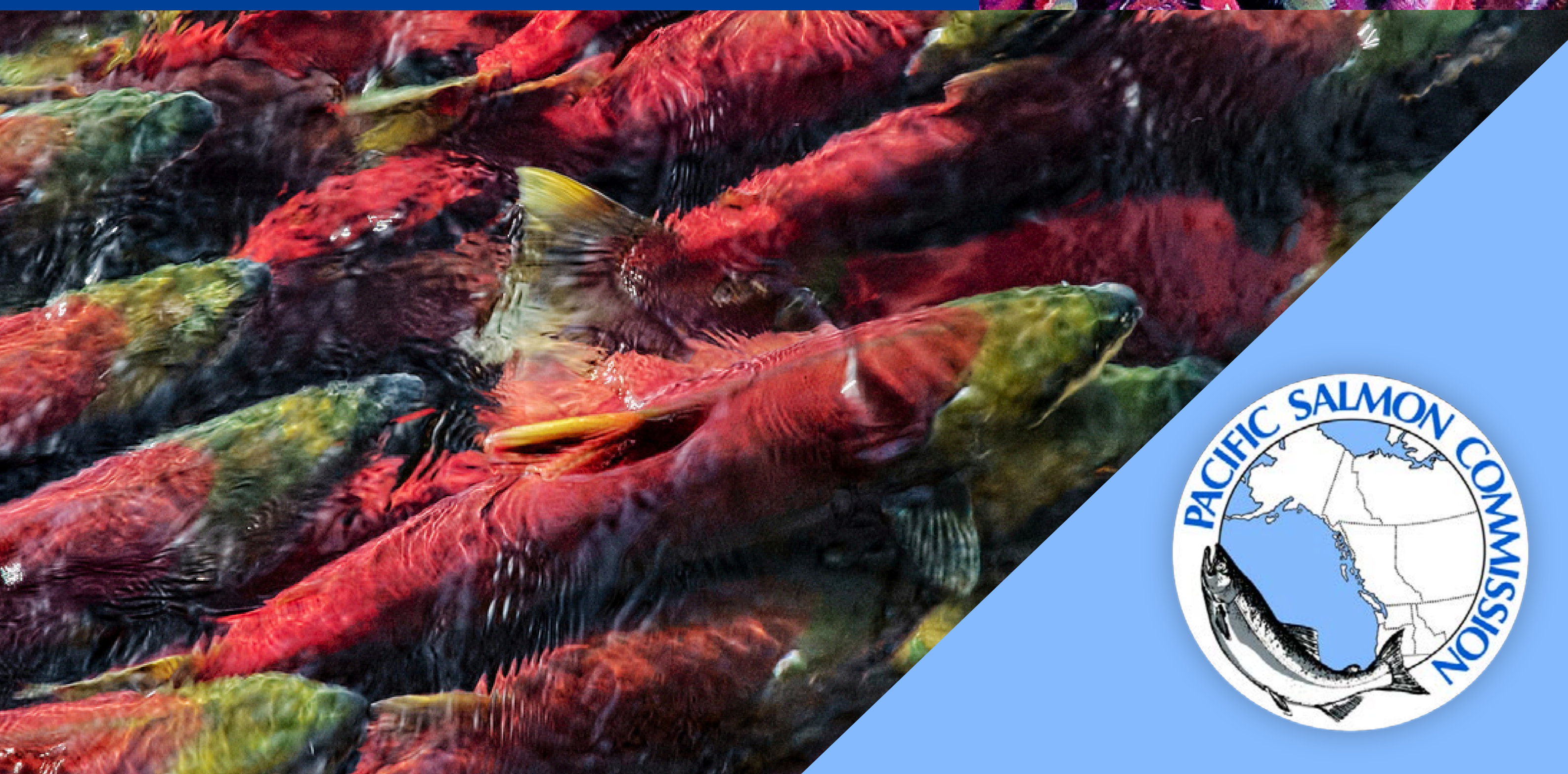
September 2026

PACIFIC SALMON COMMISSION
TECHNICAL REPORT NO. 59





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Correct citation for this publication:

Michielsens, C.G.J. and Martens, F.J. Editors. 2026. Overview of pre-season, in-season and post-season assessment methods for Fraser River sockeye salmon. Pacific Salmon Comm. Tech. Rep. No. 59, 403 p. https://www.psc.org/reports/psctr-59.

Correct citation for individual chapters in this publication, example:

Forrest, M.R. 2026. Environmental forecast. In: Michielsens, C.G.J. and Martens, F.J. Editors. Overview of pre-season, in-season and post-season assessment methods for Fraser River sockeye salmon. Pacific Salmon Comm. Tech. Rep. No. 59, 31-36 p. https://www.psc.org/reports/psctr-59

Acknowledgements

This report would not have been possible without the support of Pacific Salmon Commission Secretariat staff, past and present. We would like to thank current Commission staff: Angela Phung, Catherine Ball, Christina Langlois, Dejan Brkic, Eric Taylor, Jacqueline Nelitz, Jordan Maguire, Julie Sellars, Kristen Hayward, Maxine Forrest, Merran Hague, Rachael Hornsby, Sai Chandra Madduri, Serena Wong, Steve Latham and Tosh Sutherland, as well as staff that have left the PSC: Bruce White, Cory Lagasse, Jessica Gill, Erica Jenkins, Jim Cave, Jim Gable, Jim Woody, Keith Forrest, Ian Guthrie, Mike Lapointe, Pasan Samarasin, Yunbo Xie. In addition, special thanks to our colleagues at Fisheries and Oceans Canada (DFO), Scott Decker, Sean Everitt and Kaitlyn Dionne, and at the Northwest Indian Fisheries Commission (NWIFC), Gordon Rose for coauthoring a few of these reports. We would also like to acknowledge Julie Ehrmantraut for collating this report.

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Introduction

Fraser River sockeye and pink salmon are managed according to Chapter 4 of the Pacific Salmon Treaty which has been in effect since 1985 (PST 2025). Ensuring Treaty obligations are met and implementation is followed correctly entails gathering data and information for assessment purposes. This is done in support of Fraser River Panel management actions aimed at meeting objectives pertaining to (1) achieving spawning escapement targets, (2) meeting international catch allocation goals and (3) meeting domestic catch allocation objectives. As a result, data and information are collected throughout the year and analyzed from the perspective of pre-season planning, in-season management and post-season review. This technical report serves to document the pre-season, in-season and post-season assessment methods supporting Fraser River Panel management of Fraser River sockeye salmon. This report is an update from Technical Report No.49 (Michielsens and Martens 2022) as it incorporates post-season assessment methods, increases both pre-season and in-season topics discussed and provides updates to previously published chapters. Although some information on Fraser pink salmon is available in this technical report, the focus is primarily on sockeye salmon and more detailed information on pink salmon can be found in Technical Report No. 56 (Michielsens and Martens 2025). The report itself is a compilation of short chapters that document different data collection and assessment methods for Fraser River sockeye salmon. Each chapter can potentially be used as a separate, stand-alone document or sub-report when wanting to provide others with information on the topic. Each chapter/sub-report contains all the technical details required to understand, critique and replicate the methods. This includes, among others, an overview of the data and the methods used and planned changes or areas for improvement. To ensure the accessibility of the individual chapters and prevent readers from being overwhelmed by details, the individual chapters are restricted to about five pages. If the information on a topic is too lengthy, it is spread over several chapters, either by providing first a more general overview followed by one or more chapters that go into further detail (e.g., a chapter discussing the overall hydroacoustic program at Mission followed by several chapters of the different components of the hydroacoustic program), or by spreading one topic over several chapters (e.g., separate discussion of marine versus in-river test fisheries). The use of individual chapters as sub-reports allows more flexibility in terms of adding additional documentation for new methods.

This technical report aims to inform members of the Fraser River Panel and technical committee, academia and the general public about the different data collection and assessment methods for Fraser River sockeye salmon. This report does not aim to provide the results of these assessments, which can be found in the Fraser River Panel annual reports available on the PSC website (www.psc.org). Questions regarding this technical report and its content can be directed to info@psc.org.

Assessment overview of Fraser River sockeye salmon

Annual pre-season planning of the fisheries management season for Fraser River sockeye starts by gathering the necessary inputs for the PSC Planning Model (Chapter A9), a simulation tool used by the Fraser River Panel to assess the ability of different fisheries plans to reach management targets given the information and forecasts available preseason (Chapter A10). Fisheries and Oceans (DFO) provides some of this information: run size forecasts for the different management groups (Chapter A1), marine timing and northern diversion rate forecasts (Chapter A2), the environmental forecast (Chapter A4) and the spawning escapement plan (Chapter A5), while PSC Secretariat staff provide forecasts of test fishing catches (Chapter A8) and forecasted estimates of en route losses, i.e., differences between predicted and observed escapement estimates (DBEs, differences between estimates). The latter inform the Management Adjustment (MA, Chapter A3) which refers to the additional fish added to an escapement target to increase the likelihood of achieving that target. The Planning Model relies on a forward reconstruction with assumptions on fish movement and migration behaviour (Chapter A11) as well as assumptions about the vulnerability of sockeye to different fisheries operations (Chapter A12). The Planning Model helps create pre-season fisheries schedules and assesses the sensitivity of fishery plans and the achievement of management targets to alternative biological and management scenarios. This helps guide pre-season planning for stakeholders and informs early in-season management prior to the availability of updated in-season information. In addition to the information needed for the planning model, the PSC operates the test fishing and hydroacoustics programs to gather the necessary data for the assessment of sockeye and pink salmon. The schedule is determined by the expected timing and abundance of the returning sockeye and pink salmon run (Chapter A6). Due to the costly nature of operating the test fishing program, a pre-season budget is developed based on the number of test fisheries as well as their duration (Chapter A7) and refined leading up to the season based on the expected forecast and potential harvest opportunities.

In-season fisheries management relies on real time data of returning sockeye to adjust and refine preseason fisheries plans and helps guide fisheries management decisions. One of the key data sources in-season are the test fisheries (Chapter B1) that provide information on abundance, timing, and diversion rates as well as species and stock composition information for use in stock assessments. Test fishing occurs in marine approaches (Chapter B2) to the Fraser River (Johnstone Strait, Juan de Fuca Strait and the Strait of Georgia) and within the Fraser River (Chapter B3). While purse seine and gillnets form the main gear types used for quantitative assessments, the PSC test fisheries also include troll/hook and line test fisheries to assess delaying sockeye in the Strait of Georgia, and reef net test fisheries. One key data set collected by these test fisheries is the catch-per-unit-effort (CPUE) data (Chapter B4), which is used to estimate daily sockeye abundances in the test fishing areas. For marine test fisheries in Johnstone Strait and Juan de Fuca Strait, the CPUE data along with an expansion line estimate (the inverse of the catchability coefficient) are used to derive daily abundances (Chapter B5). At the start of the season, historical expansion line estimates are applied, derived from data from past years. Because abundances predicted this way may deviate substantially from the true abundance due to the high variability in expansion lines, both between years and within a season, expansion lines are updated once sufficient in-season observations have been obtained. The abundance estimates based on marine CPUE data are considered early indicators of the expected in river abundance given that it takes sockeye approximately 6 to 8 days to migrate from marine areas to the Fraser River. In the Fraser River, daily sockeye abundance estimates are primarily based on hydroacoustic data collected at Mission (Chapter B14). If Mission hydroacoustic data are unavailable or unreliable to estimate sockeye abundance due to the dominance of other species, the CPUE data collected at the Whonnock test fishing site can be used in combination with in-river expansion lines (Chapter B6).

Fish caught by the test fisheries, and by commercial fisheries when they occur, are sampled on a regular basis to collect a range of biological information used for in-season assessments. Biological information includes length, weight and sex information (Chapter B7). Length measurements can be used to supplement stock identification, and they are used as inputs into hydroacoustic models to differentiate fish species. Weights are important for understanding fish condition and provide the fishing industry with information on potential value of fishing opportunities. Biological samples also include DNA and scales that are collected in a procedural manner to ensure up-to-date stock identification data are available for each Panel meeting. Scale data (Chapter B9) provides information about fish age, growth rate and stock identification when DNA estimates are not (yet) available. For stock identification, scales are compared against scales of known stock origin using a linear discriminant analysis in combination with a principal component analysis (Chapter B10). The output from this model provides stock proportions for each sample and stock assignment probabilities for individual sockeye salmon. DNA-based stock identification (Chapter B11) is however the preferred method for identifying salmon stocks. DNA has been used by the PSC since 2002 and uses genetic profiles from fishery catches of unknown stock composition and compares this to a genetic baseline with known stock origin using a Bayesian statistical framework. The genetic identification of salmon stocks is essential for stock-specific reconstructions to assess the total run size and timing by management group (Early Stuart, Early Summer, Summer and Late run sockeye). Adequate sample sizes, along with transparent communication of uncertainty associated with DNA-based estimates (Chapter B12) improves the assessment of the run size by management group. Timely detection of changes among the four timing groups is equally important, however the information is not always available when needed. As this delay could cause a data gap, a Bayesian multinomial logistic regression was developed to predict future stock proportions (Chapter B13).

Another in-season assessment program operated by the PSC is a hydroacoustics program which provides daily estimates of salmon passage in the Fraser River throughout the summer (Chapter B14). Because of the large 400-meter river width, a combination of four hydroacoustic systems are deployed to adequately monitor the salmon migration past the area. The left bank area, where most of the upstream migration typically occurs, is monitored by an ARIS imaging sonar (Chapter B15) deployed at the end of a fish deflection weir. The ARIS system collects more visually intuitive data and has recently replaced the left bank split-beam system which was the main monitoring system used in the past (Michielsens and Martens 2022). The left bank ARIS system increases the accuracy of the left bank, especially during periods of high abundance when the split-beam system has been known to underestimate abundances. The nearshore right bank area is monitored using another ARIS imaging sonar, covers up to 30 meters and typically observes less than 20% of the daily upstream salmon migration. The remaining offshore region is monitored by a mobile, downward-looking ARIS system deployed from a sampling vessel that transects the river (Chapter B16). The data collected from the three ARIS systems is combined and input into the flux model to derive the daily salmon estimates. On years of abundance, there are both Food, Social, Ceremonial (FSC) fisheries and Economic Opportunity (EO) fisheries that occur within the boundaries of the Mission hydroacoustic site. Such fishing activity at the site results in temporary cessation of offshore data collection. As a result, a data imputation is done on these days to account for the impacts of the fishing activity and the resulting data gaps (Chapter B17). In addition to abundance information, the ARIS systems on both the left and right bank also provide estimates of salmon species composition using a mixture model based on acoustically observed fish lengths (Chapter B18).

The total salmon estimates when combined with species composition estimates provide daily sockeye abundance information. Several different data sources and methods exist to derive species composition

(Chapter B19) and each has its own shortcomings depending on sample size and the number of species migrating in the river at that time. The daily sockeye abundance estimates can be further split up into abundance of the four different management groups through the application of stock proportion estimates derived from test fishing catch samples taken in the same area (Chapter B20). Stock proportion estimates are also applied to catch and CPUE data. The resulting stock-specific estimates of catch and escapement past Mission are then used in reconstructions (Chapter B21), applied both forwards and backwards. Forward reconstructions predict stock-specific escapement into the river based on marine daily abundances derived from stock-specific CPUE data from marine test fisheries combined with assumptions about migration speed and delay behaviour. Backward reconstructions add stock-specific daily estimates of marine and lower river catches to stock-specific daily escapement estimates to reconstruct the total daily abundance in marine areas. The resulting estimates are used to derive the total run size, marine migration timing and diversion rate. While most Fraser River sockeye salmon migrate directly from marine test-fishing areas into the Fraser River, some populations, like Harrison, Late Shuswap, Portage, Weaver and Cultus, can delay upstream migration for days or weeks. To improve in-season management of delaying stocks, it is important to be able to assess how many are delaying in the Strait of Georgia. In-season, this is estimated by comparing total abundance entering the Strait with the total number migrating past the Mission hydroacoustic site four days later, adjusted for catches between these locations (Chapter B22). Although delay is best quantified from reconstructions, a Gulf Troll test fishery operated in August and September can verify the presence of delaying sockeye and provide indicators of relative Late Run abundance and species composition in the Strait, and a coarse signal of upstream migration timing. However, Gulf Troll data are insufficiently precise to quantify the length of the migration delay or inform run size estimates.

Prior to all sockeye salmon passing by the riverine hydroacoustic site, in-season run size and timing estimates are obtained through the application of a Bayesian time-density model (Chapter B23) fit to CPUE data from marine gillnet and purse seine test fisheries in Johnstone Strait and Juan de Fuca Strait and reconstructed daily marine abundance estimates. For Harrison and Late run stocks that delay their upstream migration, only marine CPUE are used to assess the run, resulting in larger run size uncertainty in comparison to stocks that also rely on marine reconstructed data. Given the larger uncertainty associated with these Late-run run size estimates and the fact they make up a substantial portion of the total Fraser River sockeye run on the 2022 cycle line, an additional model is applied in high abundance years. This assessment, known as SMURFing (Smolt Method for Updating Run-size Forecasts, Chapter B24) uses an in-season run size estimate for Early Thompson together with relative smolt abundance estimates collected two years prior for Late Shuswap/Portage versus Early Thompson stocks to predict the run size for Late Shuswap/Portage. It assumes the same marine survival for Late Shuswap/Portage as for Early Thompson. While it does not provide the final in-season run size for Late run stocks, it does provide an early indicator if the run size is smaller or larger than the pre-season forecast.

An additional component the Fraser River Panel considers when planning fisheries are potential en route losses due to adverse migration conditions within the Fraser River. To increase the likelihood of achieving spawning escapement targets for the four management groups, the Panel uses Management Adjustments (MA, Chapter B25) which are the additional fish allocated to escape fisheries for the purpose of increasing the likelihood of achieving these targets. To select appropriate MA values, the Panel will take into account observed and predicted estimates of temperature and discharge within the Fraser River (Chapter B26) and other factors that can cause adverse migration conditions and differences between predicted and observed spawning ground estimates (DBEs). While the selection of appropriate MAs is the purview of the Fraser River Panel, predicting DBEs is the responsibility of PSC staff. In-season DBE predictions can be based on variety of different methods: based on medians, cycle line-specific medians of historical or more recent pDBE estimates, using models that include temperature, discharge (Chapter B27) or timing covariates (Chapter B28), using medians of years with similar environmental conditions (Chapter B31), or using stock-specific pDBE estimates weighted by run size to derive estimates by management unit (Chapter B25). Retrospective analyses of the different methods identify the best performing methods and provide a clearly defined and transparent approach to assist the FRP in selecting MAs for pre-season planning and in-season management (Chapter B29). Adverse migration conditions are also monitored through visual counts at Hells Gate. This program has been in place since the early 1960's and is another tool that helps management adaptively respond to adverse migration conditions (Chapter B30). The FRP also relies on a number of other tools which include comparison of environmental conditions with historical observations and associated MA estimates, temperatures in different parts of the Fraser watershed, reports of discharge and migration past migration bottlenecks, comparison of abundances at different locations with the Fraser River, reports on fish condition, spawning ground reports and predictions of available harvest based on run size and DBE scenarios (Chapter B31). All these inputs provide further information for making informed in-season management MA decisions.

In-season fisheries opportunities are determined by the availability of International total allowable catch (TAC, Chapter B32). This is calculated as the Fraser River sockeye abundance available after the spawning escapement target (SET), the Management Adjustment (MA), the agreed Aboriginal Fisheries Exemption (AFE) and the expected catch in panel authorized test fisheries are deducted. If there is sockeye or pink abundance available for harvest, the United States share will not exceed 16.5 percent of the sockeye TAC and 25.7 percent of the pink TAC. The remaining TAC in addition to AFE catches are assigned to Canada. While TAC may be available early in the season, the in-season data may be insufficient to reliably assess run sizes. To guide fisheries planning during this period the FRP relies on the Criteria for Fishing Decisions table, a table populated with the FRP Fisheries Planning Model results, allowing for comparison of the preseason forecasts of sockeye abundance and stock composition with in-season estimates. This table helps assess whether observed conditions are consistent with preseason expectations that support proposed fishery openings (Chapter B33). When TAC is available, fisheries proposals can be put forth by Canada and the United States. To assess if proposed fisheries are consistent with Treaty regulations, PSC staff compare median catch predictions by species to the available TAC remaining at the time of the proposal (Chapter B34).

Post-season, the Fraser River Panel is charged with evaluating the achievement of its management objectives (PST 2025). This requires post-season run size estimates, which integrate spawning escapement estimates (Chapter C1), catch information (Chapter C2), and Run Size Adjustments (RSAs), that account for stock-specific uncertainty and bias in spawning escapement and catch estimates, as well as en route mortality (Chapter C6). These post-season run size estimates form the basis for assessing exploitation rates, productivity, generating pre-season forecasts (Chapter A1), and assessment of long-term escapement strategies (Chapter A5). The annual assessment of sockeye salmon spawning escapement within the Fraser River watershed (Chapter C1) is central to Canada's obligations under the Pacific Salmon Treaty (PST 2025). Biological samples collected on the spawning grounds, including otoliths and scales, are read post-season to determine age composition. These data are used to estimate total age-specific production for each brood year (Chapter C2). Post-season run-size estimates are finalized through the Run Size Adjustment (RSA) process, which aims to improve post-season run size estimates by deriving stock-specific en route mortality rates and examining potential sources of bias in the main components of run size: spawning escapement, catch, and en route mortality (Chapter C6). The resulting post-season run size is inclusive of catch, escapement, and mortality adjustments and constitutes the best available estimate of total return abundance. Calculations of RSAs are conducted by a bilateral expert group composed of Canadian and United States members (Chapter C7).

Although marine run reconstructions are conducted in-season, they are repeated post-season to address limitations and inconsistencies arising from provisional in-season data. Enhanced stock resolution is achieved through the Catch and Racial 100 (CR100) files, which support stock-specific summaries of catch, Mission passage, and upstream movement for Fraser River sockeye (Chapter C3). Post-season reconstructions not only benefit from improved data processing, finer stock resolution, clearly defined model assumptions, but also from a standardized set of decision rules when estimating daily marine abundances (Chapter C4). High-resolution stocks such as Chilko, for which catch and escapement data are available at a daily resolution, allow to generate accurate daily reconstructed abundance estimates, provided en-route losses are limited (Chapter C5).

Post-season estimates of Differences Between Estimates (DBEs) are derived by comparing the predicted number of spawners expected to reach the spawning grounds and the observed number of spawners counted post-season (Chapter C8). While most Fraser River sockeye catch is accounted for in-season, post-season estimates incorporate bycatch of Fraser sockeye in pink-directed fisheries in coastal southeast Alaska, i.e., District 104 (Chapter C9). Scale samples collected during these fisheries provide age-composition information, which can be compared to age structures observed in fisheries closer to the Fraser River (Chapter C10). All updated post-season information is incorporated into the Fraser River sockeye production dataset, which integrates spawner, juvenile, and adult return data to support assessment, forecasting, and management (Chapter C11). Given increasing demand for data at finer spatial, temporal, and stock resolutions, and the associated uncertainty, PSC staff have developed data quality indicators to score and communicate relative uncertainty across datasets that differ in methodology and resolution (Chapter C12).

A suite of purpose-built databases underpins Fraser River sockeye salmon assessments. The Test Fishing Database stores detailed information from Panel and non-Panel area fisheries, including fishing effort, catch, gear characteristics, environmental conditions, and seal observations (Chapter C13). The Hydroacoustic Database consolidates Mission hydroacoustic data and integrates standardized acoustic outputs, biological measurements, behavioural metrics, and records of Food, Social, and Ceremonial fisheries from 2018 onward (Chapter C14). The Scale Database contains detailed stock-of-origin and age information for Fraser River sockeye from 1912 to present (Chapter C15) and can be linked to genetic stock identification results (Chapter C17). Complementing the Scale Database, the scale and otolith image library documents variation in scale and otolith characteristics across stocks, brood years, and life histories, serving as both an archival reference and training resource (Chapter C16). The Database of Individual Nerka and Gorbuscha Salmon (DINGS) houses genetic stock identification data matched to individual biological records, enabling analyses of historical trends in size, age, sex, and stock composition since 2003 (Chapter C17). The Run Size, Fishing, and Escapement (RuFEs) database integrates daily catch and passage at Mission, annual spawning escapement, RSA results, DBEs, and brood-stock removals for approximately 50 Fraser River sockeye stocks, with automated routines for aggregation and disaggregation across multiple resolutions (Chapter C18). While the database holds records from 1893 onward, the available data and resolution decreased further back in time. Finally, the Daily Reconstructed Marine Abundance (DARMA) database provides post-season time series of reconstructed daily marine abundances from 2003 onward, enabling flexible aggregation and export for further analyses and data requests (Chapter C19). Many of these data products are made publicly accessible through web-based applications available on the Pacific Salmon Commission website (Data - Pacific Salmon Commission).

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A1. Pre-season Run Size Forecast

J.A. Gill, M.J. Hague, A.M. Phung, K. Dionne and C.G.J. Michielsens

Summary

Fisheries and Oceans Canada (DFO) provides run size forecasts to the Pacific Salmon Commission (PSC) as part of their obligations under the Pacific Salmon Treaty (Chapter 4, Paragraph 4). Forecasted returns of Fraser River sockeye salmon (*Oncorhynchus nerka*) stocks based on historical stock-recruitment data are a key input into pre-season planning for fisheries. Prior to the start of the season, run size forecasts are used directly in calculations of management objectives (e.g. spawning escapement targets, total allowable catch, Chapter A5) and in simulations of alternative fishing scenarios (Chapter A9). These forecasts also play an important role in the early in-season management of Fraser River sockeye salmon, prior to the availability of updated estimates based on in-season information and are utilized throughout the fishing season as informative prior distributions for stock assessment models (Chapter B23).

Individual return forecasts are generated for 27 component stocks and then aggregated into four management groups: Early Stuart, Early Summer, Summer and Late run. Run sizes are forecasted using traditional stock-recruit models (e.g. Ricker, Larkin) unless recruitment data are lacking, in which case average survival estimates from related stocks are relied upon (Cass et al. 2006). Selection of the model used to forecast a stock is based on a retrospective evaluation of the performance of the multiple models and subsequent ranking of the models based on various performance and selection criteria. Given the uncertainty in the modelled stock-recruit relationships, a Bayesian approach is used to generate posterior probability distributions of run size for the various component stocks. Sensitivity of management decisions to alternative run size scenarios can then be evaluated by drawing different quantiles from the posterior distributions.

Introduction

Fisheries and Oceans Canada (DFO) provides run size forecasts prior to the fishing season to the Pacific Salmon Commission (PSC) as part of their obligations under the Pacific Salmon Treaty (PST 2020, Chapter 4). Individual return forecasts are generated for 27 component stocks and then aggregated into four management groups: Early Stuart, Early Summer, Summer, and Late run. Despite the uncertainty associated with run size forecasts based on historical stock-recruitment data, the forecasted distributions of run size for different stocks and management groups of Fraser River sockeye play an important role in the pre-season planning and in-season assessments of stock size. Run size forecasts for Fraser River sockeye are a key input into DFO's Integrated Fisheries Management Plan, or IFMP (DFO 2025). Key management objectives such as total allowable catch (TAC), spawning escapement targets (SET), management adjustments (MAs), low abundance exploitation rates (LAERs), and aboriginal fisheries exemptions (AFEs) are all directly influenced by the size of aggregate returns for each management group. In addition, the PSC utilizes both the run size forecasts and associated management inputs to evaluate the sensitivity of fishing plans and the probability of achieving management objectives across a range of run size scenarios using a fisheries simulation model. Prior to the availability of in-season data which are used to refine estimates of run size and timing, early management decisions rely on the results of the pre-season simulations to evaluate catch proposals made by each country.

Finally, while the Fraser River Panel typically adopts updated run sizes based on in-season stock assessments, the stock-specific forecasts and the mean and standard deviation (SD) of the probability distributions provided by DFO pre-season continue to be used as priors in Bayesian run size assessments.

Data

Detailed descriptions of the data used to forecast Fraser River sockeye salmon run size can be found in Grant et al. (2010), Cass et al. (2006) and Chapter C11. Time series of stock recruit data are currently available for 20 of the 27 forecasted stocks. The majority rely on spawning escapement and estimates of returns by age, while some also have historical time series of juvenile abundance in terms of fry or smolts (Grant et al. 2010; Table 1). Spawning escapement is usually quantified as the number of females contributing to the spawning population based on potential egg deposition (i.e., effective females spawners (EFS), Cass et al. 2006). The one exception is the Cultus Lake population where estimates of EFS are poorly determined; therefore, total adult escapement data are used instead (Cass et al. 2006). Stocks identified in the forecast as miscellaneous rely solely on historical timeseries of escapement data to generate the forecast given their lack of sufficient recruitment information (Table 1).

Most Fraser sockeye stocks are comprised of four-year-old salmon that entered the ocean at age 2 (4_2 sockeye) and five-year-old salmon that have spent an additional year in the ocean (5_2). The total forecasted recruitment in a given year is therefore based on the sum of the estimated number of 4 and 5-year-old recruits from different brood years. For Fraser River sockeye salmon, only the Harrison stock has a different age structure as they enter the ocean as one-year old smolts and the resulting recruitment forecast is comprised of forecasted estimates of 3 and 4-year-old salmon (3_1 and 4_1 sockeye).

In addition to biological data, environmental covariates are used to improve the fit of traditional stock-recruit models. 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 (Ei) or Pine Island (Pi), and Fraser River peak and mean discharge (FRD) from April to June measured in Hope (Grant et al. 2010). In 2026, mean winter sea surface temperatures at Entrance (EiW) and Pine Island (PiW) were added, to reflect the winter preceding smolts entry (Dionne and Lilly 2026). Because of the potential impact of competition among Pacific salmon in the Pacific Ocean, a series of ecological covariates have been added, reflecting the abundance of pink, chum, sockeye or total Pacific salmon in the North Pacific Ocean during the second year at sea (Xu et al. 2024).

Method

A wide range of different models are considered for the forecast (Table 2) of Fraser River sockeye salmon run size. Detailed descriptions and model structures of the pre-season run size forecast models can be found in MacDonald and Grant (2012), Grant et al. (2010) and Cass et al. (2006). The complexity of the forecast models is dependent on data available for each stock. Non-biological models, which are also termed naïve models as they assume no underlying biological mechanism, calculate return forecasts based on historical estimates of returns or returns per effective female spawner or per juvenile (MacDonald and Grant 2012). These models rely on historical years or a subset of years or, in case data for a stock are missing (e.g., miscellaneous stocks), on historical data from other stocks as proxy (Dionne and Gao 2025).

Biological models are used when sufficient stock-specific spawner-recruitment data are available. Biological models are based on a relationship between spawning escapement or juvenile abundance and subsequent recruitment and include: 1) Ricker models (Ricker 1954); 2) power models; 3) Larkin models;

and 4) sibling models (MacDonald and Grant 2012). The sibling models rely on the return of a younger age class one year prior to predict returns of the older age class to account for shared productivity between siblings. The various biological models may also include environmental variables as covariates, which are especially of use when recruits encountered extreme environmental conditions during earlier parts of their life history. Uncertainty in parameter estimates and the resulting return run size forecasts are quantified by estimating Bayesian posterior probability distributions using Markov Chain Monte Carlo (MCMC) simulations run through WinBUGS software (Spiegelhalter et al. 2003).

Both non-biological and biological models produce estimates of the total number of recruits, irrespective of the age and year in which they return to the Fraser River for spawning. To determine the total number of returning sockeye salmon in a given year, the recruitment forecasts need to be split up by age using age proportion estimates based on historical data. Age-specific recruitment is calculated by multiplying the total return forecast by historical age proportions (Appendix 3 in Grant et al. 2010, MacDonald and Grant 2012). Sibling models however forecast returns of the older age group based on the productivity calculated for their younger siblings that returned the previous year. The resulting forecast for the older age group is subsequently combined with the forecast for the younger age group.

The selection of the model used to forecast a stock is an expert driven process, usually taking place over 2 days, and relies on a retrospective evaluation of the performance of the different models and subsequent model ranking based on various performance criteria (MacDonald and Grant 2012). For each model, the resulting time series of forecasted run sizes are compared against historical observations through the calculation of a suite of model performance measures: 1) mean raw error (MRE), 2) mean absolute error (MAE), 3) mean proportional error (MPE), and 4) root mean square error (RMSE; Grant et al. 2010). For each stock, the relative performance across models is calculated by applying a rank (from best to worst) for each metric (Grant et al. 2010) and then averaging the ranks of individual models across the performance metrics to generate a single performance index for each model (MacDonald and Grant 2012). For the 2026 forecast, the retrospective analysis window to evaluate performance was updated for the most recent time period (2011-2024, Dionne and Lilly 2026).

The results of the retrospective analysis are also graphically presented in a Taylor diagram (Figure 1, Xu et al. 2024). This diagram presents three statistics of predictive power: the Pearson's correlation coefficient, the normalized standard deviation, and the normalized root mean square error (RMSE) (Kell et al. 2016). The preferred model is the model that has a relatively high correlation, a small normalized RMSE, and a normalized standard deviation close to 1. More specifically, the model with the best predictive power is the model closest to the observation within the Taylor diagram (Figure 1). The performance of the various models is compared for the total population as well as for age 4 and 5 separately. The total and age-specific forecasts from the top-ranked models are compared as well as their implied productivities. Because many stocks have shown declines in productivity in recent years, an effort is made to select a model that captures this change in productivity, often through the use of environmental covariates (Dionne and Lilly 2026). Models that incorporate ecological covariates, such as the abundance of pink salmon in the Pacific Ocean, are used primarily as references rather than as the basis for the forecast. The expert-driven process to select the forecast model may vary annually but is described and reported in the annual forecast document (Dionne and Lilly 2026).

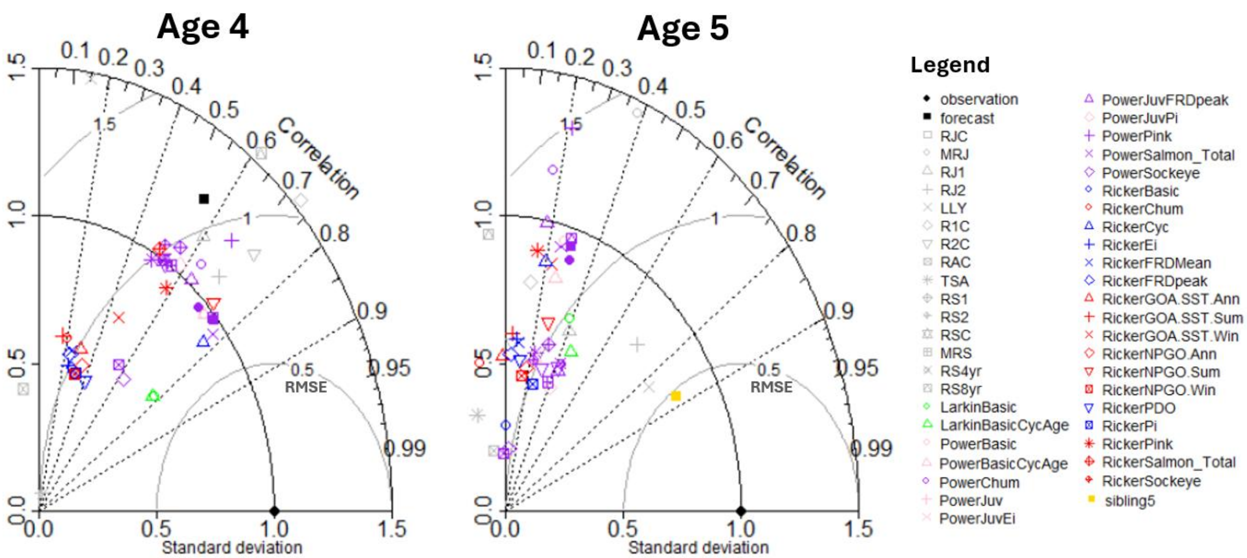

Figure 1. *Taylor diagrams for age 4 and age 5 Chilko sockeye, comparing model forecasts against the observation (black solid circle on the x-axis, at 1 standard deviation). The angle describes the correlation (0 to 1) between the model forecasts and the observation. The arcs around the observation indicate the root mean square error (RMSE). The model closest to the observation has the best predictive power (DFO 2026).*

Results

Uncertainty in the forecast results is expressed in terms of a probability distribution which is described in the forecast document (Dionne and Lilly 2026) in terms of the following percentiles: 10%, 25%, 50%, 75%, and 90%. The median forecast (50th percentile, or p50) represents an equal chance (i.e., a one in two chance) that the return will fall above or below the forecast value for each stock (Grant et al. 2010, Dionne and Lilly 2026; Table 3). 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, 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 (Grant et al. 2010).

Table 3 lists the various forecasted stocks, the model used to generate that forecast, and percentiles that define the forecast. For example, the Chilko stock (Table 3) was forecasted using a Larkin model to predict 4-year-olds and a sibling model to predict 5-year-olds. At the 10% (p10) probability level, there is a one in ten chance that the actual return will fall at or below 604,000 fish, while at the 90% (p90) probability level, there is a one in ten chance the actual return will be above 4,953,000.

Planned Changes and Potential Areas for Improvement

Multivariate Autoregressive State-Space (MARSS) models are currently being investigated as a way to explicitly account for time-varying productivity (Freshwater et al. 2018). Although a Kalman Filter model (Peterman et al. 2000) was previously included in the suite of forecast models (MacDonald and Grant 2012), these models often experienced convergence issues. In addition to the models used, it is also explored if the stock groups for which forecasts are generated could be improved.

There has been some criticism of the simplified approach of summing total returns across individual forecasts by summing the probability levels. For example, the p25 forecast for all Fraser River sockeye stocks combined is currently based on the sum of the p25 forecast of the individual stocks. This approach assumes that stocks will all return at the same probability level (i.e., variation over time is fully correlated). A more statistically valid approach would be to incorporate the observed correlation in run size estimates between the component stocks (Hawkshaw et al. 2020).

Table 1. *Available data for each Fraser River sockeye salmon stock included within the annual forecast (Grant et al. 2010, MacDonald and Grant 2012).*

Management Group	Name of forecasted stock	PSC Catch and Racial (C&R) group name	Years of available data (by return year)	Additional data
Early Stuart	Early Stuart	Early Stuart	1952 -	Fry (not used in forecast)
Early Summer	Bowron	Nadina/Bowron	1952 -	
	Upper Barriere (Fennell)	North Barriere	1971 -	
	Gates	Gates/Nahatlatch	1972 -	Fry (not used in forecast)
	Nadina	Nadina/Bowron	1973 -	Fry
	Pitt	Pitt/Alouette/Coquitlam	1956 -	
	Scotch	Early South Thompson	1984 -	
	Seymour	Early South Thompson	1952 -	
	Misc (EShu)[1]	Early South Thompson	1952 -	Scotch/Seymour R/EFS used as proxy
	Misc (Taseko)[1]	Taseko	1952 -	Chilko R/EFS used as proxy
	Misc (Chilliwack)[2]	Chilliwack	1952 -	Early Summer-run stocks R/EFS used as proxy
	Misc (Nahatlatch)[1]	Gates/Nahatlatch	1952 -	Early Summer-run stocks R/EFS used as proxy
Summer	Chilko	Chilko	1952 -	Smolt
	Late Stuart	Late Stuart	1952 -	
	Quesnel	Horsefly/Mitchell	1952 -	Fall Fry
	Stellako	Stellako	1952 -	Fry (not used in forecast)
	Harrison	Harrison	1952 -	
	Raft	Raft/North Thompson	1952 -	
	Misc (N. Thomp. Tribs)[1]	Raft/North Thompson	1952 -	Raft and Fennel R/EFS used as proxy
Summer continued	Misc (N. Thomp. River)[1]	Raft/North Thompson	1952 -	Raft and Fennel R/EFS used as proxy
	Misc (Widgeon)[1]	Widgeon Slough	1952 -	Birkenhead R/EFS used as proxy
Late	Cultus	Weaver/Cultus	1952 -	Smolt
	Late Shuswap	Late Shuswap/Portage	1952 -	Fall Fry
	Portage	Late Shuswap/Portage	1957 -	
	Weaver	Weaver/Cultus	1970 -	Fry
	Birkenhead	Birkenhead/Big Silver	1952 -	
	Misc (Harrison/Lillooet)[1]	Birkenhead/Big Silver	1952 -	Birkenhead R/EFS used as proxy

[1]Stocks are designated miscellaneous stocks by DFO until sufficient length of spawner-recruit time series are available.

[2]For Chilliwack, spawner-recruitment data are starting to be of sufficient length to consider stock-recruit models in addition to using R/EFS from a proxy stock.

Table 3. *List of candidate models organized by two categories (non-biological and biological) with descriptions. Adapted from Cass et al. (2006).*

MODEL ACRONYM	MODEL DESCRIPTION
A. Non-biological Models	
RS (used for miscellaneous stocks)	Product of average survival on time series for specified stocks and the forecast brood year EFS
RSC (or RJC)	Product of average cycle-line survival (entire time-series) and the forecast brood year EFS (or juvenile/smolt)
R1C	Return from 4 years before to forecast year
R2C	Average return from 4 and 8 years before the forecast year
RAC	Average return on the forecast cycle line for all years
TSA/TAC	Average return across all years
RS1 (or RJ1)	Product of average survival from 4 years before the forecast year and the forecast brood year EFS (or juvenile/smolt)
RS2 (or RJ2)	Product of average survival from 4 and 8 years before the forecast year and the forecast brood year EFS (or juvenile/smolt)
RS4yr (or RJ4yr)	Product of average survival from the last 4 consecutive years and the forecast brood year EFS (or juvenile/smolt)
RS8yr (or RJ8yr)	Product of average survival from the last consecutive 8 years and the forecast brood year EFS (or juvenile/smolt)
MRS (or MRJ)	Product of average survival for all years and the forecast brood year EFS (or juvenile/smolt)
B. Biological Models	
Power	Power function combining all cycle lines
Power-cyc	Power function combining one cycle line
Ricker	Ricker function combining all cycle lines
Ricker-cyc	Ricker function combining one cycle line
Larkin	Larkin function combining all cycle lines
Kalman Filter Ricker	Ricker function with a Kalman filter on the Ricker α parameter combining all cycle lines
Smolt-jack	Considers both smolt abundance and the age-3 (jack) returns from the same brood year[1]
Sibling model (4 year old)	Considers relationship between returning year classes, applying additional information from age-3 (jack) survival to forecast age-4_2 sockeye
Sibling model (5 year old)	Considers relationship between returning year classes, applying additional information from age-4_2 survival to forecast age-5_2 sockeye

[1]Wood and Parken 2004

Table 4. *2026 Fraser River sockeye forecasts. Forecasts are presented from their 10% to 90% probability levels. At the median of the forecast distribution (50% probability level), there is a one in two chance the return will fall above or below the specified forecast value for each stock, based on the historical data. Results above 1,000 have been rounded to the nearest 1,000; between 100 and 1,000 to the nearest 100; and between 10 and 100 to the nearest 10 (DFO 2026).*

Run timing group	Forecast	Probability that Return will be at/or Below Specified Run Size				
Stocks	Model	10%	25%	50%	75%	90%
Early Stuart	*Ricker(PiW)4Sibling5*	17,000	31,000	63,000	122,000	228,000
Early Summer Total		318,000	607,000	1,164,000	2,049,000	3,211,000
Total excluding misc. stocks		299,000	524,000	965,000	1,727,000	2,849,000
Bowron	*Ricker(PiW)*	3,000	6,000	10,000	20,000	35,000
Upper Barriere (Fennell)	*Ricker(PiW)Sibling5*	2,000	5,000	10,000	20,000	39,000
Gates	*LarkinBasic4Sibling5*	5,000	9,000	17,000	33,000	58,000
Nadina	*RickerCyc4Sibling5*	205,000	348,000	620,000	1,083,000	1,690,000
Pitt	*PowerBasicCycAge4Sibling5*	15,000	26,000	44,000	76,000	127,000
Scotch	*LarkinBasic*	42,000	81,000	170,000	325,000	606,000
Seymour	*Ricker(Pi)4Sibling5*	27,000	50,000	94,000	170,000	294,000
Misc (EShu)	*R/S*	16,000	76,000	177,000	279,000	289,000
Misc (Taseko)	*R/S*	500	1,000	4,000	5,000	5,000
Misc (Chilliwack)	*R/S*	700	2,000	7,000	15,000	26,000
Misc (Nahatlatch)	*R/S*	1,000	3,000	11,000	24,000	42,000
Summer Total		1,264,000	2,260,000	4,305,000	8,685,000	16,475,000
Total excluding misc. stocks		1,263,000	2,258,000	4,300,000	8,674,000	16,454,000
Chilko	*LarkinBasic4Sibling5*	604,000	999,000	1,741,000	2,943,000	4,953,000
Late Stuart	*RS14Ricker(Pi)5*	63,000	163,000	465,000	1,298,000	3,318,000
Quesnel	*Ricker(PiW)*	414,000	811,000	1,592,000	3,517,000	6,554,000
Stellako	*Ricker(EiW)*	144,000	208,000	339,000	560,000	884,000
Harrison	*LLY3Sibling4*	25,000	51,000	118,000	272,000	599,000
Raft	*LLY4Sibling5*	14,000	25,000	45,000	84,000	147,000
Misc (N. Thomp. Tribs)	*R/S*	100	200	400	1,000	2,000
Misc (N. Thomp River)	*R/S*	900	2,000	3,000	9,000	17,000
Misc (Widgeon)	*R/S*	10	40	900	1,000	2,000
Late Total		354,000	870,000	2,212,000	5,471,000	10,686,000
Total excluding misc. stocks		354,000	868,000	2,188,000	5,435,000	10,641,000
Cultus	*PowerJuv(PiW)*	400	700	1,000	3,000	4,000
Late Shuswap	*RickerBasic4Sibling5*	140,000	469,000	1,415,000	3,890,000	7,748,000
Portage	*RickerCyc*	31,000	53,000	86,000	149,000	242,000
Weaver	*PowerJuv(PiW)4Sibling5*	18,000	43,000	95,000	229,000	487,000
Birkenhead	*LLY4Sibling5*	164,000	302,000	591,000	1,165,000	2,159,000
Misc Harrison/Lillooet	*R/S*	400	1,000	24,000	36,000	46,000
TOTAL SOCKEYE SALMON		1,953,000	3,767,000	7,743,000	16,328,000	30,600,000
Total Sockeye excluding misc. stocks		1,933,000	3,681,000	7,517,000	15,958,000	30,171,000

Note: Model descriptions can be found in Table 2.
Stocks are designated miscellaneous stocks by DFO until sufficient spawner-recruit data are available.

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A2. Timing and Diversion Rate Forecasts

J.A. Gill, M.J. Hague, A.M. Phung and C.G.J. Michielsens

Summary

Fisheries and Oceans Canada (DFO) provides the Pacific Salmon Commission with annual forecasts of the migration timing, and migration route around Vancouver Island in accordance with the Pacific Salmon Treaty. These forecasts are based on a series of different statistical models that include various environmental covariates. These models are evaluated retrospectively over 19 years. A model-averaged median forecast is generated from the ten top-ranked models, with forecast uncertainty expressed as the range of median forecasts across those models (Gao and Dionne 2025). The resulting preseason forecasts of timing and diversion rates are important for pre-season expectations of abundance and planning of fisheries (Chapter A9) and serve as informative prior probability distribution inputs into the in-season stock assessment models (Chapter B23). DFO provides timing forecasts for Early Stuart and Chilko stocks, while diversion rates are produced for the aggregate Fraser River sockeye run.

Introduction

Fisheries and Oceans Canada (DFO) produces annual forecasts of the marine migration timing and migration route around Vancouver Island as part of their obligations under the Pacific Salmon Treaty (PST 2020, Chapter 4, Folkes et al. 2018). Marine timing for Fraser River sockeye is defined as the date when 50% of a stock has passed through the marine areas on route to their natal freshwater stream for spawning (Folkes et al. 2017, Figure 1). It is common to use the DFO statistical area 20 (Area 20) in Juan de Fuca Strait as the reference location for the marine timing (Chapter B21). The Area 20 timing then refers to the date when 50% of a stock has passed Area 20 assuming the entire run migrated through Juan de Fuca Strait. The use of the Area 20 as a reference point for timing is largely due to the fact that International Pacific Salmon Fisheries Commission (IPSFC) historically used catch data collected from the southern migration route to derive marine migration timing (Folkes et al. 2018). DFO only produces timing forecasts for the Early Stuart and Chilko stocks. PSC staff uses the correlations between timing estimates or the timing offsets between stocks to derive timing forecast of the other Fraser River sockeye stocks. The diversion rate refers to the route an individual salmon might take to return to the Fraser River to spawn (Folkes et al. 2018). More specifically, the (northern) diversion rate indicates the proportion of the salmon that migrates through Johnstone Strait (northern approach) as opposed to Juan de Fuca Strait (southern approach, Figure 2). Estimates may reflect the diversion over a week or a few days or across the entire migration season. Diversion rates have traditionally been derived for the total Fraser River sockeye aggregate are now also available for individual stocks or management groups (Chapter C4). The forecasts of timing and diversion rate can be combined with the pre-season run size forecasts and historical estimates of the length of the returning run (spread) to derive forecasts of daily abundances migrating through Juan de Fuca and Johnstone Strait (Chapter A9).

Data

Annual estimates of marine migration timing for Early Stuart and Chilko are derived from post-season daily reconstruction abundances estimates (Chapter C4) based on daily hydroacoustic estimates obtained at Mission (Chapter B14) plus seaward catches. The timing is defined as the date when the cumulative abundance of these stock exceeds 50% of the total run size. Timing and diversion rate data are publicly available on the FRP annual report Shiny App where the data can be viewed and downloaded along with supporting documentation (PSC 2026). To generate the forecasts, data from 1993 onwards are used.

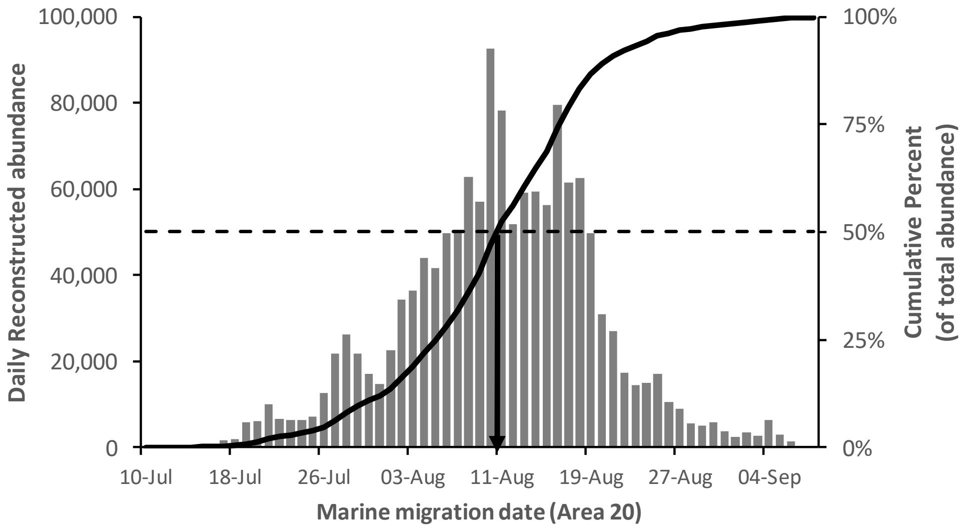

Figure 1. *Example of the method used to estimate marine timing, based on reconstructed abundance data. The marine timing is the date when the cumulative daily abundance exceeds 50% of the total abundance (horizontal dashed line) and is denoted by the vertical arrow (adapted from Folkes et al. 2018).*

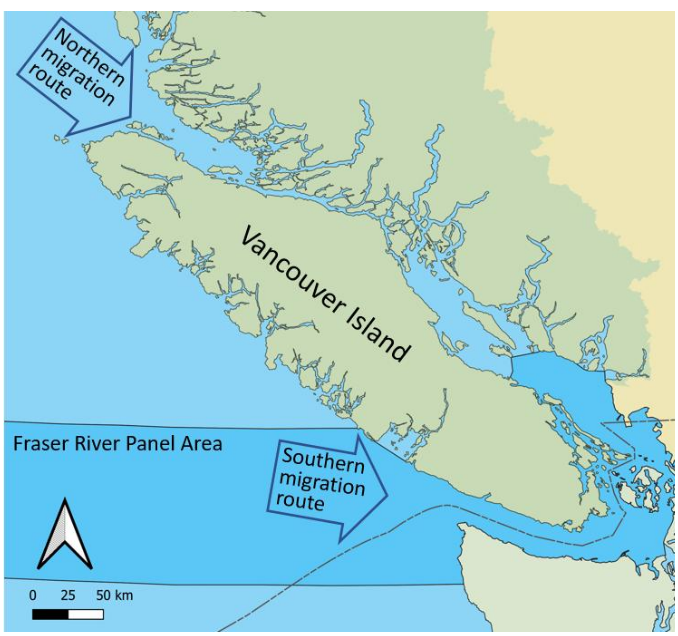

Figure 2. *Southern B.C. coast map depicting the two routes taken by adult Fraser sockeye when returning to the Fraser River. The proportion of total run returning via the northern route is considered the diversion rate.*

Annual post-season estimates of northern diversion rate of the aggregate Fraser River sockeye population are estimated by dividing the total abundance migrating through the northern (Johnstone

Strait) approach by the total abundance (Folkes et al. 2018). Since 1998, estimates of diversion are based on catch-per-unit-effort (CPUE) data from test fisheries operating in Juan de Fuca and Johnstone Straits (Putman et al. 2014). From 1982 to 1997, diversion rate estimates were derived from an earlier version of the reconstruction model described in Cave and Gazey (1994). For the years 1952 to 1981, diversion rates were instead based on the assumption that the Johnstone Strait fishery harvested a fixed proportion of the weekly sockeye abundance for each day fished and the assumed harvest rate was adjusted over time to reflect changes in fleet fishing power and the duration of weekly fishing periods (McKinnell et al. 1999, based on personal communication from J. Woodey).

In addition to historical estimates, the forecast methods for migration timing and diversion rate also incorporate environmental covariates known or assumed to influence these behaviors, in particular sea surface temperature (SST) and surface current velocity. These variables are summarized for each oceanographic polygon (Figure 3) in terms of monthly means (January to May). Because migration timing is most likely influenced by near-coastal currents, current-velocity predictors are derived for polygons 1 to 3. For SST, temperatures from all grid locations outside polygons 1–3 (collectively referred to as polygon 0) are also included to capture broader ocean-scale thermal conditions.

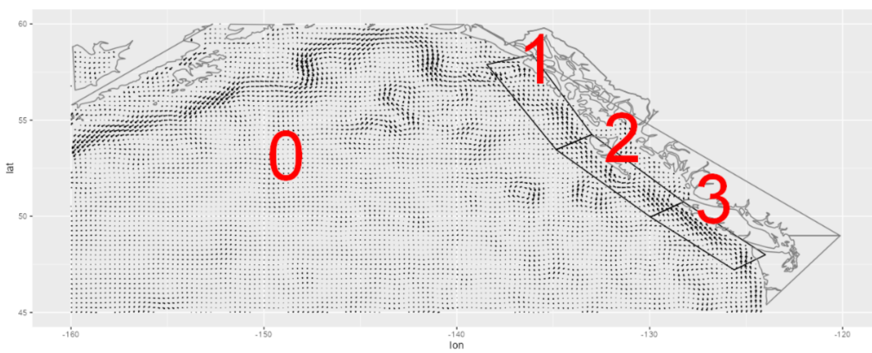

Figure 3. *Map of the Pacific Ocean depicting the polygons where environmental covariate data are collected to predict timing (0 to 3) and diversion rate (1 to 3).*

Method

A set of multivariate linear regression models fit to data from 1993 onwards are used to produce the timing (*T*) and diversion rate (*D*) forecasts. Model covariates are monthly (*m*) means (January to May) of sea surface temperature (*SST*) and current velocity vectors (*u* and *v*), summarized for four oceanographic polygons (*p*) (Figure 3). Models follow the general form:

1) T or D ~ SST[p, m] + u[p, m] + v[p, m] + cycle

With the diversion rate logit-transformed before fitting the model. Current velocity vectors u and v must always come from the same polygon-month combination, but SST can be drawn from a different polygon-month. Beyond the permutations arising from different choices of polygon and month, models can also include a categorical factor (cycle) that distinguishes the 2020 cycle line from all other cycle lines to account for systematic differences in run timing or diversion rate.

Models are evaluated retrospectively using a non-exhaustive k-fold cross-validation approach, in which the most recent years, ending in the current forecast year, are repeatedly split into years used to fit the model and years to evaluate the forecast (Gao and Dionne 2025). Performance metrics are computed over the 19 preceding years, excluding the current forecast year, using mean raw error (MRE) and root mean square error (RMSE). Years for which observed timing estimates are unavailable, such as 1997, 2001, and 2003 for Chilko, are excluded from the performance metric calculations. The ten top-ranked models are then used to generate a median forecast through model averaging, with forecast uncertainty reported as the range of median forecasts across the top ten models (Gao and Dionne 2025).

Forecasts in each year depend on the performance of individual models and the available environmental data. From an assessment point of view, there are three time periods for which forecasts are required: preliminary planning in February and April, updated planning in June, and in-season assessments in July and August. At the time of preseason planning in February, forecasts of timing and diversion rates are usually based on naïve models that account for differences between cycle line years, i.e. medians of historical estimates. Models that include environmental covariates are used from June onward, as environmental covariate data collected closer to the season have greater predictive power for timing and diversion, and May covariate data are available by that point. In-season, the timing forecasts are used as informative prior probability distributions within the time density model to generate in-season posterior probability distributions of timing (Chapter B23).

DFO only produces timing estimates for Early Stuart and Chilko. PSC staff uses the correlations between timing estimates or the timing offsets between stocks to produce timing forecast for the remainder of the stock groups modelled preseason and in-season. The Retrospective Evaluation Framework (REF) tool was created to standardize decision-making regarding pre-season migration timing estimates. The REF tool allows PSC staff to retrospectively evaluate methods to derive migration timing estimates across different stocks and cycle lines.

Results

Timing forecasts are provided by DFO for both Early Stuart and Chilko stocks. The retrospective performance of the top-ranked Chilko model is illustrated for 2024 in Figure 4 (Gao and Dionne 2024). The figure shows that forecasted timing generally tracks observed timing well across the evaluation period, with most observed values falling within the model's 95% predictive intervals. Only in 2005, when migration timing was exceptionally late, does the observation fall outside the interval. The inclusion of the cycle 2020 covariate contributes meaningfully to model fit: years belonging to the 2020 cycle line (identified by red dashed lines) display a consistent pattern of earlier timing that the model successfully captures.

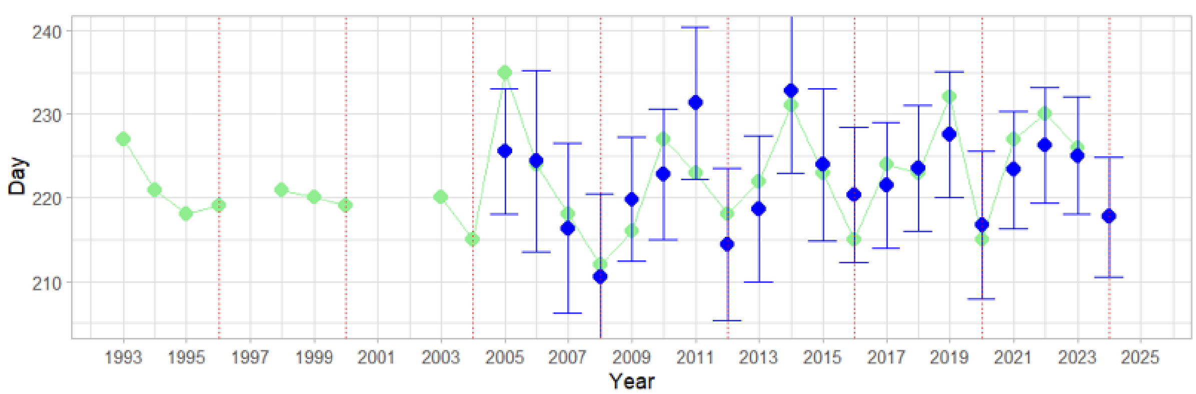

Figure 4. *Retrospective forecasts of Chilko sockeye migration timing using the top-ranked model: T ~ SST[0,4] + u[2,3] × v[2,3] + cycle2020 (Gao and Dionne 2024). Timing is expressed as day of year. Observed migration timing is shown as green connected points. Blue points and vertical bars represent the retrospective forecast and associated 95% predictive interval for each year, derived from cross-validation. Red dashed lines denote years belonging to the 2020 cycle line. Note that observed timing estimates were unavailable for 1997, 2001, and 2003.*

Table 1 presents the 2024 Chilko timing forecasts (Gao and Dionne 2024), summarizing the results of the ten highest-performing models identified through cross-validation. All ten models include the 2020 cycle line categorical covariate (cycle2020), indicating that accounting for systematic differences in migration timing between 2020 cycle line years and other years consistently improves retrospective forecast performance relative to models that exclude this term. Median timing predictions across the top ten models range from 1 August to 11 August, a 11-day spread, and the overall model-averaged median forecast is 6 August. This value aligns with the top-ranked model, which predicts a median timing of 6 August with a 95% predictive interval of 29 July–12 August. Key predictors in this top-ranked model include April SST from polygon 0, March current velocity vectors from polygon 2, and the cycle2020 factor.

Across the top-ranked models, nearshore current velocities from polygons 1 and 2 in March and May appear repeatedly, indicating that early-season coastal current conditions are the most influential environmental predictors of Chilko migration timing. SST predictors are also important and most frequently involve polygon 0, although the selected SST month varies across the ten models, suggesting greater temporal variability in thermal effects than in current-related effects. Results for Early Stuart timing and the northern diversion rate are presented using the same framework.

Table 1. *Top ten ranked models for forecasting Chilko sockeye migration timing for 2024, evaluated retrospectively over the preceding 19 years (Gao and Dionne 2024). Median timing and 95% predictive intervals are reported as calendar dates. All top-ranked models include Sea Surface Temperature (SST), current velocity vectors u and v and a categorical covariate distinguishing the 2020 cycle line (cycle2020). Model covariates are denoted as SST[p, m], u[p, m], and v[p, m], where p is the oceanographic polygon (0–3) and m is the month, 1 = January through 5 = May.*

Rank	Median timing	95% Predictive Interval			Model equation
1	06-Aug	29-Jul	-	12-Aug	T ~ SST[0,4] + u[2,3] + v[2,3] + cycle2020
2	06-Aug	28-Jul	-	12-Aug	T ~ SST[0,5] + u[2,3] + v[2,3] + cycle2020
3	06-Aug	28-Jul	-	13-Aug	T ~ SST[0,3] + u[2,3] + v[2,3] + cycle2020
4	06-Aug	28-Jul	-	12-Aug	T ~ SST[0,5] + u[2,3] * v[2,3] + cycle2020
5	07-Aug	29-Jul	-	14-Aug	T ~ SST[0,2] + u[2,3] * v[2,3] + cycle2020
6	06-Aug	29-Jul	-	12-Aug	T ~ SST[0,4] + u[2,3] * v[2,3] + cycle2020
7	03-Aug	23-Jul	-	11-Aug	T ~ SST[0,3] + u[1,5] + v[1,5] + cycle2020
8	01-Aug	22-Jul	-	09-Aug	T ~ SST[1,5] + u[1,5] + v[1,5] + cycle2020
9	11-Aug	02-Aug	-	18-Aug	T ~ SST[0,2] + u[1,1] + v[1,1] + cycle2020
10	09-Aug	31-Jul	-	17-Aug	T ~ SST[0,5] + u[1,1] + v[1,1] + cycle2020

Potential Areas for Improvement

The historical reconstruction file system has been reworked to standardize file assumptions, increase the stock and spatial resolution of reconstructed abundances, and populate a run reconstruction database. It is now possible to query the resulting database to obtain improved yearly timing estimates at varying stock resolution as well as obtain annual and in-season diversion rate estimates at different stock resolution.

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A3. Management Adjustments

M.R. Forrest and M.J. Hague

Summary

The Management Adjustment (MA) refers to additional fish added to an escapement target to increase the likelihood of achieving that target. MAs account for en route loss and other factors that cause differences between predicted and observed escapement estimates (DBEs, differences between estimates). Early pre-season planning relies on historical DBE data (Chapter C8) to forecast DBEs while immediately prior to the season in June, the top-performing model identified through a retrospective analysis (Chapter B29) is selected to predict the DBE for each management group. For Early Stuart, Early Summer and Late-run sockeye, the pre-season forecast is based on median values of historical estimates. For Summer run, the forecast is based on the pre-season temperature and discharge model informed by the long-range Fraser River environmental forecast (Chapter A4).

Despite the uncertainty inherent in pre-season DBE forecasts, they provide managers with an early indication of the expected discrepancy between the potential spawning escapement (PSE) and the spawning escapement (SE) (Chapter C8). This facilitates a more informed decision-making process and allows the Fraser Panel to respond proactively to adverse environmental conditions by adopting appropriate MA estimates and adjusting the fishing pressure to increase the probability of achieving spawning escapement targets.

Introduction

Under the Pacific Salmon Treaty, the Fraser River Panel has the discretion to add additional fish to the spawning escapement target (SET) set by Canada for Fraser River sockeye salmon (*Oncorhynchus nerka*) to ensure spawning requirements are met (PST 2025). The additional fish added to the escapement targets for the different management units of Fraser River sockeye are termed the Management Adjustments (MAs) and they are used for the purpose of increasing the likelihood of achieving the SET. The idea is that extra fish are allowed to escape upriver of Mission to account for anticipated negative differences between in-season versus post-season estimates of spawning escapement caused by en route mortality due to poor environmental conditions during upstream migration, such as high discharge levels and warmer water temperatures. The differences between in-season and post-season estimates can however also stem from biases in the in-season and post-season assessments and the resulting catch and spawner estimates. In this case, the resulting bias can be positive or negative.

For pre-season planning, it is important to make accurate assumptions about the Management Adjustment to ensure the SETs are met. Practically, this means managers must predict the likely difference between estimates (DBE). Historically, when discharge levels or temperatures are above average, DBEs also tend to be high. For Late-run sockeye, historical DBEs are related to the date when half the run has migrated past Mission (i.e., Mission 50% date), which captures the negative impact of the early migration behaviour observed since the mid-1990s on the migration success of these stocks (Lapointe et al. 2003, Cooke et al. 2004). A wide range of different methods exist to predict DBEs, either relying on historical data or statistical models that relate environmental river conditions to historical DBEs. Prior to June, managers use median values from the historical dataset for each management group. In June, when long-range forecasts of temperature and discharge are available (Chapter A4), the method to predict the DBE for the individual management groups depends on the results of the retrospective analysis (Chapter B29). The following sections provide an overview of the pre-season data and methods to predict DBEs.

Data

The in-season and post-season spawning escapement estimates (Chapter C1), the 50% migration dates at Hells Gate and Mission (Chapter C3) and the temperature and discharge at Hells Gate (Chapter A4) are the primary biological data used to predict DBEs. These are used as inputs in the statistical models (Chapter B25). Hells Gate is used as the geographic reference point to describe Fraser River environmental conditions because it is a well-known impediment to successful upstream salmon migration (Chapter B30).

The DBE data are derived from the historical differences between in-season projections of spawning escapement (i.e., Mission escapement minus catch above Mission, or potential spawning escapement, PSE) and post-season estimates (i.e., spawning ground estimates, spawning escapement, SE, Chapter C8).

The 50% Hells Gate date for Early Stuart, Early Summer and Summer run are used to determine the mean temperature and discharge experienced by the management group across 31 days. The 50% date at Mission for Late run is used in the DBE run timing model (Chapter B28). The 50% migration date at Hells Gate or Mission for the different management groups is the date at which 50% of that group has passed these locations in the Fraser River. The Hells Gate and Mission dates are derived from marine migration timing estimates in statistical Area 20, Juan de Fuca Strait (Chapter C4). The travel time from Area 20 to Mission is assumed to be 6 days for Early Stuart, Early Summer and Summer-run sockeye. The Late-run sockeye travel time to Mission depends on their delay before upstream migration but is assumed to be 8 days when travelling without delay. The travel time from Mission to Hells Gate is assumed to be 5 days for all four management groups.

Pre-season, the long-range forecasts for temperature and discharge are provided to PSC staff by Fisheries and Oceans (DFO) Environmental Watch (EWatch) Program (Patterson and Hague 2007, Chapter A4). In combination with predicted migration timing forecasts (Chapter A2), the daily estimates of the long-range forecast allow for the creation of 31-day mean Fraser River temperature forecasts at Qualark, B.C. and 31-day mean Fraser River discharge forecasts at Hope, B.C. (Morrison and Foreman 2005, Morrison 2005, Hague and Patterson 2014). These long-range forecasts are provided by the DFO Environmental Watch Program in June in the form of 10,000 paired predictions of Fraser River discharge and temperature that capture the uncertainty associated with these forecasts. In addition to the long-range forecast, the pre-season DBE models also use historical Fraser River temperature and discharge estimates. The DFO Environmental Watch group maintains a database of these data and an updated copy of historical observed Fraser River temperature at Qualark and discharge at Hope are provided to the PSC annually.

Method

PREDICTIONS USING MEDIAN VALUES

Pre-season planning begins in early February. At this time, reliable long-range environmental forecasts are not yet available and early pre-season MAs are therefore based on median values of historical datasets (Chapter C8). Median values are calculated by using the time series of ln(PSE/SE) data. This median is then converted to a pMA (proportional MA) using the following equation:

$$pMA = \left[exp\left(\frac{PSE}{SE}\right) - 1\right] \quad (1)$$

The pMA is converted to the official pDBE (proportional DBE, rounded to two decimal places) using the following equation:

$$(2) \qquad pDBE = \left[\frac{1}{(1+pMA)} - 1\right]$$

For some management groups, like Early Stuart, Early Summer and Summer run, there have been no substantial differences detected between the pDBEs of different cycle lines. Therefore, the median pDBE has been based on all historical years. For Early Stuart, there has however been an increase in en-route losses in recent years and as a result, pre-season predictions based on the median DBE since 1995 perform better than relying on data for all available years (Chapter B29). The pDBEs for the Late-run groups vary depending on the cycle line. In Dominant Late Shuswap years, pDBEs may differ substantially from those observed in non-dominant years, suggesting either that this group responds differently to adverse environmental conditions when abundance is high or that assessment errors in dominant years differ from those in non-dominant years (Chapter B29). Therefore, the Late-run dataset might be reduced to only Dominant years when calculating the median pDBE for those years. However, this significantly reduces the number of data points used to calculate the median.

MODEL PREDICTIONS USING LONG-TERM ENVIRONMENTAL FORECASTS

In June, DFO's EWatch Program provides PSC staff with long-range forecasts of lower Fraser River temperature at Qualark, B.C. and discharge at Hope, B.C. (Chapter A4). These allow PSC staff to generate pDBE predictions based on statistical DBE (Chapter B29). The statistical models use long-range forecasts of river conditions in combination with in-river migration timing predictions (Chapter A2) to produce current year forecasts.

For Early Stuart, Early Summer and Summer-run sockeye, these regression models relate freshwater conditions defined by temperature (T) and discharge (Q) to differences between estimates (MacDonald et al. 2010, Chapter B27). The forecasted 31-day mean T and Q centered around the 50% date at Hells Gate is used as a model input to forecast the DBE for the current year. The 31-day model captures 90% or more of a run's exposure to environmental conditions at Hells Gate and provides a better fit to the historical DBE data than environmental data averaged over a shorter time-period (Hague and Patterson 2007).

For Late-run sockeye, the statistical model is a regression model that relates early upstream migration to differences between estimates (Chapter B28). The DBE run-timing model prediction is based on a pre-season prediction of upstream timing, which is dependent on the number of days the salmon delay in the Strait of Georgia (Chapter B22). The estimate of delay is based on historical delay patterns for the different cycle lines.

RETROSPECTIVE ANALYSIS

To identify the best performing pre-season pDBE prediction methods, a retrospective analysis was performed for a wide variety of different models (Chapter B29): based on medians, cycle line-specific medians of historical or more recent pDBE estimates, using medians of years with similar environmental conditions, using models that include temperature, discharge (Chapter B27) or timing covariates (Chapter B28), or using stock-specific pDBE estimates weighted by run size to derive estimates by management unit (Chapter B25). The performance of the models was evaluated using the last 12 years of data by comparing the annual pDBE predictions with the observed values using two performance measures: Mean Raw Error (MRE) and Mean Absolute Error (MAE).

Results

In February, management considerations for the upcoming season are presented to the Panel. The preliminary pDBE estimates for consideration by the Fraser River Panel at this time are based on the median pDBEs. These very preliminary pDBEs are used by PSC staff to seed the planning model and by DFO in the preliminary escapement plan. In April the preliminary pDBEs are reviewed again with possible changes depending on updated information and Fraser River Panel guidance. The resulting pMAs are then used for all of the April planning model work. In June, the DFO Environmental Watch group provides the pre-season long-range forecasts of temperature and discharge (Chapter A4) and PSC staff rely on the results of the retrospective analysis (Chapter B29) to select the method to predict the pDBE for Early Stuart, Early Summer, Summer and Late-run sockeye. The Panel may choose to adopt (if either party accepts) or not adopt (if both parties reject) the recommended pDBEs or may choose a different value as they see fit (by bilateral agreement). The adopted pMA is then used in the pre-season planning model for in-season fisheries management until the Panel adopts an in-season pMA.

Planned changes and potential areas for improvement

There remains considerable uncertainty in both the pDBE forecast estimates and the long-range pre-season temperature and discharge forecasts used as inputs to the model (Chapter A4). This uncertainty has contributed to the Fraser River Panel's reluctance to adopt pre-season DBEs derived from long-range environmental forecasts. Instead, the Panel has often preferred to rely on historical data when developing pre-season plans.

This reluctance motivated a Southern Endowment Fund project designed to address key recommendations from the recent Canadian Science Advisory Secretariat (CSAS) review of Fraser Sockeye Run Size Adjustments (RSAs, Chapter C6), particularly those related to improving Management Adjustments (MAs) (DFO 2025). The project focuses on (1) the development of alternative methods to generate MAs that better reflect the dynamic trade-offs in management objectives, (2) improving temperature and discharge exposure estimates for in-season and post-season applications and (3) the development of updated temperature, discharge and timing-based mortality models. Collectively, these areas of work will also support an upcoming CSAS request from DFO Resource Management to Science regarding Fraser River sockeye MAs, scheduled for winter 2027.

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A4. Environmental forecast

M.R. Forrest

Summary

The DFO Environmental Watch (EWatch) Program provides PSC managers with scientific advice and environmental data to assess the impact of different environmental factors on the migration success of Pacific salmon in freshwater (Patterson et al. 2007). Pre-season, the EWatch Program generates long-range forecasts of lower Fraser River temperature at Qualark, B.C. and discharge at Hope, B.C. These long-range forecasts are used in pre-season models (Chapter A3) to provide the Fraser River Panel with a pre-season indication of adverse environmental conditions and potential en-route losses that may impact their fisheries management decisions (Chapter A9).

Introduction

For the management of Fraser River sockeye salmon, the Fraser River Panel relies on Management Adjustments (MAs), which are the additional fish allowed to escape fisheries to increase the likelihood of achieving the spawning escapement target (SET) and account for potential en-route losses due to adverse environmental conditions (Chapter B24).

Prior to June, biologists estimate potential en-route losses using median proportional Difference Between Estimate (pDBE) values derived from historical data. These early-season estimates provide a baseline for anticipated migration challenges. Later in June, DFO's Environmental Watch (EWatch) Program supplies long-range forecasts of Fraser River water temperature and discharge. These forecasts offer an early indication of in-season environmental conditions and are incorporated into statistical models that relate river temperature and discharge to observed discrepancies between predicted and actual spawning ground counts, i.e., pDBE estimates. These models use forecasted 31-day average temperature at Qualark, B.C., and discharge at Hope, B.C., aligned with the 50% migration date for each management group (Chapter A3) and are used to refine predictions of en-route loss and inform corresponding management adjustments.

The following sections provide an overview of the data sources, modeling approaches used to generate the pre-season forecasts of water temperature and discharge, which are critical inputs to both the pre-season forecasts of the pDBE as well as sockeye salmon management decisions. Examples of the results presented annually to the Fraser River Panel are also discussed.

Data

River temperature and discharge in the Fraser River are influenced by a complex interplay of physical factors, including precipitation, air temperature, solar radiation, wind speed, cloud cover, and forest fire smoke (Patterson and Hague 2007). To generate long-term forecasts of Fraser River temperature and discharge, DFO's EWatch Program integrates a wide range of environmental datasets.

Hells Gate is a well-documented impediment to salmon migration (Roos 1991, MacDonald et al. 2000). Long-term environmental monitoring at nearby stations in Hope and Qualark provides robust historical datasets, making these locations the primary geographic reference points for describing Fraser River conditions (Patterson and Hague 2007, MacDonald et al. 2010). Table 1 provides a detailed overview of the various data sets used to derive the long-term forecast of Fraser River water temperature at Qualark, B.C. and discharge at Hope, B.C.

Table 1. *Overview of datasets used by DFO's EWatch Program to forecast Fraser River temperatures at Qualark, B.C. and discharges at Hope, B.C.*

Dataset	Description	Source / Link
Fraser River Water Temperature (Qualark, B.C.)	Historical daily mean temperatures	Patterson et al. 2007; EWatch Program
Upstream Water Temperatures	Observed daily temperatures	Water Survey of Canada; EWatch Program
River Discharge (Hope, B.C.)	Daily discharge data	Hydrometric Data Portal
Air Temperature Anomalies	Seasonal air temperature forecasts	Environment and Climate Change Canada
Air Temperature Forecast Maps	Canada-wide forecast maps	Environment and Climate Change Canada
Snowpack Water Volume Forecasts	Monthly bulletins estimating snowmelt	Snow Survey & Bulletin
Runoff Forecasts	Flow predictions for Shelley, Quesnel, and Spences Bridge	Streamflow & Flood Forecasting

Method

The temperature and discharge forecasts are generated annually in June from a combination of simple and multivariate linear models. The choice of models depends on the winter snowpack accumulation, summer air temperature forecasts and the correlation between the starting temperature and starting discharge. (M.J. Hague, PSC, pers. comm.). Due to the inverse relationship between discharge and thermal capacity (Webb et al. 2003), discharge is a strong predictor of water temperature variability (Neumann et al. 2003, van Vliet et al. 2011).

The performance of the long-range forecasting models in the lower Fraser River was evaluated by Patterson and Hague (2007). They quantified the uncertainty in the temperature and discharge forecasts arising from uncertainty in the model structure and in the predictor variable. They found the main trade-offs to consider when selecting the most appropriate temperature forecast method are the seasonal availability of the data, model performance, and predictor variable uncertainty and that the precision of discharge forecasts deteriorated throughout the summer.

To account for the uncertainty in the forecast, the daily temperature and discharge forecasts provided by the EWatch Program are in the form of 10,000 paired predictions of 31-day mean Fraser River discharge and temperature. These predictions have a random-normal distribution around the point estimate and account for the covariation of discharge and temperature.

Below we describe the relationships used by the EWatch Program to forecast both temperature and discharge.

RIVER TEMPERATURE FORECAST MODELS

A variety of statistical models are employed to predict river temperatures based on historical data and environmental variables. These models range from simple linear regressions to more complex multivariate approaches. Below is an overview of the key modeling strategies used by the EWatch Program.

Historical temperature trends

To assess long-term changes in river temperature, a linear regression is fitted between calendar years and historical mean river temperatures. This model captures temporal trends and is used to project future water temperatures based on past patterns (Patterson et al. 2007).

Temperature-discharge correlation

River temperature often exhibits a negative correlation with discharge, meaning that higher flow rates tend to coincide with lower water temperatures (MacDonald et al. 2000). Leveraging this relationship, water temperature can be forecasted directly from predicted discharge values (Patterson et al. 2007).

Summer air anomaly

Each June, Environment and Climate Change Canada (EC) releases forecasts of summer air temperature anomalies—deviations from the standard reference period for climate monitoring (Patterson et al. 2007). These anomalies are derived from two distinct forecasting models, resulting in 12 anomaly values that are categorized as “near normal,” “below normal,” or “above normal” (Figure 1). To quantify air temperature forecast uncertainty, the EWatch program uses two different bootstrap methods. The first method attempts to mimic the actual forecasting process as outlined on the website of EC and the second method predicts forecast error using the historic trend in summer air anomalies. For each bootstrapped anomaly, predicted river temperatures are generated using a simple linear regression between historic summer anomalies and river temperature data (Patterson et al. 2007).

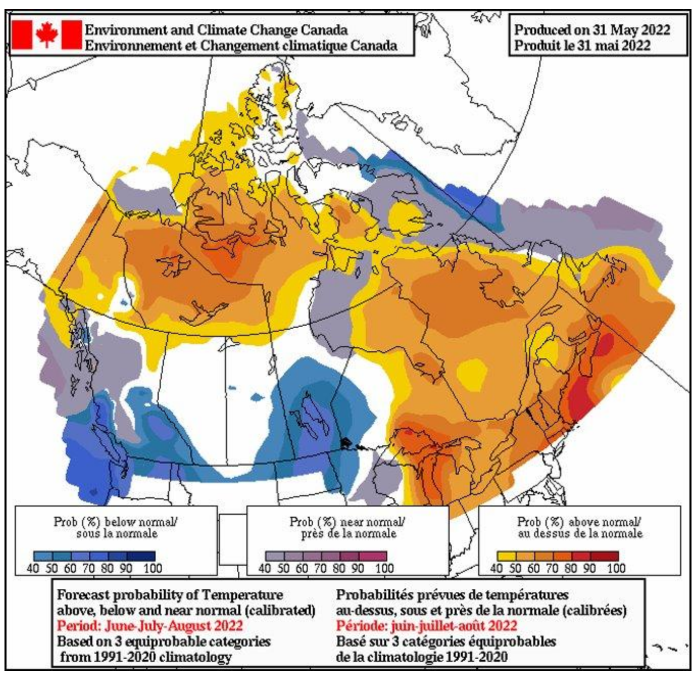

Figure 1*. Environment Canada's 2022 summer air temperature anomaly forecast evaluated relative to the climatological baseline (1991-2020). Forecast categories include “near normal,” “below normal,” and “above normal”.*

Spring air anomaly

Spring air anomalies, also published by EC in early June, are based on direct measurements. These values allow for the computation of prediction intervals using a linear regression between spring anomalies and river temperatures (Patterson et al. 2007).

Multiple regression

River temperature is influenced by a combination of factors, including discharge, air temperature, and broader climate trends. To account for these interdependencies, the EWatch Program employs multivariate linear regression models. These models explain a greater proportion of variance in historical river temperatures compared to single-variable regressions, improving predictive accuracy (Patterson et al. 2007).

RIVER DISCHARGE FORECAST MODELS

Forecasting river discharge involves a combination of climatological indices, hydrological modeling, and statistical regression techniques. The following text describes the method used to predict flow volumes in the Fraser River basin.

Snowmelt volume forecasts

Fraser River discharge is strongly influenced by winter snowpack and spring weather conditions. The BC River Forecast Centre (RFC) issues monthly Snow Survey and Water Supply Bulletins (Figure 2). These bulletins rely on hydrological models and regression analyses to produce basin-specific forecasts of snowmelt-derived water volume. The forecasts for April 1, May 1 and June 1 are used by the EWatch Program to estimate the volume of snowmelt expected to pass the Fraser River at Hope through September 30, assuming average weather conditions. This is done by converting the observed discharge at Hope, e.g. on April 1, to volume (volume = 0.0864 * discharge) and subtracting the run-off forecast from April to September. Similar estimates can be generated based on May 1 or June 1 forecast, and the associated uncertainty will be smaller due to the shorter prediction period.

Three sub-basins are critical to forecasting Fraser River runoff through September: the Upper Fraser River, the Quesnel River and the Thompson River. Together these sub-basins contribute approximately 69% of the total runoff volume observed at Hope during Fraser sockeye salmon migration. The runoff in these basins is monitored at Shelley, Quesnel and Spences Bridge respectively.

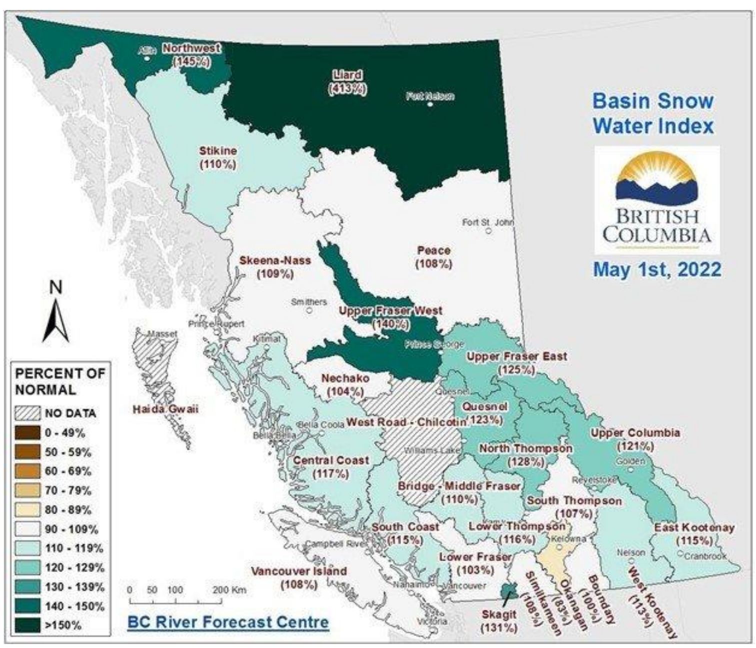

Figure 2. *Basin Snow Water Index for May 1, 2022, generated by the BC River Forecast Centre.*

Results

Table 2 illustrates the runoff forecast for the Fraser River through September 30 based on forecasts generated in April, May and June, 2022. In this example, the June forecast anticipates runoff levels to be 27% above the historical average, a substantial increase from the 9% above-average forecast produced earlier in the year. Figure 3 displays the forecasted daily water temperature and discharge values (±1 standard deviation) for the Fraser River in comparison to historical norms. During the early part of the 2022 season, coinciding with the migration of Early Stuart sockeye, water temperatures are expected to remain near average. However, discharge levels are projected to be elevated, which may cause migratory challenges for Early Stuart due to the increased flow rates. Later in the season, water temperatures are expected to exceed historical averages, coinciding with the migration of Summer run sockeye. These elevated temperatures may surpass the critical threshold of 19.4°C, beyond which sockeye survival rates decline (Eliason et al. 2011). To support pre-season planning, in June the EWatch Program annually generates 10,000 paired predictions of the 31-day average temperature and discharge, aligned with the 50% migration date for each management group. These predictions are provided to the PSC Secretariat and serve as key inputs for pre-season modeling to estimate management group-specific pDBEs.

Table 2. *Forecasted Fraser River runoff through September 30, 2022, based on snowpack forecasts generated in April, May and June 2022 and comparison with historical norms.*

	Apr 1 – Sept 30	May 1 – Sept 30	Jun 1 – Sept 30
Hope Volume Forecast ($kdam^3$)	70,240	63,955	58,543
Percent of historical norm	109%	109%	127%

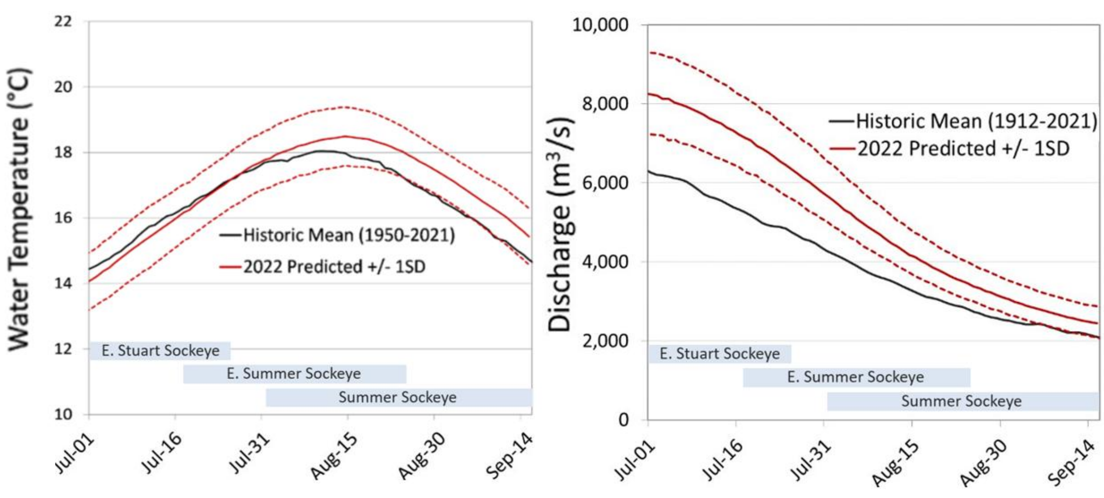

Figure 3*. Forecasted mean Fraser River water temperature at Qualark, B.C. and Fraser River discharge at Hope, B.C. for 2022, each shown with ± 1 standard deviation and compared against the historical mean.*

Planned changes and potential areas for improvement

Fraser Panel members often point out the need to communicate the uncertainties in the long-range environmental forecasts. This was also one of the conclusions of Patterson et al. 2007, where they noted the need to acknowledge and communicate the limitations of long-range environmental forecasts and quantify these uncertainties where possible.

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A5. Fraser River Sockeye Spawning Escapement Plan

C.G.J. Michielsens and S. Decker

Summary

Fisheries and Oceans Canada (DFO) provides pre-season escapement plans to the Pacific Salmon Commission (PSC) as part of their obligations under the Pacific Salmon Treaty (PST 2025, Annex IV, Chapter 4, Paragraph 4). Long-term escapement strategies for Fraser River sockeye stocks are derived through the FRSSI (Fraser River Sockeye Spawning Initiative) process and vetted through domestic consultation. The simulation model used as part of the process evaluates the performance of different control rules and assesses their robustness to different sources of uncertainty such as assumptions about population dynamics and future patterns of productivity. The resulting escapement plan is defined in terms of a TAM (Total Allowable Mortality) rule that accounts for both fishing and natural mortality due to adverse environmental conditions en route to the spawning grounds. The TAM rules for the different management groups are defined by Lower and Upper Fishery Reference Points, TAM caps and Low Abundance Exploitation rates (LAERs). The use of TAM rules as part of the escapement plan results in dynamic escapement goals that are updated repeatedly in-season based on updated information on run size and adopted Management Adjustments (MAs). The resulting pre-season TAC (Total Allowable Catch) is calculated as the aggregated Fraser River sockeye abundance available for harvest after the escapement target, the Management Adjustment, the agreed Fraser River Aboriginal Fisheries Exemption (AFE) and the expected catch in Panel-authorized test fisheries are deducted from the pre-season run size forecasts.

Introduction

As part of Fisheries and Oceans Canada (DFO) obligations under the Pacific Salmon Treaty (PST 2025, Annex IV, Chapter 4), escapement targets are provided to the Pacific Salmon Commission (PSC) prior to the fishing season. These spawning escapement targets are defined through an escapement plan that takes into account the run size as well as adverse environmental conditions that could reduce the probability of reaching those targets. The latter is achieved by increasing the escapement by adding fish to the target in the form of a Management Adjustment (MA, MacDonald et al. 2010). The escapement plan has been derived through the Fraser River Sockeye Spawning Initiative (FRSSI), a multi-year collaborative planning process by DFO to develop a long-term escapement strategy (Pestal et al. 2008). FRSSI was designed to improve understanding of the complex interactions between the population dynamics of individual stocks and escapement plans that, due to practical constraints on in-season management, are applied to groups of stocks, i.e., Management Units or MUs. The simulation model that is part of the FRSSI process allows for the evaluation of the performance of different escapement strategies through the application of different harvest control rules. In addition, it explores the robustness of these strategies to different key sources of uncertainty such as possible alternative population dynamics and future patterns of productivity. The use of a harvest control rule as part of the escapement plan results in dynamic escapement goals that are updated repeatedly during the fishing season from updated information on run size and in-season environmental conditions (Pestal et al. 2012).

Data

The simulation model used within the FRSSI process is populated using the stock-recruitment data for 19 distinct Fraser River sockeye stocks that, on average, make up 98.6% of the total sockeye run for the Fraser River (Pestal et al. 2008). These data are also used for the forecast (Chapter A1) and are described in detail in Chapter 10 and Grant et al. (2010). Forecasts for most of the stocks rely on spawning escapement (Chapter C1) and estimates of returns by age (Chapter C2), while some stocks also have historical time series of juvenile abundance in terms of fry or smolts (Grant et al. 2010).

Method

The simulation model developed as part of the FRSSI process aims to evaluate the long-term performance of different harvest control rules under a wide range of alternative biological assumptions and hypothesized future states of nature (Chaput et al. 2013). The model includes 19 different stocks, grouped into 4 MUs (Early Stuart, Early Summer run, Summer run and Late run). The abundance of the stocks is simulated into the future based on historical stock-recruitment relationships. The simulation models differ depending on the assumptions they make on the population dynamics of the stocks, which includes different assumptions about stock-recruit relationships and interactions between cycle lines, different future trends in productivity and natural mortality. Within the simulations, the different population dynamic scenarios are used to evaluate specific escapement strategies for the different management groups, defined by a harvest control rule. The outputs from the model simulations are used to track the status of the individual component stocks.

For Fraser River sockeye salmon, the ability to achieve the escapement goal for each individual Management Unit (MU) is not only impacted by fisheries, but also by mortality caused by adverse environmental conditions. The specific control rules for each Fraser sockeye MU is therefore formulated in terms of a TAM (Total Allowable Mortality) rule (Figure 1) and accounts for both fishing and natural mortality. The TAM rule is defined by a Lower Fishery Reference Point (LFRP), an Upper Fishery Reference Point (UFRP), 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 Fraser sockeye MUs or other salmon species, is permitted, and this incidental harvest needs to remain well below the Low Abundance Exploitation rate. In a case where the in-season run-size estimate is above the Upper Fishery Reference Point, the Total Allowable Mortality (TAM) rate remains fixed at the TAM cap. The projected MA is subtracted from the TAM to calculate the final allowable ER calculation (DFO 2022). Between the Lower and Upper Fishery Reference Points, a fixed escapement target, equal to the Lower Fishery Reference Point, is assumed. The different components of the TAM rule are derived through the simulation modelling and the FRSSI process and vetted through domestic consultation (Chaput et al. 2013). The pre-season TAC (Total Allowable Catch) is derived using the TAM rule and calculated as the aggregated Fraser River sockeye abundance available after the escapement target, the management adjustment, the agreed Fraser River Aboriginal Fisheries Exemption and the expected catch in Panel-authorized test fishing catch are deducted from the pre-season run size forecast.

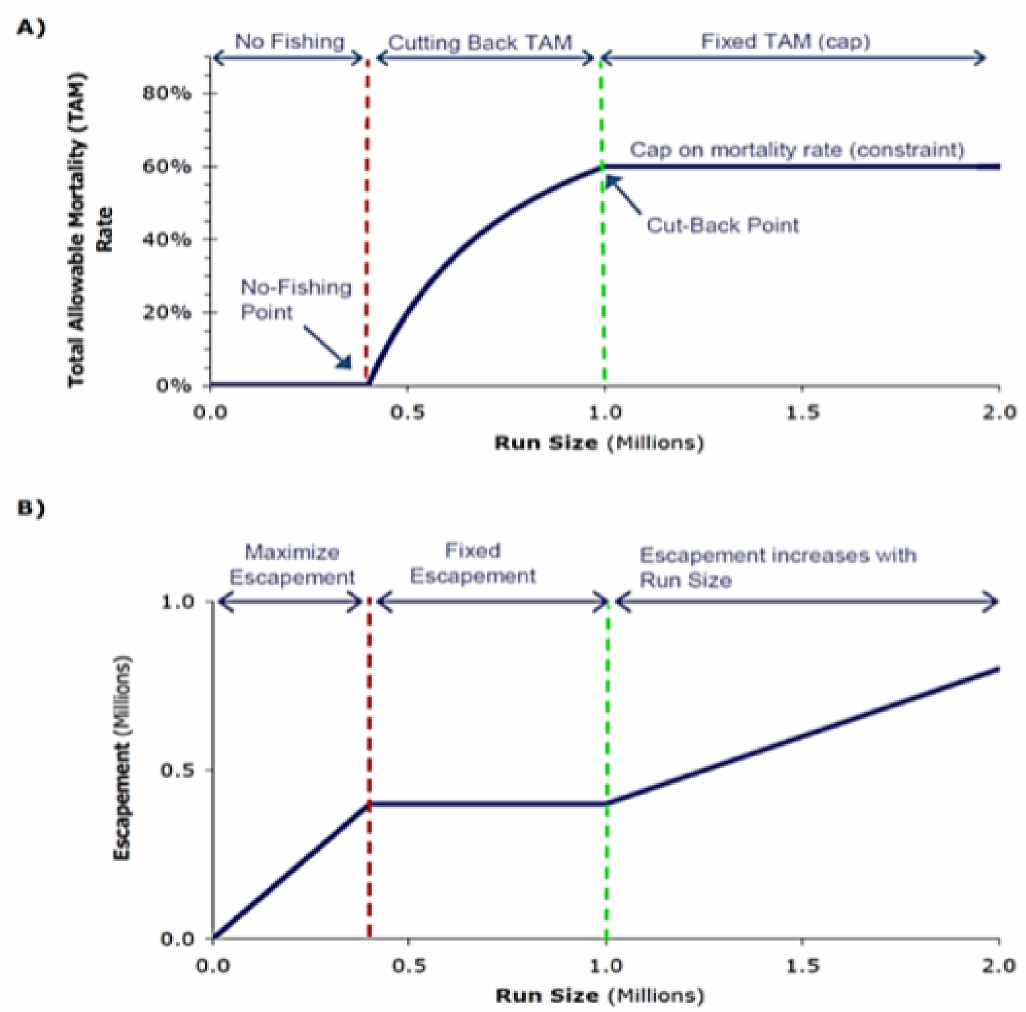

Figure 1. *Graphical presentation of the Total Allowable Mortality rule for Fraser River sockeye salmon (DFO 2022). The Lower Fishery Reference Point is here represented as the No-Fishing Point while the Upper Reference Point is represented as the Cut-back Point. The Low Abundance Exploitation Rate (LAER) is applied after the TAM rule and is not shown in the figure.*

Results

The FRSSI process is used to inform a pre-season spawning escapement plan (Table 1). The top table of Table 1 describes the TAM rule: the low abundance exploitation rate (LAER), the TAM cap, the Lower and the Upper Fishery Reference Points and the pre-season pMA at the p50 level of the Fraser River sockeye forecast (Chapter A1). The subsequent tables illustrate the application of the TAM rule for different run size forecast levels for each of the four management groups. More specifically, at the different forecast levels, the table provides the % TAM implied by the forecast level (TAM rule (%), the number of fish added to the escapement target based on the assumed pMA (Escapement Target MA), the sum of the escapement target and the MA, the low abundance exploitation rate, and the available exploitation rate given the run size, escapement target and MA. If the run size is smaller than the escapement target plus MA, the available exploitation rate is 0%. If the available exploitation rate exceeds the LAER, the allowable exploitation rate will equal the available rate. If the available exploitation rate is lower than the LAER, the allowable exploitation rate will equal the LAER but it should be emphasized that a LAER is not a target but allows for by-catch of one management group in fisheries directed at other management groups or species with available surpluses. Table 1 also translates the allowable exploitation rate into the number of sockeye available to be harvested. In order to translate this into a TAC (Total allowable catch) for the aggregate management groups, the DF Fisheries Exemption (AFE) and test fishing catches need to be removed. Subsequent information in the table illustrates the performance of the TAM rule in terms of the resulting escapement when perfectly executed and assuming the pre-season MA forecast is correct. More specifically, it calculates the number of spawners that are predicted to reach the spawning grounds while taking into account en route loss and compares these numbers against the numbers observed in the brood year (BY spawners) and on average on the cycle, both in absolute numbers as well as in percentage.

Table 1. *Spawning escapement plan for Fraser River sockeye salmon in 2022, provided to the Panel by Fisheries and Oceans Canada and based on Fraser River Sockeye Spawning Initiative (FRSSI) guidelines with input from domestic consultations (DFO 2022).*

	Harvest Rule Parameters				
Management Unit	Low Abundance ER (LAER)	TAM Cap	Lower Fishery Reference Point	Upper Fishery Reference Point	Pre-season pMA @p50
Early Stuart	10%	20%	108,000	135,000	1.00
Early Summer (w/o misc)	20%	50%	180,000	360,000	0.59
Summer (w/o misc)	20%	50%	1,250,000	2,500,000	0.06
Late (w/o misc)	20%	50%	1,100,000	2,200,000	0.22

Management Unit		Pre-season Forecast Return p10	p25	p50	p75	p90
	lower ref. pt. (w misc)	108,000	108,000	**108,000**	108,000	108,000
	upper ref. pt. (w misc)	135,000	135,000	**135,000**	135,000	135,000
Early Stuart	forecast	39,000	63,000	**105,000**	172,000	268,000
	TAM Rule (%)	0%	0%	**0%**	20%	20%
	Escapement Target	39,000	63,000	**105,000**	137,600	214,400
	MA	39,000	63,000	**105,000**	137,600	214,400
	Esc. Target + MA	78,000	126,000	**210,000**	275,200	428,800
	LAER	10%	10%	**10%**	10%	10%
	Available ER at Return	0%	0%	**0%**	0%	0%
	Max. Allowable ER	10%	10%	**10%**	10%	10%
	Max. Allowable Harvest	3,900	6,300	**10,500**	17,200	26,800
	2022 Performance					
	Projected S (after MA)	17,600	28,400	**47,300**	77,400	120,600
	BY Spawners	48,489	48,489	**48,489**	48,489	48,489
	Proj. S as % BY S	36%	59%	**98%**	160%	249%
	cycle avg S	35,041	35,041	**35,041**	35,041	35,041
	Proj. S as % cycle S	50%	81%	**135%**	221%	344%

Management Unit		Pre-season Forecast Return p10	p25	p50	p75	p90
Early Summer	*lower ref. pt. (w misc)*	375,500	375,500	**375,500**	375,500	375,500
(w/o RNT)	*upper ref. pt. (w misc)*	751,000	751,000	**751,000**	751,000	751,000
	forecast (incl. misc)	383,840	764,100	**1,579,200**	3,159,400	5,685,600
	TAM Rule (%)	2%	50%	**50%**	50%	50%
	Escapement Target	375,500	382,050	**789,600**	1,579,700	2,842,800
	MA	221,500	225,400	**465,900**	932,000	1,677,300
	Esc. Target + MA	597,000	607,450	**1,255,500**	2,511,700	4,520,100
	LAER	20%	20%	**20%**	20%	20%
	Available ER at Return	0%	21%	**20%**	21%	20%
	Max. Allowable ER	20%	21%	**20%**	21%	20%
	Max. Allowable Harvest	76,800	156,700	**323,700**	647,700	1,165,500
	2022 Performance					
	Projected S (after MA)	194,200	383,900	**793,100**	1,586,100	2,853,700
	BY Spawners	718,390	718,390	**718,390**	718,390	718,390
	Proj. S as % BY S	27%	53%	**110%**	221%	397%
	cycle avg S	350,379	350,379	**350,379**	350,379	350,379
	Proj. S as % cycle S	55%	110%	**226%**	453%	814%

Table 1, *continued.*

Management Unit		Pre-season Forecast Return				
		p10	p25	**p50**	p75	p90
Summer	*lower ref. pt. (w misc)*	1,258,200	1,258,200	**1,258,200**	1,258,200	1,258,200
(w. RNT & Har)	*upper ref. pt. (w misc)*	2,516,300	2,516,300	**2,516,300**	2,516,300	2,516,300
	forecast	1,239,370	2,231,200	**4,402,600**	8,904,000	17,468,000
	TAM Rule (%)	0%	44%	**50%**	50%	50%
	Escapement Target	1,239,370	1,258,200	**2,201,300**	4,452,000	8,734,000
	MA	74,400	75,500	**132,100**	267,100	524,000
	Esc. Target + MA	1,313,770	1,333,700	**2,333,400**	4,719,100	9,258,000
	LAER	20%	20%	**20%**	20%	20%
	Available ER at Return	0%	40%	**47%**	47%	47%
	Max. Allowable ER	20%	40%	**47%**	47%	47%
	Max. Allowable Harvest	247,874	897,500	**2,069,200**	4,184,900	8,210,000
	2022 Performance					
	Projected S (after MA)	932,000	1,253,700	**2,193,400**	4,436,000	8,702,500
	BY Spawners	1,750,333	1,750,333	**1,750,333**	1,750,333	1,750,333
	Proj. S as % BY S	53%	72%	**125%**	253%	497%
	cycle avg S	922,714	922,714	**922,714**	922,714	922,714
	Proj. S as % cycle S	101%	136%	**238%**	481%	943%

Management Unit		Pre-season Forecast Return				
		p10	p25	**p50**	p75	p90
Late	*lower ref. pt. (w misc)*	1,104,800	1,104,800	**1,104,800**	1,104,800	1,104,800
(w/o Har)	*upper ref. pt. (w misc)*	2,209,600	2,209,600	**2,209,600**	2,209,600	2,209,600
	forecast	711,400	1,603,600	**3,688,000**	8,160,000	18,285,000
	TAM Rule (%)	0%	31%	**50%**	50%	50%
	Escapement Target	711,400	1,104,800	**1,844,000**	4,080,000	9,142,500
	MA	156,500	243,100	**405,700**	897,600	2,011,400
	Esc. Target + MA	867,900	1,347,900	**2,249,700**	4,977,600	11,153,900
	LAER	20%	20%	**20%**	20%	20%
	Available ER at Return	0%	16%	**39%**	39%	39%
	Max. Allowable ER	20%	20%	**39%**	39%	39%
	Max. Allowable Harvest	142,280	320,720	**1,438,300**	3,182,400	7,131,100
	2022 Performance					
	Projected S (after MA)	466,700	1,052,000	**1,844,800**	4,081,600	9,146,200
	BY Spawners	1,584,836	1,584,836	**1,584,836**	1,584,836	1,584,836
	Proj. S as % BY S	29%	66%	**116%**	258%	577%
	cycle avg S	2,634,372	2,634,372	**2,634,372**	2,634,372	2,634,372
	Proj. S as % cycle S	18%	40%	**70%**	155%	347%
Allowable Harvest (TF, US, CDN)		470,854	1,434,720	**3,952,300**	8,253,300	16,931,400
Total projected spawners		1,629,200	2,718,000	**4,878,300**	10,180,100	20,820,700

Conservation status and management trade-offs

Significant conservation concerns exist for a number of Fraser sockeye stocks that are intercepted in mixed-stock fisheries along the migration route. The most recent Committee on the Status of Endangered Wildlife in Canada (COSEWIC) reviews (COSEWIC 2017, 2021) assessed ten Fraser sockeye stocks (Designatable Units, DUs) as endangered (Takla-Trembleur-EStu, Bowron-ES, Taseko-ES, Takla-Trembleur-Stuart-S, Quesnel-S, Seton-L, Harrison (U/S)-L, Cultus-L, Momich-ES, Fraser-ES), two as threatened (North Barriere, Widgeon) and three as extirpated. In most recent (2017) Wild Salmon Policy integrated status assessment (Grant et al. 2020), nine stocks (Conservation Units, CUs) were assessed as being in the red (poor) zone, given their high extirpation risk and likelihood of being listed as endangered by COSEWIC. These CUs require evaluations of recovery potential, identification of appropriate stock recovery activities as well as management considerations aimed to protect the stock and minimize the risk of extirpation. Four CUs were in the amber status zone, indicating they are at risk of further decline if current pressures continue but are at low risk of extirpation, while two had red/amber status. The complete summary of the most recent status assessment of Fraser sockeye CUs

(Grant et al. 2020) identified an additional eight extirpated and five data deficient CUs. DFO recently transitioned from an Integrated Status Assessment approach, which was time and resource intensive, with the result that assessments were often 5-10 years out of date, to the new Rapid Status Assessment approach, which allows the status of CUs to be reassessed on an annual basis (Pestal et al. 2023).

While the goal of Fraser sockeye management is to ensure escapement targets are reached at the MU level (PST 2025), the impact of different TAM rules on individual stocks is taken into account through the FRSSI process (Pestal et al. 2008). The Wild Salmon Policy sets out minimal requirements for harvest strategies to be compliant with the Precautionary Approach (DFO 2018). Under the WSP, stock-specific escapement benchmarks have been developed for Fraser sockeye stocks as biological indicators of stock health (Grant et al. 2020). FRSSI simulation modeling emphasized comparisons of projected escapements for individual stocks to their respective benchmarks, for example by evaluating how frequent the four-year running average escapement falls below the benchmark. A range of alternative benchmarks was explored, with the highest and lowest values used to bound the performance measures. The FRSSI simulation model was used to evaluate trade-offs between maximizing harvest opportunities at the MU level and minimizing risk of individual stocks not meeting biological benchmarks, across a range of values for the harvest control rules (LFRP, UFRP, TAM rule, TAM cap and LAER) (Pestal et al. 2012). For example, the simulation results can be used to identify a LFRP value for escapement for a particular MU that, if achieved, would result in a high probability of escapements for individual component stocks exceeding their respective WSP benchmarks.

Another key difference between Fraser sockeye fisheries management objectives and WSP conservation objectives is that the quantitative metrics used in COSEWIC and WSP status assessments (e.g., relative abundance, absolute abundance, trends in long-term and short-term abundance), and the benchmarks associated with some of these metrics are calculated based on multiple years of data (COSEWIC 2012, Pestal et al. 2023). Thus, COSEWIC and WSP statuses are unlikely to change based on the number of sockeye returning in an individual year. By contrast, the fisheries reference points (UFRP, LFRP) used for in-season fisheries management are applied to the return in a given year only. As a result, situations can arise, as for Early Stuart sockeye in 2025, in which annual returns are strong relative to these fisheries reference points, while the longer-term conservation status of the MU/CU remains poor and considered endangered, in the red zone.

Overall, annual pre-season escapement plans for Fraser sockeye are best understood as a mechanism for balancing annual fisheries management decisions with long-term conservation and rebuilding objectives. Escapement plans are developed with the intent of maintaining or rebuilding stocks to healthy levels of abundance over the longer term, as defined by COSEWIC and WSP metrics and benchmarks. They do so while taking into account potential limitations of forecasted returns in the current year and the competing goal of providing sustainable fishing opportunities.

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A6. Test Fishing and Hydroacoustic Schedule

T. Sutherland

Summary

The Pacific Salmon Commission (PSC) operates two main field programs to aid in the assessment of Fraser River sockeye and pink salmon abundances: the test fishing program (Chapter B1) and the hydroacoustic program (Chapter B14). The proposed annual schedule for the various test fisheries is developed using a template that incorporates the historical timing of the different management groups. The actual in-season start and end dates for the test fisheries are subject to change, depending on pre-season and in-season management considerations and at the discretion of the Fraser River Panel (FRP). The start date of the PSC hydroacoustics program is determined by the historical timing of the Early Stuart management group. The program ends when sockeye and pink salmon migration past the site have terminated. Unlike the test fishing program, the schedule for the hydroacoustics program is determined and approved by PSC staff. Similarly, the Qualark hydroacoustics program located upriver from the Mission site is operated and scheduled by Fisheries and Oceans Canada (DFO).

Introduction

Under the Pacific Salmon Treaty (PST 2025), PSC staff are responsible for providing recommendations for in-season run size estimates for Fraser River sockeye and pink salmon. To fulfill this responsibility, the PSC operates two field programs to gather the necessary data and information: the test fishing program, and the Mission hydroacoustics program. Each year, PSC staff develop a pre-season test fishing and hydroacoustic schedule based on the expected timing and abundance of the returning sockeye and pink salmon, following pre-designed scheduling templates. Further adjustments may be made to the schedule depending on year-specific conditions or guidance from the Fraser River Panel (FRP).

Methods

Improvements to developing the pre-season test fishing schedule occurred in 2018, following the review and workshop of Fraser River test fisheries (Nelitz et al. 2018). The workshop report recommended creating a formal test fishing scheduling template that could be followed each year. This was achieved by analyzing the historical timing of the four sockeye management groups as well as pink salmon from 1986 to 2018, summarizing the historical migration timing for each group, and determining a framework for proposing start and end dates for the test fisheries that would be consistent by cycle line. The schedule derived from the template is used as the base case scenario, and modifications may be proposed depending on year-specific considerations as directed by the FRP. Different cycle lines have different timing characteristics as well as different stock and species compositions. The three resulting scheduling scenarios are: a) High sockeye abundance, no pinks (2026 cycle line), b) moderate sockeye abundance plus pinks (2023 and 2025 cycle line), and c) low sockeye abundance, no pinks (2024 cycle line). The schedule templates based on these 3 scenarios are discussed in further detail in the sections below.

Test fishing schedules proposed in February or April based on these templates may be modified in June based on the timing forecast for Early Stuart and Chilko provided by DFO (Chapter A2). Only when the forecast in June indicates the timing is 4 or more days earlier than previously assumed would the schedule be moved forward 3 days (Figure 1). Adjustments to delay the opening of marine gillnets are usually not considered given the uncertainty in the forecast. In-season data collected from the marine and in-river gillnets allow for the in-season adjustment of the start timing of the purse seine test fishery. In July, if the timing of earlier components of the run assessed by the in-river and marine gillnets appears to be 4 or more days later than the June forecast, the opening of the marine purse seine test fishery could be delayed by 3 days. Further pre-season and in-season modifications of the schedule, such as decisions about test fishery end dates, will depend on the potential return abundance, conservation concerns and fisheries management considerations.

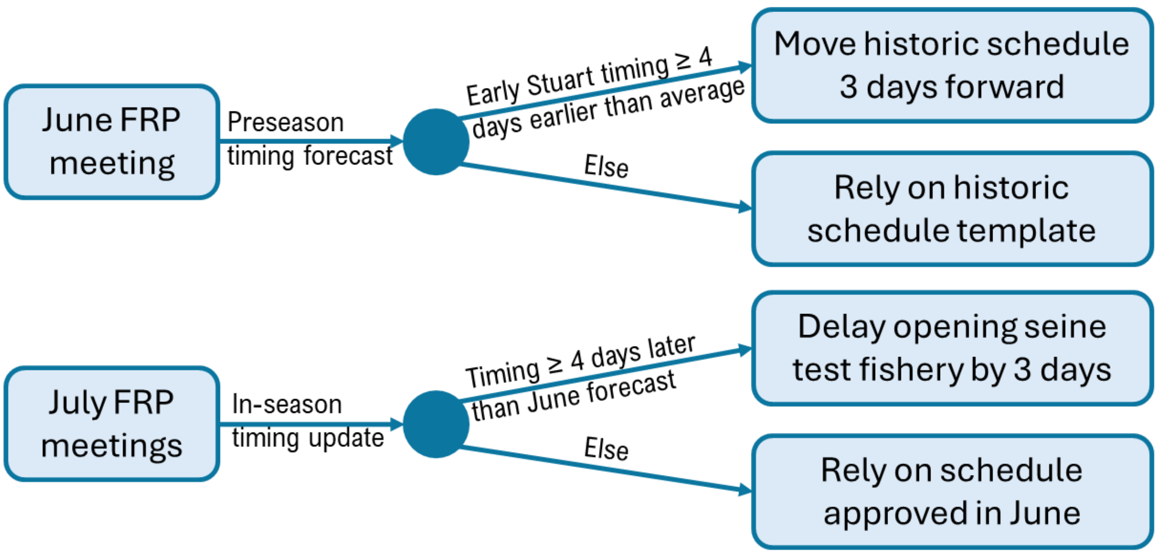

Figure 1. *Decision rules associated with adjustments to the test fishing schedule based on preseason and in-season timing estimates.*

MARINE TEST FISHERIES

The core marine test fishing program consists of the marine gillnet and purse seine test fisheries in Areas 12 and 20. These test fisheries are scheduled on all cycle lines, regardless of sockeye and pink salmon abundance (Nelitz et al. 2018, Table 1). Historically, the marine gillnet test fisheries aim to assess Early Stuart and Early Summer run sockeye abundance while the marine purse seine test fisheries are used to assess Summer and Late run sockeye and pink salmon abundance. Marine gillnet test fisheries can be used to assist in the assessment of the Summer run but do not produce abundance estimates that are as precise as those produced by the purse seine test fishery. Gillnet test fishery data are not reliable for the assessment of Late run and pink salmon. On low abundance sockeye years, marine gillnets may be excluded from the core test fishing program depending on the in-season assessment needs and conservation concerns for Early Stuart and Early Summer run stocks, e.g. 2024 (PSC 2025).

In general, the proposed start dates for each marine test fishery are designed to ensure that a specified proportion of the earliest management group that it is intended to assess is not missed prior to test fishery start-up. These dates are determined by considering the historical marine timing dates for each management group (Chapter C4). Additionally, these fisheries need to generate at least 6 days worth of paired data with the Mission hydroacoustics program to provide reliable in-season estimates of the expansion line (inverse catchability, Chapter B5). As these fisheries vary spatially with respect to their distance from Mission, additional days are added or subtracted from the Area 20 timing date to account for differential fish travel time to the Mission hydroacoustic site.

Table 1. *Overview of the marine test fisheries considered under different abundance levels and species composition scenarios (x = included, (x) = depends).*

Marine test fisheries	High sockeye abundance, non pink year	Moderate sockeye abundance, pink year	Low sockeye abundance, non pink year
Area 12, 20 gillnets	X	x	(x)
Overlap with purse seines	X	(x)	
Area 12, 20 purse seines	X	x	x
Area 13	(x)		
Area 29 Gulf Troll	X		
Area 5 gillnet	X	(x)	
Area 7 reefnet	X	x	(x)

The start and end dates of the Area 12 and 20 test fisheries in the test fishing schedule template are derived to offer optimal coverage of the run to inform in-season management decisions associated with marine fisheries targeting Fraser sockeye and pink salmon. In this case, optimal means having at least 6 days of matching test fishing and Mission hydroacoustic data before the peak migration timing, resulting in the availability of an in-season expansion line which can greatly improve the accuracy and precision of the daily abundance estimates. The end dates for the Areas 12 and 20 marine gillnets are selected to either provide adequate coverage of the Early Summer run migration or to provide a sufficient overlap with the purse seine test fisheries for in-season assessment and management needs (Figure 2).

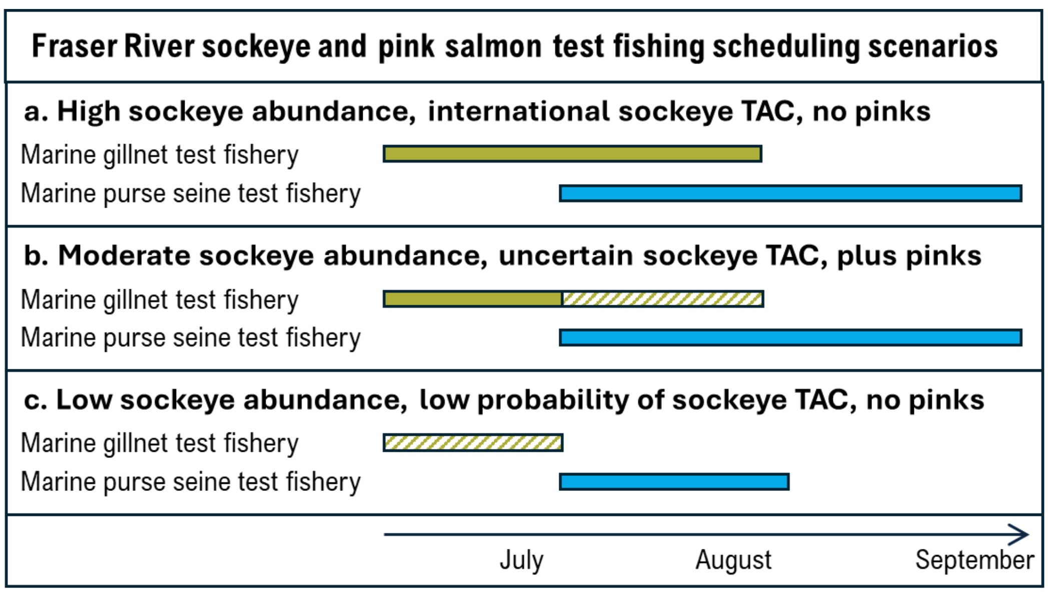

Figure 2. *Overview of the different marine test fishing schedules depending on sockeye and pink salmon abundance and the potential for international sockeye TAC. A twelve day overlap between gillnet and purse seine test fisheries ensures the availability of an in-season catchability estimates at the time the gillnet test fishery is terminated. Shaded test fishing periods may be further removed depending on sockeye abundance forecast and the probability of international TAC e.g. 2024.*

On high abundance years, at least 12 days of overlap are desired between gillnets and purse seine test fishery data. This ensures that the less precise purse seine test fishery abundance estimates using the historical expansion line is to a certain extent compensated for by the increased abundance precision provided by operating the gillnet and purse seine test fisheries simultaneously. During high abundance sockeye years, the marine gillnet test fishery may operate longer than this, if it is expected that the benefits to in-season assessment (e.g. additional stock identification samples, operational redundancy, and independent/alternative abundance estimates) outweigh the costs (i.e. financial expenses and fish mortality). On years when there is a high probability that return abundances will be too low to generate harvestable surplus or international total allowable catch (TAC), there may be no overlap of the gillnet and purse seine test fishery in the scheduling template and the first 12 days of purse seine derived abundance will be based on the historic expansion line.

The end dates for the Area 12 and 20 purse seines are based on the historical migration timing of sockeye and pink salmon through marine areas. On years with Fraser pink returns (odd years), or when Late run abundance is high enough to generate harvestable surplus, the marine purse seines continue into September to provide near full coverage of Late run sockeye or pink salmon. Because these groups exhibit delay behaviour, the marine purse seines are the primary source of in-season assessment information available in a timely manner for the prosecution of marine fisheries. On even years, the Area 20 purse seine in Juan de Fuca Strait may be scheduled to end earlier than the Area 12 purse seine in Johnstone Strait as the diversion rate is generally high at the end of the season. On years without pink salmon, and a small, forecasted return of Late run sockeye, the marine purse seines may be scheduled to provide coverage of the marine migration of the Summer run with an end date in early August. If no marine fisheries are planned, the Late run can be assessed once these salmon pass the Mission hydroacoustics site. Figure 3 illustrates the marine test fishing scheduling differences across different cycle-line years for 2022 to 2025.

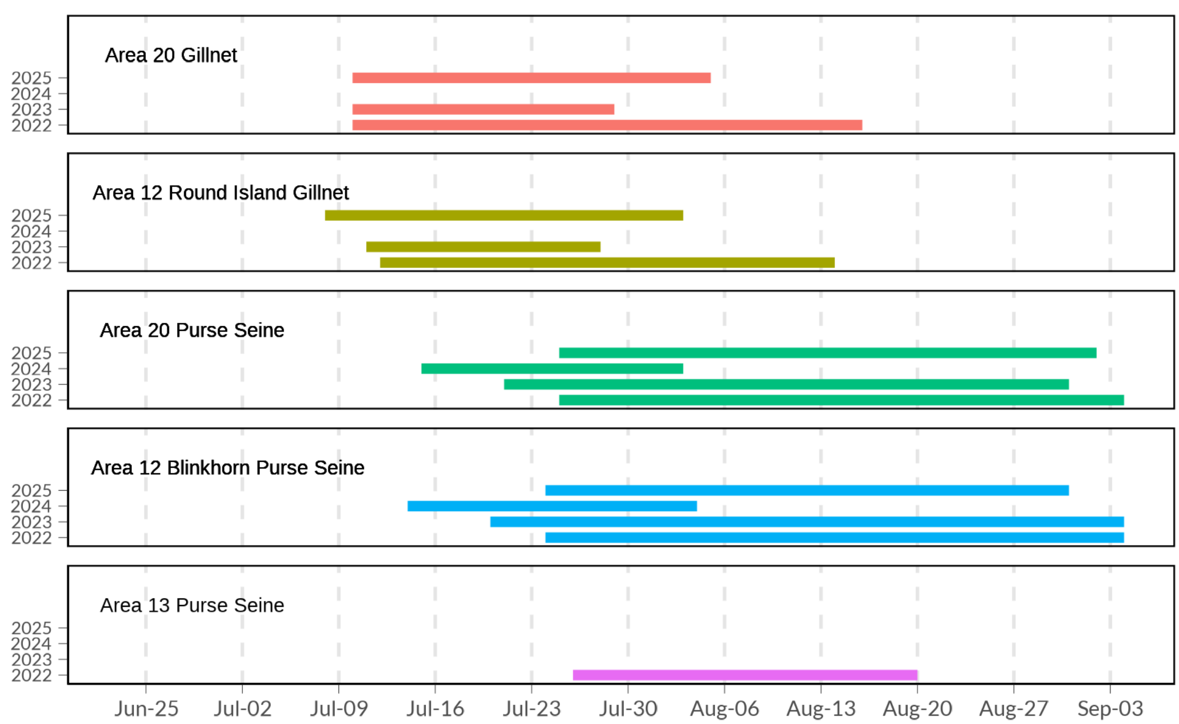

Figure 3. *Comparison of different marine test fishing schedules across cycle years.*

The Area 13 purse seine test fishery has been consistently used to confirm abundances in Johnstone Strait on high abundance years, but analyses have indicated that for most years there is limited difference in run size assessments when including the Area 13 test fishery versus relying on Area 12/20 data only, and the limited differences can signify both decreased as well as increased error in the run size (Nelitz et al. 2018). In some years, including the Area 13 test fishery can provide a stronger early signal that abundances are lower than anticipated. This test fishery is therefore usually only scheduled on high sockeye abundance years during periods when run size estimates are still uncertain, but high-impact fisheries may be scheduled to be executed.

The Area 29 Gulf Troll test fishery is not used directly to estimate abundances of daily migration blocks, but rather to provide snapshot estimates of the presence of sockeye delaying their upstream migration in the Strait of Georgia (Chapter B22). In recent years, this fishery has been used to assess delaying Late run stocks on the Shuswap dominant years (2026 cycle). The fishery generally operates for four weeks, beginning in late August, and may be extended in-season at the discretion of the FRP. The start date is based on the observed Late-run peak in Area 20, incorporating an approximate four-day travel time to Area 29. Historically, the Area 29 Gulf Troll test fishery operated three days per week with two vessels, surveying six quadrants each week. Beginning in 2026, a revised and more cost-effective sampling design has been adopted, consisting of one vessel operating two days per week and surveying two quadrants weekly. This revision was adopted by the FRP following a review of the impacts to data quality with a reduced number of surveyed quadrants (Chapter B22). The review concluded that the reduction in surveyed quadrants would not impact the assessment quality. While the revised design limits the ability to evaluate the full spatial distribution of Late-run sockeye throughout the Strait of Georgia, it maintains the core monitoring objectives of the program. Importantly, the reduced cost of the program increases the likelihood that the test fishery can be operated more consistently across years, including non-dominant cycle years. Although Area 29 Gulf Troll data could potentially contribute to pink salmon assessment, this test fishery has only been operated in two previous pink years since adult pink salmon enumeration began at the Mission hydroacoustics site, i.e., in 2009 and 2011. Operating this test fishery under the revised design, and on pink salmon dominant years, will provide additional information to evaluate whether the program could serve as a reliable tool for pink salmon assessment.

The Area 5 marine gillnet and the Area 7 reefnet test fisheries are uniquely scheduled to precede commercial or Treaty Tribal openings for Fraser River sockeye or pink salmon. Typically, 10 days are approved each year for each of the Area 5 and Area 7 test fisheries, with the exact dates being assigned in-season at the direction of the FRP. The Area 5 gillnet has historically preceded U.S. commercial fisheries in U.S. Areas 4B, 5, and 6C during the last week of July. When sockeye abundance estimates are moderate, it will depend on US fishing opportunities whether the Area 5 test fishery is needed. The Area 7 reefnet test fishery is typically deployed as needed for 3-days preceding a U.S. commercial fishery in U.S. Areas 6, 7, and 7A.

IN RIVER TEST FISHERIES

The Whonnock and Qualark test fisheries are used to assess the species composition for the hydroacoustic sites at Mission and Qualark, respectively (Chapter B19). The Whonnock test fishery's catch-per-unit-effort is also used for all passage calculations prior to, and after the operation of the Mission hydroacoustics program and to estimate sockeye abundances when pink salmon dominate abundances in the river. The Whonnock test fishery is the first to begin operations in the season and its start date is based on historical Early Stuart reconstructed daily abundance estimates above 100 fish. The start date for the Qualark test fishery is July 2 annually, one day later than the scheduled start of the Qualark hydroacoustics program, except it may be delayed on low abundance years (e.g., 2024) when there are conservation concerns (e.g., Early Stuart, Bowron). It is operated and scheduled by Fisheries and Oceans Canada (DFO).

The below bridge test fishery, historically the Cottonwood test fishery (Michielsens and Martens 2022), which has been replaced by the Brownsville test fishery as of 2025 (Sutherland et al. 2026), is primarily used for stock identification purposes to have an early indication of the stock composition of sockeye moving into the river. The start date for Brownsville Bar is based on the historical 50% migration date for Early Stuart.

The in-river test fisheries are scheduled to operate until the daily reconstructed abundances are estimated to be below 100 fish. In practice, the Whonnock test fishery continues operating until there are 3 consecutive days with a catch of 0 sockeye, whereas the Brownsville Bar test fishery will typically end earlier as its usefulness in assessing stock identification decreases late in the season when the majority of the fish are Late-run sockeye or pink salmon, or when samples are low. The Qualark test fishery operates until the end of the Qualark hydroacoustics program. Figure 4 illustrates the start and end dates for different cycle-lines between 2022 – 2025 for the in-river test fisheries.

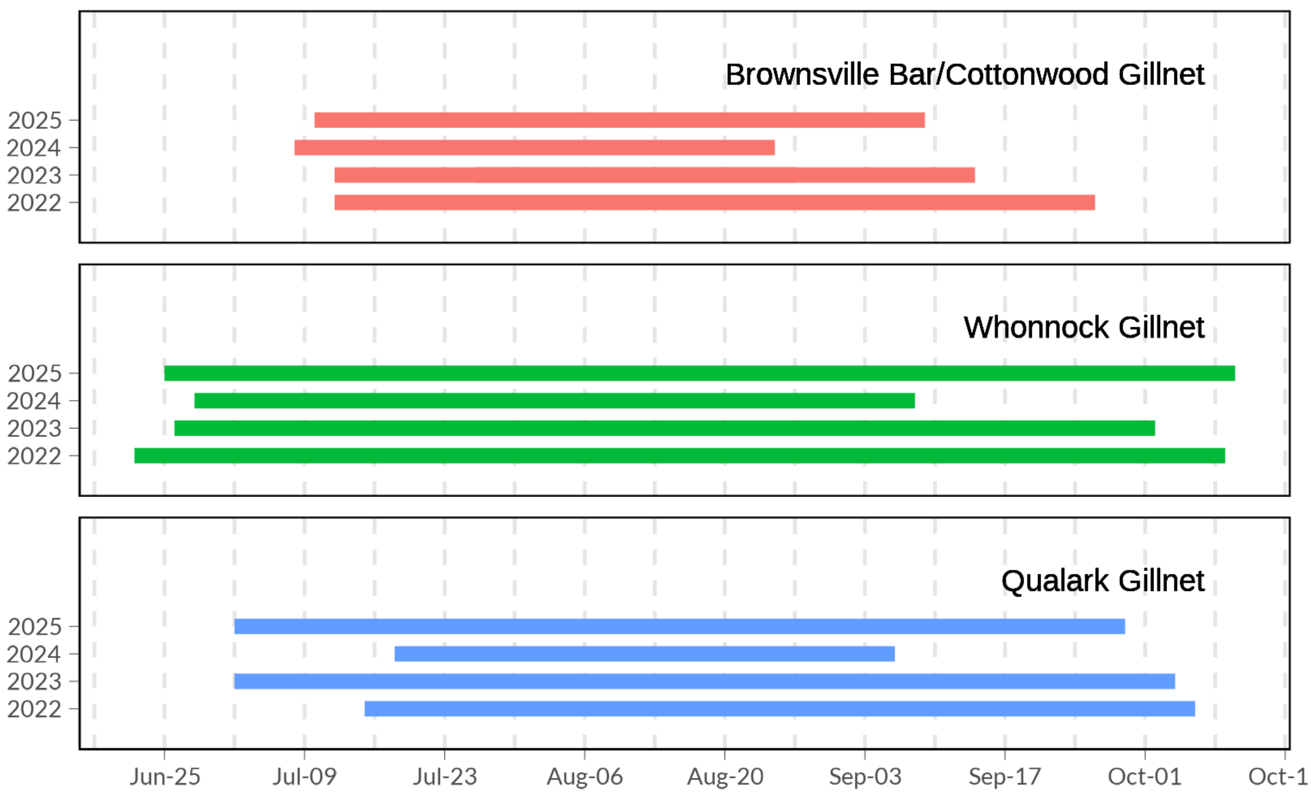

Figure 4. *Comparison of the start and end dates for the in-river test fisheries between 2022 and 2025. These years cover the transition period from the Cottonwood test fishery to the current Brownsville Bar test fishery, shown jointly in the upper panel as they occupy a similar location and serve the same assessment purpose.*

HYDROACOUSTICS

In addition to the test fishing program, the PSC operates a hydroacoustics program at a site near Mission, B.C. (Chapter B14). Unlike the test fishing program, the Mission hydroacoustics schedule is developed and determined by PSC Staff. The schedule for the Mission program is dependent on the cycle-line and timing of the sockeye and pink migration. The start date for the Mission program is based on the ability to capture the peak of the Early Stuart run. This date is determined by the marine timing date of the Early Stuart group and assuming a 6-day travel time to the Mission site. On higher discharge years, the program may modify operations to rely on the system on the left bank and the transecting vessel only. At normal, or low discharge years, the program may begin operations at full capacity. The end date for the Mission hydroacoustics program is determined in-season by its usefulness in capturing the tail of the pink run or the final upstream migration of delaying sockeye. The Mission program may operate until the first week of September or extend until the first week of October, depending on the cycle-line. On Late Shuswap-dominant sockeye years, pink salmon dominant years, or years with a significant amount of delaying sockeye stocks, the season extends into October. For more details on the hydroacoustics operations and data collection, see Chapters B14-B17.

The goal of the Qualark hydroacoustics program is to provide additional insight on fish passage during in-season assessments (Conrad et al. 2019). It is scheduled to begin operations on July 1 annually and is operated by DFO. The in-season start date of the hydroacoustic program may be delayed due to high discharge. The end date for this program is based on the Mission hydroacoustics program end date and typically ends 2 – 3 days later. Figure 5 illustrates the start and end dates for both the Mission and the Qualark hydroacoustics programs between 2022 to 2025.

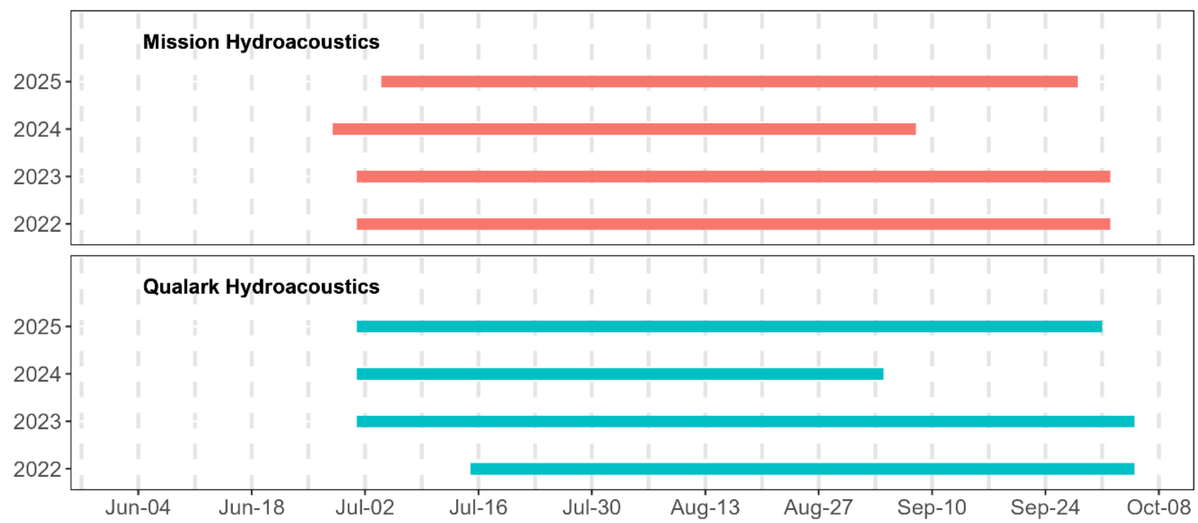

Figure 5. *Comparison of start and end dates for the Mission and Qualark hydroacoustics programs between 2022 to 2025.*

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A7. Test fishing budget

E. Taylor

Summary

The Pacific Salmon Commission (PSC) test fishing program budget is dynamic due to the inherent uncertainty in annual revenues and expenses associated with the assessment of sockeye and pink salmon. While most program costs become relatively predictable once the scope of the program is defined (Chapter A6), revenues are more uncertain due to variability in salmon abundance, catchability, market conditions, and Fraser River Panel (FRP) decisions regarding salmon retention. Budgets are forecasted three years in advance using the program from the brood year as a starting point and are progressively refined through consultation with the FRP as run size (Chapter A1), timing, and diversion forecasts (Chapter A2), management priorities, operational details, and market information become available. As the fishing season approaches and progresses, budget updates incorporate pre-season planning decisions and in-season program modifications to support informed trade-offs between program coverage, information value, and potential surpluses or deficits. This iterative and transparent budgeting process supports FRP decision-making while recognizing that final program balances cannot be known with certainty prior to, or even during the fishing season. Given the recognition that test fishing revenues do not always align with program costs, the PSC established a Test Fishing Revolving Fund (TFRF), funded by contributions from both Parties, to offset any deficits or retain any surplus funds associated with the test fishing program. While PSC staff are responsible for developing and updating budget forecasts, program scope and discretionary retention decisions remain under FRP authority.

Introduction

The Pacific Salmon Commission (PSC) test fishing program budget is unique due to its highly variable annual surpluses and deficits associated with the annual fishing season. Effective budgeting and accounting forecasts for the PSC test fishing program are essential to reducing the uncertainty and operational complexity faced by the Fraser River Panel (FRP) during both pre-season planning and in-season decision-making. Reliable financial projections support the FRP's evaluation of program utility, coverage needs, and deployment strategies. Each year's budget balance ultimately depends on the relationship between program utility, expenses and revenues, underscoring the importance of accurate forecasting and careful financial management.

This report describes the structure and forecasting process for the PSC test fishing program budget, with the objective of highlighting sources of uncertainty and how budget information is developed and updated to support FRP decision-making. In addition, it outlines how the test fishing program is funded.

Test fishing budget components

The largest component of the program expense is the aggregate charter costs paid to test fishing vessel owners who are contracted to conduct test fishing. In addition to charter costs, expenses include seasonal staff wages, administrative and dock leasing fees, repair and maintenance of PSC-owned experimental fishing gear, travel, and scientific and operational (e.g. safety) materials.

Test fishing program revenue is accrued by the sale of salmon caught and retained by the test fishing vessels. Revenue from the sale of non-discretionarily retained salmon catch, i.e., salmon retained for sampling purposes or those that cannot be released with a good chance of survival, is based on test fishing catches on previous cycle line years, adjusted to account for differences in run size (Chapter A8). These forecasts can be further adjusted depending on changes to the suite and length of proposed test fisheries compared to previous cycle years. Revenue can also be generated from the sale of discretionary salmon catch, i.e., pay fish, salmon retained beyond those required for sampling purposes. Discretionary catch forecasts are dependent on assumed average weight and price (Chapter A8). However, discretionary salmon retention is only permitted at the discretion of the FRP (Rule 25 of the PSC bylaws, PSC 2025).

While most program expenses are relatively predictable once the scope of operations is defined, revenues are inherently more uncertain, as they depend on run size, catchability, market conditions, and FRP decisions regarding discretionary catch retention.

Test fishing budget forecasting

Three years prior to the fiscal year (FY) of interest, an initial baseline budget forecast is produced, e.g. the budget for FY 2028-29 is first drafted in the fall of FY 2025-26. Estimates of expenses assume that the test fishing program will be similar to that of the sockeye brood year, e.g. the 2024 Panel-approved program would be used to develop an initial program for 2028. Revenues are also estimated using salmon sale data from the brood year program. PSC staff apply informed assumptions about inflationary increases to program expenses as well as salmon sale pricing but make no assumptions about the FRP's future program design preferences or about future salmon productivity and resulting return abundances. As the test fishing season of interest approaches, the resulting budget forecast is updated through consultation with the FRP.

At the February PSC Annual Meeting, initial refinements to the test fishing program budget are made. Revenue projections are updated as sockeye and pink salmon (odd years only) run size forecasts are provided by DFO (Chapter A1) and test fishing catch forecast models are run (Chapter A8). Program expenses are also refined at this meeting based on Panel consultation about the suite of test fisheries to operate as well as the duration of the fisheries.

During pre-season planning in the spring, additional information becomes available that further inform the design of the test fishing program for the upcoming year, e.g. escapement plans, environmental forecasts, potential for non-discretionary salmon retention. Additionally, test fishing and fish purchasing contracts are procured and negotiated, and equipment and seasonal staff are hired. At the June meeting, the FRP finalizes the pre-season test fishing plan, including the anticipated deficit or surplus.

During in-season test fishing operations, PSC staff work with the FRP to make in-season modifications to the test fishing program associated with the run size of returning sockeye and pink salmon. The program budget is updated to reflect these program changes, e.g., shortening or lengthening a test fishery. Updated budget forecasts allow the FRP to evaluate trade-offs between program coverage, anticipated information value, and potential end-of-year surpluses or deficits when considering in-season program modifications. Additionally, PSC staff monitor test fishing catches and negotiate salmon sale prices in-season. Although forecasts of future catches and fish prices are uncertain, revenue projections become more certain over the course of the season as actual catches and landings are realized and incorporated.

Funding

While program revenues are generated primarily through the sale of retained salmon, these revenues are variable and often insufficient to fully fund the test fishing program. The following section outlines the historical and current sources of program funding and the role of the Test Fishing Revolving Fund (Rule 25 of the PSC bylaws, PSC 2025).

The funding framework for test fisheries has changed substantially over time. In 2006, a decision of the Federal Court of Canada determined that it was illegal for the federal government to set aside a portion of a public resource, i.e., fish, to finance research activities (Larocque v. Canada 2006). Prior to this decision, test fishers could be compensated based on a share of the value of the catch, and fish could be retained beyond the amount required to cover program costs. Between 2006 and 2012, often referred to as “the Larocque Years,” the federal government’s ability to retain fish for research financing remained uncertain. During this period, fishers were required to be paid a fixed daily rate, and only fish needed for sampling or unavoidably killed during test fishing operations could be sold.

Currently, fishers are still paid a fixed rate but additional fish retention to fund test fishing activities is possible under the Test Fishing Policy (PSC 2021). This policy was developed by the Parties in 2021 to outline the criteria required for the discretionary retention of fish. In general, the Fraser River Panel may authorize the retention of pay fish up to the amount needed to cover current-year program costs based on recommendations from the Finance and Administration Committee, the pre-season test fishing plan, and in-season information on run size, including conservation considerations, the availability of harvestable surplus and Canada’s ability to meet First Nations food, social and ceremonial obligations. The retention of extra pay fish, i.e., fish beyond what is required to cover annual program costs, may be considered only under exceptional circumstances, such as extremely high abundance or when either Party is unable to access its full TAC. Further details can be found in the Test Fishing Policy (PSC 2021).

In recent years, it is rare that the sale of fish caught in the test fishery is sufficient to fully fund the test fishing program. The last year this was the case was in 2018, when the total sockeye run size exceeded 10 million. A total of 113,000 sockeye, including pay fish, were retained by the test fishing program, generating almost 50% more revenue than what was required to pay for the 2018 test fishing program. Since 2018, no sockeye have been taken as pay fish, including in high return years such as 2022 and 2025. The retention of pink salmon pay fish has been attempted on odd years late in the season when the impact on sockeye has been negligible. In such instances, the impact on revenue has been minimal due to the low pink salmon catches near the tail end of the run and the low price for the fish.

As a result, revenues from fish sales have generally fallen short of covering program costs in recent years. When this occurs, Canada and the United States fund the remaining expenses through the Test Fishing Revolving Fund (TFRF, Rule 25 of the PSC bylaws, PSC 2025). The PSC maintains the TFRF to help stabilize the financial position of the test fishing program. Contributions to the fund are made either directly by the Parties or from program surpluses generated through fish sales, e.g. 2018. Withdrawals occur in years when operational costs exceed revenues. Each year, the PSC Secretariat invoices the U.S.A. for its share of the forecast deficit for the upcoming season while the Secretariat invoices Canada for its share of the test fishing deficit incurred for that fiscal year. If either the Canadian or the U.S.A. TFRF balance proves to be insufficient during the test fishing season, a supplemental invoice will be issued to allow continuation of the test fishing operations without delay (PSC 2025).

References

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A8. Test Fishing Catch Forecasts

E. Taylor

Summary

Test fishing plans are developed pre-season by the Fraser River Panel with the objective to inform decisions of the Panel while minimizing negative implications for conservation and for other fisheries, i.e., minimizing the number of fish retained. Because test fishing catches are accounted for prior to allocating Total Allowable Catch (TAC, Chapter B32), they have a direct impact on potential harvest opportunities. Pre-season forecasts of test fishing catches are therefore important for planning and as inputs into the Fishery Planning Model (FPM, Chapter A9). They are also important to determine the financial outlook of test fishing operations. While test fishing catches are not limited to Fraser River sockeye salmon, the test fishing deduction to the TAC is an estimate of the total retained Fraser River sockeye catch from all Panel-approved test fisheries. This deduction is made up of two components: fish that are unavoidably killed when conducting test fishing operations or the fish required for biological samples (non-discretionary catch) and additional fish retained by the test fishery to offset test fishing costs (discretionary catch, also referred to as Pay Fish). Forecasts of non-discretionary catch are based on test fishing catches on previous cycle line years, adjusted to account for differences in run size while discretionary catch forecasts are dependent on assumed average weight and price. Pay fish however are only retained when agreed to by the Fraser River Panel and following specific conditions as set out by the PSC Test Fishing Policy (2021).

Introduction

The Pacific Salmon Commission (PSC), or its predecessor the International Pacific Salmon Fisheries Commission (IPSFC), has operated test fisheries to obtain data required to inform bilateral decisions of the Fraser River Panel since the 1960s. These test fisheries implemented under the Pacific Salmon Treaty are essential for the Fraser River Panel to fulfil its responsibilities in terms of ensuring conservation objectives are met through appropriate in-season harvest management and catch allocation. Test fishing catch refers to the number of salmon caught and retained in Panel-approved test fisheries. The test fishing catch is comprised of non-discretionary and discretionary catch. Non-discretionary catch refers to the fish that are unavoidably killed when conducting test fishing operations. This catch includes all salmon caught by gillnets and those required for biological samples. Discretionary catches refer to the retention of additional salmon by the marine purse seine or reefnet test fisheries to offset the costs of the test fishing program. Discretionary catch is often referred to as Pay Fish. Guidelines for the retention of test fishing catches and Pay Fish are described in the PSC Test Fishing Policy (2021).

Predicting test fishing catches is an important component of the pre-season planning process as reliable predictions are important to plan for potential financial surplus or deficit scenarios. In addition, test fishing catch forecasts are also important to predict Total Allowable Catch (TAC) which is derived by deducting the agreed Fraser River Aboriginal Exemption and the predicted catch in Panel-authorized test fisheries from the harvestable surplus (Chapter A5). Test fishing catches are therefore also termed test fishing deductions when discussing TAC calculations (Chapter B32). Test fishing catch forecasts are generated several years ahead based on past catches on the same cycle years and are updated annually based on preseason run size estimates, generated before the start of the fishing season. In-season, these forecasts are replaced with actual catch observations.

Data

Predictions of non-discretionary test fishing catches are based on historical catch data of all test fisheries combined, while weight and price information are used to predict the catch needed to cover the cost of the test fishing program.

Method

For non-discretionary catch, a multi-year retrospective analysis indicated that there is a strong correlation between the non-discretionary catch and historical catches over the previous three cycle years. Preseason, prior to a preseason run size forecast being available, the average of the three cycle years is used to forecast test fishing catches. Once a run size forecast is available, this estimate is used to scale the test fishing catches of the historical years by dividing the total test fishing catches by the total run sizes and calculating the non-discretionary test fishing harvest rates. These historical harvest rates, used in combination with the run size forecast, allow for the prediction of non-discretionary test fishing catch.

When discretionary catch is authorized, it is normally with the intention of achieving cost-neutrality and therefore discretionary catch predictions are based on the number of salmon needed to pay for the test fishing program minus non-discretionary catches. The forecast of the discretionary catch is dependent on the assumed average weight and price of the salmon. Under certain conditions, additional discretionary salmon could be caught beyond the salmon needed to pay for the test fishing program in the current year with the aim to supplement the test fishing revolving fund and offset future test fishing costs (Chapter A7). These conditions include extremely high salmon abundances and/or the ability of either country to harvest its full TAC (PSC 2021).

When test fishing catch forecasts are used as deductions in the TAC calculations, they need to be allocated to individual management groups, i.e., Early Stuart, Early Summer, Summer, and Late run. For non-discretionary catches, this is achieved by multiplying the total catch forecast with the average proportion by management group as observed on the previous three cycle years. For discretionary catches, the management group-specific estimates are obtained by multiplying the total discretionary catch estimates with the proportions of each management group within the predicted harvestable surplus for the current year.

Planned changes and potential areas of improvement

Overall, the use of three-year cycle line averages to predict non-discretionary and discretionary catches has been a simple and effective method and there are no changes planned to the current estimation methodology. As run sizes have declined in recent years, there has been increased attention paid to the test fishing catches as a deduction to the harvestable surplus as it determines the available TAC to be shared by Canada and the U.S. In some years, when the distribution of test fishing catch across management groups has differed substantially from the distribution based on the run size forecast, the method has been adjusted slightly to only rely on past years with similar distributions across management groups.

References

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A9. Fisheries Planning Model – general overview

M.J. Hague and E. Taylor

Summary

Pre-season, the Fraser River Panel uses a fisheries simulation model developed by PSC staff, hereafter referred to as the FRP Fisheries Planning Model (FPM), to develop preliminary fishing plans, to identify potential limitations in achieving management objectives, and to explore the effect of uncertain biological and management inputs on proposed fisheries. The goal of these plans is to create a fisheries schedule that meets Panel objectives under key pre-season assumptions. The FRP Fisheries Planning Model is a simulation tool primarily used to assess sensitivity of fisheries plans and achievement of management targets under alternative biological (e.g. run size, diversion rate) and/or management (e.g. total allowable mortality rules) scenarios. Model results are used to guide pre-season planning for stakeholders and to inform early in-season management decisions prior to the availability of updated in-season run size information (Chapter B23). This report describes the general process used to populate, run and evaluate the FRP Fisheries Planning Model. Detailed descriptions of model inputs and the technical implementation of the model structure are described in the companion Chapters A10-A12.

Introduction

Pursuant to Annex IV, Chapter 4, Paragraph 9d, of the Pacific Salmon Treaty (PST 2025), the Fraser River Panel Technical Committee (FRTC) and Pacific Salmon Commission (PSC) staff work jointly to develop fisheries and management plans for Fraser River sockeye salmon prior to the start of each fishing season using the FRP Fisheries Planning Model. The goal of these plans is to create a provisional fisheries schedule which meets Panel objectives (PST 2025) under key pre-season assumptions. Historically, pre-season fishing plans for Fraser River sockeye salmon were based on management experiences in previous years, but as the variability in biological forecasts and the complexity of the management regimes increased, managers realised the need for a more rigorous and structured planning tool (Cave and Gazey 1994). The first version of the FRP Fisheries Planning Model was created by Rod Cooke and Jim Cave (IPSFC, predecessor of the PSC) in 1984, and was used extensively beginning in 1985 (final year of the IPSFC) (J. Cave, personal communication). These models were developed in early spreadsheet software and were restricted in size and complexity due to the computer processing limitations of the day. Early run reconstruction models (Starr and Hilborn 1988) influenced later updates to the Planning Model structure and harvest rate parameterisation (Cave and Gazey 1994) and the model was re-coded in Excel in 1997 (J. Cave, pers. comm.).

Over time, the model has been adapted and updated to reflect changes to fishery structure and to address requests from the FRP and FRTC. Some of these changes include controls for individual transferable quota (ITQ) fisheries in Canada, separate accounting for release mortalities, tracking of both discretionary (i.e. pay fish) and non-discretionary test fishing catch, changes in assignment of stocks to management groups, Management Adjustment (MA) deductions, inclusion of Low Abundance Exploitation Rates (LAERs), changes to the relevance of different fisheries and refinements to underlying biological assumptions. While the spreadsheet model continued to meet most pre-season management objectives, the structural framework restricted flexibility and was prone to errors during the revision process.

In 2011, the FRTC and FRP agreed to restructure the FRP Fisheries Planning Model in R statistical software (R Core Team 2025) which could handle the increased complexity required to explicitly model many of the model assumptions. Over the next several years, PSC staff worked with Panel and Technical Committee members to develop the current Planning Model which is controlled by a Graphical User Interface (GUI) developed using the Shiny package (Chang et al. 2025). The R model has improved the transparency of underlying model assumptions and has increased the flexibility and ease with which the modellers can make changes to fisheries and stock structure.

Data

The FRP Fisheries Planning Model relies on three different types of data inputs: biological, fisheries, and management. A more thorough description of the key inputs in the Planning Model is provided in Chapter A10, but they are also briefly described here. The biological inputs define the abundance of the expected salmon return, i.e. the run size forecast, and how these salmon are distributed in space and time. The latter is defined by the timing of the run, the number of days it takes for 95% of the run to migrate through an area (i.e., the spread), the proportion of the total run migrating through Johnstone Strait (i.e. the diversion rate), the proportion of the run that delays their upstream migration into the Fraser River and the number of days of delay. Within the Planning Model, stocks are grouped for modelling purposes based on similarities in migratory patterns (12 modelling groups) but are aggregated by management group (Early Stuart, Early Summer, Summer, Late-run, and Fraser pinks) for reporting and evaluation purposes.

The fisheries inputs relate to the anticipated amount of fishing effort or resulting catch, how that effort or catch will be distributed across the salmon season and if catches will be retained or released. In the case of test fishing catches, fisheries input also includes predicted non-discretionary catches as well as discretionary catches and the schedule when these discretionary catches will be taken to pay for the test fishing program, i.e. taken as pay fish (Chapter A7).

The management inputs differ by management group and are defined by the various components of the Spawning Escapement Plan (Chapter A5): the Spawning Escapement Target (SET), the Management Adjustment (MA) (Chapter A3), the Test Fishing Deduction (Chapter A5), the Aboriginal Fisheries Exemption (AFE) and the Low Abundance Exploitation Rate (LAER). In addition, the FRP Fisheries Planning Model also requires inputs regarding the allocation of the Total Allowable Catch (TAC) across the various fisheries, both internationally as well as domestically.

Model inputs are either based on medians derived from historical time series, generated by forecast models run outside of the Planning Model structure, or based on the expert judgment from within the FRTC and FRP. Because several forecast models to produce biological inputs require covariate data and these are only available immediately prior to the season, Planning Model inputs in early spring rely primarily on medians derived from historical time series (Chapter A10). Depending on the source of the data, inputs are either updated annually, multiple times annually, or as additional information becomes available. There are two key parameterisation timeframes: the first occurs in the early spring when most inputs are typically calculated from historical timeseries, and the second occurs in late spring once more covariates for forecast models become available. The updating of management and fisheries inputs typically follows the same schedule as for the biological parameters of the model. February inputs are based on historical observations, run size forecasts, and preliminary escapement plans and are typically finalised during the June meeting once the Canadian Minister of Fisheries has approved Canada's annual Integrated Fisheries Management Plan (IFMP, DFO 2025).

Under the Pacific Salmon Treaty (Annex IV, Chapter 4, Paragraphs 3 and 4, PST 2025), Canada is responsible for producing run-size specific estimates of SETs, LAERs, and AFEs. In addition, the technical chairs provide information relating to anticipated fishing effort levels, fishing schedules for their respective countries, and domestic catch allocations for their respective countries. Secretariat staff provide advice on pre-season estimates of management adjustments, although final adoption is left to the discretion of the Panel (Chapter A3), as well as test fishery deductions and the test fishing schedule (Chapter A5). More detailed descriptions of the FRP Fisheries Planning Model inputs, including responsibilities, is provided in Chapter A10.

Model

The FRP Fisheries Planning Model assumes a daily time step with salmon moving in groups (box-cars) through a series of gauntlet-style mixed gear and mixed stock fisheries (Cave and Gazey 1994). Spatially, the model covers fishing areas in both Johnstone Strait and Juan de Fuca Strait, starting with DFO Pacific Fisheries Management Areas 12 and 20 and extending into the upper mainstem of the Fraser River, DFO Pacific Fisheries Management Area 29. Daily abundances in the most seaward areas are defined by the stock group specific forecast estimates of run size, timing and spread in addition to the diversion rate. Daily "blocks" of salmon are then moved through the different fishing areas and exposed to a sequential series of fisheries (Figures 1 and 2 in Chapter A11). The different fisheries are modelled through the application of harvest rates equations. The abundance of fish exposed to a given fishery is controlled by underlying specifications of migration rate and the length of a fishing area. For example, fish that migrate through an area over the course of several days may also be exposed to multiple days of fishing. Alternatively, this means that more than one daily migratory block of fish would be exposed to a single fishery opening in a large fishing area, or in an area in which fish are assumed to delay or slow down their migration.

Using the FRP Fisheries Planning Model, the FRTC annually explores alternative fishery scenarios to optimise the achievement of Pacific Salmon Treaty objectives (achievement of SETs and international as well as domestic catch allocations) under various biological and/or management assumptions. This is done during the bilateral FRTC meetings in April and June. User-inputs allow FRTC chairs to evaluate different fishing schedules and assume different harvest efficiencies to optimise outputs and balance conservation, fishery, and domestic objectives. Biological and/or management inputs are varied across scenarios to assess the sensitivity of fishing plans to changes in underlying assumptions. PSC staff provide the necessary modelling and administrative support when running the FRP Fisheries Planning Model prior to presenting results to the Fraser River Panel for further discussion.

The current FRP Fisheries Planning Model runs on a joint MS Excel and R (R Core Team 2025) operating platform. Excel interfaces are used for entering data inputs and summarising key model outputs. The main simulation framework is coded in the statistical software R and controlled by users through a Shiny GUI.

Results

The FRP Fisheries Planning Model summarises the results of the models in a series of tables collating fishery-specific and management related statistics (e.g. Tables 1 and 2). The FRTC chairs use these outputs to refine preseason fishing plans and to communicate results of final model runs to the Fraser River Panel. At the end of the June meeting, a Panel-approved "Base Case" model is adopted which can be referenced in-season to help guide decision making for early fisheries. The alternative model runs allow FRP and FRTC members to evaluate the sensitivity of that Base Case plan to different assumptions. Model results are communicated at various levels of resolution so that fishing plans can be evaluated in terms of meeting international (e.g. escapement targets and TAC) as well as domestic (e.g. appropriate allocation or distribution of fishery opportunities) objectives. In addition, model results may be used during the domestic consultation process to help communicate anticipated fishery plans.

Table 1. *Example FRP Fisheries Planning Model TAC summary from 2021 based on the 90th percentile of the pre-season sockeye run size forecast, and the median run size forecast for pink salmon.*

p90 Sockeye & p50 Pink Salmon

TAC SUMMARY

	p90	p90	p90	p90		p50
	EARLY STUART	EARLY SUMMER	SUMMER	LATES	TOTAL SOCKEYE	PINKS
	TAC MODEL OUTPUTS					TAC MODEL OUTPUTS
ALLOWABLE EXPLOITATION RATE	**10.0%**	**28.5%**	**45.5%**	**10.0%**		**6.4%**
TOTAL EXPLOITATION RATE (INCL TF & FIM)	**3.3%**	**22.1%**	**31.9%**	**15.0%**		**6.8%**
OVER/UNDER (INCL TF & FIM)	**6.7%**	**6.4%**	**13.6%**	**-5.0%**		**-0.4%**
TAC FOR INTERNATIONAL SHARING (EXCL AFE)	**0**	**57,500**	**1,670,100**	**0**	**1,727,600**	**188,500**
TOTAL CATCH (EXCL TF & FIM INCL AFE)	1,300	79,100	1,409,400	80,900	1,570,700	**204,300**
TOTAL MODELLED CATCH	1,400	78,300	1,399,800	79,600	1,559,100	103,400
TOTAL FIXED CATCH INPUTS	0	800	9,600	1,200	11,600	101,300
OVER/UNDER (EXCL TF & FIM)	**-1,300**	**-21,600**	**260,700**	**-80,900**	**156,900**	**-15,800**
U.S. SHARE OF TAC (INCL PAYBACK)	**0**	**9,500**	**275,200**	**0**	**284,700**	**48,400**
U.S. CATCH (EXCL FIM)	0	12,300	245,700	23,000	281,000	47,600
U.S. FIM	0	0	1,000	400	1,400	
OVER/UNDER (INCL FIM)	0	-2,800	28,500	-23,400	2,300	**800**
% OVER/UNDER (INCL FIM)	0.0%	-29.5%	10.4%	0.0%	0.8%	1.7%
BALANCE TO CANADA (INCL AFE)	**0**	**92,700**	**1,750,200**	**0**	**1,842,900**	**140,100**
CANADIAN CATCH (EXCL FIM)	1,300	66,800	1,163,700	57,900	1,289,700	157,100
CANADIAN FIM	0	0	0	2,300	2,300	
OVER/UNDER (INCL FIM)	-1,300	25,900	586,500	-60,200	550,900	**-17,000**
% OVER/UNDER (INCL FIM)	0.0%	27.9%	33.5%	0.0%	29.9%	-12.1%
ESCAPEMENT	27,100	208,500	2,846,200	250,300	3,332,100	2,804,300
OVER/UNDER	-19,900	20,800	595,200	-49,700	546,400	**-12,700**
	TAC MODEL INPUTS					TAC MODEL INPUTS
TOTAL RUN	**47,000**	**375,300**	**4,502,000**	**572,000**	**5,496,300**	**3,009,000**
TOTAL DEDUCTIONS	**80,300**	**317,800**	**2,831,900**	**592,500**	**3,822,500**	**2,820,500**
ESCAPEMENT TARGET	47,000	187,700	2,251,000	300,000	2,785,700	2,817,000
AFE	0	44,700	355,300	0	400,000	NA
pDBE	-0.41	-0.3	-0.08	-0.49		NA
MANAGEMENT ADJUSTMENT	32,400	80,700	202,600	288,000	603,700	NA
TEST FISH	900	4,700	23,000	4,500	33,100	3,500
TAC FOR INTERNATIONAL SHARING	**0**	**57,500**	**1,670,100**	**0**	**1,727,600**	**188,500**
ALLOWABLE EXPLOITATION RATE	**10.0%**	**28.5%**	**45.5%**	**10.0%**		**NA**
U.S. SHARE OF TAC (INCL PAYBACK)	**0**	**9,500**	**275,200**	**0**	**284,700**	**48,400**
BALANCE TO CANADA (INCL AFE)	**0**	**92,700**	**1,750,200**	**0**	**1,842,900**	**140,100**
MARINE FSC	0	12,500	254,300	0	266,800	39,000
IN-RIVER FSC	0	89,800	694,200	0	784,000	101,300
MARINE REC	0	800	9,600	1,200	11,600	0
IN-RIVER REC	0	1,600	19,100	2,400	23,100	0
COMMERCIAL	0	0	773,000	0	773,000	0

Table 2. *Example of a catch summary table from 2021 pre-season planning, corresponding to the TAC table in Table 1.*

ALLOCATION SUMMARY

Sockeye

		TARGET CATCH	TOTAL CATCH	TARGET %	MODELLED %	LANDED CATCH	FIMS
U.S.		284,700	282,400			281,000	1,400
	TREATY INDIAN	192,500	201,200	67.7%	71.2%	201,200	0
	ALL CITIZEN	92,100	81,200	32.3%	28.8%	79,800	1,400
CANADA		1,842,900	1,291,904			1,289,700	2,300
COMMERCIAL		773,000	209,400			207,100	2,300
	AREA B	374,900	95,700	48.5%	45.7%	93,400	2,300
	AREA D	167,000	53,200	21.6%	25.4%	53,200	0
	AREA E	194,000	49,500	25.1%	23.6%	49,500	0
	AREA G	0	0	0.0%	0.0%	0	0
	AREA H	37,100	11,000	4.8%	5.3%	11,000	0
RECREATIONAL		34,700	11,600			11,600	0
	IN-RIVER	23,100	0			0	0
	MARINE	11,600	11,600			11,600	0
FIRST NATIONS		1,050,800	1,070,904			1,071,000	0
	MARINE	266,800	269,204	25.4%	25.1%	269,204	0
	Lower Fraser	434,000	451,700	41.3%	42.2%	451,700	0
	BC Interior	350,000	350,000	33.3%	32.7%	350,000	0
TEST FISHING		33,100	31,000			31,000	0

Pinks		TARGET CATCH	TOTAL CATCH	TARGET %	MODELLED %
U.S.		48,400	47,600		
	TREATY INDIAN	24,200	23,700	50.0%	49.8%
	ALL CITIZEN	24,200	23,900	50.0%	50.2%
CANADA		140,100	157,100		
COMMERCIAL		0	20,500		
	AREA B	0	18,400	82.5%	89.8%
	AREA D	0	100	4.0%	0.5%
	AREA E	0	0	3.0%	0.0%
	AREA G	0	0	0.5%	0.0%
	AREA H	0	2,000	10.0%	9.8%
	In-River EO BS	0	0		
RECREATIONAL		0	0		
	IN-RIVER	0	0		
	MARINE	0	0		
FIRST NATIONS		140,300	136,700		
	MARINE	39,000	35,400	27.8%	25.9%
	IN-RIVER	101,300	101,300	72.2%	74.1%
TEST FISHING		3,500	400		

Planned Changes and Potential Areas for Improvement

Modellers continue to refine the model interface and dataflow to meet the continuing and evolving needs of the Fraser River Panel. At present, effective use and maintenance of the model require intermediate-to-advanced expertise in R, as well as substantial familiarity with the underlying code base. Planned improvements focus on increasing accessibility by reducing technical barriers, with the long-term objective of enabling users to interact with the model through a web-based interface. This would allow individuals to run and explore model outputs without requiring R expertise or a local R installation.

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A10. Fisheries Planning Model inputs

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Summary

The Fraser River Panel (FRP) Fisheries Planning Model (FPM, Chapter A9) is a simulation tool used by the Fraser River Panel to assess the sensitivity of fisheries plans and achievement of management targets to alternative biological (e.g. run size, diversion rate) and/or management scenarios. This report describes the key biological, management and fisheries inputs used to parameterise the PSC Planning Model and run simulations. Further details regarding model parameterisation and underlying assumptions can be found in Chapters A11 and A12.

Introduction

Pre-season, the Fraser River Panel (FRP) and Fraser River Technical Committee (FRTC) use the FRP Fisheries Planning Model to develop preliminary fishing plans, to identify potential limitations to achievement of management objectives, and to explore the effect of uncertain biological and management inputs on proposed fisheries. This simulation model requires a wide range of different inputs: biological inputs to model the behaviour of the different stocks, fisheries inputs to assess the impact of various fisheries on the stocks and management inputs to ensure management objectives are met. Early in the year, these inputs are based on historical data and preliminary schedules and plans, while just prior to the start of the season, the model inputs are replaced with improved forecasts and approved escapement plans. Model seeding, or parameterisation, occurs twice per year: once in April and a second time in June. The responsibility for providing different model inputs falls primarily onto Canada and the PSC, with the U.S. providing additional domestic-level information regarding their own fisheries as well as domestic targets and constraints. Typically, the Panel will approve the parameterisation of a "Base Case" model before the conclusion of their final pre-season meeting in June based on the best-available information.

Data

A. BIOLOGICAL INPUTS

The FRP FPM simulates the daily migration of 12 different Fraser River sockeye salmon stock groups, in addition to a single group for all Fraser River pink salmon. Table 1 provides a list of the different sockeye salmon stock groupings used in the FPM and a guide for aggregating stock-specific information from historical reconstruction and pre-season forecast files into appropriate groupings currently utilised pre-season. These groups are structured to aggregate groups of fish with identical management constraints and migratory parameters (Chapter A9). Table 2 provides a description of the key biological inputs in the FPM. Pre-season estimates of run size, timing, spread and diversion are used to parameterise normal distributions of daily abundance entering Johnstone Strait and Juan de Fuca Strait while delay information is used to model the upstream migration timing of various stocks which hold in the Strait of Georgia prior to moving up-river.

***Table 1**. Stock definitions and aggregations within the FRP FPM. At the finest resolution, stocks are defined as groups of fish with identical migratory and management parameters.*

Planning Model Group	Migratory Sub-group	Catch & Racial stock groups	Management Group
Early Stuart	North, South	Early Stuart	Early Stuart
Early Miscellaneous (above Harrison)	North, South	Nadina, Bowron, Gates, Nahatlatch Taseko	Early Summer
Early Miscellaneous (below Harrison)	North, South	Chilliwack, Pitt, Alouette, Coquitlam	Early Summer
Early South Thompson	North, South	Early South Thompson, North Barriere	Early Summer
Late Stuart, Stellako	North, South	Late Stuart, Stellako	Summer
Chilko	North, South	Chilko	Summer
Quesnel	North, South	Horsefly, Mitchell	Summer
North-Thompson	North, South	Raft, North Thompson	Summer
Harrison	North, South Delay, non-delay	Harrison, Widgeon	Summer
Birkenhead	North, South	Birkenhead, Big Silver	Lates
Non-Birkenhead Lates (above Harrison)	North, South Delay, non-delay	Late Shuswap	Lates
Non-Birkenhead Lates (below Harrison)	North, South Delay, non-delay	Weaver, Cultus	Lates

***Table 2.** A description of the key biological inputs in the FRP FPM, including timelines for updating inputs, the data source, the relevant Chapter containing additional information on how the data are used to derive model inputs and the party responsible for providing the update.*

Input	Description	Source	Relevant Chapter	Responsible Party
Run size	Pre-season run size forecast	Stock-recruit data	A1, C10	DFO
Timing	Index of migration timing, i.e. date when 50% of the run will have passed the reference location	Historical medians used until DFO oceanographic forecasts are available (for Early Stuart and Chilko)	A2, C4	PSC staff (historical medians) and DFO (oceanographic forecasts)
Spread	Number of days required for 95% of the run to migrate through an area	Historical medians	C4	PSC staff
Diversion rate	Percentage of total return that migrates through Johnstone Strait	Historical median until DFO oceanographic forecasts are available	A2, C4	PSC staff (historical medians) and DFO (oceanographic forecasts)
Delay	The proportion of the run expected to delay its upstream migration by holding in the Strait of Georgia and the number of days their upstream migration is delayed	Historical medians	B22	PSC staff

Run size

Run size forecasts are a critical aspect of the modelling process, and directly affect the value of management inputs, patterns of daily abundances, and strongly influence the pattern of proposed fisheries which optimise trade-offs between conservation and fishing targets. Fisheries and Oceans Canada (DFO) provides pre-season forecasts of sockeye salmon run size using a suite of stock recruitment and naïve models (Grant et al. 2010, Chapter A1). These forecasts are provided at a finer stock resolution than used by the FRP FPM and so must be aggregated to the model group level (Table 1). The uncertainty around the run size forecast is expressed in terms of a probability distribution. As stated in the PST (2025, Annex IV, Chapter 4), the median forecast (p50) is used as the default input for the baseline planning scenario, but the Panel may also choose to adopt a more precautionary or optimistic forecast until the in-season run size estimates are available. A key sensitivity analysis performed by the parties during pre-season fisheries planning is to vary the assumed run size from the default median (p50) estimate to either a lower (e.g. p25), or higher (e.g. p75) estimate of abundance. Pre-season run size estimates are typically available in February and do not get updated until during the season.

Marine timing

In the FRP FPM, marine timing is termed as the Area 20 50% date, or the date by which 50% of a run has passed the mid-point of statistical Area 20 assuming all sockeye salmon migrate through the southern approach around Vancouver Island (Chapter A2). Both the absolute timing as well as the offsets between the timings of the various management groups (Early Stuart, Early Summer, Summer and Late run) influence pre-season fishing plans. During the spring, timings for the different stock groups in the FRP FPM are calculated based on historical timing data derived from post-season reconstructed daily marine abundance estimates (Chapter C4). Statistical and retrospective analyses are used to determine the best available estimates for each stock in a given year. Typically, all-year medians, cycle-line medians, or all-year medians excluding 2024 cycle line data are used (Chapter A2).

In June, DFO provides additional timing forecasts for Early Stuart and Chilko based on oceanographic models (Folkes et al. 2018, Chapter A2). These estimates are applied directly to update the Early Stuart and Chilko timing estimates. For all other stock groups, the historical timing is updated either earlier or later depending on the difference between the Chilko timing forecast to the Chilko historically based timing estimate. This approach assumes the underlying oceanographic conditions affecting Chilko salmon will have the same effect on other co-migrating stocks. It is at the Fraser River Panel's discretion to utilise these updated timing forecasts, to use the historical timing estimates, or to adopt some alternative value.

Spread

Another parameter used to define the anticipated daily abundances of fish is the spread of the run. Assuming the run follows a normal distribution, the spread indicates the number of days for 95% of the run to migrate past a reference location (i.e. the standard deviation of the normal distribution). Annual spreads are calculated from reconstructed historical marine timing profiles (Chapter C4) and are quantified using the same subset of years selected for the historical timing estimates. Spread estimates for aggregated stocks are calculated by first summing daily reconstructed abundances and then re-calculating the spread of the group. The spread model inputs are only updated once a year, during the initial model seeding process.

Northern diversion rate

The diversion rate is defined as the proportion of the run that migrates through Johnstone Strait, i.e. the northern approach. For April modelling, the annual diversion rate is derived from historical observations dating back to 1978 (Chapter C4). The 2024 cycle line years are treated differently because they exhibit a lower observed diversion rate (Wong et al. 2026). Unlike other Fraser River sockeye salmon stocks, Harrison sockeye migrate predominantly through the south and a Harrison-specific diversion rate is applied. The historical daily diversion pattern is scaled so that, when applied to the abundance forecast, the resulting annual diversion matches the expected annual diversion rate. These daily diversion rate estimates are then applied to the daily abundances of the individual stock groups to estimate the abundances migrating through Johnstone Strait and Juan de Fuca Strait. In June, DFO provides an additional annual forecast of the total Fraser River sockeye salmon diversion rate, derived from a suite of oceanographic models (Folkes et al. 2018, Chapter A2).

Delay in upstream migration

A portion of Harrison (Summer run) and Late-run stocks (Late Run excluding Birkenhead and Big Silver) typically delay their migration in the Strait of Georgia for a variable period before resuming their upriver migration (Cooke et al. 2004, Chapter B22). The magnitude of this delay has proven difficult to predict and has exhibited multiple regime shifts over time. Each year, PSC staff review historical data, examining trends across years and cycle lines, and most often apply a historical median approach to estimate delay duration. The proportion of the run that delay their upstream migration, the Mission 50% migration date of both the delaying and non-delaying components, and the spread of the delay component are all inputs into the FRP FPM. These inputs are adjusted using expert judgement to produce results consistent with the historical median estimates of delay and the median 50% migration date at Mission.

B. MANAGEMENT INPUTS

Most of the bi-lateral management parameters (Table 3) are provided by Canada, pursuant to guidance in the Pacific Salmon Treaty (PST 2025, Annex IV, Chapter 4). In addition, PSC staff provide test fishing deductions (Chapter A5) and management adjustments (Chapter A3), both of which also influence the calculation of Total Allowable Catch (TAC). Preliminary escapement plans options (Chapter A5) are the responsibility of Canada and are provided for the April modelling session. A final agreed-to plan is expected to be provided in June.

TAMs, SETs, AFEs, and LAERs

Under the Pacific Salmon Treaty (PST 2025, Annex IV, Chapter 4), Canada is responsible for providing harvest control rules for the management of Fraser River sockeye stocks. Prior to each fishing season, the Minister of Fisheries, Oceans and the Canadian Coast Guard must formally approve an annual Integrated Fisheries Management Plan (IFMP) following a series of consultations with key stakeholder groups. This plan includes harvest control rules that define the Spawning Escapement Targets (SET), Total Allowable Mortality (TAM), and Low Abundance Exploitation rates (LAERs) for each sockeye salmon management group (DFO 2025, Chapter A5). Fraser River sockeye salmon follow abundance-based harvest rules and so the SET and TAM values vary as a function of the assumed run size. To determine the TAC on which the U.S. share allocation is based, the Treaty (PST 2025) also requires to deduct the Aboriginal Fishery Exemption (AFE), which represents the fish set aside for Canadian in-river and marine area Aboriginal fisheries, i.e. for First Nations opportunities to harvest salmon for Food, Social and Ceremonial (FSC) purposes (Chapter B32).

Management Adjustments

Management Adjustments (MAs) represent the expected number of additional fish required to pass the Mission hydroacoustic facility to achieve the desired SET. Initial pre-season MAs are based on historical differences between estimates (DBEs), defined as the discrepancy between the spawning escapement (SE) observed on the spawning grounds and the potential spawning escapement (PSE), derived from Mission escapement estimates after deducting catch removals above Mission (Chapter C8). Historical differences may exist because of errors in stock assessment, catch accounting, or natural en route losses. In June, a retrospective analysis is used to select the model to derive the pre-season DBE estimates (Chapter B29). For Early Stuart, Early Summer and Late-run sockeye, the pre-season forecast is based on median values of historical estimates (Chapter B29). For Summer run, the forecast relies on the Threshold Method that evaluates if the long-range Fraser River temperature forecast (Chapter A4) will exceed a threshold value above which sockeye survival is impeded, and adjusts the DBE forecast accordingly (Chapter B29). Regardless of the selected DBEs, the Panel may choose alternative MAs for any of the management groups (Chapter A3).

Table 3. *A description of the key management inputs in the FRP FPM.*

Input	**Description**	**Source**	**Relevant Chapter**	**Responsible Party**
Total Allowable Mortality (TAM)	Management group specific rules to define the total allowable mortality at different run sizes	IFMP	A5	Canada
Spawning Escapement Target (SETs)	Run size specific SET for each of the management groups	IFMP	A5	Canada
Aboriginal Fishery Exemption (AFE)	Run size specific AFE for each of the management groups	Treaty Defined Calculation	A5	Canada
Low abundance exploitation rate (LAERs)	LAER to allow for fisheries directed on co-migrating stocks and species, and in some cases, some limited directed harvest	IFMP	A5	Canada
Management Adjustment (MA)	Numerical MA deduction by management group	Various	A3	PSC staff
Test Fishery Deduction	Anticipated test fishing catches by management group	Model using historical data	A8	PSC staff

Test fishery deductions

Pursuant to the PST (2025, Annex IV, Chapter 4), the TAC is reduced by the amount of catch in Panel authorised test fisheries. Test fishing catches consist of non-discretionary catch of fish that are unavoidably killed when conducting test fishing operations and discretionary catches retained to offset test fishing costs. Pre-season, the Panel agrees to a draft test fishing plan put forth by PSC staff. A detailed description of how test fishery deductions are predicted for pre-season planning is provided in Chapter A8.

International and domestic allocations

The PST (2025, Annex IV, Chapter 4) assigns 16.5% of the sockeye TAC available for international sharing to the U.S. with the balance assigned to Canada. In addition, each country allocates their respective share across different stake-holder groups following pre-season consultations. These percentages are then used as objectives to help guide the fishing plans in the FRP FPM. Canada assigns allocations to different commercial fishing sectors: Area B seine, Area D gill net, Area E gill net, Area H troll, and Area G troll. Allocation targets are also specified for South Coast, Lower Fraser, and Mid/Upper Fraser First Nations fisheries as well as marine and in-river recreational fisheries. In the US, allocation percentages are used to divide the TAC between Treaty Tribe and All Citizen fisheries.

C. FISHERIES INPUTS

Fisheries inputs relate to the number of vessels expected to participate in a fishery, i.e. the fishing effort, or expected catches and the schedule when fishing is expected to occur. Table 4 provides a description of the key fisheries inputs in the FRP FPM.

Table 4. *A description of the key fisheries inputs in the FRP FPM.*

Input	Description	Relevant Chapter	Responsible Party
Fishing effort	Anticipated fleet size	this Chapter	FRTC chairs
Fixed catch inputs	Catches for fisheries that are not modelled dynamically	this Chapter	FRTC chairs, PSC staff
Test fishing schedule	Fishing schedules of the different test fisheries, including non-retention criteria of test fishing catches and retention schedules of non-discretionary catches	this Chapter	FRP, PSC staff
Fishing schedule	Days/hours of different planned openings. Also includes non-retention criteria, designation of ITQ fisheries, ITQ catches, harvest rates, etc.	this Chapter	FRP, PSC staff

Fishing effort

Effort-based harvest rate equations are used in the FRP FPM to generate estimates of catch for derby-style fisheries. The model is seeded with historical estimates of fishing effort (total number of vessels) for the following fisheries: marine gillnet (Area 11, Area 12), marine purse seine (Area 12, Area 13 and Area 20), troll (Area 29), Treaty Indian (Area 4B, 5, 6C and Area 6, 7, 7A), and All Citizen (Area 7, 7A).

Fixed catch (for fisheries not modelled dynamically)

Some fisheries are not dynamically modelled within the FRP FPM, either because of unparameterized harvest equations, or because they are outside of the current geographic scope. Instead, experts provide estimates of catch by management group, including estimates of release mortality in pink salmon directed fisheries. The Canadian FRTC chair provides catch estimates for the following fisheries: marine recreational catch, in-river beach seine release mortalities, and gulf seine release mortalities. PSC staff will provide catches estimates for the purse seine test fishing samples. These catches are relatively small and are estimated based on daily sample sizes and distributed across management groups based on historical stock composition information.

Fishing plans

Once the model has been fully parameterised under a given set of assumptions, the FRTC works with PSC staff to develop a fishing plan for each country. The goal of these plans is to optimise trade-offs between conservation and fishing objectives by developing fishing scenarios that meet Spawning Escapement Targets, come as close as possible to meeting the international TAC allocations as well as domestic allocation requirements. Model input requirements vary by fishery depending on the underlying equations. At a minimum, derby-style fisheries must include a start and end date, while ITQ-style fisheries (Individual Transferable Quota) must also indicate an anticipated target catch. Users can choose to specify the hours of fishing operations, the fishing effort and if sockeye catches would be retained or not. Initial fishing plans developed in April are updated and finalised following an update of the model inputs in June.

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A11. Fisheries Planning Model - biological assumptions

M.J. Hague

Summary

The FRP Fisheries Planning Model (Chapter A9) is a simulation tool used by the Fraser River Panel to assess different alternative fisheries plans and their ability to achieve management targets under various biological (e.g. run size, diversion rate) and/or management scenarios. The calculations of catch and escapement by the Planning Model rely fundamentally on assumptions associated with forward run reconstructions. This report describes the key assumptions regarding the dynamics of fish movement and migration behaviour. The sources and processes underlying the annual re-parameterisation of the biological and fisheries management inputs feeding into the model are provided in Chapter A10.

Introduction

As described in Chapter A9, and pursuant to Annex IV, Chapter 4, Paragraph 9d, of the Pacific Salmon Treaty (PST 2025), the Fraser River Panel Technical Committee (FRTC) and Pacific Salmon Commission (PSC) staff work jointly to develop fisheries management plans for Fraser River sockeye salmon prior to the start of each fishing season using the FRP Fisheries Planning Model. The usefulness of the Fisheries Planning Model as a management tool depends in part on the accuracy of biological pre-season forecasts (Chapter A1), but also on the realism of the underlying model parameterisations, primarily those relating to fish movement and vulnerability to fishery operations.

Fundamentally, the Fisheries Planning Model is a forward reconstruction model (Cave and Gazey 1994, Starr and Hilborn 1988), simulating the daily migrations of sockeye salmon as they move through a gauntlet of marine and freshwater fisheries. The model uses fishery-specific instantaneous mortality rates applied to vulnerable "blocks" of salmon to estimate fisheries-specific catches and escapement (Chapter A9). Since the original publication of the forward reconstruction model by Cave and Gazey (1994), the assumptions underlying the model have been changed to reflect both improved information about stock-specific differences in salmon migratory behaviour, and changes to fisheries and management strategies (Chapter A9). Biologically, a larger number of individual stock groups are modelled given the availability of more detailed stock-specific data since the advancement of DNA-based stock identification technology (Chapter B11). Increased understanding of stock-specific fish migration behaviour has also resulted in changes to modelling approaches for diversion rate (percentage of fish migrating via Johnstone Strait vs. Juan de Fuca Strait) and delay in the Strait of Georgia. The following report describes the main biological assumptions underlying the simulation model.

Reconstruction Model Assumptions

A. NORMAL RUN TIMING DISTRIBUTIONS

Within the FRP Fisheries Planning Model, 'stocks' are defined as aggregates of fish with a unique set of migration characteristics such as: migratory path, migration rates, delay behaviour, marine arrival timing, and abundance. These stock groups are based on the four different Fraser River management groups but with additional sub-groups based on migration differentiation. For example, Late-run fish are divided into additional groups depending on whether they migrate through Johnstone Strait (North) or through Juan de Fuca Strait (South), whether or not they delay their upstream migration, and whether they spawn below or above the confluence of the Harrison River. The full suite of Fisheries Planning Model stock groups and migration parameters are described in Chapter A10 (Tables 1 and 2). The biological model for each stock (*s*) is initialised by creating a series of normally distributed daily migration profiles centred on an index of expected median marine migration timing:

$$(1) \qquad N(d) = N \cdot \frac{1}{\sigma\sqrt{2\pi}} \cdot e^{-\frac{1}{2}\left(\frac{d-\mu}{\sigma}\right)^2}$$

where *N* is the total forecasted abundance (run size) of a stock, *d* is day, σ is the standard deviation, and μ is the median marine migration date of the run (Figure 1). The marine migration date, also referred to as the Area 20 date or marine 50% date, indicates the date when half (50%) of the run would have passed through Area 20 assuming all fish migrated via that route. The normal distributions are parameterised using pre-season forecasts of abundance, timing and standard deviation (see Chapter A10).

Next, a daily diversion rate pattern (i.e. proportion of the run migrating around the northern tip of Vancouver Island instead of through Juan de Fuca Strait) is applied to create separate entry distributions for the northern and southern approaches around Vancouver Island (Figure 1). Alternative diversion rate patterns can be applied to individual stocks to accommodate known differences in migratory routes. Fish migrating through the southern approach are initiated in Area 127 off the southwest coast of Vancouver Island, and fish migrating through the northern approach are initiated in Area 111 off the northern tip of the island (Figure 1).

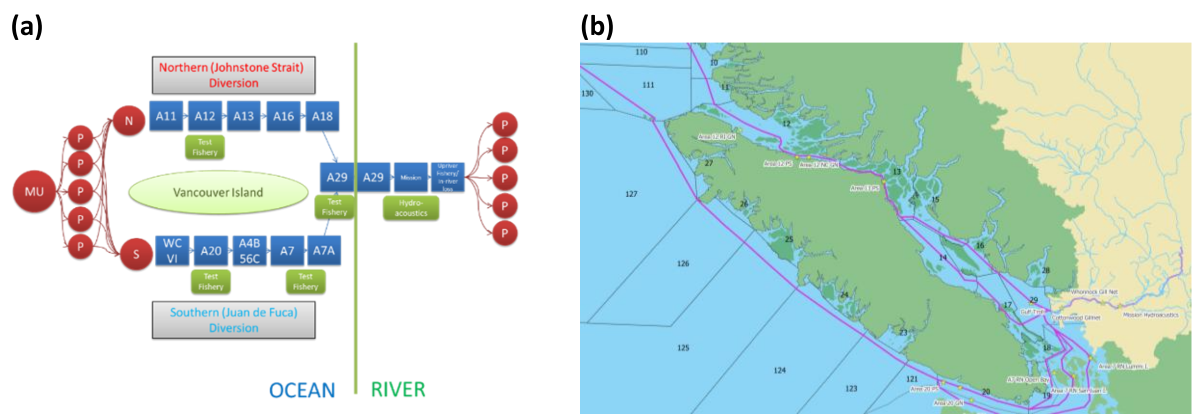

***Figure 1. (a)** Schematic illustrating the fisheries "gauntlet" modelled by the PSC fisheries planning model. **(b)** A GIS map of corresponding locations.*

B. BOX-CAR FORWARD RECONSTRUCTION ASSUMPTIONS

Once the daily abundance estimates, representing Fraser River sockeye expected to migrate through the north and south, are derived, the model uses a set of control rules to move fish through space and time from the tip of Vancouver Island to the Mission hydroacoustic site, and then continuing up the mainstem. Terminal fisheries harvests or Fraser sockeye single stock Food, Social and Ceremonial (SSFSC) fisheries, formerly known as catch excess to spawning escapement requirements (ESSRs), are not specifically addressed within the current modelling construct.

The forward reconstruction assumes a ‘box-car’ style movement of fish occurring on a daily time-step (Cave and Gazey 1994, Starr and Hilborn 1988) over most of the migration. A ‘bathtub’ assumption is also applied, meaning that on a given day fish are either fully vulnerable to or completely unaffected by, an assumed fishery opening. Migration times, and thus the exposure of a given daily migration ‘block’ of fish to a given fishery, are controlled by underlying stock-specific migration rates and lengths of each fishing area (Appendix A, Table A1). It is assumed that fish remain in a statistical area for a minimum of one day and migration times are rounded to full daily increments. Statistical areas associated with residency times greater than one day are represented by multiple model sub-areas, each representing roughly one day of migration time in the model (Appendix A, Table A1). In some cases, statistical areas represent parallel migration routes (e.g. Area 20, Areas 4B, 5, 6, and 6C). They are considered identical for migration purposes but are uniquely identified for catch accounting, i.e. fish are assumed to migrate simultaneously through Canadian Area 20 and U.S. Areas 4B, 5, 6C.

Figure 2 illustrates how the box-car movement assumptions interact with fishery exposure during the forward reconstruction. Exposure times depend on the dates of the fishery opening, the migration rate of the fish, and the size of the fishing area. In some cases, the same group of fish could be exposed to fishing pressure across multiple days of a fishery opening, while in others, a group of fish may only be vulnerable to a fishery for part of an opening.

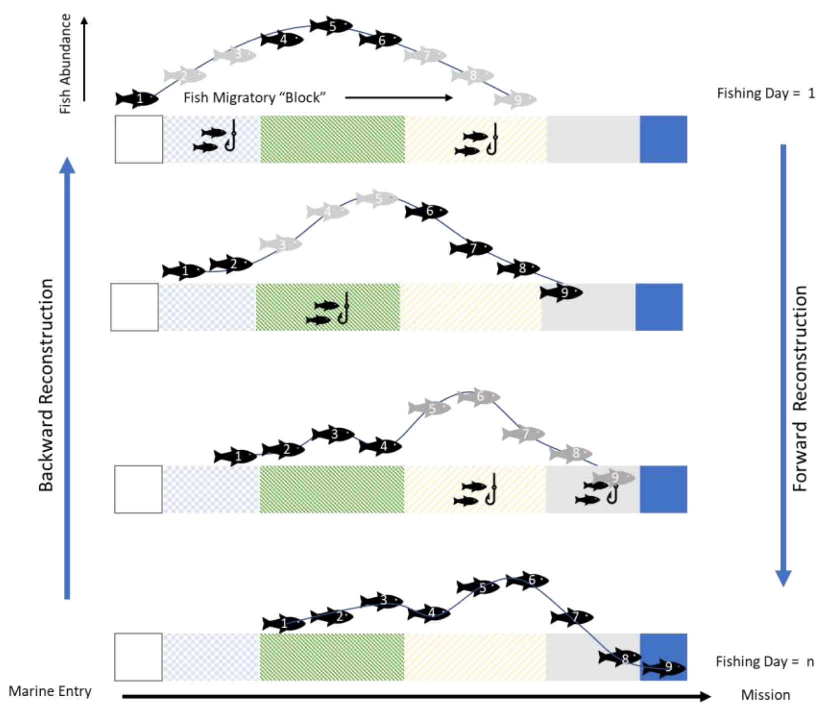

Figure 2. *Schematic illustration of a basic box-car run reconstruction model. The colored bars represent different statistical fishing areas, with the left most square representing the most seaward location. Each “fish/hook” represents one day of fishing. Each fish represents one daily block of fish. Black fish in each panel are not exposed to a fishery opening on a given day, while grey fish are. Each panel represents a daily time-step. The top panel represents the shape of the unfished run prior to entering marine approach fisheries. The bottom panel represents the shape of the run at Mission, with certain days of abundance reduced due to catch removals.*

Following the illustration in Figure 2, the escapement of fish (*N*) into area (*a*) on a given day (*d*) is reduced by an amount equivalent to the landed catches and release mortalities occurring on that day in that area. Assuming it takes one day for the fish to migrate through area *a*, the resulting escapement of fish into the downstream area (*a+1*) on the next day (*d+1*) is represented by:

(2) $$N_{a+1}(d+1) = N_a(d) - C_a(d)$$

The resulting daily escapement into the Fraser River (N_{FR}), after migrating for *m* days through all areas along the migration route and being intercepted by *k* fisheries along the way, is given by:

(3) $$N_{FR}(d+m) = N(d) - \sum_{f=1}^{k} C_f$$

C. STRAIT OF GEORGIA MIGRATION DELAY BEHAVIOUR

The exception to box-car movement occurs in the Strait of Georgia near the Fraser River Delta, where a proportion of the Late-run and Harrison stocks delay their migration prior to moving upstream (Lapointe et al. 2003, Chapter B22). Delaying fish are assumed to both slow down and to redistribute when entering the Fraser River, thus violating the assumptions of a box-car model. Subsequent to river entry, box-car movement is assumed to resume for the remainder of the freshwater migration. A separate sub-model is applied to model stocks which hold and redistribute in the Strait of Georgia (Chapter A10), for which a set of parameters that characterise the period of delay, and the new profile of upstream migration, are defined. Note that this sub-model does not apply to Late run or Harrison sockeye that do not delay their upstream migration

To mimic delay behaviour of delaying Late run and Harrison sockeye, the model adjusts the number of fish remaining in the Strait of Georgia (N_{SoG}) and the number of fish migrating into the lower river on a daily basis. This is done by assuming that delaying salmon fish accumulate over time in the Strait of Georgia, with a proportion of the available abundance migrating upstream:

(4) $$N_{FR}(d) = p(d) \cdot N_{T,SoG}(d),$$

where *p(d)* indicates the proportion of the abundance holding in the Strait of Georgia migrating into the Fraser River (*FR*), and $N_{T,SoG}$ indicates the total accumulated abundance remaining in the Strait of Georgia, following fisheries removals. The daily proportion of available fish migrating upstream is derived from a normal density function representing the run timing profile of a delaying stock as it exits the Strait of Georgia and enters the Fraser River, where σ is the standard deviation, and μ is the upstream timing:

(5) $$f(d) = \frac{1}{\sigma\sqrt{2\pi}} \cdot e^{-\frac{1}{2} \cdot \left(\frac{d-\mu}{\sigma}\right)^2}.$$

The proportion of delaying fish associated with each day of migration (*p(d)*) is then given by dividing the proportion of fish migrating upstream by the proportion of fish still present in the Strait of Georgia:

(6) $$p(d) = \frac{f(d)}{\sum_d^D f(d)}.$$

Because sockeye are assumed to accumulate in the Strait of Georgia, the daily abundance of out-migrating delay fish cannot simply be removed by subtracting from a single day of resident abundance (i.e. cannot be treated the same as a daily catch removal). Instead, the model makes the simplifying assumption that the total reduction in fish due to outmigration is spread proportionally across the remaining abundance in the Strait:

$$(7) \qquad p_{SoG}(d) = \frac{N_{SoG}(d)}{\sum_d^D N_{SoG}(d)}, \text{ with } N_{SoG}(d) = N_{SoG}(d-1) - C_{SoG}(d-1).$$

The result of this assumption is that the daily stock composition of sockeye entering the river from the Strait of Georgia will not mirror the daily stock composition entering the Strait of Georgia.

The shape of the remaining distribution fish in the Strait of Georgia after each day of upstream migration (N_{FR}) and catch (C_{SoG}) is then calculated using:

$$(8) \qquad N_{SoG}(d+1) = N_{SoG}(d) - p_a(d) \cdot N_{FR}(d).$$

In the next loop of the simulation, the escapement into the river is equivalent to the abundance out-migrating from the Strait (N_{FR}) and the escapement into the Strait (N_{SOG}) becomes re-defined by Equation 8. Due to the iterative nature of this calculation, daily escapement into the river is populated one day at a time, even in the absence of any fisheries.

Planned Changes and Areas for Improvement

There has been some interest in improving the modelling of pink salmon fisheries as well as upriver fisheries, some of which are currently entered as fixed inputs in the model. Modellers also continue to revise and improve the coding efficiency and user interfaces and address ongoing requests from the Fraser River Panel and Technical Committee.

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Appendix A: detailed movement assumptions

Table A1. *Modelled residency times within different statistical areas and offsets from the index start of Area 20.*

Statistical Area(s)	Approach	Country	Model Sub-Area(s)	Residency Time (days)	Offset from Area 20 (Southern Approach)		Offset from Area 20 (Northern Approach)	
					Summer-run	Late-run	Summer-run	Late-run
Area 20	Juan de Fuca	Can	fa7, fa8	2	0	0	NA	NA
Area 19	Juan de Fuca	Can	fa9, fa10	2	2	2	NA	NA
Area 18	Juan de Fuca	Can	fa11	1	4	4	NA	NA
Area(s) 4B,5,6C	Juan de Fuca	U.S.	fa7, fa8	2	0	0	NA	NA
Area 6	Juan de Fuca	U.S.	fa9	1	2	2	NA	NA
Area 7	Juan de Fuca	U.S.	fa10	1	3	3	NA	NA
Area 7A	Juan de Fuca	U.S.	fa11	1	4	4	NA	NA
Area 11	Johnstone Strait	Can	fa13	1	NA	NA	-3	0
Area 12	Johnstone Strait	Can	fa14, fa15, fa16	3	NA	NA	-2	1
Area 13	Johnstone Strait	Can	fa17, fa18	2	NA	NA	1	4
Area 14	Johnstone Strait	Can	fa19, fa20	2	NA	NA	3	6
Area 15	Johnstone Strait	Can	fa19	1	NA	NA	3	6
Area 16	Johnstone Strait	Can	fa20	1	NA	NA	4	7
Area 17	Johnstone Strait	Can	fa21	1	NA	NA	5	8
Area 29A	Strait of Georgia	Can	fa22	1	5	5	6	9
Area 29B	River	Can	fa23	1	6	6	7	10
Area 29D	River	Can	fa24	1*	7	8	8	12
Mission-Harrison	River	Can	fa25	1*	8	9	9	13
Harrison-Sawmill	River	Can	fa26	2	9	11	10	14
Above Sawmill	River	Can	fa27	NA	11	13	12	16

**2-day migration for Late-run sockeye salmon due to slower migration speed*

A12. Harvest rate parameterisation and catch dynamics

M.J. Hague

Summary

The FRP Fisheries Planning Model (Chapter A9) is a simulation tool used by the Fraser River Panel to assess alternative fisheries plans and their ability to achieve management targets under various biological (e.g., run size, diversion rate) and/or management scenarios. This report describes the fisheries included in the model as well as the different approaches for calculating catch and escapement based on daily estimates of sockeye abundance in the various fishing areas. The underlying migration assumptions are described in Chapter A11. The sources and processes used to derive the biological and fisheries management inputs to parameterise the model are provided in Chapter A10.

Introduction

As described in Chapter A9, and pursuant to Annex IV, Chapter 4, Paragraph 9d, of the Pacific Salmon Treaty (PST 2025), the Fraser River Technical Committee (FRTC) and Pacific Salmon Commission (PSC) staff work jointly to develop fisheries and management plans for Fraser River sockeye salmon prior to the start of each fishing season using the FRP Fisheries Planning Model. The usefulness of the Planning Model as a management tool depends in part on the accuracy of pre-season biological forecasts (Chapter A1 and A2), but also on the realism of the underlying model parameterisations, such as assumed harvest rate dynamics and assumptions about the vulnerability of migrating salmon to fisheries openings.

The types of fisheries targeting Fraser River sockeye salmon, and the management rules used to guide them, have changed substantially since the Fisheries Planning Model was first described by Cave and Gazey (1994). For example, many Canadian commercial fisheries in marine areas have changed from high intensity derby-style fisheries, to protracted, lower-impact, individual transferable quota (ITQ) fisheries. In addition, the Fisheries Planning Model now monitors the impact of both landed catch and release mortalities on estimated escapements; a relatively new concern due to increased interest in Fraser River pink salmon directed fisheries and the need for accurate accounting of exploitation rates associated with vulnerable Fraser River sockeye salmon stocks.

Daily fishery catches within the Fisheries Planning Model are both a function of the abundance and vulnerability of the salmon exposed to a given opening as well as a function of the assumed harvest rates of the fishery, or fisheries, operating in a given area on a given day. The following report describes the assumptions, parameterisations, and control rules used to quantify both the abundance of the vulnerable fish population and the fishery-induced mortality rates associated with individual fisheries. Resulting daily catch and escapement calculations are also defined as well as areas for future refinement.

Fisheries Planning Model Catch Assumptions

A. FISHERY HARVEST RATE DEFINITIONS

A detailed description of fishery parameterisations within the Fisheries Planning Model can be found in Table A1. There are four categories of fisheries within the model that are characterised by different harvest rate equations and associated parameter requirements: derby fisheries, mixed gear fisheries, ITQ fisheries, and test fisheries. Each category is described in more detail below.

Derby Fisheries

Harvest rate equations for many of the derby fisheries were parameterised with data from the 1980's and 1990's (Cave and Gazey 1994), Table A1. Catch is a function of the number of vessels, the assumed harvest rate per vessel, and the length of the opening. Historically, these fisheries were characterised by a short fishing window, high fishing effort (*E*, number of vessels participating in the fishery), and often intensive fishery exploitation. As a result, original harvest rate parameterisations were sometimes characterised for 12-hour openings, in which case the 'elemental' harvest rates (*u*) defined by Cave and Gazey (1994) were first re-scaled to daily harvest rates (*h*):

$$(1) \qquad h = 2 \cdot u + u^2, \text{ with } u = a + b \cdot E$$

where 'a' and 'b' are fishery-specific parameters (Table A1) relating effort to harvest rate. In other cases (Table 1), daily harvest rates were parameterised as a function of effort and fishery catchability (*q*) estimated from historical reconstructions:

$$(2) \qquad h = 1 - e^{-qE}$$

Many of the FSC fisheries are modelled with a single daily harvest rate (*h*), which is informed by the expert judgement of fishery managers and may change at the discretion of the Canadian Technical Committee Chair. Often, the intention of these harvest rates is not to accurately reconstruct catches, but to seed the Fisheries Planning Model with reasonable harvest expectations and to meet domestic catch constraints.

U.S. Mixed Gear Fisheries

The current harvest rate equations applied to U.S. All Citizen and Treaty Indian fisheries operating in statistical Areas 6, 7, and 7A were originally parameterised based on analyses performed in the 1980s (PSC 1990). The effort (*E*; quantified as the number of vessels or the number of landings) in these mixed gear fisheries is quantified in terms of "purse seine equivalents". A fixed gill net to purse seine catch-per-unit-effort CPUE ratio is applied to re-scale the number of gill net vessels (*GN*) participating (or modelled) during a fishery opening into a "purse seine equivalent" (E_{PS}):

$$(3) \qquad E_{PS} = \frac{CPUE_{GN}}{CPUE_{PS}} \cdot E_{GN}$$

where *E* refers to fishing effort.

The Fisheries Planning Model applies a fixed 0.2 CPUE ratio to "convert" the number of gill net vessels into an equivalent number of purse seine vessels (i.e. the effort associated with five gill nets is equivalent to the effort of one purse seine). The original analysis resulting in the application of the CPUE ratio for effort scaling has not been identified, although similar conversions of vessel effort to purse seine equivalents using CPUE ratios have been applied in other fisheries. e.g. herring fisheries in the North Sea (Bjorndal and Conrad 1987).

Harvest rates for the U.S. mixed gear fisheries are also assumed to vary across the season (elemental harvest rates, u_{early} vs. u_{late} in Table A1). The historical analysis of purse seine equivalents from the 1980s (PSC 1990) noted that catchability in Area 7 and 7A fisheries decreased in mid- to late August, potentially associated with lower catchability of Late-run fish due to behavioural differences in migration patterns (e.g. swimming lower in the water column and less accessible to gear). However, PSC Staff also hypothesized that observed seasonal differences in catchability could be associated with estimation errors related to uncertainty in Late-run reconstructions (PSC 1990). The Fisheries Planning Model somewhat arbitrarily assigns a date of August 12 in Area 7 and August 14 in Area 7A to switch from “early” to “late” harvest rates, as the stock composition generally becomes weighted more heavily towards Late-run stock components around this time. However, modellers have the flexibility to redefine the time periods over which to apply each harvest rate equation.

ITQ Fisheries

Canada’s Area B, E and H fisheries currently operate under an Individual Transferable Quota (ITQ) system. These fisheries are modelled by ‘spreading’ the total catch target (C_T) over the duration of the fishery opening (*n*) which may last 1 to 7 days (*d*):

$$C(d) = C_T/n. \qquad (4)$$

For fisheries openings spanning multiple statistical areas (e.g. Area 12 and 13 purse seine), the total daily catch is proportionally assigned to each area (*a*) based on fishing effort (*E*, number of vessels):

$$C_{a_1}(d) = \frac{E_{a_1}}{\sum_{a_1}^{A} E_a} \cdot C_T(d). \qquad (5)$$

On a given day, the catch is converted to a harvest rate (*h*) by dividing the catch by the number of salmon exposed to the fishery:

$$h(d) = C(d)/N(d) \qquad (6)$$

The resulting harvest rate is then applied across the different stock groups, assuming equal catchability. Daily harvest rates are capped at thresholds (h_T) to prevent unrealistic catches at low fish abundance:

$$h(d) = min\begin{Bmatrix} h_T, \\ \frac{C(d)}{N(d)} \end{Bmatrix}. \qquad (7)$$

If daily catch targets are not met early in the opening (i.e. $C(d) < C_T(d)$), the remaining catch is redistributed across subsequent days until the total catch target (C_T) is reached:

$$If\ C(d) < C_T\ ,\ then\ C(d+1{:}D-1) = C_T - \textstyle\sum_{d=1}^{D} C(d), \qquad (8)$$

where C_T is the total target catch over the course of an ITQ opening, *d* is fishing day, and *D* is the number of days in an opening. This approach assumes that the fishery will operate in a manner which increases the probability of reaching the target catch applied to the opening.

Test Fisheries

Gillnet test fisheries are assumed to land all catches estimated using historically derived, time varying, harvest rates (Chapter B5). Landed catches from purse seine test fisheries to meet scientific sampling requirements are calculated outside of the Fisheries Planning Model and entered as fixed catch deductions (Chapter A8). By default, all other sockeye encountered by the purse seine test fisheries are assumed to be released. However, to offset the cost of test fishing operations in some years, the purse seine test fisheries may retain their sockeye and/or pink salmon catch on some days. During retention periods, the purse seine test fisheries are modelled using the ITQ catch equations, with total target catches and opening dates provided by PSC Staff.

1) CATCH AND ESCAPEMENT PROJECTIONS

Fish Vulnerability

In addition to the harvest rate calculations, the catch on a given day of a fishery opening will also depend on the number of fish vulnerable to harvest during the opening. As discussed in Chapter A11, the Fisheries Planning Model assumes that fish migrate through fishing areas on a daily time-step and assuming fixed order of movement, i.e., box-car reconstruction. The number of daily blocks of fish migration exposed to a fishery depend on the size of the management area, the number of days a fishery is open, and the speed with which salmon migrate through the fishery. In some cases, the same group of fish might be exposed to fishing pressure over multiple days of an opening, or in sequential openings occurring in downstream areas. The Fisheries Planning Model calculates the number of fish escaping from a fishery on a daily basis, so that the vulnerable population becomes smaller over multiple days of exposure.

Instantaneous Harvest Rates

To facilitate the modelling of simultaneous fisheries and short-fishery openings (< 1 day), daily harvest rates (*h*) were re-scaled in the current Fisheries Planning Model as instantaneous fishing mortality rates (*F*), where:

$$F = \left(-1 * log(1 - h)\right). \quad (9)$$

The resulting catch for a single day is then calculated as:

$$C(d) = \ (1 - e^{-F}) \cdot N(d) \quad (10)$$

where *C(d)* is catch on a given day, *N(d)* is the total number of fish exposed to a given fishery (i.e. may include one or multiple daily “blocks” of fish migration) and *d* is fishing day. The above re-scaling does not impact catch estimation when there is only a single fishery targeting a block of fish but becomes important during simultaneous fishery modelling. Catch on subsequent days, or in subsequent areas, is then a function of the number of fish in each daily migration block escaping from the previous opening, where *N(d+1)* is the total abundance escaping from the fishery on day *d*:

$$N(d + 1) = N(d) - C(d). \quad (11)$$

Fisheries removals are indexed both by fishing day, as well as by daily migration block to calculate both daily escapements and to summarise catches. The model also summarises daily escapement from every statistical area for each stock. The impact of changes to fishing area size, partial area closures, assumed slowing or speeding up of fish through an area etc., can all be easily modelled through a simple change to the data input files.

Instantaneous fishing mortality equations can be expanded to model multiple simultaneous sources of mortality, such as when more than one fishery is operating in the same area at the same time, or with the potential future inclusion of natural sources of mortality. To do so, the total catch is first calculated using:

$$C(d) = \left(1 - e^{-\sum_1^n F}\right) \cdot N(d) \quad (12)$$

The catch is then partitioned across *n* fisheries (or alternative sources of mortality) using:

$$C(d)_n = C(d) * \frac{F_n}{\sum_1^n F} \quad (13)$$

While derby fisheries can operate simultaneously and for fractions of a day, an order of operations must still be assumed for ITQ fisheries. By default, ITQ fisheries operating in the same area on the same date are assumed to take place after any simultaneous derby fisheries, i.e., ITQ harvest rate equations are based on the abundance of fish escaping from concurrent derby fisheries. From a practical standpoint, this model simplification only impacts ITQ catches in scenarios of low abundance relative to target catch, in which case harvest thresholds may be triggered.

Release mortalities

In addition to landed catch, the Fisheries Planning Model also models the mortality associated with the non-retention of sockeye catches during pink-directed fishery openings i.e., release mortalities. The assumed loss of fish is calculated by multiplying the harvest rate associated with a directed fishery by a gear-specific release mortality rate (Table A1). For the purposes of escapement calculations, release mortalities are removed from daily migration blocks of salmon in the same way as landed catch; however, release mortalities are tracked separately for the purposes of catch accounting.

Planned Changes and Areas for Improvement

Most harvest rate equations within the Fisheries Planning Model were parameterised using data from years with very different fisheries, and fish conditions compared to current. It also has been noted that some of the U.S. harvest rate equations produce negative values when fleet size drops below a certain threshold. Given the changes in fish abundance, fleet size, and fishing technology over the last 40 years, the parameterisation of these fisheries (Table A1) requires updating and should be interpreted with caution.

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Appendix A: Detailed fisheries descriptions

Table A1. *General characteristics of each fishery currently used in the Fisheries Planning Model. Elemental daily harvest rates (h) are converted to instantaneous fishing mortality rates (F) using the formula:* $F = (-1 * log(1-h)) * T$*, where T=1 is a full fishing day.*

Fishery	Location	Country	User	License	Gear	Length (km)	Days of fish Residency	Derby harvest Equation	Parameters	ITQ Harvest Threshold	Release Mortality	Daily Catch Threshold	Annual Catch Threshold
A20 B	A20	Can	Comm	B	Purse seine	94	2	$h = 1 - e^{(-q*E)}$	q = 0.00685	30%	25%	n/a	n/a
A18 H	A18-4	Can	Comm	H	Troll	45	1	h *(stock-specific)*	n/a	5%	10%	n/a	n/a
A11 D	A11	Can	Comm	D	Gill net	29	1	$u = a + b * E$ $h = 2 * u + u^2$	a = 0.006628 b = 0.000346	n/a	60%	n/a	n/a
A12 D	A12	Can	Comm	D	Gill net	96	2	$u = a + b * E$ $h = 2 * u + u^2$	a = 0.0064239 b = 0.000373	n/a	60%	n/a	n/a
A12 B	A12	Can	Comm	B	Purse seine	96	2	$u = a + b * E$ $h = 2 * u + u^2$	a = 0.30342 b = 0.0012	65%	25%	n/a	n/a
A13 B	A13	Can	Comm	B	Purse seine	91	2	$u = a + b * E$ $h = 2 * u + u^2$	a = 0.29159 b = 0.001	55%	25%	n/a	n/a
A12 H	A12	Can	Comm	H	Troll	48	1	$h = h_{max} * v$	h_{max} = 0.02 v = stock specific scaler	8%	10%	n/a	n/a
A13 H	A13	Can	Comm	H	Troll	91	2	$h = h_{max} * v$	h_{max} = 0.04 v = stock specific scaler	8%	10%	n/a	n/a
A29 H	A29	Can	Comm	H	Troll	41	1	$h = q * E$	q = 0.004	0.2%	10%	n/a	n/a
A29 B	A29	Can	Comm	B	Purse seine	41	1	h	n/a	50%	25%	n/a	n/a
A29 E	A29	Can	Comm	E	Gill net	70	2	h	n/a	80%	60%	n/a	425,000
A20 FSC	A20	Can	FSC	n/a	Mixed	47	1	h	n/a	n/a	n/a	n/a	260,000 (marine FSC total)
A1213 FSC	A12, A13	Can	FSC	n/a	Mixed	31	1	h	n/a	n/a	n/a	n/a	260,000 (marine FSC total)
StevHR FSC	Steveston - Harrison	Can	FSC	n/a	Mixed	100	3	h	n/a	n/a	n/a	95,000	400,000
HRSM FSC	Harrison - Sawmill	Can	FSC	n/a	Mixed	73	2	h	n/a	n/a	n/a	95,000	400,000
AbSM FSC	Above Sawmill	Can	FSC	n/a	Mixed	n/a	n/a	h	stock-specific	n/a	n/a	n/a	190,000
A67 TI	A6, A7	US	TI	n/a	Mixed	81	2	u_{early} $= a + b * \ln(E)$ $u_{late} = a + b * E$	a_{early} = -0.1823 b_{early} = 0.0928 a_{late} = 0.0443	n/a	25%	n/a	n/a

								$h = 2 * u + u^2$	b_{late} = 0.00088				
A7A TI	A7A	US	TI	n/a	Mixed	45	1	$u_{early} = a + b * \ln(E)$ $u_{late} = a + b * E$ $h = 2 * u + u^2$	a_{early} = -0.3602 b_{early} = 0.212 a_{late} = 0.0405 b_{late} = 0.00378	n/a	25%	n/a	n/a
A67 AC	A7, A7	US	AC	n/a	Mixed	81	2	$u_{early} = a + b * \ln(E)$ $u_{late} = a + b * E$ $h = 2 * u + u^2$	a_{early} = -0.1823 b_{early} = 0.0928 a_{late} = 0.0443 b_{late} = 0.00088	n/a	25%	n/a	n/a
A7A AC	A7A	US	AC	n/a	Mixed	45	1	$u_{early} = a + b * \ln(E)$ $u_{late} = a + b * E$ $h = 2 * u + u^2$	a_{early} = -0.3602 b_{early} = 0.212 a_{late} = 0.0405 b_{late} = 0.00378	n/a	25%	n/a	n/a
A4B56C	A4B, A5, A6C	US	TI	n/a	Gill net	94	2	$h = q * E$	q = stock specific	n/a	60%	n/a	n/a
A20 GN TF	A20	Can	TF	n/a	Gill net	94	2	h	n/a	n/a	60%	n/a	n/a
A20 PS TF	A20	Can	TF	n/a	Purse seine	94	2	h	n/a	n/a	2%	n/a	n/a
A12 GN TF	A12	Can	TF	n/a	Gill net	48	1	h	n/a	n/a	60%	n/a	n/a
A12 PS TF	A12	Can	TF	n/a	Purse seine	144	3	h	n/a	n/a	2%	50,000 (across A12, A13)	n/a
A13 PS TF	A13	Can	TF	n/a	Purse seine	91	2	h	n/a	n/a	2%	50,000 (across A12, A13)	n/a
A29 Cott TF	A29 (Cottonwood)	Can	TF	n/a	Gill net	35	1	h	n/a	n/a	60%	n/a	n/a
A29 Whonn TF	A29 (Whonnock)	Can	TF	n/a	Gill net	35	1	h	n/a	n/a	60%	n/a	n/a

B1. PSC Test Fisheries

E. Taylor

Summary

The Pacific Salmon Commission funds and operates test fisheries to inform bilateral decisions of the Fraser River Panel through the collection of data on Fraser River sockeye and pink salmon in southern British Columbia and northern Washington State. These test fisheries provide information on abundance, timing, and diversion rates as well as species and stock composition information for use in stock assessments to inform fisheries management. PSC Secretariat involvement in these test fisheries ranges from financial assistance to complete responsibility for day-to-day operations. This report outlines the purpose of Panel-approved PSC test fisheries and administrative responsibilities for the test fishing program.

Introduction

The Pacific Salmon Commission (PSC), and its predecessor the International Pacific Salmon Fisheries Commission (IPSFC), have operated test fisheries to obtain data required to inform bilateral decisions of the Fraser River Panel since the 1960s. These test fisheries are authorised under the Pacific Salmon Treaty to assess Fraser River sockeye and pink salmon and occur in three key geographic areas (Figure 1): the northern and southern marine approaches to the Fraser River (Johnstone Strait and the Strait of Juan de Fuca, respectively) and the lower Fraser River.

Figure 1. *Map of PSC test fisheries, consisting of marine test fisheries in Johnstone Strait (Round Island gillnet test fishery, Upper (Area 12/Blinkhorn) and Lower (Area 13) Johnstone Strait purse seine fisheries) and Juan de Fuca Strait (Area 20 gillnet and purse seine test fisheries, Area 5 gillnet test fishery and Area 7 US reefnet test fishery), in the Strait of Georgia (Gulf troll test fishery) and in-river gillnet test fisheries at Brownsville Bar, Whonnock and Qualark. The map also indicates the location of the Mission hydroacoustic site.*

Test fishing is the deployment of fishing efforts to gather information about fish either moving through or residing in a particular area. This is done by the deployment of consistent fishing effort in a particular area so that quantitative catch and biological data can be used for fisheries stock assessments (Chapter B23). Test fisheries are sometimes equipped with specialized fishing gear in order to target or avoid certain species or stocks. Additionally, test fisheries have observers aboard the vessels to monitor effort and catch (Chapter B4) as well as collect biological data and samples (Chapter B9) for use in stock assessment. Gear types used by the PSC test fisheries include purse seines, gillnets (both single and variable mesh), troll/hook and line, and reefnets.

Table 1. *Overview of PSC test fisheries, currently approved by the Fraser River Panel, in terms of the area of operation, administrative responsibility, period of operation, gear used, species and management group assessed, monitoring purpose, data use and derived abundance estimates.*

	Current Panel approved PSC test fisheries										
	Area 20 Gillnet	Area 20 Purse seine	Area 12 Gillnet Round Island	Area 12 Purse seine Blinkhorn	Area 13 Purse seine	Area 29 Brownsville Bar Gillnet	Area 29 Whonnock Gillnet	Area 29 Gulf Troll	Area 5 Gillnet	Area 7 Reefnet Observation	Qualark Gillnet
Region											
Fraser River & Georgia Strait						X	X	X			X
Juan de Fuca Strait & US Waters	X	X							X	X	
Johnstone Strait			X	X	X						
Panel Area											
Panel Area Waters	X	X				X	X	X	X	X	
Non-Panel Area Waters			X	X	X						X
Period of operation											
1960s	X	X					X				
1970s	X	X					X				
1980s	X	X	X	X			X	X			
1990s	X	X	X	X	X		X	X		X	
2000s	X	X	X	X	X		X	X	X	X	X
2010s	X	X	X	X	X		X	X	X	X	X
2020s	X	X	X	X	X	X	X	X	X	X	X
Gear											
Gillnet	X		X			X	X		X		X
Purse Seine		X		X	X						
Troll								X			
Reefnet										X	
Mangement group											
Early Stuart	X		X			X	X		X		X
Early Summer	X		X			X	X		X	X	X*
Summer	X	X	X	X	X	X	X		X	X	X*
Late run		X		X	X	X	X	X		X	X*
Pink		X		X	X		X			X	*
Monitoring purpose											
Core in-season assessment	X	X	X	X	X	X	X	X			
Qualitative	X	X	X	X	X	X	X	X	X	X	X
Quantitative	X	X	X	X	X	X	X	X			X
Research						X					X
Data uses											
Timing	X	X	X	X	X		X	X	X	X	
Abundance	X	X	X	X	X		X	X	X	X	
Stock ID	X	X	X	X	X	X	X	X	X	X	X
Diversion	X	X	X	X	X						
Specie composition							X				X
Harvest rate					X						
Late-run management		X		X	X		X	X			
Pink management		X		X	X		X				
Project Mission escapement	X	X	X	X	X	X	X	X			
Project abundance entering US	X	X							X	X	
International allocation	X	X	X	X	X	X	X		X	X	
Verification					X	X					X
Estimate abundances in											
Marine areas	X	X	X	X	X						
Commercial catches	X	X	X	X	X				X	X	
US Waters	X	X	X	X	X				X	X	
Strait of Georgia		X		X	X	X	X	X			
Fraser River at Mission	X	X	X	X	X	X	X				

*The Qualark test fishery only provides information for stocks that migrate past Qualark.

Purpose of PSC test fisheries

The specific purpose of each PSC test fishery varies but collectively their data are used in conjunction with information from the in-river hydro-acoustics program to provide in-season estimates of run size, timing and diversion of Fraser River sockeye and pink salmon management units. Table 1 provides an overview of the different PSC Panel-approved test fisheries. The raw data provided by the test fisheries are catch by stock and species (based on sampling), effort, and other biological information such as age, sex, and weight (Chapter B7). Collectively across the test fishery program, these data are used as inputs to the PSC models to assess abundance (Chapter B23), timing, the diversion rate, stock composition (Chapters B10 and B11), species composition (Chapter B19), vulnerability (which stocks are susceptible to capture by particular gear in particular areas) and catchability (the proportion of the available abundance captured per unit of effort) (Chapters B5 and B6). In addition to providing inputs into the PSC's in-season modeling process, the data from various test fisheries are sometimes used to project the magnitude of catches in potential fisheries (Chapter B34). Individual test fisheries can also provide relevant information on local abundances for certain users. Finally, many of the test fisheries also catch non-target stocks and other salmon species, which provides an incidental source of information on those stocks and species.

During 2016 and 2017, two workshops were commissioned to compile available information on historic and existing test fisheries, to gather input from a variety of experts in both Canada and the United States, as well as to undertake technical analyses. The results of these workshops and resulting technical review were published in a technical report and provide further details regarding the purpose of the various test fisheries (Nelitz et al. 2018).

Administration

Panel-approved test fisheries are operated in-season to provide information to the Panel in support of Fraser River sockeye and pink salmon management. All Panel-approved test fisheries are overseen by PSC Secretariat staff and the Panel. They are funded and approved through the Panel process (Chapter A6 and A7) and any decisions that 1) influence the financial state of the PSC test fishing program, 2) affect mortality of Fraser River sockeye and pink salmon, or 3) affect the Panel's ability to manage Fraser River sockeye and pink salmon are made by the Panel with advice from PSC staff. In general, day-to-day operations are the responsibilities of PSC staff, DFO staff, and First Nations administrators and major decisions and direction are the responsibility of the Panel.

Test fisheries fall under two categories depending on whether they occur within Panel Area waters or not (Figure 2). Test fisheries occurring in Areas 12 and 13 as well as upstream of the Mission Bridge take place in Non-Panel Area waters, are operated by Fisheries and Oceans Canada (DFO), and tend to involve administrative assistance from First Nations whose traditional territory the test fisheries are operated within. The test fisheries within Johnstone Strait are administered by the Namgis A-Tlegay Fisheries Partnership. The Qualark Gillnet test fishery, located in the Fraser Canyon near Yale, is operated by DFO with support from Yale First Nation. DFO is responsible for selecting test fishing contractors and fish buyers. The remaining test fisheries occur within Panel Area waters and are operated by PSC Secretariat staff. Selection of test fishers and buyers, as well as financial accounting for these test fisheries are all performed by PSC Secretariat staff.

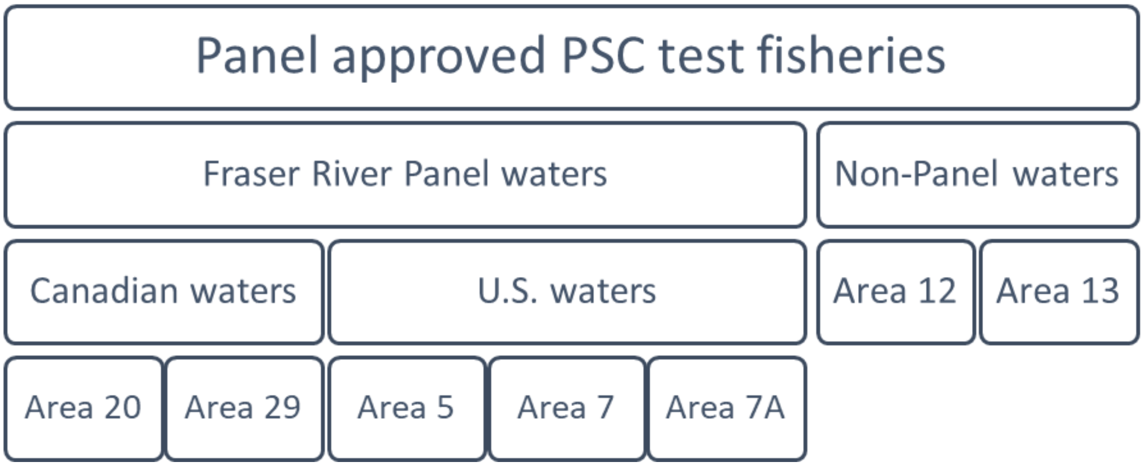

Figure 2. *Hierarchy table of Panel approved PSC test fisheries depending on location.*

Planned changes and potential areas of improvement

Many of the planned changes and potential areas of improvement are outlined in the Summary of a Review of Fraser River Test Fisheries (Nelitz et al. 2018). In addition, there are ongoing modifications to the test fishing program to reduce costs and increase the information gained per dollar spent. A Southern Endowment Fund project is expected to start in 2026 to determine how available funding is best allocated to meet the needs of the Fraser River Panel.

References

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B2. Marine Test Fisheries

J. Maguire

Summary

Fraser River Panel-approved marine test fisheries operate along the southern and northern marine approach routes around Vancouver Island to the mouth of the Fraser River. These test fisheries provide information on marine abundances, timing, and diversion of Fraser River sockeye and pink salmon (Chapter B23) and collect biological samples for demographic analysis and stock identification (Chapter B7) to inform fisheries management decisions. Four gear types are used for marine test fisheries: gillnets, purse seines, reefnets, and troll/hook-and-line. This report summarises the purpose, timing, and operations of each marine test fishery for the assessment of Fraser River sockeye and pink salmon. It also summarises the numerous analyses evaluating the impact of different test fishing factors on the precision of resulting abundance estimates. A more general overview of PSC test fisheries including a location map can be found in Chapter B1 while further details regarding the operational periods of each fishery are described in Chapter A6. Catch and CPUE data from the various marine test fisheries can be found in the Fraser Panel Data Application (2024).

Introduction

As per the Pacific Salmon Treaty (PST 2025), the Fraser River Panel is responsible for conducting test fisheries to monitor Fraser River sockeye and pink salmon. Marine test fisheries are used to estimate abundances, timing, and diversion of Fraser River sockeye and pink salmon through Johnstone Strait and Juan de Fuca Strait in Canadian and U.S. waters and to collect biological samples for demographic analyses and stock identification. The marine gillnets and purse seine test fisheries in Area 12 and 20 form the core of the in-season assessment program, assessing the abundance of non-delaying stocks on average 6 days prior to their migration past the Mission hydroacoustics site. For Harrison sockeye, delaying Late-run sockeye and pink salmon, the marine test fisheries are the only source of assessment information timely enough for in-season marine fisheries management decisions. Other marine test fisheries enhance the available information (e.g. the Area 13 purse seine test fishery) or are used to support U.S. fisheries planning (e.g. the Area 5 gillnet and the Area 7 reefnet test fisheries). This report details the purpose of each Panel-approved marine test fishery in the assessment and management of Fraser River sockeye and pink salmon, as well as their timing, operations and limitations. Additionally, this report also summarises the research evaluating the different test fishing factors impacting the precision of resulting abundance estimates.

Marine Gillnet Test Fisheries

The marine gillnet test fisheries in Area 20 and Area 12 are used to assess the abundance, timing, and diversion of Early Summer and Summer-run sockeye through Juan de Fuca and Johnstone Strait, respectively. A matching set of Area 20 and 12 CPUE data are needed in-season to produce daily estimates of abundance for migration graphs and for the predictions of abundance en route to Mission. While particularly effective for the assessment of Early Summer run sockeye, the effectiveness of these test fisheries decreases as salmon catchability decreases as the season progresses. As a result, these test fisheries are not considered suitable for the assessment of Late-run sockeye and pink salmon. The gillnet test fisheries can provide valuable information for the assessment of the Summer run, however information gathered by the purse seine test fishery is used preferentially. In addition to the CPUE data, these test fisheries collect DNA, scales and other biological information for stock identification purposes (Chapter B7). All the catch is landed, as mortality is unavoidable, including mortality of non-target species. However, starting in 2025 a release mortality of 60% for the marine gill net test fisheries was applied in accordance with a recent Canadian Science Advisory Report (CSAS, DFO 2025) to improve estimates of release mortalities for Chinook and coho that are not required for sampling purposes and that would be expected to have a good chance of survival are released. Operated annually, the marine gillnets begin in the second week of July and conclude between late-July and mid-August depending on assessment and management needs (Chapter A6). Prior to 2015, the gillnet test fishery in Area 20 started much earlier to assess Early Stuart sockeye which migrated primarily through Juan de Fuca Strait and not Johnstone Strait. Early Stuart conservation concerns and the lack of harvestable surplus for this stock have removed the need to assess its abundance in marine areas. More general conservation concerns for the total Fraser sockeye run following a record low forecast estimate led the Fraser River Panel not to operate marine gillnet test fisheries in 2024 (PSC 2026).

AREA 20 SAN JUAN GILLNET

The Area 20 San Juan Gillnet test fishery has been in operation annually since 1962, north of the international boundary in Juan de Fuca Strait. The gillnet used is 300 fathoms long and 90 meshes deep, with a 5.125” multistrand mesh. In 2023, this test fishery started transitioning to an Alaska Twist net which is a 5” mesh size. The multistrand net will eventually be phased out. Fishing occurs between San Juan Point and Sombrio Point at depths between 40 and 140 fathoms, between the hours of 8 p.m. and 6 a.m. Each night, two vessels complete two 3-hour sets each. Using two vessels instead of one allows for greater coverage of the salmon migration and reduces the chance of missing data. Operating two vessels also benefits safety but doubles the cost. In general, it is assumed that it takes non-delaying sockeye 6 days to migrate from this test fishing location to the Mission hydroacoustic site. Non-target stocks and species of note encountered by the Area 20 gillnet are Lake Washington sockeye, Puget Sound pinks, Fraser River coho and Chinook as well as other Canadian and U.S. salmon stocks (Nelitz et al. 2018).

AREA 12 ROUND ISLAND GILLNET

The Area 12 Round Island gillnet test fishery has operated annually since 1986, 1 to 1.5 nautical miles east of Round Island in Queen Charlotte Strait. A 200 fathom, 60-mesh deep Alaska Twist gillnet with a 5” mesh size is used. Starting in 2019, the Round Island gillnet started a multi-year transition from the use of the older style 5.125” multistrand nets to 5” Alaska Twist nets (Labelle & Van Will 2022). The full transition occurred in 2023. One vessel is used each night, completing three sets, taking approximately 2 to 3 hours each. In general, it takes non-delaying sockeye 8 days to migrate from the Round Island test fishing location to the Mission hydroacoustics site. Non-target stocks and species of note encountered by the Area 12 gillnet include Sakinaw and Nimpkish sockeye, Canadian South Coast and Puget Sound pink salmon, Fraser coho and Chinook and other Canadian and U.S. salmon stocks (Nelitz et al. 2018).

AREA 5 JUAN DE FUCA GILLNET

The Area 5 Juan de Fuca gillnet test fishery began operating in 2005 on the U.S. side of Juan de Fuca Strait between Kydaka Point and Pillar Point. At the discretion of the Panel, it operates in years with planned U.S. Area 4B/5/6C commercial fisheries. This test fishery targets Early Summer and Summer-run sockeye and lands all catch, including non-target species. It begins operating 7 to 10 days prior to the scheduled start date of the commercial fisheries and operates for 7 to 14 days. Although net configuration has varied across vessels, a 440 fathom, 200-mesh deep Alaska Twist gillnet with a 5.125” mesh size is most commonly used to complete two overnight sets each day. It is assumed that it takes sockeye salmon on average 5.5 days to migrate from this area to the Mission hydroacoustics site. Because this test fishery's location is more remote, timely transport of DNA samples is logistically difficult. As a result, in-season Area 20 test fishery samples are used to represent stock proportions in Area 5. Statistical analyses indicate no real differences in proportions between Area 20 and Area 5 gillnet proportions of Barkley Sound or Early Stuart sockeye but Early Summer-run proportions tend to be lower and Late run catches tend to be higher in the Area 5 test fishery (Brkic and Latham 2022).

Marine Purse Seine Test Fisheries

The marine purse seine test fisheries are used to assess the abundance, timing, and diversion rate of Summer and Late-run sockeye, and on odd years, pink salmon. Like the gillnet test fisheries, a matching set of Area 20 and 12 CPUE data is needed to produce total daily estimates of abundance and for the predictions of abundances en route to Mission. Purse seines are generally not used to assess Early Summer-run given their larger daily operating costs versus using gillnets in marine areas. Compared to gillnets, purse seine nets are much deeper, which results in less of a reduction in catchability when salmon migrate deeper in the water column. This is often believed to be the case for Late-run sockeye salmon and pink salmon. For Summer-run stocks, purse seine data allows for the assessment of abundances 6 days prior to their migration past Mission, but for stocks that delay their migration prior to migrating into the Fraser River (i.e. Harrison sockeye, certain Late-run stocks, and pink salmon), it provides in-season run size assessments up to 3 weeks prior to their migration past Mission. Purse seine catches are also used to predict sockeye encounter rates and release mortality in pink-directed fisheries. With the exception of those salmon collected for sampling and stock identification purposes, and in rare cases, retained at the discretion of the Fraser River Panel to be sold to cover program costs, purse seine test fishing catch is released, resulting in limited impacts on target and non-target species. However, as noted above for marine gill nets, reporting on release mortalities for purse seines was also undertaken in 2025 with a release mortality rate of 10%. In 2026, this release mortality was revised to 2% by Panel decision following a review of the available scientific information and retroactively applied for the 2025 season. The impact of purse seine test fishing can be further reduced by releasing fish following live sampling, which has proven to be feasible but requires additional funding as well as the necessary technical support (PSC 2026). When retaining discretionary catch for sale (pay fish), injuries and mortality of non-target species is increased. The marine purse seine operation starts annually between mid-July and early August and concludes between late August and early September, depending on assessment and management considerations (Chapter A6).

AREA 20 SAN JUAN PURSE SEINE

The San Juan Purse Seine has been in operation continuously since 1962. This test fishery uses an 875-mesh deep net with a length of 300 fathoms (549 metres), colloquially known as a "westcoast" net. Six sets per day are completed between Bonilla Point and Owen Point on the west coast of Vancouver Island in Juan de Fuca Strait at depths between 40 and 180 fathoms. An effort is made to set perpendicular to shore along the "Blue Line", i.e. the western border of the statistical Area 20, however tides, weather, and sockeye abundance may influence set locations. Non-target stocks and species of note encountered by the Area 20 purse seine are Lake Washington sockeye, Puget Sound pinks, Fraser River coho and Chinook as well as other Canadian and U.S. salmon stocks (Nelitz et al. 2018).

AREA 12 BLINKHORN PURSE SEINE

The Blinkhorn Purse Seine has operated annually since 1986. This test fishery uses a 575-mesh deep net with a length of 217 fathoms (397 metres), colloquially known as an "inside" net. Six sets are completed at shore tie-off points between Blinkhorn Peninsula and Fine Beach on the east coast of Vancouver Island in Johnstone Strait. The location of each set is determined by tides, weather, salmon abundance, and distributions. Overall, there is high variability in catch between sets within a day. Of the different environmental conditions, cloud cover and wind speed have the biggest impact on test fishing CPUE estimates in Area 12 (Siegle and Ma 2020). The first set of the day is executed at the most eastward test fishing locations, often Robson Bight or Fine Beach, and the next 5 sets follow in a westward direction (Figure 1). Commercial or FSC fishing, when scheduled, are expected to occur eastward of the test fishery to limit their impact on in-season assessments. When the entire set is retained in the Area 12 test fishery, the overall mortality of non-target species is less than in the Area 20 seine test fishery given their lower relative abundance. Non-target stocks and species of note encountered by the Area 12 purse seine include Sakinaw and Nimpkish sockeye, Canadian South Coast and Puget Sound pink salmon, Fraser coho and Chinook and other Canadian and U.S. salmon stocks (Nelitz et al. 2018).

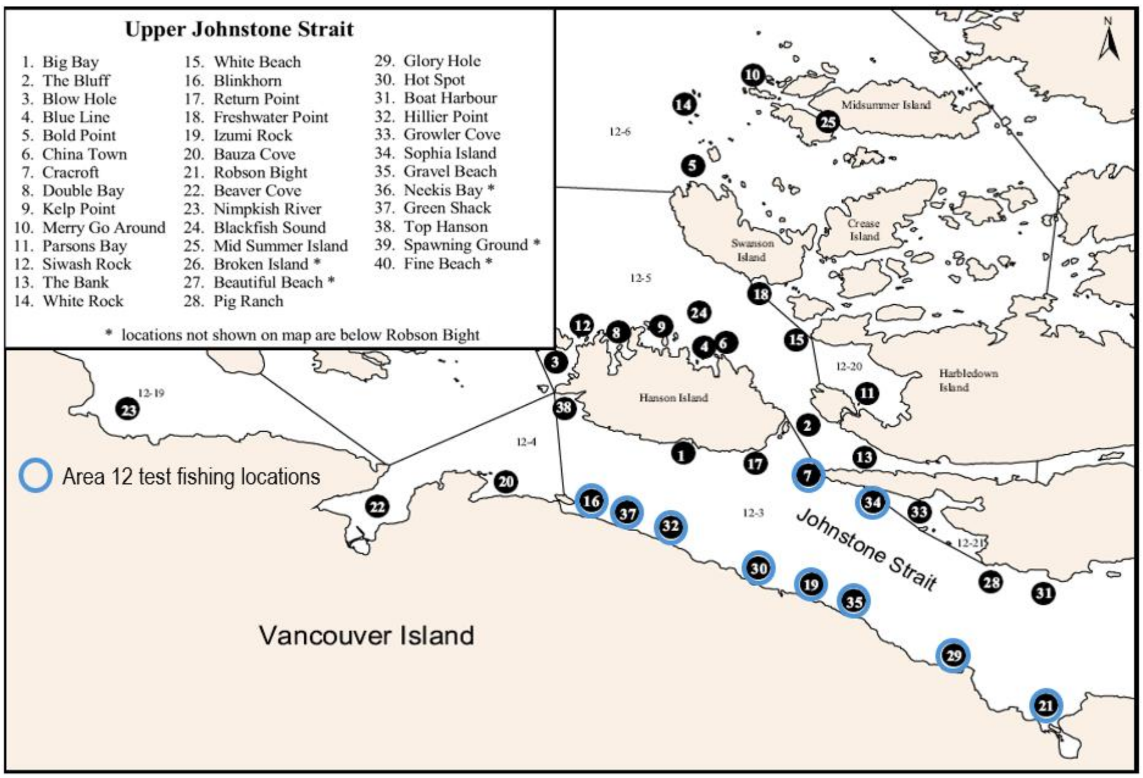

Figure 1. *Location of Area 12 test fishery set locations in Johnstone Strait used for the assessment of Fraser River sockeye and pink salmon (blue circles). Map courtesy of DFO.*

AREA 13 PURSE SEINE

The Area 13 Purse Seine has operated since 1995, usually in higher abundance sockeye years and pink years. It is designed to assess abundance of Summer and Late-run sockeye and is not as effective for assessing Early Summer-run sockeye. Similar to the Area 12 purse seine test fishery, this test fishery uses a 575-mesh deep net with a length of 217 fathoms (397 metres), colloquially known as an “inside” net. Operations typically start between the third week of July and first week of August and continue until the beginning of September. The test fishing vessel aims to complete 6 sets per day at shore tie-off points on Sonora, Quadra, and Vancouver Island (Figure 2). The location of each set is determined by tides, weather, and salmon abundances and distribution. Of the different environmental conditions, current speed and tidal cycle phase have the biggest impact on test fishing CPUE estimates in Area 13. Catches in Area 13 in general tend to be higher than in Area 12 due to the narrower width of the Strait in Area 13, and due to a higher propensity for salmon to aggregate in set locations influenced by strong tides and currents.

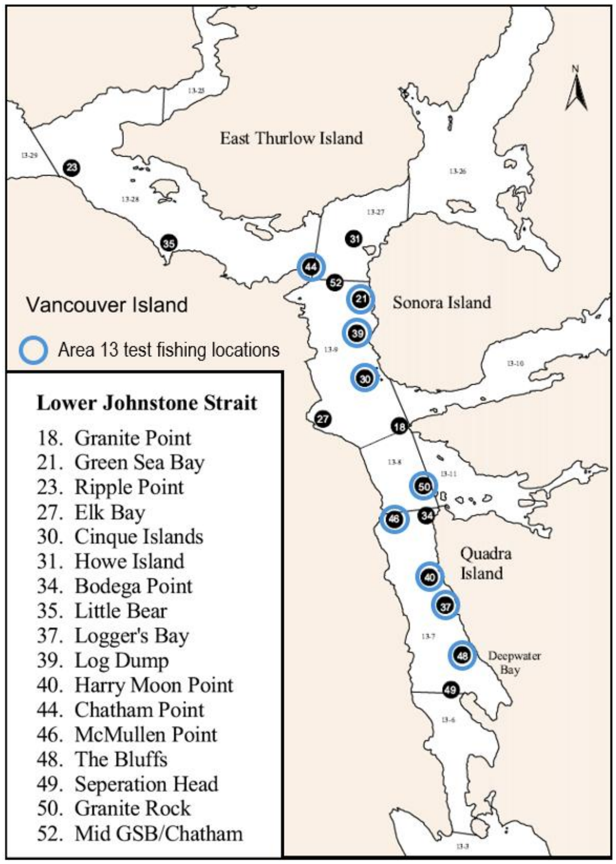

Figure 2. *Location of Area 13 test fishery set locations used for the assessment of Fraser River sockeye and pink salmon (blue circles). Map courtesy of DFO.*

Area 29 Gulf Troll

The Area 29 Gulf Troll test fishery is used to assess the abundance of Late-run Fraser River sockeye in the Strait of Georgia. The fishery was first operated in 1987 and is operated in years where there are high abundances of delaying Late run sockeye in the Gulf, prior to their migration up the Fraser River. This test fishery provides several sequential estimates of abundance over the season as well as an imprecise indicator on the timing of the upstream migration. It is generally assumed that catchability declines in September as fish stop feeding and are less attracted to gear. In addition, catch rates also drop when sockeye move onto the “flats” of the Fraser River delta where they are inaccessible to the fishing gear and/or when they migrate upstream. Gulf Troll test fishing operations begin between late August and early September, depending on Late-run timing. Operations conclude approximately 10 to 30 days following the start of the fishery, depending on management requirements. In the past, two vessels operated independently, each fishing within one of 6 pre-defined quadrants in the Strait of Georgia between Bowen Island and Georgina Point Lighthouse on Mayne Island (Michielsens and Martens 2022). However, a recent review of this fishery indicates the average CPUE from quadrants 3 and 4 provides the same predictive ability as the CPUE averaged across all six quadrants (Chapter B22).

The primary drawback of reducing the survey to only quadrants 3 and 4 is the reduced ability to evaluate the spatial distribution of Late-run sockeye across the Strait of Georgia. With this new sampling design, fishing will occur for approximately 8 hours per day, 2 days per week, using one fishing vessel. The vessel is equipped with 6 mechanical reels and lines (gurdies), each fitted with 10 to 20 artificial lures. Encounter rates of non-target species are generally low and their mortality can be negligible when gear is handled carefully. As with marine gillnet and purse seine test fisheries, improvements to release mortality estimates are also required for the Gulf Troll test fishery. In the meantime, a provisional release mortality rate of 10% will be applied.

U.S. Area 7 Reefnet

The U.S. Area 7 Reefnet test fishery is used to determine the presence of Early Summer, Summer, and Late-run sockeye in U.S. Panel waters. It has been operated since 1997 in years where there are scheduled U.S. commercial fisheries in Panel waters. The test fishery begins prior to these scheduled fisheries in early July. This fishery is observational, and no fish are retained unless directed to by the Fraser River Panel. Observations occur for approximately 8 hours per day at 2 sites near San Juan Island and Lummi Island to cover the primary migration routes through U.S. Panel waters. The release mortality rate for this test fishery is very low at 0.5%. Consistent with improvements to release mortality estimates for other marine test fisheries, this rate was first applied in 2025 and will continue to be applied moving forward. Observations are conducted from a platform above the reefnet gear and hourly counts are reported. The hours of observation shift daily to align with the appropriate tide needed for observation. This test fishery is highly susceptible to environmental conditions, as overcast skies, rain, winds, tides and water clarity affect the consistency of the observation (Nelitz et al. 2018). The fixed gear positions do not allow movement to better sites as fish distribution changes. Of the reefnet locations, Lummi Island CPUE data provides the best indicator of daily abundance, but across years, the CPUE data from reefnet test fisheries is a poor predictor of daily abundance (Nelitz et al. 2018).

Test fishing related research

Marine test fisheries are a core part of the in-season assessment program for Fraser River sockeye and pink salmon. As such a considerable amount of research has been undertaken to ensure the PSC test fisheries provide the best possible CPUE data to estimate marine abundance. This has resulted in numerous analyses of the impact of different test fishing factors on the precision of resulting abundance estimates, e.g. the type of test fisheries (gillnet versus purse seine), the number of vessels and number of sets, and the test fishing or set location. The following section provides a brief overview of some of the research results. Further details on the individual analyses can be found in the referenced reports.

In general, the precision of abundance estimates based on purse seine data is greater than based on marine gillnet data, especially later in the season when salmon catchability in marine gillnet test fisheries decreases (Chapter B5). Using a second boat to calculate the marine gillnet CPUE has a limited impact on the resulting precision in abundance as the inter- and intra-annual variability in catchability has a much bigger impact (Nelitz et al. 2018). In the Area 20 gillnet test fishery, having a second test fishing boat results in more precise estimates of CPUE, but leads to only a modest increase in run size precision (4%, Nelitz et al. 2018). In Area 12, there is little evidence that an alternative gillnet test fishing location at Naka Creek, operated for 10-12 days per year from 2009 to 2015, would produce more precise estimates of salmon abundance than the current test fishery at Round Island (Nelitz et al. 2018).

Test fishery results are more robust when averaging estimates across statistical fishing areas or across days (Nelitz et al. 2018). Averaging the daily abundance estimates derived from Area 13 and Area 12 test fishery data improves the daily estimates by removing some of the daily variability but has a lower impact on abundance over 6-day periods (Nelitz et al. 2018). Increasing the purse seine test fishing effort in the same statistical area from 1 to 4 vessels reduces the variation in the CPUE but this would result in only a modest gain in certainty of in-season run size estimates (Gazey 2001). Environmental factors like tide, current, cloud cover and wind speed have also been explored to improve abundance estimates based on test fishing CPUE data. The adjusted R^2 between Area 12 and Area 13 purse seine CPUE estimates and abundance only increase by 2.4% and 2% respectively when including environmental covariates, regardless of whether fine-scale data or publicly available area-wide environmental data are used (Siegle and Ma 2020).

Substantial research has been conducted to evaluate and/or improve the test fishing or set locations. Sheringham Point, 50 km south-east of the "Blue Line", has been explored as an alternative/additional test fishing location for the Area 20 purse seine test fishery but overall CPUE estimates were lower, potentially due to a shift in the migration to the United States side of Juan de Fuca Strait between the "Blue Line" and Sheringham Point (Cave 2003). In Area 12, two sites (Cracroft Point and Sophia/Splash Island) tend to catch fewer fish and are more variable than other sites (Nelitz et al. 2018). These locations are unique among the commonly used locations because they are on the opposite sides of the Strait and are open water sets in contrast to the other locations that are beach sets (Figure 1). While these locations tend to catch fewer fish, they help inform the amount of sockeye migration through the north side of the Strait. Excluding these two infrequently sampled sites from daily CPUE estimates does not result in an improved relationship between daily CPUE and abundance (Nelitz et al. 2018). In Area 13, one site, McMullen Point, is an open water set at the west side of the strait and tends to catch fewer fish than the other beach sites (Figure 2). Another site, Chatham Point, tends to catch more fish than other sites. Exclusion of these two sites to calculate the CPUE does not result in an improved relationship between daily CPUE and abundance (Nelitz et al. 2018).

In 2014, it was evaluated if the morning purse seine sets at Fine beach or Neekis Bay in the Area 12 purse seine test fishery could be eliminated and replaced with unlimited Area B ITQ fishing at either location, given that the precision of the ITQ catch-per-set information is more strongly related with daily abundance estimates compared to test fishery data (Ma et al. 2019). This experiment was not successful as only a limited subset of Area B data reached PSC staff in-season and with at least a 4-day time lag (PSC 2015). A subsequent feasibility study in 2018 indicated that the data challenges could be overcome by adopting eLog software and supporting technology but the usefulness for in-season assessments was restricted by not having similar data available in Juan de Fuca Strait (Ma et al. 2019). Similar to using ITQ data to supplement test fishery data, it was evaluated if marine FSC data, as well as CPUE data from participating First Nation harvesters, could provide reliable estimates of daily abundance. Results indicated that these data, in the form in which they were received for this study, were not a consistent and reliable source to supplement the PSC test fishery program and could not be used to generate unbiased estimates of daily abundance (Alameddine et al. 2023).

Constraints and potential areas of improvement

Marine mammal presence has increased in test fishing areas in recent years. Avoiding encounters and interactions with marine mammals can cause delays to test fishing operations and sometimes prohibit them all together. Acoustic deterrents are being explored as a potential option to avoid interactions. Incidental by-catch of non-target salmonids can also be unavoidable. During years of low abundance of Fraser River sockeye salmon, live sampling has been explored on board purse seine test fisheries as an option to avoid mortality for sampling purposes (PSC 2026).

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B3. In-River Test Fisheries

J. Maguire

Summary

In-river test fisheries operate throughout the reaches of the lower Fraser River to inform fisheries management decisions for Fraser River sockeye and pink salmon. These test fisheries provide stock and species composition estimates that are used to generate stock-specific daily abundance estimates when combined with the total salmon estimates generated by the in-river hydroacoustics programs (Chapter B14). The Whonnock test fishery can also be used to generate sockeye abundance estimates based on CPUE data and is primarily used once pink salmon dominate abundances at Mission (Michielsens and Martens 2025). The primary in-river test fisheries operated in support of the Fraser River Panel use gillnets, however, mesh sizes and net structure vary depending on each fishery's purpose. This report summarises the purpose, timing, operations, and constraints of these in-river test fisheries. This report also provides similar summaries for two additional test fishing operations: the Albion Chinook and chum salmon test fishery as well as the lower Fraser River fishwheel. Neither are core test fisheries for the assessment of Fraser River sockeye and pink salmon, but they do provide data used to estimate species composition (Chapter B19).

Introduction

Under the Pacific Salmon Treaty (PST 2025), the Fraser River Panel is responsible for conducting test fisheries to aid in the in-season management of Fraser River sockeye and pink salmon. The in-river test fisheries deployed annually are used to estimate stock composition (Chapter B11) and abundance of sockeye and pink salmon entering the Fraser River. Additionally, they collect information on the species composition of all salmonids (Chapter B19) and the data are used to produce species specific hydroacoustic abundance estimates at Mission and Qualark. The core test fisheries all use gillnet gear, with the structure of the net varying between fisheries depending on their assessment use. This report details the timing, operations, purpose and constraints of each in-river test fishery used in the Fraser River Panel management process.

Area 29 Whonnock Gillnet

The Whonnock Gillnet test fishery has operated yearly since 1958. This test fishery serves three purposes: 1) to collect species composition information to generate daily sockeye abundance estimates when used in combination with the total salmon estimates generated by the Mission hydroacoustics site (Chapter B19), 2) to estimate sockeye abundances when pink salmon dominate migration passage (Michielsens and Martens 2025) as well as before and after the Mission hydroacoustics site is operational, and 3) to obtain sockeye stock identification data based on DNA samples collected (Chapter B11). The latter purpose became more important in recent low abundance years when sample size requirements were not being met at Cottonwood (Michielsens and Martens 2022), prior to relocating the Cottonwood test fishery to Brownsville Bar. One major downside of using Whonnock for stock identification purposes, however, is the lack of Pitt and Widgeon in the catch samples.

This test fishery typically begins during the last week of June and operates daily until late September or early October depending on Late run sockeye timing (Chapter A6). Sets are conducted at two locations depending on water heights. During periods of high water levels, typically during freshet, sets are conducted at Glen Valley Bar at the southern tip of Crescent Island in order to improve catchability. When water levels decrease, sets are conducted further downstream, closer to the middle of the river channel at the Whonnock Channel site (Figure 1). Two 20-minute sets are conducted daily during "slack water" conditions when the river current is counteracted by the flooding tide. Given the focus on species composition estimates, this test fishery uses a 7-panel, 175-fathom multistrand gillnet consisting of 7 different mesh sizes: 4", 4.625", 5.25", 6", 6.75", 7.75", and 8.75". The gillnet is rotated between sets, so each end of the net is fished nearest to the shore each day. Catchability tends to decrease when transitioning from a late evening to an early morning drift and this discrepancy is more pronounced early in the season when catches are low. The CPUE calculations of this test fishery take into account the length of the net as well as the time the gillnet is in the water, i.e., the soak time. When more than 50 salmon are caught, a correction factor is applied that is meant to correct for gear saturation and the loss of fishing efficiency when the net is being picked (Chapter B4). Details on the Whonnock expansion line (inverse of the catchability) used in combination with the CPUE estimates to calculate the sockeye abundance migrating past the test fishing site can be found in Chapter B6.

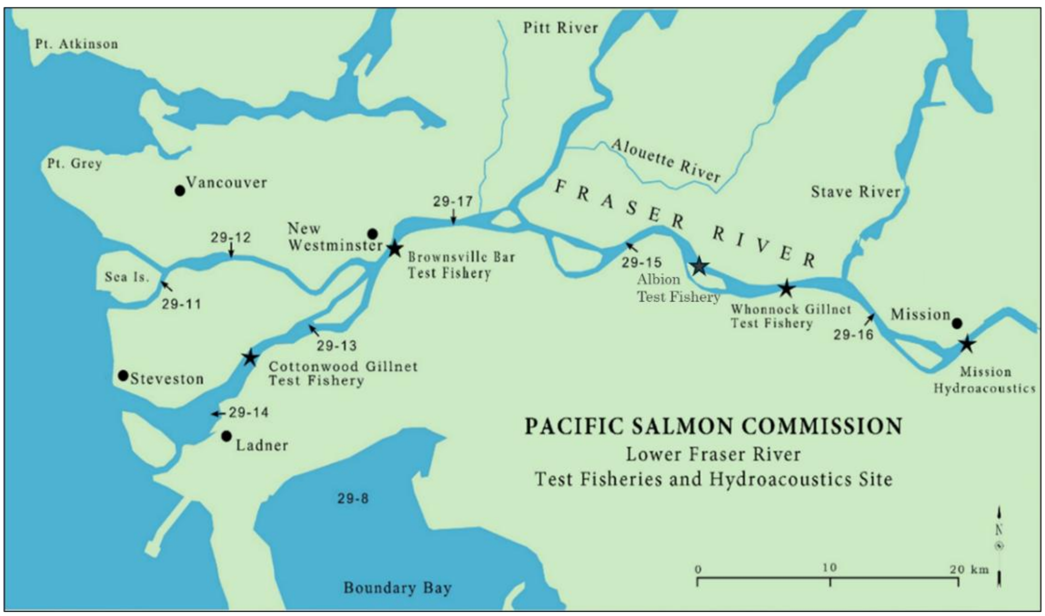

Figure 1. *Map of the Lower Fraser River, indicating the location of PSC gillnet test fisheries at Cottonwood (discontinued), Brownsville Bar and Whonnock as well as the Albion test fishery site. The Qualark test fishery is located upstream, near Yale.*

Whonnock catches also include Chinook, coho, chum, and steelhead. Since 1998, PSC observers have sampled Chinook and coho catches and submitted samples and data to DFO. Non-lethal sampling of steelhead catches has also been conducted since 2019. Chinook, coho, and chum that are not required for sampling purposes and that would be expected to have a good chance of survival are released. All sturgeon and steelhead are released. Potential injury and mortality is however unavoidable.

There have been some concerns about biases in both species and stock composition estimates at Whonnock. Because the gillnet samples the offshore section of the river, catches may underrepresent species and stocks migrating closer to shore. More specifically, the Whonnock test fishery catch tends to underestimate the proportion of pinks given that they migrate closer to shore and overestimate the proportion of Chinook that migrate further offshore than sockeye (van Dam-Bates et al. 2025). In terms of stock composition, no consistent pattern of site-specific differences in stock composition has been observed across years, except for Late Stuart and Stellako (Sutherland et al. 2026).

Area 29 Brownsville Bar Gillnet

The Brownsville Bar Gillnet test fishery is used to gather information for stock identification of sockeye entering the Fraser River for all management groups (Chapter B11). Unlike the Whonnock test fishery, it intercepts all Fraser sockeye stocks, including Pitt and Widgeon and is therefore essential to generate total Fraser River sockeye run size estimates. Operated annually, this test fishery begins in mid-July and concludes in early September. A 120-fathom, 60-mesh multi-panel Alaska Twist gillnet is used with 4 different mesh sizes: 4.25”, 4.75”, 5.25”, and 5.75”, all aimed at catching sockeye salmon. As a result, this test fishery is not suitable to derive species composition estimates. All sets are conducted at an area colloquially known as Brownsville Bar located downstream of the staləw̓asəm Bridge, which replaced the Patullo Bridge in 2026. This area is a well-known and highly productive gillnet fishing location above the confluence of the north and south arms of the lower Fraser River. Two 20-minute sets are conducted during “slack water” conditions each day during the season. The gillnet is rotated between sets, so each end of the net is fished nearest to the shore each day.

The test fishery has operated annually since 2021 as part of a Southern Boundary Restoration and Enhancement Fund project to assess its suitability to replace the Cottonwood Gillnet test fishery in the lower Fraser River (Sutherland et al. 2026). The Fraser River Panel elected to officially replace the Cottonwood test fishery with the Brownsville Bar test fishery in 2024. Overall, the transition to the new location substantially increased sockeye sample sizes available for stock identification. In addition to low catches at Cottonwood, there had been concerns about stock identification bias, given that the Cottonwood test fishery did not intercept salmon migrating through the North Arm of the Fraser River. In addition, Cottonwood tended to overestimate Late run stocks as delaying sockeye tend to push in and out of the river before making their final migration upstream. Brownsville Bar is less impacted by this behaviour given its location further upstream (Sutherland et al. 2026). In addition to the low catches and biased stock identification, the Cottonwood test fishery had also suffered from substantial amounts of commercial vessel traffic, seal predation, a strong tidal influence and the build-up of debris from high discharge events. From 2009 to 2016 an electric net had been used at Cottonwood to reduce seal predation (Forrest et al. 2009). In the past there has been variable success in using Cottonwood CPUE data to estimate sockeye and pink salmon abundances. To what extent Brownsville Bar test fishery CPUE data are a useful indicator of sockeye and pink salmon abundance is still under examination. Brownsville Bar catches also include Chinook, coho, and steelhead. DFO annually provides updated sampling and retention procedures for these species.

Area 29 Qualark Gillnet

The Qualark Gillnet test fishery first operated in 2000 and is located approximately 1 kilometer upstream of Emory Creek. Test fishing operations coincide with the Qualark hydroacoustic program, as the primary purpose of the test fishery is to derive stock composition and species composition assessments for the hydroacoustics program. Test fishing operations typically begin between late June and early July, and end between late September and early October.

The nets used at Qualark are 16 fathoms of a single mesh size. Six different mesh sizes are used: 4”, 4.75”, 5.25”, 5.75”, 6.75”, and 8”. The test fishing vessel conducts 3 sets each morning and evening, all nearshore of the right bank. The meshes are organized into two groups: one group includes 4”, 5.25”, and 6.75”, while the other includes 4.75”, 5.75”, and 8”. Each group is fished in sequence, starting with the smallest mesh size and progressing to the largest. One group is fished in the morning, and the other in the evening. Which group is fished first alternates daily. This ensures that each set uses only one mesh size, and all six mesh sizes are fished once per day. A 7th set is conducted 1-2 times per week in the offshore portion of the river using the 5.25” mesh size to assess offshore species composition. Most, if not all, the migration occurs in close proximity to the right and left bank. One major downside of the Qualark test fishery, in particular for the assessment of Fraser River sockeye salmon, is that several stocks including Chilliwack, Pitt, Harrison, Widgeon, Birkenhead, Big Silver, Weaver and Cultus do not migrate past Qualark. As a result, Qualark test fishery data in combination with Qualark hydroacoustic estimates can only be used to assess between 30 and 80% of the total Fraser sockeye run depending on the year (Conrad et al. 2019).

Area 29 Albion Gillnet

The Albion Gillnet test fishery, which is operated by Fisheries and Oceans Canada, provides information for the assessment of Fraser River Chinook and chum salmon and is located at Albion, near Fort Langley near the old Albion ferry crossing. This test fishery is not within the scope of the Fraser River Panel. Test fishing operations begin in May and end at the end of November.

The Chinook test fishery is used to collect CPUE and stock composition information during the Chinook migration to inform Canadian domestic fisheries management decisions related to the Chinook chapter of the Pacific Salmon Treaty (PST 2025, Nelitz et al. 2018). This test fishery runs every day until early September and every other day through to mid-October. The Chinook test fishery uses two different gillnets, both 200 fathoms long: a standard Chinook net with an 8” mesh, and a multi-panel net with 4 different mesh sizes: 6”, 7”, 8” and 9”. The multi-panel net aims to obtain a representative Chinook sample, taking into account the wide range of Chinook sizes. The chum test fishery collects CPUE and stock composition information during the chum migration period used to inform decisions related to the chum chapter of the Pacific Salmon Treaty (PST 2025, Nelitz et al. 2018). It runs on alternating days starting in September and uses a gillnet that is 150 fathoms long with a 6.75” mesh. From mid October onwards, the chum test fishery operates daily. While this test fishery catches sockeye and pink salmon, overall catches of these species are lower compared to the sockeye and pink salmon directed test fisheries, and the resulting species and stock estimates are assumed to be biased (Nelitz et al. 2018).

Lower Fraser River Fishwheel

Fishwheels have been used in the Fraser River to catch, sample and tag salmon since 2009 with the aim to assess en route losses in addition to providing species and stock composition information and information on fish health (Robichaud et al. 2010). Over the years, two different fishwheels have been operated approximately 9 km downstream of the Mission hydroacoustics site. The small fishwheel has three baskets (3.4 m long × 3.0 m wide × 2.1 m deep) that are framed with aluminum tubing (3.8 cm square) and lined with white, knotless, nylon mesh (6.4 cm stretch, English et al. 2018). The baskets are designed to fish up to 3 m below the water surface. The large fishwheel has larger baskets (6.1 m long × 4.3 m wide × 3 m deep) which are designed to fish 5.8 m below the water surface (English et al. 2018). The lower Fraser River fishwheels have been operational on odd years since 2009 and on a couple of even years due to tagging and brood stock collection for Big Bar research purposes within the Lower Fraser River (2020 and 2022). Prior to 2023, the fishwheels were independently operated by Matsqui First Nations in collaboration with LGL Limited and the Lower Fraser Fisheries Alliance. Although this program was not part of the Fraser River Panel test fisheries, the fish length data collected has been used in mixture models to derive species composition estimates (Grant et al. 2014, Chapter B18). In 2023, the Fraser River Panel agreed to pay for the operation of the fishwheel for a short period during early August in order to supplement the species composition information available to PSC staff. In addition, in odd years, daily estimates of sockeye and pink salmon abundances can be derived by combining Mission hydroacoustic counts with species composition estimates from the Matsqui fishwheels for the nearshore area (e.g., first 50 m) and Whonnock test fisheries for the offshore area (Robichaud et al. 2010, English et al. 2016, 2018). Fishwheels may however overestimate pink proportions in nearshore areas (English et al. 2018) due to the fact that fishwheels do not cover the entire nearshore area and that pink salmon migrate closer to shore than other salmon species (van Dam-Bates et al. 2025).

Potential consolidation of in-river test fisheries

Nelitz et al. (2018) reviewed and evaluated potential refinements to and consolidations of the current suite of in-river test fisheries. The analysis recognised opportunities but did not provide a definitive basis for deciding upon the optimal configuration of in-river test fisheries. One of the benefits of consolidating different in-river test fisheries is savings in terms of program cost and fishing mortality. However, in all cases when reducing or combining in-river test fisheries, potential mitigative measures would have to be taken and the associated costs would offset potential savings. In addition, additional calibration studies would need to be conducted prior to substituting test fisheries and these would require sufficient years of data during which both the old and new test fishing configurations are run. The feasibility of reconfiguring test fisheries or operational periods would also include logistical considerations, e.g. mesh sizes, program location and duration, and discussion of potential mitigation measures that would span multiple Chapters of the PST (PST 2025, Nelitz et al. 2018). Other groups beyond the Fraser Panel would need to be engaged, in particular when considering changes to the Albion test fishery.

Constraints and Potential Areas of Improvement

Because of their location in the lower Fraser River, operations at Brownsville Bar and Whonnock can be delayed due to marine traffic, preventing sets from being made on the optimal high slack tide. Additionally, marine mammal predation can affect CPUE estimates, especially during periods of low abundance. Acoustic marine mammal deterrents are currently being explored as an option to improve data quality in these test fisheries. At Brownsville Bar, the use of a shorter net is being explored to support operational sustainability during high sockeye abundance by reducing the strain on crew and observers. Extended picking times associated with larger catches can also present navigational challenges, due to conflicts with other commercial vessel traffic and structural constraints such as bridge footings. A reduced net length may help mitigate these concerns.

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B4. Catch-per-unit-effort (CPUE) calculations

E. Taylor

Summary

Catch-per-unit-effort (CPUE) is arguably the most important test fishing data to estimate abundances. The Pacific Salmon Commission (PSC) relies on four different test fishing gear types to assess the abundance of Fraser River sockeye salmon: 1) seine nets, 2) gillnets, 3) troll/hook and line, and 4) reefnets. In most cases the calculation of CPUE is based on catch and fishing effort, whereby the effort will be gear dependent. But in some cases, the CPUE may be corrected to account for gear saturation or other factors that may bias the relationship between abundance and CPUE. The following report provides an overview of the calculation of CPUE for the different PSC test fisheries.

Introduction

As part of the Pacific Salmon Treaty agreements (PST 2025, Chapter 4), the Fraser River Panel is responsible for conducting test fisheries on Fraser River sockeye salmon. Test fishery data include catch-per-unit-effort (CPUE) data that, when multiplied by an expansion line (inverse catchability, Chapters B5 and B6), provides an estimate of daily abundance. CPUE data are calculated differently depending on the type of gear and the associated measure of fishing effort. The four gear types employed by PSC test fisheries are purse seine, gillnet, troll, and reefnet. Additionally, the in-river gillnets differ slightly from their marine counterparts and require the use of a catchability correction factor when catches are above a certain level. The following report will describe the calculation of CPUE for each of the four gear types.

Data

Before discussing CPUE calculations, it is important to define what catch and fishing effort data will be used in the calculation of CPUE. During test fishing operations, the quality of catch data is often negatively impacted by weather, equipment failure, and/or tides and currents. Under these circumstances, the test fishing skipper and observer are asked to assign a quality score of 2, 1, or 0 to the collected data. A score of 2 signifies that the data are of good quality and there were no issues to note. A quality score of 1 signifies that there were one or more issues with the collected data, but that the skipper and observer agreed that the issues did not result in the catch being unrepresentative of what would have been caught had there been no issues. Finally, a quality score of 0 signifies that the skipper and observer deem the catch being unrepresentative of what would have been caught had no issues occurred. All catch data with a set quality score of 0 are marked as non-assessment data and are excluded from calculations of CPUE.

Methods

PURSE SEINE TEST FISHERIES

The calculation of sockeye CPUE in the purse seine test fisheries is the simplest among all the gear types, as the total sockeye purse seine catch on a given day (C) is divided by the number of assessment sets performed, i.e., the fishing effort (E):

$$(1) \qquad CPUE = \frac{C}{E}$$

Under normal circumstances, the purse seine test fisheries perform six sets per day (Chapter B2). In the event of mechanical failure or in case the quality of a set is deemed compromised, the number of sets and the catch are adjusted accordingly.

GILLNET TEST FISHERIES

Gillnet test fishery CPUE calculations are somewhat more complicated as gillnet fishing effort (E) calculations consider the length of the net as well as the length of time the fishing net is in use, i.e., the soak time:

$$(2) \qquad E = \frac{Net\ Length\ (fathom) \times Soak\ Time}{1000}$$

The soak time is calculated as the time the net is entirely in the water, plus half of the time that it takes to set the net and to retrieve it:

$$(3) \qquad Soak\ Time = Start\ In\ Time - \ Full\ Out\ Time + \frac{Full\ In\ Time - \ Start\ In\ Time}{2} + \frac{Full\ Out\ Time - Start\ Out\ Time}{2}.$$

The CPUE is then calculated by the total number of sockeye caught, divided by fishing effort (equation 1).

The efficiency of salmon gillnets is affected by several technical and biological factors. One such technical factor, gear saturation, occurs when the gillnet loses its efficiency as a greater number of target individuals are present in the net. In the lower Fraser River gillnet test fisheries, this saturation results in a reduced catch rate or catchability through either space limitation, or gear avoidance. Catchability correction factors are used to adjust the catch rate when the total number of salmon caught in the gillnet is so large that it restricts the catch rate of additional salmon. Historically, a catch level of 50 total salmon in a single set is thought to be the point where the relationship between total salmon CPUE and total salmon catch begins to become non-linear, to the extent that a catchability correction factor should be applied.

When the total salmon catch is larger than 50, the sockeye CPUE is calculated as:

$$(4) \qquad CPUE_{sockeye} = C_{sockeye} \times correction\ factor$$

The methodology used to calculate a correction factor is the slope of the regression line fitted through catch and CPUE data of sets with less than 50 salmon caught. Under these conditions, it is believed that gear saturation is minimal. The total salmon catch is the independent variable and the uncorrected total salmon CPUE is the dependent variable. When this linear regression is performed, the intercept is forced to zero. Figure 1 illustrates the derivation of the correction factor for the Whonnock sockeye gillnet test fishery.

This regression is re-run each year separately for the Whonnock and Brownsville Bar gillnet test fisheries (Chapter B3). The analysis is performed on a subset of historical data, based on the fisher, the net used, and recency. Updates to the gillnet correction factor are only made when it deviates substantially from other years. Analyses have not been performed to determine quantitatively the catch level where the relationship becomes non-linear.

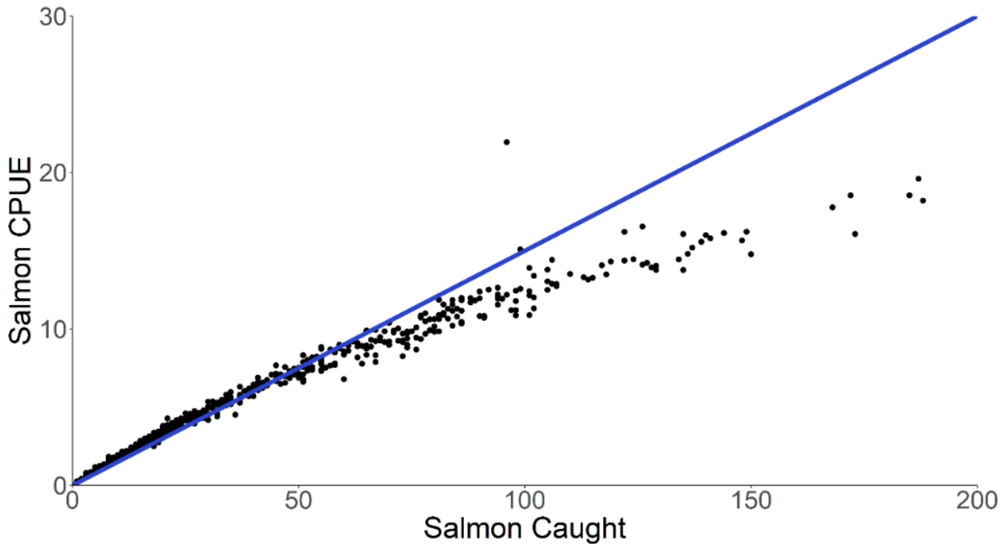

Figure 1. *Salmon catch and catch-per-unit-effort (CPUE) in Whonnock gillnet test fishery sets in the years 2010, 2014, and 2018. The blue line represents a slope of 0.15 and was generated by running a linear regression on sets where less than 50 salmon were caught. As total salmon catch increases past 50, the salmon CPUE does not continue to increase linearly. This effect is believed to be due to gear saturation of the gillnet.*

TROLL TEST FISHERIES

The Gulf Troll CPUE is defined as catch-per-1000 hook minutes, where hook-minutes are calculated as the total daily fishing time multiplied by the average number of hooks per line on each vessel (Cave 1997, Chapter B2). However, once a hook has caught a fish, it is no longer fishing. The dynamics of the decline in effort of a fishing line with hooks was the subject of a study by Cave (1989, unpublished). It concluded that unbiased measures of CPUE (catch/1000 hook-minutes) were well related to gross measures of catch, total minutes fished, and average number of hooks per line. Unbiased sockeye CPUE was calculated as (Cave 1997):

$$(5) \qquad CPUE_s = \frac{C_S}{C_T} e^{\left(i + a_1 \ln CPUE_T + a_2 (\ln CPUE_T)^2\right)}$$

Where C_s/C_T is the proportion sockeye (*s*) in the total catch (C_T) and $CPUE_T$ is the unadjusted all-species catch-per-unit-effort. The latter is based on the catch of all target and non-target species including shakers (under-sized juvenile salmonids) and effort in 1000 hook-minutes, calculated as:

$$(6) \qquad Effort = \frac{Total\ hooks \times total\ minutes\ fished}{1000}$$

The regression constants are $i = 0.123$, $a_1 = 1.012$ and $a_2 = 0.0746$.

The PSC Troll test fishery fishes in two different statistical areas (quadrants 3 and 4) and the CPUE for a survey period is estimated by averaging the CPUE of the two quadrants (Chapter B22).

REEFNET TEST FISHERIES

The CPUE in the reefnet test fisheries is referred to as counts per minute (C/Min) (Chapter B2). Fishing effort in the reefnet test fishery is strictly the number of minutes spent counting. There are no adjustments made to CPUE based on fish abundance or counting conditions.

Missing test fishing sets and data imputation

Matching sets of Area 20 and Area 12 CPUE data are needed in-season to produce daily estimates of abundance for migration graphs, for predictions en route to Mission, or when calculating multi-day average for diversion rates and expansion lines. Missing daily CPUE may occur in season due to adverse weather, mechanical failure, fishing gear repairs, or refueling. When daily CPUE data are unavailable or determined to be unrepresentative, imputation of missing daily CPUE is recommended. Imputation of single days of missing CPUE data is done by averaging the CPUE of the days before and after. Imputation of one day of missing CPUE data versus assuming the data are not available has limited impact on run size estimates derived by the time-density model (Chapter B23).

Most test fisheries rely on more than one fishing set to generate daily CPUE estimates. This reduces the probability of missing daily estimates but may still result in less than the optimal sets being available. Some causes of non-attempts of fishing sets are controllable, e.g., mechanical or fishing gear repairs, refueling, time cutoffs for sample and fish delivery schedules, while most are not, e.g., weather and tidal conditions, marine mammal presence, extremely large catches including catches of non-salmonid species that are more challenging to remove from the net. In addition, fishing sets are only included in assessments of abundance if they are determined to be good, i.e. representative of underlying abundances. In most cases this will mean fewer sets will be available to derive daily CPUE estimates. Marine purse seine test fisheries normally require 6 sets per day and the impact of a reduced number of sets has been evaluated. Overall, missing sets have a bigger impact in Area 12 than in Area 20, as catchability tends to be more variable across set locations, particularly on low abundance days (Table 1). As more sets are completed, the resulting CPUE becomes more predictive of the final CPUE based on six sets.

Table 1. *Adjusted R^2 values when using CPUE based on 1 to 5 sets to predict final CPUE across a full six sets assessments. The analyses for days with less than 120 sockeye caught represent low abundance days.*

	All Days		***Days with less than 120 sockeye caught***	
Set	**Area 12**	**Area 20**	**Area 12**	**Area 20**
1	0.69	0.40	0.11	0.47
2	0.78	0.58	0.21	0.66
3	0.88	0.64	0.43	0.79
4	0.94	0.73	0.61	0.88
5	0.96	0.92	0.78	0.94
6	1.00	1.00	1.00	1.00

Planned changes and potential areas of improvement

Under the current workflow, gillnet correction factors are calculated pre-season based on historical data and this correction factor is applied to in-season catches. In the future, it may be beneficial to calculate season specific correction factors and make in-season adjustments to the daily CPUEs.

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B5. Marine catchability estimates

C.G.J. Michielsens

Summary

In-season run size assessments for Fraser River sockeye salmon rely on estimates of daily abundance (Chapter B21). The most seaward daily abundance estimates come from marine test fisheries in Johnstone Strait (Area 12) and Juan de Fuca Strait (Area 20). The catch-per-unit-effort (CPUE) data from these test fisheries (Chapter B4) can be used in combination with an expansion line estimate (inverse catchability) to derive daily abundances. At the start of the season, a historical expansion line estimate is applied, derived from data for past years. Due to the high variability in expansion lines, both between years and within a season, the predicted abundances based on CPUE data used in combination with historical expansion lines may deviate substantially from reconstructed abundances based on Mission hydroacoustic data and seaward catch. Predicted abundance estimates can be improved if the expansion line is updated using in-season observations. The following report provides an overview of the evaluation of different historical and in-season expansion line estimates for marine gillnet and purse seine test fisheries.

Introduction

As part of the Pacific Salmon Treaty agreements (PST 2025, Annex IV, Chapter 4), the Fraser River Panel is responsible for conducting test fisheries on Fraser River sockeye salmon. Test fishery data include catch-per-unit-effort (CPUE) data, species composition and stock identification, and other biological metrics such as length, weight, and age. The CPUE data are a relative index that, when multiplied by an expansion line (inverse catchability), provides an estimate of daily abundance (Chapter B21). There is a minimum 6-day lag before CPUE-based abundances can be aligned with reconstructed estimates derived from hydroacoustic data due to the travel time between marine test fishing locations and the lower Fraser River hydroacoustic site located near Mission, B.C. (Michielsens and Cave 2019). But while CPUE-based abundances provide more timely estimates, they are less accurate than reconstructed values due to the high degree of uncertainty in the associated expansion line. Early in-season, the expansion lines are based on historical data, but once there is sufficient overlap between CPUE-based and reconstructed timeseries, these estimates can be updated with in-season observations.

Early in-season, gillnet test fishing vessels are used to assess Early Stuart and Early Summer-run sockeye while purse seine data are traditionally used to assess Summer- and Late-run stocks, and later-timed components of the Early Summer-run (Nelitz et al. 2018, Chapter B2). While the gillnet test fishery costs less to operate, the catchability is too low and uncertain to derive reliable abundance estimates for Summer- and Late-run stocks. In Johnstone Strait, the Area 12 gillnet test fishery occurs at Round Island. Due to safety considerations, two gillnet vessels are used to assess abundance in the Area 20 of Juan de Fuca Strait. It is assumed to take 8 and 6 days, respectively, for sockeye observed in these gillnet test fisheries to reach the Mission hydroacoustic site. Traditionally, the primary purse seine test fishery in Johnstone Strait takes place in Area 12 (7 days seaward of Mission), but Area 13 (6 days seaward of Mission) offers an alternative test fishing location with a potentially higher catchability due to the narrower size of the Strait there (Chapter B2). In Juan de Fuca Strait, salmon encountered by the purse seine fishery in Area 20 take about 6 days to migrate to the Mission hydroacoustic site.

Data

Expansion line analyses relied on daily CPUE data from both purse seine and gillnet test fishing vessels (Chapter B2) and daily reconstructed abundances based on Mission hydroacoustic estimates plus seaward catches (Chapter B21). Expansion line estimates were evaluated using data from 1998 to 2014. To reduce the impact of the variability in test fishing catches on the analyses, in-season expansion line estimates were based on six days of observations. A total of 524 matched Area 12 and Area 20 daily gillnet CPUE estimates, 642 matched Area 12 and Area 20 purse seine CPUE estimates, and 602 matched Area 13 and Area 20 purse seine CPUE estimates were analyzed. To evaluate density dependence, total catch data for both sockeye and pink salmon were also included in the analyses. Sockeye stocks that delay their upriver migration by holding in the Strait of Georgia, such as Late-run and Harrison stocks (Lapointe et al. 2003), were analyzed separately given that the variable delay and redistribution in the Strait of Georgia violates the "box-car" migration assumptions required for run reconstructions (Cave and Gazey 1994).

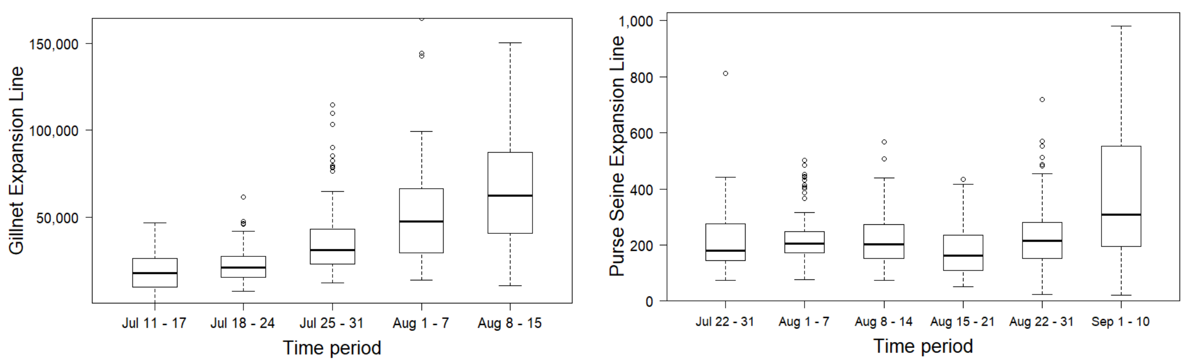

Figure 1. *Boxplot of 6-day gillnet and purse seine expansion line estimates across the season (1998 to 2014). Gillnet estimates relate to Early Stuart, Early Summer and Summer-run stocks excluding Harrison while purse seine estimates relate to Summer-run excluding Harrison stocks. The high purse seine expansion lines in September are associated with low marine abundances.*

Methods

Optimizing the in-season application of expansion line (inverse catchability) estimates to daily CPUE data requires decision rules which have been obtained through retrospective analyses that evaluate the accuracy of different marine expansion line strategies to predict abundances at Mission 6 to 8 days later (Table 1). Due to time-varying trends (Figure 1) and density-dependent effects on catchability, simply applying the lagged observed expansion line values may not provide the best estimates. In addition, because in-season daily catchabilities cannot be calculated for delaying stocks, the validity of catchability estimates derived from other stock components must be assessed.

Using the data from 1998 to 2014, retrospective analyses for different expansion line strategies (Table 1) were performed by predicting the total annual abundances for a given stock group ($\widehat{N_y}$) and comparing this to the observed total abundances (N_y). The bias (i.e. mean percent error, MPE), and precision (i.e. mean absolute percent error, MAPE) of the predicted annual abundances were calculated using:

(1) $$\text{MPE} = \frac{100}{\text{n}} \cdot \sum \frac{\widehat{N}_y - N_y}{N_y}$$

(2) $$\text{MAPE} = \frac{100}{\text{n}} \cdot \sum \left| \frac{\widehat{N}_y - N_y}{N_y} \right|$$

where $\widehat{N_y}$ is the predicted total annual abundance, derived from the daily Johnstone Strait (A12 or 13) and Juan de Fuca Strait (A20) CPUE data and the expansion line (1/catchability, q):

$$(3)\qquad \widehat{N_y} = \sum_d \left(\frac{CPUE_{y,d,A20}}{q_{y,d,A20}} + \frac{CPUE_{y,d,A12}}{q_{y,d,A12}}\right).$$

When using Area 13 purse seine data, catches seaward of the Area 13 purse seine test fishery ($C_{y,d,SeaA13}$) are added to predict the abundance in Area 12.

$$(4)\qquad \widehat{N_y} = \sum_d \left(\frac{CPUE_{y,d,A20}}{q_{y,d,A20}} + \frac{CPUE_{y,d,A13}}{q_{y,d,A13}} + C_{y,d,SeaA13}\right).$$

For gillnet (GN) test fisheries, it was assumed that the sockeye catchability is the same in both test fisheries:

$$(5)\qquad q_{GN,A20} = q_{GN,A12}.$$

The relative catchability of the different purse seine test fisheries was assumed to be related to the relative width of the area swept or sampled, i.e., the width of the migratory channel at the test fishing site in relation to the size of the fishing net. Because the relative width of the area swept in relation to the size of the fishing net in Johnstone Strait is 2.2 times larger than in Juan de Fuca Strait, it is assumed that the catchability of the purse seine test fishery in Area 12 is 2.2 times greater than in Area 20:

$$(6)\qquad \mathrm{q}_{\mathrm{PS,A12}} = 2.2 \cdot \mathrm{q}_{\mathrm{PS,A20}}.$$

Similarly, the catchability in Area 13 is assumed to be 1.5 times greater than in Area 12:

$$(7)\qquad \mathrm{q}_{\mathrm{PS,A13}} = 1.5 \cdot \mathrm{q}_{\mathrm{PS,A12}}.$$

Because the catchabilities of the different fisheries are assumed to be related, often only Area 20 expansion lines are reported ($1/q_{y,d,A20}$).

Table 1 provides an overview of the main in-season expansion line strategies for the different stock groups and test fisheries that have been evaluated to determine the optimal approach for estimating $q_{y,d,A20}$. Performance of the strategies was evaluated for different subsets of years: (1) all years, (2) recent 8-year period (2007-2014), (3) high and low abundance years, (4) pink salmon (odd) years, and (5) by cycle line. In addition to the main strategies, additional strategies evaluated the length of days on which to base the in-season expansion line (6 days versus 1 day, 3 days, all dates to date) and the size of the adjustment to the expansion line. An expansion line strategy that relied on 6 days of in-season data for example would rely on daily reconstructed abundances and CPUE data observed 7 to 12 days prior because it takes an additional 6 days to travel from the marine test fishing locations to the lower Fraser River hydroacoustic site. The resulting Area 20 in-season expansion line is calculated as follows:

$$(8)\qquad \frac{1}{\mathrm{q}_{\mathrm{d}_1,A20}} = \sum_{d_2=d_1-7}^{d_1-12} N_{d_2,A20} \Big/ \sum_{d_2=d_1-7}^{d_1-12} CPUE_{d_2,A20}.$$

Adjustments to in-season expansion lines were made to account for time-varying trends across the season and density-dependent effects. Adjustments had been implemented either by multiplying the in-season expansion line for Area 20 ($1/q_{y,d,A20}$) with the adjustment or by adding or subtracting the adjustment.

Comparing performance using total abundance instead of daily estimates reduced the susceptibility of the analyses to violations in migration speed assumptions and reduced the weight of low abundance days while also increasing the importance of high abundance days. In addition, comparing total estimates allowed the same performance measures to be used to assess the expansion lines for delaying Late-run and Harrison stocks.

Table 1. *Overview of the main expansion line strategies evaluated for different test fisheries and stock groups by comparing the MAPE and MPE. Additional strategies evaluated the length of days on which to base the in-season expansion line (6 days versus 1 day, 3 days, all days to date) and size of the adjustments to the expansion lines.*

Expansion line strategy	Gillnet data		Purse seine data			
	All excl.Harr. Late run	Harrison	Early Summer	Summer excl.Harr.	Harrison	Late run
Constant historical expansion line			x	x	x	x
Increasing historical expansion line depending on date	x	x				
In-season expansion line based on observed 7-12 days prior	x		x	x		
In-season observed expansion line for other groups		x			x	x
In-season expansion line adjusted	x		x	x		
In-season observed expansion line for other groups adjusted		x			x	x
In-season observed expansion line, set-specific adjusted					x	
In-season expansion line adjusted based on CPUE	x		x	x		
In-season expansion line adjusted based on total catch	x		x	x		
In-season expansion line adjusted, set-specific adjusted			x	x		

Results

Using gillnet test fishery data, if the gradual increase in the historical expansion line is accounted for, the resulting run size estimates for Early Stuart, Early Summer and Summer run excluding Harrison are unbiased (Figure 2, a1, strategy 1) but the estimates are not very precise (Figure 2, b1). Using an in-season expansion line increases the precision, but due to the lag in updating the observations, the resulting abundance estimates are biased low (Figure 2, a1 and b1, strategy 2). The bias can be corrected on average by multiplying the observed expansion line with a factor of 1.25 to account for the increasing trend (Figure 2, a1 and b1, strategy 3). Further improvements can be made by adjusting the expansion line depending on total daily catch, with smaller catch days requiring larger adjustments compared to larger catch days (Figure 2, a1 and b1, strategy 4, Table 2). When restricting the data to recent years, results are similar but the patterns are slightly more pronounced (Figure 2, a2 and b2). Applying the same gillnet expansion lines from non-Harrison stocks to estimate daily abundances for Harrison results in abundances that are too low, even if in-season adjusted expansion line estimates are used (Figure 2, a3). Assuming the expansion line for Harrison is double the expansion line for other stocks removes the bias and improves the precision of the daily estimates (Figure 2, a3, b3).

For purse seine test fishery data (Figure 3), in-season expansion lines are more precise than historical expansion estimates but, in the case of Summer run excluding Harrison, may slightly overestimate abundance unless the in-season expansion line is reduced (Figure 3, a1 and b1). Abundance estimates can be improved by adjusting the expansion line depending on total catch, with larger catch days requiring bigger downward adjustments (Table 2). Adjusting expansion lines of individual fishing sets does not seem to further improve abundance estimates. For Harrison sockeye, the best expansion line strategy relies on the in-season expansion line for Summer run excluding Harrison without adjustments (Figure 3, a2 and b2). For Late-run sockeye, the best strategy is also to rely on in-season expansion lines for Summer run but to adjust them based on total catch (Figure 3, a3 and b3). Using an historical expansion line of 230 for Late-run results in unbiased but imprecise total run size estimates. A full overview of the recommended expansion line strategies is provided in Table 2.

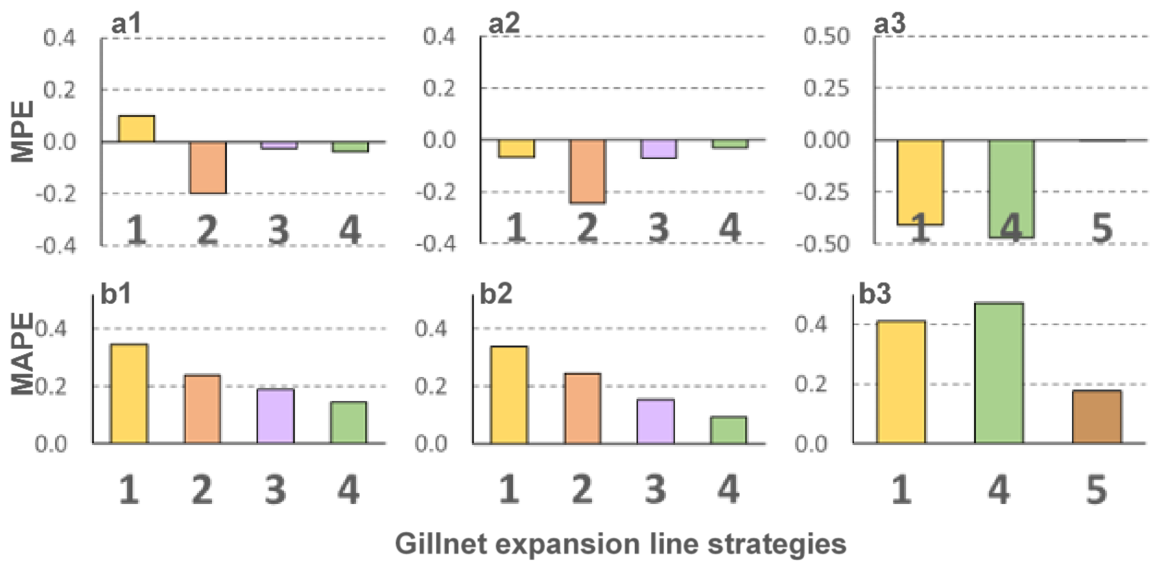

Figure 2. *Overview of the performance in terms of bias (MPE, a) and precision (MAPE, b) of different expansion line strategies evaluated for marine gillnet test fisheries targeting Early Stuart, Early Summer and Summer-run sockeye excluding Harrison across all years (a1 and b1), in recent years (a2 and b2) and Harrison sockeye across all years (a3 and b3). Expansion line strategies include: 1) increasing historical expansion line depending on date, 2) in-season expansion line, 3) adjusted in-season expansion line, 4) in-season expansion line adjusted based on catch, and 5) in-season expansion line with Harrison specific adjustment.*

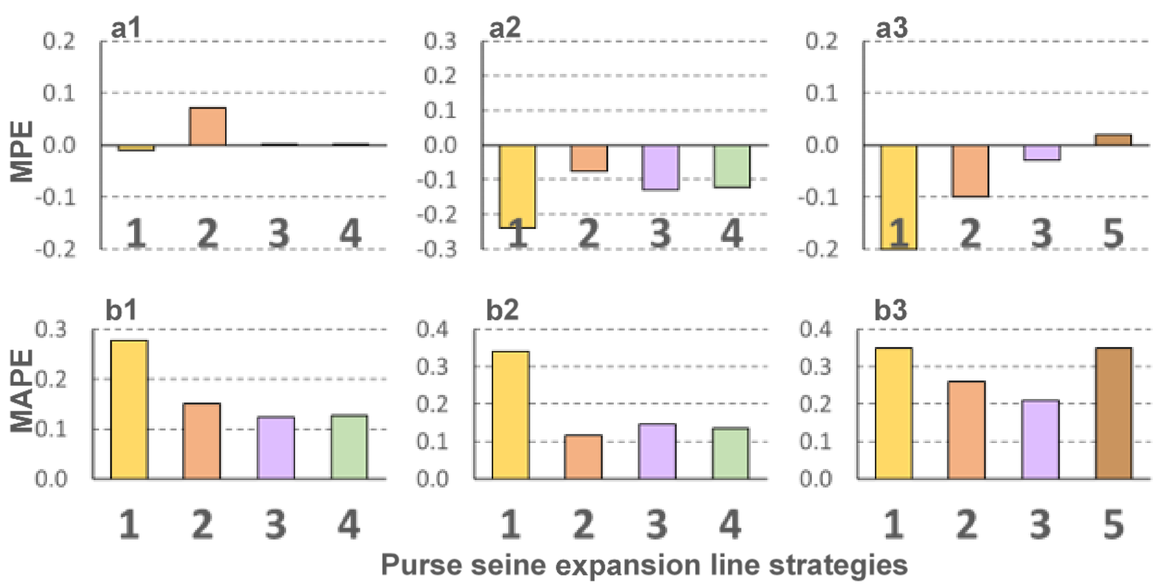

Figure 3. *Overview of the performance in terms of bias (MPE, a) and precision (MAPE, b) of different expansion line strategies evaluated for marine purse seine test fisheries targeting Summer run excluding Harrison (a1 and b1), Harrison (a2 and b2) and Late run sockeye (a3 and b3). Expansion line strategies include: 1) historical Summer-run excluding Harrison expansion line, 2) in-season expansion line based on Summer-run excluding Harrison, 3) adjusted in-season Summer-run excluding Harrison expansion line depending on total catch, 4) set-specific adjustment of in-season Summer-run excluding Harrison expansion line depending on total catch, and 5) historical Late-run expansion line.*

Table 2. *Overview of the top performing expansion line strategies evaluated for different test fisheries and different stock groups through retrospective analysis of data covering 1998 to 2014.*

Gillnet catchability	
Early Stuart, Early Summer, Summer run excl. Harrison	In-season expansion line x1.25 to account for time-varying expansion line trends. Further improvement can be made depending on total catch: • If total catch < 500, in-season expansion line x1.5 • If 500 < total catch < 1000, in-season expansion line x1 • If total catch > 1000, in-season expansion line x0.9 Prior to in-season estimates being available, rely on historical expansion line depending on date.
Harrison	In-season observed expansion line for Summer run excl. Harrison x 2. Prior to in-season observed estimates being available, rely on historical Summer run excl. Harrison expansion line depending on date x2.
Late run	Insufficient data available to assess gillnet catchability. When needed, apply the same expansion line as other non-Harrison stocks.
Purse seine catchability	
Early Summer, Summer run excl. Harrison	In-season expansion line -20 to account for slightly decreasing expansion line. Further improvement can be made depending on total catch: • If total catch < 500, in-season expansion line • If 500 < total catch < 10,000, in-season expansion line -20 • If total catch > 10,000, in-season expansion line -40 Prior to in-season estimates being available, rely on 180 historical expansion line.
Harrison	In-season observed expansion line for Summer run. Prior to in-season estimates being available, rely on historical Summer run expansion line -20.
Late run	In-season observed expansion line for Summer run (Figure 4). Further improvement can be made depending on total catch: • If total catch < 500, in-season expansion line Summer run + 10 • If 500 < total catch < 10,000, in-season expansion line Summer run - 10 • If total catch > 10,000, in-season expansion line Summer run - 50 Prior to in-season observed Summer run estimates being available, rely on historical Late-run expansion line of 230.

The recommended expansion line strategy for Late-run stocks (Table 2) is supported by the relationship between annual end-of-season expansion lines for Summer run and those for delaying Late-run stocks (Figure 4A). Overall, the relationship indicates that Late-run expansion lines are generally comparable to Summer-run expansion lines, i.e., close to the 1:1 line. However, annual expansion lines for Birkenhead, Big Silver do not show a similar relationship with Summer-run expansion line estimates (Figure 4B).

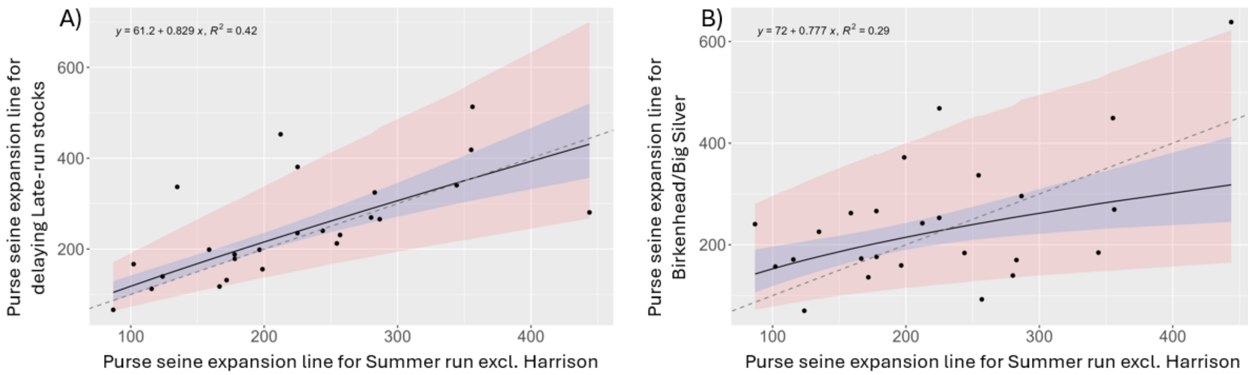

Figure 4. *Relationship between the annual, end-of-season expansion lines for Summer run excl. Harrison and A) delaying Late-run stocks (Late Shuswap, Portage, Weaver and Cultus) and B) Birkenhead/Big Silver. The plot also shows the 80% Credible Intervals (purple), the 80% Prediction Intervals (pink) and the 1:1 lines (dashed).*

Potential Areas for Improvement

The above analyses include data up to 2014 and the historical catchability could be updated by including more recent data. This is especially important at the start of test fisheries when historical expansion line estimates are relied upon and in the case of a recent trends in annual estimates. Once in-season expansion line estimates are available and relied upon, the potential impact of trends in historical data is removed. Generally, the start dates of purse seine test fisheries are selected so that in-season expansion line estimates are available by the time the first major fisheries are planned.

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PST. 2025. Treaty between the government of Canada and the government of the United States of America concerning Pacific salmon as amended through November 2025.

B6. In-river catchability estimates

S. Wong and M.J. Hague

Summary

Mission hydroacoustic data is the primary source for estimating daily sockeye salmon abundances in the lower Fraser River. However, in cases when sockeye estimates based on hydroacoustic data are either (1) unavailable, or (2) unreliable due to dominance of other salmon species, catch-per-unit-effort (CPUE) data from the Whonnock test fishery can provide alternative sockeye passage estimates. High variability in the historical Whonnock expansion line (inverse of the catchability) results in uncertain abundance estimates when derived from CPUE data. The following report describes the derivation of the historical expansion line estimates that can be applied in-season to estimate sockeye passage in the absence of hydroacoustic assessments (Chapter B14) or when hydroacoustic-based sockeye abundance estimates are unreliable due to pink salmon dominance (Chapter B19). It also describes the criteria used to decide when historical expansion lines should be adjusted based on the information observed in-season.

Introduction

As per the Pacific Salmon Treaty (PST 2025, Chapter 4), the Fraser River Panel is responsible for the enumeration of sockeye and pink salmon escapement in the Fraser River. Traditionally this is done through the collection of hydroacoustic data at Mission, B.C. (Chapter B14). The resulting total salmon estimates are divided among the species present through the application of a variety of species composition estimation processes. Under certain circumstances, species composition can be derived from test fishing catches collected by the gillnet test fishery at Whonnock (Chapter B19). On odd years, when pink salmon are the dominant species (late August - September) and the uncertainty associated with the species composition is large, sockeye abundance is instead derived directly from Whonnock catch-per-unit effort (CPUE) by multiplying this estimate by an in-river "expansion line" (1/catchability). In addition, Whonnock CPUE-based abundance estimates are also used when the Mission hydroacoustic program is not operational, e.g., during high discharge periods, before the hydroacoustic program has started, or after it has shut down for the season.

CPUE-based abundance estimates rely on catchability estimates which are derived from historical observations of CPUE and hydroacoustic-based abundances. It is well-recognized that catchability can vary across a multitude of factors and rarely displays a linear relationship with fish abundance (Brannian 1982). As such, Whonnock CPUE-based estimates of sockeye salmon abundance are inherently more uncertain than hydroacoustic-based estimates. An understanding of the key variables that affect the Whonnock catchability is therefore critical to determine what expansion line estimate should be applied to in-season CPUE data to produce the best abundance estimates and reduce the associated uncertainty. The following report describes the method used to derive historical sockeye expansion line estimates for the in-river gillnet test fishery at Whonnock as well as the criteria used to decide when historical expansion lines should be adjusted based on the information observed in-season.

Data

The primary purpose of the Whonnock gillnet test fishery in the lower Fraser River is to collect species composition information (Nelitz et al. 2018, Chapter B3). Historical expansion lines are applied to Whonnock CPUE data to derive sockeye abundance in-season. Expansion lines were calculated by dividing an estimate of "true" abundance by test fishery CPUE. In 2023, the historical timeseries of true abundances was updated to include hydroacoustic-based sockeye abundance estimates in even years and prior to August 16, and data from a backwards reconstruction in odd years, after August 15, when pink salmon tend to be dominant in the river. Including data from the backwards reconstruction enabled biologists to calculate historical expansion lines during a critical time period when pink salmon dominate species composition in the river. The backwards reconstruction (Chapter C5) was based on spawning ground estimates for Chilko sockeye salmon plus in-river catch, with the dates of both the reported daily catch and daily escapement data offset depending on distance and migration speed to corresponding dates when these groups of fish both passed Mission. Chilko abundances were then rescaled to total sockeye using proportions derived from genetic stock identification. Reconstructed abundances were not included for 2019 due to concerns relating to impacts of the Big Bar landslide on data quality.

For the purpose of calculating CPUE, catch was defined as the number of gilled and girthed sockeye salmon and fishing effort was calculated by multiplying the length (in fathoms) of the fishing net/1000 by the fishing time, i.e., the time the whole net is in the water plus half of the setting and picking time. A correction factor based on historical observations was applied to the raw CPUE data to calculate in-season expansion lines to adjust for effects of gear saturation on catchability at high abundances. To reduce variability associated with very low catches, only days with total gilled, girthed, and tangled catch of at least five sockeye were used to calculate the historical expansion lines.

Methods

Correlation and trend analyses such as linear regressions (in the case of continuous variables) and ANOVAs (in the case of categorical variables) were conducted to identify covariates that could explain a significant proportion of the historical variance in expansion lines, with the aim to improve in-season predictions. In addition to the Whonnock test fishery data and sockeye abundance estimates, a series of associated metadata were included in the analyses to evaluate trends prior to the 2023 update, i.e., information about the day, year, and fishing location (Whonnock Channel or Glen Valley Bar). Additional covariates were explored to evaluate their impact on catchability: total catch, sockeye catch, sockeye passage, number of seals, discharge levels, water temperature and wind direction (Table 1).

Uncorrected ("raw") CPUE data were used to calculate the expansion lines for the trend analysis so that the correction for gear saturation did not mask other underlying trends. The analysis of the in-river expansion line only included CPUE data for days where at least five sockeye were caught to remove the impact of small sample sizes on the uncertainty associated with the expansion line. To further reduce the impact of the variability in test fishing catches on the analysis, expansion line estimates were based on six days of observations, identical to the approach applied to derive expansion line estimates for marine test fisheries. Therefore, expansion line estimates for a given day were calculated using total passage and total CPUE over six days, covering three days before and two days after the day of interest. If a 6-day period contained less than 4 days with sufficient catches, the estimates for this period were not included in the analysis.

Because of a temporal trend in the expansion line estimates across the season, additional cross-correlation analyses were conducted for the other covariates that removed the effect of the day of the year on the expansion line. Because the change in expansion line across the season was non-linear, the expansion line data were also summarized by calculating the mean expansion line over a period of two weeks based on the geometric means of the daily estimates across subsets of years. This allowed assessment of trends across all years, all years excluding the 2022 cycle line, by cycle line, even years only, and odd years only.

As noted in the Data section, data were updated in 2023 to include two more years as well as data from a backwards reconstruction. These data were used to update the average historical Whonnock sockeye expansion line for each 2-week period but was not included in the correlation and trend analyses to detect possible covariates. After September 15, abundances from the backwards reconstruction were highly uncertain and produced unreasonably low expansion lines. Thus, data on odd years after September 15 were eliminated from the estimation of historical expansion lines.

Results

There was a high degree of variability in historical expansion lines – with values based on 6 days of data ranging from 558 to 109,978 after the catch threshold of ≥ 5 sockeye salmon was applied (Figure 1). Regressions between expansion line and day demonstrated a positive correlation (R^2=0.28, p-value < 0.001), with expansion line increasing throughout the season (Figure 1B). This trend was consistent across years, with greater variation in expansion lines within than between years (Figure 1). In addition to the temporal trend, significant correlations were noted for several covariates: sockeye passage, total catch, discharge, fishing location, sockeye catch, and water temperature, even though the correlations for the latter two were very low, with an R^2 of 0.09 and 0.03, respectively. The difference in expansion lines between fishing location was significant, but this was mainly due to differences in discharge as the test fishery was most often in operation at Glen Valley Bar during periods of high discharge earlier in the season. Year, seal presence, and wind direction were unable to explain significant variation in expansion lines. In the case of seal predation, this could be due to the uncertainty in the seal data, which were based on visual observations from the observer aboard the test fishing vessel.

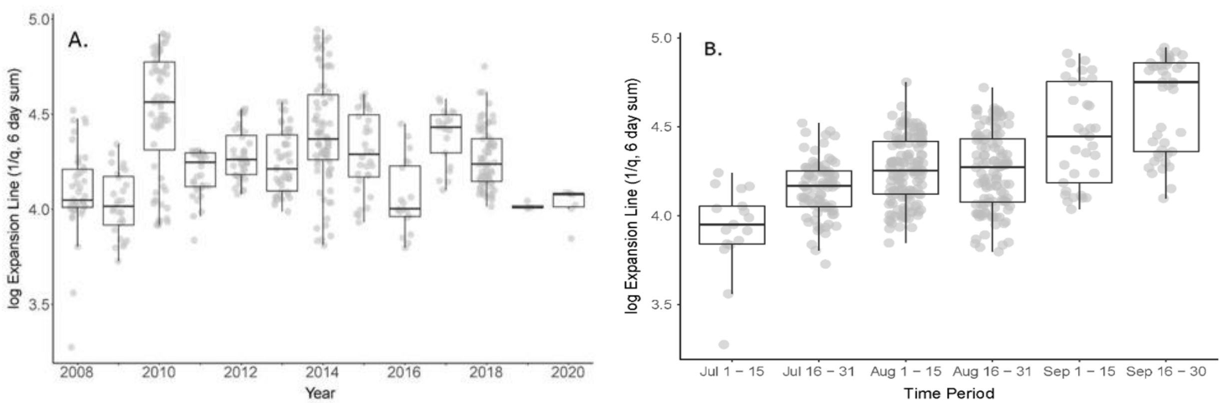

Figure 1. *Boxplot of 6-day expansion lines by year (A) and by in-season period across years (B) from 2008-2020. Data from the backwards reconstruction are not included.*

Alternatively, multiple regression models with interactions between day or discharge, and catch, passage, or water temperature generally explained more variation in the expansion line data than models without the interaction term. The two co-variates which explained the greatest percentage of the historical variability in Whonnock expansion line were day and sockeye passage past Mission (Table 1). Sockeye abundance at Mission cannot be used as a covariate for in-season catchability estimation, since CPUE-based estimates are only employed when independent hydroacoustic-based abundance estimates are unavailable. Day of the year is a good proxy for abundance, with abundances being low for

Early Stuart and increasing later in the season when Summer and Late run sockeye enter in the river. This explains the significant correlation of the expansion line with day.

Table 1. *Overview of the relationship between expansion line and various covariates. When the variable was continuous, a linear regression was performed, and the table notes the coefficient of determination (R2) and if the correlation was significant (*, p-value < 0.001). When the variable was categorical, an ANOVA was performed and significance (*, p-value < 0.001) indicates that the variation in expansion line between groups is larger than the within-group variation. Data are from 2008-2020 and do not include values from the backwards reconstruction.*

Variable	**R^2**		
	Expansion Line ~ Variable	**Expansion Line ~ Variable * Day**	**Expansion Line ~ Variable * Discharge**
Day	0.28*	-	-
Year	0.003	-	-
Fishing location	*	-	-
log_{10} Total catch	0.17*	0.37*	0.30*
log_{10} Sockeye catch	0.09*	0.32*	0.22*
log_{10} Sockeye passage at Mission	0.30*	0.45*	0.36*
Number of seals present	-	-	-
Discharge	0.15*	-	-
Water temperature	0.03*	0.27*	0.16*
Wind direction	-	-	-

The pattern in abundance is not consistent across years but differs by cycle line, with the dominant 2022 cycle line seeing a sharper increase in sockeye abundance compared to other cycle line years when later-timed Early Summer-run sockeye enter into the river. On 2024 cycle line years, overall salmon abundance trends downward faster compared to other years, while on odd cycle line years it is the increase in pink abundance later in the season that increases overall salmon abundance. Summarising the historical expansion line data for two-week periods shows a stepwise increase in expansion lines across the season (Table 2) that fits well to the observations across all years (Figure 2). Across cycle lines, the 2022 cycle line shows an increase in expansion line in the beginning of August while on odd years, this increase only occurs in September when pink salmon increase overall salmon abundance in the river. In comparison, on 2024 cycle years, most of the run would have already migrated past Mission at the start of September.

Table 2. *Average historical Whonnock sockeye expansion lines for 2-week periods for different year subsets based on corrected CPUE data for days with total sockeye catch ≥ 5 salmon. Data are from 2008-2022 and includes values from the backwards reconstruction on odd years from August 16 to September 15.*

Mission date	**Expansion Line**							
	All years	**Even years**	**Odd years**	**2022 Cycle**	**2023 Cycle**	**2024 Cycle**	**2025 Cycle**	**All excl. 2022 cycle**
Jul 1-15	6,910	6,827	7,091	7,770	-	5,480	7,091	6,476
Jul 16-31	9,752	10,110	10,287	10,078	8,021	11,076	11,186	9,687
Aug 1-15	12,131	13,994	10,106	18,436	9,901	10,546	11,005	10,200
Aug 16-31	13,607	12,586	14,446	16,029	15,896	8,395	14,233	13,597
Sep 1-15	17,113	16,379	18,025	16,379	15,446	-	22,569	18,025
Sep 16-30	18,156	18,156	-	18,156	-	-	-	-

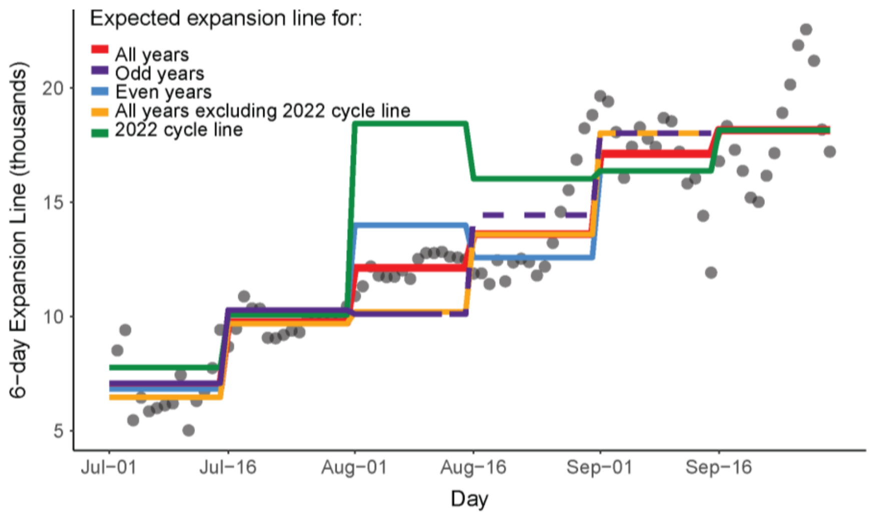

Figure 2. *Average historical expansion lines across two-week periods based on geometric average 6-day expansion lines across various year subsets, i.e., all years, odd years, even years, all years excluding 2022 cycle line years, and 2022 cycle line years. The geometric means of the 6-day expansion lines across all years are presented as grey dots. Historical expansion lines were calculated using corrected CPUE data from the test fishing database (Chapter C12) for days with at least 5 salmon caught. Data are from 2008-2022 and includes values from the backwards reconstruction on odd years after August 15 and prior to September 16 (dotted line).*

In-season Application

In the absence of other sources of in-season information, the historical expansion line estimates (Table 2, Figure 2) can be applied directly to corrected Whonnock CPUE data. Given the limited historical data available early in the season, averages should be calculated across all years until July 15 (Figure 3). Later in the season, the expansion line applied may vary by cycle year and depend on the correspondence of the historical expansion lines with the expansion line observed in-season. In case the historical expansion line deviates substantially from the in-season estimates (for periods dominated by sockeye salmon when such comparisons can be made), the average ratio between observed and historical expansion lines can be used to rescale the historical expansion line up or down for the remainder of the season. This approach both adjusts for in-season conditions while still accounting for historical patterns of seasonality. Given the high variability in CPUE based abundance estimates, the implied species composition estimate should continuously be monitored and compared to other observations of species composition (Chapter B19) to ensure resulting sockeye abundance estimates fall within realistic ranges. A full overview of the decisions in terms of in-season expansion line estimates can be found in Figure 3.

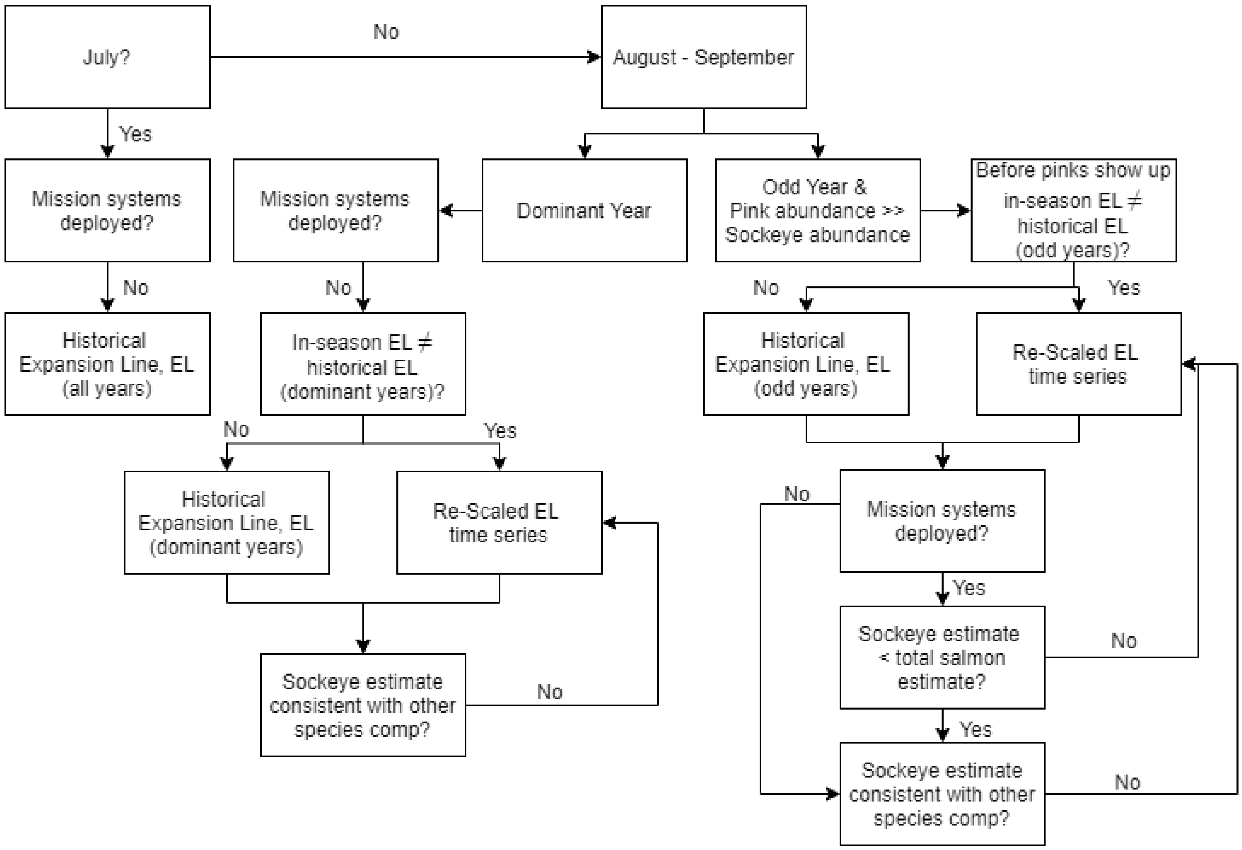

Figure 3. *A decision-flow diagram to guide the selection of in-season Whonnock expansion line estimates for calculating daily sockeye abundances when the Mission hydroacoustics program is either not operating or is not being used to generate abundance estimates.*

Potential Areas for Improvement

Current results are based on a limited dataset that only includes 2008-2020 for the analysis of covariates and 2008-2022 for the estimates of historical expansion lines. While inclusion of the backwards reconstruction data somewhat improves data limitations later in the season on odd years, data are still limited at the start and end of the season. Since values from the backwards reconstruction were highly uncertain after September 15, and thus removed from the data set, historical expansion lines for the two-week period starting on September 16 are solely based upon years on the 2022 cycle. This especially impacts sockeye abundance estimates on odd years when pink salmon are in the river, as the assumed expansion line will have been derived from data collected when no pinks were in the river and when Late-run stocks were dominating sockeye abundance. The potential bias this may create should be examined. In addition, while the two-week periods generally match the pattern of increasing expansion line well throughout the season, resulting abundance estimates are more likely to be biased around the time of the step increase. The impacts of using a stepped method rather than a linear increase could be further investigated. Finally, knowledge from fishers suggests that both water clarity and fish size impact catchability and thus could potentially aid in exposing patterns in expansion lines.

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PST. 2025. Treaty between the government of Canada and the government of the United States of America concerning Pacific salmon as amended through November 2025.

B7. Sampling protocol

A.M. Phung and D. Brkic

Summary

This report reviews the sampling protocol relevant to in-season assessments of sockeye salmon. DNA and scale samples are collected regularly from test fisheries, and opportunistically from commercial fisheries as fisheries occur. This sampling design is intended to provide up-to-date stock identification data for in-season Fraser River Panel (FRP) meetings which occur twice a week. Depending on the test fishery, it typically takes between 2 and 5 days from when a fish is caught and sampled to when the data are available at FRP meetings. The delay is affected by the geographic location of the fishery, the availability of shipping services, and how samples for various fisheries are prioritized depending on changing management needs. Commercial samples are obtained at fish plants. When sampling, one scale sample and one DNA sample are collected per fish and stored respectively in a scale book and on Whatman filter sheets. Scale samples are shipped to the Pacific Salmon Commission (PSC) Secretariat office where they are read, and the metadata is stored in a database. The DNA is shipped to the Pacific Biological Station for analysis. Once the DNA has been analyzed, the data are further processed by the stock identification biologists at the PSC Secretariat office (Chapter B11).

Introduction

During the in-season period, the Pacific Salmon Commission (PSC) operates a suite of test fisheries along the northern (Johnstone Strait) and southern (Juan de Fuca Strait) approaches (Chapter B2) and in the lower Fraser River (Chapter B3) to obtain an index of sockeye and pink abundance throughout their migration towards Mission. DNA (Chapter B11) and scale (Chapter B9) samples collected from catches in marine test fisheries give an early indication of the ages and stock composition of salmon that are returning to the Fraser River. In addition to age of fish, scale samples provide information on growth rate and can potentially be used to determine the stock of origin. Lengths and weights of fish are also often recorded in test fishery and commercial fishery sampling (Chapter B8). Normally, samples are taken from fish that are caught and landed. Live sampling has been tested on board purse seine test fisheries, while feasible, requires additional funding and technical support (PSC 2026).

In addition to sampling of test fishing catches, commercial catches are also sampled in-season. The main objective of the commercial catch sampling program is to gather information from DNA samples, scale samples, and biological data in order to estimate stock composition of the total commercial catch. In comparison to test fisheries, which generally collect information on sockeye migration (i.e., all of the sockeye in an area at a given time), commercial fisheries are sampled with a focus on estimating catches. The number and magnitude of commercial fishery openings vary from year to year depending on the Fraser salmon return, market conditions, and constraints imposed by other comigrating salmon species, particularly sockeye during a Fraser pink return year. When run sizes are high, the large number of samples obtained from commercial fisheries may provide better representation of the sockeye catch than test fisheries. The information from commercial catch samples is used to help determine the relative exploitation of each of the Fraser River sockeye management groups within a commercial fishery opening. This information can also contribute to run-size assessments, especially when used in conjunction to data from the test fisheries. During Canadian commercial fisheries openings, processing plants in the vicinities of Nanaimo and Vancouver are targeted for sampling landings. For commercial openings in northwest Washington State, processing plants in Bellingham are primarily targeted to sample landed catches.

Sampling design

TEST FISHERIES

The goal of sampling test fishery catches is to provide the most up-to-date stock composition information during in-season Fraser River Panel (FRP) meetings which occur on Tuesdays and Fridays. The geographic location of test fisheries coupled with limitations in air carrier services can lead to delays in data flow in-season. When fish are caught in Area 12 test fisheries, samples can take three (in the case of purse seine catch) to five (for gillnet catch) days until the stock composition data are available to be presented at the Friday FRP meetings. For the Tuesday FRP meeting, it can take three to four days after fish are caught to obtain Area 12 gillnet data and Area 12 purse seine data, respectively. When fish are caught in Area 20 test fisheries, samples can take two (purse seine) to three (gillnet) days until the data are available to be presented at the Tuesday or Friday Panel meeting. Purse seine samples are generally prioritized over gillnet samples as purse seine samples are considered to be more representative of the true population. This is because gill nets are believed to be selective towards certain stocks and fish that swim closer to the surface (Šmejkal et al. 2015), and because of size-selectivity imposed by the mesh size. The sampling schedule for collecting biological information varies depending on the test fishery. Table 1 shows a hypothetical sampling schedule assuming all test fisheries are running and lists the target daily sample sizes for each test fishery. A sample consists of one DNA tissue "punch" (obtained using a one-hole punch on the adipose fin), one scale, and biological data including length, weight, and sex (Chapter B8). The schedule and sample sizes may vary between years depending on shipping logistics and size of the catch.

Table 1. *Sockeye DNA and scale samples collected per day for each PSC test fishery.*

PSC test fishery	Number of boats	Schedule	DNA samples per day	Scale samples per day
Brownsville Bar	1	DAILY	50	50
Whonnock	1	DAILY	50	50
Area 20 Gill Net	2	Sun, Tues, Thurs, Sat	100	115
		Mon, Wed, Fri	None	115
Area 20 Purse Seine	1	Sun, Mon, Thurs, Fri	100	115
		Tues, Wed, Sat	None	115
Round Island Area 12 Gill Net	1	Sun, Tues, Fri	100	115
		Mon, Wed, Thurs, Sat	None	100
Blinkhorn Area 12 Purse Seine	1	Sun, Tues, Thurs, Sat	100	115
		Mon, Wed, Fri	None	100
Area 13 Purse Seine	1	Tues, Thurs, Sat	100	115
		Sun, Mon, Wed, Fri	None	100
U.S. Area 4B,5 GN	1	DAILY	100	100
Qualark GN	1	DAILY	50	50
Gulf Troll	1	DAILY	(per boat) 100	(per boat) 115
U.S. Area 7 Reefnet	3	Twice a week	100	115

The sample sizes shown in Table 1 represent the maximum targets under ideal, high-abundance conditions. In low-abundance years, the protocol is adjusted to account for reduced daily catches that frequently fall below the required sample size. For all test fisheries, any shortfall in the DNA sample size target on a given day is carried over and added to the target for the following day. For example, if the Whonnock test fishery catches only 40 sockeye on a given day, the target for the following day increases to 60. For marine gill net fisheries, this typically means sampling occurs daily regardless of the standard schedule, as catches during low-abundance years rarely meet the sample size target. Note that this carry-over protocol applies to DNA samples only; scale-only samples do not require compensation.

COMMERCIAL FISHERIES

Commercial fishery samples are collected opportunistically as fisheries occur. Generally, the target for a sampling trip is to collect 100 samples from each commercial fishery opening by gear type and key statistical area if fish are caught. This usually results in about 200-300 samples per sampling trip. Some commercial fisheries are sampled more intensively than others depending on catch numbers, logistics, and utility of the collected information at the time to the FRP meeting. When sampling purse seine commercial fishery catches, ideally more than 100 samples would be collected per area as catches tend to be higher than for other gear types. Unlike test fisheries which follow a strict sample collection schedule outlined pre-season, samples for commercial fisheries are more challenging to plan for due to uncertainty around where and when catches are going to be landed. Table 2 provides a summary of guidelines for sampling frequency during a year with ample available TAC such as 2018. Canadian commercial catches from Areas B, D, E and H are sampled at fish plants in Vancouver while catches from Areas B, D, G and H are sampled at fish plants in Nanaimo. U.S. commercial catches in Areas 7 and 7A are sampled at fish plants in Bellingham. In-season communication with fish plant representatives is crucial to planning sampling trips to maximize the amount of information that can be obtained.

***Table 2.** Sampling frequency guidelines for commercial fisheries by key statistical area in a high TAC year. Sampling frequency describes the number of sampling trips, not the total number of samples collected. Most sampling trips involve the collection of two or three sample sets of 100 fish from multiple statistical areas.*

Fishery User	Gear Type	Key statistical areas	Sampling frequency
Area B	PS	Area 12, 13, 29	3 times per week
Area D	GN	Area 12, 13	2 times per week
Area E	GN	Area 29	After every opening
Area H	TR	Area 12, 13 and 29	1 time per week
Area G	TR	Area 125, 126, 127	Infrequent
US-AC	PS, GN, RN	Area 7, 7a	2 times per week
US-TI	PS, GN, RN	Area 7, 7a	2 times per week

When catches are large, commercial sampling may include ratio counts. Ratio counts involve estimating the proportion of rare, visually identifiable fish types (e.g., adipose-clipped fish and/or jacks) to other fish within the catch and includes additional targeted sampling of those fish. Jacks may be an indicator of abundance for the following years, while sampling adipose-clipped fish is used to assess stocks of interest more precisely such as the Cultus Lake sockeye stock.

Method

The protocol for collecting DNA and scale samples and biological information is the same for both test fishery and commercial fisheries. Samplers distinguish sockeye from other salmon species by following guidelines outlined in the Sampling Manuals for test fishing observers and port samplers. Scale samples, DNA samples, and/or biological data, such as fish length, weight, and sex are collected on the boat, after landing, or at a processing plant. DNA, scales and biological data are primarily collected as “matched samples”, meaning each piece of information can be traced back to the same fish. This permits comparisons of age, size, sex, and growth between and within stocks. In some instances, there are scale samples taken without associated DNA or biological information (Table 1). This “scale-only” sampling is performed because there are limitations in how many DNA samples can be analyzed due to costs and efforts needed to collect, analyze and process these samples. On many occasions, an extra 15 scale samples are taken with no matching DNA. These scale samples are taken to account for scale samples that could not be read due to being regenerated or damaged. Scale samples that do not have matching DNA, including those from scale-only sampling days, are generally not analyzed in-season but may provide useful information in the future and are generally easy to collect. For commercial sampling, time is a limiting factor and sampling information is triaged. DNA has the highest priority, followed by scales, lengths, sexes, and finally weights. If time is a limiting factor due to scheduled fish plant operations, samplers may opt to exclude lower-priority information from the collection.

Sample collection is done in a way to ensure samples are representative of the overall population. For fisheries that use variable mesh gillnets such as Whonnock and Brownsville Bar, fish are sampled from each mesh at a ratio equal to the ratio of the total catch. For example, if 50% of the fish are caught in the 5-inch mesh, then 50% of the samples are taken from that same mesh. Fish that are gilled are prioritized over tangled fish as they are more representative of the mesh they were caught in. In marine purse seine test fisheries, efforts are made to sample proportionally from each fishing set. Without knowing what the catch would be in future sets, this strategy risks not meeting the sample size minimum. Additional fish caught in the first set are therefore not released but kept, to cover any shortfall. Once the final set has been processed and these additional fish are not needed to reach the sample size target, up to 15 scale-only samples are taken from some of the additional kept fish (Table 1). In low-abundance years, conservation concerns may require the release of all unsampled fish after each set, making it more difficult to ensure samples are spread across the sets.

Scale samples are placed in a scale book along with all the biological data from that individual salmon and the DNA sample number. The “preferred scale” is selected from each salmon unless it is missing or damaged and is located on the left side of the salmon, on the second scale row above the lateral line in a diagonal line from the posterior of the dorsal fin to the anterior of the anal fin (Figure 2). If the preferred scale is missing, the next closest scale is taken as long as it is at least two scale rows above the lateral line and behind the front of the dorsal fin. Scales higher than four scale rows above the lateral line may be sampled in rare cases if all scales near the preferred scale location are missing. This is because the characteristics of the scales on a sockeye vary dorso-ventrally (top to bottom). In this case, the sampler notes that a non-preferred scale was used. If there are no usable scales on the left side of the fish, a right-side scale may be used, but the sampler must take note of this because it can affect how the scale is read. If neither side of the fish has appropriate scales to sample, the sampler should pick another fish if there is an adequate number of fish to sample.

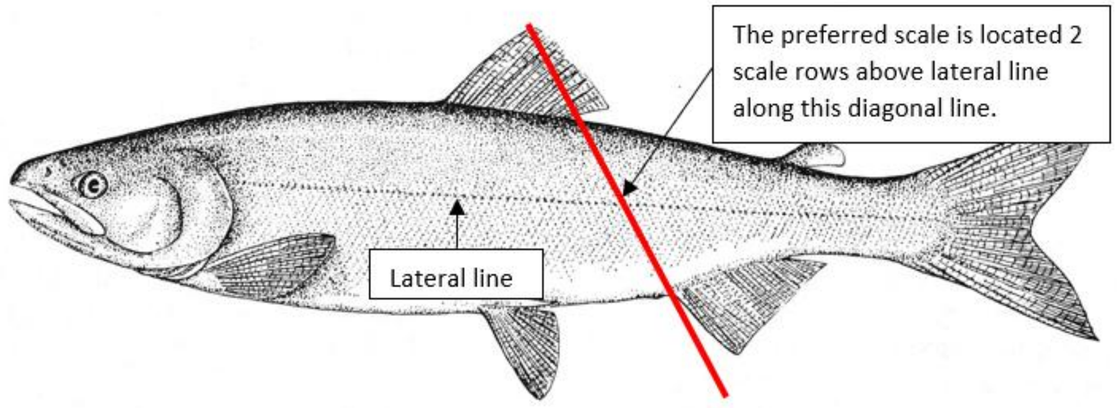

Figure 2. *The preferred location of the scale to sample. Scales higher than four scale rows above the lateral line are non-preferred.*

DNA samples are collected by using a one-hole punch and punching one small, thin disk from the margin of the adipose fin of the salmon. If the adipose fin is missing, a caudal fin clip is taken instead. While the sample is still wet, the DNA is placed on a Whatman sheet. The alternative storage of DNA in ethanol vials is less desirable but is used in cases where Whatman paper is not available or if heavy wind and/or rain make using Whatman sheets difficult. To prevent contamination, sampling equipment is rinsed after each sample is taken.

The procedures to gather biological data such as length, weight, and sex, are described in Chapter B8. Ratio counts are determined by dividing the total number of jacks or adipose-clipped fish encountered by the total number of fish counted. To conduct ratio counts in a fish plant, the number of fish without an adipose fin is counted as fish pass by on a conveyor belt as they are being off-loaded. DNA and scale samples as well as biological information are collected for jacks and fish missing their adipose fin (adipose-clipped or adipose-damaged).

Scale samples are analyzed at the Scale Lab within the PSC Secretariat office in Downtown Vancouver (Chapter B9, B10). DNA samples are analyzed by the Molecular Genetics Lab at the Pacific Biological Station (PBS) in Nanaimo (Chapter B11). For the Johnstone Strait test fisheries, test fishing observers drop off biological samples at an air carrier service to be shipped as soon as possible to Vancouver. For the Area 20 Juan de Fuca test fisheries, the test-fishing observer delivers biological samples to a contractor in Port Renfrew who drives the samples to AC Taxi in Nanaimo in the evening. In the morning, AC Taxi delivers the DNA samples to PBS and the scale samples to an air carrier service. The samples are picked up from the air carrier service in Vancouver by PSC staff. In-river DNA samples from Brownsville Bar and Whonnock are generally delivered to the PSC office by staff while Qualark samples are delivered to the PSC office by Canada Post. DNA samples from these fisheries are flown to Nanaimo using the air carrier service.

Shipping and processing samples is particularly challenging in low-abundance years, when small catch sizes mean that samples must be batched together to remain cost- and time-efficient. As a result, the number of shipping days per week is often reduced to allow a sufficient number of samples to be consolidated into each shipment. For marine purse seine fisheries, this may require DNA sampling days to be rescheduled to ensure samples remain fresh upon delivery.

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B8. Fish length, weight, and sex

D. Brkic and A.M. Phung

Summary

Biological information of salmon collected by the Pacific Salmon Commission (PSC) includes length, weight, and sex information. Length measurements are used to supplement stock identification information (Chapter B11) and as inputs into models that differentiate fish species based on hydroacoustic lengths, i.e., length-based mixture models (Chapter B18). Weights in combination with lengths are important for understanding fish condition but also provide the fishing industry with information on the potential value of expected catches. Sex information is equally important as analyses of lengths and weights often requires separation of the sexes. Lengths are measured and recorded in terms of fork length, postorbital fork length (POF), and postorbital hypural length (POH). Length measurements are taken using a "POF stick" while weights are measured using industrial scales. Sex is determined by making an incision in the abdomen and inspecting the gonads by touch.

Introduction

The Pacific Salmon Commission (PSC) collects and stores biological information – including length, weight, and sex – from salmon sampled from commercial and test fishery catches. Differences in average historical length between fish stocks may be used during stock identification to help resolve uncertain stock assignment (Chapter B11). Fish lengths also help distinguish different species within a mixture of different length estimates obtained from hydroacoustic data (Chapter B18). Multi-year records of length and weight may reveal deviations from average, which could be important in fisheries planning as larger fish are more valuable both in terms of catch and in terms of brood stock. Determining the sex of sampled fish is important as morphological differences between the sexes may lead to differential catchability in fishing gears as well as varying offload weights when fish are sold. Analyses done on length and weight data also generally require separation of the sexes.

Length definitions

The Pacific Salmon Commission collects three different types of length measurements: fork length, postorbital fork length (POF), and postorbital hypural length (POH). Figure 1 shows the difference between fork length, POF, and POH.

Fork length is the length from the anterior-most part of the fish to the posterior end of the middle caudal rays. Fork length is best used to determine the overall size of a fish when it has deeply forked tails and difficult-to-distinguish hypural plates as is the case for salmon. The PSC uses fork lengths in the hydroacoustic length-based mixture models.

The postorbital fork (POF) length measures the length from the posterior of the orbit (the back of the eye) to the posterior end of the middle caudal rays. Excluding the snout of the fish in the measurement helps circumvent the impact of highly variable snout lengths, as male salmon tend to develop distinct hooked snouts during maturation. The PSC sometimes uses POF to supplement stock identification information based on scales and DNA. POF is also used to track changes in length-at-age across return years.

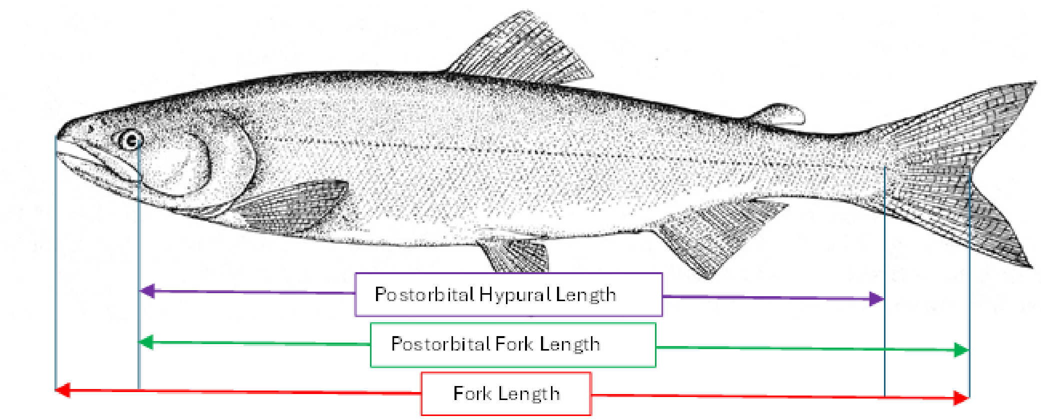

Figure 1. *Illustration of the different salmon length measures recorded by the PSC.*

The postorbital hypural (POH) length is the length from the posterior of the orbit to the hypural notch. This length measure is especially used during sampling on the spawning ground (Chapter C1) when the caudal fins tend to degrade, especially among females, causing the POF to become highly variable. Both the orbit and hypural notch, used to determine the POH, can be identified on even highly degraded carcases.

Other types of fish lengths include mid-eye fork length (MEF) and standard length. These lengths are generally not taken by the PSC but are entered into the PSC's scale database when samples are received from other organizations. MEF is the length from the middle of the orbit to the fork in the tail. MEF length is generally taken in fishery samples by the Alaska Department of Fish and Game. Standard length is the length from the tip of the snout to the hypural notch and is generally taken for spawning ground samples by Fisheries and Oceans Canada.

Sampling design

There are five main types of biological data collected in the field by the PSC: fork length, POF, POH, weight, and sex. Tables 1 to 3 show which lengths are taken at each fishery, whether weights are taken, and the sample sizes for lengths and weights.

Fork lengths are generally only measured at the Whonnock gillnet test fishery and the Brownsville Bar gillnet test fishery. Fork lengths are measured for sockeye, pink, chum, Chinook, and unreleased (dead) coho salmon. Fork lengths are not measured for steelhead and released (live) coho. Fork lengths from Whonnock and Brownsville Bar are typically used within hydroacoustic length-based mixture models. If there are insufficient fork length samples available from Whonnock and Brownsville Bar, additional fork lengths data may be required from other test fisheries or commercial fisheries.

Postorbital fork (POF) lengths are measured at all PSC test fisheries and when commercial fisheries are sampled. POF is only measured for sockeye and pink salmon. For commercial fisheries and reef net test fisheries, sample sizes for length are determined by catch sizes and DNA sample requirements. Every fish sampled for DNA has an associated POF measurement unless the samplers are facing extreme time limitations at fish plants.

Postorbital hypural (POH) lengths are the primary length measurements for spawning grounds samples. At the Brownsville Bar and Whonnock test fisheries, POH is measured for adipose-clipped Chinook, and coho salmon.

Weights of individual fish are measured only for sockeye and pink salmon and only at the Brownsville Bar, Whonnock, Area 20 GN, Area 20 PS, Area 4B/5 GN, Qualark GN, and Area 7 RN test fisheries.

Individual weights are also measured for commercial fishery samples. Weights are not measured for individuals that are incomplete such as fish that are damaged by seals or dressed. For commercial samples, individual weights may not be measured if time is a limiting factor. Bulk weights, which is the net weight of a tote, may also be recorded and are used to calculate the average weight. For Chinook, chum, and coho caught at test fisheries, only bulk weights are recorded when the fish are sold.

Sexes are recorded for all sampled sockeye and pink salmon whenever possible. For commercial samples, sexes may not be determined if time is limiting.

Table 1. *Sockeye sampling summary by fishery. The types of lengths taken at each fishery are shown as well as whether weights are taken and the sample size of each.*

Fishery	Length type	Weight	Sample Size (up to)
Brownsville Bar GN	FL/POF	Yes	50/day
Whonnock GN	FL/POF	Yes	50/day
Area 20 GN	POF	2 days/week	115/day
Area 20 PS	POF	2 days/week	115/day
Area 12 GN	POF	No	115/day
Area 12 PS	POF	No	115/day
Area 13 PS	POF	No	115/day
Area 4B/5 GN	POF	Yes	100/day
Qualark GN	POF	Yes	50/day
Gulf Troll	POF	No	115/boat/day
Area 7 RN	POF	Yes	Variable
Commercial	POF	Yes	Variable
Spawning Grounds	POH	No	Variable

Table 2. *Pink sampling summary by fishery on odd years only. On even years, the Area 12 PS test fishery sometimes samples up to 100 pinks per week.*

Fishery	Length type	Weight	Sample Size (up to)
Brownsville Bar GN	FL/POF	Yes	100/week
Whonnock GN	FL/POF	Yes	100/week
Area 20 PS	POF	No	100/week
Area 12 PS	POF	No	100/week
Area 13 PS	POF	No	100/week
Qualark GN	POF	Yes	100/week
Gulf Troll	POF	No	100/week
Area 7 RN	POF	Yes	Variable
Commercial	POF	Yes	Variable
Spawning Grounds	POH	No	Variable

Table 3. *Chinook, coho and chum sampling summary by fishery.*

Fishery	Species	Length type	Weight	Sample Size
Brownsville Bar GN	Chinook	FL/POH*	No	All fish
Brownsville Bar GN	Coho	FL/POH	No	All fish
Brownsville Bar GN	Chum	FL	No	All fish
Whonnock GN	Chinook	FL/POH*	No	All fish
Whonnock GN	Coho	FL/POH	No	All fish
Whonnock GN	Chum	FL	No	All fish

**adipose-clipped fish only*

Method

All lengths are measured using a "POF Stick": a custom-made 1-metre aluminum ruler with one fixed post at the zero marker and one sliding post. The posts are 6-7cm long and generally have a fine-pointed tip. The accuracy of POF sticks is tested by setting the POF stick measurement to 50cm, then measuring from the inner edge of the fixed post to the point of the sliding post using measuring tape or another ruler (Figure 2). Lengths are recorded in centimeters or millimeters and are rounded to the nearest millimeters.

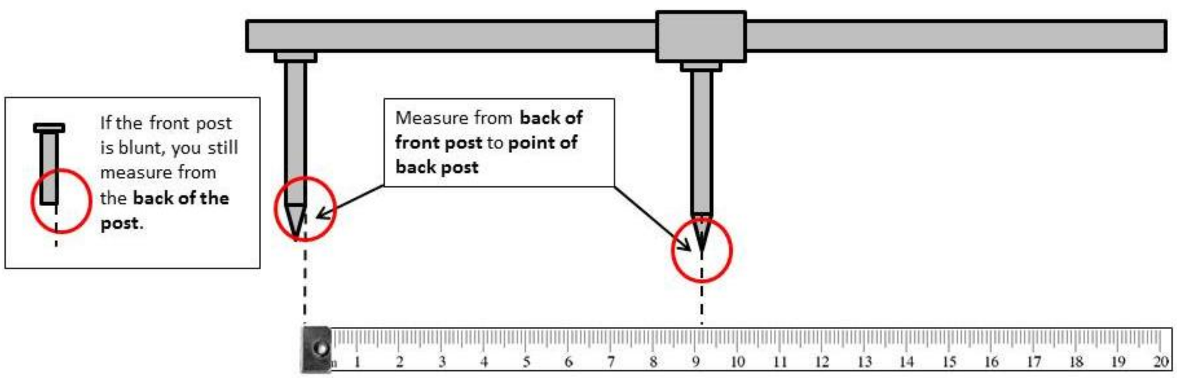

Figure 2. *A POF stick and how it can be used to measure lengths. Lengths are measured from the front of the fixed post to the point of the sliding post*

Fork lengths are measured by placing the inner end of the fixed post of the POF stick in front of the fish snout and moving the point of the sliding post to the fork in the tail. Fork length is not measured if damage to the snout or tail prevents an accurate reading.

Postorbital fork (POF) lengths are measured by placing the fixed post of the POF stick into one of the eye sockets of the fish. The point of the sliding post is then moved to the fork in the tail. POF lengths are not taken if damage to the eye sockets or tail prevents an accurate reading.

Postorbital hypural (POH) lengths can be measured in three different ways. For the first method, the flesh covering the hypural plate is cut away with a knife to reveal the hypural notch. The fixed post of the POF stick is then inserted into the eye socket and the sliding post is pointed at the hypural notch. This is the preferred method for spawning grounds sampling as it is the most accurate. For the second method, the sampler feels the tail of the fish to estimate the location of the hypural notch. The hypural plate is distinctly elevated at the base of the caudal fin rays. The measurement is taken from the eye socket to the estimated position of the hypural notch. This method is preferred for test fishery sampling as it is the most time-efficient and does not damage the fish and reduce retail value. The third method involves folding over the rays of the caudal fin until it can no longer be bent. The measurement can then be taken from the eye socket to the position of the final bend. This method is another time-efficient alternative to the first method but is less accurate.

Weights are measured using a Kilotech industrial dial scale or an AND SK-WP digital scale. The scales are calibrated using two known weights: 1.000 kg and 3.915 kg. Weights are recorded either in pounds or kilograms and are always rounded to one decimal place. Average weight is calculated by dividing the total weight of fish in a sample by the sample size. If bulk weight was recorded, the average is calculated by dividing the net weight of a tote by the number of fish in it.

To determine the sex of a fish, a cut is made in the belly (approximately five cm) from between where the pectoral fins originate and along the midline of the stomach. The sampler inserts their finger into the cut until the spine is reached, feeling along the surfaces of the internal organs. If the fish is female, the lumpy texture of the egg-filled ovaries can be felt. If the fish is male, the smooth testes can be felt. If the sampler is inexperienced or if the sex is indistinguishable by feel, the cut in the belly can be extended further to the posterior and the body cavity opened for a visual examination. For spawning grounds samples, the sex can be determined by visual examination of exterior morphology, but the body cavities of females are still examined to evaluate egg deposition or success of spawn.

Planned Changes and Potential Areas for Improvement

Erroneous or anomalous length and weight measurements can enter the database unnoticed despite some existing preventative measures. An error-checking tool is under development to detect outliers in length-weight data so errors can be caught and rectified earlier. If the source of an error cannot be identified or if it cannot be fixed, anomalous data can be flagged and subsequently excluded from analysis if desired. Obvious errors can be removed, such as when fork lengths are shorter than POF lengths. The tool can also track data accuracy by fishery, allowing fishery-specific sources of errors to be addressed.

B9. In-season scale and age reading methods

J.E. Sellars and M.R. Forrest

Summary

Fraser sockeye salmon stocks are managed by four management groups: Early Stuart, Early Summer run, Summer run and Late run. This stipulation within the Pacific Salmon Treaty (PST 2025) requires salmon run size, catches and escapement estimates to be split into these four groups using stock composition estimates. In-season, stock composition estimates are derived from catch samples through scale reading, i.e., by analysing scale characteristics and growth patterns and comparing the resulting patterns against the patterns of salmon with known stock origin. While DNA-based stock identification (Chapter B11) replaced scale-based methods as the primary method in 2002, scale-based methods still have an important role in the assessment for Fraser River sockeye salmon: they provide stock-ID information earlier and when DNA estimates are not available and they provide additional information to refine DNA-based stock proportions. In addition to providing stock-ID data, scales are the primary method to assess fish age. Since the majority of Fraser sockeye return as four-year olds, the portion of age four compared to age five sockeye is an important indicator to evaluate the strength of the sockeye run in relation to the strength of the run in the previous year. High age five proportions in-season may indicate that returns are less favorable than the previous year.

Introduction

In the early 1900s, Dr. C.H. Gilbert first recognized that the freshwater scale patterns of Fraser River sockeye salmon stocks differ (Henry 1961) as they reflect unique variations in growth patterns that develop while stocks are spatially isolated, such as during juvenile residence in lakes or streams, or during certain phases of marine residence (Gable and Cox-Rogers 1993). In addition, it is also possible that genetic differences between stocks play a role in observed scale pattern differences (Gable and Cox-Rogers 1993).

Sockeye salmon scales contain a permanent record of the life history of a fish beginning with the early fry stage. As the fish grow in body size, corresponding radial scale growth takes place. New basal plates are formed under existing plates and hyalodentine ridges (circuli) are deposited on the margins between adjoining plates. The circuli appear under magnification as partially concentric rings which radiate outward from the scale focus (Figure 1, Gable and Cox-Rogers 1993). Widely spaced bands of circuli reflect rapid growth in the summer, and compactly spaced bands of circuli growth reflect slow growth in the winter (Bilton and Ludwig 1966). Scales contain two distinct zones of scale growth: the freshwater zone, consisting of thin, narrowly spaced circuli, and an outer marine zone, consisting of thick, widely spaced circuli (Figure 1). A third zone lies between the freshwater and marine scale zone. This is the “spring growth” or “plus-growth” zone. Circuli in this zone are of intermediate size and form just prior to, or soon after, ocean entry. Circuli counts in the freshwater and spring growth zones as well as distance measures within these zones are used by the PSC for stock identification and to evaluate the rate of growth in freshwater in a given year.

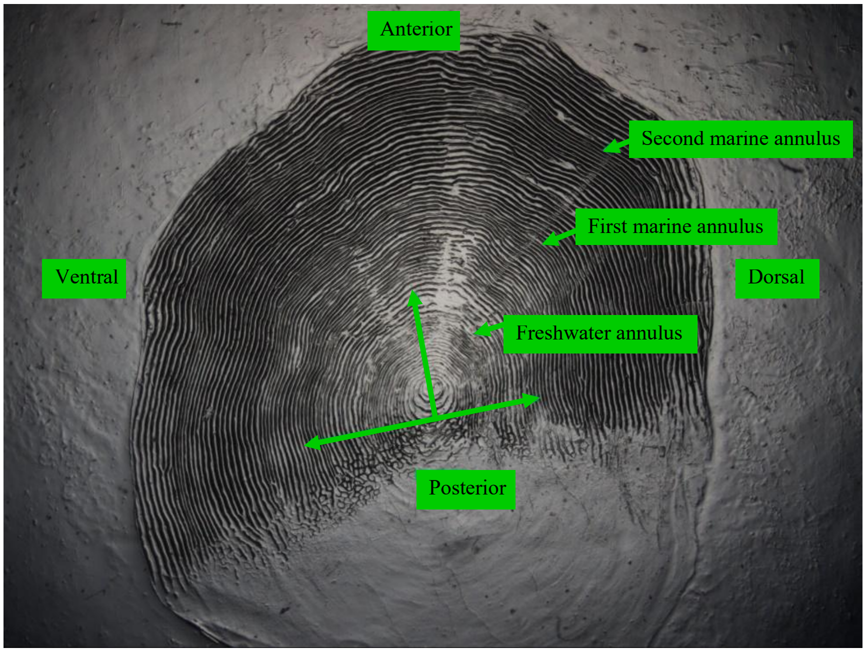

Figure 1. *Scale image with labels and radial line along which circuli counts are made.*

Data

In-season scale samples are collected regularly from test fisheries, and opportunistically from commercial fisheries as fisheries occur. For each sockeye sampled, one scale is collected, stored in a scale book and shipped to the Pacific Salmon Commission (PSC) Secretariat office. The PSC scale lab reads the scales and archives the associated information in a database together with other relevant information collected during the sampling process. The associated metadata can be used to match scale information of individual fish with DNA results as well as biological and fisheries information collected in the field. The PSC scale database contains records dating back to 1912. Initially only spawning ground scale samples were represented but since 1977 commercial and test fishing scale samples have also been collected and stored in the database. In addition to the adult scale information, the database also contains smolt scale information from 1948 to present. Since 1991, the lab analyses between 15,000-51,000 sockeye scales annually, both for freshwater growth patterns as well as age.

Method

Scales are forwarded to the PSC scale lab from multiple temporal and spatial locations in scale books. Each scale is removed from the scale book and cleaned before mounting onto a gummi card. Heat and pressure using a hydraulic press are used to make an impression of the scales on to a clear sheet of acetate. It is the microscopic image of the scale impression on the acetate that is used for scale aging and analysis. Using a microscope connected to a camera and computer, the image of the scale is captured, stored and analyzed using Image-pro Premier software and the resulting scale measurements are stored in an Excel spreadsheet (Batchelor 2016).

Using expertise and experience, in combination with the image software, the scale analyst will examine and document the condition of the scale using condition codes (Table 1) and documents the circuli count of the freshwater growth zone, the spring growth count, the diameter of the focus, the distance from the focus to the fifth circulus, the distance from the focus to the annulus and the age. Circuli counts are made along a specific radial line for consistency of results (Figure 1), chosen to be the ventral

20° radial line (Clutter and Whitesel 1956). This line extends ventro-anteriorly from the focus of the scale, forming an angle of 20° with the horizontal or longitudinal axis of the scale and is disclosed by overlaying the transmitted scale image with a grid onto which a longitudinal axis and two 20° radial lines have been etched. The circulus count is then made along the ventral 20° radial line.

Table 1. *Condition codes used to describe scale condition and available information.*

CONDITION CODES (CC)

	CC	Scale info available	Scale Condition
READABLE	**1**	AGE & CC	READABLE
	2	AGE & CC	RESORBED SCALE - Age questionable
	3	AGE BUT NO CC	AGEABLE BUT CC UNREADABLE
	4	AGE & CC	AGE BASED ON SCALE NOT OTOLITH
UNREADABLE	**5**	NO AGE OR CC	LATERAL LINE
	6	NO AGE OR CC	NON-SOCKEYE
	7	NO AGE OR CC	UNREADABLE
	8	NO AGE OR CC	MISSING
	9	NO AGE OR CC	REGENERATED
	10	FW AGE	SOCKEYE THAT HAS MATURED IN FRESHWATER
READABLE	**12**	AGE & CC	1/3 is good and the rest is resorbed 2-3 circuli **OR** 2/3 is good but 1/3 is resorbed and into the last annulus
READABLE	**13**	AGE & CC	Growth to 1st Marine is small in comparison to the growth to the 2nd Marine - ie. The spacing is not the same from the focus to the 1st as it is to the 2nd marine.
READABLE	**14**	AGE & CC	Scale too big to be digitized
READABLE	**15**	AGE & CC	Special note
READABLE	**16**	AGE & CC	Growth to 1st marine is extremely large.
READABLE	**17**	AGE & CC	Unusual 1st year marine growth for 52s

Sockeye have multiple age classes (Table 2) and the PSC uses the Gilbert and Rich nomenclature for age classification (Clutter and Whitesel 1956). The first number denotes the age at spawning and a subscript or second number denotes the age at which the sockeye migrated to sea. For example, a 4_2 aged sockeye returns to its natal stream to spawn and die at four years of age. It has spent one year in the lake, migrated to sea in its second year of life and returned to its natal stream after 2 years at sea. The scales of the sockeye are aged by examining the number of annuli in the freshwater zone and the number of annuli in the marine zone. For Fraser sockeye, the majority of the adult salmon will be 4_2 and 5_2 fish.

Table 2. *Common age classes of adult Fraser River sockeye salmon. Ocean or sea type sockeye only spend one year in freshwater while for sockeye maturing in freshwater, the age of spawning equals the number of years in freshwater.*

Age of	Number of years in freshwater			
spawning	1 year	2 years	3 years	4 years
2 years	2_1	2_2		
3 years	3_1	3_2	3_3	
4 years	4_1	4_2	4_3	4_4
5 years	5_1	5_2	5_3	5_4
6 years		6_2	6_3	6_4
7 years		7_2	7_3	7_4

When all scales of a sample have been aged, each of the scales is re-aged by the same analyst. The scale data are then merged with the field and sample data within an Excel application that allows for data entry, data merging, error checking and summarising data. As an error checking tool, it highlights missing data, outliers, data that does not fall within specific boundaries and unusual data. Once the data have been merged and error checked, a second scale analyst will re-age and check a large proportion of the scales. This is another step to ensure aging accuracy, but also to ensure scale interpretation remains consistent between analysts. Analysts must be experienced and well-trained in aging to differentiate true annuli from stresses and false checks. The data are then summarized and uploaded into the scale database for use by the stock identification biologists (Chapter B11).

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B10. Stock composition estimates based on scale pattern analyses

P. Samarasin and S. Latham

Summary

Returning Fraser River sockeye stocks differ in timing and are aggregated into “management groups” to facilitate their management. Assessments in support of management therefore require stock composition information. The stock composition of mixed stock fishery samples can be estimated by comparing the scales from these samples against scale patterns from fish with known stock origin (i.e., scales collected at spawning grounds). Until 2002, scale-based methods were the primary mode of stock identification for Fraser River sockeye salmon. Within the current assessment framework, stock composition estimates derived through scale pattern analyses provide additional information to refine DNA-based stock proportions (Chapter B11) or provide estimates when DNA-based stock identification is not available. Although scale pattern analyses have been used for the last 50 years, the statistical approach has changed over time. This report provides a summary of historical and current (2018) approaches for scale pattern analysis for identification of Fraser River sockeye salmon stocks. The current scale pattern analysis method is a combination of two multivariate statistical methods – linear discriminant analysis (LDA) with principal components analysis (PCA). Scale pattern data from spawning ground samples are used to develop discriminant functions for separating Fraser River sockeye stocks, and the derived functions are applied to in-season scale samples from mixed-stock fisheries to estimate sample stock proportions. The model output provides stock proportions for the sample and stock assignment probabilities for individual sockeye salmon.

Introduction

The recognition of differences in scale characteristics among sockeye salmon stocks is attributed to Gilbert (1914-1925). However, use of scales to identify Fraser River sockeye stocks was first examined in the mid-1900s by Hamilton (1947) and Clutter and Whitesel (1956). At that time, the analysis used number of circuli in the freshwater zone of the scale to distinguish between stocks within the Fraser River watershed. Fraser River sockeye typically spend their first year in freshwater where they can differ considerably in their growth rates. Growth rates depend on freshwater conditions, and rearing lakes differ in temperature, food availability, and other factors that affect growth. Fish growth is closely related to scale growth (Clutter and Whitesel 1956), and growth is recorded in the scales which can be used to infer the origin of returning adult fish. There is variation in growth rate from year to year, however, resulting in differences in scale characteristics for any given stock among years. The stock composition of a mixed-stock fishery can be estimated by comparing growth patterns in a sample of scales from caught fish to growth patterns of fish with known stock origin (scales collected at spawning grounds). Here, the *sample* refers to a collection of scales removed by fisheries observers for determining the stock composition of the catch.

Data

Sockeye salmon scales (one per fish) collected from fisheries and spawning grounds are read by PSC scale analysts who determine each salmon's age and measure scale characteristics (Chapter B9). The following scale variables are directly measured or calculated by scale analysts and are used in the statistical model to estimate stock composition: first count (count of circuli to the 1^{st} freshwater annulus), plus or "spring" growth (circulus count between the freshwater annulus and marine growth), measured distances from the center to annulus, from the center to the 5^{th} circulus, from the 1^{st} circulus to the annulus, from the 1^{st} to 5^{th} circulus, and the adjusted center width. For generating discriminant functions: spawning ground scales with readable freshwater zones and known ages (from otoliths) are used. Only readable scales are included in mixtures for scale pattern analysis, and these may include or exclude individuals with resorption of their scales that would tend to underestimate the true age.

Methods

Scale pattern analysis methods have changed over time as statistical methods and implementation have evolved with increasing computation power. Two Pacific Salmon Commission (PSC) technical reports outline the use of scale pattern analysis for identification of Fraser River sockeye salmon stocks. First, Henry (1961) documented the univariate scale pattern analysis procedure for the identification of Fraser River sockeye stocks. This method used the number of freshwater circuli to estimate stock composition of the sample. Historical timing differences among major stock groups and the presence of plus growth were used to refine estimates but were not formally incorporated in the method. However, this method was not adequate when there were more than four stocks in the sample and only performed well in very simple situations. From the late 1970s onwards, PSC staff investigated multivariate methods to distinguish Fraser River sockeye stocks. In 1987, Henry's univariate method was replaced by a multivariate discriminant analysis method. Gable and Cox-Rogers (1993) documented this multivariate discriminant analysis, which used first count, plus growth, and distance from 1^{st} circulus to the freshwater annulus to discriminate among stocks. Stocks expected to be present at more than 5% in a given statistical area during a given catch were included in the discriminant function analysis model and the expected presence was predicted based on in-season timing abundance curves, historical timing data, and forecasted run sizes. From 1987-2001, this multivariate scale pattern analysis was the primary in-season method of stock identification for Fraser River sockeye salmon. DNA-based stock composition estimation (Chapter B11) became the main method of stock identification in 2002 but scale-based estimates were still frequently used. From 2009 to 2017, scale-based stock compositions were infrequently incorporated into accounting files except when suitable DNA-based results were not available. For each stock, the discriminant function was based on scale standards obtained from spawning ground samples of the same cohort that returned a year earlier (i.e., age 3_2 samples were used for the age 4_2 model and age 4_2 samples were used for the age 5_2 model) and the samples from the previous year on the cycle (e.g., 2014 age 4_2 spawning ground samples for 2018 age 4_2 model). The resulting stock composition estimates from the discriminant analysis were further revised using a classification matrix correction procedure (Cook and Lord 1978) which employed misclassification rates of the spawning ground scales as determined during the development of discriminant function models. The current statistical approach for scale analysis (2018 onwards) generates stock assignment probabilities for individual scales (salmon) in the sample (see Table 1), and these probabilities are used to revise DNA-based stock composition estimates in a total weight of evidence approach (Chapter B11).

The current method is a combination of principal component analysis (PCA) and discriminant analysis (mainly linear discriminant analysis), where discriminant analysis is performed on principal component scores instead of scale variables directly. Principal component analysis allows information from all measured scale variables to be used in the discriminant analysis by creating synthetic variables (called principal components) that are linear combinations of the original variables. Discriminant analysis is a classification method that allows assignment of stock membership based on a set of independent variables extracted from non-independent trait measurements (the measured scale variables can be strongly correlated, so this procedure is necessary). As in the past, scale pattern analyses are conducted separately for age 4_2 and age 5_2 sockeye salmon. For the age 4_2 model, spawning ground scales from age 4_2 individuals from 4 years prior and spawning ground scales from age 3_2 individuals from the previous year are used as scale standards (i.e., training data). For the age 5_2 model, spawning ground scales from age 4_2 individuals from the previous year are used as scale standards. Principal component analysis is performed first on scale variables and the principal component scores for the top five principal components are retained. A discriminant analysis is performed on principal component scores to generate discriminant functions from the training data (without incorporating the stock-specific sample sizes of the training data). Figure 1 illustrates the discriminant function space of 2018 age 4_2 Summer-run Fraser River sockeye salmon spawning ground samples, which are training data for the 2022 age 4_2 scale model.

Once the discriminant function has been developed, it can be used to estimate stock assignment probabilities of in-season scale samples from various fisheries. Scale samples from in-season fisheries are read and a principal component analysis is performed first on the quantified scale variables. Principal component scores are retained and rotated similar to the training data. Next, discriminant analysis is performed to apply the previously developed discriminant functions to the in-season sample to generate stock assignment probabilities for individual scales in the sample (Table 1), and sample stock composition estimates (Table 2). Here, prior probabilities are obtained from the relative daily abundance forecast from the Fisheries Planning Model (Chapter A9). Stock composition estimates for age 4_2 and age 5_2 sockeye in the sample are estimated by assigning each scale to its highest probability stock (i.e., stock 1) and then applying the bias-correction procedure (Cook and Lord 1978, Table 2) to the results for each of these ages. A total estimate is obtained through a weighted sum of the stock composition across ages (including some ages for which no formal statistical model is run, e.g., Harrison age 3_1 and 4_1 scales).

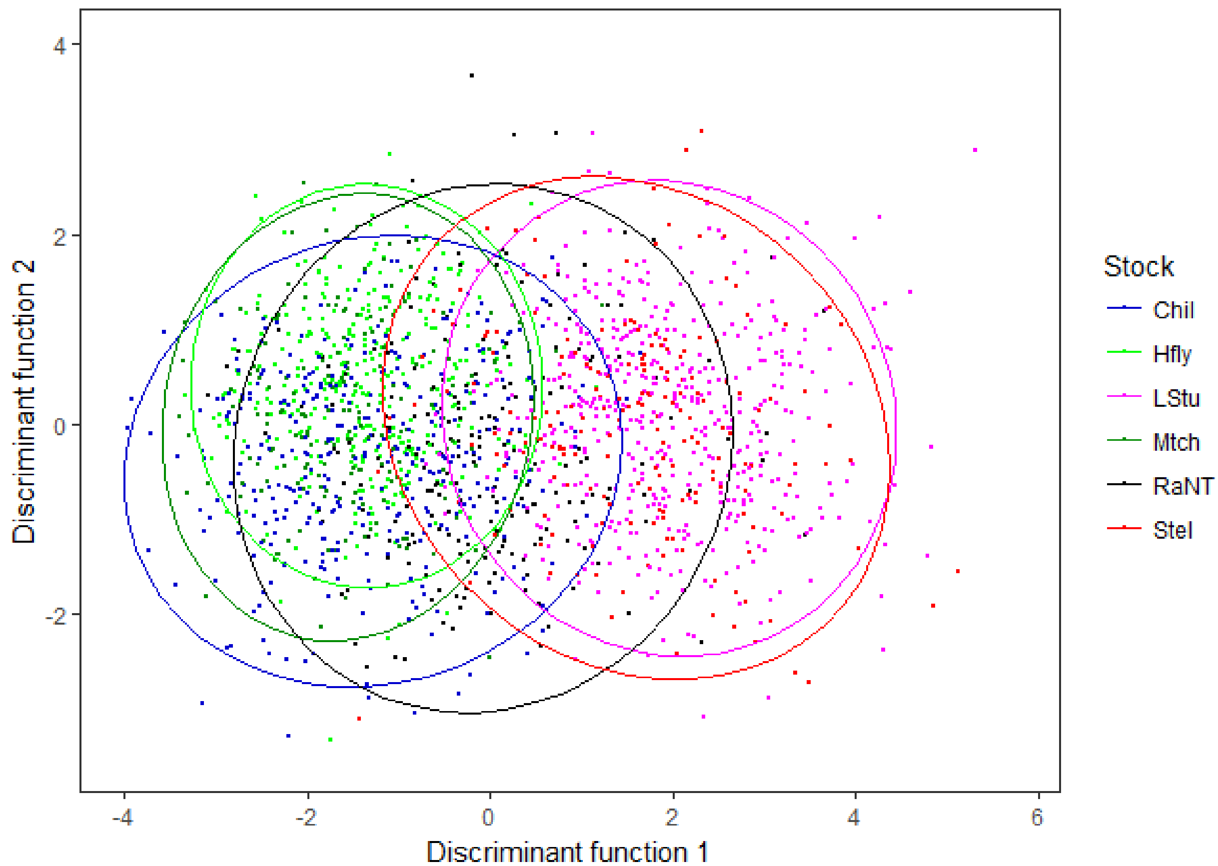

Figure 1. *Discriminant function space of 2018 age 4_2 Summer-run Fraser sockeye salmon from spawning ground scales.*

Table 1. *Example scale model output showing assignment probabilities for each scale in the sample.*

Fish Code	Stock 1	Probability 1	Stock 2	Probability 2	Stock 3	Probability 3	Stock 4	Probability 4	Stock 5	Probability 5
2018122717	Stel	0.59	Weaver	0.18	LStu	0.08	LShP	0.04	Hfly	0.04
2018122718	LShP	0.78	ESTh	0.13	Chil	0.08	Mtch	0	Hfly	0
2018122719	LShP	0.77	Chil	0.12	ESTh	0.11	Mtch	0	Nahatlatch	0
2018122747	Hfly	0.42	Mtch	0.17	RaNT	0.13	Birkenhead	0.13	LShP	0.06
2018122748	LShP	0.83	ESTh	0.15	Chil	0.02	Mtch	0	Hfly	0
2018122749	Stel	0.57	LStu	0.12	RaNT	0.11	Birkenhead	0.05	Weaver	0.05
2018122750	LShP	0.81	ESTh	0.13	Chil	0.04	Mtch	0.01	Hfly	0
2018122752	Weaver	0.48	Big.Silver	0.4	Stel	0.08	LStu	0.02	Nadina	0.01
2018122753	LShP	0.86	ESTh	0.07	Chil	0.06	Mtch	0	Hfly	0
2018122754	LShP	0.88	ESTh	0.11	Chil	0.01	Mtch	0	Hfly	0
2018122755	LShP	0.77	Chil	0.16	ESTh	0.07	Mtch	0	Hfly	0

Table 2. *Example scale model output showing stock composition estimates for the sample with and without bias correction*

Stock	Scale probability (uncorrected)	Scale probability (bias-corrected)
Big Silver	0	0.01
Birkenhead	0.01	0
Bowron	0	0
Chil	0.03	0
Chwk	0	0
Cultus	0	0
ESTh	0	0
EStu	0	0
Gates	0	0.04
Hfly	0.06	0.05
LShP	0.82	0.61
LStu	0	0.03
Mtch	0	0.05
NBar	0	0
Nadina	0	0
Nahatlatch	0	0
PiAC	0	0
RaNT	0	0.18
Stel	0.07	0
Tsko	0	0.01
Weaver	0.01	0
Widg	0	0.01

Planned changes and potential areas for improvement

1. Potentially non-Fraser stocks will be included in the scale model (e.g., Lake Washington, Baker Lake, Nimpkish, etc.).
2. For in-season purposes, spawning ground scale data from previous years will be supplemented with in-season scale data that have a high confidence stock-of-origin (through DNA analysis) for developing discriminant functions.
3. The improvement afforded by updating discriminant functions in the post-season with new spawning ground samples and new relative abundance priors will be evaluated.
4. The bias-correction method will be reviewed and improved or replaced.

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B11. DNA-based stock ID method

P. Samarasin and S. Latham

Summary

Fraser River sockeye fisheries are regulated at the level of stock aggregates (Early Stuart, Early Summer, Summer, and Late run) called management groups, making the identification of Fraser River sockeye salmon stocks a fundamental requirement for their assessment and management. Sockeye salmon is an excellent candidate for performing DNA-based stock identification because of strong natal fidelity, which has led to strong genetic differentiation over time. DNA-based stock identification has been regularly used by the Pacific Salmon Commission (PSC) staff since 2002 (Beacham et al. 2004). Prior to 2002, scale-based stock identification methods were the primary means of stock identification for sockeye. Genetic stock identification (GSI) involves extraction of DNA from tissue samples collected from fisheries and generation of a multi-locus genetic profile. Genetic profiles from fishery catches of unknown stock composition are subsequently compared against a genetic baseline of known stock origin using, in our case, the Bayesian framework as implemented by the Cbayes stock identification program. Cbayes generates stock assignment probabilities for individual fish in a sample and summarizes the sample's overall stock composition. In-season, GSI results are used to determine stock-specific catch estimates and stock-specific estimates of upstream migration (Chapter B20). As such, GSI results are essential for stock-specific reconstructions to assess the total run size and timing by management group (Chapter B21).

Introduction

In accordance with the Pacific Salmon Treaty (PST 2025, Chapter 4, section 3), Fraser River sockeye salmon are managed as four management groups, with each management group consisting of one or more stocks (Table 1). The membership of stocks among management groups is determined by their relative migration timing and not based on spawning ground location (Figure 1). For example, the Early Summer-run management group contains stocks such as Pitt River sockeye and Nadina River sockeye with spawning grounds that are approximately 1000 km apart, whereas other stocks that are spatially closer to these stocks belong to different management groups, e.g., the Stellako stock which is spatially proximal to Nadina is part of Summer-run management group. Consequently, stocks within a management group may experience very different migration difficulties and spawning conditions as adults and freshwater rearing conditions as juveniles. This may result in disparate survival and productivity estimates for individual stocks within a management group, requiring assessments at finer stock resolutions in addition to coarser assessment at the management group level. Therefore, high resolution stock identification is a key component of in-season Fraser River sockeye salmon assessments.

Until 2002, scale-based analysis of mixed-stock fisheries samples (Chapter B10) was the primary means of Fraser River sockeye stock identification. Even though the PSC's use of DNA to identify stocks is relatively new, underlying population genetic principles for conducting genetic stock identification (GSI) have been well established for decades. DNA-based GSI of other fish and wildlife, using the same principles, have been conducted since the early 1990s (e.g., van de Ven et al. 1990).

Sockeye salmon populations are excellent candidates for application of DNA-based GSI methods because of the high degree of natal fidelity and local adaptation exhibited by the species, leading to strong genetic differentiation among populations over time (Taylor 1991, Quinn 2005, Keefer and Caudill 2014). The level of genetic differentiation among stocks of interest is the most important determinant of the success of DNA-based stock identification methods. If genetic differentiation among stocks of interest is high, GSI methods can easily determine the origin of each fish in a mixed-stock fishery sample (Araujo et al. 2014). Levels of genetic differentiation between sockeye salmon stocks in the Fraser River and nearby areas have been studied and shown to be significant among most stocks of interest (Beacham et al. 2004, Beacham et al. 2010). Thus, GSI for estimating Fraser River sockeye salmon stocks in marine and in-river fisheries gained prominence over time as the scientific basis, accuracy, and utility of these methods were demonstrated.

Figure 1. *Spatial location of 27 Fraser River sockeye salmon stocks, which are aggregated into four management groups, i.e., Early Stuart, Early Summer, Summer, and Late run).*

Table 1. *Relationship of DNA baseline samples to Fraser River sockeye stock groups and management groups.*

DNA Baseline Sample	Stock (aggregated to 19 Fraser River stocks)	Management Group
Driftwood-Narrows Dust-Sinta Bivouac-Rossette Paula-Felix	Early Stuart	Early Stuart
Chilliwack_Kok Chilliw_lake DollyVarden_Cr	Chilliwack	Early Summer
Pitt_River Coquitlam_Kok Alouette_Kok	Pitt / Alouette / Coquitlam	
Bowron Nadina	Nadina / Bowron	
Gates_Creek Nahatlatch	Gates / Nahatlatch	
Taseko	Taseko	
Upper_Barriere	North Barriere	
Scotch Seymour Eagle Upper_Adams Cayenne	Early South Thompson	
Harrison	Harrison	Summer run
WidgeonSlough	Widgeon Slough	
Middle_River Pinchi_Creek Tachie Kuzkwa_Creek	Late Stuart	
Stellako	Stellako	
Chilko_south Chilko_north Chilko	Chilko	
Lower_Horsefly McKinley Mid_Horsefly Upper_Horsefly	Horsefly	
Mitchell Wasko-Roaring Blue_Lead_Ck	Mitchell and other non-Horsefly Quesnel	
Raft NorthThompson	Raft / North Thompson	
Birkenhead Big_Silver	Birkenhead / Big Silver	Late run
Eagle_late LittleRiver-LittleShu Lower_Adams Lower_Shuswap MiddleShuswap Portage_Creek	Late Shuswap / Portage	
Weaver Cultus_Lake	Weaver / Cultus	

Data

Sockeye salmon DNA is obtained from a small amount of tissue, in the case of Fraser River sockeye salmon usually collected from the adipose fin of the fish. The baseline or reference samples comprise tissues collected from salmon on the spawning grounds (stock of origin is known). Samples of unknown origin, which get compared to the baseline, are collected from various fisheries. Further details of the DNA sampling procedure can be found in Chapter B7. Collected tissue samples are sent to the Molecular Genetics Laboratory (MGL) at the Pacific Biological Station (Fisheries and Oceans Canada, Nanaimo, BC) where DNA is extracted, loci of interest are amplified through polymerase chain reaction (PCR), and genotypes are scored at 14 microsatellite loci (Beacham et al. 2004) and five single nucleotide polymorphism (SNP) loci (Beacham et al. 2010). The resulting multi-locus genotypes constitute the genetic profiles of individual sockeye salmon that are used for further GSI analyses.

Methods

At a conceptual level, GSI analyses are similar to scale-based stock composition analyses. Both methods compare some characteristics of sockeye of unknown origin against characteristics of salmon with known origin to estimate the stock composition of the unknown sample. In scale pattern analyses, scale characteristics are compared, whereas GSI compares allelic frequencies to infer stocks of origin. Genotypes of fish from spawning ground locations have been collected over years and serve as a reference to assign individuals of unknown origin to a stock by determining how similar their observed genetic profiles are to different baseline samples. The genetic baseline for Fraser River Panel sockeye analyses includes 50 Fraser River stocks, organized into 19 reported stock groups (Table 1), and 37 non-Fraser stocks. First, individuals in a mixed-stock fishery sample are assigned to their stocks of origin by calculating the probability of the individuals originating from different spawning ground locations (Table 2). Once all individuals are assigned to stocks of origin with corresponding probabilities, these assignment probabilities are summed to calculate the stock composition of the entire sample (Table 3). Up to 100 individuals are usually analyzed simultaneously to estimate the stock composition of a sample. Individuals missing scores at eight or more genetic loci are excluded from the analysis.

Table 2. *Example Cbayes output showing stock assignment probabilities for individual fish in the sample. Only the top two stocks are shown here but the actual output shows up to the top seven.*

Fish ID	Stock 1	Region 1	Probability 1	Stock 2	Region 2	Probability 2
Area20PS_PSC(17) seine 43501	Chilko_south	13	0.96	Chilko_north	13	0.02
Area20PS_PSC(17) seine 43502	Tachie____	11	0.93	Stellako__	12	0.07
Area20PS_PSC(17) seine 43503	Chilko_south	13	0.58	Chilko_north	13	0.42
Area20PS_PSC(17) seine 43504	Tachie____	11	0.70	Stellako__	12	0.30
Area20PS_PSC(17) seine 43505	Tachie____	11	0.90	Nadina____	4	0.08
Area20PS_PSC(17) seine 43506	Pitt_River	3	1.00			
Area20PS_PSC(17) seine 43507	Birkenhead_	17	0.99	Harrison__	9	0.01
Area20PS_PSC(17) seine 43508	Stellako__	12	0.97	Tachie____	11	0.04
Area20PS_PSC(17) seine 43509	Harrison__	9	0.96	Tachie____	11	0.03

Table 3. *Example Cbayes output of stock composition estimates for a sample.*

Stock code	Stock name	Stock composition	Standard deviation
1	Early Stuart	3.4	(2.1)
2	Chilliwack	0.0	(0.2)
3	Pitt / Alouette / Coquitlam	19.8	(3.9)
4	Nadina / Bowron	2.4	(1.8)
5	Gates / Nahatlatch	3.0	(1.7)
6	Taseko	0.0	(0.1)
7	North Barriere	0.0	(0.2)
8	Early South Thompson	3.0	(1.8)
9	Harrison	7.3	(2.6)
10	Widgeon Slough	0.0	(0.1)
11	Late Stuart	17.8	(4.6)
12	Stellako	7.7	(3.2)
13	Chilko	30.5	(4.6)
14	Horsefly	0.2	(0.6)
15	Mitchell and non-Horsefly Quesnel	0.0	(0.2)
16	Raft / North Thompson	0.0	(0.2)
17	Birkenhead / Big Silver	1.0	(1.0)
18	Late Shuswap / Portage	0.0	(0.4)
19	Weaver / Cultus	0.0	(0.1)

Assignment of individuals to their stocks of origin is implemented in the Cbayes software program (Neaves et al. 2005). This program analyzes stock mixtures by implementing a Bayesian model described in detail by Pella and Masuda (2001). Compared to maximum likelihood methods of estimating stock composition such as SPAM (Debevec et al. 2000), this Bayesian mixture model has more relaxed model assumptions and more flexibility to deal with incomplete genotypes when some genetic loci are not successfully amplified by PCR for some individuals. Pella and Masuda's (2001) Bayesian mixture model treats baseline genotypes as a sample, rather than a population parameter that is known precisely, relaxing the need to have very large baseline sample sizes for each population. Genotypes found in the mixture can also be used to update allele frequency estimates in the baseline sample. Furthermore, this method better addresses the problem of underestimating more abundant stocks and overestimating rare stocks (Pella and Masuda 2001). The Fraser River Panel transitioned from using SPAM estimates to using Cbayes estimates between 2008 and 2011, during which all previous years' sockeye DNA samples were re-analyzed with Cbayes.

When running Cbayes, the Gelman-Rubin diagnostic is used to assess convergence of ten independent Markov chain Monte Carlo (MCMC) chains. This diagnostic evaluation helps determine if the probability space is explored adequately by the search algorithm and if sufficient MCMC samples are utilised when summarizing results. The raw stock composition results from the Cbayes program are corrected for small stock bias by reassigning stock estimates below a threshold determined by the sample size. This removes very small stock estimates that are based on fractions of an individual and reassigns those proportions to the most frequent stock in the mixture. Next, for each individual, GSI results are aligned with the scale-based information and size data. If there is sufficient evidence from these additional pieces of information to indicate that the GSI result for an individual is inaccurate, the stock identification biologist adjusts the results based on expert integration of the combined evidence.

Evaluation

Research at the MGL characterized the population genetic structure of Fraser River sockeye salmon (Withler et al. 2000, Beacham et al. 2004) and established the scientific basis for using DNA-based stock identification (Beacham et al. 2004, Beacham et al. 2006, Beacham et al. 2010). Beacham et al. (2004) examined inter- and intra-population genetic variation for Fraser River sockeye populations, population genetic differentiation, power of individual loci used for analyses, and accuracy of stock composition estimates. With few exceptions, Fraser River sockeye salmon populations of interest exhibit strong genetic differentiation from each other, and this facilitates successful GSI. The performance of various GSI methods has been evaluated in the scientific literature (e.g., Araujo et al. 2014, Brenden et al. 2015). At levels of genetic differentiation typical among Fraser River sockeye stocks, Araujo et al. (2014) found no significant difference in performance between Cbayes and ONCOR (Kalinowski et al. 2007), a formerly popular alternative GSI software program.

Planned changes and potential areas for improvement

Additional work planned to be undertaken includes:

1. Incorporation of new GSI software for improved error metrics (Chapter B12).
2. Exploration of an alternative marker set (i.e., DFO SNP baseline, Chapter C9) to potentially improve identification of similar stocks, such as Late Stuart and Stellako.
3. Potential implementation of a new baseline for the Fraser River Panel's in-season GSI work, if high-quality DNA extraction can be accelerated to facilitate real-time analyses, similar to what is accomplished using lower quality extraction methods that accommodate the current microsatellite chemistry.

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B12. GSI sample size and precision

S. Latham and A.M. Phung

Summary

When the Fraser River Panel began using genetic stock identification (GSI) for sockeye management beginning in 2002 (Chapter B11), the legacy of management's use of scale pattern analysis (SPA, Chapter B10) exerted an influence on the objectives and requirements of the new method. In the years since, the sockeye stock identification program came to rely more upon GSI, sample numbers generally decreased, stock resolution and precision of results increased, and applicability of results expanded (objectives broadened). The budget remained relatively consistent, generally varying with abundance depending upon samples available from test fisheries and from user-group fisheries. How best to allocate resources among multiple competing objectives has not been formally determined. Here we use examples to describe the degree to which several objectives can be met, based on sample sizes and related precision of estimates in contrasting years, 2024 and 2025. Further work on GSI sample requirements for management and on the proper propagation of uncertainty in GSI estimates is needed as the nature of Fraser sockeye fisheries and management continues to change.

Introduction

The Fraser River Panel (FRP) uses genetic stock identification (GSI) to estimate the proportions of stocks within mixtures. Due to the differentiation among Fraser sockeye populations and efficacy of this technique (Chapter B11), the precision of these estimates in a single mixture can be largely determined by the relative frequency of the stocks of interest and the total sample size of the mixture, as follows. A sample will comprise stocks with different estimates of proportions and associated uncertainties. These uncertainties can be represented by absolute (e.g. standard deviation) or relative measures of precision (e.g. coefficient of variation, *CV*), and are well characterized theoretically for perfectly identified stocks. For example, Allen-Moran et al. (2013) explored the effect of sample size on precision using a simple binomial model and estimated required sample size for a target CV using this equation:

$$n_T = \frac{1 - p_J}{p_J \cdot CV_J^{\,2}}$$

where n_T is the total sample size, p_J is the proportion of stock J in the mixture, $1 - p_J$ is the proportion of all other stocks, and CV_J is the target coefficient of variation for the estimated proportion of stock J.

The required total sample size for a given CV_J grows rapidly as p_J decreases but, because this equation simplifies when p_J approaches zero and rearranges to $CV_J^2 = 1 / (n_T \cdot p_J)$, the required sample size for a given stock J becomes nearly constant over a broad range of proportions (e.g., p_J from 0.1 to 0.001, Table 1).

Note here that the above applies to the estimation of a perfectly identified stock in a single mixture, such as a representative sample from a spatially and temporally homogeneous fishery. Satisfying goals for precision even in this simple circumstance may be difficult because various stocks or stock groups of interest will differ in their relative proportions, and these proportions will vary in space and time among similar fishery sampling contexts. This has motivated some agencies to adopt a general standard for GSI precision, and to discount estimates or aggregate stocks that are too infrequent to have a reasonable chance of meeting that standard, e.g., Alaska Department of Fish and Game (Chapter C9).

Table 1. *Total sample size, n_T, required (and number of individuals of stock J that would be identified, $n_J = n_T \cdot p_J$) to achieve a given CV when stock J is at each of three proportions: 0.1, 0.01, and 0.001, assuming a binomial model with no misclassification.*

CV	p_J	n_T required	n_J required ($n_T x p_J$)
0.25	0.1	144	14
	0.01	1,584	16
	0.001	15,984	16
0.2	0.1	225	23
	0.01	2,475	25
	0.001	24,975	25
0.15	0.1	400	40
	0.01	4,400	44
	0.001	44,400	44
0.1	0.1	900	90
	0.01	9,900	99
	0.001	99,900	100

Importantly, the management framework employed by the FRP does not rely upon stock composition estimates of only single mixtures. Decisions made by the FRP depend upon aggregate GSI results integrated across heterogeneous strata and across multiple platforms. For example, a proposed fishery opening will be considered by the FRP, on a given date, in terms of various inputs available to the FRP at that time, by stock or stock group: cumulative escapement estimate, cumulative catch estimate (total, by country, and by user group), migration timing estimate, and projected catch estimate (Chapter B34). Morishima (2007) notes that surprisingly little attention has been paid to the precision and confidence in estimates of catch across heterogeneous sampling strata, never mind the other specialized factors mentioned here (e.g., escapement and timing) that also incorporate GSI estimates from various heterogeneous spatial and temporal strata. Furthermore, the FRP reviews these inputs simultaneously for multiple stocks of interest and, challengingly, for multiple levels of stock resolution. A comprehensive exploration of how the FRP's GSI sampling program satisfies its multiple in-season and post-season objectives across different stocks and stock aggregates is beyond the scope of this chapter. Here, we instead describe recent progress in assessing the precision of the resulting estimates, and we provide examples from 2024 and 2025 that demonstrate the impact of sample size on the precision of stock-specific Mission passage estimates (Chapter B14), which are a critical component of the FRP sockeye management framework. Some historical background is provided in Appendix A regarding the sampling effort underlying the FRP's sockeye GSI program.

Methods and Data

The Database on Individual Nerka and Gorbuscha Salmon (DINGS), houses GSI data for individual sockeye salmon examined in the FRP process since 2003 (Chapter C17). These data are associated with matching age, sex, size, and other information, depending upon the measurements taken and data were recorded at the time of capture (Chapter B7). Using a 50% probability threshold for stock of origin in analyses with the GSI software program Cbayes (Neaves et al. 2005, Chapter B11), over 270,000 of these have been identified to one of 27 Fraser stocks of origin, over 10,000 have been assigned to non-Fraser stocks, and over 11,000 have not met the 50% threshold to be assigned. The number of successful individual assignments (Table 2) provides information on stock-specific sample sizes available for research on stock-specific age, body size, date of capture, and other parameters valuable to FRP management. Individual stock-specific assignments are presented here, however, as a key metric with respect to the precision of mixture composition estimates and subsequently derived estimates. Stock-specific sample sizes are well correlated with the quality of derived estimates, as will be shown below for estimates of migration past Mission by stock and for catch estimates by stock in the lower Fraser River fisheries that provide GSI samples for estimating Mission passage-by-stock. Stock-specific Mission passage (Chapter B20) is estimated using GSI results from multiple locations (the Whonnock test fishery, the Brownsville Bar test fishery, and other samples), which adds complexity to uncertainty calculations that has not yet been resolved. Results below may differ slightly from current official estimates but are presented for illustrative purposes, providing context for evaluations of estimates various FRP fisheries and processes.

Table 2. *Numbers of sockeye individuals assigned to one of 27 Fraser stocks with a posterior probability > 50%, as estimated by GSI using Cbayes (Neaves et al. 2005), from 2003-2025. Stocks captured in lower Fraser River fisheries (downstream of Mission) are shown; stocks not migrating past mission are shaded grey. Sample sizes from other fishery regions are shown in Appendix B.*

Stock	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Early Stuart	39	129	293	23	57	199	285	204	56	100	431	233	35	45	36	172	12	37	229	392	132	2	890
Chilliwack	23	123	7	8	27	321	50	25	19	196	119	30	49	152	16	6	2	45	20	16	130	77	7
Upper Pitt	15	116	30	48	22	19	37	8	31	36	93	38	102	83	45	18	4	3	67	30	110	35	10
Alouette+Coquitlam	2	0	0	0	7	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	2	0	2
Nadina	5	153	40	35	3	305	65	38	61	19	35	109	190	76	1	365	25	28	47	662	646	325	79
Bowron	44	20	5	16	13	38	13	7	39	25	10	30	24	14	2	22	0	7	11	15	18	3	23
Gates	29	122	26	16	23	205	94	23	186	117	141	42	68	110	36	17	23	18	158	21	141	67	90
Nahatlatch	7	21	1	3	6	5	10	2	26	13	17	11	18	13	1	3	3	1	11	20	45	18	13
Taseko	2	7	1	3	2	8	3	5	7	0	1	0	26	4	2	2	3	2	7	6	14	6	18
North Barriere	36	37	21	42	39	26	8	12	58	22	22	30	15	11	4	6	0	2	3	13	16	15	12
Adams Lake	2	139	2	2	2	32	4	0	1	13	3	2	1	0	0	3	1	0	1	4	2	1	3
Early Shuswap	64	30	21	738	66	24	122	1,345	280	9	129	1,095	96	15	19	1,011	16	2	70	408	150	7	102
Harrison	65	41	161	95	379	84	577	511	1,624	225	527	621	239	180	85	20	45	66	43	36	87	223	59
Widgeon	0	0	0	0	0	0	1	1	1	1	0	1	0	1	0	0	0	0	0	0	0	1	1
Late Stuart	67	513	364	98	58	562	387	79	144	242	242	176	78	101	272	243	36	45	808	276	177	162	927
Stellako	121	408	52	153	60	263	51	49	152	228	42	688	176	93	31	112	36	25	43	135	234	385	55
Chilko	835	379	412	601	825	1,109	806	1,251	2,030	542	1,509	1,441	1,345	704	669	913	365	79	1,545	1,247	1,399	532	1,753
Horsefly	285	114	719	176	183	48	333	54	100	11	104	793	46	10	113	990	47	0	54	1,186	206	16	82
Mitchell	173	72	564	73	98	47	313	61	106	10	153	522	34	11	100	499	27	2	99	558	85	8	155
Raft	18	101	51	28	11	40	15	6	28	45	21	28	32	53	23	8	1	4	11	11	32	70	20
North Thompson	34	29	89	20	61	55	118	14	168	67	125	42	130	110	61	21	1	3	43	43	27	14	69
Birkenhead	265	89	42	139	199	112	188	55	402	208	108	45	99	145	53	38	6	13	149	153	354	107	258
Big Silver	3	19	1	14	12	11	18	0	27	30	8	7	16	10	15	0	2	1	3	3	2	0	0
Late Shuswap	432	10	19	2,032	332	18	164	2,342	471	6	417	2,513	100	7	68	2,262	19	0	54	1,428	60	7	159
Portage	59	1	14	15	17	6	11	15	15	1	24	6	4	1	7	36	0	0	2	30	4	1	4
Weaver	223	110	71	66	299	292	302	74	522	182	166	26	14	2	152	42	4	0	261	398	126	7	199
Cultus	6	0	2	7	2	17	7	9	12	5	7	3	3	16	3	0	1	3	1	1	1	1	1
Total	2,854	2,783	3,008	4,451	2,803	3,846	3,982	6,190	6,566	2,353	4,454	8,532	2,940	1,967	1,814	6,812	679	386	3,740	7,092	4,200	2,090	4,991

Cbayes currently reports a standard deviation for each proportional estimate that it generates, but other functionality with respect to error estimation and propagation is limited. The estimated uncertainty is appropriate for use cases in which a sample n_T is collected for GSI from a very large population and treated as a random sample drawn with replacement. This model of uncertainty reflects the variation expected among alternate n_T samples collected from the same population, and this approach is common in GSI software. This model does not reflect the FRP's catch-accounting use case, however, especially when sample size is large relative to the landed catch. In nearly all fisheries managed by the FRP, GSI samples are obtained from the landed catch (Chapter B7). The resampling model is appropriate to estimate uncertainty in stock proportions of unsampled individuals in the overall catch, but there should be no sampling error associated with the portion of the catch within the GSI sample. That is, stock composition uncertainty for the sampled portion of the catch n_T is only associated with GSI model error, and sampling error (involved in extrapolating the stock composition in the sample) applies to the unsampled portion of the catch. In many FRP test fisheries (Chapter B1), a high proportion of the catch is sampled, especially when catches are low. When the GSI sample comprises a high proportion of the catch, the uncertainty for the whole catch is much lower than could be calculated from Cbayes output. We contracted the improvement of rubias (Moran and Anderson 2019), a popular GSI software program to address this issue. The improved software (Anderson 2025) can accommodate the following use cases:

- sampling from populations without replacement, as in the FRP catch-accounting use case,
- sampling from populations with replacement, as in catch and release without mortality,
- sampling from populations with partial replacement, as in catch and release with an intermediate mortality rate.

The FRP uses the same samples obtained from landed catch in the lower Fraser River to estimate both the stock-specific catch in lower Fraser River fisheries and the stock-specific passage at Mission (Chapter B20), but the uncertainty must be modeled differently. Whereas a given sample n_T is part of the catch and is known to be increasingly representative as the relative size of catch decreases, that sample is not a part of the Mission passage, so the stock composition of the Mission passage is fully extrapolated. GSI uncertainty of Mission passage is implemented in rubias by modeling as though the sample is representative but suffers 100% mortality on release. The assumption that the catch, and therefore the sample, is representative of the escapement past Mission is critical and any violation of this assumption is not accounted for in uncertainty metrics.

The other improvement achieved in rubias is the ability to propagate uncertainty across analyses. For example, the estimate of total sockeye passage at Mission has its own inherent uncertainty regardless of any GSI analysis to disaggregate the estimate into passage by component stocks. The probability distribution of the aggregate estimate can be combined with the calculation of uncertainty from the GSI analysis (sampling error and GSI model error) to obtain a realistic estimate of the overall uncertainty of stock-specific Mission passage. This has not been done yet, but it will soon be possible to integrate the hydroacoustic and species composition uncertainty with the GSI uncertainty using this new functionality within rubias. (The same approach can be applied to estimates of catch, if those are uncertain.)

Evaluation

Evaluation of the adequacy of sampling requires consideration of the project goals with respect to signal detection and the noise in the system. A given level of sampling will achieve a desired precision more frequently when noise is limited. With respect to stock identification, the FRP's sockeye GSI program provides more signal than scale pattern analysis (SPA) on a per-fish basis, and therefore GSI requires fewer samples to overcome inherent noise and achieve the same goals. As Fraser sockeye run sizes have evolved, however, so has the fishery, its management, and the availability of samples. Specific objectives for precision have not been articulated by the FRP (as risk tolerance has not been articulated regarding failure to satisfy various management goals) but estimates for different stocks can be compared to provide context for an evaluation of adequacy. Run size is a critical parameter of the management system, and passage at Mission is a key component of both in-season and post-season run size estimates. Here we estimated the Mission passage of Fraser sockeye in the small 2024 return year and the large 2025 return year. This analysis was conducted at two levels of stock resolution in each year: highly granular RSA stocks and run-size groups (stocks aggregated by migration timing for in-season run-size modelling). In addition, we estimated the catch of Fraser sockeye in sampled fisheries in the lower Fraser River in the same two years, to demonstrate the effect on uncertainty of sampling from a finite catch. Whonnock and Brownsville Bar test fisheries were sampled extensively in both years, and a short Area E commercial fishery centered on August 19 was sampled in 2025. Table 3 summarizes the results.

Table 3. *Annual stock-specific Mission passage and stock-specific combined catch from lower Fraser River test and commercial fisheries in 2024 and 2025. Estimates are provided at two levels of stock resolution: at the level of run-size groups (stocks aggregated for in-season modeling based on timing), and at the level of RSA groups (more granular estimates important for post-season assessments). Only stocks or groups that migrate upstream of Mission are included.*

		2024					2025				
		n	Catch		Passage		n	Catch		Passage	
	Stocks		**Mean**	**CV**	**Mean**	**CV**		**Mean**	**CV**	**Mean**	**CV**
Run-size Groups	EStu	2	5	0.51	2,174	0.52	890	2,363	0.21	739,066	0.02
	Chwk	77	90	0.07	24,855	0.12	7	27	1.11	9,053	0.47
	NdBo/GaNh/Tsko	419	513	0.02	142,327	0.04	223	1,105	0.28	232,608	0.10
	NBar/ESTh	23	28	0.15	7,433	0.23	117	816	0.35	165,574	0.12
	Harr	223	243	0.02	73,096	0.07	59	185	0.28	110,014	0.18
	LStu/Stel	547	662	0.02	161,486	0.04	982	10,357	0.10	1,746,058	0.04
	Chil	532	542	0.01	147,805	0.04	1,753	25,725	0.05	3,465,208	0.02
	Hfly/Mtch	24	42	0.13	11,730	0.19	237	4,784	0.18	497,245	0.08
	RaNT	84	96	0.07	23,826	0.14	89	455	0.48	218,217	0.15
	BiBS	107	112	0.03	26,464	0.12	258	2,085	0.25	441,056	0.08
	LShP/WeCu	16	36	0.15	10,711	0.23	363	1,318	0.33	497,428	0.06
Average CV				**0.11**		**0.16**			**0.33**		**0.12**
RSA stocks	Early Stuart	2	5	0.51	2,127	0.54	890	2,356	0.21	739,725	0.02
	Chilliwack	77	90	0.07	24,893	0.12	7	27	1.15	8,960	0.47
	Nadina	325	399	0.03	112,776	0.05	79	158	0.23	48,455	0.15
	Bowron	3	5	0.46	1,260	0.59	23	314	0.71	30,149	0.33
	Nahatlatch	18	22	0.15	5,567	0.26	13	65	0.39	22,299	0.40
	Gates	67	79	0.06	21,094	0.13	90	499	0.38	107,316	0.15
	Taseko	6	8	0.19	1,922	0.37	18	73	1.16	25,035	0.37
	North Barriere	15	17	0.22	4,282	0.32	12	59	0.47	25,343	0.36
	Adams Lake	1	1	0.55	635	0.77	3	44	2.46	5,397	0.66
	Early Shuswap	7	9	0.21	2,588	0.38	102	716	0.38	135,227	0.13
	Harrison	223	242	0.02	72,520	0.07	59	178	0.22	109,175	0.18
	Late Stuart	162	320	0.05	81,672	0.08	927	8,294	0.13	1,632,939	0.04
	Stellako	385	342	0.05	79,848	0.07	55	2,090	0.38	111,895	0.26
	Chilko	532	543	0.01	147,885	0.04	1,753	25,734	0.05	3,467,684	0.02
	Horsefly	16	27	0.19	7,132	0.27	82	1,681	0.33	160,501	0.15
	Mitchell	8	15	0.18	4,682	0.31	155	3,084	0.23	336,096	0.10
	Raft	70	75	0.09	16,317	0.16	20	228	1.01	54,728	0.32
	North Thompson	14	23	0.17	7,456	0.34	69	257	0.23	161,046	0.19
	Birkenhead	107	112	0.03	26,307	0.12	258	2,069	0.24	438,372	0.08
	Big Silver	0	0	2.88	214	1.52	0	4	5.22	1,332	1.41
	Late Shuswap	7	20	0.24	5,665	0.29	159	786	0.46	210,228	0.12
	Portage	1	4	0.61	1,087	0.69	4	40	0.72	37,852	0.42
	Weaver	7	10	0.25	3,631	0.47	199	461	0.48	250,227	0.06
	Cultus	1	1	0.32	348	0.93	1	5	4.64	1,545	1.23
Average CV				**0.31**		**0.37**			**0.91**		**0.32**

Overall, as expected, infrequent and poorly sampled stocks or stock groups tended to be estimated less precisely (with a higher CV) in both Mission passage and catch estimates. Standards regarding acceptable CV may be context-specific, even for GSI in a given system. For example, the Yukon River Joint Technical Committee proposed target CVs of 0.10 and 0.20 for different chum fisheries within the Yukon River (JTC 1997). If choosing a standard of 0.20 for Fraser sockeye here, aggregation of RSA stocks into run-size groups would reduce the number of poor estimates but not generally improve the number of good estimates. In 2024, eight of eleven run-size groups met a 0.20 standard for Mission passage (ten met it for catch), and nine of 24 RSA stocks met the standard for Mission passage (14 met it for catch). In 2025, ten run-size groups met the standard for Mission passage (three met it for catch), and thirteen RSA stocks met the standard for Mission passage (two met it for catch).

It should be noted that results shown for run-size groups used in-season are applicable to the Mission-based final run-size estimates, and the precision shown here is relevant to management goals and decisions at that time. Precision goals for in-season management should be considered at multiple dates, however, as bilateral management decisions rely on estimates available on meeting dates in-season (Michielsens and Cave 2019). When these decisions are made, the sample sizes for later-returning management groups may be much smaller than those available at the season's end. For example, the decision to open the Area E fishery in 2025 was approved on August 15, when the lower Fraser sample sizes of Early Stuart, Early Summer, Summer, and Late-run sockeye were 890, 321, 1,527, and 100, or 100%, 89%, 48%, and 16% of the end-of-season sample sizes, respectively.

Focusing on end-of-season estimates, catches were estimated more precisely than Mission passage in 2024. In that year, there was no commercial fishery in the lower Fraser River and test fishing catches were low, such that the GSI sample was a very high proportion of the catch, reducing the CV of the catch estimate. In contrast, catch far exceeded sample size in 2025, and the uncertainty associated with catch exceeded the Mission passage uncertainty. To facilitate further investigation of differences between years, we plotted the log-transformed CV of the estimate of each stock, J, versus the log-transform of its sample size, n_J (Figure 1). For a given sample size, the catch in 2024 was estimated most precisely, the catch in 2025 was estimated least precisely, and the precision of Mission passage estimates was relatively similar in 2024 and 2025. Theoretical values ("Model") from Table 1 were plotted for comparison, and these were also similar to the Mission passage estimates from 2024 and 2025.

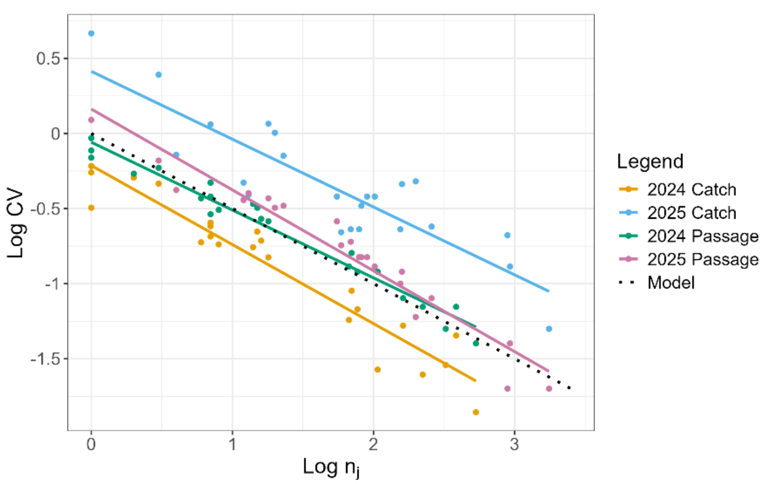

Figure 1. *Log CV of catch and Mission passage versus Log n_J (estimated here by individuals identified to stock J with a probability > 50%) for 27 Fraser sockeye stock groups in 2024 and 2025. Sample sizes were the same within years, i.e., the same samples were used for catches and for Mission passage estimates and distributed identically across strata. "Model" refers to theoretical estimates from Table 1.*

The overlap between the precision of stock-specific Mission passage estimates and the model was unexpected, given that the model assumed representative sampling from a single mixture and no misclassification. The rate of misclassification among Fraser sockeye stocks tends to be low (Chapter B11), but the temporal strata involved in estimating Mission passage were not sampled proportional to Mission abundance and therefore deviated significantly from the representativeness assumed by the model. The system is likely robust to this violation due to slow change in stock compositions relative to sampling frequency over the course of the season (numerous strata were similar enough to ameliorate the effect). This was not the case for catch in 2025, which was estimated with far less precision than the model. Two-thirds of the sampled catch in 2025 occurred during a brief Area E commercial opening from which only 181 GSI samples were obtained. When the catch of the Whonnock and Brownsville test fisheries was evaluated (the Area E fishery was excluded), precision of the 2025 catch estimate became similar to the model (not shown).

These results highlight the challenge of evaluating the adequacy of a given sampling regime and the precision it confers with respect to multiple FRP objectives. Years of low returns and poor catches may yield precise catch estimates by stock (despite low sample sizes), because high proportions of the catch may be sampled, as in 2024. Years of stronger returns may yield imprecise catch estimates, especially if large catches are sporadic in time and space, as exemplified by the 2025 data. Nevertheless, stock-specific sample sizes appear to relate well to the theoretically expected precision of estimates Mission passage and, until a comprehensive management strategy evaluation can be conducted, some guidance on the adequacy of GSI sampling can be taken from the summary provided here.

Planned changes and potential areas for improvement

Additional work will be needed for proper parameterization of simulations and retrospective analyses regarding the optimization of GSI effort in the future:

4. Improvements should be made to the estimated uncertainty in stock-specific migration past Mission by including and propagating uncertainty in the estimate of total sockeye passage at Mission, for example.
5. Uncertainty metrics should be calculated for more fisheries and escapements across years.
6. Estimates of GSI uncertainty assume representative sampling, but this assumption has rarely been assessed. Observed fluctuations in GSI estimates should be analyzed as part of a broader evaluation of the degree to which these assumptions underestimate the true sampling error.
7. The challenge of heterogeneity among catch strata in stock composition and abundance may be mitigated by managing to spread catch among strata (e.g., transferrable quota versus derby fisheries), by improving predictability regarding which strata are likely to be most important for estimation so additional sampling effort can be directed there, and by over-sampling – sample collection is less expensive than sample analysis, and funds can be allocated after the end of the management season, when it is easier to determine which strata require more samples.
8. A multi year management strategy evaluation, including GSI sampling effort, is planned and approved for initial funding by the PSC's Southern Fund.

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Appendix A: Historical background

Scale pattern analysis (SPA) was the primary source of stock composition information for the FRP until 2002 (Chapter B10). In that year, genetic stock identification (GSI) was introduced to complement SPA for in-season management (Chapter B11). Sampling protocols at the time followed long-standing practices: fishery samples consisted of collections of 115 scales (one scale per sockeye) (Chapter B7), with scale sample booklets specifically designed to hold this number. In practice, this yielded approximately 100 readable scales per daily collection from test fisheries, and multiple collections of similar size for large commercial fisheries. Historically, these sample sizes were sufficient to estimate the relative proportions of non-Fraser sockeye and the four management groups of Fraser sockeye as their abundances shifted throughout the management season. DNA sample sizes for GSI were 100 sockeye for GSI in each collection (Chapter B7), and between 92 and 96 usable genotypes were typically obtained per collection. Due to cost and logistical constraints, however, GSI results were generated only every 2 to 4 days. As a result, overall GSI sample sizes were substantially smaller than those for SPA. For example, in 2002, in-river test fisheries produced 3,465 samples across 39 GSI collections, compared to 10,151 samples from daily SPA collections. Despite this disparity in sampling frequency and total sample size, GSI became the primary focus of the FRP sockeye stock identification program.

GSI can provide confident stock-of-origin estimates for individuals (Chapter B11), the smallest sample size, and this capacity has been particularly valuable for detecting the presence of stocks at low frequencies, for example when detecting early upstream migration of Late-run sockeye. The relative value of GSI has been less apparent when stocks of interest are at intermediate proportions. From a management perspective, a major challenge associated with GSI was high inter-sample (day-to-day) variability, much of which was attributed to limited sample sizes. This issue prompted investigations between 2005 and 2007, including a special Technical Committee meeting dedicated to the topic in March 2006. Key aspects of the GSI sampling plan were evaluated, including the temporal allocation of sampling effort across the season, the merits of proportional versus even sampling in test fisheries, and the possibility of increasing sample sizes by analyzing fewer genetic markers per fish. Ultimately, no strategic changes to the sampling plan were implemented, for the following three main reasons. First, in many subsequent years, poor sockeye returns constrained achievable sample sizes in test fisheries. Second, commercial fisheries shifted toward smaller harvests, sometimes distributed over more days (e.g., under individual transferable quota fisheries), which reduced sensitivity to day-to-day variability. Third, the management system itself became more sophisticated and robust to high variability among GSI strata (Michielsens and Cave 2019).

Although sample sizes for many stocks have been too low to support granular stock resolution in some fishery management applications (e.g., in-season run-size estimation), GSI has played an important role in the ability of management to respond to increased attention to small stocks in Canada's Wild Salmon Policy (DFO 2005) and heightened conservation concerns (Grant et al. 2020). In addition, the accumulation of samples over time of even the rarest stocks has proved valuable for other FRP management decisions. For example, information derived from GSI on the characteristic migration timing and behaviour of small stocks (Wong et al. 2026) informs the implementation of fishing windows and helps determine vulnerabilities to flow and temperature challenges in the Fraser River (DFO 2025). Further, GSI sample sizes were sufficient to allow the FRP to make decisions regarding the stock membership of Management Groups. In 2012-2013, Raft and North Thompson were reassigned to the Summer run from the Early Summer run (the closely related North Barriere stock was not), and Harrison and Widgeon stocks were reassigned to the Summer run from the Late run (PSC 2019). At the time of these decisions, cumulative GSI sample sizes in marine approach areas for North Barriere and Widgeon were 485 and 16, respectively (Appendix B). These data clearly distinguished the migration timing of

North Barriere from that of Raft and North Thompson and distinguished the timing of Widgeon from Late-run stocks (Figure A1).

The background outlined above provides context for understanding current sample sizes and illustrates how various FRP priorities may differ with respect to sample size requirements. For well identified but poorly studied stocks like Widgeon, even an average sample size near one per year can yield useful information cumulatively.

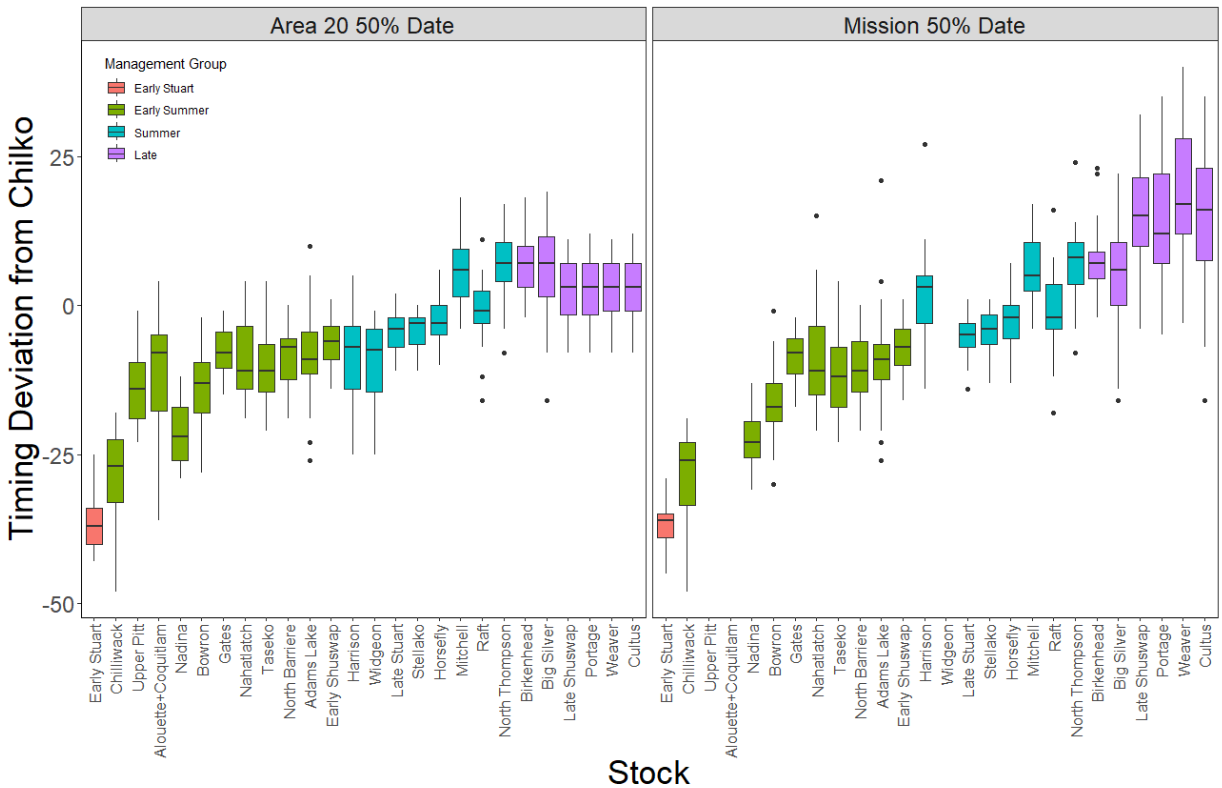

Figure A1. *Estimates of relative median migration timing for RSA groups by Area 20 date (left-side panel) and by Mission date (right-side panel) from 2003 to 2025. Box plots are coloured by Management Group: pink – Early Stuart, green – Early Summer, aqua – Summer, violet – Late run. The estimated median date for the Chilko River is subtracted from the median date of each RSA group in each year (negative values denote earlier timing). The Chilko River stock is excluded from the figure because the difference is zero in each year. Stocks that do not migrate upstream past Mission are excluded from the right-side panel.*

Appendix B: Marine sample sizes

There is a clear connection between stock-specific sample size and the precision of a stock's estimate in catch or Mission passage. The annual GSI sample sizes in northern and southern approach routes to the Fraser River, which relate to marine abundance estimates, diversion rate estimates, and other factors considered during the FRP management process, are shown below. (Sample sizes in the Fraser River upstream of Mission, off the Fraser River mouth, and in outside marine areas are not presented.)

Table B1. *Sample size of sockeye individuals caught in the southern marine approach to the Fraser River. Individuals assigned to one of 27 Fraser stocks with a posterior probability > 50%, as estimated by GSI using Cbayes (Neaves et al. 2005) are shown, from 2003-2025.*

Stock	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Early Stuart	32	81	229	153	24	48	367	332	37	135	379	185	24	20	112	161	23	13	172	118	58	3	554
Chilliwack	10	58	16	11	12	145	53	26	47	292	102	6	17	68	40	6	8	84	8	11	51	5	6
Upper Pitt	78	125	104	98	142	56	146	19	122	274	365	52	116	230	290	36	19	73	109	93	220	50	23
Alouette+Coquitlam	0	0	0	0	1	1	0	1	1	0	0	0	1	0	0	1	0	1	0	0	3	0	0
Nadina	4	75	49	63	6	230	92	81	112	57	39	68	77	68	23	331	129	118	37	411	642	131	52
Bowron	38	29	10	24	16	40	14	8	20	50	8	12	13	10	3	12	7	15	14	10	12	6	16
Gates	28	52	35	17	31	205	69	24	89	218	101	7	26	59	26	14	13	48	108	9	69	28	48
Nahatlatch	3	1	0	1	8	4	3	0	11	19	8	0	9	1	6	1	1	6	12	7	10	1	6
Taseko	5	7	1	11	3	4	7	12	4	8	3	1	9	7	0	4	0	5	7	3	4	7	14
North Barriere	14	23	18	39	80	35	19	12	33	26	16	13	8	9	7	5	5	7	3	8	13	4	6
Adams Lake	1	97	2	1	5	52	3	1	1	12	5	2	1	0	2	3	2	2	2	0	0	1	1
Early Shuswap	49	13	13	1,189	98	29	57	1,101	171	21	121	252	60	4	26	732	19	14	58	288	74	2	77
Harrison	28	18	169	100	642	75	514	531	1,252	294	344	510	229	331	225	34	121	419	101	23	95	139	34
Widgeon	0	0	0	1	0	0	5	0	2	2	2	0	1	2	1	0	2	0	0	0	2	1	0
Late Stuart	51	311	298	143	105	486	276	85	75	494	147	59	16	57	323	118	35	161	662	186	89	92	751
Stellako	75	218	44	207	138	561	45	68	90	623	66	181	106	91	119	78	82	126	95	63	154	228	68
Chilko	659	165	375	819	1,288	1,386	569	940	1,001	1,309	856	257	686	387	493	590	150	231	1,110	991	510	169	1,197
Horsefly	177	31	619	185	269	95	203	44	54	24	67	165	20	2	89	809	30	4	52	863	88	10	64
Mitchell	59	14	750	61	112	51	225	17	25	8	77	50	14	2	57	224	9	3	59	416	20	0	102
Raft	14	22	23	21	45	61	41	4	18	71	28	3	30	18	5	3	5	15	1	11	12	32	16
North Thompson	7	8	66	5	61	43	88	2	32	64	63	5	34	29	17	9	2	25	17	5	7	16	45
Birkenhead	117	24	23	81	273	171	178	34	233	279	78	11	89	87	33	12	4	45	92	147	150	31	189
Big Silver	4	10	2	5	5	15	12	4	9	29	8	3	7	16	4	0	1	1	3	5	0	0	0
Late Shuswap	159	6	66	2,231	317	35	311	1,835	236	15	287	933	62	4	72	1,242	7	3	54	733	42	3	68
Portage	18	0	11	5	16	4	19	7	16	1	19	2	2	0	2	7	0	2	3	20	0	0	16
Weaver	51	26	75	35	244	289	177	32	462	160	130	8	9	14	82	8	2	5	280	212	149	3	158
Cultus	0	0	0	7	3	19	3	2	15	17	7	5	6	24	4	0	0	2	0	4	0	0	1
Non-Fraser	92	86	118	278	151	34	185	352	73	122	341	157	494	191	235	73	43	43	109	83	191	50	112
Total	1,773	1,500	3,116	5,791	4,095	4,174	3,681	5,574	4,241	4,624	3,667	2,947	2,166	1,731	2,296	4,513	719	1,471	3,168	4,720	2,665	1,012	3,624

Table B2. *Sample size of sockeye individuals caught in the northern marine approach to the Fraser River. Individuals assigned to one of 27 Fraser stocks with a posterior probability > 50%, as estimated by GSI using Cbayes (Neaves et al. 2005) are shown, from 2003-2025.*

Stock	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Early Stuart	2	6	227	6	1	7	19	23	19	5	9	75	33	11	11	9	13	10	32	60	24	0	121
Chilliwack	4	70	17	3	4	3	12	2	12	55	3	17	16	77	16	5	10	36	2	10	12	25	0
Upper Pitt	75	230	84	43	84	12	63	13	97	60	31	54	95	156	143	13	23	36	34	36	24	32	5
Alouette+Coquitlam	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	2	1	0	0	2	1
Nadina	0	91	48	14	1	12	28	3	27	0	0	66	124	50	9	211	221	49	8	221	139	152	8
Bowron	20	38	11	5	9	5	10	4	12	10	4	15	16	3	6	12	6	1	2	4	5	7	5
Gates	35	184	30	17	12	97	87	19	118	141	101	18	77	121	67	18	57	73	77	20	63	36	34
Nahatlatch	6	18	1	4	13	4	10	4	22	13	4	12	11	10	12	4	10	11	5	8	11	15	4
Taseko	2	8	2	3	2	2	1	1	0	1	2	0	11	4	0	1	6	7	2	1	4	4	2
North Barriere	19	90	5	23	38	2	2	8	25	17	8	8	2	5	0	2	5	5	1	8	5	3	5
Adams Lake	0	160	6	1	1	24	1	1	2	13	2	3	1	3	0	1	2	1	0	6	0	4	1
Early Shuswap	68	23	3	626	54	6	31	979	180	7	105	477	74	19	64	602	53	20	34	283	34	8	44
Harrison	8	5	53	52	199	4	154	91	355	33	45	208	103	88	70	10	32	56	5	7	2	41	10
Widgeon	0	0	1	0	1	1	0	0	3	0	0	0	0	0	0	0	1	0	0	0	1	1	0
Late Stuart	53	670	201	67	64	110	355	54	70	125	204	71	52	87	587	179	60	99	504	177	51	124	596
Stellako	152	514	113	134	89	240	81	122	154	320	149	438	316	135	251	106	341	243	159	191	337	346	94
Chilko	806	395	310	448	889	598	794	776	1,215	1,083	1,470	716	1,220	727	1,167	771	1,061	362	948	1,175	695	254	926
Horsefly	330	68	463	148	160	53	297	35	42	8	100	360	33	7	153	633	156	7	15	737	63	11	40
Mitchell	207	41	661	79	181	79	290	63	49	3	178	225	46	9	170	339	47	3	29	367	57	0	98
Raft	10	58	36	12	25	30	48	4	19	57	18	9	34	48	12	2	1	21	4	3	7	54	7
North Thompson	15	31	72	30	107	50	74	9	68	117	88	24	168	55	73	15	14	2	24	15	19	8	22
Birkenhead	406	69	45	220	504	149	202	57	255	189	50	19	90	80	41	27	17	35	39	65	97	20	99
Big Silver	17	32	2	17	29	7	12	8	6	24	11	7	16	15	20	4	1	1	0	0	0	0	0
Late Shuswap	491	6	44	3,085	502	35	233	2,513	348	6	479	1,721	112	4	244	2,286	59	4	62	649	67	0	87
Portage	18	2	3	4	27	11	26	13	12	2	48	28	1	1	10	37	0	0	2	16	9	0	1
Weaver	203	71	67	76	362	229	409	39	497	132	102	38	33	13	326	29	15	16	198	183	263	9	116
Cultus	1	1	0	7	4	3	8	4	20	2	6	16	2	21	5	1	1	3	1	2	0	0	3
Non-Fraser	31	97	62	72	110	124	105	152	186	198	136	143	155	144	68	134	202	60	214	147	159	130	386
Total	2,979	2,978	2,567	5,196	3,472	1,897	3,353	4,997	3,814	2,621	3,353	4,768	2,841	1,893	3,525	5,451	2,414	1,163	2,402	4,391	2,148	1,286	2,715

B13. Stock ID projection model

A.M. Phung and S. Latham

Summary

In-season management of Fraser River sockeye relies on the assessment of the four different management groups (Early Stuart, Early Summer, Summer and Late run), and being able to accurately detect changes in their relative contributions in a timely manner. Delays in detecting changes in stock composition may result in overexploitation or foregone fishing opportunities. In-season logistics associated with the collection and analysis of samples taken from test fisheries reduce the timeliness of stock composition results for samples, as it may take two to four days before results from collected DNA are available (Chapter B7). This delay in the availability of genetic stock identification (GSI) results will cause a data gap unless stock proportions for the most recent days of assessments are imputed. One simple solution is to apply the stock composition of the most recent available results and assume no changes in stock composition since those sampled fish were caught. This would result in stock compositions estimates biased toward earlier-returning stocks, especially during periods of rapid change. To avoid this bias, a Bayesian multinomial logistic regression model was developed to predict future stock proportions. This model uses the most recent trend in stock composition estimates to predict stock proportions, in marine areas and lower Fraser River areas. There are slight differences in the implementation of the marine and the in-river versions of the stock projection model.

Introduction

Fraser River sockeye salmon are managed as four management groups per the Pacific Salmon Treaty (PST 2025, Chapter 4, section 3), but each management group comprises smaller, genetically distinct stock components. Stock identification is critical for effective assessment and fisheries management (Begg et al. 1999). DNA samples collected from test fisheries are used in genetic stock identification (GSI) analyses to apportion daily catches and estimated sockeye abundances into their stock components during the in-season assessment process (Chapter B11, B20). Stock-specific catches and Mission hydroacoustic abundances are then used to re-construct daily marine abundances, informing total run size and timing by management group (Chapter B23).

In-season, different information types become available at different times. For example, test fishing catches and Mission hydroacoustic abundance estimates by species are often only available the day after the data are collected. However, after DNA samples are collected, they need to be shipped to the Molecular Genetics Laboratory at the Pacific Biological Station (PBS) in Nanaimo, BC, for analysis, leading to a typical delay of two to four days before DNA sample results for marine areas are available for a given catch (Chapter B7). Factors which may affect delay time include missed shipments, analytical issues, sampling location, and sampling time (marine gill nets catch is typically sampled on the date following the start of fishing). This report provides an overview of the model used to predict stock proportions several days into the future, both in marine areas and in the Fraser River.

Data

After GSI results are sent from the lab to the Secretariat office (Chapter B7), the data are adjusted at the 19-stock group resolution while taking into account additional information on fish size, age, scale measurements, and other factors to inform stock identity (Chapter B11). The resulting stock proportions are input into the model.

GSI results from Area 12, Area 20, or both areas combined can be used to inform the marine stock ID projection model after aligning the data to a common Area 20 date. The marine stock ID projection model may incorporate both gill net and purse seine data, or only one of the two depending on sampling biases expected at the time and whether both gear types are running simultaneously.

GSI results from both in-river test fisheries at Whonnock and Brownsville Bar (and previously Cottonwood) inform the in-river stock ID projection model by aligning the data to a common Area 20 date. Additionally, the in-river projection model may incorporate the marine data from Area 12 and 20 depending on how representative the marine samples are expected to be of in-river stock proportions. For example, if the marine samples comprise a large proportion of stocks expected to delay prior to entering the river, they can be excluded from the model.

Because of the limited number of observations for smaller stock groups, the 19 stock groups (Chapter B11) are combined into 10 groups prior to modelling: non-Fraser sockeye, Early Stuart, Chilliwack/Nadina/Bowron, Early Summers excluding Chilliwack/Nadina/Bowron, Harrison/Widgeon, Late Stuart/Stellako, Chilko/Quesnel, Raft/North Thompson, Birkenhead/Big Silver, Late Shuswap/Portage/Weaver/Cultus. For the in-river stock groupings, Pitt/Alouette/Coquitlam is combined with non-Fraser sockeye and treated uniquely in the modelling process.

Methods

There are two main methods to address the data gap from delayed GSI results. A simple method uses the most recent stock proportion estimates from the test fishery and assumes no change for more recent days (Figure 1). However, stock proportions can change quickly in-season, resulting in stock proportion predictions that lag behind the true proportion. The second method uses recent trends in stock proportions to predict the proportions several days into the future. For this second method, Bayesian multinomial logistic regression is used to model the simultaneous change in stock components over time, which is assumed to be a linear function of the sampled data (Albert and Chib 1993). This model is run using WinBUGS software (Lunn et al. 2000) and implemented through the statistical application R (R Core Team 2025). The multinomial distribution is used to represent the probabilities of more than one stock, while the Bayesian framework combines prior information and observations to make future predictions (Beck and Katafygiotis 1998). The marine version of this stock projection model is fitted to the GSI results of either Area 12 or Area 20, or the combined areas, after removal of stocks that are expected to have a preferred migration route e.g. Harrison and non-Fraser sockeye. The in-river stock projection model version is fitted to GSI results from the Whonnock and Brownsville test fisheries, after removal of Pitt stocks given that these stocks exit the Fraser River mainstem prior to reaching the Whonnock test fishery location. In years with low in-river catches, the marine GSI results can be used in the in-river model once Harrison and delaying Late-run stocks (Late Shuswap, Portage, Weaver and Cultus) are removed. The removal of delaying Late-run stocks ensures that proportions of the remaining stocks are comparable. The number of recent observations used to inform the model for predictions can vary depending on the amount of variability observed among samples (noise), the amount of trend in stock compositions (signal), and the number of observations available.

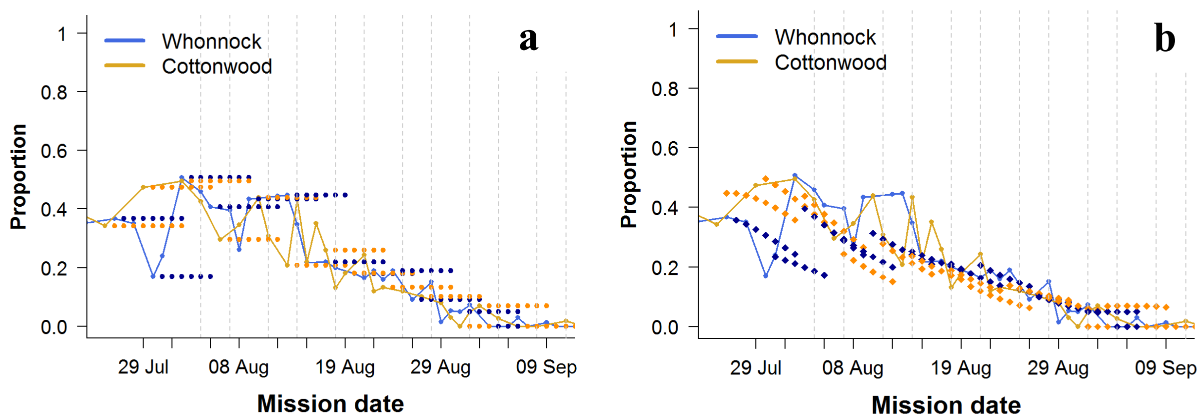

Figure 1. *Projections of 2014 Early Summer-run proportions in Fraser River test fisheries. Dotted lines show stock proportion projections assuming (a) constant proportions or (b) proportions based on the trend among recent observations.*

Not all stocks are modelled using a Bayesian multinomial logistic regression model (Figure 2). Stock proportions for stocks that comprise less than 4% of recent samples are assumed to be constant, since predictions on such small stock components could be very biased. In addition, stocks that differ systematically between the two areas are each modelled separately using a binomial generalized linear model (GLM), i.e., non-Fraser and Harrison stocks in the marine stock projection model and Pitt stocks in the in-river model. Once predictions have been generated for all 10 stock groups, the resulting proportions are normalized to ensure the total of the proportions sums to one. Predictions from the multinomial logit model are produced at the 10-stock group resolution but results are subdivided back into the 19-stock group resolution using average sub-stock proportions based on the most recent three observations.

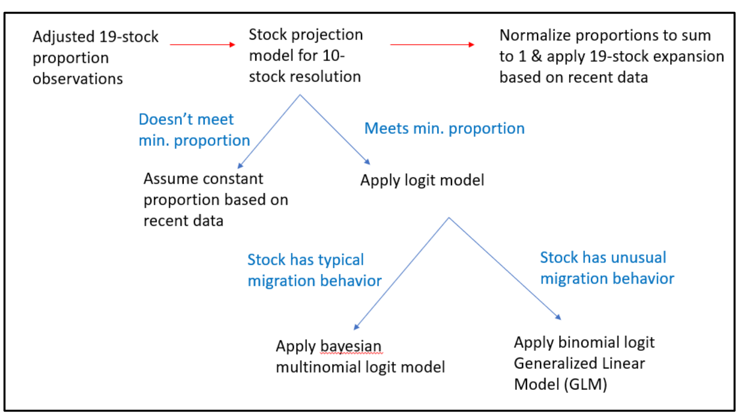

Figure 2. *Decision tree showing the implementation of the stock projections model. Stocks with unusual migration behaviour in the marine areas include Non-Fraser stocks and Harrison which tend to migrate through Juan de Fuca. In the river, the Pitt/Alouette/Coquitlam stocks don't migrate past Whonnock, while delaying stocks (Harrison & Late Shuswap/Portage/Weaver/Cultus) may not enter the river right away. These stocks with unusual migration behaviour are modelled with the binomial GLM model.*

Results

Stock projection model outputs are shown below for marine Areas 20 and 12 (Figure 3A) and in-river for Whonnock and Cottonwood (Figure 3B). When both Area 12 and Area 20 data are used simultaneously, differences in stock-specific proportions between each area are mainly due to differences in Non-Fraser and Harrison proportions that are modelled separately. Similarly, differences in stock proportions of Pitt or delaying stock components can contribute to differences between stock-specific proportions at Whonnock and Cottonwood. Table 1 shows an example of stock ID projection model results broken down into 19-stock components. Further adjustments of the model results may be made based on expert knowledge when results significantly deviate from expectations, appear too extreme in predictions for rare stocks, or other unusual situations.

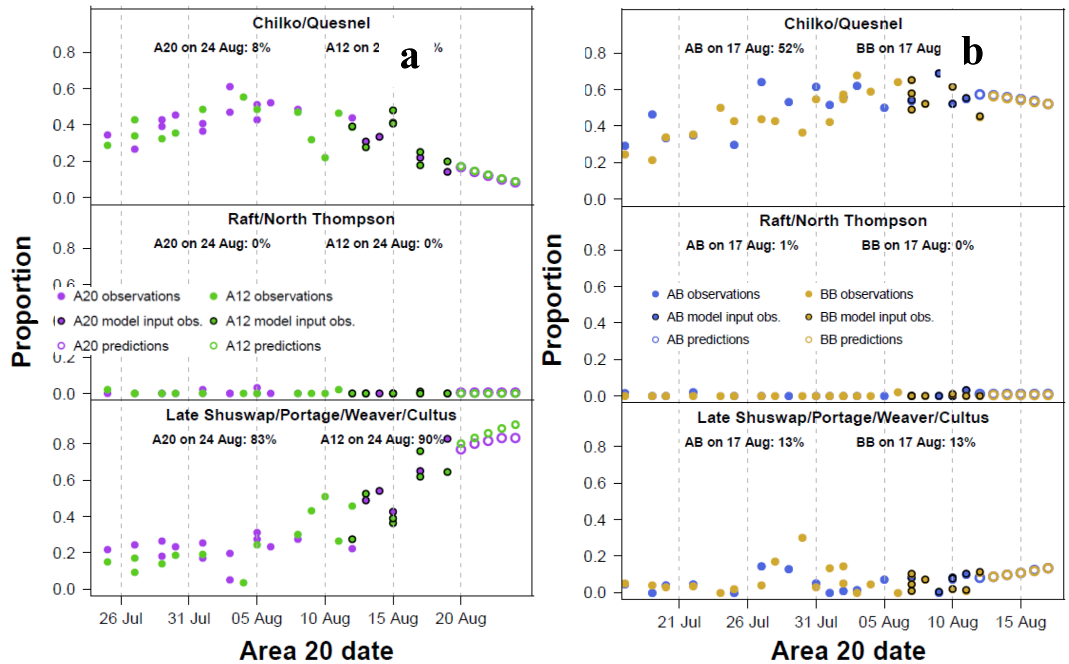

Figure 3. *Stock projections by Area 20 date for three out of ten stock groups on August 21, 2018. Similar plots are produced for the remaining seven stock groups. Open circles are projections, filled circles are observations, and filled circles outlined in black are the observations used to inform the projections. Marine projections show a decrease in Chilko group proportions with a corresponding increase in the proportions of the Late Shuswap group (a). In-river projections show a slight decrease in the proportions of the Chilko group, and a corresponding increase for the Late Shuswap group (b). Within the in-river projections, AB (Above Bridge) refers to Whonnock and BB (Below Bridge) refers to Cottonwood or Brownsville Bar.*

The adjusted projections for the 19 stock groups are used to apportion catches and Mission hydroacoustic abundances during the in-season stock assessment process. Marine stock projections are applied to marine catch data and also inform the projected component of the reconstructed marine abundances. In-river stock projections are applied to in-river catches as well as in-river abundance estimates (Chapter B20). Projected stock compositions are replaced with observations when more recent GSI results become available. While the stock projection model requires careful use, scrutiny and expert knowledge, it is an important tool used to fill the temporary data gap in GSI results to apportion catch and escapement data by stock during in-season stock assessments.

Table 1. *Area 20 stock projections for ten stock groups sub-divided into 19 stock groups using observed stock proportions available up to and including August 21, 2018.*

Area 20 Date	20-Aug	21-Aug	22-Aug	23-Aug	24-Aug
NonF	1.4	2.0	2.9	4.0	5.7
EStu	0.0	0.0	0.0	0.0	0.0
Chwk	0.0	0.0	0.0	0.0	0.0
PiAC	0.0	0.0	0.0	0.0	0.0
NdBo	0.0	0.0	0.0	0.0	0.0
GaNh	0.1	0.1	0.0	0.0	0.0
Tsko	0.0	0.0	0.0	0.0	0.0
NBar	0.0	0.0	0.0	0.0	0.0
ESTh	2.6	2.0	1.5	1.1	0.9
Harr	0.0	0.0	0.0	0.0	0.0
Widg	0.0	0.0	0.0	0.0	0.0
LStu	0.5	0.5	0.5	0.5	0.5
Stel	0.5	0.5	0.5	0.5	0.5
Chil	10.3	8.7	7.3	6.0	4.9
Hfly	3.1	2.6	2.2	1.8	1.5
Mtch	3.2	2.7	2.2	1.8	1.5
RaNT	0.0	0.0	0.0	0.0	0.0
BiBS	1.1	1.1	1.1	1.1	1.1
LShP	76.0	78.6	80.6	81.8	82.2
WeCu	1.1	1.2	1.2	1.2	1.2

Planned changes and potential areas for improvement

Additional sensitivity analyses on model inputs should be conducted on historical data to optimize methodology relative to observed values and conditions. For example, further evaluations can be done regarding the number of observation days inputted into the model when stock components change rapidly compared to when slower rates of change are expected. Continued data collection will support an updated retrospective evaluation of model performance, in particular given constrained sample sizes and reduced test fishing in recent years due to low Fraser sockeye productivity.

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B14. Estimation of daily salmon passage at Mission

J. Maguire, C.R. Lagasse and Y. Xie

Summary

The Pacific Salmon Commission (PSC) operates a hydroacoustic site near Mission, BC, that provides daily estimates of salmon passage in the Fraser River throughout the summer. When used in combination with daily species composition estimates (Chapter B19), these estimates contribute to in-season assessments by providing daily sockeye and pink salmon abundance information for run reconstructions (Chapter B21) and predictions of Fraser sockeye and pink salmon escapement to the spawning grounds. To sample the entire width of the river, a configuration of multiple ARIS imaging sonar systems is operated at the site, including two shore-based sonars (Chapter B15) and a mobile, downward looking sonar (Chapter B16). The cross-river location of each sonar and its observed fish targets are determined based on GPS coordinates and then input into a flux estimation model to determine the total daily salmon passage.

Introduction

Accurate estimates of daily migration abundance are an integral component of in-season assessments of Fraser sockeye and pink salmon. Hydroacoustic monitoring provides a non-invasive, continuous means of monitoring fish migration that is widely used by fisheries agencies for assessing salmon populations. The PSC and its predecessor the International Pacific Salmon Fisheries Commission (IPSFC) have operated a hydroacoustics monitoring facility on the lower Fraser River every summer since 1977 to assess upstream passage of sockeye and pink salmon. By providing accurate and timely estimates of passage, information from the PSC hydroacoustics site contributes to in-season run reconstructions (Chapter B21) of Fraser sockeye and pink salmon runs and predictions of Fraser sockeye and pink salmon escapement to the spawning grounds.

The PSC hydroacoustics site is located two kilometres upstream of the Mission Railway Bridge and approximately 80 kilometres from the mouth of the Fraser River (Figure 1). This location was originally selected because it is just above the commercial fishing boundary and almost all sockeye populations migrate past it on their upstream migration (with the exception of Pitt River and Widgeon sockeye). The river is approximately 400 metres wide at the site and influenced by tidal changes in water height.

Due to the large width of the river, a combination of three hydroacoustic systems is deployed to monitor salmon migration at Mission (Figure 2): two shore-based ARIS systems to monitor the nearshore (40-metre range) for both the left and right banks, and a mobile, downward looking ARIS to monitor the remaining offshore region. To integrate the shore-based data to the offshore mobile data, a linear interpolation is applied to the 40-50 metre range of both banks. This is done by interpolating between the salmon passage estimates from the 30–40m shore-based range and the mobile survey estimates from the nearest offshore range (50–60 m). Prior to 2025, the 40-50 metre left-bank range was covered by a shore-based split-beam sonar (Michielsens and Martens 2022). To produce a daily estimate of salmon passage, the data collected by each hydroacoustic system are processed, analyzed and input into the FishR program, a salmon passage model coded in R (Hornsby and Hayward 2024). This report describes the sonar sampling design based on a configuration of multiple sonars and the abundance estimation process at the Mission site.

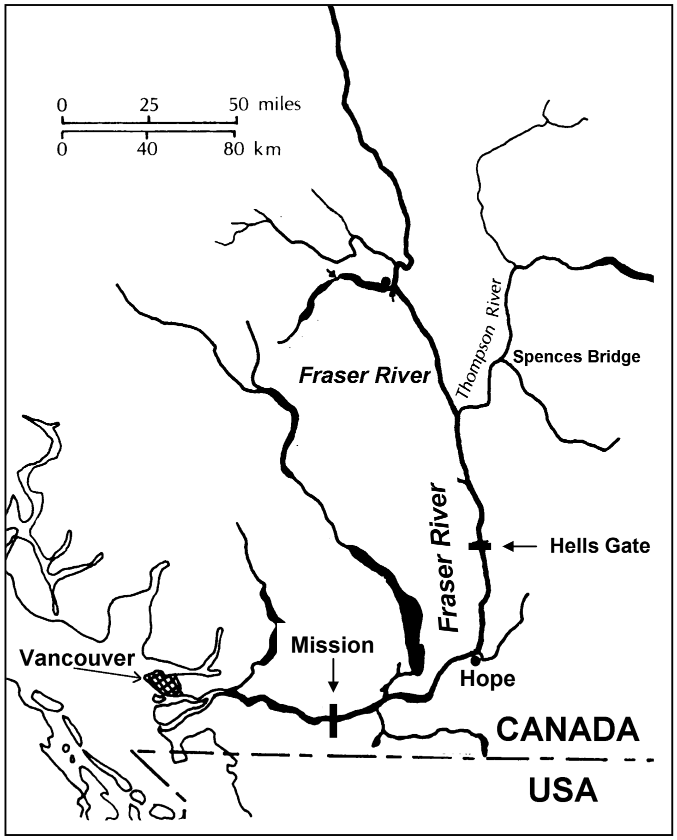

Figure 1. *Map of the Lower Fraser River indicating the Mission hydroacoustics monitoring site.*

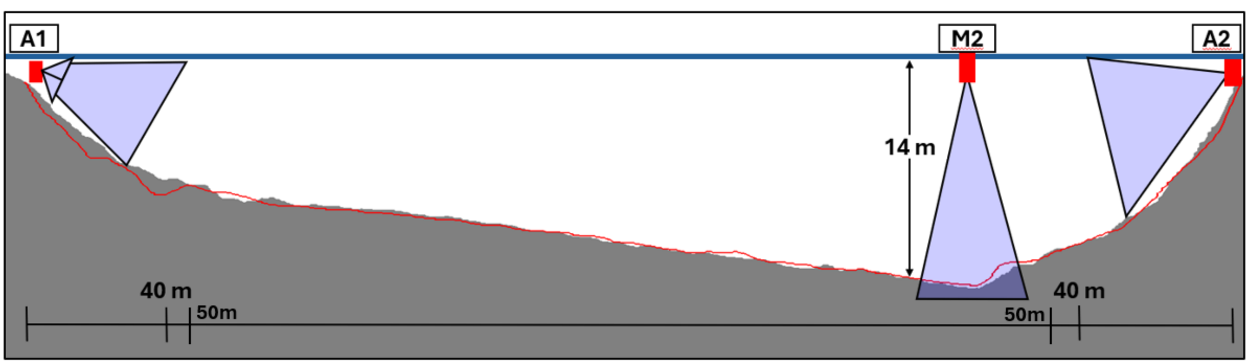

Figure 2*. Cross-river view of the sampling geometry of the sonar systems operated at the Mission hydroacoustics site. The three systems shown are the left-bank ARIS (A1, covering 0–40 m), the mobile ARIS (M2, covering the offshore area up to approximately 50 m from shore), and the right-bank ARIS (A2, covering the final 40 m near the opposite bank). A linear interpolation between the near-shore abundance in the 30-40m range and the offshore abundance in the 50-60m range is used to estimate abundance in the 40-50m offshore range. The approximate beam geometries of the systems are represented by the shaded triangles. The gray filled area represents the river bottom. Note that the cross-river range scale on the x-axis is compressed relative to the vertical depth scale on the y-axis.*

Data

A combination of three hydroacoustic systems are deployed to monitor the salmon migration at Mission (Figure 2). The nearshore areas (40 metres closest to shore) are monitored using ARIS 1800 imaging sonars (Chapter B15). The nearshore left bank area, where most of the upstream migration typically occurs, is the key focus of monitoring efforts at Mission, while the nearshore right bank area typically observes less than 20% of the daily upstream salmon migration. Both systems are mounted at the end of fish deflection weirs to prevent any salmon passage from occurring behind the system. Each hour, the right bank ARIS system systematically records fish passage for 15 minutes in each of the four 10-metre range bins. In the first left bank range bin from 0 to 10 metres, two ARIS aims are needed to sample the entire water column due to the shape of the nearshore river bottom on the left bank (Chapter B15). Accounting for the additional aim in the first 10 metres, the left bank ARIS system systematically records fish passage for 10 minutes each hour for each of the five stratified sampling zones. In addition to abundance information, the ARIS systems on both the left and right bank also provide estimates of salmon species composition based on acoustically observed fish lengths using a mixture model (Chapter B18). The remaining offshore region is monitored by a mobile, downward looking ARIS 3000 imaging sonar deployed from a sampling vessel that transects the river (Chapter B16).

All the ARIS systems operated at the Mission hydroacoustics site sample throughout the day and night with the shore-based systems operating continuously for 24 hours a day. Assuming there are no gaps in data collection, each estimate of daily salmon passage is based on 24 hours of monitoring data. When unforeseen data gaps do occur, an imputation process is used to fill them (Chapter B17). To group each day and night period into the same assessment interval, the daily estimates do not coincide with calendar days, but instead begin at 05:00 each day. For example, the estimate of daily salmon passage at Mission for July 4 would include data beginning at 05:00 on July 4 and continuing to 04:59 on July 5.

Methods

To determine salmon passage across the entire river channel at the Mission hydroacoustics site, the passage estimates from the three monitoring systems (left bank ARIS, A1; mobile ARIS, M2; and right bank ARIS, A2) must be combined. To accomplish this, the cross-river width is divided into 5-metre range bins, with the salmon passage for each bin being derived from a single monitoring system. The range bins sampled by each system are determined from their GPS location along with their sampling range and compass bearing. These sampling areas are updated throughout the field season as the river levels drop and the systems are moved further offshore. The analysis of the positioning, selection, and addition of sonar system configurations for the daily estimate are completed using the FishR program, a salmon passage model coded in R, developed by Ashlu Environmental Consulting and the PSC (Hornsby and Hayward 2024).

If a range bin is sampled by multiple systems, only the most accurate system is used for the salmon passage estimate, while other estimates are excluded to avoid double-counting. Estimates from shore-based systems are preferred over mobile estimates due to their higher sampling intensity and greater precision. For the 40-50m region, the interpolation is preferred due to the limited range of the shore-based sonars, and the mobile sonar’s low sampling intensity and vulnerability to near-shore avoidance behaviour, which could contribute to a negative bias (Xie et al. 2008).

Data collected by each of the systems are reviewed and processed by 8:30am every morning by PSC staff throughout the field season to generate the estimate of salmon passage for the previous day. Summary statistics are calculated for the daily estimate of salmon passage including the ratio of fish travelling downstream (A1/M2 Ratio downstream, Rd), the proportion of daily passage observed by each sonar system, the percentage of passage extrapolated in unsampled areas, the number of transects performed by the mobile sampling vessel and the number of daily targets observed by the mobile vessel (Table 1). The summary statistics also include total salmon estimates based on alternative system configurations (e.g., M2 and A1+M2). Once the daily estimate of total salmon passage is published, the species composition of salmon (Chapter B19) is estimated to determine the daily passage of sockeye and pink salmon past Mission.

Results

The distribution of salmon passage across the river channel tends to change throughout a season depending on river flows, species composition, tidal fluxes, and other factors. River flows and turbidity are higher in July than August or September, and a greater proportion of the migration occurs in the offshore areas observed by the mobile system. As flows decrease, the tidal influence on water heights increases and fish passage becomes more concentrated along the shorelines (Table 1). During odd-numbered years when pink salmon return to the Fraser River, migration past the Mission hydroacoustics site is highly concentrated in nearshore areas, with less than 10% of daily passage observed in offshore regions.

Table 1. *Summary statistics for the estimate of daily salmon passage using August 12, 2024 as an example. JD is the Julian calendar date.*

Mission Date	JD	A1 Flux Proportion	Mobile Flux Proportion	A2 Flux Proportion	Total Salmon Official	Lower 95% CI	Upper 95% CI	Systems For Estimate
Aug 12, 2024	225	41%	52%	8%	**16,618**	14,665	18,758	A1+M2+A2

Total Salmon Estimates by Sonar Configuration			
A1+M2+A2	**A1+M2**	**M2**	**IMPUTATION**
16,618	13,607	9,992	N/A
Other Statistics:			
Downstream Ratios			**Expansion**
A1	**A2**	**M2**	**A1**
6%	7%	6%	3%
Data Collected			
Hours A1	**Hours A2**	**Transects M2**	**Targets M2**
24	24	95	75

Planned Changes and Potential Areas for Improvement

PSC staff are investigating the use of multiple automation methods to facilitate automation of the daily estimate (e.g., Echoview, machine learning). In the future, portions of the estimate may be calculated from automated processes.

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B15. Shore-based imaging sonar systems

J. Nelitz and R. Hornsby

Summary

Imaging sonar technology, such as the ARIS system, provides visually intuitive data used by the PSC hydroacoustic program to estimate salmon abundance and species composition in the Fraser River. This technology has been utilized officially at the Mission hydroacoustics site to monitor abundance close to shore since 2009 and offshore abundance since 2023. This document outlines the deployment, sampling design, and counting methods for the two shore-based Sound Metrics ARIS 1800 systems currently used by the hydroacoustics program.

Introduction

The Pacific Salmon Commission (PSC) hydroacoustics program has been enumerating adult salmon passage through the lower Fraser River at Mission since 1977. Over the history of the site, various technologies have been tested and adopted to improve the accuracy of salmon passage estimates (Chapter B14). The ARIS imaging sonar systems deployed on both the right and left bank are the official shore-based systems in use and capture approximately 60-80% of the total daily salmon passage (Conrad et al. 2019). Past shore-based hydroacoustic configurations and set ups can be found in Michielsens and Martens (2022). A downward looking ARIS system on a vessel continuously transecting the river has been used to assess the fish passage in the mid-section of the river (Chapter B16). This mobile system was adopted as the official offshore abundance estimator during the 2023 season, following two years of testing (Xie et al. 2024). This document focuses on shore-based ARIS data collection and counting methodology used to produce nearshore abundance estimates.

Method

SYSTEM DEPLOYMENT AND DATA COLLECTION

The PSC Mission hydroacoustic site is located 80km upstream from the mouth of the Fraser River where the maximum width of the river is approximately 450 metres, and the maximum depth varies from 13 to 20 metres depending on discharge levels. The site is operational during the sockeye and pink salmon migration periods, generally from early July to September or October each year. The shore-based data collection occurs on the left bank field site, which houses most of the field site equipment, and the right bank field site, directly across the river from the left bank site.

Right bank

The right bank field site is an off-grid location, powered by a battery bank which is charged by solar and gas-generator power. The ARIS system is mounted with a pole-mount to an aluminum cross arm attached to the end of a telescopic fish weir (Enzenhofer and Cronkite 2005). When fully deployed, the fish weir extends 20 metres from the riverbank. The river profile on the right bank has a gradual downward slope and is ensonified by an ARIS 1800 unit using one vertical aim, varying between -2° to -5° depending on water levels, to a maximum range of 40 metres. The aim is split into four 10-metre range bins (Figure 1) and the ARIS system is programmed to monitor fish passage in each range bin for 15 minutes per hour, 24 hours per day. The resulting files are transferred wirelessly to the left bank trailer for on-site processing.

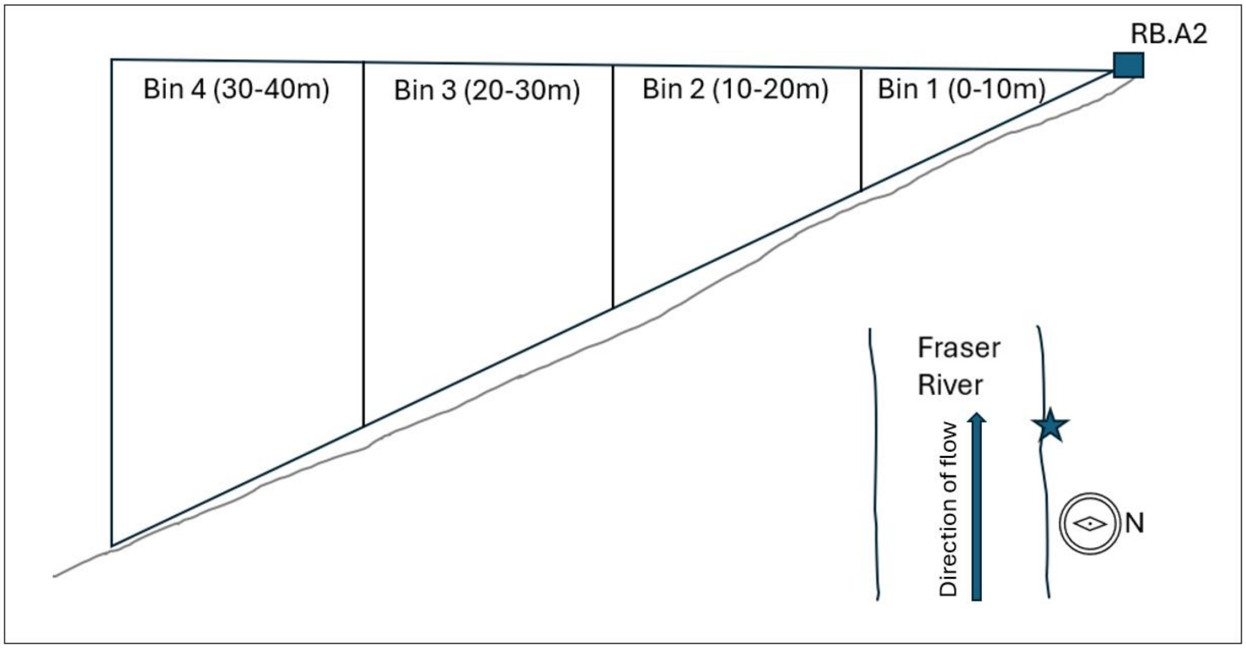

Figure 1. *Side-view diagram of the right bank ARIS sampling scheme at Mission, BC. The right bank aim is split into four 10-metre range bins, which are each monitored for 15 minutes every hour.*

Left bank

Up to 80% of the daily salmon passage is monitored on the left bank using an ARIS 1800 mounted to the end of a large fish weir. The ARIS system covers a total range of 40 metres from the left bank. Due to the semi-convex shape of the nearshore river bottom on the left bank and limited vertical beam-width of the imaging sonar, two vertical aims (approximately -15°, 0° depending on system location and water height) are required to sample the entire water column in the first range bin of 0-10 metres (Figure 9). These two nearshore aims are configured to minimise "blind areas" near the river bottom and upper water column and enable assessment of high salmon passage close to shore. The three farther range bins (10-40 metres) are sampled using a single aim (approximately -4°), as the vertical beam width of the ARIS system covers most of the water column at those ranges. Each aim and range bin are sampled individually on a systematic hourly sampling schedule. Fish passage in each of the stratified spaces is monitored for 10 minutes every hour, 24 hours per day.

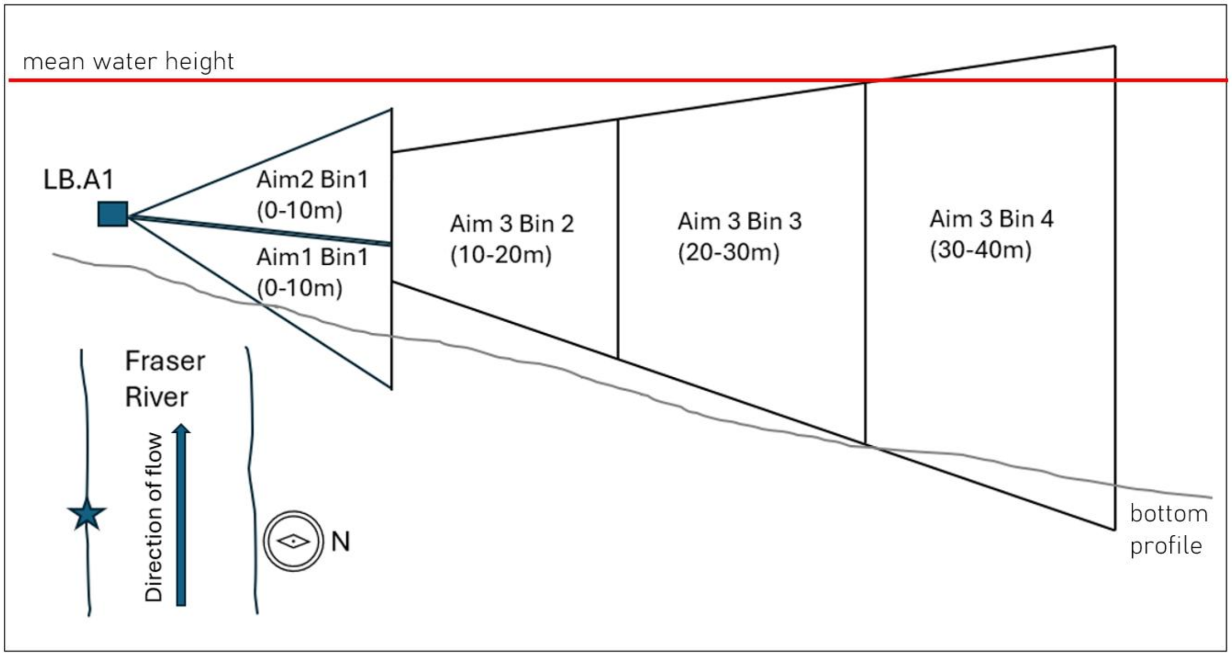

Figure 2. *Side-view diagram of the left bank ARIS sampling scheme at Mission, BC. The left bank sampling is split into five stratified aim/range bins, which are each monitored for 10 minutes every hour. The mean water height is shown in red, and the bottom profile is shown in grey. Black lines outline the sampling areas of each configuration (aim/range bin).*

DATA PROCESSING

Counting Procedures

The ARIS data are collected hourly, and each aim/range bin is either sampled for 10 or 15 minutes per hour depending on location (Figure 1 and 2). The files are uploaded to the central processing computer where fish targets within the files are counted by hydroacoustics staff using the custom ARISFish software (Sound Metrics). Staff count upstream and downstream fish targets ≥35cm with tally counters for the first 5 minutes of each file. The coefficient of variation (CV) associated with the resulting hourly fish count estimates is 6.5% (Xie and Martens 2014). It is possible to count 10 minutes of each recording, but the gain in precision is minor (CV of 5.5%) and is not time efficient. During low abundance scenarios, the playback frame rate of the sonar files can be increased to complete counts faster. When passage rates increase, it becomes challenging to count files in real time, so the frame rate is decreased to ensure accuracy.

To verify counts, a subset of files are recounted. There are three approaches for choosing files to recount: 1) in season, a random number generator is used to select 3 hours per 8-hour time period for each configuration (up to 9 files per configuration/day), 2) specific files from hours or days that seem misaligned with a secondary system covering the same area at Mission or misaligned with Qualark estimates, and 3) specific files covering the periods when abundances or environmental conditions change dramatically, i.e., at the start of peak pink migration or during large tidal swings. In season, the number of files recounted is subject to time availability. Post-season, additional files may be recounted to fill in gaps or to further explore misalignments (method 2). Typically, counts that deviate by less than 10% from the recounts are acceptable, except when abundances are extremely low, e.g., 1-2 fish in a file. If a recount differs by more than 10% from the original count, a third counter may be used to determine which count is correct. Counts and recounts are typically evaluated for outliers using 1:1 and Bland-Altman plots for outliers (Altman and Bland 1983).

Length Measurement Procedures

PSC staff measure sonar lengths for the first 20 fish ≥ 35cm within each file during every 3rd hour (5 am, 8 am, 11 am, 2 pm, 5 pm, 8 pm, 11 pm, 2 am) in the stratified areas covering the 20 metre closest to shore. Due to beam spreading and intra-frame motion artifact at the far ranges, lengths from the 10 to 20 metre range are used to represent the 20 to 40 metre range. These lengths are used in a length-based mixture model (Chapter B18) as a method of species composition (Chapter B19).

Generating an Imaging Sonar Passage Estimate.

Once fish counts are completed for the 24-hour period, a total daily nearshore fish passage estimate (*N*) for each bank is calculated using the following method:

$$1)\ N = \sum_{j=1}^{C} \frac{24 \times 60\ \sum_{i=1}^{n_j} x_{ij}/t_{ij}}{h_j}$$

Where:

- x_{ij} is the count for the i-th period in configuration *j*, with 4 stratified areas on the right bank and 5 stratified areas on the left bank,
- t_{ij} is the number of minutes counted for the i-th period in configuration *j*, normally 5 minutes,
- n_j is the total number of available i period counts in a day for configuration *j*, normally 24 counts,
- h_j is the total number of hours recorded for configuration *j*, normally the number of hours is the same as the number of counts,
- C is the total number of stratified areas within a configuration, normally 5 on the left bank and 4 on the right bank,

In general, this method uses 5-minute counts per hour for the different aim/bin ranges to generate passage per day for each configuration, then sums the estimates across configurations. If passage is not recorded for an individual aim/bin for an hour, e.g. during system malfunctions, an average hourly count can be produced for that aim/bin range based on the available hours of data and combined with estimates for the other stratified areas. If entire hours are missing across the stratified areas, then a linear or non-linear hourly data imputation (Chapter B17) is used to fill in the data gap. Once a nearshore passage estimate is produced for each bank, it is combined with the offshore abundance estimate (Chapter B16) within a salmon density model to produce a total daily salmon passage estimate for the site (Chapter B14).

Left-Bank passage Expansion

The bottom profile impacts the ability of ARIS system to monitor the full water column. On the right bank, the natural bottom profile allows complete coverage of the water column using a single aim (Figure 1). In contrast, the left bank

positioned closer to the shore. A_{aj} and A_{bj} are the areas of configuration *j* that are respectively above (*a*) the mean water height and below (*b*) the bottom profile (Figure 2).

Next, the total underwater areas for the individual configurations ($A_{u,j}$) are calculated based on the mean water height and available bottom profile for the chosen configuration. Third, expansion factors (F_j) are calculated based on the proportion of underwater area versus sampled area:

$$3)\ F_j = \frac{A_{uj}}{A_j},$$

and applied to the raw passage for each configuration (N_j) in order to calculate the expanded passage (N_{ej}):

$$4)\ N_{ej} = N_j \times F_j.$$

The impact of left bank expansions for individual configurations to daily total left bank passage estimates is monitored throughout the season by calculating the proportion of expanded passage (*E*):

$$5)\ E = \frac{\sum N_{ej}}{\sum N_j} \times 100.$$

Planned changes and improvements

The current left-bank expansion uses the mean daily water height to calculate available underwater area, while removing portions of the sampling area that may be above the surface of the water (in side view). However, salmon passage is not consistent through the entire 24-hour period and increases in passage are often observed during high tide. We plan to explore the implementation of a refined hourly expansion calculation, which considers the water height and associated hourly passage. For example has a more complex bottom profile, requiring two aims to cover the 0–10 metre range (Figure 2). Even with this configuration, portions of the water column remain unsampled, particularly within the first 20 metres, which can lead to underestimation of fish passage if not addressed. To estimate left bank fish passage for the full water column, a three-step procedure is used: 1) calculate the sampled area for each aim/bin configuration, 2) estimate the total underwater area for each configuration, 3) calculate the expansion factor, the ratio of total area to sampled area, and apply it to the raw passage counts. Because the ARIS system cannot determine the vertical position of fish in the water column, each expansion assumes a uniform distribution of fish throughout the underwater area for the configuration. As each left bank configuration varies in vertical sampling area, a unique expansion is calculated for each within the PSC FishR program (Chapter B14).

First, the sampled area (*A*) of the individual configurations (*j*) is calculated via trigonometry, using the opening angle θ (either 15 or 16 degrees, depending on the sonar) and the maximum range (*R*) in meters from the sonar:

$$2)\ A_j = 0.5 \times R_j \times \left(R_j \times tan\left(radians(\theta)\right)\right) - \sum_{n=1}^{j-1} A_n - A_{b,j} - A_{a,j}$$

Where ΣA_n is the sum of the sampling areas closer to shore than A_j. For the 0–10 m sampling area, the subtracted area represents the area from the end of the fish weir to the sonar, with the sonar, if 1000 salmon pass during high tide, the expansion would be larger than during hours when 1000 salmon pass during low tide. This refinement would improve precision of expanded passage estimates, even without available vertical passage information. As the Mission site moves towards the automation of salmon counts, the different tools for hydroacoustic data processing are being tested, such as Echoview. This work is in the initial stages, but starting in 2025 this tool will be tested in-season to allow comparisons with manual counts.

Unlike recounts, verification of lengths is not a well-defined process. While the length measurement methodology is detailed and repeatable, it is more difficult to conduct large scale repeat length measurements by different staff in-season. Developing a more efficient process for measuring lengths is a priority, and automation through Echoview may be an alternative method for large scale verification.

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B16. Offshore salmon passage based on transecting mobile ARIS

R. Hornsby and J.L. Nelitz

Summary

At the Mission hydroacoustics site, salmon are known to utilize the full 450m width of the Fraser River for upstream migration. On average between 20 to 40% of the salmon migrate offshore. Offshore abundance may however increase substantially when fisheries take place at the Mission site (Chapter B17), as well as during periods of high discharge and when salmon tend to mill more, in particular later in the season. As of 2024, salmon migrating more than 40 meters offshore, beyond the range of shore-based sonars, are monitored by a downward looking mobile ARIS 3000 deployed from a transecting vessel. The transect sampling of the river by the mobile ARIS acquires information on fish density and swim direction. This information is combined with shore-based swim speed statistics through a salmon density model to produce daily estimates of offshore salmon passage.

Introduction

The Pacific Salmon Commission (PSC) hydroacoustics program has operated a mobile split-beam system to estimate total fish passage since 1977 (Michielsens and Martens 2022). Since 2004, the focus has been on the estimation of fish passage beyond the range of shore-based sonars (Chapter B14). Estimating offshore fish passage requires data on fish density, along with behavioural statistics such as fish swim direction and speed. Conrad et al. (2019) highlight several challenges with the mobile split-beam system that introduced biases in the offshore fish passage estimates. These challenges include 1) ambiguous targets and difficulty distinguishing migrating salmon from debris; 2) narrow sampling volume, which amplifies the effect of near-shore vessel avoidance (Xie et al. 2008); and 3) the reliance on fish direction and speed derived from the left-bank sonar, rather than directly observing these metrics in the offshore region. This lack of direct observations increases uncertainty regarding the effects of fishing events on fish behaviour, such as milling or offshore holding.

In recent years, the introduction of the ARIS 3000 (Adaptive Resolution Imaging Sonar) offered a solution to the long-standing challenges associated with the mobile split-beam. The ARIS 3000 possesses a large sampling volume compared to the narrow sampling volume of the split-beam (30° vs. 6°). This increases coverage of the mid-river sampling area and may reduce the effect of nearshore vessel avoidance. The ARIS 3000 operates at high frequencies (1.8 or 3.0 MHz) characteristic of imaging sonars and offers the choice between 128 or 64 narrow vertical beams. The resulting high-resolution image allows to easily differentiate targets from debris, to determine fish swim direction and to a certain extent fish swim speed (Xie et al. 2024). In 2023, after two years of experimental data collection and analysis, the mobile ARIS 3000 was officially implemented as the offshore sonar to address the long-standing challenges of offshore estimation at the site.

Data

SYSTEM DEPLOYMENT

The mobile imaging sonar data are collected using a downward looking (-90º) ARIS 3000 housed in a specially designed tow-body mounted on the port side of a vessel (Figure 1). The sonar is towed by a vessel that transects the Fraser River every 5 minutes over a 24-hour period, at a speed of approximately 1.33 m/s. On average, the vessel completes 180 to 200 transects per day, stopping every 3 hours for shift changes and/or data extraction.

The current tow body has a few limitations when collecting data. First, it cannot operate effectively when discharge levels within the Fraser River are high, as high flows disrupt the tow-body's flight and make it difficult to keep the sonar submerged. This happens at flows greater than 14,000 m^3/s at Mission, which occur when discharge at Hells Gate exceeds 9,000 m^3/s. These flows also exceed the theoretical threshold for sockeye passage, reducing the concern of missing salmon passage data when discharge levels are this high. Second, special care is required when changing direction at the end of each transect to avoid reducing the tow-body's -90° angle, thereby misplacing targets and exaggerating their depth, leading to calculation errors.

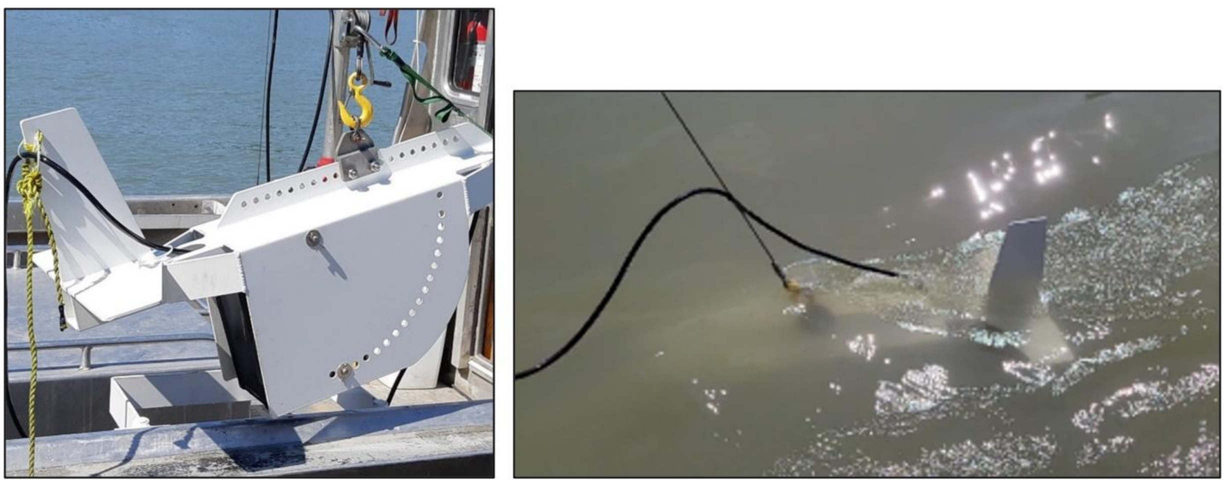

Figure 1. *(Left) The tow-body housing the downward looking ARIS 3000 imaging sonar; (Right) the tow-body being towed by the vessel during data collection. Prior to 2025, the sonar was towed on the starboard side of the vessel, as shown in these photos. In 2025, the sonar was switched to the port side of the vessel to accommodate docking.*

DATA COLLECTION

Obtaining a clear image with minimal intra-frame distortion using the mobile ARIS 3000 depends on two key settings: the number of samples and the frame rate. The frame rate is influenced by both the sampling range and the number of beams used. The ARIS 3000 is capable of utilizing 128 beams to a maximum depth of 20m; however, achieving an optimal frame rate of 12 fps or higher requires reducing the number of beams to 64 and limiting the depth to a maximum of 15m. The optimal settings for generating a clear, continuous image of targets were determined through testing during the 2021 season and have been consistently applied since then (Table 1). The high number of samples ensures sufficient data for accurate length and speed measurements. Further details on data collection settings can be found in Xie et al. (2024).

Table 1. *Optimal settings used when collecting data from the ARIS 3000 imaging sonar.*

Depth	Number of beams	Number of samples	Frame rate (fps)
≤15m	64	1500	≥12.0

An external GPS receiver operates alongside the ARIS 3000 and is integrated into the ARIS software to assign GPS coordinates to the vessel transects (10 records per second). Each identified fish target is associated with a latitude and longitude, ensuring accurate placement within the salmon density model. Proper spatial placement of fish targets is essential for eliminating the risk of double counting in nearshore areas where coverage of shore-based and offshore systems overlaps.

DATA PROCESSING

ARIS 3000 data files are viewed using the ARISFish program developed by Sound Metrics. Upon opening the file in ARISFish, the field of view in the imaging sonar window is inverted. Since the mobile ARIS collects data from a down-looking perspective, the sonar footage in the file must be flipped to correct the orientation. Next, an echogram is generated to display the entire file with multiple transects. The echogram also allows for selecting fish targets and determining their direction of travel (Figure 2). Once fish targets are selected, related information, such as target depth, latitude, and longitude, and swim direction, is compiled into an output file.

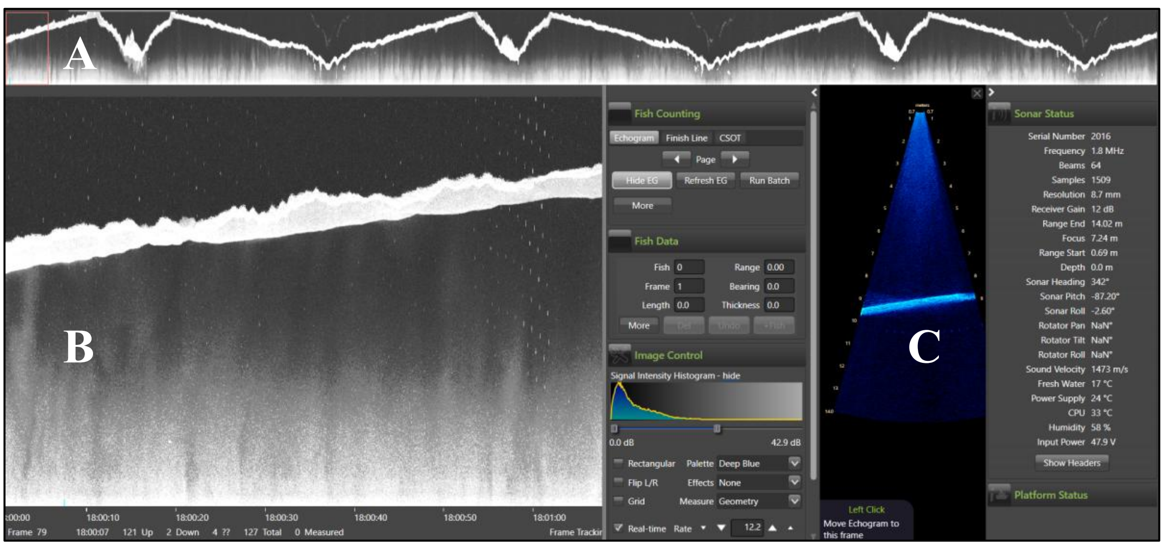

Figure 2. *(A) Transect view of entire data file; (B) echogram view; (C) sonar view using ARISFish software.*

Method

DETERMINING FISH TARGETS

When analyzing a mobile ARIS file, identifying potential targets involves using the sonar view, echogram view, and transect view of the file (Figure 2). Once an object is located in the echogram, the sonar view is used to confirm whether the object is a fish target, debris or bottom profile feature. If the object is identified to be a fish target, the approximate length is measured by marking the body from nose to tail using the sonar view. Only salmon-sized fish targets greater than 35 cm are counted. Decision metrics for determining whether to classify an object as a salmon target are outlined in Table 2.

Table 2. Decision metrics for determining whether to classify an object as a salmon.

	Salmon identification metrics
Necessary metric	• The object has a brighter echo intensity relative to surrounding backgrounds on the echogram view. • The object does not have a repeated presence across multiple transects.
Supportive metrics	• The object shows a 'V' shaped trace on the echogram view. • The side-view shape of the object looks like a fish in the image view, e.g., head, tail, fins can be identified. • The object flexes like a fish when moving.
Sufficient metric	• The object's length is salmon-sized, i.e. larger than 35cm.

DETERMINING FISH SWIM DIRECTION

Fish swim direction can be directly observed from the mobile ARIS and is categorized into one of three groups: upstream, downstream, or undefined. The "undefined" category is used when the direction cannot be determined, i.e. when fish move parallel to the transect while milling or holding, or when the vessel is turning nearshore. Both the transect echogram view and sonar image view are necessary to determine swim direction, as the interpretation depends on whether the vessel is transecting from the left bank to the right bank or from right bank to left. If the vessel is travelling left to right bank, then upstream fish will travel right to left through the sonar image view (Figure 3A). While if the vessel is travelling right to left bank, then upstream fish will travel left to right through the sonar image view (Figure 3B). Once a fish target is identified using the salmon identification metrics (Table 2) and assigned a swim direction, it is selected (Figure 3C). The resulting data for all selected salmon include count and swim direction information. The summary of these data is exported into text files.

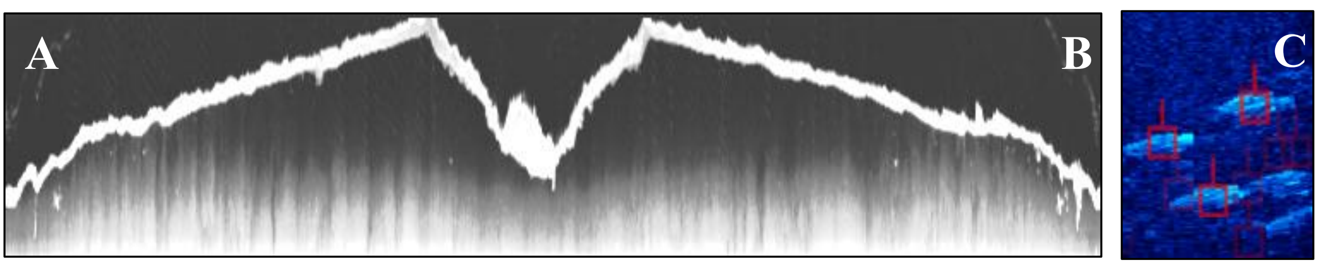

Figure 3. *(A) Vessel travelling from left to right bank; (B) vessel travelling from right to left bank; (C) selecting fish and direction of travel (red-upstream; green-downstream; yellow-undefined).*

DETERMINING OFFSHORE SALMON PASSAGE

A salmon density model is used to calculate daily offshore salmon passage. The model currently uses two main sources of information: the daily number of salmon migrating upstream as well as downstream in the offshore area, and both upstream and downstream swim speeds from the left-bank sonar. Mobile ARIS count data are imported into the PSC FishR program along with associated GPS information, allowing the cross-river spatial distribution of the fish to be plotted (Figure 4). To derive the total daily abundance in the offshore area, the offshore salmon density data are summarized in individual 5 x 1m cells. Individual cell passage can either be determined using a uniform offshore downstream ratio (used until 2026) or cell-specific, dynamic downstream ratios (available as of 2026). Passage from individual cells is summed to create a net daily passage for the offshore region. As shown in Xie et al. (2005), the daily salmon passage in each cell can be calculated by combining salmon count density data with behavioural statistics of swim direction and speed using the following formula:

$$p = \frac{m_T v_u}{L}\left[1-(1-\frac{v_d}{v_u}\right]\cdot\left[\frac{n_d}{n_d+n_u\cdot v_d/v_u}\right]\cdot\left[1-2\frac{n_d}{n_d+n_u}\right]$$

Where:

- L is the full-width of the sound-beam at mean depth of the cell,
- m_T is the mean number of salmon detected per transect at the cell over a 24-hr sampling period by the mobile ARIS system,
- v_d is the mean downstream speed of salmon detected by the left-bank sonar,
- v_u is the mean upstream speed of salmon detected by the left-bank sonar,
- n_d is the total number of downstream salmon (either uniform offshore or cell-specific value) detected by the mobile ARIS over the 24-hr sampling period,
- n_u is the total number of upstream salmon (either uniform offshore or cell-specific value) detected by the mobile ARIS over the 24-hr sampling period, and
- p is the salmon passage for the individual cell.

This is the same formula applied previously for the mobile split-beam, with the improvement of obtaining the upstream and downstream swim directions directly from the offshore area through the mobile ARIS, rather than the left-bank sonar.

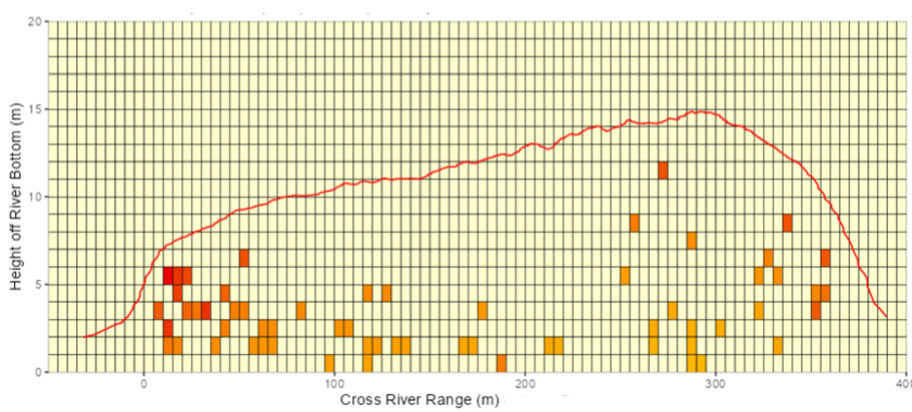

Figure 4. *A plot of July 31, 2024 hourly cross-river salmon passage: number of fish migrating upstream through individual cells (5m horizontal by 1m vertical) per hour with darker coloured cells representing a higher number of fish migrating upstream. The total passage estimated by the mobile system for this day is 476 fish/hour. Note: the passage data are displayed in the plot using the river bottom as the vertical reference so that the flat surface waterline is transformed to a curvy line (the red line), which mirrors the river bottom.*

Planned changes and improvements

There are two key changes planned for the offshore estimation related to model inputs:

1) **Source of speed data:** Currently, the left-bank sonar provides the mean upstream and downstream speeds used in the salmon density model. This approach assumes that swim speeds are statistically similar between the left-bank nearshore and the offshore region. Recent work by Xie et al. (2024) have demonstrated that swim speeds can be directly observed in the offshore by using the mobile ARIS, with adjustments made using the left-bank swim speed data to account for vessel motion. Although in season time constraints have previously hindered the implementation of offshore mobile ARIS speeds, efforts have been made to integrate this process into the in-season workflow. We plan to test the use of offshore speeds during the 2026 season.
2) **Stratified offshore swim speed and swim direction:** Until recently, ratios of upstream to downstream salmon migration and upstream and downstream speeds were assumed to be uniform across the entire offshore sampling area for offshore passage estimation. However, Xie et al. (2007) have demonstrated that fish behaviour can vary significantly across the offshore, the left bank and the right bank. As of the 2026 season, the PSC Flux Estimator program will be replaced by the updated, R-based FishR program. The new program includes the ability to apply a dynamic, stratified downstream ratio method to estimate offshore passage. This enables application of cell-specific (5 x 1m area) downstream ratios, if sufficient sample sizes are achieved. Once further exploration of mobile speed procedures is completed, dynamic, stratified offshore swim speeds will also be allowed to vary in a similar method by the FishR program.

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B17. Imputation of abundance during fishing periods

K.M. Hayward

Summary

The estimation of daily salmon abundance at the PSC Mission hydroacoustics site assumes that 24 hours of monitoring have occurred. However, any fishing activity within site boundaries results in temporary cessation of offshore data collection and could introduce biases in abundance estimation by impacting fish behaviour. As of 2022, the Mission Imputation Protocol has enabled the PSC to address data quality concerns by interpolating data that are impacted by fishing activity. Customized R scripts are used to produce the Mission Imputation Report, which documents options (linear or non-linear) for imputation of sonar-specific daily abundances, results of each potential method and relevant information for decision-making. Using the report and applied knowledge, PSC biologists select an imputation approach for each sonar system. On average, percent error associated with imputed estimates of daily salmon abundance is less than half the error of simpler interpolations, such as use of daily averages or assuming the previous day's abundance. The resulting imputation method can also be applied to fill in missing data due to other causes, e.g., when systems are moved, during system malfunctions.

Introduction

The Mission hydroacoustics site uses three sonar systems to monitor salmon abundance: one ARIS for each nearshore area and one mobile, downward-looking ARIS for the offshore region (Chapter B8). Estimates of daily abundance from each area assume that 24 hours of monitoring data are available. However, data gaps may occur due to technical issues (e.g., relocation of systems due to changing water heights, system malfunctions, vessel mechanical issues), or safety concerns (e.g., docking of the mobile transecting vessel due to weather). If less than 24 hours of data are available, an imputation of missing data is required.

In 2022, Semá:th First Nation, DFO, and the PSC signed a memorandum of understanding that exempts Semá:th Food, Social, and Ceremonial (FSC) driftnet fisheries from fishing boundary closures at the PSC Mission hydroacoustic site (Semá:th, DFO, and PSC 2022). This operational protocol stipulates that the PSC will cease mobile transecting during FSC fisheries, in order to respect Semá:th First Nation's inherent rights and allow fishing to occur safely. Cessation of transecting, however, creates data gaps that violate the assumption of 24-hour monitoring in the site's offshore region. In addition, fish behavioural responses (e.g., milling, holding, altered cross-river distributions) during and directly after fisheries can introduce bias to both shore-based and mobile-based estimates (Conrad et al. 2019).

The Mission Imputation Protocol aims to mitigate these concerns and improve quality of daily abundance estimates for days with FSC fishing at the Mission site. Development of the imputation involved a retrospective analysis, which compared daily salmon abundance estimates obtained by imputing artificial and historical fishing data gaps to corresponding, original daily estimates from both Qualark and Mission. As of 2022, the resulting imputation procedure has been implemented as needed during in-season monitoring. On days that FSC fisheries occur (or data gaps are otherwise produced), the imputation is performed once system-specific data have been processed and the standard procedures for abundance estimation based on available data has already occurred (Chapter B8).

Methods

INTERPOLATIONS

The Mission imputation provides two options for interpolating data: one linear and one non-linear method. Both approaches use data from non-imputation hours (i.e. data from outside of the data gap for a given day) to fill in or impute salmon abundance during the data gap for a target day (Figure 1a). For both methods of interpolation, the abundance from non-imputation hours (n_t) and interpolated abundance from imputation hours (i_t) are recombined to provide a daily estimate of total salmon abundance (N_t) on the target day:

$$(1) \qquad N_t = i_t + n_t.$$

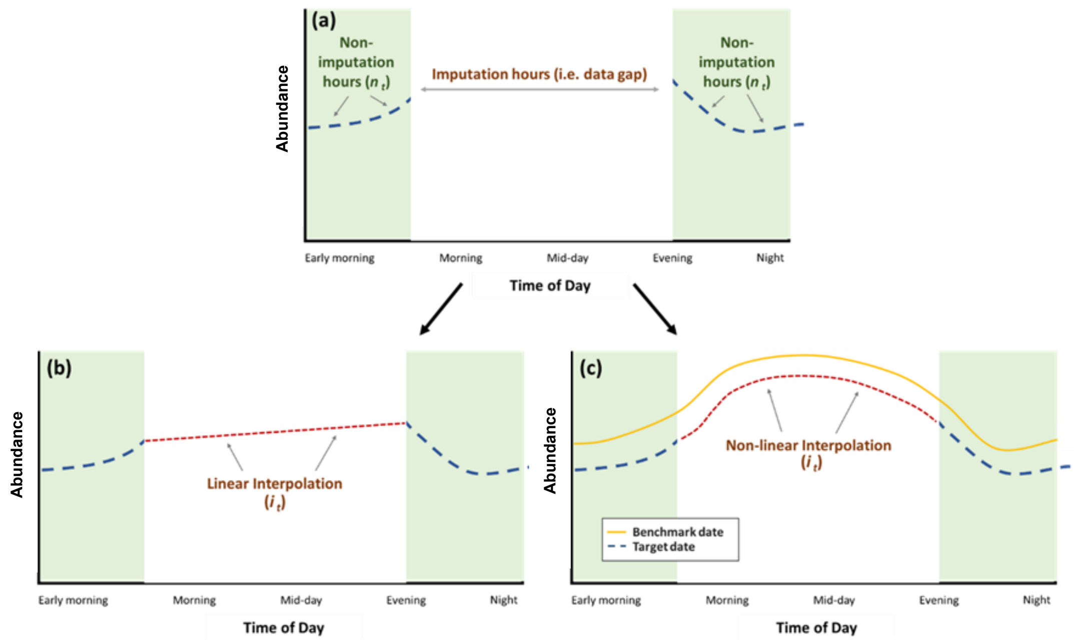

Figure 1. *The Mission Imputation is required when a "target day" has a data gap i.e., consists of non-imputation and imputation-required hours (a). There are two methods to interpolate missing hourly abundance data: (b) a linear interpolation that linearly approximates between the hours directly before and after a data gap, and (c) a non-linear interpolation that applies the ratio between salmon abundance during non-imputation (n_t) and imputation (i_t) hours from a previous benchmark day to the target day.*

How the abundance during the hours with missing data (i_t) is estimated differs between the two interpolation methods. The linear method performs a simple linear approximation to connect abundance immediately before and after a data gap (Figure 1b). In contrast, the non-linear approach requires data from a previous day (typically one directly preceding a target day) to be used as a 'benchmark' (Figure 1c), and assumes that hourly abundance patterns on benchmark and target days will be similar due to daily tidal patterns. A benchmark day is selected based on proximity to the target day and absence of data continuity or quality concerns (e.g., due to fishing, system moves). To perform the non-linear interpolation, data from the benchmark day are designated as imputation (i_b) and non-imputation (n_b) hours to mirror the target day (Figure 2).

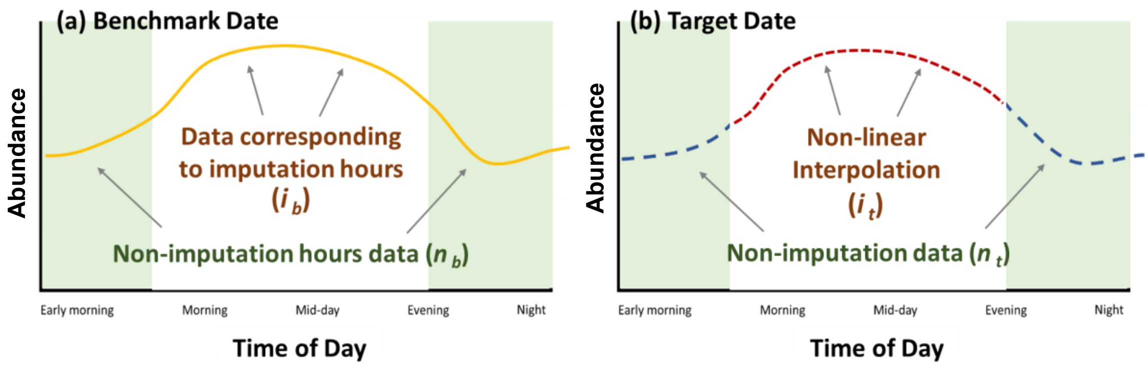

Figure 2. *The non-linear imputation involves: (a) splitting benchmark day data into imputation (i_b) and non-imputation (n_b) hours, which are coincident with (b) a data gap (imputation hours, i_t) and available data (non-imputation hours, n_t) from the target day, respectively.*

Based solely on benchmark day data, a ratio of salmon abundance during imputation (i_b) to non-imputation hours (n_b) is calculated. This ratio is then applied to non-imputation data (n_t) from the target day to interpolate abundance for the target day's imputation hours (i_t):

$$(2) \qquad i_t = \left(\frac{i_b}{n_b}\right) n_t \,.$$

Combining Equations 1 and 2, the daily abundance for a target day using the non-linear imputation is:

$$(3) \qquad N_t = \left(\frac{i_b}{n_b}\right) n_t + n_t.$$

RETROSPECTIVE PERFORMANCE

To test the performance of the interpolation methods prior to in-season implementation, a retrospective analysis using a four-year dataset (2018-2021) was conducted (Bzonek and Hornsby, 2022). Linear and non-linear methods were applied to: (1) artificially simulated fisheries, produced by removal of offshore data from non-fishing days, and (2) historical fishing days. Evaluations also explored the impact of fishery length (simulated or historical) and consecutive fishing days on the performance of the imputation methods. Performance was assessed by comparing imputed daily abundance estimates to corresponding, non-imputed (original) estimates from both Mission and Qualark.

Applying the imputation to simulated and historical fisheries reduced daily estimates by 1.5% and 0.4% over full seasons, respectively. Overall, the imputation brought Mission- and Qualark-based abundance estimates 1% closer (Bzonek and Hornsby, 2022). Imputed Mission abundance estimates specifically had an unweighted average bias of -4%, with bias being slightly larger for linear (-5%) than non-linear interpolations (-3%) and the linear bias being more pronounced during high and very high abundance days. Relative to simpler interpolation methods such as using daily averages or assuming the previous day's abundance, imputed Mission estimates displayed half the percent error compared to the simpler methods.

Both linear and non-linear interpolation methods show relatively low bias when applied to short fisheries openings (<10 hours). However, the performance of the linear method is negatively impacted by long fisheries (10 hours+). Linear interpolations significantly underestimate abundance during long fisheries, which is likely due to smoothing over daily, tidal-related patterns of salmon migration. In contrast, performance of the non-linear method was affected by consecutive days of fishing. As the relevance of the benchmark day to the target day decreases with more days in between, consecutive fishing days result in larger potential error. To reduce error, the PSC has recommended shortening fisheries openings, particularly on a third day of consecutive fishing, to enable use of the linear method. Overall, these findings have informed a default preference for the linear method during short and medium-length fisheries and the non-linear method during long fisheries and high abundances (with an exception in the case of consecutive fishing).

IN-SEASON APPLICATION

For days requiring imputation, a daily total salmon estimate is produced using available data and the standard abundance estimation protocols (Chapter B8). Once an estimate is created, customized R scripts can be used to produce the Mission Imputation Report. Within the scripts, users can specify which sonar systems require imputation, target and benchmark days, and hours requiring imputation. Imputation is performed for each sonar system individually and thus, users decide for each system: (1) whether to use non-imputed abundance or imputed abundance estimates and (2) which method to use if imputation is selected (non-linear or linear).

Selection of an interpolation approach is complicated by multiple factors that influence imputation performance. Decision-making is currently assisted by diagnostics provided in the Mission Imputation Report, visual inspection of system data, and assessment of contextual cues and expectations. The report suggests a “best” method for each system based on length of imputation period and three diagnostic flags (two linear, one non-linear). For imputations less than 10 hours, the report will typically advise the linear method. The non-linear method is favored for longer time periods, during high abundance (e.g., peak pink salmon), and when the linear method displays poor fit (two diagnostic flags) during shorter periods (Bzonek and Hornsby 2022). If diagnostics raise concerns for both methods, the report will default to the linear method.

Both the linear diagnostics attempt to identify extreme values that could have undue impact on / bias the linear estimate. The first linear diagnostic provides a flag when abundance values directly adjacent to an imputation period are extreme, i.e. within the most extreme 10% of hourly values. The second linear diagnostic provides a flag when the value directly following the imputation period differs drastically from the average of the next two hours. The non-linear diagnostic aims to assess the level of mismatch between the chosen target and benchmark days, providing a flag when the total difference between their scaled hourly values is flagged as high based on historical simulations (Bzonek and Hornsby, 2022). The level of mismatch in temporal patterns between the benchmark and target days should also be evaluated using the plots provided by the Mission Imputation Report.

The suggestions provided by the Mission Imputation Report are best used to inform and guide, rather than provide sole justification for decision-making. Users may or may not select the method proposed by the report, as it is still currently limited in its ability to assess all factors impacting imputation performance. Prior to generating the report, users should consider migration conditions and how fishing activity (e.g., effort) may impact fish behaviour. Of particular note are the characteristics of the fishery (location, effort), as well as changes in observed fish behaviour, e.g., milling/holding, shifts in cross-river distribution between target and benchmark days. Once the imputation is performed, users should assess whether the imputed values make sense in the observed context. Due to this inherently subjective nature of decision making, a decision tree was created to aid standardization (Figure 4).

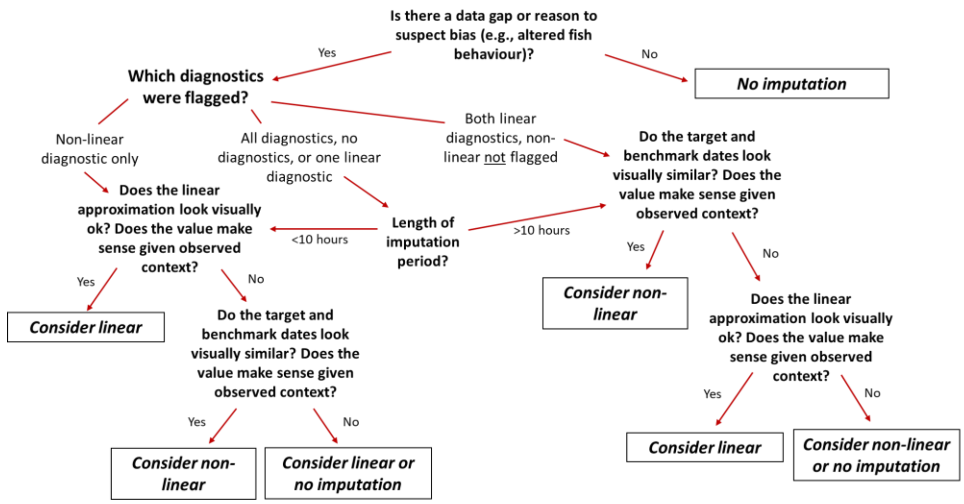

Figure 4. *A decision-tree to facilitate the selection of imputed values for the different sonar systems based on the information provided in the Mission Imputation Report.*

Planned Changes & Potential Areas for Improvement

Current planning includes exploration into improving the current diagnostics and development of new ones to aid decision-making and reduce subjectivity. Some prospective diagnostics include comparing shore-based:offshore abundance ratios between benchmark and target days, indicators of altered fish behaviour (e.g., based on downstream ratios), and environmental markers. Other interpolation methods may also be investigated, along with work on improving the current methods (e.g., added ability to impute across days).

The current agreement between Semá:th, DFO and PSC does not permit the use of set nets within the Mission boundary. Ongoing set-net experiments are assessing how their use may affect the quality of Mission estimates, with the goal of identifying and evaluating ways to mitigate the impact going forward.

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B18. Length-based mixture model for imaging sonars

K.M. Hayward, J.L. Nelitz, C. Lagasse, and Y. Xie

Summary

The Pacific Salmon Commission (PSC) has multiple methods at its disposal to assess relative abundances of co-migrating salmon species (Chapter B19). Since 2011, information collected from imaging sonars on the left and right banks of the PSC hydroacoustic site at Mission, BC has been used for one such method of species composition evaluation. Current procedures involve staff measuring a subsample of fish lengths from 24 hours of ARIS data. As of 2024, only targets larger than 35 cm in length (excluding sturgeon) are included. A mixture model with test fishing-derived priors for species-specific fish lengths is fitted to the distribution of unweighted daily length data through maximum likelihood estimation. The model ultimately generates nearshore proportion estimates of jack Chinook, adult Chinook, sockeye, and pink salmon, with the latter two used for in-season assessments of Fraser River sockeye and pink salmon (Chapter B19).

Introduction

The PSC hydroacoustic program at Mission, BC uses Adaptive Resolution Imaging Sonars (ARIS) to enumerate salmon migrating along both banks of the Fraser River (Chapter B15). As the mandate of the Mission program specifically relates to sockeye and pink salmon, co-migrating species must be differentiated. At various times, sockeye and pink migration overlap (mid-August to September), as well as adult/jack Chinook (June through October), chum (late September), and coho (late September) salmon. The PSC deploys multiple methods to evaluate species composition in these nearshore areas (Chapter B19), including a mixture model that relies on hydroacoustic-derived fork length measurements. In 2011, Mission began applying this model to officially estimate sockeye and pink-specific nearshore abundances. This document describes the key data and procedures for application of the length-based mixture model used to evaluate nearshore species composition at the PSC Hydroacoustic site in Mission, BC.

Data

The mixture model requires two data inputs to create length-based estimates for nearshore species composition: 1) fork length measurements from shore-based imaging sonars on the left and right bank, and 2) prior information on salmon fork lengths from current and historical test fishing data.

ACOUSTIC-DERIVED FORK LENGTHS

Daily, a total of 8 hours (per sonar configuration) of sonar imaging data are subsampled for fork length measurements (Chapter B15). The 8 hours are evenly distributed throughout the 24-hour period (5 am, 8 am, 11 am, 2 pm, 5 pm, 8 pm, 11 pm, 2 am). For both left and right bank ARIS, lengths are measured on all sonar configurations up to a range of 20 metres. Beyond 20 metres, image quality is unsuitable for length measurements. Hydroacoustic staff use Sound Metrics' ARISFish software to measure the first 20 targets identified as larger than 35 cm, excluding sturgeon. Since 2024, only targets with fork lengths larger than 35 cm are counted and measured. It is assumed all fish larger than 35 cm are predominantly salmon but include a small proportion of large resident fish, while targets of 35 cm or smaller are assumed to be small resident fish (e.g., Peamouth Chub, Red-sided Shiners). Using the software, lengths are completed on selected targets by measuring from nose to tail fork. Although measurements are subject to random error associated with image resolution (i.e., blurring of nose or tail fork), comparisons between biological and acoustic-derived measurements of sockeye show no directional bias (Xie et al. 2013). By sampling each sonar configuration up to 20 metres offshore, up to 480 salmon-sized targets are measured each day using left bank ARIS data, while up to 320 targets are measured daily using right bank ARIS data.

TEST FISHING-DERIVED PRIORS

Prior information on mean fork length and coefficient of variation (CV) are required as inputs for the mixture model. Typically, mean fork length is calculated based on the observed lengths of Whonnock test fishery catch during the previous 7 days. This is to ensure that priors reflect current in-season lengths of actively migrating stocks. If sample sizes from Whonnock are insufficient, such as early in season, either a longer period or historical prior may be used until sufficient data are obtained. During the migration of pink salmon, Whonnock has a known bias toward catching larger salmon. If the Matsqui fishwheel is operational, lengths from wheel-caught pink salmon will be included to help mitigate this bias.

Because acoustically-derived fork length data are subject to random error due to factors such as target range and aspect angle, the model uses a sigma or CV that is larger than that of the true length distribution, i.e., 13% vs. 6% (Figure 1). A CV of 13% is assumed for both sockeye and Chinook length distributions. CV is assumed to remain constant throughout the season based on data collected during initial imaging sonar studies conducted at the Mission site (Xie et al. 2013).

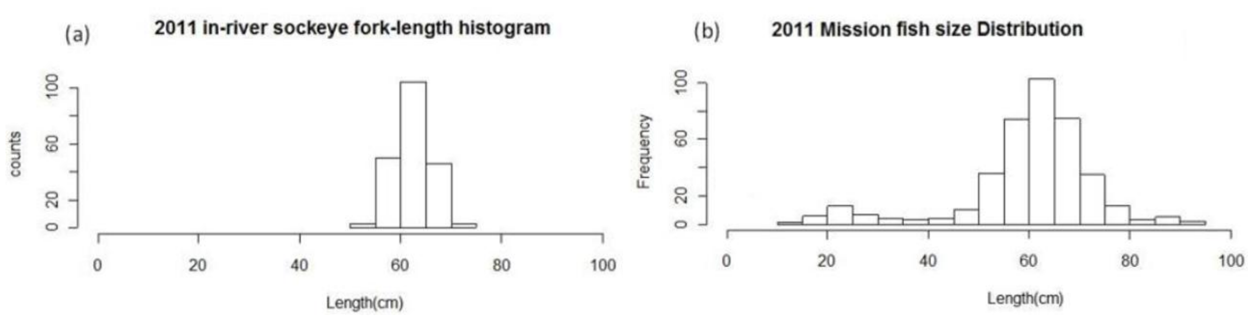

Figure 1. *Fork Length data from Whonnock and Mission, Aug 17-20, 2011 (Xie et al 2013): (a) histogram of fork-length from 206 sockeye salmon caught at Whonnock, and (b) histogram of lateral length measurements of 394 Sonar fish images at Mission during the sockeye dominant migration period. The mean of the biological fork length is 62.4 cm and the mean acoustically measured length is 62.3 cm. The standard deviations of the two data sets are 3.6 cm and 8 cm, resulting in coefficients of variation of 6% and 13%, respectively.*

Methods

To estimate the proportion of each salmon species based on salmon length measurements obtained from sonar imaging data, a mixture model is fitted to the distribution of hydroacoustic-derived fork length data. An unweighted maximum likelihood estimation approach is used for each individual sonar configuration (range, aim configuration). The term unweighted refers to all length data collected throughout the day being assessed equally, rather than weighted by abundance for individual hours. In other words, for each sonar configuration, all length measurements are pooled for the day. On low abundance days when less than 20 salmon-sized targets can be identified and measured from the sonar imaging files, the approach automatically morphs into a weighted approach based on the number of available size measurements. For each individual configuration, daily fork length data are plotted as a distribution and separate length-based mixture models are fit to each (Figure 2). Models are performed using customized R scripts (https://rstudio.com/). For each sonar configuration, the scripts require the following specifications:

1) the number of groups or species to be classified (3 or 4),
2) the mean fork length prior for each salmon group to be classified,
3) the modelling approach to be used: maximum likelihood estimation (MLE), discriminant function analysis (DFA), or a single-value-threshold (SVT) method. By default, the MLE (unweighted) model is used for species composition estimation. The other two models are for comparative purposes only.

The most common number of groups to fit to the data is 3: large resident fish/jack chinook, sockeye, and adult Chinook. Because lengths of jack Chinook overlap significantly with lengths of large resident fish such as northern pikeminnow and sucker fish, the model currently treats these as one group and is therefore unable to provide accurate estimates of jack Chinook. On odd years, pink salmon may be added as a fourth group during their migration. Depending on the year and the difference in mean length between sockeye and pink salmon, the overlap in fork length distributions between pink and sockeye salmon may be substantial, thereby increasing the difficulty to obtain reliable model results.

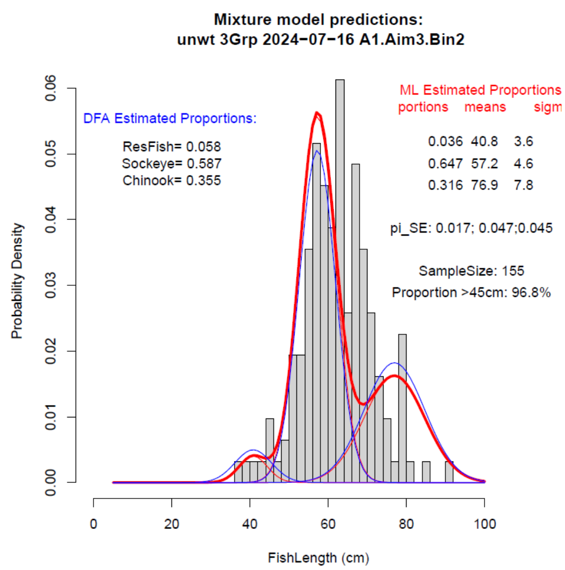

Figure 2. *Fit of the length-based mixture model to fork length data from 155 targets (> 35 cm) imaged by the left bank ARIS in the 20-30 metre range on July 16, 2024. Using the length distribution and provided priors, the mixture model (unweighted, MLE option) estimates 3.6% large resident fish/jack Chinook, 64.7% sockeye, and 31.6% adult Chinook salmon. In this figure, the term “ResFish” refers to a mixture of large resident fish and jack Chinook.*

Planned Changes & Potential Areas for Improvement

In 2024, significant changes were made to the total salmon estimation process by excluding targets smaller than 35 cm, negating the need for a length-based model to differentiate small resident fish from salmon. This has resulted in the discontinued use of the previous mixture model methods outlined in Michielsens and Martens (2022).

However, species composition estimates continue to be subject to large uncertainties during periods of pink migration and/or relatively high jack Chinook abundance. This is due to large overlaps in average fish lengths among species, as well as biases in test fishing-derived priors, e.g., due to differing and changing relative catchability among species.

Due to limitations associated with the MLE model, a new species composition modelling approach is currently being developed (van Dam-Bates et al. 2025). The project aims to estimate species composition proportions at both Mission and Qualark by applying a Bayesian integrated model. This model will integrate hydroacoustic-derived fork length measurements, species-specific test fishery counts and relies on additional information such as species-specific differences in the distance to shore and variation in species-specific catchability.

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B19. Species composition

C.G.J. Michielsens

Summary

Species composition estimates are essential for translating daily fish passage estimates at the hydroacoustic site at Mission, BC (Chapter B14) into daily sockeye abundance estimates. A wide variety of different data sources and methods have been developed and implemented to derive species composition estimates. The different methods each have their own shortcomings which may be more pronounced depending on sample sizes and the relative and/or absolute abundance of the different species. The selection of the method to estimate species specific abundances is dependent on the concurrence between estimates, known biases under different conditions, and sample sizes. Because of the large uncertainty associated with the various species composition estimates, a new integrated Bayesian model is being developed (van Dam-Bates et al. 2025). The following reports provide an overview of the currently available methods and describes some of the biases.

Introduction

As part of the Treaty agreements (PST 2025, Diplomatic Note of August 13, 1985), the Fraser River Panel is responsible for the collection of hydroacoustic data at Mission, BC, and the enumeration of sockeye and pink salmon passage past the site. Within the Fraser River, Chinook, chum, and coho salmon comigrate with sockeye and pink salmon, requiring daily species composition estimate to derive stock-specific time series. Although the Whonnock test fishery (Chapter B3) employs a net with multiple mesh sizes, traditional species-composition estimates based on Whonnock catch proportions are biased due to differences in catchability among species and sizes. These biases are particularly pronounced in odd-numbered years, when pink salmon are present in high abundance relative to other co-migrating species. The resulting bias is most evident in the overestimation of Summer-run sockeye compared with spawning-ground assessments, and in the unrealistically high estimates of Chinook and coho salmon during pink salmon migration.

A variety of alternative analytical approaches exist to estimate species composition; however, all have distinct and differing limitations, and none consistently outperform the others across years or across shifting in-season conditions. Consequently, current in-season assessments rely on comparing outputs from multiple methods, with the selected approach determined subjectively based on convergence between methods. The following paragraphs outline each of the different species composition methods and known sources of bias.

Methods

A multitude of different species methods are used to derive daily sockeye and pink salmon abundance estimates from the total daily salmon passage estimates (Table 1, Martens et al., 2019, Michielsens and Cave, 2013). Traditionally, salmon species composition is derived from **catch data collected by the Whonnock test fishery** with the proportions based on gilled and girthed catch (Chapter B3). In case of low daily salmon catch numbers (<15), catches also include tangled salmon. When catches are low, these estimates are however very uncertain and highly variable. In addition, this method has some known biases as pink salmon, who migrate primarily near-shore, tend to be less vulnerable to this test fishery, resulting in an underestimate of pink salmon abundance. Chinook salmon on the other hand tend to have a higher catchability, resulting in an overestimation of Chinook abundances. Similar analyses can be done with the **catch data from the Qualark test fishery** (Chapter B3). The resulting daily sockeye abundance estimates can be considered minimum estimates of the abundance that passed the Mission site given the fact that several sockeye stocks migrate past Mission but do not pass Qualark, i.e. Chilliwack (Early Summers); Harrison (Summers); and Birkenhead, Big Silver, Weaver, and Cultus (Late run). For Chinook, the daily abundance estimates at Qualark early in the season can be considered estimates of the Chinook abundance at Mission given that the Chinook stocks that do not migrate past Qualark, i.e. Chilliwack and Harrison, are later timed fall Chinook. The same concerns about assuming equal catchability applies for this method. The **catchability correction model** (Xie et al. 2025) aims to reduce the potential biases due to differences in catchability by estimating a different catchability for the different salmon species. In recent years, the correction to the resulting sockeye abundances have been limited to the low sockeye catches.

An alternative estimate of daily sockeye abundance at Mission can be obtained by using **sockeye CPUE data from the Whonnock test fishery** (Chapter B3) in combination with a historical expansion line estimate (1/catchability, Chapter B6). This method is regularly relied upon early in the season when no hydroacoustic data are yet available, or in pink salmon years when daily salmon abundances are dominated by pink salmon stocks. While the daily sockeye abundance estimates derived from CPUE data may differ substantially from the hydroacoustic based sockeye abundance estimates when available, averaged over three days, the CPUE based method produces similar abundance estimates unless catchability in a given year deviates substantially from average. The **Chinook CPUE data from the Albion test fishery** (Chapter B3) can be similarly used in combination with a historical expansion line estimate to derive daily Chinook abundance estimates at Mission (Hawkshaw 2018). In cases when salmon species are limited to sockeye and Chinook salmon, the daily sockeye abundance can be estimated by subtracting the daily Chinook abundance estimates from the total daily salmon estimates. Similar concerns remain about the representativeness of the historical catchability estimates in the current year.

In the past, there has been clear evidence that the differences in catchability estimates can lead to overestimated Chinook abundance estimates, whereby the sum of the daily reconstructed Chinook abundance greatly exceeded the total post-season run size of Fraser River Chinook. To ensure daily estimates are in-line with realistic total run size estimates for Chinook salmon, the **preseason Chinook run size forecasts** of 6 different Chinook groups (Spring 1.2, Spring 1.3, Summer 1.3, Summer 0.3, Chilliwack and Harrison) (DFO 2026) are used in combination with the timing and spread of each stock group to forecast daily Chinook abundances across the season and the associated uncertainty around those daily estimates i.e. the 95% probability interval (Figure 2). In case no alternative species composition data are available due to a lack of test fishing catches or if the resulting estimates are considered unreliable, the median forecast of the daily Chinook abundance can be used to derive daily sockeye abundance estimates. Alternatively, the upper 97.5% confidence limit can be used to cap the daily Chinook abundance estimates derived from test fishing catch data. While it is possible to exceed the upper confidence limit on a given day or several days, consistently exceeding this limit would require that Chinook returns exceed the 97.5th percentile of the forecast.

In recent years, returns of Fraser River sockeye have been extremely low. As a result, the relative sockeye abundance has decreased, and the importance of accurate species composition estimates increased. The majority of the species composition methods discussed thus far rely on in-river test fisheries whose catches decrease with decreasing abundances. In recent years, it has been especially challenging to obtain catch data early in the season when abundances are lowest or for catches to be sufficiently large to obtain desired sample sizes from which to derive species composition estimates. Hydroacoustic length information has not experienced similar sample size challenges and the **stratified species composition method** has been used to derive salmon species composition estimates (Chapter B18). The method is stratified as it relies on the hydroacoustic length information and the mixture model for the species composition of the salmon abundance along the left and right bank and the Whonnock test fishing catch data for the species composition in the midsection of the river. The mixture model however performs best when the different species differ substantially in mean lengths which is the case when distinguishing sockeye from resident fish. Pink and sockeye salmon are however more similar in length and especially in years with larger pink salmon and smaller sockeye, the limited difference in average lengths may result in increasingly uncertain species composition estimates. Alternatively, fish wheel information can be used for the species composition along the shore.

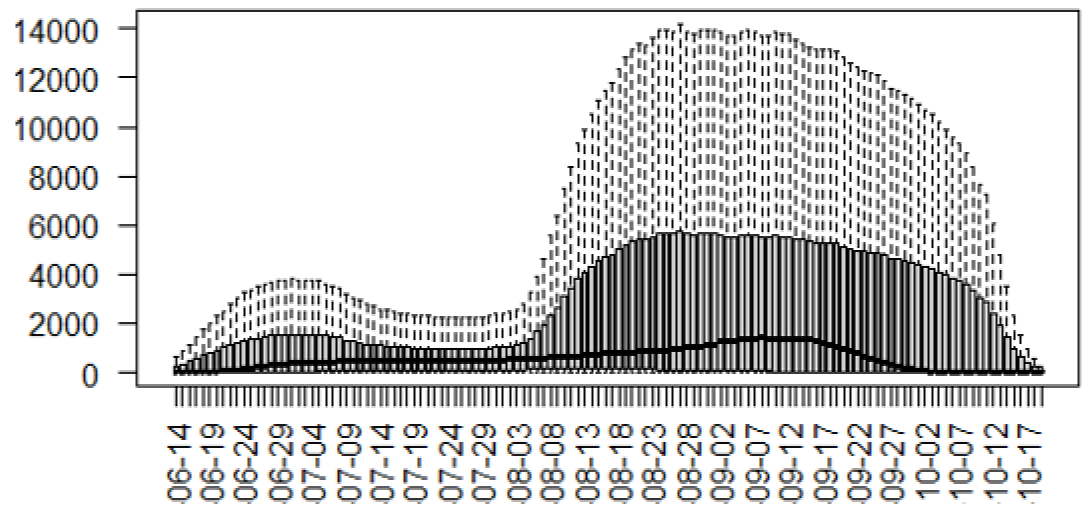

Figure 1. *Boxplot of daily Fraser River Chinook abundance forecasts, based on 2020 run size forecasts for Spring 1.2, Spring 1.3, Summer, 1.3, Summer 0.3, Chilliwack and Harrison Chinook, used in combination with migration timing and spread estimates (DFO 2020).*

Other methods exist to estimate in-river species composition and these are tracked but not used very often given the large associated uncertainty. One of those methods relies on **marine CPUE data** of Fraser River sockeye used in combination with an expansion line (Chapter B5). The resulting daily marine abundance estimates can be used in a forward reconstruction to predict the number of sockeye within the river. When using this method for species composition, only historical expansion lines can be used, resulting in the larger uncertainty as using the in-season expansion line requires knowing the sockeye abundance at Mission.

While there exist many different methods to estimate species composition, they all have some shortcomings that may substantially bias species composition estimates under certain conditions. In-season, the different methods are run jointly, and the resulting sockeye, Chinook and pinks salmon abundances are compared. Concurrence in abundance estimates when relying on multiple different methods will provide increased confidence in the use of species composition estimates derived from those methods while deviation from other estimates will decrease an estimate's credibility.

Planned Changes and Potential Areas for Improvement

Improvement to the estimation of the species composition has been one of the recommendations identified during the Hydroacoustic Review (Conrad et al., 2019). Currently, an integrated Bayesian species composition model is being developed that combines the species-specific catch data from the Whonnock test fishery with hydroacoustic length information (van Dam-Bates et al. 2025). It is anticipated this model will remove the subjective choices associated with picking a species composition method under a wide variety of challenging in-season scenarios.

Table 1. *Overview of different data sets and methods used to estimate daily abundances of different salmon species at Mission, their in-season use and concerns regarding their application.*

Data and method	In-season use and concerns
Whonnock catch proportions	• Traditional species composition method • Sample sizes may be insufficient to derive (reliable) estimates • Catchability differs across species • May overestimate Chinook and underestimate pink salmon
Qualark catch proportions	• Resulting Chinook and sockeye estimates can be used as minimum estimates at Mission • Sample sizes may be insufficient to derive (reliable) estimates • Catchability differs across species
Catchability correction model	• Reduces potential biases due to differences in catchability • Corrections may be insufficient to remove substantial biases
Whonnock CPUE-based sockeye abundance	• Used prior to the start of the hydroacoustic program • Used when pink salmon dominate in-river abundances • Sample sizes may be insufficient to derive (reliable) estimates • Daily catchability may vary greatly, and 3-day average is more stable • Catchability may differ from average historical catchability
Albion CPUE-based Chinook abundance	• Used to estimate sockeye by subtracting Chinook from total salmon estimate when dominated by sockeye and Chinook • Sample sizes may be insufficient to derive (reliable) estimates • Catchability may differ from average historical catchability
Pre-season Chinook forecast and 95%CI	• Used to ensure daily Chinook estimates are reasonable given the total Chinook forecast • Forecasts are uncertain • Daily estimates may fall outside the 95% CI
Length-based mixture model	• Used when test fishing sample sizes are too low to derive catch proportion estimates • Uncertain when mean length differences between species are small
Forward reconstruction based on marine data	• Early predictor of in-river abundances • Highly uncertain given the uncertain marine catchability estimates

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B20. In-season application of stock ID information

E.S. Jenkins, F.J. Martens and C.G.J. Michielsens

Summary

Fraser River sockeye are managed by management group, as per the Pacific Salmon Treaty. Therefore, stock proportion estimates must be applied to catches, in-season abundance indices, and escapement estimates in order to split the data into the four current management groups. Sockeye catch samples are taken from test fisheries (Chapter B7), as well as other fisheries when available, and the mix of stocks within that sample is determined through scale and genetic analyses (Chapters B10 and B11). The resulting stock proportion estimates are not only used to determine the stock proportions of the total catch from which the sample was taken, but are also assumed to represent the stock proportions of the sockeye that escaped the fishery and continued their upstream migration. If no samples are taken to represent a particular catch, then stock proportion estimates based on another catch (that best represents that group of fish) are applied. The resulting stock-specific estimates of catch and escapement past Mission are then used in further reconstructions to assess, for each management group, the total run size in marine areas (Chapter B21), as well as the potential escapement to the spawning grounds.

Introduction

According to the Pacific Salmon Treaty (PST 2025, Chapter 4, section 3), Fraser sockeye salmon stocks are managed as part of four stock management groups: Early Stuart, Early Summer run, Summer run and Late run. This stipulation within the treaty requires salmon catches and escapement abundance estimates to be split into the four different stock aggregates corresponding with each of the four different management groups.

PSC staff conduct sampling programs designed to identify stock proportions of Fraser River sockeye salmon in marine areas as well as in the river. This is done by sampling the catches from test fisheries; these samples are assumed to represent the stock composition of the available fish. The resulting stock composition estimates are used in combination with daily abundance estimates obtained from in-river hydroacoustic data (Chapter B14) and from marine catch-per-unit effort (CPUE) data (Chapter B4) to derive daily abundance estimates by management group, both in marine areas as well as in the river. Stock proportions are also applied to assign catches by the different fisheries (commercial, test, Ceremonial & Subsistence (C&S), First Nations, and recreational fisheries) to different management groups.

Stock proportion estimates are essential for reconstructions. For backwards reconstructions (Chapter B21), the stock-specific daily escapement estimates past Mission are added to the stock-specific catch abundances seaward of Mission, resulting in stock-specific daily marine abundance estimates. These marine daily abundance estimates allow for assessment of the associated run size, either using time density models (Chapter B23) when only part of the run has been observed in-season, or using the total marine abundance when the entire run has been observed. Similarly, forward reconstructions using stock-specific daily escapement estimates past Mission, in combination with stock-specific daily catch abundance estimates upstream of Mission, allow for the prediction of the number of spawners expected to reach the spawning grounds or other locations within the watershed (Qualark, for example).

Data

The data required for daily reconstructed abundance estimates include catch, escapement, and stock ID (as well as the stock ID sample size). To derive time-series' of stock-specific daily abundance estimates, the daily estimate of total sockeye escapement past the hydroacoustic site at Mission is multiplied with stock proportion estimates derived from catch samples. Stock-specific catch data are included for backward reconstructions of the marine abundance estimates, as well as the forward reconstructions of the potential spawning escapement. Further information on the derivation of daily abundance estimates at Mission, daily catch information, and daily stock proportion estimates from catch samples can be found in Chapters B14, B21, and B10, B11, respectively.

Currently, 20 different sockeye stocks are accounted for in the stock proportion estimates: 19 Fraser River sockeye stocks and the remaining non-Fraser stocks, which are combined into one group (Chapter B11). The majority of the samples analyzed using scale reading and DNA methods are obtained from test fishing catches (Chapter B7). As a result, for each of the test fishing locations, there exist 20 time-series of stock proportions covering the entire duration of a fishery. Additional catch samples from commercial, C&S, First Nations, and recreational fisheries are also analyzed. However, the logistics of collecting, transporting and analyzing samples from these additional fisheries in a timely fashion for in-season assessments is complex, and the resulting time series of stock proportion estimates may not cover all fisheries in all areas for their full duration. In addition, limited abundances and / or low salmon catchability may result in sample sizes below the recommended 100 fish in marine area test fisheries and 50 fish for in-river test fisheries. Therefore, the size of the sample from which the stock proportion estimate has been derived is important for the successful application of stock proportion estimates. The sample size helps to determine the uncertainty associated with an estimate; it can also indicate the need to combine stock proportion estimates across multiple days.

Method

Stock proportion estimates are applied to both abundance and catch estimates. It is important that the stock proportion estimates are applied to *all* days and areas associated with the abundance time series, not only the days on which the catch was taken or for the fisheries from which the catch was taken. There are several options to estimate stock proportions when no sample was taken or analyzed on a given day or for a particular area. Stock proportions can be borrowed from a previous or following day, interpolated between days before and after, or borrowed from a nearby fishery. In cases where information from other fisheries is used, the date of the information is offset to reflect the time required for the sockeye to migrate between the two fishing areas, therefore ensuring that the stock proportion information from the other fishing area reflects the same block or group of fish. In cases where a sample size is much smaller than the recommended amount, the samples for several days may be combined and the resulting stock proportions applied to the catches on all of the days included in the sample. Especially in the river, limited sample sizes can be a serious issue that requires more complex methods to combine stock proportion information from various samples.

Once stock proportion time series have been completed and cover all days, areas, and fisheries for which abundance estimates or catch data are available, they can be multiplied to generate stock-specific daily abundances and catch estimates (Figure 1). These stock-specific estimates can be summed by management group and across days to generate management-group-specific estimates of abundance and catch to date. In addition, the stock-specific daily estimates can also be used within backward reconstructions to generate stock-specific daily marine abundance estimates, or within forward reconstructions to calculate stock-specific daily abundance estimates expected to reach the spawning grounds (Chapter B21).

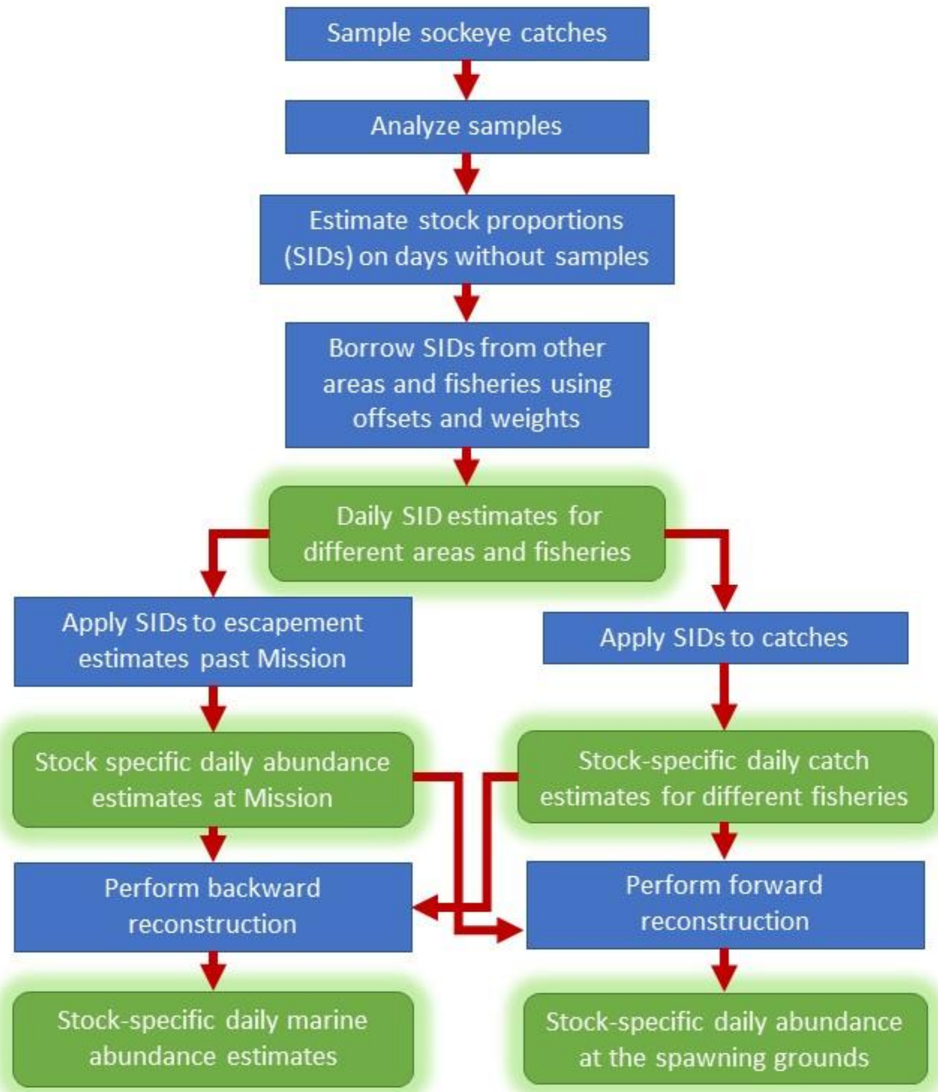

Figure 1. *Data flow for the collection and application of stock proportion estimates to escapement estimates and catch data. Used within reconstruction models, it allows the generation of stock-specific daily abundance estimates in marine areas (to be used for run-size assessment purposes) and at the spawning grounds (to be compared against spawning escapement targets). Processes are represented by blue rectangles and resulting estimates by green rectangles with rounded corners.*

Planned Changes and Potential Areas for Improvement

Currently, within the in-season files, 20 different sockeye stock groups are accounted for by the stock proportion estimates. The files associated with the assignment of stock proportion estimates to catch and escapement data are therefore called the CR20 files (Catch and Racial files for 20 groups). Based on DNA stock ID methods, the number of groups can however be expanded to close to 50 Fraser stocks and 37 non-Fraser stocks. To generate stock-specific summaries of catch and passage past Mission, PSC staff have developed CR100 files that allow to store the data at their finest resolution (Chapter C3). This ensures increased flexibility in terms of grouping the different stocks and ‘rolling-up’ the estimates according to the different groupings. At present, the CR100 files have only been used post-season

(Chapter C3) and to populate the RuFEs (Run Size, Fishing, and Escapement) database (Chapter C17). It is however possible to use the CR100 framework as well in-season, but it would require the addition of stock-specific tracking of catch release mortalities and the inclusion of Fraser River pink salmon in the files.

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B21. In-season marine reconstructions

M.J. Hague and C.G.J. Michielsens

Summary

Run reconstructions are a key tool for fisheries stock assessment and allow biologists to combine catch and escapement data to estimate daily abundances and annual run size. The Pacific Salmon Commission (PSC) is responsible for developing and applying run reconstruction models for Fraser River sockeye salmon as well as disseminating and archiving the resulting estimates. In-season reconstructions are applied both forward and backwards. Forward reconstructions predict stock-specific escapement into the river based on marine daily abundances derived from stock-specific catch-per-unit-effort (CPUE) data from marine test fisheries (Chapters B2 and B4) combined with assumptions about migration speed and delay behaviour (Chapter B22). Backward reconstructions add stock-specific daily estimates of marine and lower river catches to stock-specific daily escapement estimates (Chapter B20) to reconstruct the total daily abundance in marine areas. The estimates are used to derive time series of marine timing, migration spread and diversion rate. Backward reconstructions also allow to update in-season test fishing catchability estimates (Chapter B5). The following report describes the basic structure and underlying assumptions of the reconstruction model, and the time series it generates.

Introduction

Management of Fraser River sockeye salmon fundamentally relies on accurate estimates of run size (for deriving the amount of total allowable catch (TAC)), and migration behavior (to determine how to access the TAC). As part of the Pacific Salmon Treaty (PST) agreements (PST 2025, Chapter 4, paragraph 13(a)), PSC staff are responsible for providing in-season updates to Fraser River sockeye salmon run size, timing, and diversion rate.

Run reconstructions have been a key tool for salmon fisheries management for over 80 years; their application first thoroughly described by Starr and Hilborn (1988). PSC Secretariat Staff are responsible for developing and applying run reconstruction models for Fraser River sockeye (Cave and Gazey 1994) and archiving their results. Within these reconstruction models, stock-specific daily marine and lower river catches are added to stock-specific daily escapement estimates obtained by the PSC Mission hydro-acoustic facility (Conrad et al. 2019) to reconstruct daily abundances as the salmon run as it approaches the marine areas around Vancouver Island. In-season, daily reconstructed abundances are used to provide the best in-season estimate of run-size, timing, and diversion for Fraser River sockeye populations, either directly from the reconstructed abundance or when used within in-season assessment models (Michielsens and Cave 2019), project abundances of fish expected to be available to different fisheries, and update test fishery catchability estimates (Chapter B5).

After the fishing season concludes, reconstructions are used to update several time series of sockeye migration behaviour, including marine timing (date when 50% of a run has passed through marine areas), northern diversion (percent of a run migrating through Johnstone Strait), spread (number of days comprising 95% of the marine migration), and delay (days holding off the mouth of the Fraser River in the Strait of Georgia). In addition, Canada relies on historical time series of run size, timing, and diversion to generate pre-season forecasts (Chapters A1 and A2) which are critical inputs for pre-season planning and simulations (Cave and Gazey 1994, Chapter A9 and A10) and are also used as informative priors in Bayesian in-season run size models (Michielsens and Cave 2019, Chapter B23). In addition, historical run reconstructions are used in retrospective evaluations of fishery harvest rates (PSC 1995) and to develop decision rules for updating in-season test fishery catchability coefficients (Chapter B5).

Data

The key data used to reconstruct daily marine abundances along the Johnstone Strait and Juan de Fuca Strait route are: test fishery catch-per-unit-effort (CPUE) data (Chapter B4), test fishery catchability (Chapter B4), landed catches, Mission daily abundances (Chapter B14) and stock identification (Chapter B11). To populate the reconstruction model, information is also required regarding migration distances between fishery areas and the river, as well as assumed migration rates (Hague et al. 2021). Summer-run sockeye are assumed to migrate a distance of 257km in 6-days, corresponding to an average daily migration rate of 43km/day between the Area 20 purse seine test fishing location and the Mission hydroacoustic site. Late-timed sockeye are assumed to take an average of 8-days, covering 32km/day, to make the same journey.

Methods

The box-car run reconstruction model assumes salmon move in groups, i.e., box-cars, from the marine areas to the Fraser River through a series of fisheries that will impact the number of salmon in a group (Cave and Gazey 1994). The assessment of Fraser River sockeye relies on two different reconstruction approaches: backward reconstruction and forward reconstruction, and both are used to assess Fraser River sockeye salmon (Figure 1).

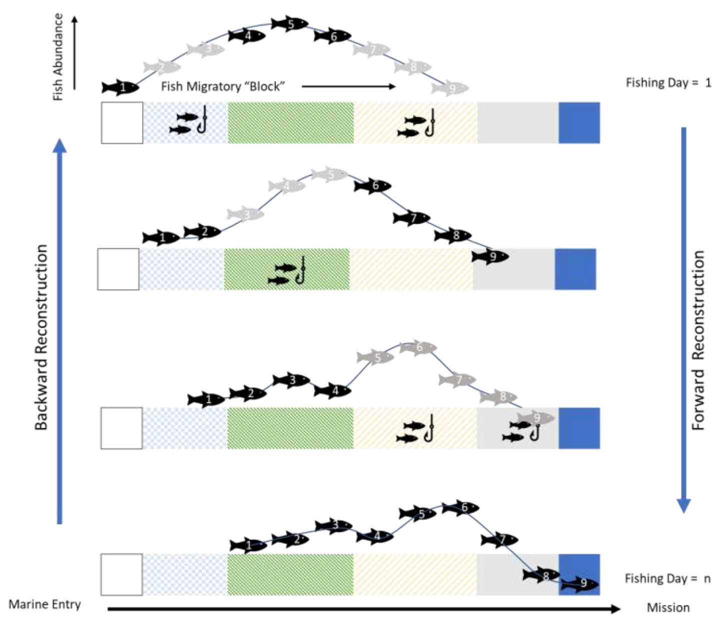

Figure 1. *Schematic illustration of a basic box-car run reconstruction model. The colored bars represent different statistical fishing areas, with the left most square representing the most seaward location. Each "fish/hook" represents one day of fishing. Each fish represents one daily block of fish. Black fish in each panel are not exposed to a fishery opening on a given day, while grey fish are. Each panel represents a daily time-step. The top panel represents the shape of the unfished run prior to entering marine approach fisheries. The bottom panel represents the shape of the run at Mission, with certain days of abundance reduced due to catch removals.*

The backwards box-car reconstruction is used to estimate total daily marine abundances by adding seaward catches (*C*) onto daily abundance estimates (*N*) at Mission. To simplify the reconstruction, dates (*d*) associated with the daily catch report (the catch date) from each fishery (*f*) in each statistical area (*A*) and the daily abundance data at Mission (the upstream migration date) are adjusted to the date associated with a geographical reference point. For the reconstruction and assessment of Fraser River sockeye salmon the reference point used is the site of the Area 20 purse seine test fishery located at the seaward entrance of Juan de Fuca Strait. The dates associated with the data from other areas are adjusted based on the amount of time (rounded to the day) it takes for sockeye to migrate to these areas from the reference point. Assuming it takes 6 days for Summer run sockeye to migrate between Area 20 (A_{20}) and Mission ($A_{Mission}$) implies a 6 day offset ($o_{A20,\ Mission}$) that would result in the Area 20 date (d_{A20}) associated with abundance estimates at Mission ($N_{Mission}$) to be 6 days earlier than the actual date:

$$(1) \qquad N_{d_{A20},A_{Mission}} = N_{(d-o_{A20,Mission}),A_{Mission}} = N_{(d-6),A_{Mission}}.$$

The same assumptions about migration speeds and associated offsets are also made for the sockeye migrating through Johnstone Strait. For example, it takes about 7 days to migrate from the Area 12 purse seine test fishing site to Mission, resulting in an offset of -1, making the corresponding Area 20 date for catches caught by purse seine test fishery ($f_{PS,TF}$) in the Area 12 (A_{12}) one day later than the actual date:

$$(2) \qquad C_{d_{A20},f_{PS,TF},A_{12}} = C_{(d-o_{A20,A12}),f_{PS,TF},A_{12}} = C_{(d+1),f_{PS,TF},A_{12}}.$$

The following description assumes that all the dates associated with the data have already been adjusted to the correspond to the Area 20 reference date. Also, the reconstruction is implemented for individual stocks (*s*) but this has been omitted from the descriptions to simplify the equations. Information on the application of stock ID within the reconstructions can be found in Chapter B20.

In addition to adjusting all dates to a common reference date, reported catch data that may include catches across several 'blocks' of fish (due to the large size of the statistical area for which they are reported) are spread across *n* migration days depending on the fishery and the statistical area so that the sum of the catch proportions (p_n) equals the total catch reported:

$$(3) \qquad C_{d_{20},f,A} = \textstyle\sum_1^n p_n \cdot C_{d_{20}-n+1,f,A}.$$

For the actual backward reconstruction, all the daily seaward catches along both approach routes are added to the daily Mission passage estimates to reconstruct the total daily abundance ($N_{d_{A20}}$) at the entry of the marine fishing areas:

$$(4) \qquad N_{d_{A20}} = N_{d_{A20},A_{Mission}} + \textstyle\sum C_{d_{A20},f,A}.$$

In-season, forward reconstructions are used that remove the daily catches between the marine area and Mission from the daily marine abundance estimates to predict daily abundances at Mission.

$$(5) \qquad N_{d_{A20,A_{Mission}}} = N_{d_{A20}} - \textstyle\sum C_{d_{A20},f,A}.$$

In this case, the daily marine reconstruction estimates are based on test fishery CPUE data (Chapter B4), used in combination with catchability estimates (Chapter B5). CPUE-based marine abundances and the derived Mission abundances are important in-season as they provide an early indication of abundances prior to fish arriving at Mission. Both gillnet and purse seine CPUE data are relied upon in-season. Each day, the marine reconstruction model allows stock assessment biologists to select which test fisheries to rely upon as well as to average estimates when data from more than one test fishery are available for a particular area. Within the reconstruction files, marine test fishery CPUE data are also combined with reconstructed abundances from Mission to provide in-season updated catchability estimates (Chapter

B5). This further allows the selection of catchability estimates for the different test fisheries in the reconstruction, i.e. rely on historical pre-season expansion lines or a variety of different in-season and adjusted in-season expansion lines depending on the available test fishery data.

Derived time series

Both forward and backward reconstructions are essential to derive additional time series of diversion through Johnstone Strait, the proportion of Late run delaying its upstream migration, the timing of the run and the spread.

The daily (northern) diversion rate estimates, i.e. the proportion of the total daily estimate migrating through Johnstone Strait, are based on CPUE data from test fisheries operating in Juan de Fuca and Johnstone Straits (Putman et al. 2014).

The reconstruction is also used to derive daily estimates of delaying Late run and Harrison stocks (Lapointe et al. 2003, Chapter B22). Delaying Fraser River sockeye stocks are defined as holding in the Strait of Georgia for an extended number of days (or weeks) prior to redistributing and migrating upstream, resulting in a roughly bimodel distribution. Instead of using Mission passage to update test fishing catchability estimates for delaying stocks, the difference between marine abundances and upstream escapement is used to estimate the number of salmon delaying their upstream migration. The quality of these predictions will depend on the quality of the CPUE-based daily abundance estimates. Post-season, the estimates of delay can be improved by rescaling the CPUE-based abundances so that the total of CPUE-based daily abundances equals the total post-season run size, i.e. the sum of the total reconstructed daily abundance estimates at Mission plus seaward catch. It should be noted that in the case of delaying stocks, it is not possible to run the backward reconstruction as the box-car movement assumption is broken and the Mission escapement and catches cannot be aligned with seaward abundances.

The reconstructed daily abundance time series are also used to derive estimates of timing and spread. The marine migration date, also referred to as the Area 20 date or marine 50% date, indicate the date when half (50%) of the run would have passed through Area 20 assuming all fish migrated via that route. The spread is defined as the number of days of migration comprising 95% of the run.

These historical time series are used in forecasting models (Chapter A2) that set pre-season expectations, allow for the prediction of fisheries impacts (Chapter A9 and B34) and serve as informative prior probability distribution inputs into the in-season stock assessment models (Michielsens and Cave 2019, Chapter B23).

Potential Areas for Improvement

More complex post-season reconstruction files have been developed, with increased stock resolution, improved flexibility and transparency in migration assumptions, and the ability to reconstruct abundance time series to multiple locations of interest (Hague et al. 2021, Hague and Michielsens 2022, Chapter C4). These post-season files also incorporate additional information and a more complex series of decision rules to derive marine abundances used in forward reconstructions and for delaying stock groups. While several of these improvements are only possible post-season, the ability to reconstruct time series to key index locations would improve the capacity for evaluating route-specific catches and abundances as well as generate projections of species and stock-specific encounter rates in-season.

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B22. Assessment of migration delay in the Strait of Georgia

C.G.J. Michielsens and M.J. Hague

Summary

While most Fraser River sockeye salmon migrate directly from marine test-fishing areas into the Fraser River, some populations, like Harrison, Late Shuswap, Portage, Weaver and Cultus, can delay upstream migration for days or weeks. When these fish eventually migrate, redistribution makes it impossible to directly relate daily abundance estimates from marine test fisheries to hydroacoustic-based daily reconstructed abundance estimates. To improve in-season management of delaying stocks, it is important to be able to assess how many are delaying in the Strait of Georgia. In-season, this is estimated by comparing total abundance entering the Strait with the total number migrating past the Mission hydroacoustic site four days later, adjusted for catches between these locations. The difference represents the number of sockeye holding before initiating upstream migration. Fish that hold in the Strait of Georgia avoid the elevated river temperatures associated with early entry into the Fraser River, thereby reducing thermal stress and associated mortality (Lapointe et al. 2003, Chapter B28). Although delay is best quantified from reconstructions (Chapter B21), a Gulf Troll test fishery operated in August and September can verify the presence of delaying sockeye and provide indicators of relative Late Run abundance and species composition in the Strait, and a coarse signal of upstream migration timing. However, Gulf Troll data are insufficiently precise to quantify the length of the migration delay or inform run size estimates.

Introduction

As part of Pacific Salmon Treaty (PST) agreements (PST 2025, Chapter 4, paragraph 13(a)), PSC staff provide in-season updates on Fraser River sockeye run size, timing, and diversion rate. For most stocks, preliminary daily abundance estimates from marine test-fishery CPUE are replaced post-season with more precise reconstructed daily abundance based on hydroacoustic data at Mission plus seaward catches (Chapter B23). Some stocks, like Harrison, Late Shuswap, Portage, Weaver and Cultus, delay upstream migration and hold in the Strait of Georgia for days to weeks (Lapointe et al. 2003). From an ecological point of view, delay behavior can mitigate freshwater thermal exposure. Without delay, Late run sockeye entering the Fraser River earlier are exposed to elevated temperatures longer and suffer higher mortality (Lapointe et al. 200, Chapter B28). Because these delaying fish redistribute, Mission-based abundance estimates cannot be used for these stocks to update the initial daily abundance estimates from marine test fisheries. The highly variable and unpredictable nature of the extent of the delay further complicates their in-season assessment. To improve in-season information for delaying stocks, a troll test fishery, i.e. the Gulf Troll test fishery, was established in 1987 in the Strait of Georgia (Chapter B2, Nelitz et al. 2018). It has proven useful for indicating the presence/absence and relative abundance of delaying Late Run sockeye and for predicting Late Run proportions and species composition in Area 29 troll catches. The following sections describe the data, and the methods used to estimate the abundance in the Strait of Georgia, both based on reconstruction and Gulf Troll test fishery data, and present the results, including the limitations encountered.

Data

While reconstructions generally offer the most accurate estimates of delay, the presence of delaying sockeye in the Strait of Georgia can be verified in-season using Gulf Troll test-fishery data. This test fishery usually runs from mid-August through September, with end dates dependent on upstream migration timing. Since 1987, six defined quadrants have been surveyed weekly (Figure 1, Michielsens and Martens 2022). Two vessels each fish approximately 8 hours per day to cover one quadrant each, completing all six quadrants in three days (Lagasse et al. 2020). Historically, operations focused on dominant and sub-dominant cycle years with high Late run abundance and expected delay behaviour.

Recent analyses show that catch-per-unit-effort (CPUE) calculated from a subset of quadrants (Q-3 and Q-4) retains the same predictive power for estimating the abundance of delaying sockeye as using all six quadrants. Beginning in 2026, the survey will focus on Q-3 and Q-4 over two days, averaging the CPUE across the two quadrants (Figure 1). This change in survey design supports robust data collection at lower cost and may enable surveys in non-dominant years and exploratory assessment of pink salmon delay in the Strait of Georgia.

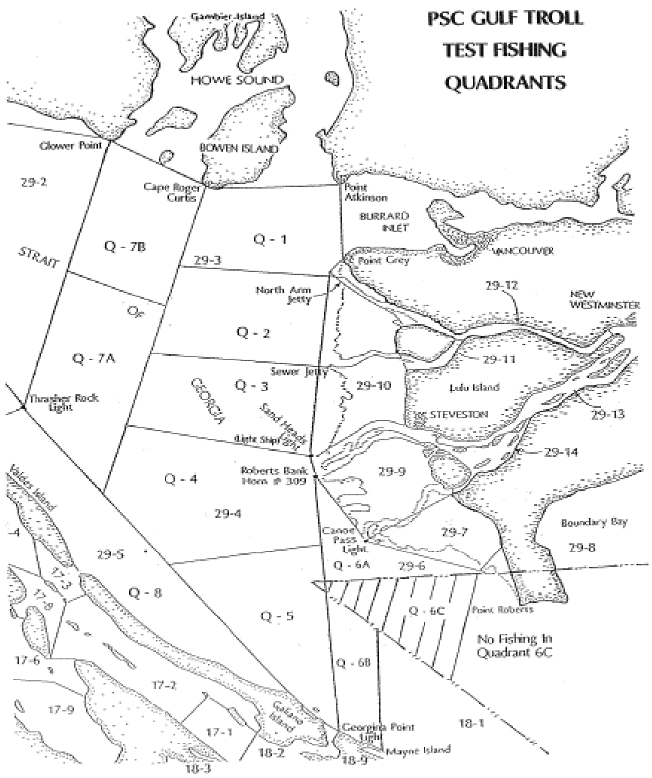

Figure 1. *Location of the six quadrants (Q-1 to Q-6A) surveyed by the Gulf Troll test fishery since 1987 (Michielsens and Martens 2022). Starting in 2026, only quadrants 3 and 4 will be surveyed over the course of 2 days and the CPUE averaged across the two quadrants.*

The Gulf Troll catch-per-unit-effort (CPUE) is defined as catch-per-1000 hook minutes, where hook-minutes are calculated as the total daily fishing time multiplied by the average number of hooks per line on each vessel (Cave 1997, Chapter B4). To account for density dependent effects on the catchability of the troll test fishery (a hook cannot catch fish once occupied), the total CPUE data of all fish species is corrected to derive sockeye-specific CPUE:

$$(7) \qquad CPUE_s = \frac{C_s}{C_T} e^{\left(0.123+1.012 \cdot ln\, CPUE_T + 0.0746 \cdot (ln\, CPUE_T)^2\right)}$$

where C_s/C_T is the proportion sockeye (*s*) in the total catch (C_T) and $CPUE_T$ is the unadjusted all-species catch-per-unit-effort. The latter is based on the catch of all target and non-target species including shakers (under-sized juvenile salmonids). These calculations are done for individual quadrants and the resulting CPUE is subsequently averaged across the quadrants. While previously, CPUE estimates were weighted by the proportion a quadrant contributes to the total area surveyed (Michielsens and Martens 2022), this did not statistically improve predictions.

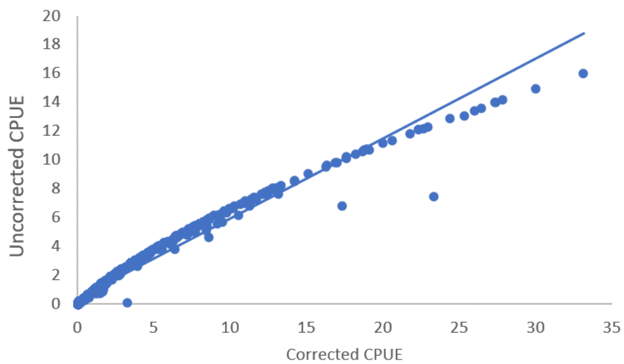

Figure 2. *Relationship between corrected (Equation 1) and uncorrected sockeye CPUE in the Gulf Troll test fishery. The solid line is the 1:1 relationship. Outliers are rare occurrences where effort was low, catch of other salmon species was high, and catch of sockeye was low.*

Methods

Post-season estimates of daily sockeye abundances in the Strait of Georgia are estimated using a forward reconstruction of daily abundance estimates based on seaward test fisheries (Chapter B21). In the post-season, these daily marine abundances are rescaled so that the total marine estimate is equivalent to the final in-season run size estimate based on Mission abundance plus seaward catch (Chapter C4). In the forward reconstruction, a fixed 7-day migration time is assumed between the marine test fishing areas and the entrance to the Strait of Georgia. Once delaying Late run sockeye resume their spawning migration, it is assumed they need an additional 4-days to migrate from the Strait of Georgia to the Mission hydroacoustic site. As with other reconstructions (Chapter B21, C4), the dates associated with the data from different areas are adjusted based on the amount of time (rounded to the day) it takes for sockeye to migrate to these areas from the marine test fishing locations, i.e. Area 20 in Juan de Fuca Strait and Area 12 in Johnstone Strait. Aligning dates in this way greatly simplifies the reconstruction, as well as the equations in this report.

The abundance in the Strait of Georgia on a given day is based on the cumulative difference between the abundance entering the area and the abundance leaving the area. More specifically, the historical abundance estimates of sockeye resident in the Strait of Georgia on a given day ($N_{d,SoG}$) are calculated by removing catches (*C*) and estimates of daily migration into the Fraser River ($N_{d,Mission}$) from the cumulative abundance of fish entering the Strait of Georgia:

$$(1) \qquad N_{d,A_i} = \left(\sum_{d=1}^{n} N_d - \sum_{A=A_1}^{A_{i-1}} C_{d,A}\right) - \left(\sum_{d=1}^{n} N_{d,Mission} + \sum_{A=A_i}^{A_j} C_{d,A}\right)$$

where A_i indicates the Strait of Georgia area, A_1 to A_{i-1} indicate all the areas seaward of the Strait of Georgia and A_i to A_j include all the areas seaward of Mission until and including the Strait of Georgia. Because Late run sockeye take approximately 11 days to migrate from the marine test fishing areas to the Mission hydroacoustic site, it takes 11 days before it is possible to assess if a group of Late run sockeye will delay and contribute to sockeye resident in the Strait of Georgia.

In addition to using reconstructions, the abundance in the Strait of Georgia can also be estimated from Gulf Troll test fishing data. Historically, the total abundance in the Strait of Georgia was estimated using a log-linear regression model that relates historical estimates of Gulf Troll CPUE to total abundances in the Strait of Georgia on a given day (N_d):

$$(2) \qquad ln(N_d) = a + b \cdot ln(CPUE_d)$$ (Michielsens and Martens 2022).

The performance of this model is evaluated in the results section, including a comparison of the log-transformed versus original-scale model fits. Because predictions from the log-linear regression are highly uncertain once back-transformed to the original scale, it was evaluated if the Gulf Troll CPUE data could be used as a qualitative signal of relative Late-run delay abundance. Specifically, it was examined if consistently low CPUE values correspond to low reconstructed abundance estimates, and whether higher CPUE values reliably signal the presence of larger numbers of delaying sockeye.

Results and discussion

The relationship between Gulf Troll CPUE and reconstructed sockeye abundance in the Strait of Georgia shows important differences depending on whether the analysis is conducted on the log-transformed or original scale. Although the log-transformed relationship between Gulf Troll CPUE and reconstructed abundance in the Strait of Georgia appears strong (R^2 = 0.59), the transformation overstates the strength of the association when evaluated on the original, biologically meaningful scale (R^2 = 0.43, Figure 3). When the analysis is further restricted to cases where the CPUE exceeds 1, typically the range of greatest management interest, the relationship weakens substantially (R^2=0.16). This indicates that making quantitative predictions of the amount of late run delay and subsequent run size estimation based on large Gulf Troll CPUE values (> 1) is unsuitable for in-season assessment.

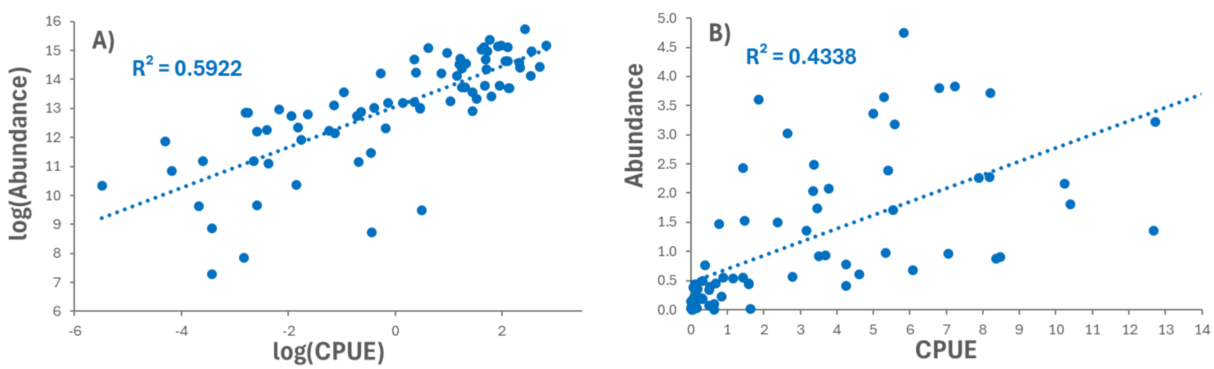

Figure 3. *Relationship between Gulf Troll catch per unit effort (CPUE) and reconstructed sockeye abundance in the Strait of Georgia, using A) log-transformed and B) untransformed data from six quadrants. The log-transformed relationship yields a stronger linear fit (R^2= 0.59) compared to the untransformed data (R^2=0.43) but overstates the predictive power of the relationship when applied back on the original scale.*

Further analyses show that CPUE calculated using only quadrants Q-3 and Q-4 retains the same predictive ability (R^2=0.43) as CPUE averaged across all six quadrants. This finding supports a streamlined monitoring approach beginning in 2026, in which only Q-3 and Q-4 will be sampled. This revised design will reduce operational costs and may make it feasible to resume Gulf Troll surveys in non-dominant years or evaluate their utility for assessing pink salmon delay. However, it will also reduce the ability to examine the spatial distribution of delaying sockeye across the Strait of Georgia.

When compared with in-season reconstructed abundance estimates, CPUE-based Gulf Troll estimates perform substantially worse, both in predicting the magnitude of the delay and in identifying the timing of upstream migration (Figure 4). Although in-season reconstructions can either overestimate, e.g. 2014, or underestimate, e.g. 2018, 2022, the post-season abundance of delaying sockeye, they generally reproduce the pattern and relative timing of peak and declining abundance. This consistency, coupled with the daily resolution of hydroacoustic and seaward catch data, makes reconstruction-based estimates more suitable for in-season management.

In contrast, Gulf Troll CPUE data are collected only once per week, limiting its usefulness for interpreting within-week changes in abundance or migration timing. In addition, when CPUE declines in a given week, at least one additional week of data is needed to determine whether the decline reflects upstream migration timing rather than variability in the data. These limitations reduce the usefulness of Gulf Troll data for estimating the percentage of the run that has migrated to date, an input needed to predict the 50% migration date past Mission, which in turn feeds into the run-timing model used to determine the Management Adjustment for delaying Late run stocks (Chapter B28).

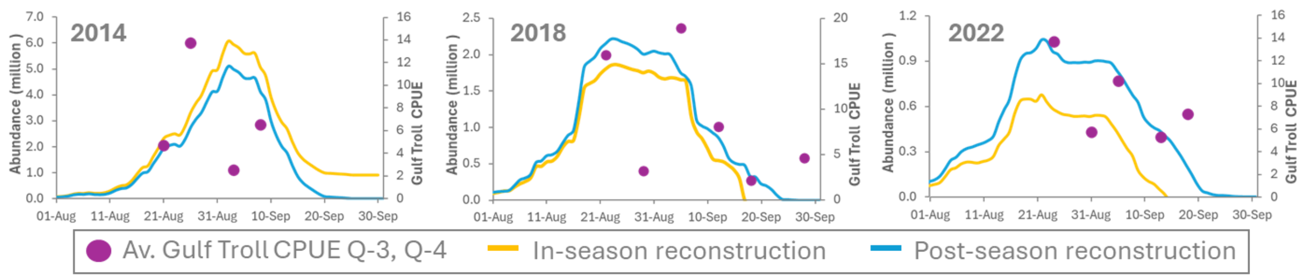

Figure 4. *In-season versus post-season daily reconstructed abundance estimates in the Strait of Georgia compared to estimates based on Gulf Troll data for the three most recent years when Gulf Troll data were collected, 2014, 2018 and 2022.*

Despite its limited quantitative precision, Gulf Troll CPUE data remain useful as a qualitative indicator. Across historical data, CPUE values below 1 are consistently associated with low reconstructed abundance (typically less than 0.5 million fish), whereas CPUE values ≥ 1 usually signal the presence of substantially larger numbers of delaying sockeye (generally more than 0.5 million fish, Table 1). Therefore, while CPUE cannot be used to generate accurate estimates of abundance, it retains value as a coarse indicator of whether substantial numbers of sockeye are holding in the Strait of Georgia.

Table 1. *Summary of reconstructed sockeye abundance in the Strait of Georgia associated with low (CPUE < 1) or high (CPUE ≥ 1) Gulf Troll catch-per-unit-effort values, median abundance and 10% - 90% range, sample size (n) and coefficient of determination (R^2).*

			Median abundance in the Strait of Georgia	
Gulf Troll CPUE	**n**	**R^2**	**Median**	**10% - 90% range**
CPUE < 1	35	24%	190,000	5,000 – 500,000
CPUE ≥ 1	44	16%	1.8 million	0.5 – 3.8 million

Potential Areas for Improvement

Historically, Gulf Troll surveys have been carried out primarily during dominant and sub-dominant Late Run cycle years, when delaying behaviour is expected to be most pronounced and assessment benefits are greatest. The transition to a streamlined survey design focused on quadrants Q-3 and Q-4 beginning in 2026 substantially reduces operational requirements, creating new opportunities to expand data collection into non-dominant years and during pink salmon migration.

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B23. In-season time-density model

C.G.J. Michielsens

Summary

The in-season assessment of Fraser River sockeye salmon relies on the Bayesian implementation of a time-density model to estimate run size and associated run timing. This model is fitted to available catch-per-unit-effort (CPUE) data from gill net test fisheries in statistical fishing Areas 12 and 20, purse seine data in Areas 12, 13 and 20 (Chapter B4), and reconstructed daily abundance estimates derived from hydroacoustic data collected at Mission (Chapter B14) and seaward catches. The model relies on prior probability distributions of run size, timing, standard deviation (or spread), diversion rate, and test fishery catchability based on pre-season forecasts or historical observations (Chapters A1 and A2). Updated posterior distributions are produced by the model for timing, abundance, diversion, and sometimes spread, but the catchability priors are not updated. Instead, the daily catchabilities are assumed to be fixed but uncertain inputs, based initially on historical estimates, and later on in-season observations as they become available (Chapter B5). Early in-season, the model tends to underestimate the number of days for the salmon to pass through marine areas, and therefore the standard deviation of the migration (spread) is also considered a fixed but uncertain parameter. If necessary, this assumption can be relaxed after the peak of the run has been observed. The model is applied to stock aggregates which share similar migration timing and fall within the same management groups. For stocks that delay their upstream migration, only marine CPUE are used to assess the run, resulting in larger run size uncertainty in comparison to stocks that also rely on marine reconstructed data.

Introduction

The Fraser River Panel is responsible for the in-season management of Fraser River sockeye stocks, as stipulated by the Pacific Salmon Treaty between Canada and the United States (PST 2025). Under the terms of the Treaty, Commission staff are responsible for providing the Panel and Technical Committee with in-season updates of run size. Historically, two different methods had been relied upon for the in-season assessment of salmon stocks: regression models relating indicators of abundance (or cumulative abundance) on a given date with total run-size estimates obtained post-season (Fried and Hilborn 1988, Ryall 1998) and time-density (or cumulative time-density) models that estimate the proportion of the migration on a given date (Walters and Buckingham 1975, PSC 1995, Springborn et al. 1998). These time-density models rely on the date of peak abundance as well as the shape of the daily abundance profile over time. They can be fit to abundance indices such as catch-per-unit-effort (CPUE) data from commercial or test fisheries, as well as absolute estimates of abundance reconstructed from catch and real-time escapement data.

Time-density models have the advantage that run timing is an estimated model parameter rather than a fixed input. This differs from alternative in-season assessment models that rely on regression analyses using catch or CPUE (PSC 1995, Ryall 1998). However, the simultaneous estimation of timing and run size can also pose challenges. The peak of the run can only be confirmed once more than 50% of the migration has been observed. Consequently, prior to the peak, runs that are small and early or late and large may be indistinguishable (Adkison and Cunningham 2015). The integration of all available sources of data and information within the assessments is therefore important to ensure timely in-season management decisions. Bayesian methods offer an ideal platform for such analyses while also accounting for the uncertainty in the resulting estimates (Fried and Hilborn 1988, Hyun et al. 2005). This document describes a general time-density model developed in a Bayesian framework for the in-season assessment of run size and timing for Fraser River sockeye salmon.

Data

The in-season assessment of Fraser River sockeye stocks relies on four types of data: Lower Fraser River daily abundance estimates from the hydroacoustic program at Mission, catches seaward of the hydroacoustics program, test fishing catch and effort, and stock identification data (Woodey 1987). The reduced allowable exploitation of Fraser River sockeye in recent years has increased the reliance on test fishing CPUE information rather than commercial data as an index of abundance. The main marine test fisheries for in-season assessments are the gill net and purse seine test fisheries in DFO statistical Areas 12 and 13 (Johnstone Strait), and Area 20 (Juan de Fuca Strait). The combined CPUE data from these two Straits provide time series of relative daily abundance. Reconstructed estimates of daily absolute abundance in the same areas are derived through backward reconstruction methods (Starr and Hilborn 1988) using upstream daily passage estimates by the Mission hydroacoustics program in combination with seaward catches (Chapter B21). Both the CPUE and the reconstructed data are multiplied by stock proportion estimates (Chapter B20) to produce multiple timeseries resolved at finer stock resolutions. Separate models are then parameterized for stock aggregates within each management group that have distinctly different migration timing, catchability, or migration behaviour (e.g. delay or non-delay). To simplify the model description within this report, stock indices have been omitted from the model equations.

In-season, the marine CPUE data are considered early indicators of the expected daily abundance at Mission 6-days later, as it takes Fraser sockeye approximately 6-days to travel from the marine test fishery locations to the hydroacoustic site at Mission. Therefore, in-season, there is a 6-day lag between CPUE and reconstructed timeseries. In addition, reconstructed marine abundance estimates are only available for stocks that do not delay their upstream migration into the Fraser River due to the violation of basic reconstruction assumptions (Chapter B22). For stocks like Harrison and delaying Late run stocks, only marine CPUE data can be used to assess these stocks, resulting in larger run size uncertainty.

Methods

The following model description assumes that all timeseries have been offset in order to align with a single geographical reference location associated with the Area 20 purse seine test fishing site (Chapter B21). Date indices corresponding to data from all other locations are adjusted accordingly based on the relative difference in assumed fish migration time between Area 20 and Mission, and the migration time between the location of interest and Mission. For example, it takes approximately 7-days for sockeye to migrate from the Area 12 purse seine test fishing site to Mission, making the corresponding Area 20 date for the CPUE data of the purse seine test fishery in Area 12 one day later than the actual date. All dates mentioned in the description of the time-density model below refer to Area 20 dates.

IN-SEASON TIME-DENSITY MODEL

The in-season time-density model to assess the run size and timing of different Fraser River sockeye groups relies on a time-density function to represent the daily salmon migration past the marine test fishing locations (Mundy 1979, Cave and Gazey 1994, Springborn et al. 1998). Two different versions of the time-density model are used depending on the available test fishing data and the associated quality.

The marine gill net data are of lower quality as a relative index of abundance compared to the purse seine data given the substantially lower catchability of sockeye salmon by gill nets versus purse seines, i.e., they catch a much smaller proportion of the run. The marine gill net data are however essential for the assessment of early-timed, low abundance stocks for which the cost of running expensive purse seine test fisheries would be prohibitive. Given the high variability in the individual gill net CPUE time-series for the Area 12 and 20, the two time-series are combined into a total CPUE time-series to assess the combined abundance migrating through marine areas. In cases where purse seine CPUE data are available, a more detailed version of the model assesses the abundance in both approaches separately. The following paragraphs will first describe the model using marine gill net data, followed by a description of a more complex model version incorporating data from both gear types.

The daily abundance of salmon (N_d) passing the marine reference locations on a given day *d* can be represented as:

$$(1) \qquad N_d = N \cdot f(d)$$

where *f(d)* is the time-density function of migrating salmon, i.e., the daily proportion of the total run size and *N* is the total run size or the total recruitment of salmon, available to coastal fisheries. For Fraser sockeye, we assume a normal distribution of migrating salmon over time (Gilhousen 1960, Cave and Gazey 1994):

$$(2) \qquad f(d|T,S) = \frac{1}{S\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{d-T}{S}\right)^2}$$

where *T* is the mean timing of the salmon migration and *S* is the standard deviation. Reconstructed daily marine abundances (N_t^{obs}) deviate from the daily abundances predicted by the time-density model (N_d):

$$(3) \qquad N_d^{obs} = N_d + v_d$$

with $v_d \sim N(0, \sigma_v^2)$ reflecting the deviation. Based on the salmon abundance available on a given day (N_d), the associated CPUE by the gill net (*GN*) test fishery on that day ($I_{d,GN}$) is given by:

$$(4) \qquad I_{d,GN} = q_{d,GN} \cdot N_d$$

where *q* represents the catchability coefficient, i.e., the proportion of the daily abundance taken as catch by one unit of effort. The observed CPUE data differ from the model predictions assuming lognormal residual errors:

$$(5) \qquad I_{d,GN}^{obs} = I_{d,GN} \cdot exp\left(w_{d,GN}\right)$$

with $w_{d,GN} \sim N\left(0, \sigma_{w,GN}^2\right)$.

In cases when purse seine test fishery data are available in addition to gill net data, the time-density model is expanded to include daily abundance estimates in Johnstone as well as Juan de Fuca Strait:

$$(6) \qquad N_{d,A12} = N \cdot D \cdot f(d) \; and N_{d,A20} = N \cdot (1 - D) \cdot f(d)$$

where $N_{d,a}$ is the daily abundance on a given day *d* in area *a* (*A12* or *A20)*, and *D* is the (northern) diversion rate, i.e. the proportion of the run migrating through Johnstone Strait (*A12*) (Chapter A2). For gill net test fisheries, it is assumed that the sockeye catchability is the same in Johnstone Strait versus Juan de Fuca Strait. Therefore the Gill net CPUE on a given day ($I_{d,GN}$) is:

$$(7) \qquad I_{d,GN} = q_{d,GN} \cdot \left(N_{d,A12} + N_{d,A20}\right).$$

For purse seine test fisheries, it is assumed that the catchability depends on the relative width of the area swept or sampled, i.e., the width of the migratory channel at the test fishing site in relation to the size of the fishing net. Because the relative width of the area swept in Juan de Fuca Strait is 2.2 times larger than in Johnstone Strait, it is assumed that the sockeye catchability of the purse seine test fishery in Area 12 is 2.2 times greater than in Area 20. Similarly, the catchability in Area 13 is assumed to be 1.5 times greater than in Area 12, or 3.3 times greater than in Area 20. The purse seine CPUE on a given day in the Area 12, 20 and 13 ($I_{d,PS,a}$) is therefore respectively:

$$(8) \qquad I_{d,PS,A20} = q_{d,PS,A20} \cdot N_{d,A20},$$

$$(9) \qquad I_{d,PS,A12} = 2.2 \cdot q_{d,PS,A20} \cdot N_{d,A12}, \textit{ and}$$

$$(10) \qquad I_{d,PS,A13} = 3.3 \cdot q_{d,PS,A20} \cdot \left(N_{d,A12} - C_{d,A12}\right)$$

where $C_{d,A12}$ is the total catch taken between Area 12 and 13 on a given day. The observed CPUE data for the different test fisheries (f) differ from the model predictions assuming lognormal residual errors:

$$(11) \qquad I_{d,f}^{obs} = I_{d,f} \cdot exp\left(w_{d,f}\right)$$

with $w_{d,f} \sim N\left(0, \sigma_{w,f}^2\right)$. Reconstructed daily marine abundances (N_d^{obs}) deviate from the daily abundances (N_d) predicted by the time-density model:

$$(12) \qquad N_d^{obs} = N_{d,A12} + N_{d,A20} + v_d$$

with $v_d \sim N(0, \sigma_v^2)$ reflecting the deviation. For stocks that delay their upstream migration, reconstructed daily abundance estimates will not be available.

BAYESIAN IMPLEMENTATION INCORPORATING PRIOR KNOWLEDGE

The time-density model described above requires the simultaneous estimation of total run size (N), timing of the migration (T), the diversion rate (D), and the variances of the residual error terms (σ_v^2 and σ_w^2). For several of the model parameters, additional information is available to formulate informative prior probability distributions which can be incorporated using a Bayesian estimation approach (Gelman et al. 1995). The prior probability distributions for run size, timing and diversion rate are based on the pre-season forecasts (Chapters A1 and A2). The assumed distributions for run size, timing and diversion rates are respectively a lognormal, normal and beta distribution (Table 1). The normal prior probability distribution for the standard deviation of the migration (S) is based on historical data. Because early in-season, the model tends to underestimate the spread of the migration (i.e. the number of days it takes for the 95% of the run to pass through the marine test fishing areas), this model parameter is considered fixed but uncertain by default. However, this model parameter can be estimated if in-season data clearly indicates a strong deviation from historical standard deviations.

For the catchability coefficient (q), a normal prior probability distribution is assumed for the inverse of the catchability coefficient (q^{-1}), i.e., the expansion line. At the start of the season, the prior probability distributions for the gill net and purse seine expansion lines are based on historical data, but later in the season, these distributions are based on in-season observations (Chapter B5). Unlike other prior probability distributions, these distributions for expansion lines are not further updated by the model. Uninformative gamma distributions are used as priors for the residual error terms (σ_v^2 and σ_w^2).

Figure 1 provides a graphical overview of the Bayesian time-density model as described above. This model was developed and is run in WinBUGS 1.4 (Spiegelhalter et al. 2003) and called from the statistical software package R (R Core Team 2022). All the model results undergo diagnostics to remove the impact of initial MCMC samples, to eliminate the negative impact of autocorrelation within the MCMC chains and to ensure convergence (Best et al. 1995). We assume the reported statistics of the posterior probability distributions represent the true underlying distributions.

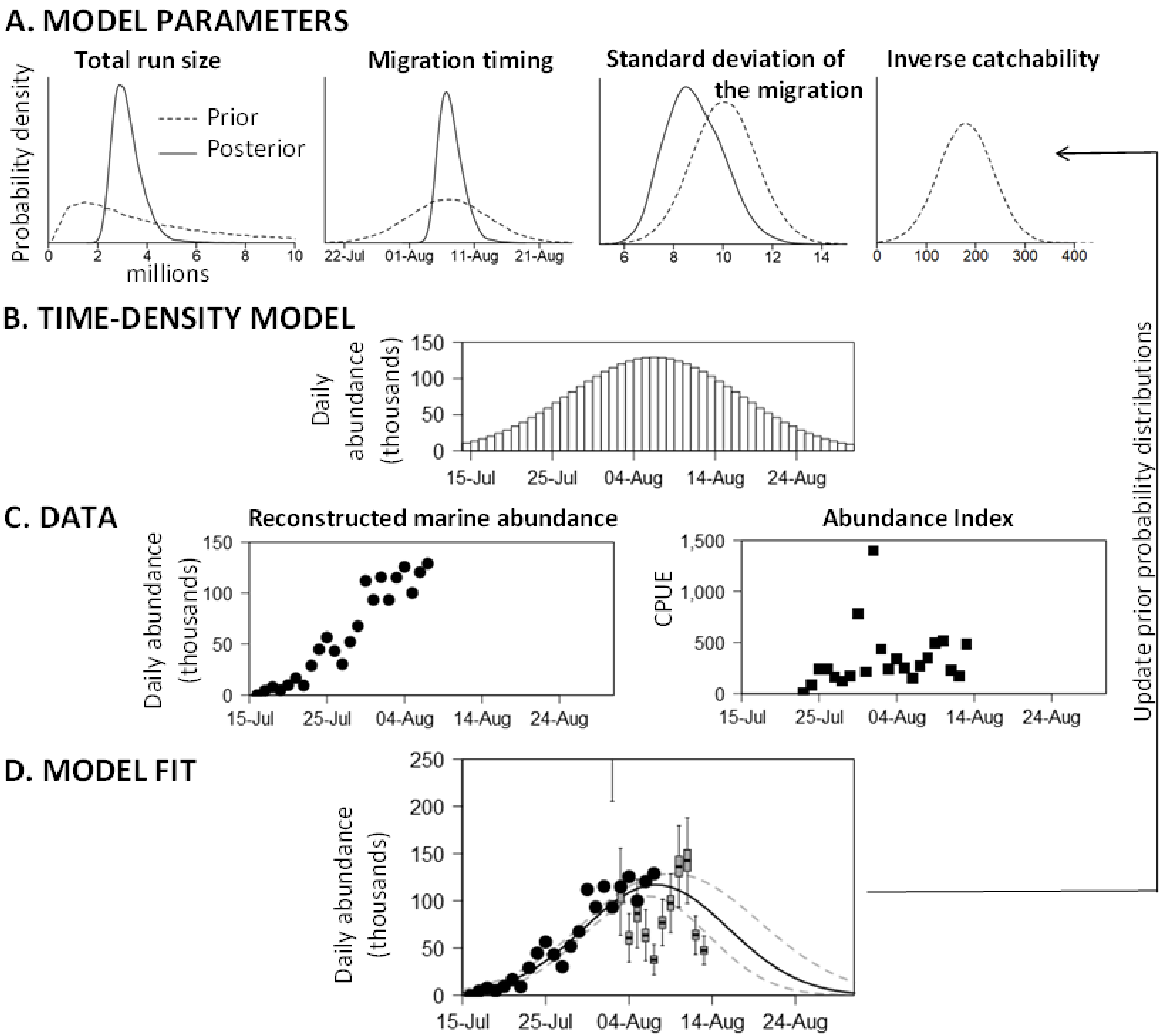

Figure 1. *Graphical overview of the Bayesian time-density model when applied for the in-season assessment of Fraser River sockeye. Prior probability distributions (A) based on preseason forecasts of run size, migration timing and standard deviation of the migration allow the prediction of the daily abundance of salmon assuming a normal distribution of migrating salmon over time (B). Reconstructed daily marine abundance estimates and marine test fishery CPUE data are collected and updated continuously throughout the salmon migration (C) and the model predicted daily abundance estimates are fitted to these data. Relative abundance estimates such as CPUE data however require an additional model parameter, in this case a catchability estimate. The uncertainty in daily abundance estimates derived from CPUE data is therefore represented using boxplots. Comparing the model predictions against the data allows the model to derive the posterior probability distributions of the model parameters (A). To simplify this figure, the probability distribution for the diversion rate and the variance parameters have been omitted.*

Table 1. *Probability density functions (pdfs) of the Bayesian time-density model and the parameter values of the prior pdfs used to assess Fraser River sockeye salmon.*

Prior probability density function	Parameter values for Fraser River sockeye
R ~ Lognormal(ln(m), 1 / ln(1 + CV^2))	Median and CV derived from the run size forecast
T ~ Normal(μ, 1 / $(μ * CV)^2$)	Mean and CV derived from the timing forecast
S ~ Normal(μ, 1 / $(μ * CV)^2$)	Mean and CV derived from historical data
D ~ Beta(μ * η, (1 - μ) * η)	Mean derived from the diversion rate forecast, η = 20
q^{-1} ~ Normal(μ, 1 / $(μ * CV)^2$)	Mean and CV based on historical data, later on in-season data
1 / σ_v^2 = τ_N ~ Gamma(0.001,0.001)	Mean = 1, variance = 1000
1 / σ_w^2 = τ_I ~ Gamma(0.001,0.001)	Mean = 1, variance = 1000

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B24. In-season SMURF model

S. Latham and C.G.J. Michielsens

Summary

The in-season assessment of run size and associated run timing of Fraser River sockeye salmon consists primarily of the Bayesian implementation of a time-density model (Chapter B23). This model relies on reconstructed daily abundance estimates (Chapter B21), which are initially based on marine test fishery data until, six days later, these preliminary estimates can be replaced by daily hydroacoustic estimates of migration past Mission (plus seaward catch). For Late-run stocks, which delay and redistribute prior to migration into the Fraser River, it is not possible to replace the daily estimates from test fishing with daily hydroacoustic-based estimates, and this leads to larger in-season run size uncertainty. To ameliorate impacts of this uncertainty when assessing Late-run stocks and fill the Late-run information gap when making in-season management decisions, an alternative abundance-prediction method (SMURFing, i.e., Smolt Method of Updating Run Forecasts) was developed. This method relies on in-season estimates of early-returning stocks to predict abundances of later-returning stocks, assuming equal post-smolt marine survival among stocks. This method takes advantage of juvenile sampling programs and stock compositions of seaward-migrating juveniles produced by those programs. To the degree that relative abundances are the same in returning adults as in the outmigrating juveniles, the estimated returns of earlier stocks are predictive of the returns of later stocks. During dominant Shuswap return years, this method is applied to predict the abundance of Late Shuswap/Portage from in-season run-size estimates of Early Thompson in combination with estimates of relative abundance from the juvenile outmigration. Uncertainty in juvenile stock compositions and in-season run size estimates for Early Thompson stocks contribute to uncertainty in the predicted run size for Late Shuswap/Portage, as do potential violations of assumptions.

Introduction

Due to extreme interannual variability in marine survival, return strengths of Fraser River sockeye have been highly unpredictable in recent years. For example, recruits per effective female spawner varied from less than 1 in the 2005 brood year to more than 12 in the 2006 brood year (DFO 2018), resulting in returns below the 10th percentile and above the 90th percentile in pre-season forecasts in 2009 and 2010, respectively. Due to such variability, the prediction intervals of forecasts have broadened, reducing their utility for effective fishery planning, and intensifying demand for accurate and timely in-season assessments of abundance. For example, in 2026, the 80% probability interval for the total return of Fraser River sockeye was 2 - 30 million (Chapter A1).

The challenge of forecasting Fraser sockeye abundance in the pre-season has necessitated an intense in-season assessment program, and run sizes are typically estimated with time-density models. These models rely on the date of peak abundance and the shape of the daily abundance profile over time (Chapter B23). The daily marine abundance estimates are derived through reconstructions (Chapter B21) and are initially based on test fishery data. Once the salmon migrate into the Fraser River and pass the hydroacoustic site at Mission, these initial estimates are replaced with hydroacoustic-based estimates for most stocks. Unfortunately, some Late-run stocks delay and redistribute prior to migration into the river, making it impossible to replace the uncertain test fishing-based estimates. In addition, in-season run-size estimation using the time-density model is only possible when 50% of the run has been observed. Prior to the peak, runs that are small and early or late and large may be indistinguishable (Adkison and Cunningham 2015). As a result, management is under-informed about Late-run sockeye when making fisheries management decisions. Other information, however, may be available to help bridge this gap.

Stock proportions are important for planning fisheries in their own right, with respect to impacts on non-target stocks. In addition, the relative abundances they represent are somewhat less difficult to predict than absolute abundances (run sizes), reflecting positive correlation in productivity among stocks (Latham and Michielsens 2022). Broad regional correspondence in productivity trends emphasizes the important role of factors impacting survival in coastal areas where the stocks share similar environments early in their marine lives (Mueter et al. 2002). To take advantage of correlated marine survival, a 'Smolt Method of Updating Run Forecasts' (SMURF) was developed that uses the in-season run size estimates of an earlier-returning 'Reference Stock' and the ratio among stocks in out-migrant juveniles to provide an in-season run-size estimate of the later-returning 'Predicted Stock'. This estimate is both independent of the pre-season forecast and available before traditional in-season run-size updates for the Predicted Stock. As described below, this method helps to fill the information gap between the pre-season forecast and the in-season time-density model results that become available after the peak of the run has been observed.

Data

The model for SMURFing requires at least two highly processed data inputs: (i) relative stock composition estimates among outmigrant juveniles (smolts or post-smolts) captured two years prior to the year of return, and (ii) in-season estimates of the run size of 2-ocean sockeye from a Reference Stock in the year of return. Stock compositions are estimated for outmigrating juveniles with DNA following Beacham et al. (2004). Run size for a Reference Stock is generally estimated using a time-density model (Chapter B23) or reconstruction-based (Chapter B21), but also alternate estimates of run size can be used, e.g., terminal hydroacoustics for Chilliwack sockeye on the 2020 cycle line. If stock composition estimates (Chapter B11) used in generating daily abundances and run-size estimates for the Reference Stock use the same method as for the juvenile stock composition, biases inherent in the method may be at least partially offset.

Stock compositions of returning adults are estimated mostly from catches in Statistical Areas 12, 13, 20, and 29 (Chapter B7). Samples of outmigrating juveniles can be collected from multiple locations, including lake outlets, river main stems, or marine locations where a high proportion of the outmigration passes during a short period of time (e.g., the Discovery Islands in Areas 12 and 13, Neville et al. 2016). The latter may be preferable (Latham and Michielsens 2022), but more replicates across years should be obtained to test that idea. For returns in 2018, juvenile samples were collected in 2016 from (i) the Mission downstream trap operated by DFO (Mahoney et al. 2013), (ii) salmon trawl and seine programs operated by DFO in Areas 12-16 (Neville et al. 2016), and (iii) hand-operated seine sampling conducted in Areas 12 and 13 by Hakai Institute (Johnson et al. 2019). Resulting genotypes were graciously shared with the PSC Secretariat by these organizations.

SMURFing could theoretically be used in many circumstances but could be most beneficial in predicting in-season run size of later-timed stocks that (i) are important for fisheries management considerations, and (ii) are difficult to estimate in a timely manner using traditional time-density methods or other methods. The Late run on Shuswap dominant years is a prime example, due to the effects of their migration delay and redistribution as described above (Chapter B22). It is important for fisheries management to obtain early in-season run-size estimates for these Late-run stocks, and even more so given the overlap in migration between management groups. Therefore, in-season run-size estimates of Early Thompson are used in combination with relative juvenile abundance estimates of Early Thompson in comparison to Late Shuswap/Portage to produce early in-season Late-run run size estimates.

In-season age composition estimates are additional data inputs required for some applications of this method. As most Fraser River sockeye are 2-ocean fish upon their return, stock proportions of smolts and post-smolts two years earlier are most similar to stock proportions among returning adults. For Early Thompson and Late Shuswap/Portage on Shuswap dominant cycle years, the proportion of other ages is negligible. With other years or other stocks, however, the proportion of 2-ocean individuals in both the Reference Stock and the Predicted Stock must be estimated from scale samples from sockeye identified to those stocks using DNA in-season. The abundance of 2-ocean sockeye in the Reference Stock predicts the abundance of 2-ocean sockeye in the Predicted Stock, with the latter scaled-up to represent the return of all ages. In-season age estimates are derived from scales collected and analyzed at the PSC Secretariat Office (Chapter B9).

Methods

Depending upon several critical assumptions, in-season estimation of earlier-returning stocks can, in combination with the ratio between earlier stocks and later stocks among out-migrating juveniles, be used to produce a quantitative prediction regarding the abundance of later-returning stocks. Of the various assumptions made when using this method, the most critical are the assumptions of equal catchability of juveniles among stocks and equal survivability among stocks between the juvenile sampling period and recruitment to adulthood. That is, SMURFing requires unbiased, representative samples of the post-smolt stock proportions, and it requires that those proportions are the same when the sockeye return to the Fraser River. The method makes other assumptions, but violations of those other assumptions (e.g., equivalent maturity schedules in the Reference Stock and Predicted Stock) are more amenable to study and estimated to have a relatively minor impact. A more complete list and evaluation of assumptions can be found in Latham and Michielsens (2022). Violations of most assumptions are expected to be reduced among stocks with juveniles that smolt at similar sizes and follow similar migration routes on similar dates.

The following paragraphs provide a detailed description of the model as it was applied to assess the run size of Late Shuswap/Portage in 2018. The model assumed that the abundance (*N*) of Late Shuswap/Portage (*LShP*) stocks versus Early Thompson (*ETho*) stocks was the same, in a relative sense, for post-smolt juveniles (*J*) as for returning adult recruits (*R*):

$$(1)\quad \frac{N_{J,ETho}}{N_{J,LShP}} = \frac{N_{R,ETho}}{N_{R,LShP}}.$$

The ratio of post-smolt abundances could be rewritten as:

$$(2)\qquad \frac{N_{J,ETho}}{N_{J,LShP}} = \frac{N_{J,ETho}/(N_{J,ETho}+N_{J,LShP})}{N_{J,LShP}/(N_{J,ETho}+N_{J,LShP})} = \frac{p_{ETho}}{p_{LShP}} = \frac{p_{ETho}}{(1-p_{ETho})}$$

with p_{ETho} representing the proportion of Early Thompson post-smolts from the combined sample of post-smolts from Early Thompson, Late Shuswap/Portage. Equation 1 could then be re-written as

$$(3)\qquad N_{R,LShP} = N_{R,ETho} \cdot ((1 - p_{ETho})/p_{ETho})$$

with $N_{R,ETho}$ being the in-season run size for Early Thompson, and $N_{R,LShP}$ the in-season run size for Late Shuswap/Portage.

Early during the in-season management period, the run size of Early Thompson was derived through the application of a time-density model fitted to daily reconstructed marine abundance estimates as well as catch-per-unit effort (CPUE) data collected by gillnet and purse test fishing vessels in Statistical Areas 12 and 20 (Michielsens and Cave 2019, Chapter B23). As the season progressed, the Early Thompson run size was derived by combining: 1) daily reconstructed marine abundance estimates on days for which abundances had been estimated at the Mission hydroacoustic site, 2) six-day projections of marine abundances based on marine CPUE data in combination with marine catchability estimates, and 3) predictions of the abundance seaward of marine test fisheries based on the time-density model. The resulting run size estimate for Early Thompson, including the associated uncertainty, was used as an uncertain input into the model to predict the run size of Late Shuswap/Portage. For this model, we assumed a lognormal distribution for the Early Thompson run size:

$$(4) \qquad N_{R,ETho} \sim \text{Lognormal}\big(\ln(m), 1/ln(1+CV^2)\big)$$

With *m* and *CV* being the median and coefficient of variation of the in-season run size distribution for Early Thompson.

The proportion of Early Thompson post-smolts (p_{ETho}) among out-migrating smolts of both Early Thompson and Late Shuswap/Portage was estimated assuming the observed Early Thompson smolt proportions p_{ETho}^{obs} from various juvenile sample collection programs in different areas (*A*) followed a binomial distribution:

$$(5) \qquad p_{ETho,A}^{obs} \sim \text{Binomial}(p_{ETho}, n_A)$$

where n_A was the total sample size of Early Thompson and Late Shuswap/Portage post-smolts in area *A*. Bayesian application of this model required a prior probability distribution for the Early Thompson post-smolt proportion, which was assumed to be an uninformative, uniform distribution between 0 and 1:

$$(6) \qquad p_{ETho} \sim \text{Uniform}(0,1).$$

The model described above was developed and run in WinBUGS 1.4 (Spiegelhalter et al. 2003). Model results underwent diagnostics to remove the impact of initial MCMC samples, to eliminate the negative impact of autocorrelation within the MCMC chains, and to ensure convergence (Best et al. 1995). We assumed that the reported statistics of the posterior probability distributions represented the true underlying distributions. Results were reported in terms of the median and the 80% probability interval (PI).

Results

In 2018, the median pre-season forecast for the return of Late Shuswap/Portage sockeye was 7.0 million (80% PI: 3.3 – 15.1 million), comprising 99.5% 2-ocean sockeye. At the median forecast, this group was forecast to contribute 95% of the total return of the Late-run management group. Two years prior, in 2016, the ratios of Late Shuswap/Portage to Early Thompson out-migrating juveniles did not differ significantly across juvenile programs (p = 0.31), and the average was 4.4 to 1 (80% PI: 4.1 – 4.8). This ratio was applied to the in-season run size estimate of Early Thompson to generate an estimate of the Late Shuswap/Portage run. On August 10, the first in-season Late Shuswap/Portage SMURFing estimate was presented to the Fraser Panel, 3.6 million (80% PI: 2.6 – 5.0 million), based on an Early Thompson estimate of 0.81 million (80% PI: 0.63 – 1.07 million). Two weeks later (August 24), when the Early Thompson estimate was 1.26 million (80% PI: 1.23 – 1.32 million), the corresponding SMURFing estimate for Late Shuswap/Portage was 5.6 million (80% PI: 5.2 – 5.9 million).

The resulting uncertainty in the run-size estimate for Late Shuswap/Portage was a function of the uncertainty in the ratio of Late Shuswap/Portage to Early Thompson in the juvenile sample and the uncertainty in the in-season run size estimate of Early Thompson. The former estimate (the ratio and its uncertainty) was a fixed property of the juvenile sample, whereas the latter estimate fluctuated as dictated by in-season data, trending toward lower uncertainty as more of the Early Thompson run size was accounted for by high-precision hydroacoustic and catch accounting methods. SMURFing estimates change with every update to the estimated abundance of the Predicted Stock.

The results from SMURFing can be compared against other in-season and post-season estimates. In 2018, the first time-density model estimate of Late Shuswap/Portage was reported to the Panel on August 21 (6.3 million; 80% PI: 4.3 – 19.0 million). On August 24, a more precise estimate (6.3 million; 80% PI: 3.7 – 9.4 million) was presented. From August 28 through mid-September precision of this estimate varied little; the median estimate fluctuated between 5.7 and 6.5 million, while the 80% PI was stable near 3.7 – 7.2 million. The estimated return of Late Shuswap/Portage at the end of the season was 4.5 million, which was 97.5% of the accounted Late run. The final in-season ratio of Late Shuswap/Portage to Early Thompson stocks was 3.4, significantly lower than the ratio of 4.4 estimated from post-smolt samples. In 2014, this ratio was more similar between post-smolt samples and eventual estimates in the 2014 return year (Latham and Michielsens 2022).

Planned changes and potential areas for improvement

Because SMURFing to assess Late Shuswap/Portage is only done on 2026 cycle years, and historical juvenile data are limited, evaluations of the performance of this model in comparison to other in-season run-size models has been restricted to 2014, 2018 and 2022 and is somewhat anecdotal. For 2022, the model did not perform as well as in 2014 and 2018 (PSC 2024), as the smolt information in 2020 had been of a much lower quality compared to previous years because the sampling programs of out-migrating smolts had been impacted by COVID. This resulted in the number of samples available for SMURFing to be one tenth of the data available in 2014 and 2018. Because data on the performance of SMURFing is limited, it is important to better understand the assumptions underlying SMURFing: the degree to which these assumptions are violated, factors that minimize or exacerbate those violations, and the impact of those violations on assessments. Future analyses will include a greater number of potential pairs of Reference Stocks and Predicted Stocks to better understand these uncertainties and possibly expand the applicability of SMURFing in Fraser Panel assessment and management.

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B25. In-season Management Adjustments

M.R. Forrest and M.J. Hague

Summary

Management Adjustments (MAs) are the additional fish allocated to escape fisheries for the purpose of increasing the likelihood of achieving the spawning escapement target (SET). The selection of an appropriate MAs is within the purview of the Fraser River Panel (FRP) who take into account en-route losses due to adverse migration condition but also other factors that cause differences between predicted and observed spawning ground estimates (DBEs, Differences Between Estimates). Historical DBE estimates (Chapter C8) are based on differences between the actual number of spawners on the spawning grounds (spawning escapement SE) and the predicted spawning ground estimates based on the number of salmon migrating past the hydroacoustic site at Mission minus the total catch above Mission (potential spawning escapement PSE, DBE=SE-PSE). Sources for DBEs include en-route mortality as well as errors (bias and imprecision) introduced through the estimates of Mission escapement, spawning ground escapement, First Nations and recreational catches above Mission, and stock composition. Pre-season and in-season, DBE predictions can be obtained through a variety of different methods: based on historical discrepancies or based on observed or forecasted environmental conditions or migration timing. The Fraser River Panel uses these DBE predictions and other tools and information to agree upon MAs for pre-season planning and in-season management.

Introduction

In-season, PSC staff incorporate Fraser River Panel agreed upon MAs into TAC calculations in accordance with the Pacific Salmon Treaty Chapter IV, section 13b. The Panel relies on a variety of different pieces of information to derive the MA: historical estimates of difference between post-season observations and in-season projections of spawner numbers, i.e., the difference between estimates (DBEs), in-season environmental observations, and in-season model predictions of the DBE. The latter are based on statistical models using observed and in-season forecasts of river conditions and in-river migration timing. The models consider the historical differences between post-season spawning ground estimates (spawning escapement SE) and in-season projections of spawning escapement, i.e., Mission escapement minus catch above Mission (potential spawning escapement PSE, DBE= SE-PSE). For Early Stuart, Early Summer-run and Summer-run stocks, the models relate historical DBE estimates to river conditions measured near Hope, B.C. in the Fraser River (Chapter B27). When discharge levels or temperatures are above average, DBEs also tend to be high. In addition, for Early Stuart and Early Summer runs, in-season estimates are consistently higher than spawning ground estimates even when migration conditions are within normal ranges, and this tendency is also captured by the models. For Late-run sockeye, historical DBEs are related to the date when half the run has migrated past Mission (i.e., Mission 50% date), which captures the impact of the early migration behaviour observed since the mid-1990s on the migration success of these stocks (Lapointe et al. 2003, Chapter B28).

Data

The historical escapement differences, 50% migration dates at Hells Gate and Mission and the associated 19-day mean and 31-day mean temperature and discharge estimates are the primary biological data used in the statistical models. The historical DBE estimates (Chapter C8) and the 50% migration dates (Chapter C4) are summarised primarily by management group, except for some stocks like Pitt, Chilliwack, Harrison/Widgeon and Birkenhead/Big Silver, whose location closer to the mouth of the Fraser River decreases expected en-route losses associated with adverse migration conditions. The resulting DBE data therefore relates to the following groups: Early Stuart, Early Summer run without the Pitt and Chilliwack River components, Pitt River, Chilliwack River, Summer run without the Harrison/Widgeon component, Harrison/Widgeon, Late run group without the Birkenhead/Big Silver component and Birkenhead/Big Silver. Data for other groupings are also maintained, however, currently not used. The historical data ranges from 1977 to present. Some years are excluded for a management group or component to avoid potential biases in escapement estimates: if the year is not representative, if the data collection is not comparable to current practice or if the circumstances resulting in the estimates are unlikely to happen again. A list of the excluded years for each of management group or component can be found on the PSC SharePoint site for the Fraser River Panel among the data set files and is updated regularly.

The 50% Hells Gate date for a management group is determined from its Area 20 date (Chapter C4). The travel time from Area 20 to Mission is assumed to be 6 days for the Early Stuart, Early Summer and Summer run sockeye. The subsequent travel time from Mission to Hells Gate is assumed to be 5 days for the Early Stuart and Summer run sockeye and only 4 days for the Early Summer run sockeye. The Late run travel time from Area 20 to Hells Gate depends on their delay before up-stream migration and varies substantially across years.

The Fisheries and Oceans (DFO) Environmental Watch Program provides both historical as well as in-season observed and forecasted Fraser River temperatures and flows (Chapter B26). In-season the observations and forecasts of daily temperature and discharge are provided twice weekly, are presented in graphs to Fraser River Panel (Figure 1), and are used within mathematical models to predict the discrepancy between the SE and PSE, i.e., to predict the DBE. The forecasts allow the Fraser River Panel to make informed in-season fisheries decisions 3-4 days after the 50% date in Area 20 but prior to all 19 days of temperature and discharge data are available. This facilitates a more informed decision-making process and allows the Fraser Panel to proactively update in-season management adjustments to improve the probability of achieving spawning escapement goals.

In addition to the data used within the models predicting the DBE, the Fraser River Panel also incorporates additional information in their decision-making process. To that aim, the DFO Environmental Watch group also provides temperature data from the Fraser River mainstem and tributaries and how they compare to historical estimates (Table 1). Additional observations such as migration challenges, observed mortalities, pooling fish and observations on the spawning grounds are collected by DFO (DFO Stock Assessment, DFO Resource Management and other research groups) and communicated to the Fraser Panel (Chapter B31). This includes the migration challenges encountered at Hells Gate (Chapter B30) as well as migration challenges following the Big Bar rockslide and subsequent remediation work.

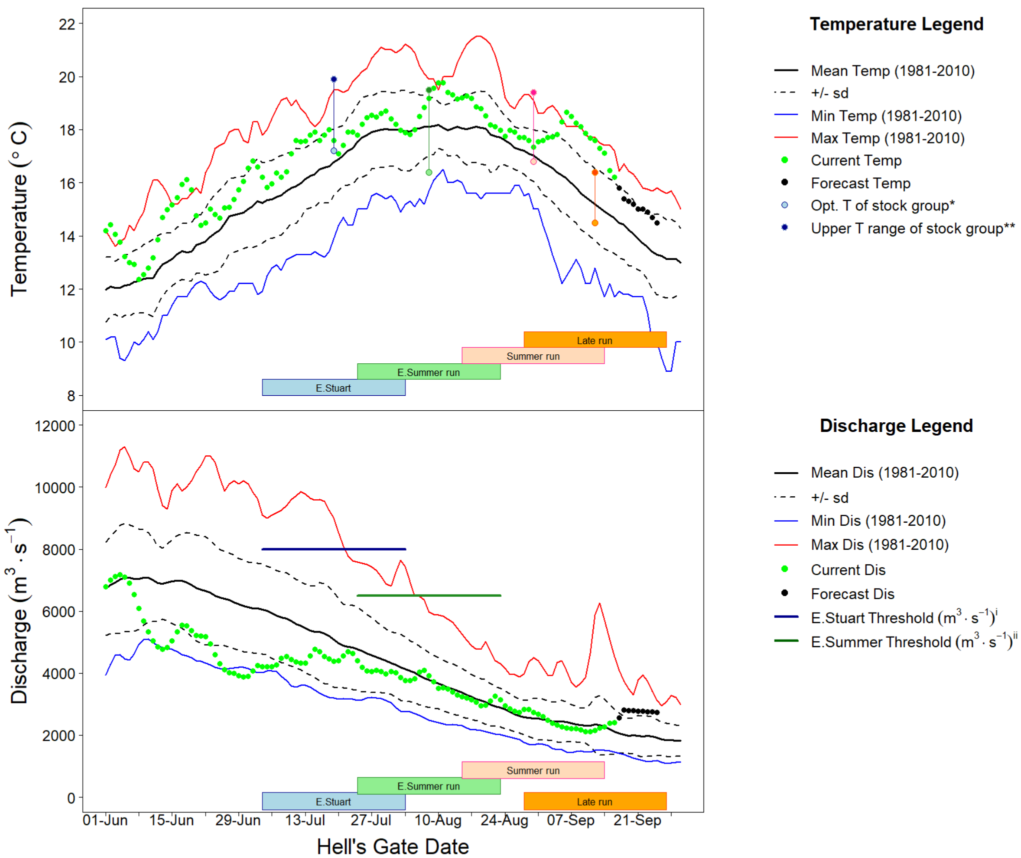

Figure 1. *Example of in-season Fraser River temperature at Qualark, B.C. and Fraser River discharge at Hope, B.C. graph.*

Table 1. *Example of in-season Fraser River mainstem and tributary temperatures.*

Upriver of Slide	Map #	Current Temperatures 14-Jul	Daily Mean	Historic Median	Deviation from Historical Median	Historic Year Range
		Fraser River Mainstem				
	1	Fraser River @ Qualark	17.8	16.2	1.6	1981-2010
	2	Fraser River @ Texas Creek	17.2	16.6	0.6	2006-2016
►	3	Fraser @ Marguerite	NA	NA	NA	
►	4	Upper Fraser @ Shelley	13.6	13.8	-0.2	1994-2016
		Fraser River Tributaries				
	5	Thompson R. @ Ashcroft	17.4	15.7	1.7	1995-2016
	6	South Thompson @ Chase	18.2	16.6	1.6	1994-2016
	7	North Thompson @ McLure	14.8	12.5	2.3	2008-2016
►	8	Quesnel R. @ Quesnel	16.5	14.6	1.9	2000-2016
►	9	Nechako R. @ Isle Pierre	20.1	18.4	1.7	2006-2016
►	10	Stuart R. @ Ft. St. James	18.7	17.5	1.2	2000-2016

Method

A variety of different methods can be used in-season by PSC staff to generate DBE predictions. These include approaches based on medians or cycle-line-specific medians of historical or more recent pDBE estimates, medians from years with similar environmental conditions (Chapter B29), and methods that rely on different medians depending on environmental threshold (Eliason et al. 2011) information above which sockeye survival is impeded (Chapter B29). Additional approaches include models with temperature, discharge (Chapter B27) or timing covariates (Chapter B28), as well as stock-specific pDBE estimates weighted by run size to derive estimates by management group (Chapter B29). To assist the Fraser River Panel in selecting MAs for in-season management using a clearly defined and transparent process, PSC staff recommend pDBE estimates for the different management groups based on the model demonstrating the strongest retrospective performance.

Some components of a management group are excluded from the models and alternative methods to predict the DBEs for those components are used: Pitt River and Chilliwack for the Early Summer run group, Harrison/Widgeon for the Summer run group, and Birkenhead/Big Silver for the Late run group.

Among Early Summer run stocks, Pitt River sockeye do not pass Mission and their passage is therefore not well estimated. In addition, their upstream migration distance within the Fraser River is short and thus they have minimal exposure to adverse river conditions. Given the data issues, a fixed DBE is used for Pitt River based on the median of all years with suitable data. The upstream migration distance to Chilliwack is similarly short, resulting in minimal exposure to adverse river conditions. The timing of this stock is substantially earlier than the timing of other Early Summer run stocks and this would impact the 50% migration date when combined with other Early Summer run stocks. In addition, the abundance of Chilliwack sockeye has not been estimated well prior to the use of DNA to identify stocks. Given the low abundance of Chilliwack on certain years, the DBE for Chilliwack is based on the median of all suitable years of data that have more than 30 sockeye identified as Chilliwack fish within the river. And on dominant and subdominant years, when Chilliwack abundances are higher and the quality of the DBE estimates is therefore greater, only the dominant and subdominant years of data are used to derive the median.

For Summer run sockeye, Harrison/Widgeon sockeye data are excluded from environmental DBE models because of their shorter migration distance within the Fraser River and because the relationship between Harrison/Widgeon DBEs and environmental conditions is poor. The DBE for Harrison/Widgeon sockeye can also be significant while the DBEs for other Summer run sockeye is much smaller. The DBE for Harrison/Widgeon sockeye is based on the median of all suitable years since the start of the DNA collection.

For Late-run sockeye, Birkenhead/Big Silver sockeye are excluded from the DBE models because, unlike other late run stocks, these sockeye don’t delay their upstream migration in Georgia Strait. The DBE for Birkenhead/BigSilver sockeye is based on the median across all suitable years.

The Fraser River Panel however manages Fraser River sockeye by management group. To accommodate the different DBEs for each component of a management group, a weighted proportion DBE (pDBE) approach is used. The MA models predict the pDBE for each management group excluding the components that rely on historical medians. Subsequently, a weighted average pDBE is calculated to combine the estimates of the different components. This is done by weighting the pDBE of each component by the associated relative abundance. Because the management group pDBEs depend on the relative abundance of the components, in-season DBEs can change with changes in run-size, regardless of changes in DBE predictions. When the abundances of the components are small relative to the total management group, weighting the pDBE by the components has almost no impact on the aggregate pDBE. The weighted approach is most beneficial for Late run stocks with high proportions of Birkenhead/Big Silver (Chapter B29). Following the results of additional retrospective analyses, the Panel has foregone the weighted approach when the abundance of the components is small relative to the total management group.

For in-season Fraser River Panel meetings, the Panel is provided with graphs of Fraser River temperature at Qualark, B.C. and Fraser River discharge at Hope, B.C. (Figure 1), a table of Fraser River mainstem and tributary temperatures (Table 1) and the predictions of the DBE models (Chapters B27 and B28) as well as in river observations such as carcass counts, fish holding behavior and fish condition and reports from the spawning grounds or from other areas with potential migration challenges such as Big Bar (Chapter B31).

The Panel may choose to adopt (if either party accepts) or not adopt (if both parties reject) the MA estimate corresponding to the pDBE prediction for a management group or may choose a different value as they see fit (by bilateral agreement).

Planned changes and potential areas for improvement

The Canadian Science Advisory Secretariat (CSAS) has received a request from DFO Resource Management regarding Fraser River sockeye MAs. The objectives are to document and evaluate current preseason, in-season, and postseason methods used to estimate DBEs and derive management adjustments (MAs) for Fraser River sockeye management groups; assess historical MA performance, including underlying assumptions, impacts on spawning escapement, and the influence of model error; develop and evaluate new DBE models that better account for environmental and migratory variability while supporting practical and stable in-season management; and propose improved MA approaches, including alternatives to threshold-based methods, with an explicit evaluation of trade-offs between accuracy and management variability. The CSAS meeting is expected to occur in 2027.

Appendix

Table A1. *Derivation of historical DBE estimates and subsequent transformations (DBE = Difference Between Estimates, SE = Spawning Escapement, PSE = Potential Spawning Escapement, pDBE = Proportional Difference Between Estimates, pMA = Proportional Management Adjustment, MA = Management Adjustment).*

1. $DBE = SE - PSE$	2. $pDBE = \frac{(SE-PSE)}{PSE}$
3. $pMA = \left(\frac{PSE}{SE}\right) - 1$	4. $pDBE = \frac{1}{1+pMA} - 1$
5. $pMA = \frac{1}{1+pDBE} - 1$	6. $MA = SET \cdot pMA$

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B26. EWatch temperature and discharge forecasts

M.R. Forrest, M.J. Hague and D. Patterson

Summary

The DFO Environmental Watch (EWatch) Program provides PSC managers with scientific advice and environmental data to assess the impact of different environmental factors on the migration success of Pacific salmon in fresh water (https://www.pac.dfo-mpo.gc.ca/science/habitat/frw-rfo/index-eng.html#info). In-season EWatch generates Fraser River forecasts of water temperature at Qualark, B.C. and discharge at Hope, B.C. and provides this information to the Fraser River Panel twice weekly from July to September. They also provide real time temperature data from key EWatch temperature monitoring stations within the Fraser River watershed and real time Fraser River discharge data from a Water Survey of Canada (https://wateroffice.ec.gc.ca) site in the lower river. The temperature and discharge forecasts are used along with observed daily temperature and discharge in environmental models (Chapter B27) to provide the Fraser River Panel with early indications of adverse environmental conditions and potential en-route losses, that may impact their Management Adjustment (MA) decisions (Chapter B25).

Introduction

For the management of Fraser River sockeye salmon, the Fraser River Panel relies on Management Adjustments (MAs), which are the additional fish allowed to escape fisheries to increase the likelihood of achieving the spawning escapement target (SET) (Chapter B25). To select appropriate values for the MAs, the Panel relies on a wide range of different pieces of information that allow to evaluate in-river migration conditions and potential en-route losses. Among the information are the results of the models that relate temperature and discharge within the Fraser River to differences between predicted and observed spawning ground estimates, i.e., to Differences Between Estimates (DBEs) (Chapter C8). These models use 19-day average Fraser River temperature at Qualark, B.C. and discharge at Hope, B.C., associated with the 50% migration date of the management group, as model inputs. Of the 19 days, 15 days of data precede the Hells Gate migration date. The DFO Environmental Watch group is responsible for providing both observed and forecasted Fraser River temperature and flows twice weekly throughout the migration season. The 10-day forecasts (Morrison 2005, Morrison et al. 2005, Hague et al. 2014) provide managers with an early indication of the expected DBE and allow the Fraser River Panel to make informed fisheries decisions 3-4 days after the 50% date in Area 20. This facilitates a more informed decision-making process and allows the Fraser Panel to proactively adjust management actions to improve the probability of achieving spawning escapement goals.

Water temperature and discharge are forecasted by different methods. In the past, a complex hydrological model (Morrison 2005) that required intensive meteorological inputs was used to make the 10-day forecasts of Fraser River temperature at Qualark. Currently the Hope Statistical Model (HSM) (Hague et al. 2014) and a generalized additive mixed effects model (GAMM) (Gardner 2016) are used to forecast Fraser River temperature at Qualark, B.C. The evaluations of the HSM (Hague et al. 2014) and the GAMM (Gardner 2016) models confirmed the benefit of using these less data intensive models to inform fisheries decisions. These models using air temperature and discharge covariates explained a significant proportion of the variability in daily summer water temperatures in the Fraser River. To produce the 10-day forecast of Fraser River discharge at Hope, the first 3 days are forecasted using a routing model based on upstream flows and the next 7 days are forecasted using an historic decay model that tracks the shape of historic hydrograph.

Data

The EWatch program has an environmental monitoring program which consists of a comprehensive network of temperature logger stations along key salmon migration routes throughout the Fraser Watershed (https://www.pac.dfo-mpo.gc.ca/science/habitat/frw-rfo/index-eng.html#info) (Figure 1). The EWatch program provides the PSC with observed Fraser River water temperature data from this network of real-time data loggers and from others that are operated by Water Survey Canada. The EWatch group also provides the PSC with observed discharge data from Water Survey of Canada (https://www.canada.ca/en/environment-climate-change/services/water-overview/quantity/monitoring/survey.html).

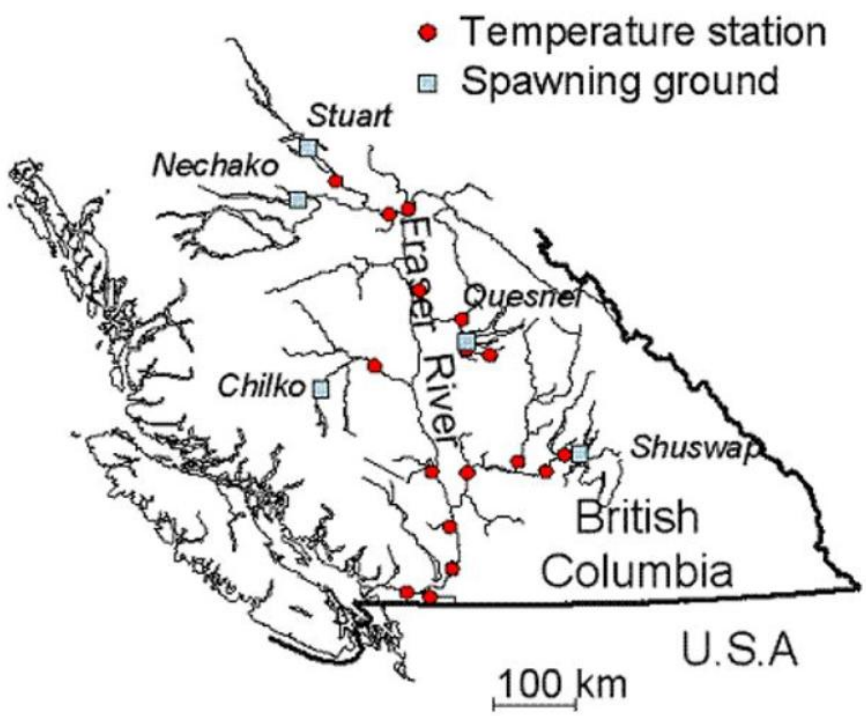

Figure 1. Locations of key EWatch and WSC temperature monitoring stations and major Fraser River sockeye salmon *spawning* grounds (https://www.pac.dfo-mpo.gc.ca/science/habitat/frw-rfo/index-eng.html)

Because Hells Gate forms a well-known impediment to salmon migration (Roos 1991, MacDonald et al. 2000) and because there exist long time-series of historical environmental conditions associated with the monitoring stations located at Hope and Qualark (Patterson et al. 2007, MacDonald et al. 2010), these two sites are used as the main geographic reference points to describe Fraser River environmental conditions.

The following list provides a detailed overview of the various data sets used to derive the observed and forecasted water temperature and discharge time series:

- Historical daily mean Fraser River water temperatures recorded near Qualark, B.C.: data prior to 2007 (Patterson et al. 2007), data from 2007 to current (DFO, EWatch Program).
- Observed daily Fraser River upstream temperatures measured by Water Survey of Canada (https://wateroffice.ec.gc.ca/login_e.html). Verified and collated by the EWatch program.
- Observed and Historical daily discharge recorded near Hope, B.C.: Wateroffice, Government of Canada - Real-Time Hydrometric Data (https://wateroffice.ec.gc.ca/login_e.html).
  Due to the inverse relationship between discharge and thermal capacity (Webb et al. 2003), discharge explains a significant proportion of the variability in water temperature (Neumann et al. 2003, van Vliet et al. 2011). Daily mean river discharge near Hope, B.C. was identified as providing the best fit to Qualark water temperatures (Hague et al. 2014).
- Air temperature – Environment and Climate Change Canada (https://weather.gc.ca/).
  Water temperature has a high correlation with air temperature (Cluis 1972, Kothandaraman and Evans 1972: Stefan and Preud'homme 1993) because they are influenced by the same heat transfer processes (Mohseni and Stefan 1999). Air temperatures from Kamloops, B.C. were shown to provide the best fit to Qualark water temperatures relative to that from other locations further upstream or downstream in the watershed (Hague et al. 2014).
- Air temperature forecast - Forecasts of air temperature come from both Environment and Climate Change Canada (https://weather.gc.ca/) and Weather Network (https://www.theweathernetwork.com/ca).
- Hope discharge forecast - Since 2020, forecasted flows have been supplemented by the BC River forecast center, using the CLEVER model (http://bcrfc.env.gov.bc.ca/freshet/map_clever.html).

Method

The EWatch group uses a combination of the Hope Statistical Model (HSM, Hague et al. 2014) and a generalized additive mixed effects model (GAMM) (Gardner 2016) to produce 10-day forecasts of Fraser River temperature at Qualark.

The statistical model to produce 10-day daily forecasts of river temperature (Hague et al. 2014) is a stochastic model in which daily water temperature (*T*) is predicted using a combination of seasonal and non-seasonal components, similar to Caissie et al. (2001):

$$T = S + R + r \qquad (13)$$

whereby *S* is the seasonal (harmonic) variability in water temperature, *R* is the non-seasonal variability driven by exogenous environmental variables and *r* is the non-seasonal variability driven by serial autocorrelation. A range of different statistical models following equation 1 are used to forecast the daily temperature. While *S* and *r* are common to all these models, the non-seasonal variation in water temperature *R* is distinct for each model by using seasonal residuals of air temperature, discharge, or air temperature and discharge. A harmonic method (Cluis 1972, Caissie et al. 2001, Hague et al. 2014) to model seasonal trends for the water temperature, air temperature and discharge is applied. The advantage of using statistical models is the relative simplicity and minimal data requirements (Benyahya et al. 2007, Hague et al. 2014). They require less physical input data and typically use readily available measurements of air temperature, river flow, and water temperature along with historical seasonal trends to generate short-term river temperature forecasts (Gardner 2016).

The GAMM model is the second model used for short-term forecasting of river temperature and provides broader spatial coverage with more flexible and cost-effective implementation of river temperature forecasting (Gardner 2016). This approach models in-season temperatures by combining a linear regression model for daily water temperature with a sinusoidal smoothing spline of seasonal trends (Gardner 2016):

$$(14) \quad T_{i.j} = (\alpha + \mu_j) + \beta_1 A_{i-1,j} + \beta_2 Q_{i-1,j} + \beta_3 T_{i-1,j} + \beta_4 A_{i-1,j} \cdot L + \beta_5 Q_{i-1,j} \cdot L + f(day_i) + \varepsilon_{i,j}$$

$$\text{With } \varepsilon_{i,j} \sim N(0, \sigma_e^2) \text{ and } \mu_j \sim N(0, \sigma_u^2).$$

In equation 2, $T_{i,j}$ is the predicted river temperature on day *i* in year *j*, A_{i-1}, Q_{i-1}, T_{i-1} are respectively the air temperature, the discharge and the water temperature of the previous day, $A_{i-1}xL$ is the interaction of air temperature and location and *f* represents a cubic regression spline smoothing function of Julian day, which allows the model to fit the seasonal trend. The residual error (ε), and year-specific variation of intercept (μ_j) are normally distributed with a mean of zero. In this model, discharge, air temperature, water temperature, and location are all fixed effects. Discharge (*Q*, m^3/s) is used as a predictor variable to account for the inverse relationship between discharge and river temperature (Webb et al. 2003). Air temperature (*A*, °C) is included due to the high correlation between air and water temperature (Kothandaraman and Evans 1972, Stefan and Preud'homme 1993) from heat exchange processes (Mohseni and Stefan 1999). Current water temperature (*T*, °C) is a predictor of water temperature in the near future (Caissie et al. 1998). Location (*L*) is included as a fixed effect due to the differences in mean temperature at different locations, as well as the location-specific effects of air and discharge on river temperature.

The model choice (HSM versus GAMM) and forecast inputs are a function of past model performance and the available data. Both the HSM and the GAMM model are evaluated annually by the EWatch group using three main performance metrics (root mean square error, mean raw error and mean absolute error) which compare forecasted and observed water temperature values. Errors in forecasted discharge and temperature are also evaluated. In addition, the model's performance is evaluated using type I (false-positive) and type II (false-negative) error rates which are associated with critical temperature thresholds related to salmon migration performance and mortality (18-21°C). In future, type I and type II error rates which are associated with critical discharge thresholds will be evaluated as well.

Discharge is forecasted by two different models. For the first 3-days of the forecast, a routing model based on upstream flows is used (pers. comm. D. Patterson). For the last 7-days of the forecast a historic decay model is used (pers. comm. D. Patterson). This model uses the historic slope for a given day of the year applied to the previous days forecast. Reports describing the methods and comparative analyses to methods used by the B.C. River Forecast Centre are still in progress.

Potential areas for improvement

As indicated above, the temperature and discharge forecasts are used in-season along with observed temperature and discharge in statistical models to provide managers with an early indication of the expected discrepancy between the predicted and observed spawning ground estimates, i.e. the difference between estimates (DBEs). These DBE models incorporate uncertainty through Bayesian estimates. The Fraser Panel is provided with a confidence level on the likelihood of obtaining different values of a parameter when particular data have been observed (Ellison 1996). However, the Fraser

Panel would also like to see the uncertainty in the temperature and discharge forecasts being incorporated.

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B27. DBE temperature and discharge model

M.R. Forrest and M.J. Hague

Summary

Since 2002, the Pacific Salmon Commission has used environmental conditions in the lower Fraser River to predict differences between potential spawning escapement based on Mission estimates minus upstream catch and escapement on the spawning grounds (MacDonald et al. 2010). Reliably predicting the discrepancy between estimates (DBEs) increases the probability of achieving spawning escapement targets. Temperature and discharge models are used by the PSC to provide the Panel with likely spawning escapement outcomes and the Panel uses this information to determine how many extra fish are needed to meet spawning objectives, i.e. the size of the Management Adjustment (MA, Chapter B25). In these models, mean Fraser River temperature at Qualark, B.C. and mean Fraser River discharge at Hope, B.C. (Morrison 2005, Morrison et al. 2005, Hague et al. 2014) are related to historical timeseries of escapement discrepancies to generate either pre-season or in-season DBE predictions for Fraser River sockeye salmon (*O. nerka*) management (or run timing) groups.

Introduction

Under the Pacific Salmon Treaty, the Fraser River Panel has the discretion to add additional fish to the spawning escapement target (SET) set by Canada for Fraser River sockeye salmon (*O. nerka*) to ensure spawning requirements are met (PST 2025, Article IV, Chapter 4, Paragraph 3b). These additional fish are called the Management Adjustment (MA) and are meant to increase the likelihood of achieving the SET (Chapter B25). Post-season, MAs are defined by the differences between estimates (DBEs), i.e., the difference between the predicted spawning ground estimates (Potential Spawning Escapement, PSE, i.e. the number of salmon migrating past the hydroacoustic site at Mission minus the total catch above Mission), and the actual postseason estimates of the total number of spawners at the spawning grounds (Spawning Escapement, SE), with DBE=SE-PSE. Pre-season and in-season, DBE predictions can be derived through a variety of different methods: based on historical discrepancies, based on observed or forecasted environmental conditions or based on migration timing. This Chapter focuses on the temperature and discharge models developed jointly between the PSC and DFO to predict the DBE for Early Stuart, Early Summer-run and Summer-run sockeye (MacDonald et al. 2010). Each run timing group experiences distinct river conditions, with a greater likelihood of extreme discharge during the early runs and extreme temperature during the summer runs. Environmental extremes are known to create migratory challenges and contribute to increased levels of mortality during the return spawning migration. Historically, when discharge levels or temperatures within the Fraser River are above average, DBEs tend to be high. In addition, for Early Stuart and Early Summer runs, in-season Potential Spawning Escapement estimates are consistently higher than spawning ground estimates even when migration conditions are within normal ranges, and this tendency is also captured by the DBE models.

Data

The historical escapement differences (DBEs, Chapter C8), Hells Gate 50% dates and associated 19-day mean and 31-day mean temperature and discharge data (Chapter B26) are the primary data used in the environmentally-based DBE models. The DBEs are calculated as the difference between the spawning escapement (spawning ground estimate) and the potential spawning escapement (Mission passage minus catch upstream of Mission). Each management group has its own DBE dataset because each group experiences different environmental conditions depending on when they migrate up the Fraser River.

The Hells Gate 50% date is the date on which 50% of the management group will pass Hells Gate in the Fraser River. The Hells Gate date is calculated based on marine migration dates indexed to statistical Area 20 in Juan de Fuca Strait (Chapter B30). The travel time from Area 20 to Mission (the location of the PSC hydroacoustic monitoring program) is assumed to be 6-days for the Early Stuart, Early Summer and Summer run sockeye. The travel time from Mission to Hells Gate is assumed to be 5-days for the Early Stuart and Summer run sockeye and 4-days for the Early Summer run sockeye. In-season, the Area 20 dates for the different management groups derived through the run size assessment models are converted into Hells Gate Migration dates. This date in return is essential to derive the mean temperature and discharge information for the different management groups as the 19-day mean water temperature and discharge estimates used in-season rely on data 15 days before and 3 days after the Hells Gate date. Post-season, 31-day means are used to summarise the environmental conditions in the Fraser River, based on 15 days of observations before and 15 days after the Hells Gate date.

The DFO Environmental Watch Program provides updates of observed and forecasted Fraser River water temperature at Qualark, B.C. and discharge at Hope, B.C. twice weekly throughout the migration season (Chapter B26). Daily observed discharge values are accessed from the Environment Canada Water Office online database (https://wateroffice.ec.gc.ca/login_e.html) and daily observed Fraser River water temperature at Qualark is provided by the DFO Environmental Watch group (Patterson et al. 2007) who also provides the 10 day forecasts of temperature and discharge. The temperature forecast is predicted by a statistical model that uses water temperature, air temperature, river discharge and seasonal trends (Hague and Patterson 2014) while the discharge forecast is derived by a routing model based on upstream flows and a historic decay model (pers. comm. D. Patterson).

Method

The temperature and discharge models use environmental conditions in the Fraser River as predictive variables to predict the DBE. There are significant relationships between lower river environmental conditions and historical DBEs for Early Stuart, Early Summer-run and Summer-run management groups (MacDonald et al. 2010, Cummings et al. 2011, Figure 1).

The resulting DBE temperature and discharge model is expressed as:

$$(1) \qquad ln\left(\frac{PSE}{SE}\right) = a + b_1 \cdot \mu_T + b_2 \cdot \mu_T^2 + b_3 \cdot \mu_Q + b_4 \cdot \mu_Q^2$$

With μ representing the 19-day (in-season) or 31-day (post-season) mean of the Fraser River temperature (*T*) or discharge (Q) around the Hells Gate migration date. The dependent variable is expressed as the ratio of the Potential Spawning Escapement (PSE) over the Spawning Escapement (SE). The log transformation of the dependent variable is required to meet the assumptions of homoscedasticity (Zar 1996) and to constrain predictions in the range 0 or higher. The predictive variables are the 19-day or 31-day mean Fraser River temperature (T) and discharge (Q). The quadratic term for both discharge and temperature is included ($T+T^2$, $Q+Q^2$) in the regression equation.

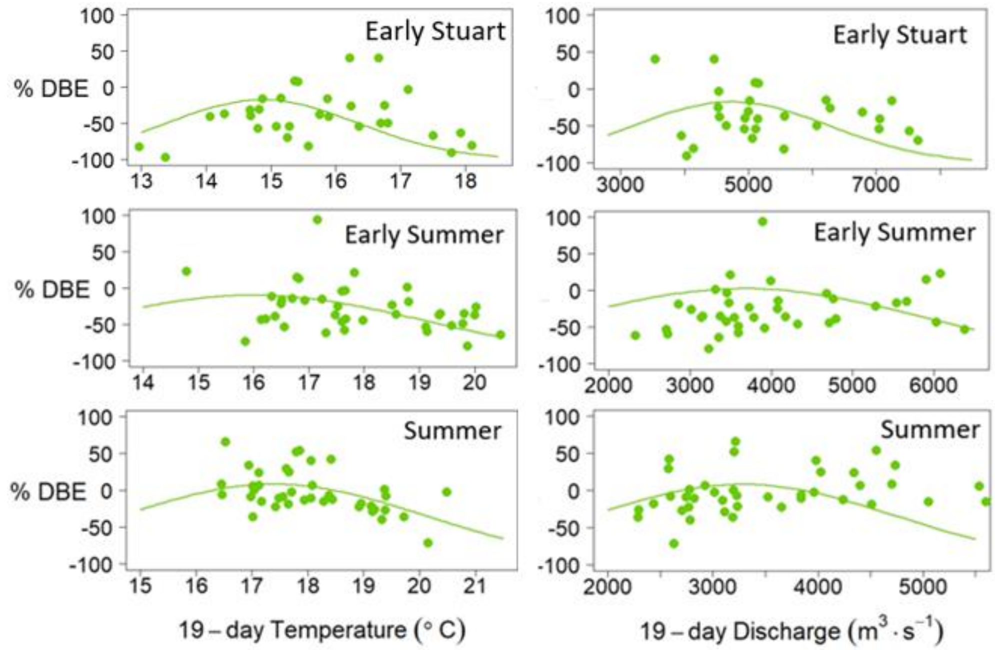

Figure 1. Relationship between the average 19-day *temperature* at Qualark and the %DBE (Difference between estimates) and between the average 19-day discharge at Hope and the %DBE for Early Stuart, Early Summer run and Summer-run sockeye.

In-season the 19-day means are based on 9 or more days of observed data and 10 or less days of forecasted data, given predictions are only made 10 days out because of constraints in forecasting daily environmental data (Hague and Patterson 2014). The 19-day model provides managers an early in-season indication of the expected DBE in order to be more proactive in their management process as it allows a %DBE prediction to be made between 3 to 4 days after the Area 20 50% date and 1 to 2 days prior to the Mission 50% date. Post-season, once 31 days of observed T & Q data are available for a management group, the MA models are fit to a 31-day mean T and Q centered around the 50% date at Hell's Gate. The 31-day model captures 90% or more of a run's exposure to environmental conditions at Hell's Gate and provides a better fit to the historical DBE data than environmental data averaged over a shorter time-period (Hague and Patterson 2007).

The model is run in WinBUGS (Spiegelhalter et al. 2003) with an R (R Core Team 2025) interface. This program allows the application of Bayesian methods to calculate the probability of the value of a parameter given the observed data (Wade 2000) and to provide an explicit expression of the amount of uncertainty in these parameter estimates (Ellison 1996). As a result, it is also possible to quantify the uncertainty of the forecasted DBE and provide a probability interval (Ellison, 1996) in addition to the point estimate for the forecasted DBE.

Each management group has its own historical dataset and MA models are run separately for each group. This is because each management group experiences different conditions depending on when they migrate up the Fraser River. Early Stuart sockeye salmon often experience higher discharges due to freshet that might continue into early July. Early Summer-run sockeye salmon can experience both high discharges and high temperatures, as they start their migration while discharge might still be high due to late freshet, and they may migrate through the peak of high summer water temperatures in the Fraser River. Summer-run sockeye often experience high temperatures as they also migrate during the peak of summer; however, depending on their timing they might migrate when days are getting shorter and night cooling begins.

The current temperature and discharge models predict a DBE for each management group but do not incorporate stock specific information despite known differences in tolerances to adverse environmental conditions (Eliason et al. 2011). Stock-specific differences are addressed by reducing the number of years in the historical dataset used for predicting DBEs. For example, in Dominant or Subdominant Early South Thompson years, the Early Summer-run dataset might be reduced to only Dominant or Dominant and Subdominant years. Early South Thompson sockeye generally dominate the Early Summer run management group in Dominant and Subdominant years and it is believed that their response to environmental conditions would be better reflected by years in which they make up larger proportions of the Early Summer run. The datasets can also be reduced to odd years in pink years and cycle line years. However, this generally reduces the data points and influences the fit of the model. Another method used to address stock-specific differences is the weighted pDBE approach described in Chapter B29.

Results

The temperature and discharge models produce prediction of the DBEs, including the 80% probability interval (PI), for Early Stuart, Early Summer and Summer run stocks for different Area 20 dates indicating the timing of the run (Table 1). In-season, the Area 20 date or marine migration date will be obtained from the run size assessment models (Chapter B23). Depending on the Area 20 migration date, the Hells Gate 50% date will differ and this in turn will impact the 19-days of temperature and discharge data used within the DBE model. For example, on August 21, the mean temperature and discharge when assuming the Area 20 timing is August 7, will be based on 19 days of observed data, 15 days observed prior to the Hells Gate date of August 17 and 3 days after. Because all of the 19 days of temperature and discharge data for this example are based on observations, no forecasts are needed to calculate the 19-day means. However, if the Hells Gate migration date is August 18, the 19-day mean used as input in the DBE model will be based on 18 days of observed data and one forecasted day (August 21). Thanks to the 10-day forecasts of temperature and discharge, DBE predictions can be made 3 to 4 days after the 50% migration date in Area 20. This allows the Fraser Panel to proactively adjust management actions to improve the probability of achieving spawning escapement goals and facilitates a more informed decision-making process.

Table 1. *In-season table produced on 21 August 2018 containing the model predictions of expected percent Differences Between Estimates (%DBEs) and the implied proportional Management Adjustment (pMA). Depending on the assumed migration timing (Area 20 Date) of the management group, the 19 day mean temperature and discharge values will differ, resulting in different DBE predictions.*

Area 20 Date	Hells Gate Date	Average Temperate °C (19 days)	Average Discharge m^3/s (19 days)	Number of obs. days	Number of forec. days	Predicted % DBE median	80% PI 10%	80% PI 90%	Implied Proportional MA (pMA) median	80% PI 10%	80% PI 90%
Pre-Season Values											
8-Aug	18-Aug					-19%			0.23		
Current model predictions											
04-Aug	14-Aug	20.0	3016	19	0	-48	-2	-73	0.92	0.02	2.70
05-Aug	15-Aug	20.0	2977	19	0	-46	3	-72	0.85	-0.03	2.57
06-Aug	16-Aug	19.8	2933	19	0	-42	13	-70	0.72	-0.12	2.33
07-Aug	17-Aug	19.7	2887	19	0	-36	28	-67	0.56	-0.22	2.03
08-Aug	18-Aug	19.5	2838	18	1	-29	44	-65	0.41	-0.31	1.86
09-Aug	19-Aug	19.3	2788	17	2	-24	58	-64	0.32	-0.37	1.78
10-Aug	20-Aug	19.2	2734	16	3	-19	76	-62	0.23	-0.43	1.63

Model evaluation

DBE models and the derived Management Adjustment are used by managers to achieve spawning escapement targets while maximizing harvest. Underestimates of the DBE can lead to conservation concerns if excess catch causes too few fish to reach spawning grounds, whereas overestimates of DBE can result in foregone catch (Cummings et al. 2011). Various studies have evaluated the performance of the various DBE models (Cummings et al. 2011, Dionne and Patterson 2018) used to predict in-river loss. Cummings et al. (2011) found that although the best DBE models varied depending on the management group and performance measures, there was strong evidence that DBE forecasts and derived MA estimates based on some combination of environmental or biological data outperformed the approach of applying no MA at all.

A study by Hague et al. (2008) examined whether data from lower Fraser River temperature and discharge stations are appropriate environmental indices for the basin as a whole. Adult salmon encounter a range of temperatures and discharges along their up-river migration route and these values may not be consistently well-correlated to lower river conditions, particularly for populations with natal spawning grounds >500km from the ocean or for populations entering the river after mid-August. Results suggested that, in general, lower Fraser River environmental conditions were well correlated to conditions upriver; however, correlation strength decreased as a function of increasing distance and/or slower migration rates.

A thorough evaluation of the different DBE models has been done using a retrospective analysis (Chapter B29). This evaluation is a clear and transparent approach to select the best DBE model for in-season management based on past performance.

Planned changes and potential areas for improvement

Given the cost to underestimating or overestimating DBEs, DFO's EWatch group and PSC staff continuously work to improve the models and tools used to estimate en-route loss (Dionne and Patterson 2018). A review by the Canadian Science Advisory Secretariat (CSAS) is scheduled to occur in 2027.

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B28. DBE Run Timing Model and Upstream Migration Timing Model

M.R. Forrest and M.J. Hague

Summary

Late run sockeye stocks excluding Birkenhead/Big Silver traditionally delay their migration to the Fraser River in the Strait of Georgia. Since 1995, these stocks have however entered the Fraser River earlier, resulting in extended freshwater residence times, exposure to higher river temperature and discharge; and increased mortality (Lapointe et al. 2003, Cooke et al. 2004). The 50% migration date at Mission captures the early migration behaviour and is used as a predictive tool in the DBE run timing model that relates the upstream migration timing to the migration success of these stocks, i.e. the difference between the predicted and the observed spawning escapement (difference between estimates, DBEs). DBE predictions based on the upstream migration should be available prior to observing all the late run sockeye upstream to be useful for marine fisheries management. Therefore, the upstream migration timing model uses the historic relationship between the proportion upstream migration to-date and upstream timing to predict the 50% migration date at Mission for Late run sockeye excluding Birkenhead/Big Silver.

Introduction

Late run stocks excluding Birkenhead/Big Silver do not migrate immediately upstream. Instead, they hold in the Strait of Georgia close to the mouth of the river before initiating up-river migration. Since 1995, Late run sockeye arrive in the Strait of Georgia at the normal time but migrate up the river earlier than normal. There is a high mortality associated with this diverging behaviour resulting in a higher observed DBE (difference between estimates) between potential spawning escapement based on Mission estimates minus upstream catch and escapement on the spawning grounds (Macdonald et al. 2010). In order to mediate these en-route losses, additional fish are allowed to escape upriver of Mission to account for anticipated DBEs, i.e., differences between in-season versus post-season estimates of spawning escapement. The addition of fish to an escapement target for the purpose of increasing the likelihood of achieving the spawning escapement target (SET) is called the Management Adjustment (MA, Chapter B25). The Fraser River Panel relies on both in-season observations as well as DBE predictions to derive appropriate MA estimates. For Late-run sockeye excluding Birkenhead/Big Silver, the DBE run timing model in combination with the upstream migration timing model are used to predict the DBE. The DBE run timing model uses the relationship between the historical 50% migration date at Mission and the historical DBEs to make in-season DBE prediction. The in-season estimate of the upstream migration date in turn is derived through the upstream migration timing model for Late run sockeye excluding Birkenhead/Big Silver which relies on the historical relationship between the percentage of upstream migration to date and the 50% migration date at Mission. The percentage upstream migration to date indicates the proportion of the sockeye that continued their upstream migration into the Fraser River and the sockeye that made it to the Strait of Georgia (Area 29, Chapter B22).

Data

The historical differences between estimates (DBEs) and Mission 50% migration dates for Late run sockeye are the primary data used in the DBE run timing model (Chapter C8). Birkenhead/Big Silver stocks are excluded from the Late run DBE and 50% migration data because they do not delay their upstream migration. The Mission 50% migration timing relates to the date when 50% of the run will have passed Mission. Additional data used to predict the upstream migration timing for Late-run excluding Birkenhead/Big Silver are the reconstructed abundance estimates of these stocks in the Strait of Georgia. Forward reconstructions predict abundances into the Strait of Georgia (Chapter B22) based on marine daily abundances derived from stock-specific catch-per-unit-effort (CPUE) data and historical catchability estimates of marine test fisheries combined with assumptions about migration speed. Dividing the total upstream migration to date by the total reconstructed abundance in the Strait of Georgia to date gives an estimate of the proportion of upstream migration to date.

Methods

The DBE run timing model uses Mission timing as a predictive variable to predict the DBE. The DBE is expressed as ln(PSE/SE), whereby PSE is the potential spawning escapement and SE is the actual spawning escapement. The log transformation is required to meet the assumptions of homoscedasticity (Zar 1996) and to restrict predictions to positive numbers. Upstream timing is described by the Mission 50% migration date. Higher (more negative) DBEs are associated with early upstream migration (Figure 1).

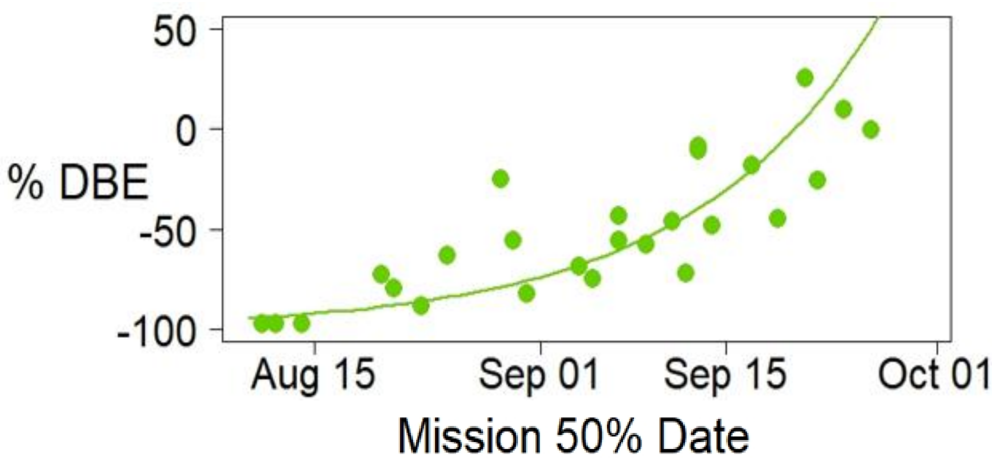

Figure 1. *Relationship between %DBE and the Mission 50% migration date for Late Run sockeye excluding Birkenhead/Big Silver.*

In-season, the Mission 50% migration date is predicted by the upstream timing model. This model looks at the historical relationship between the proportion of upstream migration to date and the post-season 50% migration date for Late-run excluding Birkenhead/Big Silver (Figure 2). The dependent value for the upstream timing model is the 50% date at Mission. The predictive variable is the percentage of resident fish reconstructed into the Strait of Georgia which have migrated past Mission on a given date. Earlier in the season, predictions of upstream migration timing are more uncertain (lower R^2) compared to later in the season. The higher the proportion of upstream migration to date, the more precise the timing estimate. Uncertainty around the upstream timing will impact the uncertainty around the resulting DBE predictions.

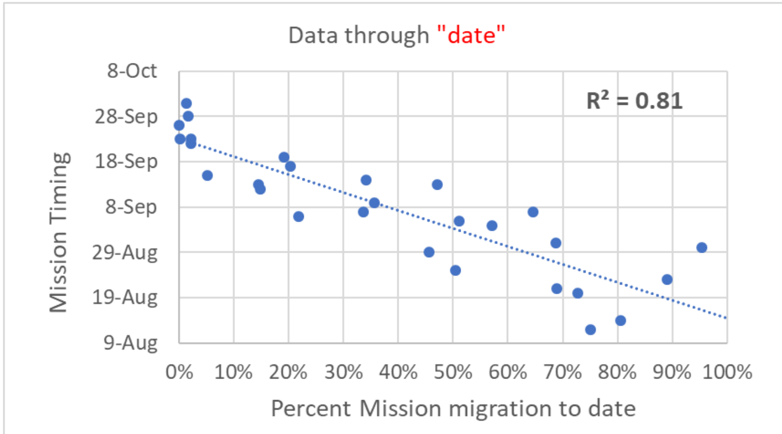

Figure 2. *Example of the relationship between the 50% date at Mission and the percentage of resident fish reconstructed into the Strait of Georgia which have migrated past Mission on a given date.*

The DBE run timing and upstream migration timing models incorporate uncertainty through the application Bayesian estimation methods. Rather than providing the Fraser River Panel with a fixed DBE prediction or 50% migration date at Mission through frequentist statistics, the use of Bayesian methods allows the quantification of the uncertainty associated with the predictions (Ellison 1996). The Bayesian regression models are run in WinBUGS (Spiegelhalter et al. 2003) with an R-code interface (R Core Team 2025).

MODEL EVALUATION

DBE models and the derived Management Adjustment are used by managers to achieve spawning escapement targets while maximizing harvest. Underestimates of in-river loss can lead to conservation concerns if excess catch causes too few fish to reach spawning grounds, whereas overestimates of in-river loss can result in foregone catch (Cummings et al. 2011). Various studies have evaluated the performance of the DBE model (Cummings et al. 2011, Dionne et al. 2018) used to predict in-river loss for Late run sockeye excluding Birkenhead/Big Silver. Cummings et al. (2011) found that MA forecast based on the DBE model outperformed applying no MA at all.

Cummings et al. (2011) ranked the DBE run timing model for Late run sockeye as the best in terms of hind cast criteria. This model performed better than models relying on temperature and discharge. But the in-season uncertainty associated with the Mission migration date reduces the reliability of the resulting DBE predictions. When the Late-run run-size is small, estimating delay can be even more difficult.

More recently, a comprehensive retrospective analysis of the different DBE models was conducted (Chapter B29). This evaluation provides a clear and transparent basis for selecting the most suitable DBE model for in-season management, based on past performance.

Planned Changes and Potential Areas for Improvement

The DFO EWatch group and PSC staff continue to work at improving the models and tools used to estimate en-route loss given the cost to underestimate or overestimate in-river losses. A review by the Canadian Science Advisory Secretariat (CSAS) is scheduled to occur in 2027.

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B29. Retrospective evaluation of different DBE prediction methods

M.R. Forrest

Summary

Management Adjustments (MAs) are intended to increase the likelihood of achieving the spawning escapement targets (SETs) when faced with adverse migration conditions and assessment uncertainty. While the selection of appropriate MAs is within the purview of the Fraser River Panel, predicting MAs is the responsibility of PSC staff. MA predictions are made in terms of DBEs (Differences Between Estimates), i.e. the difference between observed spawning ground estimates and predicted spawner numbers assuming no en route loss or assessment error (Chapter B25). Pre-season and in-season proportional DBE (pDBE) predictions can be obtained through a variety of different methods: based on medians, cycle line-specific medians of historical or more recent pDBE estimates, using medians of years with similar environmental conditions (Chapter B31), using models that include temperature, discharge (Chapter B27) or timing covariates (Chapter B28), or using stock-specific pDBE estimates weighted by run size to derive estimates by management unit (Chapter B25). Retrospective analyses of these methods by management group identify the best performing methods and provide a clearly defined and transparent approach to assist the Fraser River Panel in selecting MAs for pre-season planning and in-season management. While PSC Staff will aim to select the best performing unbiased method, the Panel may select a different approach depending on the Panel's level of risk tolerance.

Introduction

Under the Pacific Salmon Treaty, the Fraser River Panel has the discretion to add additional Fraser River sockeye salmon (*O. nerka*) to the spawning escapement target (SET) set by Canada to ensure spawning escapement requirements are met (PST 2025, Article IV, Chapter 4, Paragraph 3b). The additional fish added to the escapement targets are termed the Management Adjustments (MAs). In a perfect world, the spawning escapement (SE) on the spawning grounds would equal the Spawning Escapement Target (SET). However, en route losses may lead to the SE being smaller than the SET, i.e. may lead to Differences Between Estimates (DBEs=SE-PSE, potential spawning escapement), unless salmon losses and potential assessment biases are taken into account by the Fraser River Panel. Different methods can be used to predict proportional DBEs (pDBEs=DBE/PSE) and knowledge of their relative performance over the years may help the Panel to select the appropriate MA to ensure the SET is achieved.

Forecasting appropriate pDBEs is difficult because discrepancies are not only affected by natural mortality resulting from extreme environmental conditions but also by biases in estimates of catch, escapement past Mission and spawners. In recent years the confidence in the environmental models with temperature, discharge or timing covariates has dwindled and the Panel has been provided with additional pDBE forecasts based on alternative prediction methods. The performance of these alternative methods can be evaluated and compared against environmental pDBE models.

Initially, a retrospective analysis was used to identify the best performing pre-season and in-season pDBE approach across all years. In 2023, drought conditions and high temperatures resulted in concerns that the best model performance on average, might not mean best performance under extreme environmental conditions. To ensure a clearly defined and transparent pDBE approach that accounts for extreme environmental events, the Panel requested an expanded retrospective analysis to identify potential environmental triggers that would indicate when a change in pDBE may be warranted. Moving forward it is anticipated that this retrospective analysis will be repeated at least every 4 years to ensure selected models are appropriate for recent environmental conditions. In addition, new models may be added as new data and methods become available and understanding of the salmon migration challenges changes and improves.

Data

The same data used to estimate annual pDBEs (Chapter C8) was used for the retrospective analyses across years. The data included the historical DBE dataset (1977-present), the 50% migration dates and the associated 19-day and 31-day mean temperature and discharge. Mean temperatures are calculated from the historic Fraser River temperature at Qualark, B.C. and discharge at Hope, B.C. provided by DFO's Environmental Watch group (Chapter B26). In addition to the data, some pDBE prediction methods rely on environmental threshold information above which sockeye survival is impeded. Eliason et al. (2011) identified temperatures above which successful migration of sockeye stocks could be limited while Patterson (DFO, personal comm) identified temperatures by management group, above which there is a statistically significant change in pDBE. These temperature thresholds were used as possible triggers for a change in pDBE approach. Discharge levels that produce migration barriers and delays in migration (MacDonald 2000, MacDonald et al. 2010) were similarly considered as possible triggers for a change in pDBE approach.

The historical pDBE estimates and the 50% migration dates are summarised primarily by management group, but exclude some stocks like Pitt, Chilliwack, Harrison/Widgeon and Birkenhead/Big Silver, whose location closer to the mouth of the Fraser River decreases expected en-route losses associated with adverse migration conditions. The pDBE data for these individual stocks were extracted from the management group specific data and were analysed separately. Some of these stocks have smaller median pDBEs than their management group (Pitt, Birkenhead/Big Silver), while other may have larger median pDBEs due to assessment uncertainty (Chilliwack, Harrison). Run size data were relied upon to combine the estimates of the individual stocks with the remainder of the stocks within a management unit.

Methods

A retrospective evaluation was used to analyse the performance of the different pDBE prediction methods, both for preseason and in-season use. The models were fit using historical data starting in 1977 unless a more recent year was specified and going up to the year for which a prediction was being made. The performance of the models was evaluated using the last 12 years of data by comparing the annual pDBE predictions with the observed values using two performance measures: Mean Raw Error (MRE) and Mean Absolute Error (MAE). As the retrospective analysis gets updated into the future, the number of years used in the evaluation will remain the same, but the years will be shifted later. The MRE is the average bias or directional error (*e*) of a pDBE prediction method across *n* years of data, calculated using the following equation:

$$(1) \qquad \mathrm{MRE} = \frac{\sum_{i=1}^{n}(\widehat{\mathrm{pDBE}}_i - \mathrm{pDBE}_i)}{n} = \frac{\sum_{i=1}^{n} e_i}{n}$$

with $\widehat{pDBE}_i$ representing the pDBE prediction for a given year *i* and pDBE representing the observed estimate. If the MRE is positive, the predicted pDBEs is on average larger than the observed pDBEs, meaning that on average more fish show up on the spawning grounds than anticipated or needed based on the Spawning Escapement Targets (SETs). Methods that result in a positive MRE are therefore considered too conservative and result in lost harvest opportunities while negative MRE values indicate a method is not conservative enough, resulting in overharvest and SETs not being achieved.

The precision of the pDBE methods was evaluated by the MAE (Equation 2), which is the average magnitude of the pDBE model error regardless of directional bias:

$$\text{MAE} = \frac{\sum_{i=1}^{n}\left|\widehat{\text{pDBE}}_i - \text{pDBE}_i\right|}{n} = \frac{\sum_{i=1}^{n}|e_i|}{n}. \quad (2)$$

The performance of a wide range of different models have been evaluated in terms of MRE and MAE (Table 1). The models were selected by management group based on past analyses, current use and available data, and excluded some permutations deemed unlikely based on exploration of the data e.g. cycle line dependent pDBE estimates for Early Stuart or Summer run.

Table 1: *Overview of different pDBE prediction methods evaluated retrospectively (2013-2024) for various Fraser River sockeye stock groups.*

	Early Stuart	**Early Summer run** Excluding Pitt Chilliwack	**Summer run** Excl. Harrison Widgeon	**Late run** Excl. Birkenhead Big Silver
No pDBE	x	x	x	x
Median pDBE				
All years	1977-	1977-	1977-	1977-
Recent years	1995-	-	-	1996-
Dom/non-Dominant years	-	1977-	-	1996-
Dom/Sub-Dom/other years	-	1977-	-	-
Dom & Sub-Dom/other years	-	1977-	-	1996-
Threshold method based on T				
Source: Eliason et al. (2011)	19.9°C	19.5°C	19.4°C	16.4°C
Source: E-Watch	17°C	18°C	18°C	-
Threshold method based on Q				
Source: E-Watch	8000 m^3/s	6500 m^3/s	-	-
Threshold method for T and Q	17°C, 8000 m^3/s	18°C, 6500 m^3/s	-	-
Environmental model				
19 day T (Temperature) model	1977-	1977-	1977-	-
Recent years	1995-	-	-	-
31 day T model	1977-	1977-	1977-	-
Recent years	1995-	-	-	-
19 day T&Q (Discharge) model	1977-	1977-	1977-	-
Recent years	1995-	-	-	-
31 day T&Q model	1977-	1977-	1977-	-
Recent years	1995-	-	-	-
Run timing model	-	-	-	1977-
Median and model combination				
Use upstream timing threshold	-	-	-	1977-

Historically, the in-season 19-day and the pre-season 31-day Temperature (T) and Discharge (Q) pDBE models (environmental models) were the main models used for predicting the pDBE for the Early Stuart, Early Summer and Summer run management groups (Chapter B27). These models were evaluated for each of the three management groups. For Early Stuart, a breakpoint in the historical data had been identified, with higher observed pDBEs since 1995. The environmental models were therefore also evaluated using data since 1995 for the Early Stuart.

For Late run, due to the early river entry behavior that began in 1995, run timing explains the majority of the variability in the environmental data (MacDonald et al. 2010). The Run Timing pDBE model, that uses the correlation between the pDBE and Mission 50% date, was therefore retrospectively evaluated for Late run. In the past, a combination of methods has also been used for Late run. This method relied on a historical median for pre-season planning and to start off the season. The pDBE was only updated if the Mission 50% date was later than the date when the Run Timing pDBE prediction was less negative than the historical median. This combination method was also evaluated.

To evaluate the confidence in the ability to predict pDBEs, the various pDBE prediction methods were also compared against the option not to use a pDBE or relying on pDBEs based on the median of past years, either all years or a subset of years. The subset of years could refer to recent years due to a shift in the median (e.g. Early Stuart and Late run) or cycle line years due to the influence of Shuswap stocks in dominant and subdominant years for Early Summer and Late run management groups. Using median pDBE estimates based on past years of data may work well on average but may not be the best approach during years of extreme discharge or temperature. This has resulted in the development of a Threshold Method for all four management groups that relies on medians of past years with similar discharge or temperature once the temperature or discharge threshold has been exceeded. If the threshold is not exceeded, the pDBE prediction would rely on the best performing method assuming average conditions. The thresholds themselves could either be identified based on the literature (Eliason et al 2011) or based on statistically significant changes in resulting pDBEs (Patterson, E-Watch, DFO, personal comm).

Recommendations are only made for total management units and not for sub-components. It was therefore evaluated if and how pDBE predictions based on the methods described in Table 1 can be combined with the pDBE predictions for individual stocks (Pitt, Chilliwack, Harrison/Widgeon and Birkenhead/Big Silver). In particular, it was evaluated if the pDBE estimates for individual components should be weighted by the run size, or if the pDBE estimates for the main stock group apply equally to the entire management group and under what conditions. Preseason, run size forecasts are used for the weighting while in-season, the in-season run size estimates determine the weighting. Whether to use a weighted approach or not in a given year is similarly evaluated through retrospective analyses.

The current methodology to evaluate different pDBE approaches retrospectively has been set up to allow for additional methods to be explored in more detail in the future, as additional data and methods become available and the knowledge about salmon migration challenges improves. It is anticipated that retrospective analyses are repeated at least every 4 years to remain relevant to current conditions.

Results

Given the number of methods included in the retrospective analyses, the results are extensive. In this report, the best performing preseason and in-season methods across management units and for sub-stocks have been summarised in Table 2. A visual comparison of some of the key model results is presented in Appendix A.

Early Stuart has seen an increase in en-route losses in recent years and as a result, the pre-season pDBE prediction methods based on data since 1995 perform better than relying on all years of data (Table 2). The median since 1995 is the best preseason predictor of the pDBE. It is slightly more accurate than the preseason 31-day temperature and discharge model using data since 1995. In-season, the Threshold Method is found to be the best performing (least biased and most accurate) forecast method for Early Stuart. It is a reactive method that adjusts the median pDBE when the temperature exceeds the 17°C threshold or when the discharge exceeds 8000 m^3/s (Appendix A, Figure A1).

Table 2. *Overview of the best preseason and in-season pDBE prediction methods for the different Fraser River sockeye management groups as well as individual stock components.*

	Preseason method	**In-season method**
Early Stuart	Median of recent years (1995-)	Threshold Approach: 17°C, 8000 m^3/s
Early Summer run	Weighted pDBE approach only on Dominant/Subdominant Chilliwack years (2024/25)	
Excl. Pitt, Chilliwack	All years median (1977-)	All years median (1977-)
Pitt	Median of recent years (2003-)	
Chilliwack	Median of Dominant or Subdominant years when DNA sample size > 30 fish	
Summer run	Summer run exc. Harrison, Widgeon, no weighted approach	
Excl. Harrison, Widgeon	Preseason 31-day Temp. model	Threshold Approach: 19.4°C
Harrison, Widgeon	Median of recent years (2003-)	
Late run	Weighted pDBE in years with large Birkenhead, Big Silver component	
Excl. Birkenhead, Big Silver	Median of Dom/non-Dominant years	Median of Dom/non-Dominant years
Birkenhead, Big Silver	Median of recent years (2003-)	

For Early Summer run excluding Pitt and Chilliwack, all pDBE forecast models tend to be too conservative on average when evaluated over the last 12 years. Relying on the all-years median is the best (least biased and most accurate) predictor of the pDBE, both preseason and in-season as well as under extraordinary environmental conditions (Table 2). Based on the performance of the all-years median in the last 12 years, the Panel may however consider adopting a bias correction. The preseason 31-day Temperature and Discharge Model is less accurate and similarly conservative (Appendix A, Figure A2), while the 19-day in-season version of this model is seriously biased and too conservative. Applying a different pDBE on high temperature or high discharge years (Threshold method) does not improve the error associated with the pDBE and makes the pDBE more conservative compared to the median. For Early Summer run, using a weighted pDBE approach to include estimates for Pitt and Chilliwack only improves model performance on dominant and subdominant Chilliwack years when the proportions of this stock within the Early Summer run is substantial.

For Summer run excluding Harrison and Widgeon, the best preseason model is the 31-day Temperature Model using the long-range forecast provided by E-Watch (Chapter B25, Table 2). The lack of 31 days of temperature data in-season prevents this model to be suitable for in-season assessments. Unfortunately, the in-season 19-day temperature model is one of the worst performing models (Appendix A, Figure A3). In-season, the best approach is to use the Threshold model and switch to the median of high temperature years when the average 19-day temperature exceeds 19.4°C instead of using the pDBE estimate from the pre-season Temperature model. On average this will decrease the overall error but generates somewhat conservative pDBE estimates. For Summer run, the weighted approach is not beneficial given the uncertainty associated with run size estimates for Harrison and Widgeon.

On average, the all-years median for Late run produces unbiased pDBE estimates but with substantial error (Appendix A, Figure A4). Changing the all-years median to the median on dominant years and the median on non-dominant years reduces the average error of the pDBE estimates and performs best both preseason, in-season and in high temperature years. While the Run Timing pDBE model also performs well, by the time the Mission 50% date is determined, it may be too late to be relevant for marine fisheries management decisions. Applying a different pDBE in high temperature years does not improve the accuracy of the pDBE estimate. For Late run, using a weighted approach to include an estimate for Birkenhead/Big Silver improves model performance when the proportion of this stock within the Late run is substantial.

Discussion

It is important to note that although environmental models do not perform as well as other methods, research has demonstrated that there is a relationship between mortality and high temperature and high discharge (MacDonald et al. 2010). There are potentially stock specific behavioral and physiological adaptations that have evolved to deal with natural variability in migration conditions (MacDonald et al. 2010) and different stocks exhibit different tolerances to environmental conditions that are outside of their optimal range (Eliason et al. 2011). In the last 12 years, Fraser River sockeye have experienced several changes. There have been smaller run sizes which have increased relative assessment errors. River temperatures have increased and there has been more flow variability. This has increased pDBE estimates, which in turn reduced fishing and spawner numbers. Less fishing and lower exploitation rates have decreased the interaction between temperature and fishing pressure. Even 12 years ago, Temperature and Discharge only explained at most 56% of the variation in the pDBE and the environmental models have reached their limit in terms of forecasting ability.

Potential Areas for Improvement

Assessments of the DBE are constrained by current models. In future it will be important to take advantage of the data available from RSA work to better understand what assessment errors are impacting DBEs. In addition, the retrospective analyses will need to be repeated at least every 4 years to ensure the selected models remain relevant for recent environmental conditions and assessment challenges.

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Appendix A

This appendix provides a visual comparison of the results of the retrospective analysis evaluating the performance (2013-2024) of a wide range of different preseason and in-season pDBE prediction methods (Table 1). Only the top performing model in addition to key alternatives are presented.

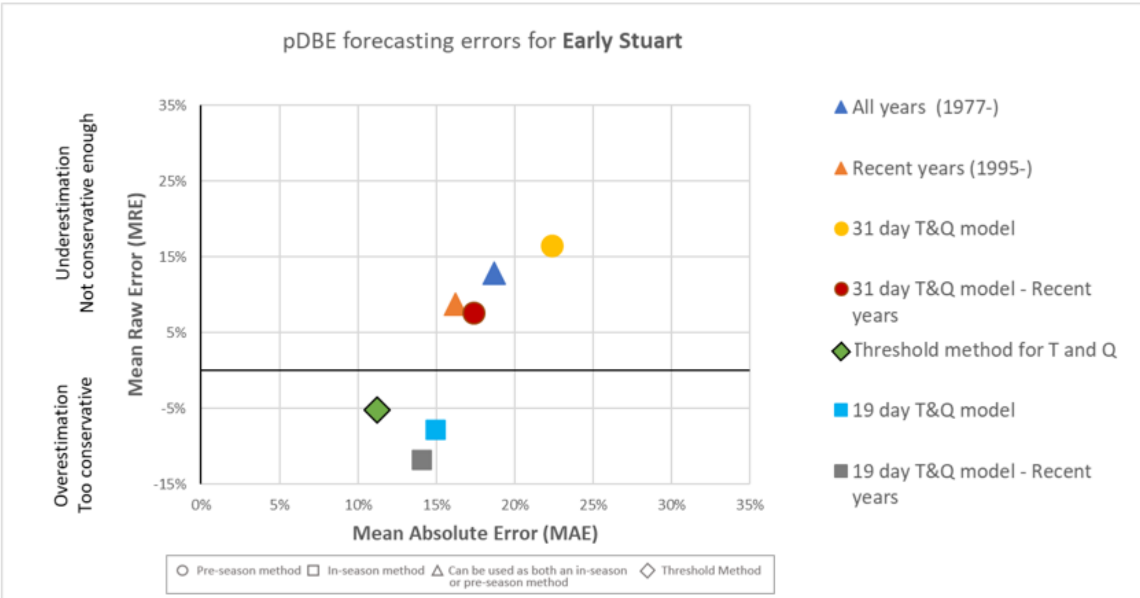

Figure A1. *Comparison of the performance (2013-2024) of different pre-season and in-season pDBE prediction methods for Early Stuart based on Mean Raw Error (MRE) and Mean Absolute Error (MAE).*

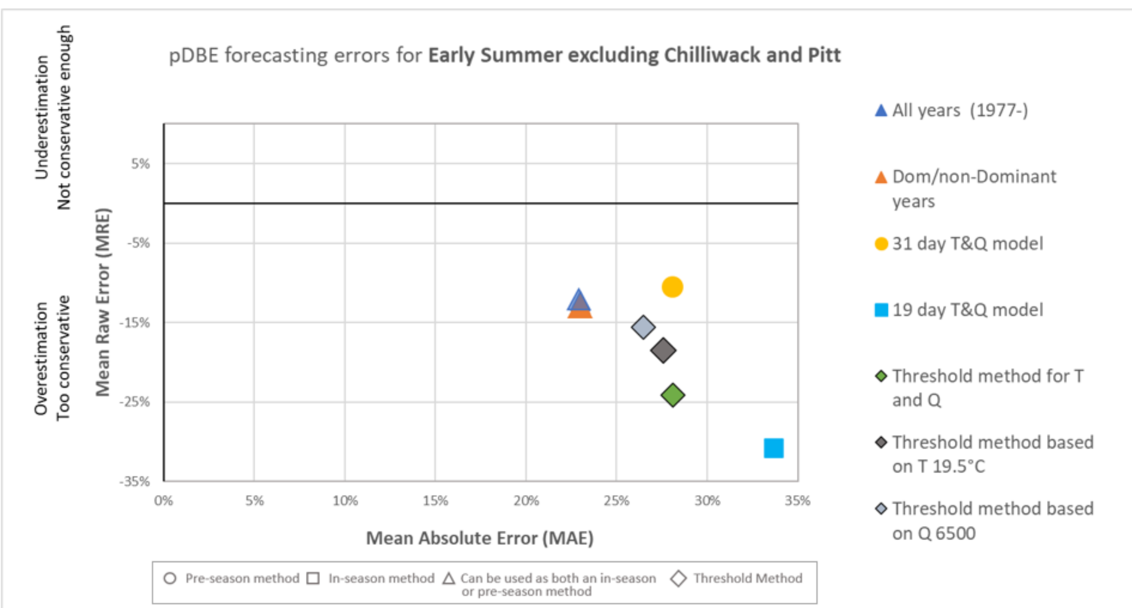

Figure A2. *Comparison of the performance (2013-2024) of different pre-season and in-season pDBE prediction methods for Early Summer run excluding Chilliwack and Pitt, based on Mean Raw Error (MRE) and Mean Absolute Error (MAE).*

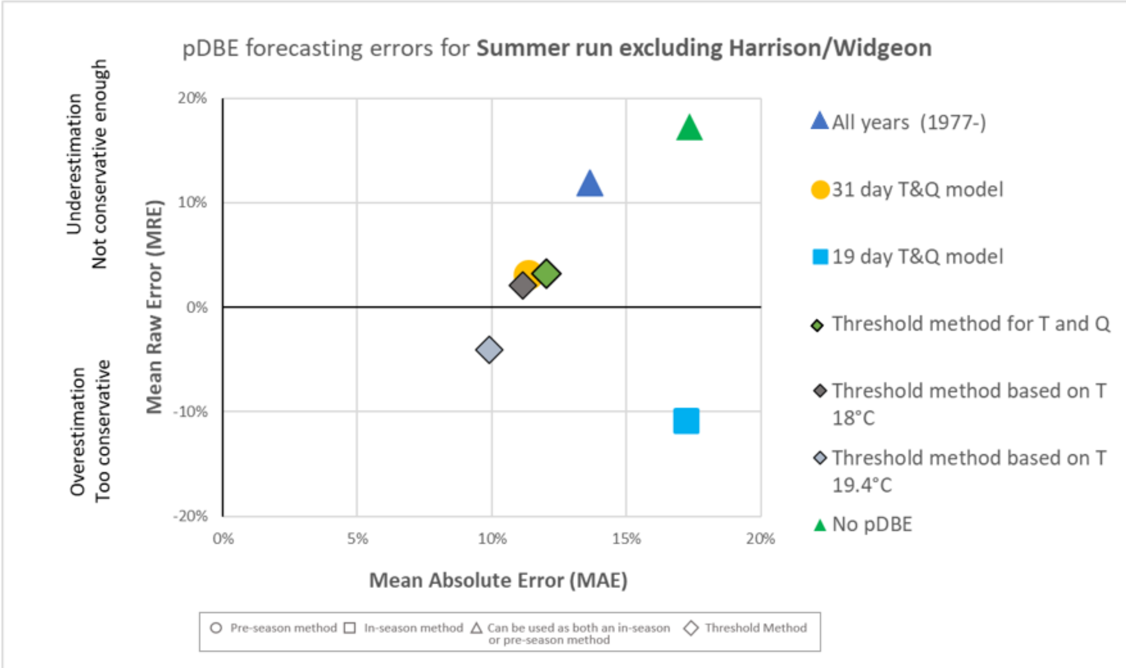

Figure A3. *Comparison of the performance (2013-2024) of different pre-season and in-season pDBE prediction methods for Summer run excluding Harrison/Widgeon, based on Mean Raw Error (MRE) and Mean Absolute Error (MAE).*

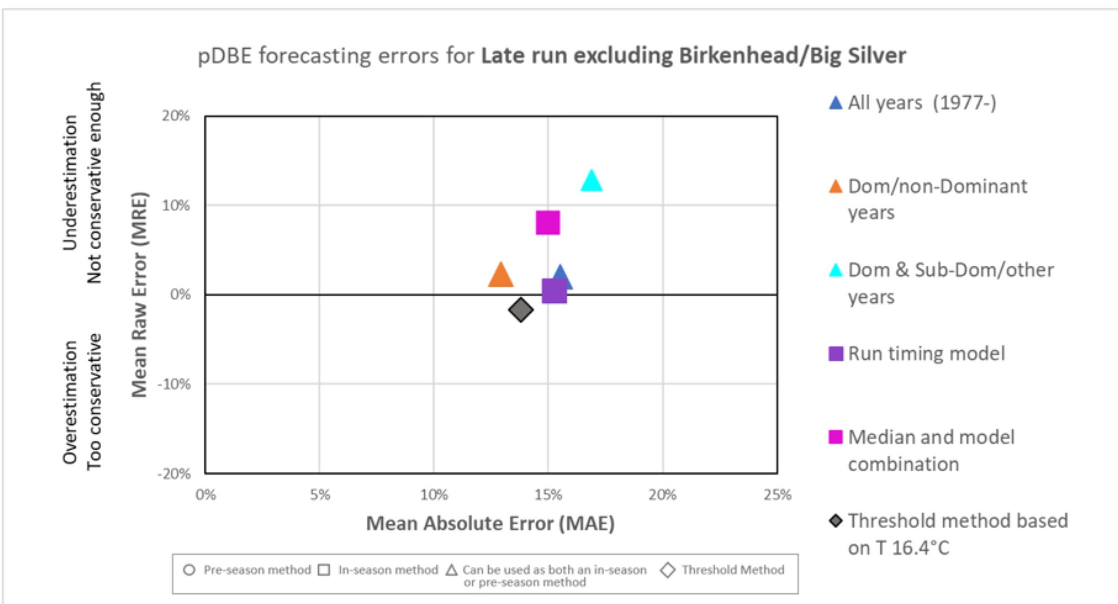

Figure A4. *Comparison of the performance (2013-2024) of different pre-season and in-season pDBE prediction methods for Late run excluding Birkenhead/Big Silver, based on Mean Raw Error (MRE) and Mean Absolute Error (MAE).*

B30. Monitoring salmon passage through Hells Gate

H. Oleynik

Summary

Hells Gate is a critical migration bottleneck for Fraser River salmon migration. Since the early 1960s, in-season shoreline observer counts have been used to monitor salmon passage and provide timely information to support in-season fisheries management. This report summarizes the current monitoring program with emphasis on observer counts for sockeye and pink salmon, evaluates their performance as indicators of abundance, and outlines planned improvements including the experimental use of video cameras. Analyses of the data from 2010 to 2025 indicate that, while observer counts are not intended to represent a census of total passage, they effectively detect relative changes within seasons. This performance supports their use as an operational tool for identifying migration challenges that may warrant increasing in-season Management Adjustments (Chapter B25).

Introduction

Hells Gate is a narrow canyon located approximately 209 km upstream from the mouth of the Fraser River. It presents one of the most difficult migration challenges for Pacific salmon in the Fraser system due to high water velocities, turbulence, and constricted flow. In 1914, railroad construction along the canyon walls triggered a major rockslide that deposited debris across the channel, effectively blocking upstream salmon migration entirely for several years. Initial attempts to restore passage by clearing the debris were unsuccessful, and salmon abundance above Hells Gate remained severely depressed through the 1920s and 1930s. Fishways were constructed on both the left and right banks of the gorge starting in the 1940s. These structures incorporate vertical baffles designed to create uniform, low-velocity flow conditions across a range of river stages. Following the construction of the fishways, many salmon populations above Hells Gate began to recover, though high-flow events continued to impede passage intermittently.

Because passage conditions at Hells Gate can vary substantially within and among years, an in-season monitoring program was established in 1961. The primary purpose of this program is not to estimate total run size, but to provide a daily index of abundance and detect migration problems as they occur so that fisheries managers can respond appropriately. In recent years, migration challenges have been addressed through the application of Management Adjustments (MAs, Chapter B25), which are the additional fish allowed to escapement fisheries for the purpose of increasing the likelihood of achieving the spawning escapement targets (SETs). The requirement to monitor upstream escapement at Hells Gate is stated in the Pacific Salmon Treaty (PST 2025) and daily observations of upstream migration at Hells Gate provide important in-season information for fisheries management.

Data

The core dataset used for monitoring salmon passage at Hells Gate consists of shoreside observer counts collected daily from July to late September. Two trained observers count migrating salmon from the left bank of the river at Hells Gate, typically between approximately 7 am and 2 pm. Fish are identified to species, with sockeye and pink salmon forming the primary focus of assessments. Chinook salmon counts are also recorded but are not used for in-season assessments or management. Observers record metadata including minutes counted per hour, water clarity, viewing quality, fish condition, water temperature, and river level.

Methods

Daily sockeye and pink salmon abundance indices are calculated from hourly observer counts using a standardized three-step expansion process. First, species-specific counts are summed across all observation periods and standardized by the total minutes counted. These counts are then converted to an equivalent eight-hour observation period by scaling to the ratio of hours observed to an eight-hour counting window. Finally, the eight-hour estimate is multiplied by two to represent approximately sixteen hours of daylight migration to produce a daily index of salmon passage.

To assess the accuracy of observer counts against an independent measure of abundance, reconstructed daily estimates were prepared for each species. For sockeye, daily reconstructed abundance estimates at Hells Gate were based on Mission abundance for stocks that migrate past Hells Gate minus catches taken between Mission and Sawmill Creek. For Chinook, daily abundance estimates were based on adult Chinook spawner numbers and stock specific timing for all stocks with spawning grounds above Hells Gate. While Chinook abundance estimates are not used to evaluate Chinook counts, they are used to generate pink abundance estimates. For pink salmon, estimates were derived from daily salmon abundance estimates at Qualark minus post-season reconstructed daily Chinook and sockeye estimates at Hells Gate. Upriver travel times of five days from Mission and three days from Qualark to Hells Gate were assumed. Daily estimates from 2010 to 2025 were used to retrospective evaluate of the performance of the observer counts.

Daily expanded observer count estimates were compared to reconstructed daily abundance estimates for sockeye and pink salmon by simple linear regression. Regressions were constructed for: (a) the full time series (2010–2025); (b) each year separately; and (c) each calendar month using all available years. This approach allowed identification of time periods with stronger or weaker relationships between counts and reconstructed abundance. Where notably poor or strong fits were identified, associated run-size data and environmental covariates were examined for explanatory patterns. Environmental variables were regressed against daily count totals and against the residual difference between observer counts and reconstructed sockeye abundance. Variables tested included: discharge at Hope, gauge height at Hells Gate, water temperature, observer-recorded water clarity score, and observer-recorded count spot quality score.

Results

Comparisons between historical shoreside observer counts and reconstructed abundance estimates for sockeye and pink salmon are presented in Figures 1 and 2. For sockeye salmon, the strength of the relationship between expanded shoreside counts and reconstructed abundance estimates varies substantially between years. The mean coefficient of determination (R^2) across years for sockeye salmon was 0.45, with the strongest annual relationship observed in 2014 ($R^2 = 0.84$). But while the sockeye observer counts provided a consistent and informative index of sockeye abundance, the index tends to underestimate absolute abundances (Figure 1). It is unclear to what extent variable migration of sockeye along the right bank and additional nighttime migration impacts the performance of the expanded observer counts as an index of abundance.

In contrast, shoreside observer counts for pink salmon generally showed stronger correspondence with reconstructed abundance estimates. The average R^2 across years for pink salmon was 0.69, with the best-fitting year observed in 2013 ($R^2 = 0.83$). Unlike the expanded observer counts for sockeye salmon, the expanded pink salmon observer counts do not consistently underestimate pink salmon abundance.

Unlike sockeye, pink salmon tend to migrate close to shore and primarily during daylight hours, aligning well with the spatial and temporal coverage of the observer program. As a result, the observer count index seems to be more reliable at capturing the relative magnitude of the pink salmon run, making it a particularly effective indicator for in-season assessment of pink salmon passage through Hells Gate.

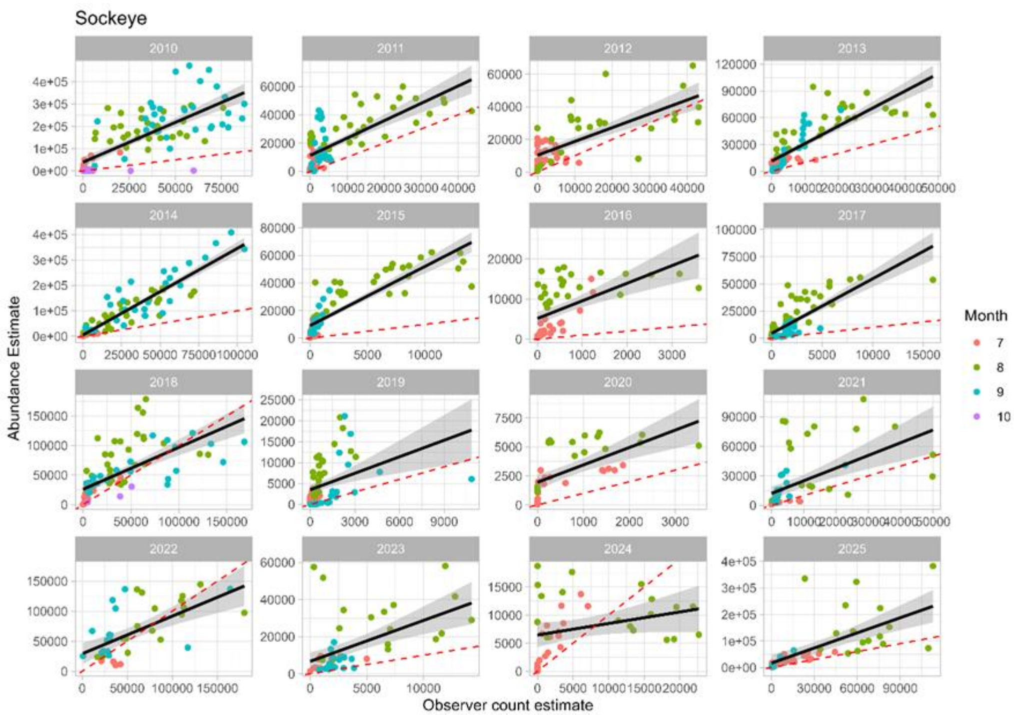

Figure 1. *Reconstructed sockeye salmon abundance estimates plotted against daily observer counts of sockeye expanded to 16 hours of daylight for 2010–2025. Points are color-coded by month. The solid black line shows the linear regression fitted to all observations, while the red dashed line indicates the 1:1 relationship.*

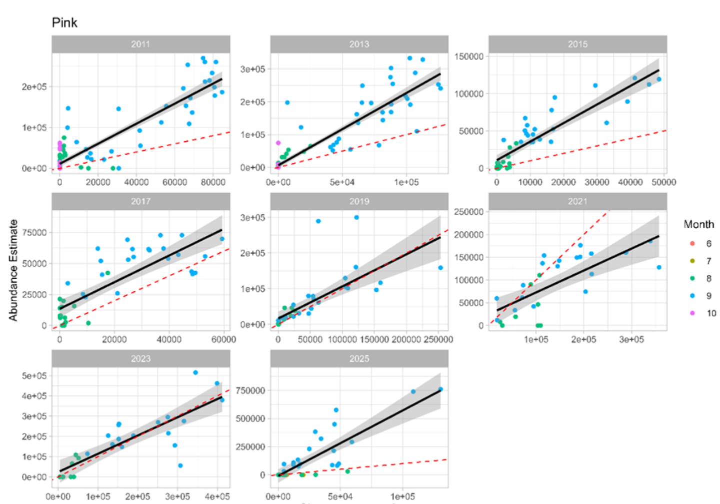

Figure 2. *Reconstructed pink salmon abundance estimates plotted against daily observer counts of pink salmon expanded to 16 hours of daylight for 2010–2025. Points are color-coded by month. The solid black line shows the linear regression fitted to all observations, while the red dashed line indicates the 1:1 relationship.*

Generally, run size and environmental covariate data such as discharge, gauge height and water temperature could not explain differences in daily expanded counts or count-abundance residuals. In contrast, the two qualitative condition metrics recorded daily by observers, water clarity and viewing spot quality showed meaningful relationships with both the magnitude of daily expanded counts (Figure 3) and the accuracy of those counts as an index of abundance (Tables 1 and 2). Days characterised by clearer water and better viewing conditions were associated with higher count totals (Figure 3). This pattern is consistent with improved observer ability to detect fish at the surface when visibility is unimpaired, rather than reflecting any genuine increase in the number of fish passing on those days. Days with a clarity score of 5 (relatively clear) yielded an R^2 of 0.61, declining to 0.47 at a score of 7 and further to 0.17 at a score of 9 (Table 1). This gradient indicates that turbid water conditions introduce substantial additional uncertainty into the daily count index. A parallel pattern was observed for count spot quality (Table 2). Days scored at 5 (the best quality category and well-represented in the dataset) produced an R^2 of 0.56 against reconstructed abundance, declining to 0.42 at a score of 7 and plateauing at 0.41 at a score of 8. The relationship between viewing spot quality and relative count accuracy may reflect both physical obstructions at the observation point, such as wave splash, glare, or debris, and positional constraints that reduce detection efficiency under difficult viewing conditions.

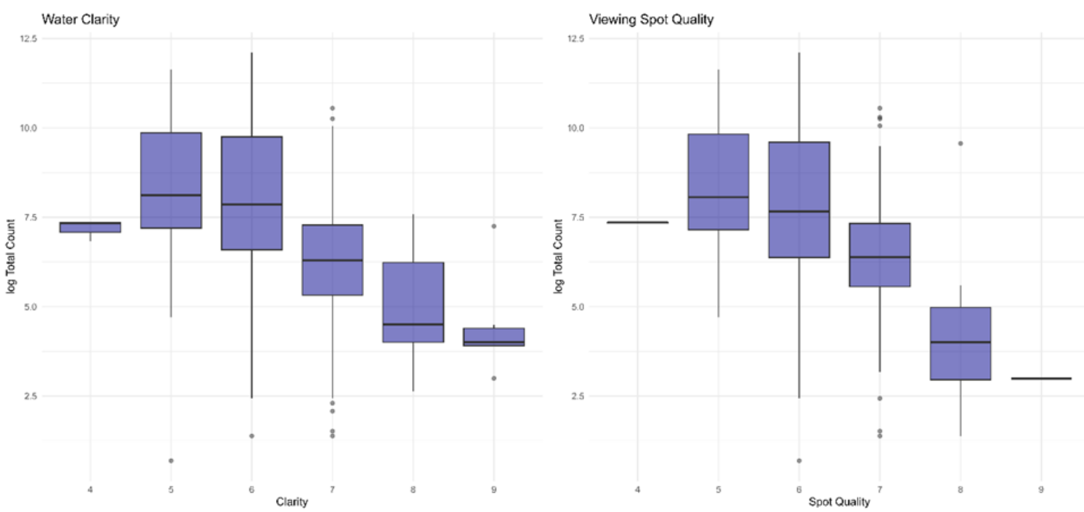

Figure 3. *Distribution of expanded salmon counts (on the logarithmic scale) across categories of water clarity and viewing spot quality as recorded by shoreside observers across all years from 2010 to 2025. One represents clear water and good viewing spot quality while ten represents muddy water and poor viewing spot quality.*

Tables 1 and 2. *Overview of extent water clarity (Table 1) and visual spot quality (Table 2) impact the relationship between shoreside observer counts and salmon abundance, in terms of* R^2*.*

Water clarity score	R^2	n (days)
5 (relatively clear)	0.61	89
6	0.58	203
7	0.47	96
8	0.26	11
9 (relatively turbid)	0.17	12

Visual spot quality score	R^2	n (days)
5 (good quality)	0.56	88
6	0.58	215
7	0.42	84
8 (poorer quality)	0.41	23

Potential Areas for Improvement

Sockeye salmon are known to migrate both during the day and at night. The regression between observer counts and reconstructed abundances consistently shows that 16-hour expanded observer counts underestimate reconstructed sockeye abundance. Adjusting the expansion factor to represent 24 hours of daily migration, i.e., applying a multiplier of 3 rather than 2, should be explored more formally and may help reduce systematic bias in the daily sockeye index.

To observe salmon migration at Hells Gate, observers have to hike down to the left bank of the river across rocky, uneven ground and sit close to the turbulent river. In addition, temperatures during the peak summer months have, in recent years, exhibited highs of up to 34 degrees Celsius. In 2025, Fisheries and Oceans Canada (DFO) installed video cameras on the right bank as part of a research initiative to explore alternative or supplementary counting methods. Camera counts were recorded in the same way as shoreside counts, including information on the number of minutes and other metadata. Fish visible in camera footage were assigned to species where possible. A large proportion of fish were however classified as unknown due to limitations in visual species identification. These unknown counts were subsequently apportioned to species using independent species-composition data collected at Qualark. In addition to challenges associated with species identification, evaluation of the 2025 camera data identified inconsistencies among individual counters, highlighting the need for further refinement of camera counting protocols and training. Despite these limitations, preliminary results indicate that camera counts have potential to supplement observer data during periods when shoreside observations are unavailable, such as days affected by illness, safety considerations, or logistical constraints. In these circumstances, camera observations may support limited data imputation and help maintain continuity of daily passage indices. However, such applications remain exploratory, and uncertainty associated with camera counts currently exceeds that of the established observer count method.

Alternative passage monitoring method

In 2005, a two-day pilot study was conducted to evaluate the feasibility of enumerating upstream-migrating sockeye salmon near Boston Bar, approximately 15 km upstream of Hells Gate (Xie et al. 2005). Results from the study indicated that the majority of salmon passage occurred close to the riverbank, suggesting that a large proportion of the run could be sampled using shore-based hydroacoustic systems (Xie et al. 2005, Chapter B15). Despite the apparent feasibility, implementation of an annual hydroacoustic monitoring program at this location would require substantial logistical effort, specialized equipment, and sustained reliance on expert technical and analytical staff. As an indication of scale, the annual cost of implementing a hydroacoustic assessment of upstream-migrating salmon was estimated in 1999 to be approximately $200,000 CAD (Jim Cave, personal communication).

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B31. Additional MA-related information

M.R. Forrest

Summary

The Management Adjustment (MA) refers to the number of additional fish added to an escapement target to increase the likelihood of meeting that target (Chapter B25). The Fraser River Panel is responsible for determining appropriate MA values, drawing on a range of predictive models and data sources used to predict differences between predicted and observed spawning ground estimates (DBEs, Differences Between Estimates, Chapter B25). These models are however limited in their ability to accurately predict DBEs. To support more informed decision-making, the Panel incorporates a broader suite of information beyond statistical modeling. These supplementary tools include, but are not limited to: bubble plots comparing current environmental conditions with historical observations and associated MA estimates, temperatures in various parts of the Fraser River watershed, reports of discharge and migration past migration bottlenecks (e.g. Hells Gate, Big Bar, Chilcotin landslide area), comparison of abundances at different locations within the Fraser River, reports on fish condition, spawning ground reports, and predictions of available harvest based on run size and DBE scenarios. Together, these inputs provide a more comprehensive foundation for making MA decisions and ensuring effective management of Fraser River sockeye stocks.

Introduction

Under the Pacific Salmon Treaty, the Fraser River Panel has the discretion to add additional fish in the form of a Management Adjustment (MA) to the spawning escapement target (SET) set by Canada for Fraser River sockeye salmon to ensure spawning requirements are met (PST, Article IV, Chapter 4, Paragraph 3b). The MA accounts for en route mortality due to poor environmental conditions during upstream migration, such as high discharge levels and warmer water temperatures, but also for biases in the in-season and post-season assessments and the resulting catch and spawner estimates (Chapter B25). To help the Panel in their in-season decision-making process, PSC staff provide the Panel with predictions of differences between predicted and observed spawning ground estimates (DBEs, Differences Between Estimates). Despite ongoing efforts to improve these models, DBE predictions remain highly uncertain (Chapter B29), thereby hampering the Panel's ability to meet escapement targets without forgoing substantial catch. To support more informed MA decisions, the Fraser River Panel relies on a suite of supplementary tools beyond the models. The following sections provide an overview of these tools and their role in enhancing in-season decision-making.

Data and information

BUBBLE PLOTS

In-season the Panel is provided with a Management Adjustment bubble plot (Figure 1) to accompany the DBE estimates for a specific management group. The plot is management group specific and illustrates historically observed proportional MA (%MA, pMA) values across varying combinations of temperature and discharge. Bubble size reflects the magnitude of the %MA historically recorded at each temperature-discharge pairing. A blue square highlights the forecasted environmental window, defined as the current 19-day average discharge ±1000 m^3/s and temperature ±0.5°C. Historical observations that fall within this forecasted range are summarized in the accompanying table, offering the Panel insight into the severity of past %MAs under similar conditions. Color-coded regions within the bubble plot highlight instances where temperature or discharge thresholds are exceeded, signaling a reduced likelihood of salmon successfully reaching their spawning grounds.

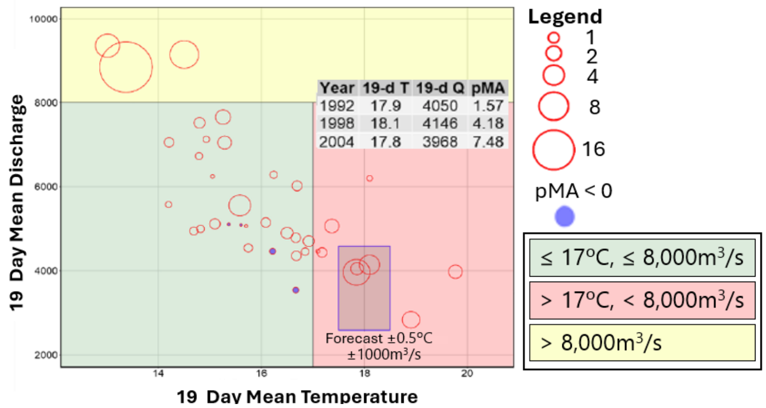

Figure 1. *Example of a bubble plot of historical proportional Management Adjustment (pMA or %MA) estimates for Early Stuart (circles) and the forecasted environmental window (blue square) based on a forecasted temperature of 18.0°C and discharge of 3,588 m³/s. The temperature forecast exceeded the threshold of 17℃, indicating an increased risk of above-average en route losses. The three historical years with similar temperature and discharge all indicated highly variable but elevated pMAs.*

TEMPERATURES IN OTHER AREAS OF THE FRASER WATERSHED

The DFO Environmental Watch group provides current and historic river temperature data from different temperature monitoring stations in the Mainstem Fraser and from different Fraser River Tributaries (Figure 2). Currently the Fraser River Mainstem locations are Qualark (1), Texas Creek (2), Marguerite (3) and Shelley (4). The different Fraser River Tributaries are Thompson River at Ashcroft (5), South Thompson at Chase (6), the North Thompson at McLure (7), Quesnel River at Quesnel (8), Nechako River at Isle Pierre (9) and Stuart River at Fort St. James (10).

Map #	Current Temperatures 09-Jul	Daily Mean	Historic Mean	Deviation from Historical Mean	Historic Year Range
	Fraser River Mainstem				
1	Fraser River @ Qualark	17.8	15.9	1.9	1991-2020
2	Fraser River @ Texas Creek	17.1	16.2	0.8	2006-2024
3	Fraser River @ Marguerite	16.7	17.1	-0.4	2015-2024
4	Upper Fraser @ Shelley	13.9	13.3	0.6	1994-2024
	Fraser River Tributaries				
5	Thompson R. @ Ashcroft	16.8	15.2	1.5	1995-2024
6	South Thompson @ Chase	16.9	16.1	0.8	1994-2024
7	North Thompson @ McLure	14.2	13.3	0.9	2006-2023
8	Quesnel R. @ Quesnel	16.0	14.2	1.7	2000-2024
9	Nechako R. @ Isle Pierre	17.4	18.6	-1.2	2006-2024
10	Stuart R. @ Ft. St. James	16.8	17.3	-0.6	2000-2024

Figure 2. Map indicating locations of monitoring stations and associated table with current temperatures.

REPORTS OF DISCHARGE, TURBIDITY AND MIGRATION PAST BOTTLENECKS

Regular in-season reports to the Fraser River Panel include updates on Fraser River discharge at Hope and salmon migration past Hells Gate, an historically significant migration bottleneck (Chapter B30). Occasionally, unexpected barriers emerge, such as the 2019 rockslide at Big Bar (PSC 2021) or the 2024 landslide in the Chilcotin River (PSC 2026). In such cases, it is critical for the Panel to receive timely and detailed information on how these events affect migration success. Big Bar poses a significant challenge during periods of high flow, especially early in the season when discharge levels are elevated (Figure 3). Prior to the remediation work, monitoring both discharge and upstream migration was essential when considering the impact of the slide on the migration success. Following the Chilcotin River landslide, water turbidity was closely monitored alongside migration activity, as elevated turbidity can negatively impact salmon migration and overall fish health (PSC 2026). Certain locations within the Fraser River are more susceptible than others to becoming migration bottlenecks for sockeye, particularly under high discharge conditions. Proactive monitoring and reporting at these vulnerable sites provide valuable insights that may not be captured by quantitative models but are nonetheless important for informing MA decisions.

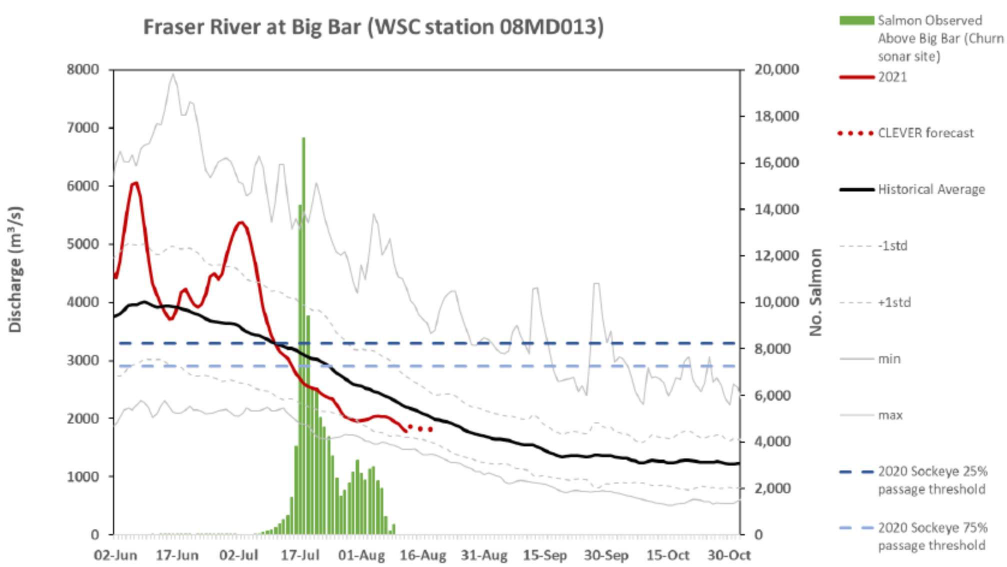

Figure 3. *Comparison of the discharge in 2021 with the upstream migration passage of salmon (Data made available by Environment and Climate Change Canada and Northwest Hydraulic Consultants, 2021). When discharge exceeds the discharge threshold, salmon passage is likely impeded. In 2021, passage at Big Bar seemed to have been impeded until mid-July.*

ABUNDANCE COMPARISONS AT DIFFERENT LOCATIONS WITHIN THE FRASER RIVER

En route losses can be estimated by comparing salmon abundance at multiple locations along the Fraser River, provided that catch and stocks not migrating past upstream sites are properly accounted for. In-season comparisons between Mission and Qualark are routinely conducted but often it is unclear if discrepancies between the sites are due to abundance estimation error at either site or due to en route losses.

Adding a third comparison site, such as Big Bar or the spawning grounds, can provide a clearer indication about potential en route losses (Figure 4). For example, in 2022 abundances observed at Mission and Qualark were much higher than abundances at Big Bar for a defined period in mid-August when temperatures also exceeded optimal temperatures, indicating potential en route loss during this period (PSC 2024).

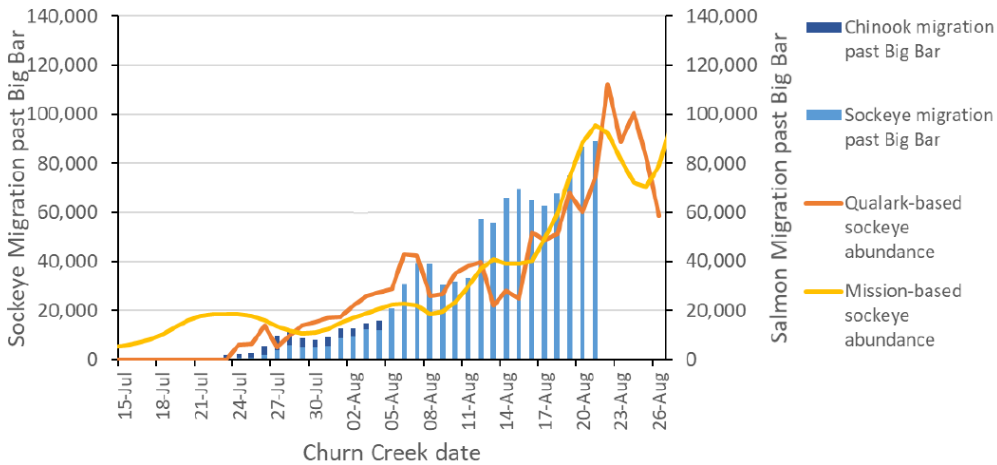

Figure 4. *Mission and Qualark-based sockeye migration prediction past Big Bar compared to observed salmon migration at Churn Creek past Big Bar, reported on August 23, 2022.*

Similar comparisons with daily spawning ground estimates are also regularly used to identify periods with potential en route losses. These spawning ground data are usually not timely enough for in-season assessments but instead are used for post-season analyses (Chapter C6). Chilko spawning ground estimates work best for comparisons with Mission and Qualark and to identify periods with potential en route loss (Figure 5). In contrast, daily spawning ground estimates for Quesnel and Nadina/Stellako tend to show greater variability between time series, making it more difficult to pinpoint periods of potential en route loss.

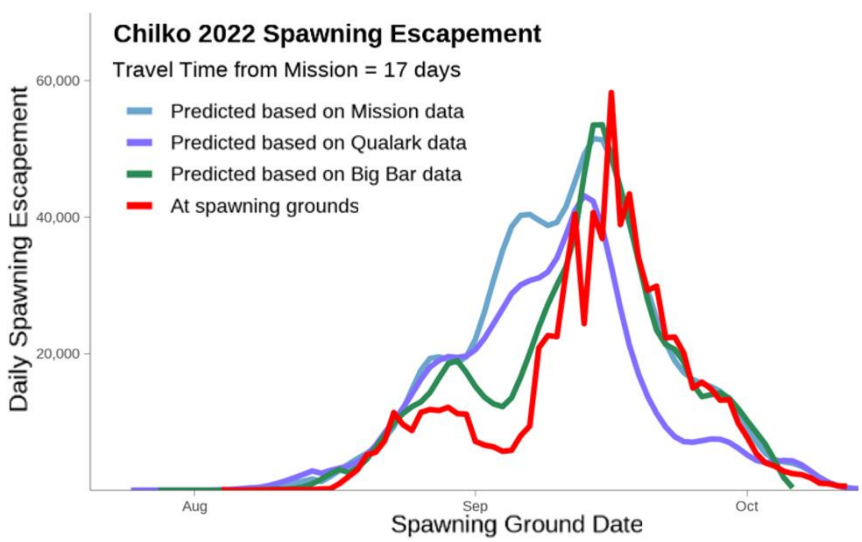

Figure 5. *Comparison of daily Chilko spawner numbers with daily reconstructed abundance estimates based on Mission, Qualark and Big Bar estimates. The gradual discrepancies between the various reconstructed abundance estimates from the end of August till the middle of September indicate a period of potential en route losses. The discrepancy between Qualark-based reconstructions and the other time series near the end of September is likely to due species composition biases at Qualark.*

REPORTS ON FISH CONDITION

During the season, Fisheries and Oceans Canada (DFO) provides weekly updates on sockeye salmon condition. These reports compile health observations gathered through patrols conducted by helicopter, boat, vehicle, and on foot. Sockeye are assessed either in-river or post-harvest, with additional data contributed by the Qualark test fishery. The information is summarized for the Fraser River Panel in terms of the number of sockeye inspected and the proportion observed to be in normal condition (Figure 6). Future work would see the resulting time series evaluated in terms of their ability to quantitatively predict en route losses.

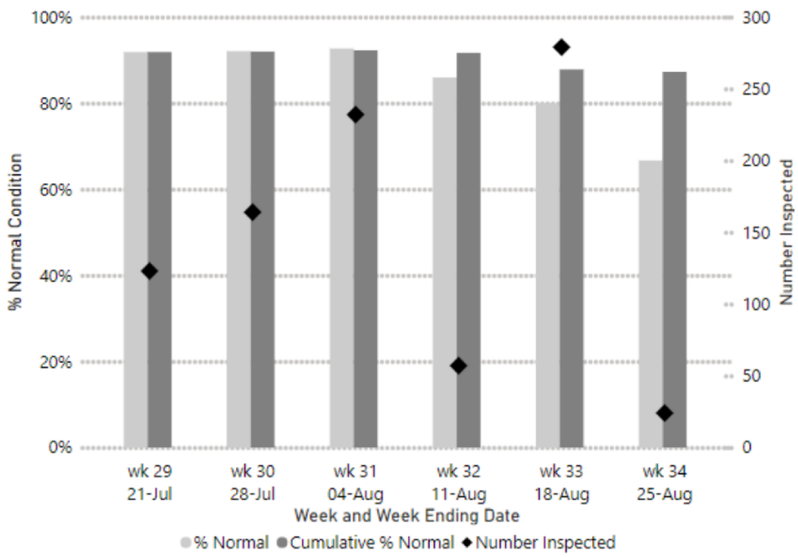

Figure 6. *Proportion of sockeye salmon in normal condition given the total number of sockeye inspected weekly.*

SPAWNING GROUND REPORTS

DFO also provides the Fraser River Panel with weekly spawning ground reports (Chapter C1). Of note for the MA are the reports of fish condition, as well as water temperatures and water condition, e.g. turbidity, water levels. Similarly to the comparison of Mission and Qualark with daily abundance estimates on the spawning grounds, these additional spawning ground observations usually arrive too late to be useful for active in-season management.

PREDICTIONS OF AVAILABLE HARVEST BASED ON RUN SIZE AND MA SCENARIOS

In-season, a clear distinction is made between %DBE and %MA estimates. Although mathematically related, %DBE predictions are made by PSC staff and the Technical Committee and based on the best available model, while the Fraser River Panel is responsible for selecting the appropriate MA/%MA estimates to guide fisheries management. In deliberating on the most appropriate MA estimate, the Panel will consider both the quantitative %DBE predictions provided by PSC staff and the additional data and information outlined in this report that may indicate potential en route losses. But beyond these technical inputs, the Panel may also factor in socio-economic considerations when selecting the final MA estimate. To support this decision-making, the Panel receives available harvest predictions by management group, based on various run size and %MA scenarios (Table 1). These projections help illustrate how changes in %MA values affect available harvest across different run size levels. Table 1 shows the impact of the selected %MA on available harvest for various run size estimates. In this 2025 example, harvest was permitted at both the pre-season p75 forecast level and the in-season adopted run size of 700,000, provided the %MA remained below 50%, which equalled the Total Allowable Mortality (TAM) cap for the Late run in 2025. The preseason forecast of the %DBE in 2025 equalled -61%, while in-season, the %DBE decreased due to the larger proportion of Birkenhead compared to other Late run stocks and the use of the weighted %DBE approach (Chapter B25).

Table 1. Predictions of available harvest of Late run sockeye based on run size and %MA (pMA) scenarios in 2025. Available harvest equals run size minus the Spawning Escapement Target (SET), the Management Adjustment (MA) and the Test Fishing Deduction. The Aboriginal Fisheries Exemption (AFE) has not been removed.

		pDBE	**-61%**	**-50%**	**-49%**	**-45%**	**-40%**	**-35%**
		pMA	1.56	1	0.96	0.82	0.67	0.54
	Run Size	SET	**Available Harvest**	**Available Harvest**	**Available Harvest**	**Available Harvest**	**Available Harvest**	**Available Harvest**
p75	**994,000**	497,000	0	0	14,300	83,900	158,500	223,100
p50	**467,600**	346,500	0	0	0	0	0	0
p25	**238,100**	238,100	0	0	0	0	0	0
Adopted	**700,000**	350,000	0	0	11,800	60,800	113,300	158,800

Planned changes and potential areas for improvement

As additional data and information become available, certain time series related to fish condition, such as percent normal, can be evaluated more rigorously using quantitative methods. Such an enhanced analysis may improve the accuracy of predicting en route losses and estimating %DBEs.

References

PSC. 2021. Report of the Fraser River Panel to the Pacific Salmon Commission on the 2019 Fraser River sockeye salmon fishing season. PSC Annual Report, Vancouver.

PSC. 2024. Report of the Fraser River Panel to the Pacific Salmon Commission on the 2022 Fraser River sockeye salmon fishing season. PSC Annual Report, Vancouver.

PSC. 2026. Report of the Fraser River Panel to the Pacific Salmon Commission on the 2024 Fraser River sockeye salmon fishing season. PSC Annual Report, Vancouver.

PST. 2025. Treaty between the Government of Canada and the Government of the United States of America concerning Pacific Salmon, as amended through November 2025.

B32. Total Allowable Catch (TAC)

F.J. Martens

Summary

Available Total Allowable Catch (TAC) is an important pre-requisite for in-season fisheries. The Pacific Salmon Treaty (PST 2025), Chapter 4, describes the calculations for TAC for Fraser River sockeye and pink salmon. TAC is calculated as the remaining portion of the annual aggregated Fraser River sockeye and pink salmon abundance available after the spawning escapement target, the Management Adjustment (sockeye only), the agreed Fraser River Aboriginal Fisheries Exemption (AFE; sockeye only) and the expected catch in Panel-authorized test fisheries are deducted. If there is a remaining portion of sockeye or pink salmon run size available for harvest in Fraser Panel Area waters, the United States (U.S.) share shall not exceed 16.5 percent of the TAC for sockeye salmon and not exceed 25.7 percent of the TAC for pink salmon. This calculation is subject to adjustments for harvest overages or underages from previous years based on post-season catch estimates (see PST 2025, Chapter 4, Paragraph 8a - 8d for details). The remaining TAC in addition to sockeye AFE catches are assigned to Canada.

The Treaty acknowledges that access to the aggregate TAC may be limited by the TAC of individual sockeye management groups or by the availability of pink salmon TAC. Accordingly, it permits a “small but acceptable” (SBA) rate of incidental harvest on management groups with little or no TAC (PST 2025). To reduce sockeye mortality when one or more sockeye management groups lack a harvestable surplus, the Fraser River Panel (FRP) has increasingly adopted non-retention requirements for sockeye in pink-directed commercial fisheries in recent years. Because catch-and-release fishing still results in some mortality, sockeye release mortalities are estimated in non-retention fisheries, including test fisheries. These release mortalities are either reported by the Parties or calculated by the Pacific Salmon Commission (PSC). Although release mortalities contribute to the overall exploitation rate, they are not counted against the TAC.

Introduction

While the Fraser River Panel’s primary objective is to reach Spawning Escapement Targets (SETs) for individual sockeye and pink salmon management units (MUs), its second objective is to achieve international allocation of the Total Allowable Catch (TAC) for both species (PST 2025, Chapter 4). The Treaty states that the U.S. share of the annual Fraser River sockeye and pink salmon Total Allowable Catch (TAC) will not exceed 16.5 and 25.7 percent of the sockeye and pink salmon TAC, respectively. The remaining available catch is deemed Canada’s share. Fraser River sockeye salmon TAC is managed separately from Fraser River pink salmon TAC. However, the Panel must take into consideration the impacts of pink salmon directed fisheries on overlapping sockeye management groups with little or no TAC (PST 2025, Chapter 4). The following document describes in detail the TAC calculation as well as additional adjustments and other considerations.

TAC Calculations

The four main deductions for calculating the TAC include the Spawning Escapement Target (Chapter A5), the Management Adjustments (sockeye only) (Chapter B25), the Aboriginal Fisheries Exemption (sockeye only) and the Panel approved test fishing catch (Chapter A8) (Table 1).

Table 1. An example of a detailed calculation of total allowable catch (TAC) and achievement of international catch shares for Fraser sockeye and pink salmon by management group, presented to the Fraser River Panel on August 18, 2025.

		Fraser Sockeye					Fraser Pinks	
		Early Stuart	Early Summer	Summer	Lates	Total		Total
RUN STATUS, ESCAPEMENT NEEDS & AVAILABLE SURPLUS								
Pre-season or Adopted In-season Run Size		725,000	400,000	7,500,000	1,000,000	9,625,000		26,965,000
Adult Spawning Escapement Target (SET)		580,000	200,000	3,750,000	500,000	5,030,000		8,089,500
%SET from TAM rules		80%	50%	50%	50%			30%
Management Adjustment (MA)		1,078,800	108,000	1,050,000	460,000	2,696,800		0
Proportional MA (pMA)		1.86	0.54	0.28	0.92			0.00
Adjusted Spawning Escapement Target (SET) *		725,000	308,000	4,800,000	960,000	6,793,000		8,089,500
Test Fishing (TF)		5,500	3,400	29,350	5,531	43,781		90,000
Surplus above Adjusted SET & Test fishing		0	88,600	2,670,650	34,469	2,793,719		18,785,500
DEDUCTIONS & TAC FOR INTERNATIONAL SHARING								
Aboriginal Fishery Exemption (AFE)		0	23,887	376,113	0	400,000		0
Total Deductions (Adj. SET + TF + Available AFE)		730,500	335,287	5,205,463	965,531	7,236,781		8,179,500
Available TAC for International Sharing		0	64,713	2,294,537	34,469	2,393,719		18,785,500
UNITED STATES (Washington) TAC								
Proportionally Distributed TAC **	16.5%	0	10,680	378,600	5,690	394,970	25.7%	4,827,870
U.S. Payback **	-0.1%	0	-60	-2,290	-30	-2,390		0
Proportionally Distributed TAC + Payback		0	10,620	376,310	5,660	392,590		4,827,870
Treaty Tribes Share **	67.7%	0	7,170	254,020	3,820	265,010	50.0%	2,413,935
All Citizen Share	32.3%	0	3,450	122,290	1,840	127,580	50.0%	2,413,935
CANADA TAC								
Aboriginal Fishery Exemption (AFE)		0	23,887	376,113	0	400,000		0
Canadian TAC + AFE		0	77,980	2,294,340	28,809	2,401,129		13,957,630
CATCH-TO-DATE								
Test		5,320	2,150	17,400	1,120	25,990		1,100
Treaty Tribes (Wash.) / Ceremonial (TRB)		0	1,440	61,630	7,940	71,000		71,860
All Citizen (Wash.)		0	1,210	20,330	2,030	23,570		20,830
Other (Wash.)***		0	0	0	0	0		0
Washington		0	2,650	81,960	9,970	94,570		92,680
First Nations Catch (including AFE)		2,700	26,660	364,290	36,090	429,750		19,880
Planned Charter & Recreational Shares		60	30	230	13	326		760
Other***		3,320	1,690	8,380	20	13,400		0
Total Commercial (including FN EO/Demo****)		210	3,950	95,270	19,030	118,460		18,920
Canada		6,290	32,330	468,170	55,150	561,930		39,560
Total Catch in All Fisheries		11,610	37,130	567,530	66,240	682,490		133,350
Exploitation Rate (catch-to-date / run size)		1.6%	9.3%	7.6%	6.6%	7.1%		0.5%
Fisheries induced mortalities (Canada, U.S. & TF)		59	1,034	21,820	3,308	26,221		
Exploit. Rate with fishery-induced mortality included		1.6%	9.5%	7.9%	7.0%	7.4%		
CATCH REMAINING (BALANCE)								
Washington		0	7,970	294,350	-4,310	298,020		4,735,190
Canada		-6,290	45,650	1,826,170	-26,341	1,839,189		13,918,070
Balance Remaining [below share / -above share]		-6,290	53,620	2,120,520	-30,651	2,137,199		18,653,260

* The adjusted SET is the lesser of the run size or the sum of the MA + TAM - defined SET.

** Washington sockeye and pink shares according to Annex IV of the Pacific Salmon Treaty.
Sockeye: 16.5% of the TAC - payback (maximum of 5% of share).
Pink: 25.7% of the TAC - payback (maximum of 5% of share)

*** May include unauthorized directed retention or unauthorized bycatch retention in fisheries directed at other species.

**** EO = FN Economic Opportunity fisheries; Demo = FN Demonstration fisheries.

Annually, Fisheries and Oceans Canada (DFO) provides escapement targets and a sockeye spawning escapement plan for each management unit (MU) as per Chapter 4, paragraph 3 of the PST (2025). For each MU, the TAM (Total Allowable Mortality) rules that account for both fishing and natural mortality due to adverse environmental conditions are incorporated to ensure sufficient fish reach the spawning grounds. Although the TAM rule defines the target levels, these levels can be further increased if the Panel decides there are other competing factors that would preclude the SETs from being reached. These factors are natural, environmental or stock assessment factors and for the purposes of the TAC calculation are referred to as Management Adjustments (MAs, MacDonald et al. 2010). MAs are additional fish added to the SET for the purpose of increasing the likelihood of achieving the SET (Chapter B25). When the SET is increased by the MA, the resulting target is referred to as the adjusted SET (Table 1). In case the sum of the SET and MA exceeds the forecasted or in-season estimated run size, the adjusted SET is capped to match that run size estimate, e.g., for all management groups in 2024 (PSC 2026). For pink salmon, the spawning escapement plan is developed using the Pink Salmon Decision Guidelines provided by DFO (Table 2) that outlines the spawning escapement target and the allowable exploitation rate (ER) (DFO 2025a) and does not change based on in-season migration conditions.

Table 2. *Fraser pink salmon Decision Guidelines (DFO 2025a).*

Run Size	Escapement Plan and allowable Exploitation rate (ER)
Less than 7.059 million	The allowable ER increases linearly from zero percent at a run size of zero to 15% at a run size of 7.059 million (For run sizes less than 7.059 million, the allowable % ER is the run size expressed in million multiplied by 15%/7.059)
Between 7.059 and 20 million	The allowable ER increases from 15% to 70% The escapement goal is 6 million, the remainder is harvestable surplus.
Greater than 20 million	The allowable ER is 70% The escapement goal increases as the run size increases beyond 20 million

In addition to the adjusted SET, the Treaty also defines an Aboriginal Fisheries Exemption (AFE) of up to 400,000 sockeye, set aside for Canadian in-river and marine area Aboriginal fisheries, i.e., for First Nations opportunities to harvest salmon for Food, Social and Ceremonial (FSC) purposes. The AFE is also deducted from the total run size prior to determining the TAC for international sharing. As the TAC is calculated by stock management group (Early Stuart, Early Summer, Summer and Late run), the AFE needs to be allocated across these four groups. For Early Stuart, the exemption is up to 20% of the AFE, and the AFE for the remaining management groups is based on the average proportional distribution of First Nations harvests for the most recent three cycles, modified annually as required. If pre-season or in-season there is insufficient harvestable surplus in any management group to allow achieving the AFE allocation for that management group, then the AFE distribution is adjusted so that AFE for that management group is the greater of the catch, the projected catch by Aboriginal fisheries or the available harvestable surplus. Lastly, any test fishing catch from Panel approved test fisheries is also removed from the total run size when calculating the available TAC for international sharing. There are no MAs or AFEs for pink salmon.

Once the TAC is defined for each of the four MUs, the U.S. share is based on the aggregate TAC, i.e., across the four MUs. To the extent practicable, the Panel shall develop and implement a fishing plan that provides the U.S. fishery with the opportunity to harvest its 16.5 percent aggregate share of the TAC of Fraser River sockeye and its 25.7 percent share of the Fraser River pink salmon TAC. To do this the Panel strives to develop and implement fishing plans that concentrate U.S. fisheries on the most abundant MU(s), i.e., the ones that provide the largest percentage of the available TAC. To the extent practicable the harvest should be distributed evenly across the available TAC for each MU. However, given that the proportion of migration of different MUs through U.S. waters on any given year may be variable, this may result in more than 16.5 percent of the TAC for one or more of the less abundant MUs (see PST 2025, Chapter 4 Paragraph 3e for details). In addition, some of the less abundant management groups may even have no TAC. To allow access to the TAC of the more abundant MUs, some incidental harvest may occur on the overlapping MUs that may have little or no TAC. Bycatch on a MU with little or no TAC is defined by the low abundance exploitation rate (LAER) which limits the exploitation rate of that group as defined by Canada's preseason spawning escapement plan (Chapter A5), to be consistent with conservation objectives. Managing to a LAER situation typically occurs for one of the following reasons: when the run size is below the lower fisheries reference point (Pestal et al. 2008), when the adjusted SET (SET + MA) is greater than the run size or when the adjusted SET is less than the run size, but the resulting TAC is small enough for the exploitation rate to be less than the LAER.

As fisheries are executed, updated sockeye and pink salmon catch numbers are provided by the countries to PSC staff to evaluate the countries remaining Fraser River sockeye and pink salmon TAC. In the case of non-retention of sockeye, countries report the associated release mortality. Release mortalities are not included in the TAC calculations but are part of the calculated exploitation rate.

In recent years, as sockeye catch and retention have become more restricted due to the lack of available harvest of sockeye salmon, unauthorised sockeye directed fisheries or unauthorized bycatch retention of sockeye in pink directed fisheries has increased. This catch is referred to as "Other catch" and is accounted for as part of a country's total catch in the calculation of the remaining TAC.

Adjustments to TAC Calculations

Adjustments are made to the U.S. share of the TAC in the case of previous-year(s) harvest overages (more fish caught than allocated share) or underages (less fish caught than the allocated share from previous years) (PST 2025, Chapter 4, Paragraphs 8a - 8b). Reasons for adjustments include the following: (1) management imprecision in U.S. fisheries, and (2) Canada impeding the U.S. from pursuing its in-season share. There are no adjustments for overages that are a result of TAC reductions after the scheduling of the last Panel approved U.S. fishery of the season, or underages resulting from an increase in the TAC at the end of the season (PST 2025, Chapter 4, Paragraphs 8c - 8d). Adjustments for underages are made if Canada directly impedes the US from obtaining its share of the TAC, but not because the U.S. failed to deploy sufficient effort, or fish were not accessible to U.S. fisheries due to northern migration patterns or harvesting constraints. Adjustments, for previous year overages or underages, are limited so that the resulting TAC is not reduced by more than 5% or increased by more than 15% unless the Panel agrees otherwise. If there is an overage or underage from a previous season to be carried forward but no available TAC in the current year, the Panel may agree to carry the overage or underage forward to subsequent years. Any residual overage or underage on the last year of the negotiated Treaty will be carried forward to the next Treaty Period.

Other TAC Considerations

ADDITIONAL SOCKEYE MANAGEMENT UNITS

Currently, the Panel considers four different sockeye MUs (Early Stuart, Early Summer, Summer and Late run) to derive SETs and the aggregated TAC. The Panel can however assign additional MUs by mutual decision (PST 2025, Chapter 4 paragraph 2f). For example, prior to 2010, the Birkenhead group formed a fifth management group. Should additional management groups be assigned, then the TAC calculation will follow the same approach as for the four MUs.

ALASKA DISTRICT 104

As agreed by the Parties (PST 2025, Chapter 4), Alaska District 104 catches are excluded from the TAC calculation. Fraser River sockeye incidentally caught in District 104 fisheries directed at pink salmon comprise a small portion of the catch in that fishery and are not considered to be the target species/stock. As a result, this catch is not included in the TAC calculation but is included in the post-season estimate of total run size.

SINGLE STOCK FOOD, SOCIAL AND CEREMONIAL FISHERIES

Fraser sockeye catch from Single Stock Food, Social and Ceremonial (SSFSC) fisheries, formerly known as escapement surplus to spawning requirement (ESSR) fisheries, is also excluded from the TAC table. This is sockeye catch from a Canadian fishery that occurs in terminal areas, e.g., Weaver Creek. As these fish are expected to exceed spawning requirement (Garner and Parfitt 2006), they are not included in the exploitation rate as this would unnecessarily inflate the exploitation rate and indicate an inaccurate portrayal of in-season management of harvest. As a result, this catch is not included in the Canadian catch in the TAC table (DFO 1999). Currently, there are no SSFSC fisheries for pink salmon.

RELEASE MORTALITIES

Release mortalities are a component of the sockeye catch that is released, i.e. not retained, and are not included in the TAC calculation. Release mortalities are however included in the calculation of the exploitation rate which may limit access to TAC, e.g., when one or more MUs are managed in a LAER.

In planning and implementing Fraser River fisheries, the Panel takes into consideration the availability of both the sockeye salmon TAC and pink salmon TAC, through the entire fishing season (PST 2025, Chapter 4). In recent years, when no sockeye TAC is available, pink salmon fisheries have been implemented with non-retention (release) of sockeye salmon caught in commercial fisheries. Because capture and handling impose stress, released sockeye experience associated mortality. Sockeye release mortality is therefore estimated in pink-directed fisheries.

Release mortality estimates are based on the proportion of sockeye within the catch and the release mortality associated with the gear. To limit release mortalities, fisheries can be implemented when and where sockeye proportions are low and using gear that minimizes release mortality (Table 3). To achieve this, the PSC provides the Panel with predicted Fraser River sockeye mortality estimates by area, gear and date (Chapter B34). This allows the Panel to make decisions regarding potential pink directed fisheries. Release mortality reporting has been inconsistent, with some fisheries reporting release mortalities either in-season or post-season, while others rely on PSC staff to estimate release mortalities based on catch reports. A recent Canadian Science Advisory Report (CSAS, DFO 2025b) notes further efforts are needed to account for release mortality. As of the 2025 Fraser management season, release mortalities are applied to all marine PSC test fisheries (Chapter B2). Although release mortalities are not included in the TAC calculation, they are included in the calculation of the exploitation rate, making it important to be properly accounted for.

Table 3. Percent release mortality associated with different gear types. Note that the release mortality of the PSC purse seine test fishing vessels (2%) differs from the release mortality reported here given that the released salmon are not brought on board (Chapter B2*)*.

Gear Type	Release Mortality
Gillnets	60%
Purse seine nets	25%
Commercial troll	10%
Beach seine/fish wheel	5%
Reef nets	0.5%
Recreational (marine)	10%
Recreational (in-river)	3%

SMALL BUT ACCEPTABLE INCIDENTAL HARVEST

Based on Annex IV, Chapter 4, paragraph 3g of the Pacific Salmon Treaty (2025), the Panel needs to take into consideration the overlap in sockeye and pink salmon migration, and the available sockeye TAC when planning pink directed fisheries. More specifically the Treaty stipulates that, to the extent practical, pink directed fisheries should minimize the impact on overlapping sockeye management groups with little or no TAC (Chapter 4, PST 2025). If there is TAC available for both pink and sockeye management groups that are impacted by the proposed fishery, TAC is the main consideration. In case there is no TAC for one of the overlapping sockeye management groups, the Treaty indicates that overlapping pink and sockeye migration may result in a 'small but acceptable' (SBA) rate of incidental harvest on one or more sockeye management groups that have little or no TAC. For a U.S. fishery to be approved when there is no sockeye TAC, the resulting sockeye catches of the U.S fisheries proposal should be deemed small but acceptable by both parties. PSC Staff are involved in predicting the catch of proposed fisheries (Chapter B34) but are not involved in the evaluation of what should be considered 'small but acceptable'.

There have been disagreements about the interpretation of paragraph 3g, most recently on September 2, 2025, when the U.S. proposed pink-directed Treaty Tribal (sockeye retention) and All Citizen fisheries (sockeye non-retention). The U.S. considered the incidental harvest rate of sockeye small but acceptable and in accordance with the Treaty, while Canada disagreed (PSC Unpublished). Similar disagreements also occurred in 2022 and 2023 (Forrest 2025).

Potential Areas for Improvements

Small but acceptable incidental harvest has been a topic of debate since 2022 and has resulted in special reports following the 2022, 2023 and 2025 Fraser River Panel management seasons (PSC 2024a, 2024b, PSC Unpublished). Recently, Pacific Salmon Commission Tribal and First Nations Caucus Commissioners signed a Memorandum of Understanding (PSC 2025). This MOU has enabled the formation of the First Peoples Salmon Caucus (FPSC), comprising members from First Nations and Treaty Tribes, to address the definition and implementation of small but acceptable incidental harvest as well as sockeye retention during pink directed fisheries. Discussions between the parties are ongoing to resolve the definition of small but acceptable.

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B33. Criteria for fishing decisions table

J.A. Gill and M.J. Hague

Summary

In-season management of Fraser River sockeye salmon depends on in-season data to assess run size estimates (Chapter B23) for the four different Fraser sockeye Management Groups, determine available Total Allowable Catch (TAC, Chapter B32), and assess fisheries proposals (Chapter B34). Early in the season, in-season data may be insufficient to reliably assess run sizes. To guide fisheries planning during this period, the Fraser River Panel relies on the Criteria for Fishing Decisions table. This table, populated with the baseline FRP Fisheries Planning Model results (Chapter A9), allows for comparison of the preseason forecasts of sockeye abundance and stock composition with in-season estimates and helps assess whether observed conditions are consistent with preseason expectations that supported proposed fishery openings. While the Criteria for Fishing Decisions table is not intended to estimate actual run size, it supports adaptive, informed in-season management.

Introduction

The Fraser River Panel (FRP) of the Pacific Salmon Commission (PSC) is the in-season regulatory authority of sockeye salmon fisheries in Panel-controlled waters under the Pacific Salmon Treaty, Chapter 4 (PST 2025). A key prerequisite for authorizing fisheries is the availability of Total Allowable Catch (TAC), which is based on run size estimates (Chapter B32). At the start of the season, insufficient data are however available for in-season run size estimates. This requires the Fraser River Panel instead to rely on the baseline PSC Fisheries Planning Model (FPM), populated using preseason forecasts of run size, timing and diversion rates, as well as fisheries plans that allow the Panel to achieve the management objectives. These objectives are as follows: 1) obtain spawning escapement goals by stock or stock grouping; 2) meet Treaty defined international allocation; and 3) achieve domestic objectives.

To support decision-making early in the season, PSC staff developed the Criteria for Fishing Decisions table. This tool compares preseason forecasts of cumulative abundance and stocks proportions based on the Fisheries Planning Model with emerging in-season data. It provides a structured framework for assessing whether conditions are consistent with those that supported fishery openings in the Panel adopted, preseason version of the Fisheries Planning Model and is included as a standard component of early-season FRP meeting materials.

Methods

To support in-season fisheries planning, forecasted abundance and stock identification estimates from the FRP Fisheries Planning Model (Chapter A9) are compared against in-season estimates of reconstructed abundance (Chapter B21) and stock ID (Chapter B11), as presented in the Criteria for Fishing Decisions table (Table 1). Discrepancies between preseason and in-season estimates may reflect differences in run size, migration timing, or a combination of both. For instance, in-season abundance estimates that exceed preseason expectations could indicate a larger-than-anticipated run, earlier migration timing, or both, and vice versa. To assess the influence of timing assumptions on these comparisons, the table includes alternative scenarios based on hypothetical 50% migration dates. These scenarios illustrate how much earlier or later the run timing would need to be for in-season reconstructed abundance estimates to align with preseason projections.

Data in the table are presented at the resolution of sockeye management groups: Early Summer, Summer, and Late run. In recent years, Early Stuart has typically been excluded from the Criteria for Fishing Decisions table given the low run sizes and the management of this group under a LAER (Low Abundance Exploitation rate), resulting in the absence of fisheries targeting Early Stuart sockeye. In-season fishing opportunities for the other management groups are typically assessed by estimating run size (Chapter B23) and calculating the associated Total Allowable Catch (TAC, Chapter B32) for the management group targeted by the fishery. However, traditional time-density models used to estimate run size cannot reliably distinguish between runs that are small and early versus those that are late and large if less than 50% of the run has been observed (Adkison and Cunningham 2015). Preseason fishing plans may however include fisheries openings scheduled before 50% of the run has been observed in marine areas. In this case, the Criteria for Fishing Decisions table is especially useful as it allows to evaluate if TAC is available and if conditions in terms of abundance and stock ID are consistent with, or more favorable, than preseason expectations, and therefore the fishery planned and evaluated in the FRP Fisheries Planning Model can be executed in-season. If in-season estimates suggest lower abundance, later timing, or a combination of both, the fishery that had been planned preseason may be postponed and the decision on the opening of the fishery re-assessed at the next in-season meeting. Once sufficient in-season data are available to estimate run size using the traditional time-density model, the Criteria for Fishing Decisions table is typically removed from the Panel distribution unless specifically requested by the Panel. It is important to note that the table is not intended to provide information on or estimates of actual run size.

Results

Table 1 presents an example of the Criteria for Fishing Decisions table provided to the Fraser River Panel on August 9, 2022, featuring estimates for the three management groups: Early Summer, Summer, and Late-run sockeye. For the Early Summer-run group, the preseason model, based on DFO's forecast of migration timing (Chapter A2), assumed an Area 20 50% migration date of August 6. According to the FRP Fisheries Planning Model, preseason expectations for cumulative abundance through August 8 (blue text, Table 1) were for 919,000 sockeye in marine areas and 507,000 sockeye at Mission. In contrast, in-season cumulative abundances were significantly lower: 457,000 and 327,000 sockeye, respectively (red text, Table 1). Adjusting the preseason migration timing assumption to August 13 yields a marine abundance estimate of 449,000, which aligns more closely with in-season estimates. This suggests the Early Summer run may be either smaller or later than anticipated, or a combination of both. However, when comparing these timing estimates to historical data shown in Figure 1, the histogram indicates that a 50% migration date as late as August 13 is unlikely. The latest recorded timing for this cycle year was August 11, and only in 2005 was the timing later. This supports the conclusion that the Early Summer run is smaller than expected, with the degree of run size shortfall dependent on any delay in migration timing. Similar conclusions can be drawn for Summer-run sockeye, while for Late run it might still be too early to detect substantial differences between preseason and in-season abundance estimates.

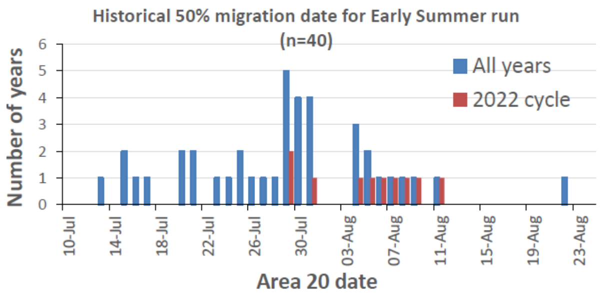
For Early Summer run, Table 1 indicates that the cumulative abundance at Mission through August 8 (327,000, red text in Table 1) closely matches the preseason model expectation of 344,000, when assuming a marine migration timing of August 9 instead of August 6. In contrast, the comparison of the cumulative abundance in marine areas implies a timing of August 13 instead of August 6 when matching marine abundances. The more pronounced discrepancy observed in the seaward abundance based on test fishery data, compared to the Mission estimates, suggests a potential weakness in the later-timed components of the Early Summer run. However, this signal could also be influenced by poor test fishing catches resulting from unfavorable fishing conditions. In general, greater caution is warranted when drawing conclusions based on marine reconstructions as these are based on test fishery data and are more uncertain than abundance estimates at Mission, which are based on hydroacoustic data.

The final column of the table displays the available Total Allowable Catch (TAC) for international sharing by management group. Values shown in blue represent preseason TAC expectations, while red values reflect the most recent in-season TAC updates. In the absence of fishing activity or changes to run size estimates, preseason and in-season TAC values should be identical. In the example presented in Table 1, the minor discrepancy between preseason and in-season estimates is attributed to an increase in test fishing deductions (Chapter B32).

Assuming a fishery targeting Early Summer-run sockeye had been planned preseason to begin shortly after August 8, the results in Table 1 suggest that, despite sufficient TAC being available, it would be prudent to postpone the fishery decision until the next Panel meeting, as the Early Summer run appears weaker than anticipated. While it remains uncertain whether this is due to later-than-expected timing, reduced run size, or both, a delay of the fishery decisions by 3 or 4 days until the next Panel meeting is unlikely to compromise future fishing opportunities given the low cumulative reconstructed abundance compared to preseason expectations. If the run is simply delayed, a fishery opening announced at the next Panel meeting would still allow for effective sockeye harvest.

Table 1. *Criteria for Fishing Decisions table for August 9, 2022. This table compares observed in-season reconstructed abundance and stock identification estimates (red text) with preseason expectations derived from the FRP Fisheries Planning Model (blue text). The comparison assesses consistency between preseason and in-season conditions to inform fisheries planning. Adjustments to preseason timing assumptions (black text) help align estimates for meaningful comparisons. International Total Allowable Catch (TAC) values reflect both preseason projections (blue) and the latest in-season updates (red).*

		Assumed A20 50% Date	Days offset from pre-season forecast	Total Reconstructed Abundance – Area 20 (Cumulative Through: 08-Aug)	Total Reconstructed Abundance – Mission (Cumulative Through: 08-Aug)	Reconstructed Stock ID % – A20PS (Last A20 Sample: 06-Aug)	Reconstructed Stock ID % – A12PS (Last A20 Sample: 06-Aug)	Int'l TAC
Early Summer	Pre-Season Model Expectations	06-Aug	0	919,333	506,807	24%	27%	228,500
	Current Timing Assumption	06-Aug	0	919,333	506,807	24%	27%	
		13-Aug	7	448,601	190,980	32%	36%	
		09-Aug	3	708,485	343,643	27%	31%	
	Reconstructions (compare to model expectations)			456,719	327,016	21%	16%	226,700
Summer	Pre-Season Model Expectations	10-Aug	0	1,789,993	807,261	58%	60%	1,909,300
	Current Timing Assumption	10-Aug	0	1,789,993	807,261	58%	60%	
		16-Aug	6	807,261	251,312	62%	61%	
		14-Aug	4	1,097,349	387,009	61%	62%	
	Reconstructions (compare to model expectations)			755,707	377,485	50%	62%	1,890,900
Lates	Pre-Season Model Expectations	18-Aug	0	298,035	----	18%	12%	1,263,300
	Current Timing Assumption	18-Aug	0	298,035	----	18%	12%	
		19-Aug	1	241,299	----	16%	10%	
		15-Aug	-3	486,450	----	26%	18%	
	Reconstructions (compare to model expectations)			279,244	----	29%	23%	1,250,900



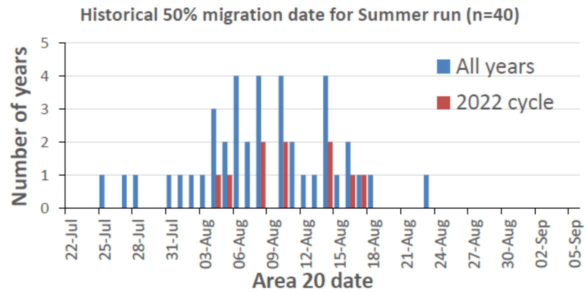


Figure 1. *Histogram of marine 50% migration dates for Early Summer and Summer-run sockeye, on all years and on 2022 cycle years only. When used in combination with the Criteria for Fishing Decisions table, these histograms help to evaluate whether migration timing estimates, used to align preseason and in-season reconstructed abundance and stock ID estimates, are realistic.*

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B34. Fishery proposal assessments

M.J. Hague and E. Taylor

Summary

Under the terms of the Pacific Salmon Treaty (PST 2025, Annex IV, Chapter 4, Paragraph 13d), Pacific Salmon Commission (PSC) staff assesses whether fishery proposals put forth by Canada or the United States for Fraser River sockeye or pink salmon fisheries in Panel area waters are consistent with in-season Panel-adopted run size, Management Adjustments and available Total Allowable Catch (TAC, Chapter B32). For some U.S. fisheries, catch predictions are generated based on in-season assumptions regarding fishing effort, vulnerable fish abundance, and catchability. As catch estimation can be highly uncertain given variability in both the underlying inputs and nature of the modelled relationship, bootstrapping is used to quantify prediction intervals around species-specific estimates of both landed catch and release mortality incurred during non-retention fisheries. PSC staff compare median catch predictions, by species, to the available TAC remaining at the time of the proposal to assess whether proposed fisheries are consistent with Treaty regulations (PST 2025).

Introduction

Under the Pacific Salmon Treaty (PST 2025, Chapter 4), Fraser River sockeye (*Oncorhynchus nerka*) and pink (*O. gorbuscha*) salmon fisheries are managed to a total allowable catch (TAC) limit. The TAC is defined as a function of run size once accounting for deductions relating to spawning escapement targets, management adjustments, aboriginal fishery exemptions and expected catch in Panel-approved test fisheries (PST 2025, Chapter B32). Each party, with support from the Pacific Salmon Commission staff, is responsible for developing and conducting fisheries which adhere to the TAC limits assigned to each country through Pacific Salmon Treaty sharing agreements (PST, Chapter 4, Paragraph 13d).

Preliminary TAC limits by species, and for each of the four Fraser River sockeye salmon management groups (Chapter A5), are initially set using pre-season forecasts (Chapter A1). During the fishing season, as salmon enter terminal fishing areas around Vancouver Island, PSC staff continuously re-assess run size estimates (Chapter B23) and "*other factors relevant to sound fisheries management decisions*" (PST 2025, Chapter 4). In combination with ongoing catch accounting, these assessments are used to update estimates of harvestable surplus and TAC available to each party (Chapter B32).

All fisheries for Fraser River sockeye and pink salmon in areas "*under the Panel's jurisdiction are closed unless opened for fishing by in-season order of the Panel*" (PST 2025, Chapter 4). During in-season meetings of the Fraser River Panel, either party may choose to put forth proposals for fisheries openings in Panel area waters. It is the responsibility of PSC staff to "*assess and provide advice as to whether proposed fishery regulations for Panel Area fisheries are consistent with [current] recommendations and projections*" (PST 2025, Chapter 4). In practice, staff are required to determine if fisheries proposals will cause resulting catches to exceed the remaining species-specific TAC for each country under in-season adopted run size and accounted catch estimates.

Multiple factors can impact the predicted catch in a fishery, including, but not limited to, the abundance of the vulnerable fish population, the level of fishing effort, i.e., the number of vessels and the length of the fishery opening, and the assumed catchability. Further complexities are introduced when catchability varies as function of fish abundance, and/or fishing effort (Harley et al. 2001). Historically, fishery proposal assessments by PSC staff were based on a combination of expert judgement, historical fishery performance, in-season abundance estimates and observed landed catches. However, in recent years, with much lower run sizes and limited available TAC, the process has evolved to use a more quantitative, standardized and objective approach.

The following documentation describes the process for the development of harvest rate and catch equations and how they are applied to generate in-season predictions of landed catch and incidental mortality, in particular release mortalities, for Fraser River sockeye and pink salmon fisheries in Panel area waters. The focus is primarily on U.S. All Citizen and Treaty Tribal fisheries operating in Areas 4B, 5, 6C and 6, 7, 7A given that, in Canadian Individual Transferable Quota (ITQ) fisheries, the total catch during a fishery opening is assumed known and equal to the domestically issued ITQ limit.

Data

Historical data on fishing mortality (catch and release mortality), fishing effort and sockeye and pink salmon abundance were required to parameterize the harvest rate relationships. Historical data on total landed catches and releases (for sockeye non-directed fisheries) by fishery, gear, species, and effort were provided by U.S. fishery managers and biologists. The current analysis used catch and effort data from 2015– 2023 for U.S. All Citizen and Treaty Tribal fisheries in Areas 4B, 5, 6C and 6, 7, 7A for sockeye salmon, and from 2011 – 2023 for U.S. purse seine fisheries in Areas 6, 7, and 7A for pink salmon. In case of mixed-gear U.S. fisheries, the gillnet fishing effort, i.e. the number of gillnet vessels, is converted into purse seine vessel equivalents using a fixed ratio representing relative catch efficiency of the two gear types. Historical daily sockeye and pink salmon abundances available to each fishery were estimated from run reconstruction models (Chapter C4, Hague et al. 2022, Wong et al. 2026), containing species-specific assumptions relating to migratory behavior and fishery vulnerability.

Methods

HISTORICAL RECONSTRUCTED ABUNDANCES

Sockeye and pink salmon run reconstruction models are described in Chapter C4 and Hague and Michielsens 2025, respectively. Given the underlying differences in migration behavior between the two species, alternative approaches were used to define the vulnerable abundance, or the abundance of fish available to a fishery on a given day (N_v) in order to estimate historical catchability.

Sockeye models used the same migration behavior and fleet distribution assumptions as applied in the pre-season planning model (Chapters A11 and A12). A fixed offset between Area 20 test fisheries and U.S. fisheries was assumed for each year. Daily reconstructed abundances (N_d) in the fishing area of interest were each multiplied by a fraction (f_d) representing the proportion of each day's abundance assumed to be available to the fleet and then summed across all migratory days (*D*) to calculate the vulnerable abundance (N_v):

$$(1) \qquad N_v = \sum_{d=1}^{D} f_d \cdot N_d$$

Pink salmon offsets between Area 20 and U.S. fisheries varied by year, reflecting the observed inter-annual differences in migration rate behaviour (Hague and Michielsens 2025). Given the challenges in estimating daily reconstructed pink salmon abundances in U.S. fishing areas, a simplified approach was applied which defined vulnerable pink salmon abundances as a 3-day running average, and assumed only a single migratory day was available to each day of fishing (Hague et al. 2022):

$$N_v = \frac{\sum_{d=-1}^{2} N_d}{3}. \quad (2)$$

HARVEST RATE EQUATIONS

Sockeye harvest rate equations for U.S. fisheries had originally been developed and parameterized for the pre-season Fraser River Panel (FRP) Fisheries Planning Model (FPM, Chapter A12) with data from the 1980s, containing high abundance and high fishing effort years (Figure 1). In addition, the focus had been solely on sockeye salmon, not pink salmon.

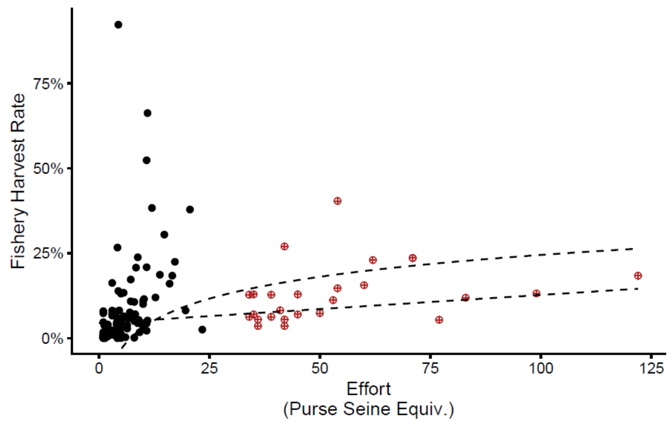

Figure 1. *Sockeye harvest rates for U.S. gillnet and purse seine fisheries in Area 6,7 as a function of fishing effort, expressed in terms of purse seine equivalents. Data from the 1980s are represented in open red circles while recent data (since 2015) are represented in solid black circles. Changes in fishery dynamics and fish abundance in recent years prompted a re-evaluation of harvest rate equations for in-season catch estimation.*

An updated analysis using recent data (2015 – 2023) calculated historical catchability (*q*) of sockeye and pink salmon in U.S. fisheries from daily fishery catch-per-unit-effort (*CPUE*) data and reconstructed vulnerable abundance estimates (N_v):

$$q_d = \frac{CPUE_d}{N_v} = \frac{C_d/E_d}{N_v}. \quad (3)$$

where catch (*C*) represented the total number of salmon caught and landed in retention fisheries or the total number of releases in sockeye non-retention fisheries, and fishing effort (*E*) was defined as the number of purse seine vessels, or equivalents. Historical vessel type conversions from the 1980s assume the fishing effort of five gillnet vessels is equivalent to one purse seine vessel (Hague 2016). No fishing effort adjustments were made for openings of less than one day.

Many studies, across a wide range of species and fishing gear, have recognized that the assumption of a linear relationship between CPUE and abundance, implying constant catchability, is rarely met (Harley et al. 2001). However, for sockeye and pink salmon, preliminary results indicated no significant relationship between catchability and effort, abundance, or year (E. Taylor, PSC, pers. comm, Hague et al. 2022). In addition, retrospective analysis showed that a simple linear equation using a fixed, recent-year median catchability provided reasonable predictions of daily encounters for both sockeye and pink salmon, and improved performance compared to the catch equations currently used in the FRP Fisheries Planning Model (Chapter A12). Therefore, a simple relationship assuming a constant catchability and a linear increase in CPUE as a function of fish density and effort (Hilborn and Walters 1992) was assumed for the in-season catch projection models for both species:

$$\hat{C}_d = q \cdot E_d \cdot N_v. \quad (4)$$

IN-SEASON IMPLEMENTATION

When a fishery is proposed in-season, the relevant party provides information on the dates of the fishery opening, the areas, gears and users participating, and the expected vessel effort. In the case of pink directed fisheries, they also indicate if incidental by-catch of sockeye salmon can be retained or needs to be released. Total daily sockeye and pink salmon abundances are either estimated directly from test fishery CPUE data and associated catchability estimates (Chapter B5), or from run size time density models (Chapter B23, Michielsens and Cave 2019). To estimate salmon abundances entering U.S. fishing areas, daily totals are first multiplied by a 5-day moving average of diversion rate to calculate abundances entering Juan de Fuca Strait, and are then adjusted for catches seaward of the fishery. Next, daily abundance projections are converted into estimates of vulnerable abundance for each day of fishing using equations (1) or (2). Finally, the median catch prediction is generated using the median species- and fisheries-specific catchability ($\bar{q}$) derived from the historical analysis, the predicted fishing effort as provided by the U.S., and the vulnerable abundance:

$$(5) \qquad \hat{C} = \bar{q} \cdot E \cdot N_v.$$

If the proposed fishery assumes sockeye non-retention, the predicted catch (fish encounters) is multiplied by gear-specific rates of release mortality to calculate the mortality impacts. The assumed release mortality is 60% for gillnets, 25% for purse seines, and 0.5% for reefnets (Chapter B2). For sockeye salmon, predictions of both landed catch and release mortality are provided by management group.

Errors in catch projections can arise from several sources, including differences between predicted and observed fishing effort, uncertainty in run size estimates, violations of key reconstruction model assumptions (such as inaccuracies in fish movement rate and spatial distribution within the fishing area), variability in fishery catchability, and uncertainty in the model used to estimate catch. In-season, uncertainty around the median catch prediction for each species, expressed in terms of 10th and 90th percentiles, is generated using a bootstrapping approach based on historical in-season abundance estimates and catchability parameters. This method is intended to propagate the combined effects of many of the sources of uncertainty described above. Currently, catch projections do not directly quantify uncertainty arising from errors in the estimates of fishing effort or the vulnerable abundance available in the fishing area.

The in-season fishery proposal assessment framework has undergone substantial changes in recent years. Most recently, R code was developed and linked to an R Shiny application to improve the efficiency and responsiveness of PSC staff to develop updated catch projections in-season (Figure 2). The model generates catch predictions for Fraser sockeye management groups, allowing the Fraser panel to better understand implications of “small but acceptable” impacts (PST 2025).

Fishery Proposal Catch Estimate

A total of 110,731 Fraser sockeye are predicted to be retained during this fishery with an 80% prediction interval of 71,106 - 247,167.
A total of 734,939 Fraser pink salmon are predicted to be retained during this fishery with an 80% prediction interval of 122,048 - 429,213.

Date	Fraser Pinks	Fraser Sockeye	Early Stuart	Early Summer	Summer	Late
Aug 18	248,139	43,069	0	710	38,597	3,761
Aug 19	245,265	36,401	0	550	32,542	3,309
Aug 20	241,535	31,261	0	434	27,856	2,971
Total	**734,939**	**110,731**	**0**	**1,694**	**98,996**	**10,041**

Figure 2. *PSC fisheries proposal assessment application with sample outputs for a proposed U.S. purse seine fishery with retention of both pink and sockeye salmon.*

Results

SOCKEYE SALMON

For conciseness, this section highlights results from the Area 6 and 7 purse seine fisheries only. Purse seine catchability estimates for Treaty Tribal and All Citizens fisheries in Area 6,7 are nearly identical. The median purse seine catchability estimate (q) for sockeye salmon in Area 6,7 is 0.008 and in 90% of cases, $q \leq 0.03$ (Figure 3). Patterns in historical catchability show limited evidence of varying by abundance or effort but there is greater variability in catchability estimates when fishing effort is low (Figure 3). This is unsurprising due to the larger uncertainty in daily reconstructed abundances when abundances and/or the number of vessels participating to a fishery (sample size) are low.

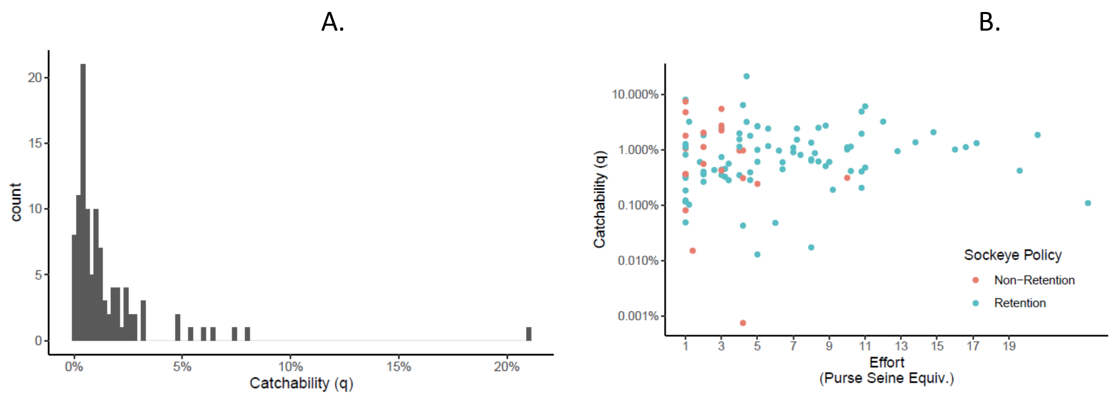

Figure 3. *Historical purse seine catchability estimates for sockeye salmon in U.S. Area 6,7 Treaty Tribal and All Citizen fisheries since 2015: A) Catchability histogram. B) Catchability as a function of fishing effort in sockeye-directed fisheries (blue dots) and in pink salmon directed fisheries with non-retention of sockeye (red dots).*

A retrospective analysis of alternative catch equations shows that the use of a constant historical median catchability is preferable to using the historical catch equations from Cave and Gazey (1994). In addition, the updated approach has the added benefit of producing catch estimates with uncertainty. An example of the retrospective performance of the fixed median catchability based on recent years versus the historical pre-season Fisheries Planning Model catch equations to predict sockeye salmon catch is provided in Figure 4. The days where catch is grossly underestimated are typically those with high variability in daily reconstructed abundances. Uncertainty in the true vulnerable abundance is likely the greatest contributing factor to the error in catch estimation.

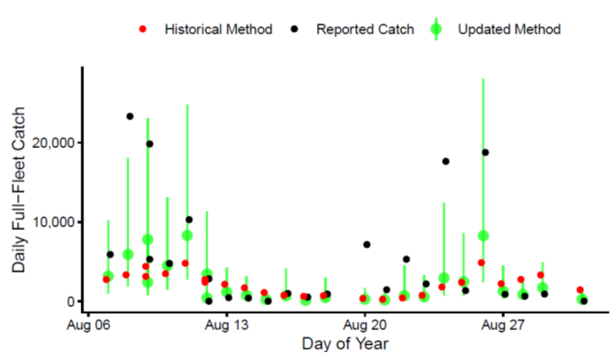

Figure 4. *Example of sockeye salmon catch predictions for U.S. Area 6,7 purse seine fisheries in 2014 using historical (pre-season Fisheries Planning Model, Chapter A12) versus updated median catchability estimates based on recent years of data.*

PINK SALMON

The median purse seine catchability estimates for pink salmon are similar across areas and user-groups (0.02, Figure 5). Similar to the sockeye analysis, variability in catchability estimates increases at low fishing effort and/or low salmon abundances. The difference in catchability between the two species is primarily driven by the different assumptions regarding vulnerable abundance. If the same vulnerability assumption is made for pink salmon as for sockeye salmon, the catchability reduces to a similar value for both species.

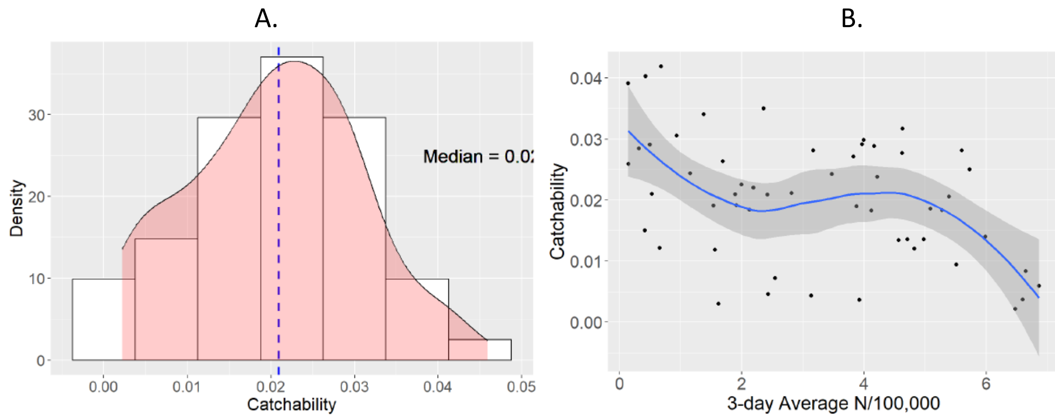

Figure 5. *Historical purse seine catchability for pink salmon in U.S. Area 6,7 Treaty Tribal and All Citizen fisheries since 2011: A) Catchability histogram after removing days with less than two vessels fishing and/or less than 10,000 vulnerable pink salmon abundance. B) Relationship between catchability and estimates of vulnerable pink salmon abundance based on 3-day moving averages.*

While the catchability for pink salmon seems constant over abundances ranging from approximately 100 – 500,000, there is some evidence of hyperstability at very large abundances, possibly due to gear saturation (Figure 6). Therefore, catches associated with large vulnerable abundances (e.g. > 500,000) could be more prone to over-estimation when applying a constant catchability relationship. Similar to the sockeye analysis, large errors associated with smaller catches are likely driven by errors in estimates of vulnerable abundance. And while there is a tendency to underestimate large catches, many of these high catch days occurred in 2013, a year with unusually high catchability compared to the historical average. Therefore, these errors are more likely associated with uncertainty in the catchability estimate.

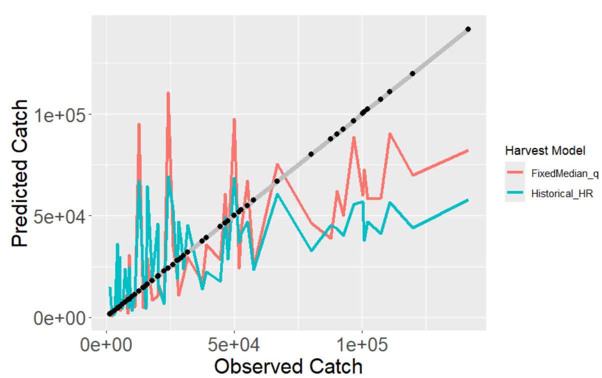

Figure 6. *Comparison of catch predictions, based on fixed median catchability for recent years and historical catch models (FRP FPM, Chapter A12), with observed catches for U.S. Area 6,7 purse seine pink salmon fisheries.*

Planned Changes and Areas for Improvement

Future improvements will focus on aligning sockeye and pink salmon modelling approaches and using a Bayesian framework to continuously integrate uncertainty from in-season abundance estimation models, variability in catchability, and model error in the fishery proposal assessment framework.

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C1. Spawning escapement estimates

C.G.J. Michielsens and S. Everitt

Summary

The annual assessment of the number of sockeye on the spawning grounds within the Fraser River watershed is central to Canada's obligations under the Pacific Salmon Treaty (PST 2025). Spawning escapement estimates, representing the number of salmon that escape fisheries and reach their natal spawning grounds, are essential for the management of Fraser River sockeye salmon. The methods used to enumerate the number of spawners varies depending on the stock, its preseason forecast and the physical attributes of the system and include visual surveys, enumeration fences, mark-recapture methods, and hydroacoustic methods. The stock-specific escapement estimates are important for fisheries management to ensure escapement targets are being met, to derive post-season run size estimates, to generate pre-season forecasts and support conservation status evaluations.

Introduction

In accordance with the Pacific Salmon Treaty (PST 2025, Chapter 4, section 3), Canada is responsible for the annual assessment of the number of Fraser River sockeye that have been able to escape fisheries and successfully reached the spawning grounds. These annual spawning ground enumerations allow managers to evaluate if the Fraser River Panel's primary objective, i.e. reaching Spawning Escapement Targets (SETs, Chapter A5) has been met. The Department of Fisheries and Oceans (DFO), through its Stock Assessment Division, is responsible for conducting these surveys and generating escapement estimates. These estimates are used to determine post-season run size estimates, assess en route mortality, reallocate catch among co-migrating stocks, and support conservation status evaluations under the Wild Salmon Policy (WSP) and Species at Risk Act (SARA). The following text provides a brief overview of the data and methods. More detailed information can be obtained from DFO.

Data

Annually, spawning ground assessments are conducted throughout the Fraser watershed. In 2022, this involved collecting data across more than 180 distinct tributary locations. The main data collected on the spawning grounds are spawner counts, but most spawning ground assessment projects also collect biological information such as sex, fish lengths, fecundity, spawning success expressed in terms of egg retention and data about the physical condition of the fish such as reports of net marks, diseases and wounds. Environmental conditions on the spawning grounds such as water level and temperature are also documented. In addition, spawning ground surveys also collect scales and otoliths to derive age composition data (Chapter C2).

Methods

SPAWNING ESCAPEMENT

Spawning escapement estimation methods are categorized by their precision and potential for bias. When expected spawning escapements are less than 75,000 spawners, visual surveys are used to assess spawner escapements in most cases (Grant et al. 2011). If spawning escapements are expected to exceed 75,000, more intensive methods are used, such as enumeration fences, mark-recapture methods and hydroacoustics. Sometimes high-accuracy methods are used on low abundances due to conservation concerns or if visual methods are poorly suited to the system. Prior to 2004, escapements exceeding 25,000 sockeye were assessed using census counts or mark-recapture. Because of the fluctuation in escapements as well as operational resources, the enumeration methods have varied across stocks and across years (Table 1).

Table 1. *Overview of the spawner estimation methods used for each of the 27 Fraser River sockeye stock groups evaluated by DFO Stock Assessment Division from 2009 to 2022 (Robinson et al. In Press).*

RSA Stock	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
1 Early Stuart	Visual	Visual	Visual	Visual	Visual	Visual	Visual	Visual	Visual	Visual	Visual	Visual	Visual	Visual
2 Chilliwack	Visual	Visual	Visual	SONAR	Visual	Visual	Visual	SONAR	Visual	Visual	Visual	SONAR	Visual	Visual
3a Pitt	M/R	Visual	M/R	M/R	Visual	Visual	Visual	Visual	Visual	Visual	Visual	Visual	Visual	Visual
3b Alouette+ Coquitlam*	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4a Nadina	Visual	Visual	Visual	Visual	Visual	Visual	Visual	SONAR	Visual	SONAR	SONAR	SONAR	SONAR	SONAR
4b Bowron	Visual	Visual	Visual	Visual	Visual	Visual	Visual	Visual	Visual	Visual	Visual	Visual	Visual	Visual
5a Gates	Visual+ Fence	Visual	Fence	Fence	Fence	Fence	Fence	Visual	Visual	Visual	Visual	Visual	Visual	Visual
5b Nahatlatch	Visual	Visual	Visual	Visual	Visual	Visual	Visual	Visual	Visual	Visual	Visual	Visual	Visual	Visual
6 Taseko	Visual	Visual	Visual	Visual	Visual	Visual	Visual	SONAR	Visual	Visual	Not Inspected	Visual	SONAR	SONAR
7 North Barriere	Visual	Visual	Visual	Visual	Visual	Visual	Visual	Visual	Visual	Visual	Visual	Visual	Visual	Visual
8b Scotch	Fence	Fence	Fence	Fence	Fence	Fence	Fence	Fence	Fence	Fence	Fence	Fence	Fence	Fence
8b Seymour	Visual	M/R	Visual	Visual	Visual	M/R	Visual	Visual	Visual	M/R	Visual	Visual	Visual	SONAR
9 Harrison	M/R	M/R	M/R	M/R	M/R	M/R	M/R	M/R	M/R	M/R	Visual	M/R	M/R	M/R
10 Widgeon	Visual	Visual	Visual	Visual	Visual	Visual	Visual	Visual	Visual	Visual	Visual	Visual	Visual	Visual
11 Late Stuart	M/R	Visual	Visual	M/R	M/R	Visual	Visual	Visual	M/R	Visual	Visual	Visual	M/R	Visual
12 Stellako	Fence	Fence	M/R	M/R	SONAR	SONAR	SONAR	Fence	SONAR	SONAR	SONAR	SONAR	SONAR	SONAR
13 Chilko	SONAR	SONAR	SONAR	SONAR	SONAR	SONAR	SONAR	SONAR	SONAR	SONAR	SONAR	SONAR	SONAR	SONAR
14 Horsefly	Visual	SONAR	Visual	Visual	Visual	SONAR	SONAR	Visual	SONAR	SONAR	SONAR	Visual	SONAR	SONAR
15 Mitchell	SONAR	M/R	Visual	Visual	Visual	SONAR	SONAR	Visual	SONAR	SONAR	SONAR	Visual	SONAR	SONAR
16a Raft	Visual	Visual	Visual	Visual	Visual	Visual	Visual	Visual	Visual	Visual	Visual	Visual	Visual	Visual
16b North Thompson	Visual	Visual	Visual	Visual	Visual	Visual	Visual	Visual	Visual	Visual	Visual	Visual	Visual	Visual
17a Birkenhead	Fence	Fence	Fence	SONAR	SONAR	SONAR	SONAR	SONAR	SONAR	SONAR	SONAR	SONAR	SONAR	SONAR
17b Big Silver	Visual	Visual	Visual	Visual	Visual	Visual	Visual	Visual	Visual	Visual	Visual	Visual	Visual	Visual
18a Late Shuswap	Visual	M/R	M/R	Visual	Visual	SONAR	Visual	Visual	Visual	M/R	Visual	Visual	Visual	M/R
18b Portage	Visual	Visual	Visual	Visual	Visual	Visual	Visual	Visual	Visual	Visual	Visual	Visual	Visual	Visual
19a Weaver	Fence	Fence	Fence	Fence	Fence	Fence	Fence	Fence	Fence	Fence	Fence	Fence	Fence	Visual
19b Cultus	Fence	Fence	Fence	Fence	Fence	Fence	Fence	Fence	Fence	Fence	Fence	Fence	Fence	Fence

Visual surveys

Visual surveys are best suited to smaller systems, with observers counting live spawners and carcasses, either on foot, by boat or by helicopter. Survey frequency is typically weekly but may be reduced due to logistical or environmental constraints. Fewer surveys may however bias escapement estimates as the likelihood of the survey coinciding with peak spawner abundance is lower. When the survey frequency is intentionally reduced, information from previous years or from nearby spawning sites are relied on to schedule the survey to increase the likelihood for the survey to coincide with peak spawning. Another reason escapement estimates may be biased low is if the peak count coincides with poor visibility within streams, as it reduces observer efficiency, i.e. the ratio of the fish observed versus the fish present. Visibility within streams varies depending on geomorphology and natural hydrologic and environmental conditions. A high density of spawners can also reduce the accuracy of an escapement estimate as sockeye are more difficult to count when they are in large groups as opposed to evenly spread out on spawning gravel.

Spawner escapement estimates are generated based on the number of live spawner counts and cumulative carcasses recovered up to the day of the peak live count, expanded using a factor to account for undetected fish and those not present during peak counts:

(1) Escapement = expansion factor x (peak live count + cumulative carcass recoveries)

Previously, the default expansion factor for Fraser River sockeye salmon was 1.8 and represented an average derived through a series of calibration studies started in 1988. These studies were conducted in small, clear streams with good visibility where the visual live counts were paired with spawner escapement estimates with high-accuracy and known precision, primarily from weir counts or mark-recapture methods. Since 2004, the calibration studies have been expanded to include larger and more turbid streams, as well as higher abundance spawning areas (Welch et al. 2017). Beginning in 2025, all visual counts of Fraser River sockeye will be expanded using models developed by DFO Fraser and Interior Area Stock Assessment (Arbeider et al. In Review). The models use decades of calibrated visual surveys across the Fraser River watershed to generate expansion factors for systems based on their physical characteristics.

Complete census methods

Complete census methods such as fence counts or complete carcass counts produce the most precise spawner enumeration but are only employed in systems where it is reasonable to count every fish. Fence counts are executed by blocking the entire migration path immediately downstream of the spawning grounds, and counting the number of sockeye through an opening in the fence. Complete carcass counts are usually only done in closed spawning channel systems. Complete census counts are labour intensive, expensive, may impact the migration of other species and are usually not practical for larger systems.

Mark-recapture methods

Simple or stratified Petersen mark-recapture methods (Schwarz and Taylor 1998) require a portion of the population to be tagged and subsequently released during their migration to the spawning grounds. On the spawning grounds, the number of tagged and untagged carcasses are recorded. In combination with the number of tags applied to live sockeye, this allows the population size (N) to be calculated through the following equation:

$$N = M^{*} C / R \quad (2)$$

Where M is the number of tagged fish, C is the total number of carcasses recovered on the spawning grounds while R is the number of tagged carcasses recovered.

Hydroacoustic methods

Hydroacoustic systems such as Dual Frequency Identification Sonars (DIDSONs) and Adaptive Resolution Imaging Sonars (ARIS) are frequently used as a high precision technique to enumerate Fraser River sockeye spawners (Holmes et al. 2006). The sonar is used 24/7 for the duration of the sockeye migration, but only a subsample of the collected data is counted, e.g. 20 minutes of every hour, and the estimates expanded to the full hour. Hydroacoustic methods are less invasive than mark-recapture and fence count methods because they do not impede natural sockeye migration. But unlike complete census estimates, not all spawners may be accounted for and the method does not facilitate the collections of additional spawning ground data. Hydroacoustic enumeration methods therefore still need to be paired with carcass surveys to obtain data regarding the age distribution, sex ratio, spawning success and spawner distribution.

EFFECTIVE FEMALE ESCAPEMENT

The total sockeye escapement to a given stream is categorized into male, female, and jack sockeye based on carcass recovery data. If the recovery sample is deemed temporally representative across the die-off period and spatially representative of the recovery area, the proportions of each group are derived directly from the sample. To correct for the lower recovery probability of jacks, due to their smaller body size, the observed number of jacks is multiplied by a factor of 1.26 to account for their lower recovery probability (Andrew and Webb 1987). If a carcass recovery sample is not considered representative in time or space, average proportions from the relevant population aggregate are applied instead. However, if no jacks are observed during the stream survey, their proportion is assumed to be zero. The adult sex ratio is calculated based on the proportions of males and females, while average female spawning success is calculated based on the weighted daily estimates of female egg retention in the female carcass recovery sample (0%, 50% or 100%). Effective female escapement is estimated by the product of total female escapement and average percent female spawning success. If the recovery sample is deemed unrepresentative, population-level averages for female spawning success are applied instead.

Results

Escapement estimates are released in stages with the earliest estimates, termed preliminary estimates, released soon after the spawning season ends and data have been processed. At this stage, the accuracy of the data has not yet been verified, and bias assessments, such as those required for mark-recapture methods, have not been conducted. Consequently, preliminary estimates are subject to revision following further analyses and are typically released according to the following schedule: Early Stuart in November, Early Summer run in December, Summer run in January, and Late run in February. Preliminary estimates are presented to the Fraser River Panel at the February meeting (Table 2). Near-final escapement estimates, released in March, represent escapement data that have been verified for accuracy, tested for bias and corrected for age composition. Further changes to near-final estimates are unlikely. Final estimates are the most accurate escapement estimates obtained after all the data have been compiled and analysed and may rely on additional assessments or additional years of data.

The escapement data for Fraser River sockeye salmon is stored within NuSEDS (New Salmon Escapement Database System). This is DFO's Pacific Region's central database containing individual spawner survey data records as well as spawner abundance estimates. The Fraser sockeye data are stored at the stream level and can easily be aggregated to match other groupings such as the 19 reporting stock groups or the four management groups. DFO annually shares the Fraser sockeye data within NuSEDS with PSC staff who store the data within RuFEs (Chapter C17). On occasion, PSC staff will modify the spawner data when no spawning ground assessments occurred, such as in 2002 for Birkenhead and Horsefly River and in 2005 for Mitchell River (Chapter C17). Note that there are currently no adjustments made to the escapement data based on the Run Size Adjustment process (Chapter C6).

Table 2. *Overview of the Preliminary 2022 spawning escapement estimates by management group presented to the Fraser River Panel.*

Management Group	Spawning Escapement	% High precision	Females	Males	Jacks	Spawning Success
Early Stuart	24,929	0%	28%	72%	0%	76%
Early Summer	546,323	77%	46%	54%	<1%	79%
Summer	1,980,438	95%	54%	46%	<1%	96%
Late run	931,346	84%	52%	48%	<1%	95%

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C2. Post-season reading of otoliths and scales

C.E. Ball, J.E. Sellars and M.R. Forrest

Summary

Spawning-ground samples are a key component of Fraser River sockeye salmon management because they provide essential age data derived from otoliths and scales. Unlike in-season samples, where scales are generally reliable, age determination on the spawning grounds relies primarily on otoliths due to the resorption and degradation of scales late in life. Both structures are examined to ensure the most complete and robust age data possible. Accurate age-composition information is critical for estimating total production in a given year and for understanding population dynamics, recruitment, growth, health and age at maturity of Fraser River sockeye. The age structure of each stock directly influences assessment outcomes, guides management decisions, and supports both short- and long-term population forecasting.

Introduction

From the early fry stage onward, sockeye salmon begin forming scales that develop concentric growth rings, or circuli, which are deposited throughout the fish's life, and provide a chronological record of growth and environmental conditions (Clutter and Whitesel 1956). In addition to scales, otoliths, calcified ear stones, also accumulate distinct growth increments that reflect the fish's developmental history. But unlike scales, the quality of otoliths does not decline due to resorption or degradation later in life. Together, scales and otoliths provide complementary information from salmon sampled in terminal spawning areas, where fish are often dead or in advanced stages of decay. Analyzing both structures allows for more robust age determination, characterization of growth patterns, and quantification of both freshwater and marine growth.

Data

Pursuant to the Diplomatic Note of August 13, 1985 regarding implementation of Article XV (Paragraph 3) of the Pacific Salmon Treaty, Canada is responsible for the collection of length, sex, scales and otoliths from sockeye on the spawning grounds (PST 2025). PSC staff annually request spawning ground samples from all Fraser River salmon stocks where assessment programs occur. Samples are also requested from locations where sockeye unexpectedly aggregate. An equal number of samples are requested from male and female sockeye, if possible, ranging from 40 to 180 samples. Samples are collected in a manner that reflects the spatial distribution and relative abundance of fish within each sampling area. Care is taken to avoid "samples of convenience," including carcass aggregations that may form in shallow water or low-velocity pockets. These areas can preferentially retain fish of certain body sizes due to hydrological sorting, and restricting sampling to such locations may introduce size- or age-selective biases in the data. If feasible, sampling is requested over three periods: during the peak of die off, 10 days before the peak, and 10 days after the peak. Period samples allow assessment of changes to age composition and scale patterns throughout the spawning period. In addition, samples from 120 jacks are requested for each system, with the understanding *a priori* that this sample size is unlikely to be met. The spawning ground sampling request is transmitted annually to Canada through a sampling request letter sent to DFO's Regional Director General.

Fisheries and Oceans Canada (DFO) Stock Assessment crews collect the samples throughout the Fraser River watershed in all the rivers and creeks where sockeye can be found. In high abundance years, e.g. 2022, the total number of samples is close to 9,000 while in low abundance years like 2019 and 2024, less than 5,000 samples are collected. Sampling in terminal spawning areas often requires collecting fish that are already dead or in advanced stages of decay. As decomposition progresses, scale quality declines, with the scale edges especially prone to deterioration or resorption (Figure 1). This loss of the outer circuli can obscure growth patterns and reduce the accuracy of age estimates derived from scales (Bilton et al. 1967). Because otoliths also collect growth information and they are not worn or resorbed during spawning, they are preferred over scales to obtain age information from spawners. Both scales (one per fish) and otoliths (two per fish) are collected in waterproof booklets prepared by PSC Scale Lab staff. These booklets will also contain metadata as well as information about the fish length, sex, percent spawned, condition and other relevant information such as reports on net marks and diseases (Chapter C1). All samples are sent to the PSC lab for processing and analysis.

A B

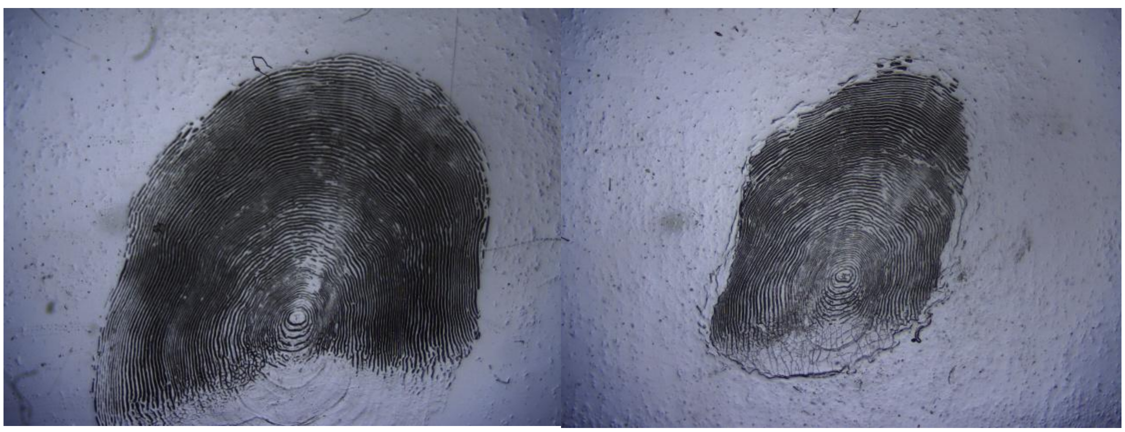

Figure 1. A. *Scale collected in marine areas showing no resorption.* **B.** *Scale collected on the spawning grounds showing resorption.*

Methods

When spawning ground samples arrive in the PSC scale lab, they are processed by scale lab technicians. To start, the booklets are labelled and inventoried into the PSC Scale database. The postorbital hypural (POH) length, the standard length and the sex data are subsequently entered as part of the sampling record. The scale is removed from the booklet, cleaned and pressed to create an acetate impression. The scale impression is analysed under a microscope and the image analyzed using Image-Pro Premier software (Chapter B9).

The otolith is placed in a dry coin envelope for storage and placed in water in a small well of a black acrylic plate for analysis (Figure 2). The black color is necessary to give contrast under the microscope. The PSC otolith analyst uses a stereomicroscope mounted with a digital camera and a modified version of the scale analysis system. The otoliths are examined at a magnification factor of 6.7x – 45x. Using experience and the rules as outlined in Clutter and Whitesel (1956), the otoliths are examined by the otolith analyst to determine the age of the fish. The annual changes in growth rate are recorded in the growth rings. Periods of slow growth create tighter rings that are clear, and periods of fast growth create rings that are more opaque. The PSC uses the Gilbert and Rich (1927) nomenclature for age classification (Chapter B9). The scale, otolith and additional biological data are matched by a unique identifying number and sample code.

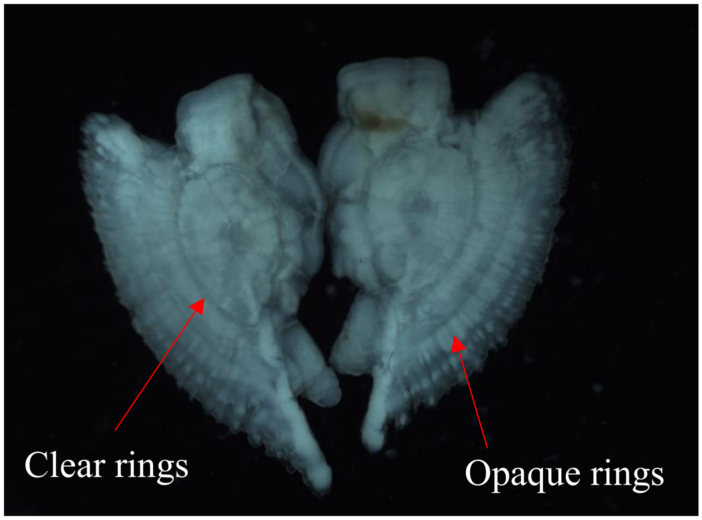

Figure 2. *Otoliths showing clear and opaque rings.*

After merging the otolith, scale, and associated data files, all discrepancies and outliers are re-examined. Where differences occur between otolith-derived and scale-derived ages, the otolith is generally considered authoritative for marine age, while the scale is considered authoritative for freshwater age. However, in some cases, specimen-specific characteristics may justify overriding this convention. In all instances, the final assigned age is verified in terms of its consistency with the observed length-at-age. All data associated with the scale and otolith are stored within the scale database (Chapter C14).

Training of new analysts

Both otolith and scale reading require dedicated training, which is provided by the PSC scale lab. Training for scale and otolith analysts typically begins on the job at the PSC scale laboratory. Novice analysts are initially mentored by experienced staff, learning the fundamental principles of interpreting growth structures on both scales and otoliths, using the Scale and Otolith Image Library as a training resource (Chapter C15). The training includes recognizing freshwater and marine annuli and understanding how growth patterns differ between the two structures. Achieving proficiency requires substantial practice, as analysts must learn to distinguish true annual increments from stress marks, false checks, resorption artifacts, and other irregularities. With sustained training and experience, analysts develop the expertise necessary to produce accurate and consistent age determinations from both structures.

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C3. Stock-specific daily catch and in-river passage

M.R. Forrest

Summary

The Catch and Racial 100 (CR100) files are a set of Microsoft Excel files designed to integrate high resolution daily stock proportions estimates with daily catch records and in-river daily sockeye salmon passage estimates. These files facilitate the generation of stock-specific summaries of Mission-based run size, catch, and passage past Mission and at various upstream locations. These files also generate the standardized formatting required to upload the data into the RuFEs database (Chapter C17) and are important inputs to the Marine Reconstruction 100 (MR100) files (Chapter C4) and the Run Size Adjustment (RSA) process (Chapter C6). Unlike the in-season CR20 files (Chapter B20), which track 19 Fraser River sockeye stocks and one aggregated group of non-Fraser sockeye, the CR100 files track 50 Fraser stocks and 37 non-Fraser stocks and is mainly used post-season. Although the CR100 workflow process generates outputs at very fine stock resolutions, the resulting stock-specific estimates of Mission-based run size, catch and exploitation should not be used at such resolution without a clear understanding of the data limitations, further highlighted in the chapter on data quality indicators (Chapter C11).

Introduction

The Pacific Salmon Treaty, Article XIV(b) states that each party must make catch, effort and related data for all Fraser sockeye salmon stocks available to the Commission (PST 2025). PSC staff, on behalf of the Fraser River Panel, is responsible for collating the daily catch data and escapement past Mission as well as applying appropriate stock proportions to these data to derive stock-specific estimates. In-season, PSC staff use CR20 files which track sockeye catches and passage past Mission and various upstream locations for 19 Fraser stocks in addition to one aggregated group of non-Fraser stocks (Chapter B20). Post-season, PSC staff use CR100 files that track catch and in-river passage of 50 Fraser stocks and 37 non-Fraser stocks, the finest stock resolution possible based on the current DNA technology (Chapter B11). Currently, CR100 files are updated and used post-season to populate the RuFEs database (Chapter C17), as inputs in the post-season Marine Reconstruction files (MR100, Chapter C4) and as input to the Run Size Adjustment (RSA) process (Chapter C6). Even though they are used in-season to cross-validate assumptions made in the CR20 files, they are not used as a primary assessment tool because the Fraser Panel does not require catch and passage numbers at such a fine stock resolution.

Data

The CR100 files rely on data and estimates from various programs: catch data inputs by date, area, user, and gear provided by the Parties and from test fisheries (Chapter B1), daily sockeye passage at Mission-based on sonar estimates generated by the hydroacoustic monitoring program at Mission, BC, (Chapter B14) in combination with species composition estimates (Chapter B19) and daily stock proportion estimates from test fishing, First Nations, Tribal, commercial and recreational catches for 87 stocks (50 Fraser stocks and 37 non-Fraser stocks, Table 1) based on genetic stock identification methods (Chapter B11). Like the in-season stock proportion data, most of the catch samples analysed are from test fishing catches. As a result, for each of the test fishing locations, there exist 87 time series of stock proportions covering the entire duration of the test fishery. The stock proportion estimates available for catches from commercial, First Nations, Tribal and recreational fisheries usually do not cover all fisheries in all areas and for their full duration.

Table 1. *The 87 stocks by management group used in the CR100 files to produce a stock-specific catch and passage time series.*

Stock number	Stocks	Management Group	Stock number	Stocks	Management Group
1	**Driftwood-Narrows**	Early Stuart	45	**Lower_Adams**	Late run
2	**Dust-Sinta**	Early Stuart	46	**Lower_Shuswap**	Late run
3	**Bivouac-Rossette**	Early Stuart	47	**MiddleShuswap**	Late run
4	**Paula-Felix**	Early Stuart	48	**Portage_Creek**	Late run
5	**Chilliwack_Kok**	Early Summer run	49	**Weaver____**	Late run
6	**Chilliw_lake**	Early Summer run	50	**Cultus_Lake**	Late run
7	**DollyVarden_Cr**	Early Summer run	51	**Baker_Lake**	non-Fraser
8	**Pitt_River**	Early Summer run	52	**LakeWashington**	non-Fraser
9	**Coquitlam_Kok**	Early Summer run	53	**Ozette_Lake**	non-Fraser
10	**Alouette_Kok**	Early Summer run	54	**Great_Central**	non-Fraser
11	**Nadina____**	Early Summer run	55	**Henderson_**	non-Fraser
12	**Bowron_____**	Early Summer run	56	**Sproat**	non-Fraser
13	**Gates_Creek**	Early Summer run	57	**Quatse**	non-Fraser
14	**Nahatlatch**	Early Summer run	58	**Phillips**	non-Fraser
15	**Taseko**	Early Summer run	59	**Klinaklini**	non-Fraser
16	**Upper_Barriere**	Early Summer run	60	**Sakinaw**	non-Fraser
17	**Scotch____**	Early Summer run	61	**Heydon**	non-Fraser
18	**Seymour___**	Early Summer run	62	**Glendale**	non-Fraser
19	**Eagle_____**	Early Summer run	63	**Nimpkish**	non-Fraser
20	**Upper_Adams**	Early Summer run	64	**Woss_Lake**	non-Fraser
21	**Cayenne____**	Early Summer run	65	**Vernon**	non-Fraser
22	**Harrison__**	Summer run	66	**Inziana___**	non-Fraser
23	**WidgeonSlough**	Summer run	67	**Amback**	non-Fraser
24	**Middle_River**	Summer run	68	**Long_Lake___**	non-Fraser
25	**Pinchi_Creek**	Summer run	69	**Smokehouse_Ck**	non-Fraser
26	**Tachie____**	Summer run	70	**Tankeeah**	non-Fraser
27	**Kuzkwa_Creek**	Summer run	71	**Lonesome____**	non-Fraser
28	**Stellako__**	Summer run	72	**Kispiox**	non-Fraser
29	**Chilko_south**	Summer run	73	**Meziadin_Weir**	non-Fraser
30	**Chilko_north**	Summer run	74	**Damdochax___**	non-Fraser
31	**Chilko_____**	Summer run	75	**Bowser______**	non-Fraser
32	**Lower_Horsefly**	Summer run	76	**Williams___**	non-Fraser
33	**McKinley**	Summer run	77	**Alastair___**	non-Fraser
34	**Mid_Horsefly**	Summer run	78	**Pinkut_____**	non-Fraser
35	**Upper_Horsefly**	Summer run	79	**FultonLate__**	non-Fraser
36	**Mitchell____**	Summer run	80	**CopperR_QCI**	non-Fraser
37	**Wasko-Roaring**	Summer run	81	**Tahltan____**	non-Fraser
38	**Blue_Lead_Ck**	Summer run	82	**Verrett____**	non-Fraser
39	**Raft_______**	Summer run	83	**Kuthai______**	non-Fraser
40	**NorthThompson**	Summer run	84	**Neskataheen**	non-Fraser
41	**Birkenhead_**	Late run	85	**Hugh_Smith_**	non-Fraser
42	**Big_Silver**	Late run	86	**Sitkoh___**	non-Fraser
43	**Eagle_late**	Late run	87	**Okanagan_River**	non-Fraser
44	**LittleRiver-LittleShu**	Late run			

Methods

Similar to the CR20 files, the CR100 files consist of a set of Microsoft Excel files that apply Fraser River stock proportions to sockeye catch data and sockeye passage estimates at Mission, but it does so for 87 instead of 20 stocks. It is important to have stock proportion estimates available for all days and areas associated with catch and sockeye abundance, even when catches were zero or when no catch sample was taken. In case of a lack of relevant stock proportion data, stock proportions can be borrowed from a previous or following day, interpolated between days or borrowed from a nearby fishery. In case stock proportion estimates from other fisheries are used, the date of the information is offset to reflect the time required for sockeye to migrate between the two fishing areas. This ensures that the information borrowed from the other fishing area reflects the same group of sockeye. In case the sample size of the catch is smaller than recommended, the samples from several days may be combined and the resulting stock proportions applied to the catches of all days included in the combined sample. This is a common occurrence in the Fraser River early in the season when limited in-river catches may require combining stock proportion information from various samples from different areas.

Once stock proportion time series have been completed and cover all days, areas and fisheries for which catch data are available, they are used to generate stock specific-catch numbers by fishery for all 87 stocks. Estimated stock proportions from several test fisheries are then weighted to derive the best estimate of stock composition for passage at Mission and for stocks leaving the Fraser River main stem before reaching Mission. Subsequently, the CR100 files use the daily stock-specific abundances estimates at Mission in a forward reconstruction to model the daily abundance along their migration to the spawning grounds. Within the files, fish are moved from reach to reach, including terminal areas (see Table 2) by accounting for the daily number of fish by stock entering the reach, removing the daily stock-specific catch within the reach and estimating the daily number exiting the reach based on the amount of time it takes for the sockeye to migrate through the reach. The CR100 files also calculate annual stock-specific Mission-based run size estimates based on the stock-specific passage at Mission plus stock-specific seaward catches.

Table 2. *River reaches and terminal areas used in the forward reconstruction of daily sockeye abundance from Mission to the spawning grounds.*

Area	Type
Mission to Harrison	River Reach
Chilliwack and Cultus	Terminal Area
Harrison	Terminal Area
Birkenhead	Terminal Area
Harrison to Hope	River Reach
Hope to Qualark	River Reach
Qualark to Sawmill Creek	River Reach
Sawmill Creek to Lytton	River Reach
Thompson	Terminal Area
Lytton to Texas Creek	River Reach
Texas Creek to Kelly Creek	River Reach
Kelly Creek to Deadman's Creek	River Reach
Deadman's Creek to Chilcotin River	River Reach
Chilcotin	Terminal Area
Chilcotin River to Navier	River Reach
Naver Creek to Isle of Pierre	River Reach
Nechako	Terminal Area
Stuart	Terminal Area

Results

The CR100 files generate the best available daily estimates of stock-specific abundance at key lower-river locations and these reconstructed daily abundance estimates have proven invaluable when comparing them to alternative time series of daily abundance, e.g. at Qualark, Big Bar or at various spawning ground locations, both in-season as well as post-season. Although these spreadsheets provide high-resolution stock-specific estimates, estimation accuracy decreases as resolution increases. As a result, individual stock estimates are less reliable, and for most applications the data are more appropriately aggregated into broader stock categories and when shared, should be accompanied by additional information about the quality of the data (Chapter C11). To facilitate user-friendly access to the CR100 data, the stock-specific catch and Mission passage estimates are uploaded into the RuFEs database (Chapter C17) from where they can be extracted at the desired level of stock aggregation. The use of a database instead of the CR100 files also reduces the risk of file corruption, ensures version control, and facilitates controlled access.

Planned changes and potential areas for improvement

At present, in-season reporting requirements only require stock breakdown at the CR20 level, and more detailed stock group resolution is needed only for post-season inputs and analyses. Using the built-in roll-ups to coarser resolutions, the CR100 files could be used for in-season assessment and Panel reporting. The addition of stock-specific tracking of release mortality would be required to support this transition. In addition, the CR100 framework is currently designed solely for Fraser sockeye, and tools or placeholders will need to be developed to accommodate Fraser River pink salmon.

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PST. 2025. Treaty between the Government of Canada and the Government of the United States of America concerning Pacific Salmon, as amended through November 2025.

C4. Post-season marine reconstructions

A.M. Phung and M.J. Hague

Summary

The Pacific Salmon Commission (PSC) generates and maintains time series of daily marine abundance of Fraser River sockeye salmon. Historically, time series of marine abundance were generated using in-season data and applying a run reconstruction model (Chapter B21). Recognising the limitations and inconsistencies in the existing in-season reconstructions, in 2018, PSC biologists embarked on the development of a new, post-season marine run reconstruction framework. Changes included: improved post-season data processing, finer stock resolution, transparently defined model assumptions, and a clear and standardised suite of decision rules for defining daily marine abundances. The resulting post-season time series of daily abundance allow biologists to derive marine timing estimates at multiple locations along both the southern and northern migration routes around Vancouver Island. In addition, both timing and diversion rate can be reconstructed at a finer stock resolution than previously available. Finally, the post-season reconstruction model ensures consistency in data quality and application of model assumptions across time, resulting in improved data integrity. The PSC Daily Reconstructed Marine Abundance (DARMA, Chapter C19) database was created in 2022 to house the improved post-season marine reconstruction time series (MR100) and the resulting time series of timing and diversion are publicly available on the Fraser River Panel Annual Report Data App (PSC 2026).

Introduction

A key part of managing Fraser sockeye salmon stocks is understanding how they are distributed through time and space, particularly as they migrate through marine areas and are vulnerable to capture by both U.S. and Canadian fisheries. As part of the Pacific Salmon Treaty (PST) agreements (PST 2025, Chapter 4, paragraph 13(a)), PSC staff are responsible for providing in-season updates to Fraser River sockeye salmon run size, timing, and diversion rate. Improved understanding of fish migratory behaviour related to arrival times and travel direction around Vancouver Island en route to the spawning grounds is important for informing stock assessment models, for planning fisheries, and for assessing fishery impacts. As abundance of many Fraser River sockeye populations declines, managers require an increased understanding of stock-specific differences in migration behaviour in order to plan fisheries which balance conservation objectives with harvest opportunities.

In-season reconstructions are inherently limited due to the requirement to make timely decisions which rely on incomplete, and sometimes incorrect, information and data. These uncertainties, in addition to variation in reconstruction model assumptions and stock resolution over time, led PSC biologists in 2018 to develop a new time series of marine abundances based on post-season data. The improved post-season run reconstructions rely on fully updated post-season datasets, finer stock resolution data, standardised model structures and assumptions, and a clearly defined suite of decision rules for determining route-specific abundances and the daily diversion rate around Vancouver Island. The marine timing, diversion, and delay estimates derived from the new post-season reconstruction model are assumed superior in quality to those previously produced from the in-season reconstructions. The following sections briefly document the data, structure, and assumptions underlying the post-season reconstruction models and the resulting improvements to historical estimates of migration behaviour. A more detailed description is available in two final reports produced for the PSC Southern Boundary Restoration and Enhancement Fund (Hague et al. 2021, 2023).

Data

The key data used to populate the run reconstruction models are: marine test fishery catch-per-unit-effort (CPUE) data (Chapter B4), test fishery catchability (Chapter B5), daily abundance estimates at Mission (Chapter B14), landed catches seaward of Mission (Chapter C3), and genetic stock proportion estimates (Chapter B11). DNA-based stock identification data obtained from fisheries sampling are used to apportion Mission passage estimates, test fishery CPUE, and catch data into 87 high-resolution DNA groups, comprising 50 Fraser River stocks and 37 non-Fraser stocks (Chapter C3). While genetic stock proportions at such fine resolution may be more uncertain and more subject to bias from sampling error, maintaining the data at such fine resolution permits greater flexibility when aggregating results across stocks, e.g., at the resolution of conservation units (CUs) (Hague et al. 2023).

A spatial database was created to store the distances of potential migration routes from Southeast Alaska to the Mission site on the Fraser River, via either Johnstone Strait or Juan de Fuca Strait. In combination with migration speeds, the distances were used to estimate the time it takes for sockeye to travel between key locations (Figure 1). Assuming it takes 6 days for sockeye to migrate from the Area 20 marine test fishery to the Mission hydroacoustic site, distances within the spatial database were used to calculate the number of days to migrate through each fishing area and the number of days offset for each fishing area relative to the Area 20 test fishing location, or to the equivalent location in Johnstone Strait. Dates associated with data from other areas are adjusted based on these offsets. In the new post-season marine reconstruction files, different offsets can be specified for specific stocks, e.g. to account for slower migration rates of delaying sockeye salmon (Hague et al. 2023).

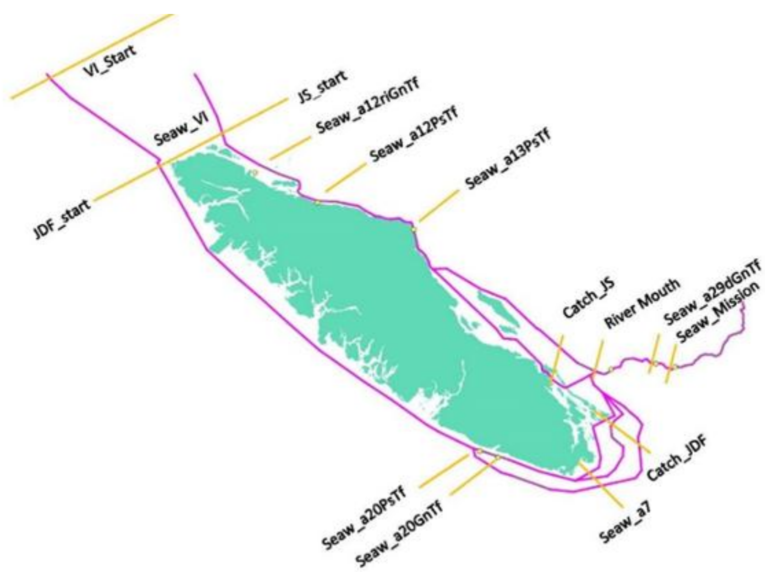

Figure 1. *Locations along the migration route of Fraser River sockeye for which the reconstruction model (Hague et al. 2021) can generate stock-specific time series of daily reconstructed abundance. VI_Start marks the most northern fishery location, i.e., Southeast Alaska district 104. JDF_start_JS_start represents the north end of Vancouver Island, before the migration divides into Juan de Fuca Strait and Johnstone Strait routes. Seaw_a12PsTf denotes the approximate location of the area 12 purse seine test fishery, Seaw_a20GnTf the approximate location of the area 20 gill net test fishery and Seaw_Mission the location of the Mission hydroacoustic site.*

Methods

The PSC applies a post-season box-car run reconstruction model programmed in Excel spreadsheets to estimate stock-specific daily marine abundances of adult Fraser River sockeye salmon beginning in 2003. Because these reconstructions align directly with the Catch and Racial 100 (CR100) files, which provide high-resolution daily stock-proportion estimates alongside daily catch data and in-river sockeye passage counts, the resulting Marine Reconstruction files are referred to as the MR100 files. The model assumes salmon move in daily blocks, i.e., box-cars, from marine areas to the Fraser River while maintaining their order of movement through a series of fisheries (Cave and Gazey 1994). Detailed equations documenting how catches and escapement are aligned with blocks of fish migration are described in Hague et al. (2023). To simplify the equations in this report, we assume all dates associated with the data have been adjusted to correspond to the Area 20 reference date. In addition, all abundances and catches are stock-specific, following the application of genetic stock proportion estimates (Chapter C3).

In the post-season reconstruction, total marine abundances are first estimated using a backward reconstruction by adding estimates of seaward catches to estimates of Mission passage. The salmon are then apportioned between the northern and southern migration route based on marine test fishing CPUE data, aided by route-specific catch data. Finally, a forward reconstruction is applied by sequentially subtracting catches at each key location point along the migration route through to the location of the Mission hydroacoustics program (Figure 1).

BACKWARD RECONSTRUCTION

The backward model is used to estimate total daily marine abundances at the north end of Vancouver Island for DNA stock groups that meet the fixed order of movement model assumption, i.e., continuous migration with no deviation in average migration speed or redistribution of fish across days. In this approach, daily (*d*) seaward catches (*C*) summed across all fisheries (*f*) occurring in all areas (*A*) along both approach routes ($\sum C_{d,f,A}$) are added to the daily Mission passage estimates ($N_{d,A_{Mission}}$) to reconstruct the total daily abundance at the entry of the marine fishing areas, i.e., the northern end of Vancouver Island ($N_{d,A_{SeaW\_VI}}$, Figure 1):

$$(1)\quad N_{d,A_{SeaW\_VI}} = N_{d,A_{Mission}} + \sum C_{d,f,A}.$$

For delaying stocks, i.e., sockeye stocks where a proportion of the run will hold and redistribute in the Strait of Georgia prior to continuing their upstream migration (Lapointe et al. 2003), the order of movement assumption implied by the box-car model is violated. Instead of estimating daily reconstructed abundances using equation (1), daily marine abundance estimates for delaying stocks are instead based on marine test fishing CPUE data in Area 20 ($N_{d,A20TF}$) and 12 ($N_{d,A12TF}$):

$$(2)\qquad N_{d,\mathrm{A}_{TF}} = \frac{I_{d,A_{TF}}}{q_{d,A_{TF}}},$$

where I_{ATF} and q_{ATF} represent, respectively, the CPUE data and the catchability coefficient for the test fishery in the area (A_{TF}). The daily CPUE-based abundances are then rescaled so that their sum equals the total reconstructed abundance (total Mission passage plus total seaward catch):

$$(3)\qquad N_{d,A_{SeaW\_VI}} = \left(N_{d,A_{20TF}} + N_{d,A_{12TF}}\right) \cdot \left(\frac{\sum N_{d,A_{Mission}} + \sum C_{d,f,A}}{\sum N_{d,A_{20TF}} + \sum N_{d,A_{12TF}}}\right).$$

Within the post-season reconstruction model, the user has a choice to either apply an annual stock-specific catchability estimate or to use the daily catchability of the Summer run for delaying Late-run stocks. In general, using purse seine test fishing catchability estimates of Summer-run sockeye excluding

Harrison to predict the catchability of delaying Late-run stocks generates estimates that are unbiased as the estimates are clustered near the 1:1 line, but R^2 is only 42%, indicating that the catchability estimates may deviate considerably.

In some cases, using the stock-specific post-season annual catchability for delaying stocks reduced the difference between the annual Mission-based vs. CPUE-based abundance estimates. The downside is that any seasonal variation in catchability, as often observed for gillnet test fisheries (Chapter B5), is lost and so while the total abundance estimate may be more accurate, there may be some compromise in terms of the accuracy of the daily migration profile.

ROUTE-SPECIFIC DECISION RULES AND FORWARD RECONSTRUCTION

Unlike the in-season forward reconstruction model, which relies solely on marine test-fishery CPUE data to estimate route-specific abundances, the post-season model provides several alternative approaches. In addition to complete user flexibility in terms of selecting which specific test fisheries CPUE data to use, the model permits abundance estimation based on landed catches and an assumed harvest rate, set to a default value of 80%. This option is useful when catches along a specific route are higher than those implied by the test fishery data, i.e., when there is evidence that the route-specific CPUE-based abundance estimate is biased low. At the beginning and end of the season, when sockeye abundances are low, landed catches and test fishery CPUE data are not always available. In this case, the modeller can also opt to use an inferred diversion rate based on previous or subsequent days to partition the abundance along each route.

A set of decision rules was created to help decide which route-specific marine abundance estimation method is most appropriate on a given day for each stock and each route (Table 3 and Figure 6 in Hague et al. 2021). Given the inherent complexity and number of assumptions in this approach, data are aggregated into six reconstruction groups with the assumption that all stocks within a group are equally vulnerable to test fisheries, i.e., have the same catchability, and migrate along the same migration routes at the same rate. The six reconstruction groups consist of the four Fraser River sockeye management groups but excluding all delaying stocks, plus the delaying Summer-run stocks (Harrison and Widgeon) and the delaying Late-run stocks (Portage, Late Shuswap, Weaver and Cultus) (Hague et al. 2023). The data for the six reconstruction groups are partitioned into DNA groups based on their relative abundance within each reconstruction group. Once decision rules have been applied to estimate abundances at the north end of Vancouver Island, a forward reconstruction model is used to reconstruct daily abundances at different key locations around Vancouver Island (Figure 1) by subtracting catches from seaward estimates of marine abundance.

Results

Historically, only reconstructed daily total marine abundance estimates were available (Hague et al. 2021). However, with the advancements of a new post-season reconstruction framework, daily abundance time series, extending back to 2003, are now derived for several key locations along the northern and southern migratory route to Mission. These daily abundance estimates are stored within the DARMA Microsoft Access database (Chapter C19) under the custodianship of the PSC Secretariat. The database allows users to extract the data at the desired level of stock aggregation, and at the desired spatial and temporal resolution (Wong et al. 2026). From the daily reconstructed abundance time series, various other time series have been derived, including: (1) migration timing, defined as the date at which 50% of the run passed a reference location along the marine migration route, (2) migration spread, measured by the number of days required for 95% of the run to pass a reference location, and (3) diversion rate, quantified as the proportion of the run that migrates through Johnstone

Strait instead of Juan de Fuca Strait en route to the spawning grounds (McKinnell et al. 1999, Folkes et al. 2018). The resulting time series of migration timing and northern diversion rate for a selection of stock aggregates are publicly available on the Fraser River Panel Annual Report Data App (PSC 2026).

Based on the historical timing estimates, marine migration timing along the southern Juan de Fuca route tends to be earlier than marine migration in the northern approach (Figure 2). This may be due to a temporal shift in northern diversion rate through the season (Figure 3) (Wong et al. 2026). Unlike the in-season forward reconstruction model, which only produces annual and daily diversion rate estimates for all Fraser sockeye stocks combined, the new post-season reconstruction model generates diversion rate estimates for all six reconstruction groups. More detailed stock- or group-specific diversion rates are calculated by dividing the stock- or group-specific abundance estimates through Johnstone Strait by the total abundance estimates for that stock or group (Putman et al. 2014, Folkes et al. 2018).

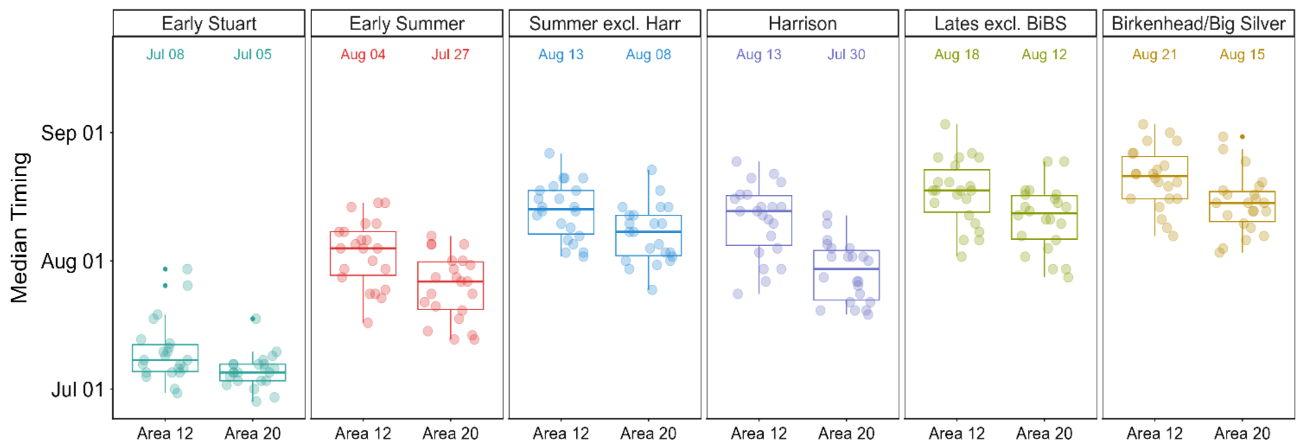

Figure 2. *Boxplots of the marine migration timing at the purse seine test fishing locations in Johnstone Strait (Area 12) and Juan de Fuca Strait (Area 20) for each of the six reconstruction groups for Fraser River sockeye salmon (2003-2022).*

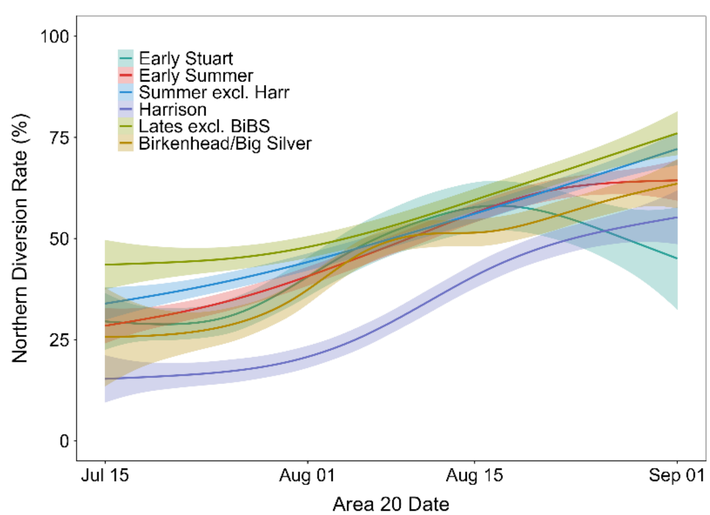

Figure 3. *Average daily diversion rates (percent of the run migrating through Johnstone Strait) and 95% confidence intervals for six Fraser River sockeye salmon stock aggregates (2003 – 2022).*

Planned Changes and Potential Areas for Improvement

Sockeye migration rate assumptions made in the post-season reconstruction files are based on historical assumptions of a 6-day migration rate offset between Area 20 and Mission. Such assumptions may not reflect current migratory behaviour of sockeye and are difficult to assess based on available information. However, future tagging studies may improve our understanding of Fraser sockeye migration, allowing us to fine-tune assumptions in our files, leading to better stock assessment predictions. Further work by the PSC could also be done to explore differences in migration rates between the northern and southern marine migratory routes by aligning historical marine time series with Mission time series.

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C5. Run reconstruction at Mission based on spawning ground estimates

C.G.J. Michielsens

Summary

Backward run reconstructions combine spawning ground abundance estimates (Chapter C1) with stock-specific catch estimates (Chapter C3). In addition to generating annual run size estimates, these methods can also be used to generate daily abundance estimates provided catch and escapement data have been collected at a daily resolution. Accurate reconstructions are dependent on the accuracy of the catch reports and of the method used to enumerate the number of spawners which can range from high precision hydroacoustic estimates to low precision overflight estimates (Chapter C1). For Fraser River sockeye, another important factor in the backwards reconstruction is the Run Size Adjustment (RSA) component, which is an adjustment to the run size to account for in-river mortality, as well as biases in the estimates of spawning escapement and catch (Chapter C6). RSAs are derived by consensus through an expert-led process that estimates en route mortality and describes and quantifies biases in assessment estimates based on available evidence combined with expert judgement. Large RSA components are especially prominent for Early Stuart and Late-run stocks, and to a lesser extent Early Summer-run stocks. Backward reconstructions are most accurate for Summer-run stocks in general and Chilko in particular, given the lower en route losses, their high relative abundance in comparison to other Fraser sockeye stocks, and the high accuracy of spawning ground estimates. The following report describes the annual backward reconstruction for Chilko and the associated uncertainty, as well as the daily backward reconstruction of both Chilko and Quesnel. The daily backward reconstruction can also be used to derive daily total Fraser sockeye abundance estimates, but reliable estimates can only be obtained for days with Summer-run migration due to the large en route losses for other management groups, assuming en route losses for Summer run are limited.

Introduction

Run reconstruction is a tool commonly used for fisheries management (Starr and Hilborn 1988). For the management of Fraser River sockeye salmon, both forward as well as backward reconstructions are used. The forward reconstructions are relied upon preseason within the fisheries planning model (Chapter A9) as well as in-season to predict in-river abundances including at the spawning grounds based on marine abundance estimates (Chapter B21). Backward reconstructions are mainly used in-season to estimate daily marine abundances based on abundances at Mission (Chapter B21). In the past, post-season applications of backward reconstructions have been hampered by substantial en route losses due to adverse migration conditions. The additional natural mortality can be accounted for in backward reconstructions by including a Run Size Adjustment (RSA). In addition to accounting for in-river mortality, the RSA also accounts for assessment biases as well as biases in spawning ground and catch estimates (Chapter C6). The inclusion of large and uncertain RSA components overall reduces the accuracy and precision of backward reconstructions. In addition, annual RSA estimates do not provide the necessary daily resolution to be useful for daily backward reconstructions, especially given that adverse migration conditions are usually restricted to part of the season.

Recently, it has been recognized that annual and daily backward reconstructed abundance estimates for stocks with limited or no en route losses can provide alternative, independent estimates of sockeye abundance. For example, species composition estimates based on in-river test fishery data are known to be biased due to differences in vulnerability to fishing gear among salmon species. Especially in years or periods of the years with low or relatively low sockeye abundance, the uncertainty in the species composition can lead to substantial uncertainty in the overall sockeye abundance. Using annual and daily backward reconstructions under these circumstances may provide independent post-season sockeye abundance estimates to evaluate alternative in-season species composition methods.

It should be noted that backward reconstructions based on spawning ground estimates have not been used to derive post-season estimates of marine timing (date when 50% of a run has passed through marine areas), northern diversion (percent of a run migrating through Johnstone Strait), spread (number of days comprising 95% of the marine migration), or delay (days holding off the mouth of the Fraser River in the Strait of Georgia). These estimates will remain based on backward reconstruction using Mission daily abundance estimates, and marine test fishery data (Chapter B21).

This report describes the annual backward reconstructions for Fraser River sockeye salmon and the application of this method to generate annual abundance estimates for Chilko at Mission while explicitly accounting for the uncertainty generated by the inclusion of the RSA. Daily backward reconstructions to the Mission site are described and applied both for Chilko and Quesnel, and both time series are used to generate daily reconstructed abundance estimates for Fraser River sockeye salmon, covering only the period with Summer-run migration.

Data

While backward reconstruction methods can be applied to any stock, the resulting abundance estimates tend to be more accurate and precise for more abundant stocks that are (1) enumerated using high precision methods such as hydroacoustics, (2) stocks that experience limited en route losses, (3) stocks that do not delay their upstream migration when encountering adverse migration conditions and (4) stocks with accurate catch reports and stock ID information. Hydroacoustic methods provide the most accurate daily enumerations on the spawning grounds (Chapter C1) and these estimates have been collected for Chilko (2008-2022), Quesnel (2009-10, 2014-15, 2017-19, 2021-22), Nadina/Stellako (2016, 2019-2022), Chilliwack (2012, 2016, 2020) and Birkenhead (2012, 2014 - 2022). High precision fence counts have been used at Cultus (2010-2022). Migration delays and stock redistributions in combination with stock ID resolution problems limit the use of Nadina and Stellako for backward reconstructions. Backward reconstructions of individual stock also require stock-specific catch estimates (Chapter C3). Because of the limited stock ID samples taken from in-river catches, the stock ID from unsampled fisheries is derived from the relative abundance of different stock group based on forward reconstructions from Mission to the spawning grounds. Reconstructions also require information regarding migration distances between different fishing areas within the Fraser River, as well as assumed sockeye migration rates (Hague et al. 2023). To illustrate the backward reconstruction, we will focus in this document on Chilko and to a lesser extent Quesnel.

Methods

ANNUAL BACKWARD RECONSTRUCTION

The simplest backward reconstruction to Mission relies on annual estimates, whereby the total stock-specific catch ($\sum C_{Mssion \to Spw.Grd}$) taken between Mission and the spawning grounds (*Spw.Grd*) is added to the total sockeye abundance estimated on the spawning grounds ($N_{Spw.Grd}$):

$$(1)\ N_{Mission} = N_{Spw.Grd} + \sum C_{Mission \to\ Spw.Grd}.$$

This equation assumes no natural mortality occurs between Mission and the Chilko spawning grounds. In recent years, high temperatures as well as high water discharge levels created adverse migration conditions within the Fraser River, resulting in a proportion of the run not making it to the spawning grounds. This can be taken into account in backward reconstructions through Run Size Adjustments (RSAs, Chapter C6). The resulting total reconstructed abundance at Mission is therefore given by:

$$(2)\qquad N_{Mission} = N_{Spw.Grd} + \sum C_{Mission \to\ Spw.Grd} + RSA.$$

In addition to en route natural mortality (*M*), RSA estimates also account for biases in escapement to the spawning grounds ($RSA_{N_{Spw.Grd}}$) and in catch estimates ($RSA_{C_{Mssion \to\ Spw.Grd}}$), as well as miscellaneous biases (RSA_{misc}), which could include other stock assessment biases (e.g. species composition bias):

$$(3)\qquad RSA_{Total} = RSA_{N_{Spw.Grd}} + RSA_{C_{Mission \to\ Spw.Grd}} + RSA_M + RSA_{misc}.$$

The above equation illustrates the uncertainty the RSA component adds to the reconstructed abundances as RSA estimates are derived by consensus through an expert-led process that estimates en route mortality and describes and quantifies biases in assessment estimates based on available evidence combined with expert judgement. As assessment methods improve, it would theoretically be possible to reduce potential biases and reduce the RSA to only reflect en route natural mortality. But even en route natural mortality might currently reflect assessment biases.

To properly account for the uncertainty associated with the RSA component when reconstructing abundances at Mission, a range of abundance estimates can be provided with the maximum abundance including the total RSA while the minimum excludes the RSA component completely.

DAILY BACKWARD RECONSTRUCTION

A box-car run reconstruction model was used to derive daily abundance estimates at Mission. This model assumes salmon move in groups, i.e., box-cars, from Mission to the spawning grounds through a series of fisheries that will impact the number of salmon in the group (Cave and Gazey 1994). Backward daily reconstructions function similarly to forward daily reconstructions but in the opposite direction (Figure 1).

A backward reconstruction can be used to estimate daily marine abundances at Mission by adding catches taken between Mission and the spawning grounds onto daily abundance estimates at the spawning grounds. To simplify the reconstruction, dates (*d*) associated with the daily catch report (the catch date) from each fishery in each area within the Fraser River and the daily abundances at the spawning grounds are adjusted to the date associated with a geographical reference point. For this report, the reference point used is the Mission hydroacoustic site. The dates associated with the data from other areas within the Fraser are adjusted based on the amount of time (rounded to the day) it takes for sockeye to migrate from Mission to these locations.

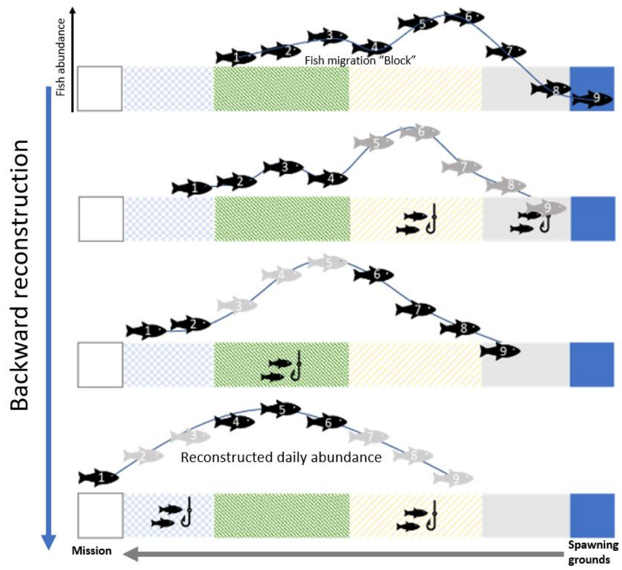

Figure 1. *Schematic illustration of a backward run reconstruction from the spawning grounds to Mission. The top panel represents the shape of the run at the spawning grounds, with certain days of abundance reduced due to catch removals. The bottom panel represents the shape of the reconstructed run at Mission prior to migrating past the various in-river fisheries. The colored bars represent different reaches of the Fraser River, with the left most square representing Mission. Each "fish/hook" represents one day of fishing. Each fish represents one daily block of fish. Black fish in each panel have not been exposed to a fishery opening on a given day, while grey fish have. Each panel represents a daily time-step (Chapter A9).*

Assuming it takes 17 days for Chilko sockeye to migrate from Mission to the Chilko spawning grounds implies a 17-day offset ($o_{Mission,\ Chilko}$) that would result in the Mission date ($d_{Mission}$) associated with abundance estimates at Chilko spawning grounds (N_{Chilko}) to be 17 days earlier than the actual date:

$$(4) \qquad N_{Chilko,d_{Mission}} = N_{Chilko,(d-o_{Mission,Chilko})} = N_{Chilko,(d-17)}.$$

Similarly, assuming it takes about 15 days for Quesnel sockeye to migrate from Mission to the Quesnel spawning grounds (*Spw.Grd*) implies a 15-day offset ($o_{Mission,\ Quesnel}$), or more generally phrased:

$$(5) \qquad N_{Spw.Grd,d_{Mission}} = N_{Spw.Grd,(d-o_{Mission,Spw.Grd})}.$$

For the daily backward reconstruction of individual stocks, all the daily, stock-specific (*s*) catch estimates from different fisheries ($C_{f,d,s}$) are added to the daily spawning ground estimates to reconstruct the total stock-specific daily abundance at Mission ($N_{Mission,d,s}$):

$$(6) \qquad N_{Mission,d,s} = N_{Spw.Grd,d,s} + \sum C_{f,d,s}.$$

The above equation assumes that all the dates associated with the spawning ground and catch data have already been adjusted to correspond to the Mission reference date (*d*).

Comparing the resulting reconstructed daily Mission abundance estimates with the daily observations at Mission tests the validity of the offset assumption in a given year, and adjustments can be made accordingly. This adjustment of the timing offset is all the more important given that migration conditions within the Fraser River may differ substantially from year to year. Not all years however will show good correspondence between migration profiles, complicating the selection of an appropriate migration timing offset.

Once stock-specific daily reconstructed Mission abundance estimates have been obtained, it is possible to derive total daily sockeye abundances at Mission by multiplying the stock-specific estimates by the inverse of the observed proportion of that stock (p_s):

$$(7) \qquad N_{Mission,d,Total} = N_{Mission,d,s} \cdot (1/p_{Mission,d,s}).$$

Because of the reliance on stock ID information, daily total sockeye estimates can only be created for those days when a stock is present at Mission, preferably in large enough proportions to provide stable stock proportion estimates. Unlike the stock-specific estimates, the total daily reconstructed sockeye abundance estimates can be used to evaluate potential species composition biases, e.g. evaluate if observed sockeye abundances at Mission exceed reconstructed sockeye abundances due to underestimation of pink salmon.

Results

When applying a backward reconstruction to obtain annual Chilko abundances at Mission, the resulting estimates can be compared against the in-season Chilko abundance estimates derived from Mission hydroacoustic data (Figure 2). Since 2015, in-season estimates have been larger than the reconstructed abundance estimate (with the exception of 2018), but accounting for en route losses through RSAs eliminates the overestimation in the last 4 years (2019-22). While en route losses could explain the deviation (or part of the deviation) between estimates when in-season abundances are larger than reconstructed abundances, the larger in-season abundances at Mission may also be due to assessment biases (see daily reconstructed abundance, Figure 3). The underestimation of in-season abundances may indicate assessment biases. Except for 2022, this seems to be the case on 2018 cycle years and on some of the other earlier years (2011-2013).

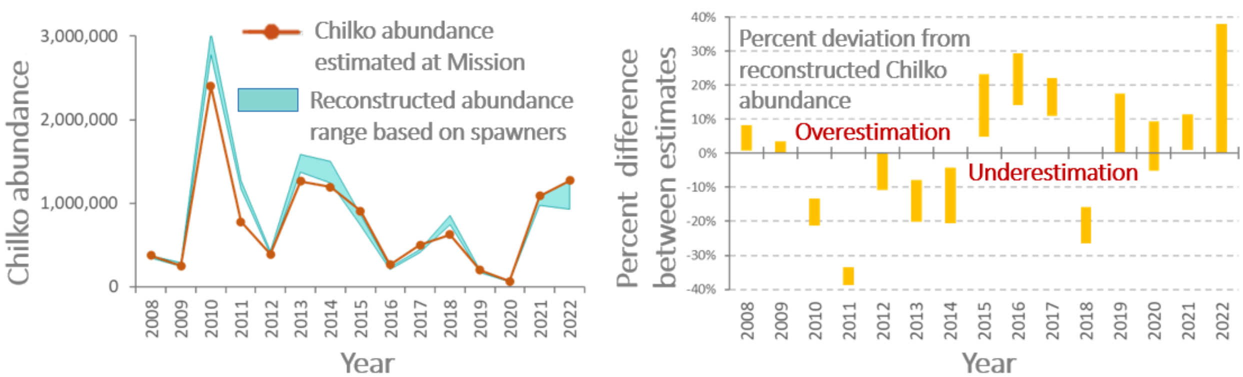

Figure 2. *Comparison of annual in-season Chilko abundance estimates at Mission and post-season backward reconstructed Chilko abundances. Results are presented in terms of abundance (left panel) and percent difference (right panel). The uncertainty associated with the reconstructed abundances is reflected by the range of estimates (with or without Run Size Adjustment, RSA).*

Daily reconstructions can provide further insights in the reasons why in-season abundance estimates deviate from post-season reconstructions. Figure 3 (top panels) shows an example for 2017 of the comparison of in-river abundance of Chilko and Quesnel at Mission with reconstructed abundances at the same location. Near the end of August, both stocks indicate higher numbers observed at Mission compared to reconstructed abundance. It is possible this discrepancy is due to adverse environmental conditions encountered at that time, but temperatures in the second half of August were below the temperature threshold and had improved compared to the beginning of August. An alternative potential explanation for the larger in-season sockeye estimates in the second half of August is that the test fishery data may have underestimated the number of pink salmon, thereby overestimating sockeye. In 2017, the Whonnock test fishery started detecting pink salmon on August 5, and in-season daily pink salmon estimates decreased in the latter half of August compared to early in August before increasing substantially by September.

While the daily reconstructed abundance estimates for 2017 look reasonable given the similar in-season migration profile at Mission, not all years show such a good correspondence. For example, in 2019 the Big Bar landslide delayed the migration of a large number of fish as the discharge at Big Bar needed to decline sufficiently before fish were able to use the nature-like fishway that had been constructed posthaste. Even later in the season, it is unclear to what extent discrepancies between the in-season estimates and the reconstructed abundances are the result of delays in migration, en route losses or a combination of both. In addition, when migration profiles differ substantially, it becomes harder to validate migration speeds by lining up the profiles. Regardless of how well the migration profiles match, it should be recognized that daily estimates may still differ substantially.

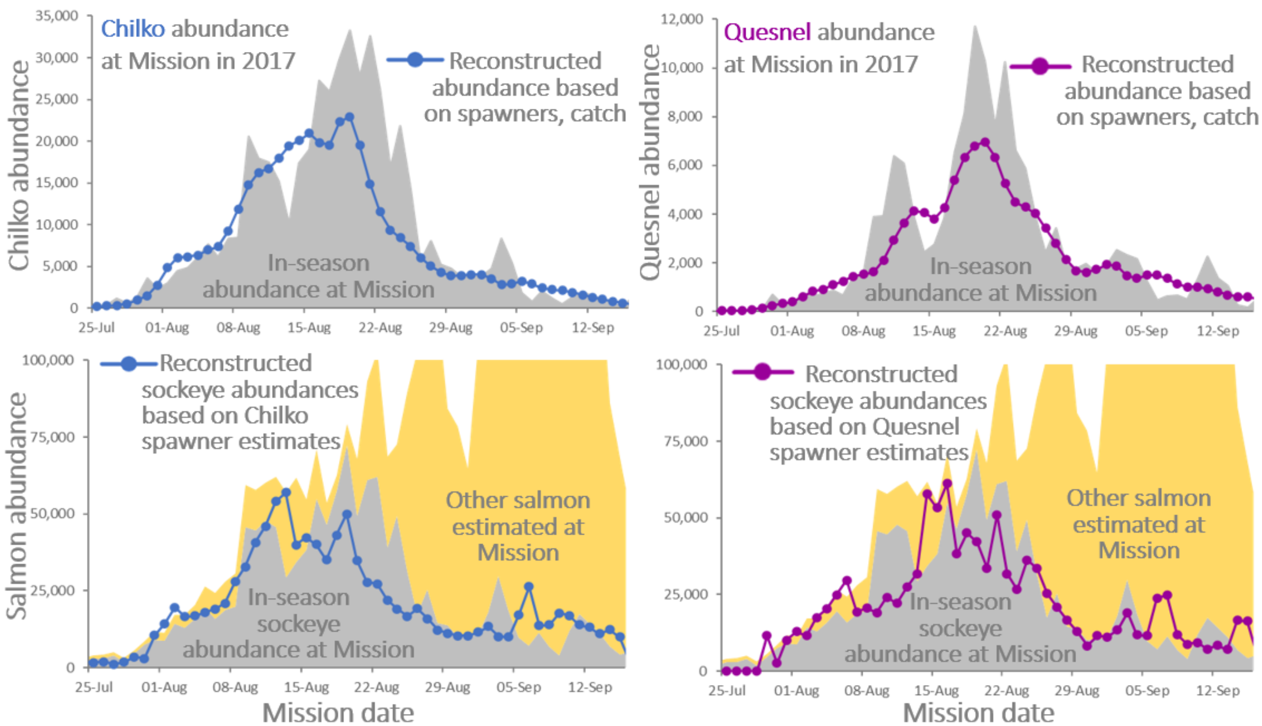

Figure 3. *Example comparison for 2017 of daily in-season abundance estimates at Mission (grey) with reconstructed abundance based on spawning ground estimates and in-river catches for Chilko (top left panel) and Quesnel (top right panel). The stock-specific daily reconstructed abundance estimates can be converted into total daily sockeye estimates by dividing the stock-specific estimates by the proportion of Chilko or Quesnel. The resulting time series of total daily reconstructed sockeye abundance (bottom panels) can be compared against in-season sockeye abundance estimates (grey) and against total salmon abundance estimates that include other salmon species (yellow).*

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C6. Run Size Adjustment process

D. Brkic and S. Latham

Summary

Traditionally, post-season run size estimates are derived by combining the number of salmon observed on the spawning grounds with post-season estimates of catch. For Fraser River sockeye, these estimates also incorporate en route mortality to account for adverse environmental and biological conditions encountered during migration. The current Run Size Adjustment (RSA) process aims to improve post-season run size estimates by deriving stock-specific en route mortality rates and examining potential sources of bias in the main components of run size: spawning escapement, catch, and en route mortality. An expert-led process annually reviews the data and estimates for 28 Fraser River sockeye stocks. The expert group includes both U.S. and Canadian Fraser River Technical Committee members, DFO Environmental Watch Program staff, DFO Catch Monitoring staff, DFO Stock Assessment staff and PSC staff. Initial RSA values and their justification are presented to the RSA group (DFO 2025), and final values are determined through discussion. Finally, the effects of the selected RSAs on the run size, exploitation rate, and productivity are reviewed with the RSA group to support refinement and confirmation of the final values. The resulting post-RSA run size should be used for post-season evaluations of return abundance, exploitation rates, productivity, forecasting, and assessments in support of long-term planning. Post-RSA run size estimates and RSA time series are publicly available on the Fraser River Panel Annual Report Data App (Figure 4, PSC 2026).

Introduction

Post-season, the Fraser River Panel is charged with evaluating the achievement of its management objectives (PST 2025). This requires post-season run size estimates, which are traditionally based on spawning escapement estimates and catch data. This definition of run size likely underestimates the true return strength in recent decades as unfavorable migratory conditions cause en-route mortality even in the absence of fishing. Strong associations of spawning escapement deficits with adverse migratory conditions, confirmed by telemetry results for tagged individuals, support the existence of recruits that die en route to the spawning grounds that are not accounted for in catch or spawning escapement. To account for en route mortality, the Fraser River Panel employs an annual Run Size Adjustment (RSA) process, undertaken by a workgroup composed of experts from both the U.S. and Canada, supported by PSC staff. The RSA workgroup examines potential sources of bias in spawning escapement and catch estimates, tries to address known biases in those components, and then estimates mortality rates based on risk factors and stock group timing (DFO 2025). The goal of this section in the report is to describe this process and its implications for the quality of stock-specific post-RSA run size estimates. Information about how the RSA process has evolved over time can be found in DFO (2025).

Methods

The RSA process is conducted annually through a series of meetings involving members of the RSA workgroup. The goal of the RSA process is to explicitly account for uncertainty and bias in spawning escapement and catch, as well as en route mortality, when generating stock-specific post-season run size estimates. The final post-season (post-RSA) run size is generated by adding a Run Size Adjustment (RSA) to the estimates of escapement and catch:

(1) Run size = Spawners + Catch + RSA.

The Run Size Adjustment represents adjustments to the spawner number estimate ($RSA_{Spawner}$) and catch (RSA_{Catch}), and accounts for en route mortality ($RSA_{Mortality}$) and RSA_{Other}:

(2) $RSA = RSA_{Spawner} + RSA_{Catch} + RSA_{Mortality} + RSA_{Other}$.

En route mortality ($RSA_{Mortality}$) in this process is based on mortality estimates derived from current research regarding salmon biology during migration to the spawning grounds while RSA_{Other} captures adjustments to the run size that do not fall within any of the 3 other categories.

RSA workgroup meetings are usually organized as a series of presentations from different speakers corresponding to each RSA component. After each presentation, the RSA group comes to a consensus regarding estimates for that RSA component to be used as inputs for subsequent steps for each of the 28 stocks/stock groups evaluated in the RSA process. RSA meetings usually concern the sockeye run from the previous year but could also include adjustments to RSA estimates from earlier years.

CATCH AND CATCH RSA

Fraser sockeye can be caught in numerous sockeye-directed and other fisheries during their migration to the spawning grounds. Depending on the fishery, there exist a wide range of catch monitoring and reporting tools. Catch values for different fisheries are provided by the DFO Catch Monitoring team. The RSA workgroup discusses how realistic the reported values are, and if there are known or expected biases for a particular fishery. Generally, concerns arise when there are unreported catches, especially in years when unsanctioned fisheries are common. If the RSA group determines that there is a known or expected discrepancy between reported catch values and actual catch, the additional catch is considered an RSA_{Catch}. If official catch estimates are ever updated to include these previously unreported catches, the catch RSAs would have to be updated accordingly. Since 2022, in-season estimates of unsanctioned catch have been reported directly to the PSC, rendering adjustments unnecessary. Even prior to 2022, RSA_{Catch} was a relatively minor component of the total RSA.

SPAWNING ESCAPEMENT AND SPAWNER RSA

Methods to estimate spawning escapement, or the number of salmon on the spawning grounds, vary for each population depending on the preseason run size and the physical attributes of the system (Chapter C1). Methods include visual surveys, enumeration fences, mark-recapture methods and hydroacoustic methods. DFO Stock Assessment reports both the official spawning escapements and estimates of the known or expected bias ($RSA_{Spawner}$). Spawning escapement values, when based on low intensity visual survey methods, are expected to be underestimates under some conditions such as high water turbidity, bad weather, difficulty in accessing spawning grounds, and an inappropriate expansion factor used in initial calculations. The RSA process documents the likely source, the direction, and the extent of the $RSA_{Spawner}$ values.

MORTALITY AND MORTALITY RSA

A significant contribution to the total RSA values comes from mortality ($RSA_{Mortality}$). Depending on run timing and spawning location, stocks face different environmental and human-induced challenges during their migration, resulting in different en route mortalities. Suggested mortality estimates (and environmental factors supporting those estimates) are presented by members of the DFO Environmental Watch Program.

To determine mortality, each stock is assigned a risk score for several environmental (or human-caused) and biological risk factors (Table 1). The risk from temperature exposure forms the basis of the overall risk assessment due to the strength of the underlying research (Eliason et al. 2011, Martins et al. 2011, Patterson et al. 2016). Exposure to high temperatures reduces the aerobic capacity of the sockeye, limiting their ability to swim and move upstream (Farrell et al. 2008, Eliason et al. 2011). It also increases their susceptibility to infections (Hinch et al. 2012, Teffer et al. 2022).

Research suggests that high discharge is linked to difficulties swimming upstream (Macdonald et al. 2010). The RSA process treats this risk analogously to temperature exposure risk. For each stock, an overall risk value is determined with the starting value based on the highest risk value among temperature and discharge exposure categories. The remainder of the risk factors (Table 1) are used to modify the mortality risk scores based on expert opinion of the RSA group (DFO 2025).

Table 1. *Table of mortality risk factors for Fraser River sockeye salmon.*

Risk Factor	Description
Temperature exposure	High temperature increases stress, energy consumption, and makes upstream migration more difficult.
High discharge exposure	High discharge increases the difficulty of swimming upstream, especially in narrow canyons.
Low discharge exposure	Low discharge can create or reveal barriers for fish passage, especially in shallow streams.
Other events	This includes natural disasters such as wildfires and landslides that might create unfavorable conditions for fish passage.
Migration behavior	Migration behavior anomalies, such as early river entry or late spawning ground arrival, can be indicators of high en route mortality.
Fishing pressure	Fishing pressure can lead to excess mortality for fish that interact with gear, due to gear-related injuries or handling prior to release, and also for fish that do not interact with gear, as gear avoidance contributes to energetic costs (DFO 2025).
Fish condition	Small body size, low lipid reserves, the presence of disease or physical damage can be indicators of en route mortality.

The next step of the process for determining mortality is to compile mortality rate estimates based on various quantitative methods (Table 2), and then compare these to mortality rates implied by the risk assessment (Table 1). The comparison is done by members of the DFO Environmental Watch Program and followed by a discussion of the suggested values by the RSA workgroup. Each member of the expert group brings their own knowledge and experience and relies on the evidence presented at the meeting. The final mortality estimate normally falls within the mortality range agreed upon by the expert group and deviations are documented. Mortality rates are then used to calculate the mortality in number of fish for each stock.

After all RSA values have been agreed upon by the RSA workgroup, the values are entered into the RSA Production File (Chapter C7) to determine the impact of the RSAs values on post-RSA run size, exploitation rate, and productivity. These diagnostics are discussed by the RSA workgroup to determine if any further changes would need to be made to RSA values or if additional RSAs need to be added under the RSA_{Other} category.

Table 2. *List of quantitative methods used to determine mortality values or ranges.*

Quantitative Method	Description
Risk Assessment	A range of mortality values based on final risk value identified in Table 1. The mortality ranges are <10%, 10-25%, 25-50%, and >50% for risk values 1-4 respectively.
MA Model DBE	The model uses the past relationships between environmental and biological conditions and percent Differences Between Estimates (%DBEs) to predict mortality based on current conditions, for individual management groups (Chapter C8).
Post-season Stock Group DBE	%DBE based on the difference between pre-RSA spawning escapement estimates and the potential spawning escapement based on in-season abundance at Mission at a coarse stock grouping level.
Historic Stock Group DBE	Average historic %DBE from 1977 to present, excluding some years deemed to be non-representative.
C&R Preliminary %DBE	Pre-RSA %DBE based on the difference between reconstructed abundance at Mission and in-season abundance at Mission by RSA stock. The reconstructed abundance at Mission is calculated using spawning escapement and broodstock plus catch upstream of Mission based on spawning escapement ratios for grouped stocks.
RSA-updated DBE	The %DBE which takes into account $RSA_{Spawner}$ and RSA_{Catch} when calculating the reconstructed abundance at Mission.
Timing Models	Mortality calculated using various timing models, e.g. based on freshwater entry date for Weaver Creek and Late Shuswap, or discharge versus threshold successfully migrating past the Big Bar landslide area.
Thermal Models	Mortality calculated using stock-specific thermal models based on Fraser River temperature at Hope or Qualark.

Guidance on the use of post-RSA run size estimates

Post-RSA run size estimates can differ substantially from Mission-based run size estimates, resulting in two similar and co-existing data sets. It is important to recognize when it is most appropriate to use one data set versus the other. In general, annual post-RSA run size estimates at the RSA stock-level should be more accurate than annual Mission-based run size estimates, given that they rely on spawning ground estimates, account for known biases in spawner numbers and catch estimates, and include an explicit estimate of in-river mortality for each RSA stock. Post-RSA estimates should be used for historical time series of stock-specific run size, allowing the generation of run size forecasts and the assessment of long-term management through status evaluations and recovery planning. Because RSA stock groupings are closely aligned with Designatable Units (DUs) or Conservation Units (CUs), the stock-specific post-RSA run size estimates fit with Canadian legislative information requirements. Stock-specific post-RSA run size estimates can also be used to explore trends in run size, exploitation or productivity, but researchers should be aware of the considerable changes in estimation methods for the different run size components as well as the change in their relative contributions to run size (DFO 2025). Post-RSA run size estimates are available on the Fraser River Panel Annual Report Data App.

Mission-based run size estimates are based on Mission abundance plus seaward catch and derived through marine reconstructions (Chapter C4). They are important for in-season fisheries management and for the evaluation of in-season management performance. More specifically, Mission-based run size estimates are used to calculate the available harvest, the Total Allowable Catch (TAC), the exploitation rate, and the achievement of the in-season management objectives of the Fraser River Panel. They are also used to calculate Differences Between Estimates (DBEs), i.e. the difference between the number of spawners on the spawning grounds and the predicted number based on the number of salmon migrating past the hydroacoustic site at Mission minus the total catch above Mission (Chapter C8). Stock-specific Mission-based run size estimates, while considered in-season estimates, are often updated post-season due to updates to the inputs: abundance at Mission, seaward catch (e.g., District 104, Chapter C9), and stock composition estimates. These estimates enable the assessment of additional in-season management actions, such as window closures.

Regardless of which run size estimate is used, care should be taken with the use of small stock-specific run size estimates and derived estimates such as exploitation rates. When abundances are low, the uncertainty associated with stock-specific catch estimates can be substantial. In this case it is advisable to aggregate the data of co-migrating stocks to reduce bias and imprecision (DFO 2025).

Future Steps

A formal review of the RSA process was conducted by the Canadian Science Advisory Secretariat (CSAS), resulting in a list of recommendations for improving the process and evaluation criteria to help prioritize the recommendations based on the objectives of different end users (DFO 2025). These recommendations include, among others: simplifying the post-season run size determination process, improving the accuracy of spawner estimates by visual survey, timely reporting of all catch from fisheries that intercept Fraser sockeye, updating and extending the en route mortality model to include all evaluated stocks, and quantifying and reducing the uncertainty in all run size components. The RSA group is committed to implement these recommendations over time.

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C7. Run Size Adjustment: Calculations

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Summary

The Run Size adjustment (RSA) process produces post-season estimates of run size, called post-RSA run size estimates, based on the number of sockeye observed on the spawning grounds, post-season catch estimates, known biases in escapement and catch data, and information on potential en route loss (Chapter C6). The individual components contributing to the post-RSA run size are documented in the RSA Production file, an MS Excel application designed to track the run size components, incorporate adjustments made during the RSA process and calculate final post-RSA run size estimates by stock and age. The tool also calculates exploitation rates and productivities for each stock and can be used during the RSA process to evaluate the effects of different RSA assumptions on run size, exploitation rate, and productivity. In addition, it provides up-to-date run size information to support stock assessments and forecasting (Chapter A1).

Introduction

A Run Size Adjustment (RSA) process (Chapter C6) is conducted annually to evaluate estimates of Fraser River sockeye run size and to estimate biases in components of the post-season run size. The goal is to use data that are only available post season to generate more accurate estimates of run size than can be accomplished in-season. The RSA Production file ("PROD100") is a tool created in MS Excel used to calculate the post-RSA run size for each stock and age as well as various metrics including productivity and exploitation rate. In-season and post-RSA run size estimates are compared throughout the file to demonstrate the difference in run size made by the RSA process.

Data

The key data inputs to the RSA Production file are: spawning escapement estimates by stream provided by DFO stock assessment (Chapter C1), individual ages of spawning ground samples from the Scale Database (Chapter C15), individual ages and stock assignments of in-season fishery samples from the PSC DINGS database (Chapter C17), Mission escapement and catch from the RuFEs database (Chapter C18), and RSA escapement, catch, and mortality values derived from the RSA process (Chapter C6). A total of 28 different stocks/stock groupings are evaluated within the RSA process (Table 1).

Methods

The RSA Production file contains a sequence of calculations to generate stock-specific post-RSA run size, exploitation rate, and productivity estimates for both jacks and adult sockeye. Adult age groups include 4_2, 5_2, 5_3, 6_2, 6_3, 3_1, 4_1, 5_1, 5_4 and 7_2, while jack age classes are 3_2, 4_3, and 2_1 (Chapter C2). In order to ensure transparency between pre- and post-RSA estimates, stock- and age-specific escapement and catch estimates are first calculated without RSA components, followed by parallel calculations that incorporate RSA adjustments ($RSA_{Spawners}$, RSA_{Catch}, $RSA_{Mortality}$ and RSA_{Other}). Notations used herein include stock (k), age (a), sex (s) and river reach (r). Subscripts m and f denote male and female while u and d denote areas upstream and downstream of Mission, respectively.

Table 1. *List of stock groupings used in the RSA process along with their component DNA Groups, and associated Production Groups and FRP Management Units.*

DNA Group	RSA Group	Production Group	FRP Management Unit
Driftwood-Narrows	1 Early Stuart	Early Stuart	Early Stuart
Bivouac-Rossette			
Dust-Sinta			
Paula-Felix			
Chilliw_lake	2 Chilliwack	Misc (Chilliwack)	Early Summer
DollyVarden_Cr			
Chilliwack_Kok			
Alouette_Kok	3b Alouette+Coquitlam	N/A[1]	
Coquitlam_Kok			
Pitt_River	3a Upper Pitt	Pitt	
Nadina	4a Nadina	Nadina	
Bowron	4b Bowron	Bowron	
Nahatlatch	5b Nahatlatch	Misc (Nahatlatch)	
Gates_Creek	5a Gates	Gates	
Taseko	6 Taseko	Misc (Taseko)	
Upper_Barriere	7 North Barriere	Upper Barriere (Fennel)	
Upper_Adams	8a Adams Lake	Misc (Shu)	
Cayenne			
Eagle	8b Early Shuswap		
Seymour		Seymour	
Scotch		Scotch	
Harrison	9 Harrison	Harrison	Summer
WidgeonSough	10 Widgeon	Misc (Widgeon)	
Middle_River	11 Late Stuart	Late Stuart	
Kuzkwa_Creek			
Pinchi_Creek			
Tachie			
Stellako	12 Stellako	Stellako	
Chilko	13b Chilko (river + north lake)	Chilko	
Chilko_north			
Chilko_south	13a Early Chilko (south lake)[2]		
Mid_Horsefly	14 Horsefly	Quesnel	
Upper_Horsefly			
McKinley			
Lower_Horsefly			
Mitchell	15 Mitchell		
Blue_Lead_Ck			
Wasko-Roaring			
Raft	16a Raft	Raft	
NorthThompson	16b North Thompson	North Thompson	
		Misc (N.Thomp. Tribs)[3]	
Birkenhead	17a Birkenhead	Birkenhead	Late
Big_Silver	17b Big Silver	Misc (Harrison/Lillooet)	
Lower_Adams	18a Late Shuswap	Late Shuswap	
Eagle_Late			
LittleRiver-LittleShu			
Lower_Shuswap			
MiddleShuswap			
Portage_Creek	18b Portage	Portage	
Weaver	19a Weaver	Weaver	
Cultus_Lake	19b Cultus	Cultus	

[1]*No production group assigned to Alouette or Coquitlam. Their returns are not included in the Fraser sockeye forecast.*
[2]*This group is generally combined with 13b Chilko.*
[3]*No available baselines for this group. Sockeye from this group are added to Raft or North Thompson RSA groups.*

The first step in the process is calculating the spawning escapement for each RSA stock group, hereafter referred to as "stock". Spawning escapement numbers by stream (E_{Stream}) are aggregated to the 28 RSA stock/stock groupings based on groupings defined in the PSC RuFEs database (Chapter C18):

(1) $$E_k = \sum E_{Stream} \,.$$

Sex-specific age composition ($p_{a,s}$) is estimated as the proportion of samples (n) in each age class.

(2) $$p_{a,s} = \frac{n_{a,s}}{n_s}.$$

These estimates are combined using sex-specific spawning escapement ($E_{s,k}$), to obtain the stock-level spawning ground age composition:

(3) $$p_{a,k} = \frac{p_{a,m,k} \times E_{m,k} + p_{a,f,k} \times E_{f,k}}{E_k}.$$

If the total spawning-ground sample size for a stock exceeds a user-defined threshold (default = 9), the stock-specific age composition is used. Otherwise, a combined spawning-ground and fishery-based age composition is applied. If sample sizes remain insufficient, age composition is manually assigned based on the age composition from related stocks.

Stock-specific catch upstream of Mission is calculated by summing the catch across Fraser River reaches ($C_{r,k}$) for each stock. For some related stock groups, stock assignment is uncertain, requiring catch to be grouped and redistributed among stocks using a backward reconstruction based on stock-specific spawning escapement estimates. This procedure is usually done for Late Stuart and Stellako, as well as for Horsefly and Mitchell stocks. Redistributed catch ($\hat{C}$) is apportioned according to each stock's relative contribution to total abundance in the reach, defined as spawning escapement plus upstream catch ($\sum C_u$). The predicted catch at reach r for stock k_1 following the redistribution between k_1 and k_2 is therefore calculated as:

(4) $$\hat{C}_{r,k1} = \frac{(C_{r,k1}+C_{r,k2}) \times (E_{k1}+\sum C_{u,k1})}{(E_{k1}+\sum C_{u,k1})+(E_{k2}+\sum C_{u,k2})}.$$

The redistributed catch is summed across all reaches to obtain total catch upstream of Mission for each stock.

In addition to stock- and age-specific escapement and catch estimates, the RSA Production file also calculates the various Run Size Adjustment (RSA) components (Chapter C6), with

(5) $$RSA = RSA_{Spawner} + RSA_{Catch} + RSA_{Mortality} + RSA_{Other}.$$

The $RSA_{Spawner}$ estimates are added to the stock-specific spawning escapement, and catch redistributions are recalculated accordingly. The difference between post-RSA and pre-RSA redistributed catch upstream of Mission represents upstream RSA_{Catch}:

(6) $$RSA_{Catch,u} = \sum\left(\hat{C}_{r,postRSA} - \hat{C}_{r,preRSA}\right).$$

The total RSA_{Catch} is then the sum of the RSA_{Catch} upstream and downstream of Mission:

(7) $$RSA_{Catch} = RSA_{Catch,u} + RSA_{Cach,d}.$$

The $RSA_{Mortality}$ estimate is calculated using a percent mortality ($p_{Mortality}$) value decided upon during the RSA process:

(8) $$RSA_{Mortality} = \left(E + RSA_{Spawner}\right) \times \frac{p_{Mortality}}{1-p_{Mortality}}$$

Total production, post-RSA run size (*N*), of each stock can be calculated by adding the total RSA estimates to the catch and spawning escapement estimates:

$$(9) \qquad N = E + \sum C_u + C_d + RSA.$$

The exploitation rate is calculated for each stock by dividing the catch by the post-RSA run size. This can be done for each type of catch separately, or for all catch combined:

$$(10) \qquad ER = \frac{C}{N}$$

Productivity, also referred to as "return per effective female" (RPF), is the number of four-year old sockeye (*N*) produced by each effective female spawner (EFS).

$$(11) \qquad RPF = \frac{N \times (p_{4_1} + p_{4_2} + p_{4_3})}{EFS}$$

with p_{41}, p_{42} and p_{43} representing the proportions of four-year-olds. The number of effective female spawners (EFS) is provided by DFO Stock Assessment (Chapter C1).

Role of the RSA production file in RSA evaluations

The RSA Production file compiles all inputs, intermediate calculations, and final outputs used during and after the RSA process. Together, these metrics support discussion, evaluation, and agreement on final RSA values. The primary purpose of the RSA Production file is to provide updated post-season run size estimates in a standardized format that can be exported for forecasting, visualization, online applications, and other downstream analyses. Run sizes are reported by age, enabling age-specific assessments.

A key secondary use of the file is to support real-time evaluations during RSA meetings. Proposed input values, such as RSA mortality estimates, can be entered directly into the file to generate updated outputs for immediate review. These outputs can then be examined for internal consistency and discussed among participants. For example, increasing RSA mortality increases post-RSA run size estimates without changing catch or escapement, resulting in lower exploitation rates and higher productivity estimates. Increasing RSA spawner estimates increases post-RSA runs size estimates, lowers exploitation, and increases productivity, but may reduce productivity in the subsequent return year of the same cycle. Increasing RSA catch estimates raises post-RSA run size estimates, exploitation rates, and productivity.

Post-RSA run size estimates can be compared to Mission-based run size estimates to determine if there are potential issues with the RSA values. Assuming Mission estimates are correct, these two types of run size estimates should match. This method is generally more reliable for stocks such as Early Stuart, which are genetically distinct from other co-migrating stocks.

Exploitation rates across co-migrating stocks can also be compared to assess whether additional RSA adjustments may be warranted. Because co-migrating stocks are exposed to the same fisheries, their exploitation rates are expected to be similar. Higher exploitation of a given stock may indicate underestimated escapement or mortality, or overestimated catch.

Productivity estimates provide an additional diagnostic check. Unusual productivity values can often be evaluated using field observations. If productivity derived in the RSA Production file does not align with observed conditions, this may indicate that escapement, catch, and/or mortality estimates require further adjustment.

Potential Areas for Improvement

In addition to the recommendations outlined in the CSAS review (DFO 2025), there are several potential ways of improving the RSA production files. Currently, the file only supports RSA stocks groupings. The current file is built around RSA stocks. Some combinations of stock groupings are accommodated for stocks that are difficult to distinguish, and calculations are included for converting RSA stock estimates into "production stocks" for forecasting. It may be possible to accommodate other stock groupings, such as Conservation Units (CUs), but the file is becoming unwieldy and additional functionality would likely require streamlining the current file by removing accommodations and conversions to a separate file.

Another improvement would be to have better integration of jack data. Jacks are currently not distinguished in files used for forward reconstructions (Chapter C3) and disentangling them in reconstructions in general is difficult due to selectivity. Therefore, the RSA production file does not fully and appropriately integrate all components of the run size for jacks. Addressing this would first require more explicit review of the inputs and calculations made in various aspects of the monitoring system and RSA process.

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C8. Post-season DBE estimates informing Management Adjustments

M.R. Forrest

Summary

Management Adjustments (MAs) are the additional fish added to the spawning escapement target (SET) to increase the likelihood of achieving that target (Chapter B25). MAs take into account en route loss and other factors that cause differences between the predicted and observed spawning escapement estimates (Difference Between Estimates, DBEs). The predicted spawning ground estimates, termed the potential spawning escapement (PSE), is based on the number of salmon migrating past the hydroacoustic site at Mission minus the total catch above Mission. Post-season DBE estimates are calculated and maintained in the RuFEs (Run Size, Fishing and Escapement) database (Chapter C17) that serves as the central repository for all necessary inputs, including stream-level spawning escapement estimates (Chapter C1), stock-specific daily passage estimates at Mission, and catch above Mission (Chapter C3). The database ensures that the data can be efficiently accessed and analyzed at the appropriate stock or management group resolution to derive historical DBE estimates. These historical DBE estimates form the empirical basis of pre-season (Chapter A3) and in-season DBE models (Chapters B25-27) and underlie the selection of Management Adjustments by the Fraser River Panel (Chapter B25).

Introduction

Under the Pacific Salmon Treaty, the Fraser River Panel has the discretion to add additional fish to the spawning escapement target (SET) set by Canada for Fraser River sockeye salmon (*O. nerka*) to ensure spawning targets are met (PST 2025, Article IV, Chapter 4, Paragraph 3b). Conceptually, these additional fish serve as a buffer, offsetting discrepancies between in-season predictions and post-season observations of actual spawning escapement, as a result of additional mortality en route to the spawning grounds and due to assessment error. The magnitude of such discrepancies is quantified through the Difference Between Estimates (DBE), the numerical difference between the predicted number of spawners expected to reach the spawning grounds and the observed number of spawners counted post-season.

This report provides a description of how the data required for DBE calculations are collected, processed, and organized within the PSC's Run Size, Fishing and Escapement (RuFEs) database (Chapter C17). The RuFEs database serves as the central repository for all necessary inputs, including stream-level spawning escapement estimates from DFO's NuSEDS system, stock-specific daily passage estimates at Mission, and catch above Mission derived from the PSC's Catch and Racial 100 (CR100) files. This structure ensures that the complete set of required data, from field-based observations to reconstructed stock-specific passage estimates, can be efficiently accessed and analyzed at the appropriate stock or management-group resolution.

Data

The observed, post-season DBE is the difference between the observed number of spawners on the spawning grounds (Spawning Escapement, SE) and the predicted or potential spawning escapement (PSE) based on the sockeye passage estimated at Mission (Chapter B14) minus catch above Mission.

Post-season estimates of spawning escapement (SE) are based on spawning ground enumerations conducted by DFO Stock Assessment (Chapter C1). The DFO Stock Assessment Program provides near-final spawning escapement estimates each February when they are presented to the Fraser Panel. These estimates have been evaluated for accuracy and assessed for potential bias. Although revisions to the near-final estimates are unlikely, adjustments may occur, for example when additional years of data have been analysed (Chapter C1). The escapement data are extracted annually from DFO Pacific Region's NuSEDS (New Salmon Escapement Database System) database, which archives spawning ground estimates for Fraser sockeye at the stream level. Stock-specific Mission passage estimates and catch upstream of Mission are generated from the PSC's Catch and Racial 100 (CR100) files (Chapter C3), which derive these estimates for 50 Fraser sockeye stock groups based on genetic stock identification methods (Chapter B11).

All data needed to calculate historical DBEs are stored in the RuFEs database (Chapter C17), i.e. spawning escapement estimates by stream and stock-specific daily estimates of Mission sockeye passage and catch above Mission. The RuFEs database allows the user to calculate the spawning escapement (SE), the potential spawning escapement (PSE), the Difference Between Estimates (DBE) and the 50% migration date past the Mission site. The DBE data extend back to 1977, the first year a hydroacoustic salmon enumeration program was operational at Mission. Because data in RuFEs are stored at the finest possible stock resolution, the DBE data can be generated at any desired level of aggregation. DBE estimates are generally summarized by management group, but exclude stocks like Pitt, Chilliwack, Harrison/Widgeon and Birkenhead/Big Silver. Some of these excluded stocks have smaller median proportional or percent DBEs (%DBEs) than their management group (Pitt, Birkenhead/Big Silver) because their spawning grounds are located close to the mouth of the Fraser River, resulting in lower expected en route losses under adverse migration conditions (Figure 1). Other excluded stocks may have larger median %DBEs compared to their management group due to higher assessment uncertainty (Chilliwack and Harrison/Widgeon). The data for these individual stocks are extracted and processed separately from the management group specific data within the RuFEs database. This separation of specific stocks from the rest of the management groups ensures that unique biological characteristics and stock-specific assessment challenges do not distort management-level DBE summaries.

Methods

Post-season DBE estimates are annual estimates calculated based on the difference between the observed Spawning Escapement (SE) and the predicted or Potential Spawning Escapement (PSE):

$$(1)\ \ \mathrm{DBE} = \mathrm{SE} - \mathrm{PSE}.$$

The potential Spawning Escapement is calculated using the passage past the Mission hydroacoustic site minus upstream catch. A negative DBE implies that the number of spawners that made it to the spawning grounds is smaller than predicted in-season and this may have a negative impact on the ability to reach the Spawning Escapement Target. Conversely, a positive DBE indicates more fish reached the spawning grounds than anticipated during in-season assessments. When working with historical DBE data across years, using absolute DBE values can be misleading. In this case, it is better to express the data in terms of the percent or proportional Difference Between Estimates (%DBE):

$$(2)\ \%DBE = (SE - PSE)/PSE.$$

This equation scales the DBE relative to the expected escapement (PSE), thereby normalizing for differences in run size. This normalization facilitates consistent interpretation of patterns across years, improves the ability to detect long-term trends or anomalies, and enables direct comparisons across stocks with very different run size or life history characteristics. As a result, the %DBE metric provides a more robust data set for pre-season (Chapter A3) and in-season assessments (Chapter B25).

Results

Generally, there are 8 different groups for which DBE estimates are calculated and extracted from the RuFEs database (Figure 1). The median %DBEs vary substantially between the different groups, with the median %DBE generally being smallest for Summer-run sockeye, excluding Harrison and Widgeon, and largest for Late-run stocks excluding Birkenhead, Big Silver, due to the increased en route losses associated with early upstream migration of delaying Late-run stocks (Lapointe et al. 2003). The largest variability in %DBEs across years is observed for stocks with higher assessment uncertainty (Pitt, Chilliwack, Harrison/Widgeon and Birkenhead/Big Silver).

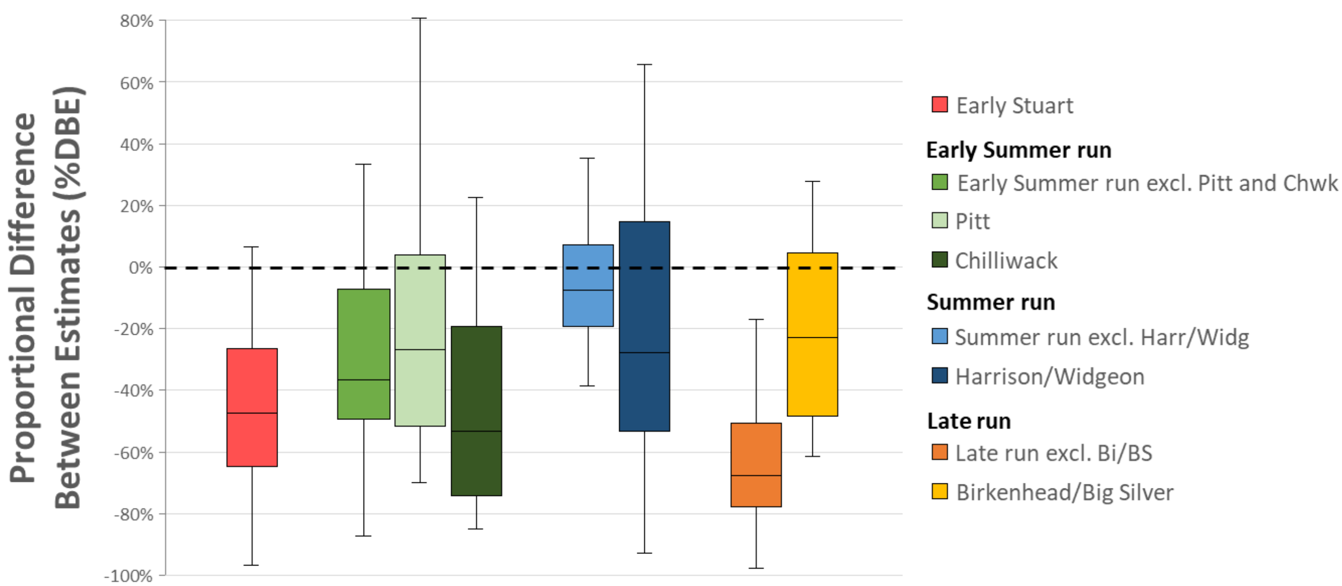

Figure 1. *Boxplots of the proportional Difference Between Estimates (%DBE) data (1977-2025) of the eight different Management Adjustment groups for Fraser River sockeye salmon.*

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C9. Stock-specific estimates of northern harvest of Fraser sockeye

S. Latham, A.M. Phung, G. Rose, and S. Decker

Summary

Fraser River sockeye are caught incidentally in coastal southeast Alaska and generally comprise a minor portion of the total salmon harvest in District 104 (D104) fisheries (PST 2025), but their harvest can be considerable on occasion (CSC 2023). The Pacific Salmon Commission (PSC) and Alaska Department of Fish and Game (ADF&G) previously used scale-based analyses (Chapter B10) to estimate these harvests independently. More recently, genetic stock identification (GSI) has been used and, since 2017, a process has been used that intentionally generates identical annual estimates across agencies for the harvest of Fraser sockeye stocks in aggregate. The Northern Boundary Technical Committee (NBTC) estimates the number of Fraser sockeye harvested in D104 fisheries by using DNA samples collected by ADF&G and analyzed by the National Oceanic and Atmospheric Administration (NOAA). Samples from individuals identified as Fraser River sockeye with sufficient confidence are shared with the PSC Secretariat. The shared samples are analyzed similarly to samples collected from Fraser River Panel (FRP) fisheries (Chapter B11). This allows the estimate of total Fraser sockeye harvest in D104 to be disaggregated into its component stocks. Sample sizes in D104 are often small, such that uncertainty is high relative to the harvest estimates of most stocks within the Fraser sockeye aggregate. Nevertheless, stock compositions of Fraser sockeye in D104 harvests appear to differ from those observed in FRP fisheries, and these differences may provide insights into migration behaviour and productivity. A working group is currently reviewing the estimation of stock-specific harvest of Fraser sockeye in D104, including the reliability and display of those estimates. This report focuses on the interim methods used during the working group's review and uses 2023 as an example.

Disclaimer: Stock composition of Fraser sockeye harvested in Alaska is under review by PIPWOG, a multi-agency PSC working group. PIPWOG members may not agree with this chapter's description of northern fisheries or of the data and analyses pertaining to them. PIPWOG will publish a more thoroughly vetted final report on this topic in 2027.

Introduction

Under the Pacific Salmon Treaty (PST 2025), the Fraser River Panel (FRP) is responsible for designing and conducting studies to "identify and discriminate between races of Fraser River sockeye … including specification of samples required … from sites outside the Area" and accounting for "the catches, wherever made, of Fraser River sockeye", as instructed in Paragraph A.1.c. and A.1.e. of the Diplomatic Note of August 13, 1985, regarding implementation of Article XV, paragraph 3 of the Pacific Salmon Treaty. Note that the FRP recognizes an operational definition of "race" for Fraser sockeye in the FRP process that equates to "stock" at a resolution of rearing lake or finer (Appendix A). Considerable catches of Fraser sockeye can occur outside of the Fraser Panel Area, and even north of Cape Caution. Canadian fisheries near Haida Gwaii and in U.S. fisheries near Noyes Island and the rest of District 104 (D104) in southeast Alaska sometimes comprise large proportions of Fraser sockeye (e.g., PSC 2021). Large harvests of Fraser sockeye in north coast Canadian fisheries have become infrequent (Nelitz et al. 2018) but, when they do occur, they are sampled and the samples are directly shared with PSC staff and processed at DFO's Molecular Genetics Laboratory (MGL) in the same manner as samples collected for FRP management (Chapter B11). For example, Area F trollers unexpectedly harvested an anomalous number of sockeye late in 2014 (whereas annual estimates for other years 2009-2025 averaged fewer than 1,000, over 40,000 were harvested in 2014, PSC 2018), so sample collection was prioritized by DFO in 2014, and the samples were shared with PSC staff.

Purse seine fisheries in D104 target pink salmon, and incidental harvest of Fraser sockeye varies substantially from year to year. In FRP datasets from 1989-2022, annual harvest of Fraser sockeye in D104 averaged over 90,000 and ranged from 0 to 311,000 (Figure 1). Large harvests of Fraser sockeye stocks in northern fisheries are of interest, particularly with respect to their stock composition and the information they can contribute toward understanding the migration patterns and productivities of Fraser sockeye stocks. The processing of D104 samples differs from the processing of FRP samples, and here we describe how the Fraser sockeye harvest is estimated in this fishery, for Fraser sockeye as a whole and for component stocks.

Importantly, the estimation and reporting of stock-specific harvest of Fraser sockeye in D104 is currently under review. After estimates for the 2022 fishing season were presented to the FRP, in 2024, ADF&G raised concerns regarding the FRP's use of samples shared from the D104 fishery, including questions about the genetic baseline, the number of Fraser stock groups estimated, the inherent uncertainty of the estimates given limited sample sizes, and communication of results (in terms of both technical review and public display). ADF&G designed the sampling program in D104 to provide weekly stock proportion estimates within 7% of their true proportions 95% of the time, for major stocks important for the implementation of Chapter 2 of the Treaty (PST 2025). These ADF&G standards are consistent with reporting stock proportions for stocks present in proportions exceeding 5%, whereas estimates for most of the 19 Fraser sockeye stocks do not meet this 5% threshold. The *ad hoc* working group charged with reviewing and resolving these issues, called PIPWOG, is expected to issue its final report in 2027. The report may include recommendations regarding both the display of results and the methods employed to generate them that differ from what is presented here. Methods and results reported here pertain to the 2023 fishing season. The 2023 data were analyzed using 'interim' methods, agreed upon to allow Treaty work to continue while PIPWOG's review is ongoing. For context, an overview of historical changes to the methodology is provided in Appendix B.

Data

Sockeye from D104 purse seine landings in southeast Alaska (from Petersburg, Craig, and Ketchikan) have been sampled for mid-eye-to-fork (MEF) length, sex, scales, and tissue for DNA analysis. There have usually been one or more fishery openings per statistical week, beginning in early to mid July and ending in mid August to early September. Each week, 260 or more samples have been targeted for collection in accordance with precision objectives, as noted earlier. After processing of these samples for GSI, weekly estimates of the harvest of Fraser sockeye (as an aggregate stock group) have been available. A subset of the collected samples has been made available for parsing the Fraser sockeye harvest into stock-specific estimates.

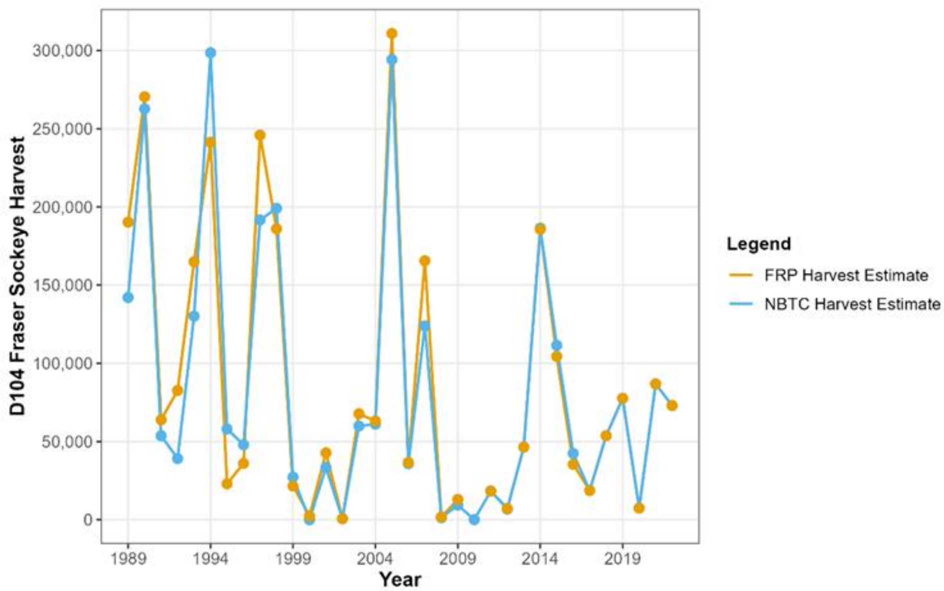

Figure 1. *Estimated harvest of Fraser River sockeye in the District 104 (D104) purse seine fishery from 1989-2022. The Fraser River Panel (FRP) has consistently adopted total Fraser sockeye harvest estimates generated by the Northern Boundary Technical Committee (NBTC) since 2017 and occasionally in years prior.*

Methods (2023)

The estimation of stock-specific Fraser sockeye harvest requires collaborative effort, and some details of the methods used by different agencies in 2023 are presented here. These methods are subject to change following a review by the PIPWOG working group.

HARVEST ESTIMATION AND SAMPLING BY ADF&G

D104 is divided into several sub-districts (from south to north: 10, 20, 30, 35, 40, and 50), and harvest can occur in any D104 sub-district. Sampling primarily targets offloads in Ketchikan and Petersburg, with sockeye sample limits of 40 and 200 applied to individual vessels and tenders, respectively, to increase representativeness of the sample within each statistical week (Reynolds-Manney et al. 2020). For reasons relating to sample size, these samples are analyzed in a single mixture per statistical week, rather than in a stratified manner across sub-districts. ADF&G samples pure landings from harvest that occurred in D104 only (Reynolds-Manney et al. 2020), and sample size targets may be missed if vessels predominantly offload fish from multiple districts. The total numerical harvests themselves are based on landing weights by species and average weights of each species as measured by port samplers for each offload. Fish tickets account for the harvest of every offloading vessel, and uncertainty in the total harvest by species in D104 is considered to be negligible (Bo Meredith, ADF&G, pers. comm. May 8, 2026).

Evaluation: In 2023, the target weekly sample size of 260 was not achieved after week 31, similar to other recent years. Sample size targets were met for only one third of these later sample weeks in 2020-2022. Sex of sampled sockeye was judged externally and, because the accuracy of these determinations is unknown, use of sex data for analyses was not recommended (Andrew Piston, ADF&G, pers. comm. Jan. 7, 2026).

REGIONAL GSI ANALYSIS BY NOAA AND FRTC

Following the 2023 fishing season but prior to January 2024 PSC meetings, the samples were transmitted to NOAA personnel at the Auke Bay Laboratories (ABL) in Juneau, where GSI analyses were conducted. The resulting stock composition estimates were shared with the NBTC, and the NBTC generated harvest estimates by reporting group, including Fraser, Skeena, Nass, Alaska, and other stocks. Harvest estimates were attributed by the NBTC to reporting groups based on single nucleotide polymorphism (SNP) genotypes generated by the NOAA lab. The SNP baseline in use has improved over time and in 2023 included information for 241 populations at 81 genetic markers (Barry et al. 2025), and those were analyzed with the software program rubias (Moran and Anderson 2019).

For FRP purposes, to meet requirements of Chapter 4 of the Treaty (PST 2025), NOAA's ABL subsequently generated individual-level results using rubias (Moran and Anderson 2019) by analyzing all D104 samples for the year in a single mixture, and individuals estimated to have a sufficiently probable origin in the Fraser River were identified for further analysis (Patrick Barry, NOAA, pers. comm. Feb. 6, 2026). A portion of the original tissue sample (a piece of axillary process or fin clip) for these individuals was then sent to the PSC Secretariat in October 2024, and on to DFO's Molecular Genetics Laboratory (MGL) in Nanaimo.

<u>Evaluation</u>: Currently, the SNP baseline used by NOAA's ABL to estimate the proportion of Fraser sockeye is under review by PIPWOG. Aspects under review include likely GSI biases, estimated uncertainties, and the potential of this baseline to produce stock-specific estimates of Fraser sockeye harvest. In addition, the bias incurred by using an independent 2-step GSI procedure (as currently used) versus an integrated multi-stage method (Hsu and Habicht 2024) is being investigated. PIPWOG is also evaluating details regarding the method and criteria used to identify which DNA samples should be shared for subsequent analyses. Specifically, the use of a 75% probability threshold for assigning individuals to the Fraser reporting group is under review (Appendix B). The evaluation includes potential biases in the individual identification of Fraser stocks depending on their distinctness, and if the application of individual probability thresholds exacerbates those biases.

LOCAL (FRASER) GSI ANALYSIS BY DFO AND PSC STAFF

When the shared 2023 samples arrived at DFO's MGL, DNA was extracted and then assayed at 14 microsatellite and 5 SNP loci, with genotypes analyzed using the software program Cbayes via comparison to a coastwide baseline, as in other GSI analyses in the FRP process (Chapter B11). This second GSI analysis was undertaken to disaggregate the NBTC estimates of Fraser sockeye harvest into component stocks. Analyses were stratified in a weekly manner to match the weekly harvest estimates that were shared by the NBTC for the aggregate Fraser sockeye stock. Because the baselines used in both the first and second GSI analyses are subject to non-zero rates of misclassification, the Fraser-only stock proportions were normalized prior to application to the aggregate Fraser harvest estimates. That is, small contributions of non-Fraser sockeye were removed so that the sum of stock-specific Fraser sockeye harvest each week in D104 equaled the weekly aggregate Fraser harvest reported by the NBTC. To maintain congruence between stock-specific Fraser estimates in D104 and other fisheries, average estimates from Cbayes (Neaves et al. 2005) were used. Due to difficulties obtaining particular metrics of uncertainty from Cbayes, these were generated using rubias (Moran and Anderson 2019), which produced similar point estimates. The weekly stock-specific estimates were entered into data files that facilitate post-season run reconstructions (Chapter C7), and the annual D104 stock-specific harvest estimates for 2023 were presented to the FRP in April 2025.

<u>Evaluation</u>: Currently, the relevant baseline and error rates are under review by PIPWOG. Aspects under review include biases and uncertainties related to the large number reporting groups within the FRP

process and the limited sample sizes available for estimating their proportions. The review includes comparisons to alternative marker sets, baselines, and analytical methods available from different GSI analytical programs. The estimation and display of uncertainty metrics are also being evaluated, in addition to language to facilitate proper interpretation of results.

Results

In 2023, northern commercial fisheries (i.e. north of Cape Caution) were estimated to harvest zero Fraser sockeye in British Columbia and 7,775 Fraser sockeye in Alaska. In Alaska, ADF&G sampled 2,452 sockeye from D104 fisheries, of which 2,127 were genotyped by NOAA's ABL in the first step of the GSI analysis. Results from this analysis indicated that nearly all of the Fraser sockeye harvest occurred in weeks 31-34 (Table 1). Due to an especially low sample size for total sockeye in week 33 (n = 40), harvest estimates and samples for week 33 were aggregated with week 32. Overall, of the 2,127 genotyped individuals, samples were shared for 117 putative Fraser sockeye, i.e., those with an estimated probability of Fraser origin exceeding 75%.

The final sample size for the second GSI step was 115 Fraser sockeye individuals, as a microsatellite genotype could not be obtained for one fish, and another was confidently identified as a non-Fraser fish by the second GSI analysis. A large proportion of the shared DNA samples had been caught in week 35, which was associated with an estimated harvest of only 77 Fraser sockeye (Table 1).

The stock-specific *proportions* estimated by DFO's MGL in the second GSI step are not shown. Instead, Table 2 displays the sum of the weekly stock-specific estimates of Fraser sockeye *harvest*. In week 30, no Fraser sockeye were identified with a probability exceeding 75% and shared. Therefore, stock-specific Fraser sockeye proportions from week 31 were applied to week 30's estimated harvest of 284 Fraser sockeye (Table 1).

The Fraser sockeye harvest in D104 primarily comprised sockeye from the Chilko, Late Stuart, Stellako, Horsefly, and Mitchell stocks (see Table 1). Whereas these stocks only contributed about 52% of the total Fraser sockeye return in 2023 (PSC 2024), they were estimated to account for 81% of the D104 harvest of 7,775 harvest of Fraser sockeye that year (the 80% credible interval generated using rubias was 72-86%).

Table 1*. Sockeye harvests, GSI sample sizes, and Fraser estimates in District 104 (D104) by statistical week in 2023. Due to the low sample size in week 33 (n=40), week 32 and 33 samples were combined by NOAA.*

Week in 2023	Total sockeye harvest	Samples collected	Samples analyzed	Percent Fraser	Fraser sockeye harvest	95% credible interval	Fraser samples received
27	440	293	281	0%	0	0 - 2	0
28	2,659	439	388	0%	0	0 - 8	0
29	15,422	320	301	0%	0	0 - 57	0
30	68,030	480	316	0%	284	17 - 960	0
31	46,892	360	328	5%	2,432	1,429 - 3,682	17
32	14,436	160	170	21%	3,036	2,889 - 5,173	27
33	4,434	40			932		8
34	9,666	160	150	10%	1,013	593 - 1,535	17
35	298	200	193	26%	77	60 - 97	48
Total	162,277	2,452	2,127		7,775		117

Table 2*. FRP estimates of total Fraser harvest by stock in District 104 (D104) in 2023. Means are shown for Cbayes and rubias, but error metrics (standard deviations and 80% credibility intervals) are from rubias only. It should be noted that many of the stock-specific estimates presented here do not meet standards for precision applied by ADF&G, but such estimates are often presented in the FRP due to utility with respect to specific objectives and general utility.*

	CBayes	**rubias**			
stock group	**mean**	mean	standard deviation	10th percentile	90th percentile
EStu	**238**	189	227	0	519
Chwk	**0**	35	85	0	111
PiAC	**0**	19	49	0	56
NdBo	**62**	96	175	0	343
GaNh	**181**	184	120	54	350
Tsko	**0**	5	23	0	7
NBar	**0**	5	23	0	7
ESTh	**9**	31	59	1	88
Harr	**0**	5	24	0	8
Widg	**0**	5	24	0	7
LStu	**446**	459	334	54	928
Stel	**946**	942	333	544	1381
Chil	**3545**	3266	502	2621	3910
Hfly	**610**	880	352	451	1351
Mtch	**762**	590	271	278	954
RaNT	**0**	11	37	0	29
BiBS	**535**	532	273	212	902
LShP	**80**	163	170	3	403
WeCu	**362**	356	183	147	607
Total	**7775**	7775			

Planned changes and potential improvements

1. The *ad hoc* working group, PIPWOG, is expected to complete its work in early 2027 and make recommendations with respect to the calculation and display of stock-specific harvest estimates of Fraser sockeye in D104. In the interim, as mentioned above, work is proceeding on several fronts. The efficacies of the current baseline and alternate baselines are being evaluated, software and analytical approaches are being reviewed with respect to GSI uncertainty calculations, and potential changes to the display of results are being examined to reduce potential misinterpretation of the relatively imprecise estimates generated. Technical evaluation of which individuals should be shared from the first GSI step for the second GSI step (e.g., application of probability thresholds) is also ongoing. The recommendations will be considered by Commissioners for implementation, and retrospective changes to analytical methods may be desired, altering some historical estimates.
2. Precise estimation of the harvest of sockeye stocks within the Fraser River is not required under Chapter 2 of the Treaty (PST 2025). As a result, precision of stock-specific estimates of Fraser sockeye is generally constrained by low sample sizes targeted for GSI analysis by the ADF&G sampling program. Unmet sample size objectives after week 31, when Fraser sockeye prevalence tends to increase, further challenge the interpretation of results for specific stocks of Fraser sockeye. Potential remedies and mitigations should be explored. Solutions may range

from increased sampling intensity (especially in latter statistical weeks) to improved variance-weighted reconstruction models (e.g., Chapter C6) that more quantitatively account for the precision of harvest estimates.

3. Large harvests of some Fraser sockeye stocks in D104 in some years are of interest beyond the harvests themselves, as they may reflect important aspects of habitat use in the open ocean and of coastward migration routes, and they may be informative about marine survival. It is reasonable to assume that D104 fisheries do not harvest all Fraser sockeye present, and their total abundance could be markedly higher than just the fish harvested. The fate of these unharvested sockeye is of some significance. Peak CPUE for Fraser sockeye is not earlier in D104 than near Vancouver Island (Nelitz et al. 2018), and stock compositions observed in D104 do not comprise later mixtures of Fraser stocks than those observed near Vancouver Island (Latham et al. 2025). This contrasts with expectations if a large proportion of Fraser sockeye migrate via D104 during their return migration. In addition, the lateness of their occurrence in D104 (given that it would likely take three weeks or more for sockeye in D104 to swim to the mouth of the Fraser River) and the poor survival of Fraser sockeye tagged near Haida Gwaii to the Fraser River (e.g., Crossin et al. 2009), suggest that high proportions of unharvested Fraser sockeye in D104 fail to successfully migrate to the Fraser River. The causes of such northern coastal arrival and unaccounted variability in Fraser sockeye production may be consequential for forecasting. Analyses of age compositions indicate that Fraser sockeye in D104 are likely mature (see Chapter C10), but tagging of these fish could provide confirmation of life history stage, empirical assessment of harvest rate, and direct estimation of migratory success rate. The Parties may choose to explore an intensive collaborative research effort to directly assess these unknowns.
4. Given continued challenges understanding annual variance in the frequency of Fraser sockeye stocks in Alaska, additional effort may be warranted to glean insight from Fraser sockeye identified in other northern fisheries (when they occur) and from other south-migrating stocks captured in D104. When non-Fraser stocks dominate catches, increased sampling intensity will yield few additional samples of Fraser sockeye, but samples of other south-migrating stocks tend to be earlier-timed and may be informative regarding the co-migration of Fraser sockeye in early statistical weeks.

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Appendix A: Memo regarding Treaty interpretation with respect to Fraser sockeye "races"

A memorandum dated October 20, 2025, from the Fraser River Technical Committee Co-chairs (Gordon Rose and Scott Decker), to the Committee on Scientific Cooperation and to PSC Commissioners, with the subject: Treaty Interpretation with Respect to Fraser Sockeye "Races", reads as follows:

The Fraser River Panel (FRP) has been asked to clarify how treaty language regarding sockeye "races" should be interpreted, to provide guidance to the PIPWOG on the information requirements to be considered for GSI work. If Commissioners have a differing opinion on this interpretation, then a revised interpretation is sought by the conclusion of the fall session so that PIPWOG can advance their work accordingly.

The Diplomatic Note of August 13, 1985, stipulates:

> *The Fraser River Panel shall assume the responsibility to "design and conduct studies to identify and discriminate between races of Fraser River sockeye and pink salmon harvested in the fisheries including specification of samples required from upriver sections of the Fraser River and from sites outside the Area." (Paragraph A.1.c.)*

The term "race" is no longer used by the Fraser River Panel. For example, the Racial Identification section of the Secretariat Staff was in 2008 renamed the Stock Identification Group. What were called "races" in previous decades have in recent years been referred to, more loosely, as "stocks".

The FRP manages and interprets information to four stock management units (MUs, Chapter 4.3.(e and f)). However, for specific Fraser River Panel technical purposes stock-level, or "race"-level, information is used for run reconstruction, forecasting, migration timing, mortality etc, that contribute to MU level parameters. Depending on the particular use, these stocks are described by up to 30 combinations of lake and migration behaviour or timing (e.g., 27 stocks in the official forecast), often summarized in 19 reporting groups for presentation. A short description of the Fraser River Panel's operational interpretation of Fraser sockeye "races" is provided below, with selected quotations supporting that interpretation.

> ***The Fraser River Panel has fulfilled its sockeye stock identification responsibilities at the level of the rearing lake with extensions for timing groups within lakes, generally consistent with both the definition of Conservation Units under Canada's Wild Salmon Policy and with annual forecasting practices.***

Quotations:

"*Throughout IPSFC reports, the term "race" was used consistently in referring to self perpetuating biological units. The word stock would now seem to be more appropriate in light of modern usage."* (Gilhousen 1992, IPSFC Bulletin XXVII)

"The annual Fraser River sockeye run … comprises more than 30 races (populations, runs) that return to their stream or river of origin…. Terms such as stock, population, run, and race have been used extensively. Stock identifies those sockeye returning to a general geographic area such as Quesnel. Within the Quesnel stock there are specific discrete races or populations such as the Horsefly River and Mitchell River runs spawning in separate areas of the Quesnel Lake system." (Roos 1991, Restoring Fraser River Salmon, p 2)

The focus of Fraser stock composition analyses has remained at a resolution of rearing lake or finer for decades, from IPSFC to current, and this focus has been consistent with Fraser sockeye “races” reflecting rearing lakes or finer resolutions.

Appendix B: Historical background

The ‘interim’ methods described above apply to only the most recent years. Here we provide information relevant to the interpretation of historical estimates.

With the exception of 2005, scale pattern analysis (SPA, see Chapter B10) was used to estimate Fraser sockeye harvest in D104 until 2007. Samples of scales, matching sexes, and mid-eye to fork (MEF) length measurements were collected by ADF&G in landings from this fishery. To allow estimation of four reporting groups, baseline or ‘training’ samples were obtained annually from Alaskan spawning grounds, fisheries near the mouths of the Nass and Skeena rivers, and fisheries in Areas 12 and 20. PSC staff and ADF&G laboratories independently read all these scales, and the two organizations developed independent models to analyze the readings. The main objective for ADF&G was to distinguish and estimate the harvest of Nass and Skeena sockeye; the main objective for PSC staff was to distinguish and estimate the harvest of sockeye belonging to the Fraser River stock aggregate. Discriminant models chosen for these tasks varied accordingly. For example, age-4_2 Fraser sockeye tended to be larger than northern sockeye of the same age, so length was more commonly included as a variable in the models used by PSC staff.

Because Fraser River sockeye returns tend to be dominated by four-year-olds, PSC staff applied models only to distinguish age-4_2 sockeye. Estimates of Fraser sockeye amongst other ages were generated under the assumption that their proportions in District 104 purse seines would be the same as their proportions in the Fraser Panel Area – if 90% of Fraser sockeye returning to the Fraser Panel Area were age-4_2, for example, the total harvest of Fraser sockeye in D104 was the age-4_2 estimate divided by 0.9. The resulting overall harvest estimates varied from those produced by ADF&G on an annual basis (see Figure 1), but no statistically significant directional bias was detected.

Over the course of those years, various methods were used to parse the estimates of Fraser sockeye harvests into component management groups and stocks. The sockeye caught in District 104 were estimated in the post-season and did not count against Total Allowable Catch (TAC, Chapter B32), but they were considered part of the production and therefore attributing them to specific Fraser stocks was important for forecasting purposes. In some years Fraser stock proportions in Alaskan harvests were assumed to be proportional to reconstructed run-sizes; in some years Fraser stock proportions were assumed to be the same as those observed in Area 12 a week or more later; and in some years hybrid approaches were used, incorporating expert judgment regarding stock-specific migratory routes and timing (e.g., Early Stuart was sometimes assumed to make landfall too far to the south to be at all vulnerable in D104).

The FRP’s GSI process is more capable of correctly generating stock-of-origin estimates for Fraser sockeye in complex mixtures than is SPA, especially at the level of individual fish (see Chapter B11). PSC staff began using GSI to generate stock composition estimates for D104 harvests in 2005 because of low abundances of Fraser sockeye in FRP areas and strong signals of Fraser sockeye in Alaskan catches in early and mid August that year. Furthermore, PSC staff had noticed increased difficulty distinguishing Fraser sockeye from Nass and Skeena sockeye using SPA, and experience with DNA indicated that GSI would be effective. Obtaining DNA samples was relatively easy, and few assumptions were required regarding the relative contributions of stocks of Fraser sockeye to the estimated harvest of Fraser sockeye in D104. For these latter reasons, PSC staff began regularly requesting that ADF&G supply tissue samples or extracted DNA for microsatellite analysis, beginning in 2007.

For similar reasons, and because GSI baselines do not require annual updates like SPA baselines, research into GSI-based assessment of sockeye harvest in this fishery was initiated (Guthrie et al. 2008). The analysis was conducted at NOAA's ABL, and the baseline initially included information for 84 populations at 45 SNP loci (Guthrie et al. 2008). This number of SNP loci would provide weak individual stock identification compared to the suite of microsatellite loci used by the FRP (Beacham et al. 2010). Because of this, and with few Fraser River and other south coast stocks included in the baseline, the ADF&G SNP baseline alone would not sufficiently distinguish among sockeye stocks within the Fraser River. Comparisons of results by PSC staff did show, however, that the detection of south-migrating stocks by NOAA's ABL (including those from the Fraser River) was unbiased compared to estimates from DFO's MGL (i.e., at intermediate proportions, false positives appeared balanced by false negatives). Instead of receiving a random subset of tissue samples for GSI (as occurred from 2005-2010), arrangements were made to receive targeted samples (based on GSI results) for D104 harvests beginning in 2011.

Results from 2011 to 2016 were based on parsing NBTC estimates of Fraser and other south migrating stocks using DFO MGL's FRP microsatellite baseline, such that the FRP's estimate of Fraser sockeye harvest could differ from that produced by the NBTC. After some improvements to the baseline used by NOAA's ABL, investigations of misidentification rates by PSC staff indicated that adopting the NBTC estimate of Fraser harvest would be less biased. Therefore, beginning in 2017, total D104 harvest estimates of Fraser sockeye are meant to equal those reported by the NBTC. This has an added benefit of reducing confusion resulting from the circulation of unequal estimates. (Minor differences have arisen due to updates in in recent years, for example, and should be corrected in databases.)

From 2011 to 2022, ONCOR software (Kalinowski et al. 2008) was used for identifying individuals that likely belonged to Fraser or other south migrating stocks. Prior to 2022, individuals were shared if their top assignment on a regional basis was to either the Fraser reporting group or to the other South Migrating reporting group. In 2022, a probability threshold was applied which reduced the number of DNA samples that would be shared (individuals assigned to Fraser and other South Migrating stocks were only shared if the posterior probability of their assignment exceeded 0.75). The same threshold was applied for putative Fraser sockeye in 2023, but no individuals assigned to other South Migrating stocks were shared.

C10. Age Compositions in Northern Fisheries

D. Brkic and S. Latham

Summary

Age samples from fisheries assist post-season run reconstructions regarding the attribution of catch to brood year (Chapter C11). Whereas age compositions of Fraser sockeye caught near the Fraser River are assumed to reflect the age composition of the return, confidence in this assumption is diminished for more distant fisheries. Fisheries north of Cape Caution (north of Vancouver Island) sometimes harvest considerable numbers of Fraser sockeye (Chapter C9), and it is worthwhile to evaluate this assumption. A northern fishery that regularly harvests and provides samples of Fraser sockeye is the District 104 (D104) fishery in southeast Alaska. Examination of the age samples will inform the applicability of reconstructions from Fraser River Panel (FRP) areas to northern fisheries and may also inform our understanding of the marine life history of Fraser sockeye.

Here, we compare age compositions of Chilko sockeye in D104 to age compositions in fisheries nearer to the Fraser River (Area 12 and Area 20); age compositions on the spawning grounds are provided for context. Based on 13 years of available data, we conclude that Fraser sockeye caught by purse seine in D104 differ in age composition from sockeye assessed closer to the Fraser River. Data for Chilko sockeye, in particular, demonstrated older age compositions (a higher frequency of sockeye that had spent three years at sea) in D104 than in more terminal areas. These results support the assumption that sockeye caught in D104 mature in their year of capture, given the rarity of Chilko sockeye spending 4 years at sea, but they refute the assumption of equal age compositions across fisheries.

Introduction

The Fraser River Panel (FRP) is responsible for accounting for the catch of Fraser sockeye, regardless of where those catches occur (Pacific Salmon Treaty, PST 2025, Paragraph A.1.e of the Diplomatic Note of August 13, 1985), in part to provide comprehensive recruitment estimates for forecasts. Post-season reconstructions by age, for estimating recruits by brood year, currently use age composition information from the spawning grounds (Chapter C2), but several factors might result in differences between age compositions on spawning grounds versus fisheries. Fraser sockeye of different ages may rear in different areas of the Pacific Ocean, may return by different routes, and may be exposed to different age-selective or size-selective mortality, for example. The cumulative influence of these factors may increase with distance from the spawning grounds. In addition, difficulty in distinguishing maturity status of sockeye (i.e., whether a fish would return to the Fraser River that year or not) increases with distance from the spawning grounds. For Fraser sockeye caught in northern fisheries (i.e., north of Cape Caution), maturity status and even sex are not usually assessed.

Pink salmon fisheries in District 104 (D104) in southeast Alaska often harvest Fraser River sockeye salmon as bycatch (Chapter C9), and this is the most distant fishery known to regularly catch Fraser sockeye. The sockeye harvest is sampled for Genetic Stock Identification (GSI) and for age, facilitating stock-specific comparisons of age composition estimates among regions. The number of Fraser sockeye harvested in D104 is highly variable year to year and is unpredictable (PST 2025, Chapter 4, Paragraph

14(c)), motivating curiosity about conditions that lead some Fraser sockeye to have high or low abundance the area. In addition to satisfying the FRP's need to attribute the harvests to brood year, examination of age compositions in D104 may be informative regarding the marine life histories of Fraser sockeye, including consequential variability in their rearing locations and migration routes.

We set out to evaluate the applicability of age-specific reconstructions of Fraser sockeye runs within the Fraser River Panel areas 12 and 20 to harvests of Fraser sockeye caught in northern fisheries, including D104. We compared the age composition of Fraser sockeye harvests in the D104 purse seine fishery to age compositions in FRP purse seine test fisheries and to Fraser sockeye on their spawning grounds, by stock and year. Inspection of available data indicated that age compositions of Chilko sockeye caught in D104 were more amenable to study than other Fraser sockeye stocks, and that investigation is presented here.

Data

Age data were compiled from the PSC Scales database (Chapter C14), which houses information obtained from scales and other biological data from individual fish. Individual GSI-based stock identity information was compiled from the PSC DINGS database (Chapter C16), which houses individual genetic assignment data that is matched to the biological data in the Scales database. The targeted data were from samples collected by the Alaska Department of Fish and Game (ADF&G) from sockeye harvested in the commercial purse seine fishery in D104 (Chapter C9), by the PSC and Fisheries and Oceans Canada (DFO) at test fisheries in marine areas near Vancouver Island (Chapter B7), and by DFO at sockeye spawning grounds throughout the Fraser River watershed (Chapter C1). Scale samples were mostly aged by the PSC (Chapters B9 and C2), but ages were also provided by ADF&G. Among samples aged by both agencies, freshwater ages occasionally differed, but ocean ages were very consistent. (Size distributions across locations also supported comparability of ages; not shown.) For individuals with no available PSC age data, we used ADF&G age data instead. Production of nearly all Fraser sockeye stocks is dominated by individuals that spend two years at sea (2-ocean ages) with relatively few individuals returning after three years at sea (3-ocean ages). A small number of Fraser sockeye stocks produce individuals that mature primarily at 3-ocean ages. Other ages are ignored for our purposes here, because 4-ocean ages are extremely infrequent in any Fraser stock and 1-ocean Fraser sockeye may not be representatively sampled in test fisheries.

Methods

Several genetic methods were used to identify Fraser sockeye in D104 samples, and tissues or extracted DNA from these fish were sent to DFO for further analysis (Chapter B7). GSI was performed on these samples as in other FRP projects (Chapter B11), and stock of origin was estimated for each individual. Sockeye were identified to the usual 19 Fraser stock groups reported for in-season analysis (Chapter B11), but stock groups were further aggregated within systems with synchronized age composition fluctuation and/or difficulty distinguishing individuals (upper Fraser River groups Late Stuart and Stellako were combined, Quesnel Lake groups Horsefly and Mitchell were combined, and Early Shuswap was combined with Late Shuswap/Portage).

Sockeye assigned to stock groups with a posterior stock assignment probability greater than 50% were included in analyses, but analyses were duplicated using a probability threshold of 90%. In addition to allowing an evaluation of sensitivity to the chosen threshold, this analysis provided an indication of representativeness. When stock proportions in the mixtures are similar, the distributions of assigned stock membership probabilities should be consistent across fisheries, but if the fraction of true members is lower in a distant fishery, the distribution of probabilities of membership should also shift lower.

Therefore, we examined the proportion of individuals retained as identified to a stock group as the probability threshold changed from 50% to 90%, both within D104 purse seine samples and purse seine test fishing samples from areas 12 and 20.

We compared the D104, Area 12, and Area 20 purse seine samples statistically. Fisher's exact tests, implemented through R version 4.5.0 (R Core Team, 2025), were applied to each year independently without Bonferroni correction, comparing the frequencies of the two ages (2-ocean and 3-ocean) among the three fishery locations. Spawning ground samples are assumed to be more accurate than GSI with respect to stock-of-origin but, in some circumstances, these samples may not be representative due to inaccurate weighting of substocks, selective sampling, or differential survival (e.g., Peterson 1954). Estimates of age composition on the spawning grounds are therefore only provided for context and interpretation.

Results

***Table 1**. Sample sizes of aged Fraser sockeye (2011-2023) from purse seine fisheries in District 104 (D104), Area 12, and Area 20, and from spawning grounds. Only 2-ocean and 3-ocean ages were included. For fishery samples, GSI was used to identify individual sockeye to stock group of origin using a 50% and a 90% probability threshold. The proportion of individuals in each area identified using the 50% threshold that also met the more stringent 90% probability threshold and were retained (Ret) for sensitivity analyses is also shown. For spawning ground samples, sample site was assumed to represent the stock of origin.*

	District 104			Area 12			Area 20			Spawning
Stock Group	50%	90%	Ret	50%	90%	Ret	50%	90%	Ret	Ground
Early Stuart	8	5	0.63	40	11	0.28	40	10	0.25	5551
Chilliwack	5	2	0.40	77	73	0.95	56	50	0.89	2455
Pitt/Alouette/Coquitlam	12	9	0.75	277	254	0.92	372	342	0.92	4234
Nadina/Bowron	24	19	0.79	482	366	0.76	470	348	0.74	6173
Gates/Nahatlatch	31	31	1.00	474	467	0.99	240	231	0.96	4681
Taseko	0	0	-	20	16	0.80	18	11	0.61	282
Upper Barriere	1	0	0.00	30	21	0.70	43	20	0.47	1636
Harrison	9	5	0.56	374	298	0.80	1351	1171	0.87	4375
Widgeon	0	0	-	0	0	-	8	8	1.00	757
Late Stuart/Stellako	235	185	0.79	3068	2583	0.84	1902	1543	0.81	12309
Chilko	1017	889	0.87	6017	5308	0.88	3980	3462	0.87	7770
Quesnel	402	331	0.82	1473	1129	0.77	1066	818	0.77	7674
Raft/N. Thompson	68	47	0.69	534	345	0.65	265	161	0.61	5073
Birkenhead/Big Silver	79	69	0.87	475	423	0.89	569	502	0.88	6358
Early & Late Shuswap/Portage	367	302	0.82	2891	2377	0.82	1886	1568	0.83	13986
Weaver/Cultus	38	33	0.87	1143	1057	0.92	819	760	0.93	6171

The three stock groups with the largest sample sizes (Chilko, Quesnel, and Shuswap/Portage) showed no indication that the proportion of individuals retained at 90% probability was lower in samples from Alaska than in samples from Area 12 or Area 20 (see Table 1). In contrast, retention rates of Early Stuart were low in Area 12 and 20 purse seine test fisheries since Early Stuart sockeye have completed migrating into the Fraser River prior to the initiation of purse seine test fisheries, and the low retention ('Ret' in Table 1) likely reflects high proportions of Late Stuart sockeye misidentified as Early Stuart individuals. (Early Stuart retention at a 90% probability threshold in earlier Area 12 and 20 gillnet fisheries is much higher, 84%, not shown.)

Because Quesnel and Shuswap/Portage comprise highly cyclically abundant stocks, years with the highest sample sizes tended to be dominated by a single age class (Appendix A). Therefore, we focus only on Chilko sockeye here. The proportions of age 3-ocean Chilko sockeye observed in samples from D104, Area 12, Area 20, and spawning grounds are displayed in Figure 1. Sample sizes were smallest in D104, and standard errors were relatively large for those estimates. In 2014, 2016, and 2022, the point estimates for all areas were within one standard error of the D104 estimate. Among the remaining years, Area 12, Area 20, and spawning grounds samples had higher 3-ocean proportions than D104 in two years (2018 and 2020), and lower 3-ocean proportions in eight years. In general, age compositions were most similar between Area 12 and Area 20, and spawning ground estimates were more similar to Area 12 and 20 samples than to estimates for D104. Besides the tendency for D104 samples to have relatively high proportions of the older age class, spawning ground samples frequently had the lowest proportions of the older age class (see Figure 1). Proportions of 3-ocean fish were more often higher in Area 12 samples than Area 20 samples, but this tendency was not tested for significance.

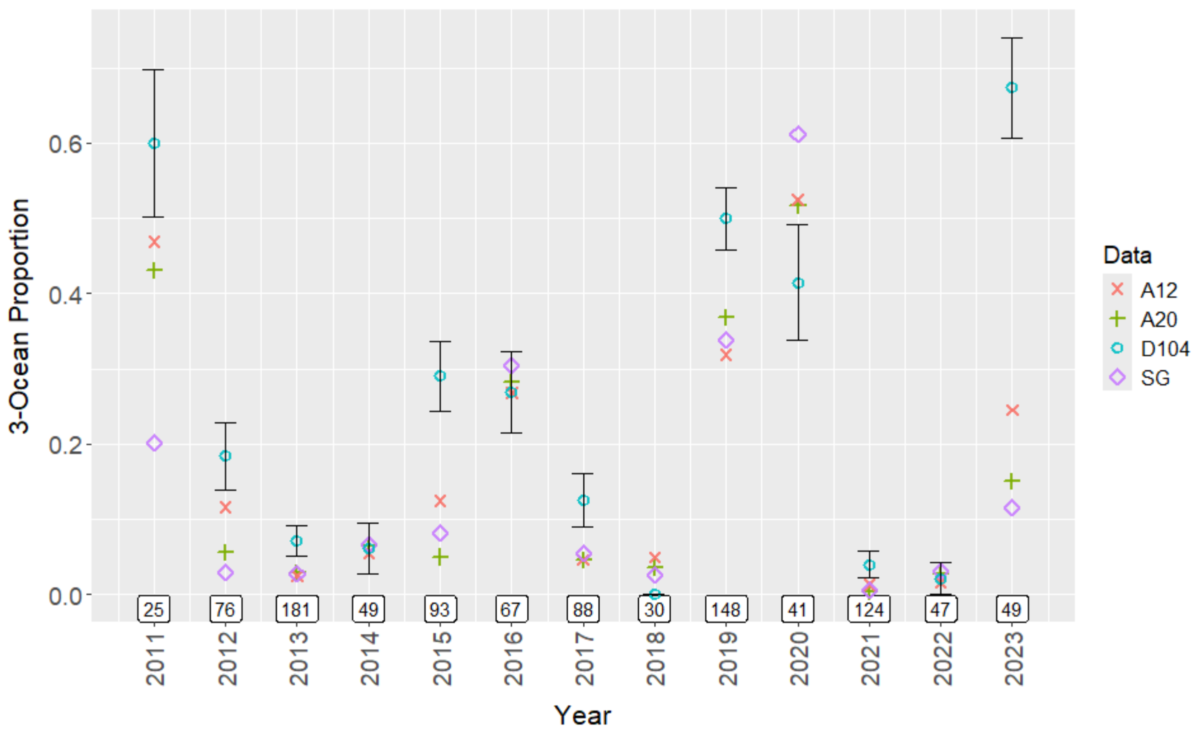

Figure 1. *Proportion of ocean age 3 Chilko sockeye in each of four sample locations: District 104 (D104), Blinkhorn purse seine test fishery (A12), San Juan purse seine test fishery (A20), and Chilko river/lake spawning ground (SG). The numbers shown at the bottom are the sample sizes from D104. Standard error bars are only shown for D104 for clarity.*

Fisher's exact tests conducted with Chilko age data evaluated the null hypothesis that age compositions were the same in each of the three purse seine catches: D104, Area 12, and Area 20. Using the 50% assignment threshold, age compositions differed significantly in 7 of 13 years (2012, 2013, 2015, 2017, 2019, 2021, and 2023), only one of which was an even-numbered year (Table 3). The only odd-numbered year with a non-significant result was 2011, the year with the smallest number of aged Chilko sockeye from D104. The non-significant results included 2018 and 2020, the only years for which the point estimate of 3-ocean sockeye proportion was low in D104 relative to other areas (see Table 2). Results were not sensitive to the use of the 90% assignment threshold: the estimated *p*-values changed, but the years found to exhibit significant differences among areas were the same (see Table 3).

Table 2. *Annual sample sizes and age compositions of Chilko sockeye from purse seine fisheries in District 104 (D104), Area 12, and Area 20, and from spawning grounds. For fishery samples, GSI was used to identify sockeye to stock group of origin using a 50% and a 90% probability threshold.*

	District 104				Area 12				Area 20				Spawning Ground	
	50%		90%		50%		90%		50%		90%			
Year	2-Ocean	3-Ocean	2-Ocean	3-Ocean	2-Ocean	3-Ocean	2-Ocean	3-Ocean	2-Ocean	3-Ocean	2-Ocean	3-Ocean	2-Ocean	3-Ocean
2011	10	15	9	13	174	154	153	145	144	110	122	99	525	132
2012	62	14	54	13	372	49	351	43	348	21	319	17	553	17
2013	167	13	141	13	693	18	603	16	428	13	365	7	686	19
2014	46	3	33	2	220	13	176	10	58	4	40	3	508	36
2015	66	27	61	22	490	70	442	59	301	16	268	14	610	54
2016	49	18	49	15	262	96	242	87	172	68	162	60	321	141
2017	77	11	64	11	622	30	536	22	353	17	311	13	576	33
2018	30	0	20	0	250	13	187	9	162	6	117	3	539	14
2019	74	74	69	63	414	194	383	167	65	38	55	37	376	192
2020	24	17	23	16	123	136	113	127	57	61	45	52	192	302
2021	119	5	107	4	656	9	604	9	756	3	681	3	680	4
2022	46	1	41	1	486	8	413	8	423	12	355	11	680	22
2023	16	33	15	30	351	114	308	95	292	52	259	44	494	64

Table 3. *Results of Fisher's exact tests comparing age compositions of Chilko sockeye identified using individual assignment, excluding putative Chilko sockeye from the analysis whose genetic assignment probabilities did not satisfy thresholds of 50% or 90%. Ages were compared in three purse seine fisheries each year: District 104 (D104), Area 12, and Area 20. NS indicates that differences among the fisheries were not statistically significant.*

	Using 50% probability threshold			Using 90% probability threshold		
Year	NS	$p < 0.05$	$p < 0.005$	NS	$p < 0.05$	$p < 0.005$
2011	✓			✓		
2012			✓			✓
2013		✓				✓
2014	✓			✓		
2015			✓			✓
2016	✓			✓		
2017		✓				✓
2018	✓			✓		
2019			✓			✓
2020	✓			✓		
2021			✓		✓	
2022	✓			✓		
2023			✓			✓

Discussion

Collected data present a temporal pattern in age composition differences between Chilko sockeye in D104 and in more terminal samples, with the largest differences in age composition observed on the 2023 cycle line (2011, 2015, 2019, and 2023). This cycle line generally comprises high proportions of 3-ocean Fraser sockeye as it follows the 2022 cycle line, which has been the dominant cycle line (strong 2-ocean returns) for many Fraser stocks in recent decades. Significantly older sockeye were also observed in D104 than in more terminal fisheries in all three years on the 2021 cycle line. The effect size was smaller than on the 2023 cycle, but sample sizes of Chilko sockeye were quite high (Figure 1). Out of six even-numbered years, by contrast, a significant difference was observed in only one. The ability to detect differences among age compositions was very limited on the 2022 cycle line because proportions of the 2-ocean age class were close to 100% for Chilko sockeye. Also, it should not be overlooked that the sample size of Chilko sockeye tended to be lower in D104 on even numbered years. Pink salmon have been hypothesized to affect date of return of Fraser sockeye salmon (Nelitz et al. 2018), possibly due to effects on size at maturity, swim speed, and marine distribution (Latham et al. 2024). A biennial effect on availability of Fraser sockeye to the D104 fishery may be a consequence of the distribution and abundance of pink salmon, not to mention possible differences in D104 fishery operations between odd- and even-numbered years. It is not clear that the temporal pattern in observed age compositions reflects a biennial effect on the distribution and/or behaviour of Chilko sockeye age classes rather than ability to detect it.

There are several possible explanations for older age classes being more frequent in Fraser sockeye in D104 samples. Chance should be ruled out as significant differences were observed across years and were insensitive to probability thresholds for individual identification. Also, methodological effects related to date of capture within years do not appear capable of generating the observed pattern – in odd-numbered years, higher frequencies of 3-ocean Chilko sockeye were observed in D104 across multiple statistical weeks (especially in 2015 and 2023; see Appendix B). Other possible sampling biases are more difficult to dismiss, however. For example, landings of sockeye may be inadvertently sorted by size while they are sorted by species, and such a process may cause different offload locations to differ in the relative availability for sampling of smaller and younger sockeye versus larger and older sockeye. No data are available here to assess such a sampling bias, and no data or research are available to suggest a difference in the prevalence of such a bias among sampling locations that would explain the observed results.

In contrast to methodological explanations, biological explanations for the observed age composition differences are consistent with reports in the literature for other species. For example, Fraser sockeye at sea for longer may stochastically reach more northern areas of the ocean and therefore occur more frequently in fisheries at high latitudes. Weitkamp (2010) found that Chinook salmon caught far from their natal streams more frequently belonged to older ocean ages than younger ocean ages, but she noted that age-specific habitat preferences could also explain the pattern. Older Chilko sockeye may show a stronger preference for cooler ocean temperatures than younger Chilko sockeye. Such a preference was inferred by Morita et al. (2010) for pink and chum salmon. Alternatively, older sockeye may be more likely to get lost and stray. A positive association between age and straying has been observed in other salmon species (e.g., Atlantic salmon, Jonsson et al. 2012; steelhead, Keefer and Caudill, 2012). Putman et al. (2014) suggest Fraser sockeye orient and navigate using geomagnetic fields and that drift in these fields affects the routes taken during homeward migrations. Older ocean ages allow for more geomagnetic drift to occur since imprinting, perhaps impairing the ability of older salmon to return.

The peak abundances and stock compositions of Fraser sockeye in D104 do not cohere temporally with the known arrival of stocks to the Fraser Panel areas, and Fraser sockeye in D104 during the fishery are unlikely to successfully migrate to the Fraser River in the same year, even if not harvested (Chapter C9). This might be explained if considerable proportions of the Fraser sockeye in D104 were not maturing in the year of capture. In that case, stock compositions would differ versus maturing Fraser sockeye, and late summer residence so far from the Fraser River would not conflict with required spawning date. Here we showed that, like stock compositions, age compositions also suggest that Chilko sockeye in D104 are not representative of the return migration assessed closer to the Fraser River. The age composition difference is opposite to expectations under this hypothesis, however. If Fraser sockeye were not maturing in their year of capture in D104, they should on average be younger than Fraser sockeye that do mature in the year of capture. Instead, Chilko sockeye samples from D104 comprised relatively high proportions of 3-ocean ages, a cohort that would return as 4-ocean fish the subsequent year. The extreme rarity of this age class in returning Fraser sockeye contradicts this explanation.

Future Steps

GSI has greatly improved our ability to make inferences from samples of northern catches. Age compositions of Fraser sockeye stocks harvested in northern fisheries have been assumed to match those of reconstructions within Fraser Panel areas. This assumption was critical in estimating Fraser sockeye harvest in D104 using Scale Pattern Analysis (SPA, Chapter B10). The harvest of 2-ocean fish that reared in a lake for one year was estimated with SPA, and the harvest of other age classes was assumed to be proportional to relative abundances in Fraser Panel areas. Higher fractions of 3-ocean ages in northern areas, as described above for some years, would have negatively biased both Fraser sockeye harvest estimates and production estimates for older Fraser sockeye age classes. Age assumptions may also be violated in other fisheries and those fisheries with adequate data should be evaluated.

As seen in the data collected to date, years vary considerably in their usefulness for comparing Fraser sockeye age compositions among areas. Highly informative years regarding D104 ages are infrequent for Fraser stocks, as high sample sizes in D104 tend to coincide with dominance by their most common age class. To improve brood-year production estimates, priorities include maintaining or improving access to Fraser sockeye samples to ensure the requisite data collection is supported and making better use of the samples that are obtained. Below are recommendations regarding the latter priority.

1. As more data are collected, including highly reliable individual identifications provided by the DFO SNP baseline (Chapter C9), use a more comprehensive and rigorous modeling approach to determine if other Fraser sockeye stocks in general show similar patterns to Chilko sockeye.
2. Expand access to and use of information from non-Fraser stocks, including those that are not south-migrating. For example, partner agencies may have data for other stocks that facilitate evaluation of possible selectivity or selective mortality.
3. Review and improve the methods by which age compositions are applied to Fraser sockeye catches (including in D104) to best estimate recruits by brood year, perhaps as part of a management strategy evaluation.

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Appendix A

Table A1. *Annual sample sizes and age compositions of Quesnel sockeye from purse seine fisheries in District 104 (D104), Area 12, and Area 20, and from spawning grounds. For fishery samples, GSI was used to identify sockeye to stock group of origin using a 50% and a 90% probability threshold. For spawning ground samples, sample site was assumed to represent the stock of origin.*

	District 104				Area 12				Area 20				Spawning Ground	
	50%		90%		50%		90%		50%		90%			
Year	2-Ocean	3-Ocean	2-Ocean	3-Ocean	2-Ocean	3-Ocean	2-Ocean	3-Ocean	2-Ocean	3-Ocean	2-Ocean	3-Ocean	2-Ocean	3-Ocean
2011	1	0	1	0	10	8	6	6	14	13	9	9	295	179
2012	0	1	0	1	4	1	3	1	4	0	2	0	63	44
2013	67	1	60	1	156	2	128	0	55	1	38	0	1200	29
2014	88	0	77	0	178	1	134	0	64	0	35	0	986	8
2015	8	10	5	5	22	28	15	23	14	3	8	2	163	126
2016	0	2	0	0	2	4	1	4	0	0	0	0	4	29
2017	62	0	53	0	204	1	168	0	99	1	77	1	782	2
2018	46	0	37	0	266	1	209	1	238	1	193	1	820	4
2019	5	44	5	35	11	101	8	70	4	21	3	17	61	429
2020	0	0	0	0	3	3	1	3	1	2	0	1	24	77
2021	6	0	5	0	28	1	26	1	54	1	39	0	626	4
2022	39	3	34	1	350	1	259	1	420	3	341	0	1068	1
2023	5	14	4	7	30	57	19	42	21	32	17	25	231	419

Table A2. *Annual sample sizes and age compositions of Early & Late Shuswap/Portage sockeye (in aggregate) from purse seine fisheries in District 104 (D104), Area 12, and Area 20, and from spawning grounds. For fishery samples, GSI was used to identify sockeye to stock group of origin using a 50% and a 90% probability threshold. For spawning ground samples, sample site was assumed to represent the stock of origin.*

	District 104				Area 12				Area 20				Spawning Ground	
	50%		90%		50%		90%		50%		90%			
Year	2-Ocean	3-Ocean	2-Ocean	3-Ocean	2-Ocean	3-Ocean	2-Ocean	3-Ocean	2-Ocean	3-Ocean	2-Ocean	3-Ocean	2-Ocean	3-Ocean
2011	1	6	0	6	70	92	59	78	68	68	51	59	718	941
2012	0	0	0	0	5	2	4	1	9	3	7	0	199	27
2013	40	0	25	0	285	1	209	1	197	2	157	1	1353	27
2014	112	0	95	0	670	6	578	4	267	9	244	7	1929	9
2015	6	13	4	9	75	43	52	34	48	6	40	3	864	446
2016	0	1	0	1	6	5	3	1	2	0	2	0	77	20
2017	9	1	5	1	121	5	79	1	26	1	18	0	842	7
2018	123	1	110	1	892	6	806	3	647	2	573	0	2060	4
2019	0	19	0	16	27	45	22	31	6	12	5	6	142	493
2020	2	0	2	0	17	1	13	1	10	2	6	1	82	6
2021	12	0	8	0	67	1	43	0	70	2	46	1	930	8
2022	18	1	17	1	357	6	291	3	360	1	285	0	1560	4
2023	1	1	1	0	59	27	43	17	53	15	43	13	1022	216

Appendix B

We compared and interpreted annual estimates of age composition for identified Chilko sockeye among fishing locations. Fraser sockeye sample sizes in D104 are often higher in later statistical weeks, possibly due to lower proportions of non-Fraser stocks late in the season. If Chilko sockeye age compositions differed between earlier and later statistical weeks, the late increase in sampling intensity could affect the age composition estimate. To evaluate whether observed differences were due to temporal subsampling issues, we inspected Chilko age compositions by week, and these are shown in Figure B1. Trends in age compositions across statistical weeks were not apparent and, for several years with significantly older ocean ages in D104 (e.g., 2015 and 2019), the pattern was consistent across weeks. The only years in which differences in fishery dates appeared to strongly influence comparisons of annual age compositions across locations were 2016 and 2020. In those years, there were weeks of D104 results that were not matched by age compositions in Area 12 and Area 20 test fisheries. The proportion of 3-ocean ages of Chilko sockeye in the D104 fishery was relatively low in weeks without matching data in Area 12 and Area 20, perhaps biasing the annual comparison to indicate younger ages in D104, contrary to observations in other years.

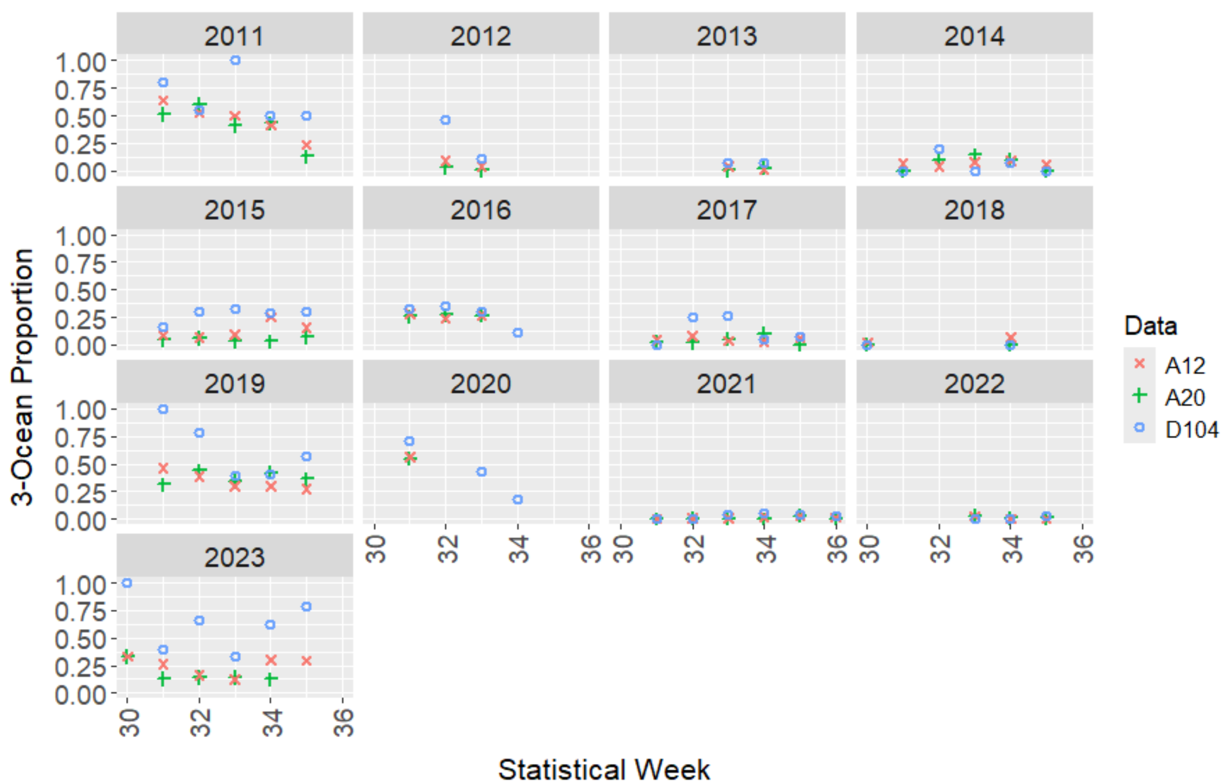

Figure B1. *Proportion of ocean age-2 Chilko sockeye (identified using a 50% probability threshold) by statistical week in each of three sample locations: District 104 (D104), A12, and A20.*

C11. Stock-specific production data

E. Taylor

Summary

The Fraser River sockeye production dataset integrates spawner, juvenile, and adult return information to support assessment, forecasting, and management of Fraser River sockeye salmon. It provides a curated, reproducible record of stock productivity and recruitment by production stock group, drawing on spawning ground and juvenile data from Fisheries and Oceans Canada (DFO) (Chapter C1) and adult return estimates developed by the Pacific Salmon Commission (PSC) (Chapter C6). Data are aggregated to 19 major and 7 miscellaneous production stock groups that align with established forecasting processes (Chapter A1). The dataset incorporates evolving recruitment estimation methods, including post-season Run Size Adjustments (RSAs, Chapter C6) and provisional in-season estimates (Chapter B21), along with metadata describing age composition (Chapter C2), stock identification quality, and data limitations. Together, these features ensure the dataset supports transparent, scientifically defensible analyses while clearly communicating uncertainty and appropriate use.

Introduction

The Fraser River sockeye production data, also termed stock-recruit data or brood-year tables, is used to support forecasting (Chapter A1), assessment (Chapter A9), and management of Fraser River sockeye salmon under the Pacific Salmon Treaty (PST 2025). It integrates spawner, juvenile, and adult return data across multiple decades to support analyses of stock productivity and recruitment at the level of defined production stock groups.

The primary purpose of the production dataset is to provide a coherent and reproducible record of spawner and juvenile abundances and recruit production for Fraser River sockeye stocks. These data support multiple objectives, including stock-recruit analyses, pre-season forecasting, post-season evaluation of returns, and broader scientific and management discussions related to productivity, survival, and long-term trends. The following text provides an overview of the collection, processing, and organization of the Fraser River sockeye production dataset, with emphasis on the key biological inputs, i.e. spawner and juvenile abundance, recruitment estimates, genetic stock composition, and age structure, and guidance on how to interpret and use the resulting production data.

Data

The production dataset for Fraser River sockeye salmon is one of the longest and most comprehensive stock-recruitment data sets for a fish stock in the world, with brood years going back to 1948. Fraser River sockeye data within the production dataset are aggregated to production stock groups, which correspond to the forecast groupings used by DFO's Fraser Interior Area Stock Assessment Division (Chapter A1). The Fraser River sockeye production stocks are represented by 19 major production stocks and 7 miscellaneous stocks, collectively representing the full set of Fraser River sockeye production units (Tables 1 and 2). Major stocks are those with sufficiently long and reliable time series of spawner and recruit data to support formal stock-recruit modeling and quantitative forecasting. Miscellaneous stocks generally lack adequate data for such analyses and are typically forecast using alternative approaches, such as escapement-based methods or proxy productivity from similar stocks.

Spawner, juvenile, and adult return data are not originally collected at the production stock group level. Spawner and juvenile data are collected at individual streams or survey sites (Chapter C1), while adult return data are derived from catch and escapement estimates that are initially resolved using genetic baseline groupings (Chapter C6). Translation tables and aggregation rules are applied to align these inputs to the production stock group framework. The aggregation methods used in this dataset are consistent with those applied in the Fraser River sockeye forecasting process. Although there is overlap between production stock groups, conservation units, and management units, these classifications are not interchangeable, and users should be cautious when comparing results across different population frameworks (Tables 1 and 2).

Table 1*. Translation of Early Stuart and Early Summer-run populations found in the Fraser River sockeye Production Files. See Table 2 for Summer- and Late-run populations. The number in parentheses in column headings refers to the total number of groups within that population classification. Catch and Racial (C&R) groupings are important for in-season assessments due to similarities in timing, stock identification, and migratory routes.*

Baseline (50)	Production Stock Code (27)	Production Group (27)	Conservation Unit	C&R (19)	Management Group (4)
Driftwood-Narrows	1	Early Stuart	Takla Trembleur - Early Stuart	EStu	Early Stuart
Bivouac-Rossette					
Dust-Sinta					
Paula-Felix					
Chilliw_lake	23	Misc (Chilliwack)	Chilliwack - Early Summer	Chwk	Early Summer
DollyVarden_Cr					
Chilliwack_Kok					
Alouette_Kok	18	Pitt	Alouette - Early Summer	PiAC	
Coquitlam_Kok					
Pitt_River			Pitt - Early Summer		
Nadina____	17	Nadina	Fraser - Early Summer Nadina-Francois - Early Summer Francois (First Run) Early Summer (extirpated?)	NdBo	
Bowron_____	4	Bowron	Bowron - Early Summer Indian/Kruger - Early Summer (extirpated?) Upper Fraser - Summer		
Nahatlatch	24	Misc (Nahatlatch)	Nahatlatch - Early Summer	GaNh	
Gates_Creek	16	Gates	Anderson Seton - Early Summer Middle Fraser - Summer		
Taseko	22	Misc (Taseko)	Taseko - Early Summer	Tsko	
Upper_Barriere	14	Upper Barriere (Fennell)	North Barriere - Early Summer	NBar	
Upper_Adams	21	Misc (EShu)	Shuswap - Early Summer	ESTh	
Cayenne____					
Eagle_____					
Seymour___	8	Seymour			
Scotch____	15	Scotch			

Table 2. *Translation of Summer- and Late-run populations found in the Fraser River sockeye Production Files. See Table 1 for Early Stuart and Early Summer-run populations. The number in parentheses in column headings refers to the total number of groups within that population classification. Catch and Racial (C&R) groupings are important for in-season assessments due to similarities in timing, stock identification, and migratory routes.*

Baseline (50)	Production Stock Code (27)	Production Group (27)	Conservation Unit	C&R (19)	Management Group (4)
Harrison__	19	Harrison	Harrison River - Summer Kawkawa - Late	Harr	Summer
WidgeonSlough	27	Misc (Widgeon)	Widgeon - Summer	Widg	Summer
Middle_River Kuzkwa_Creek Pinchi_Creek Tachie____	2	Late Stuart	Takla Trembleur - Summer	LStu	Summer
Stellako__	3	Stellako	Francois-Fraser - Summer Fraser - Early Summer Upper Fraser - Summer	Stel	Summer
Chilko_____ Chilko_north Chilko_south	7	Chilko	Chilko - Summer Chilko - Early Summer	Chil	Summer
Mid_Horsefly Upper_Horsefly McKinley Lower_Horsefly	6	Quesnel	Quesnel - Summer Middle Fraser - Summer Cariboo - Summer	Hfly	Summer
Mitchell____ Blue_Lead_Ck Wasko-Roaring	6	Quesnel	Quesnel - Summer	Mtch	Summer
Raft_______	5	Raft	Kamloops - Summer	RaNT	Summer
NorthThompson	26	Misc (N. Thomp. River)	Kamloops - Summer	RaNT	Summer
	25	Misc (N. Thomp. Tribs.)[1]		RaNT	Summer
Birkenhead_	10	Birkenhead	Lillooet-Harrison - Late Harrison (D/S) - Late	BiBS	Late
Big_Silver	28	Misc (Harrison/Lillooet)	Harrison (D/S) - Late	BiBS	Late
Lower_Adams Eagle_late LittleRiver-LittleShu Lower_Shuswap MiddleShuswap	9	Late Shuswap	Shuswap Complex - Late	LShP	Late
Portage_Creek	12	Portage	Seton - Late Middle Fraser - Late	LShP	Late
Weaver____	13	Weaver	Harrison (U/S) - Late	WeCu	Late
Cultus_Lake	11	Cultus	Cultus - Late	WeCu	Late

[1]No available baselines for this group. Sockeye from this group are lumped into Raft or North Thompson in-season.

The production dataset is not a raw data repository. Rather, it represents a curated synthesis of multiple assessment programs, each with its own uncertainties, methodological changes, and data limitations. The production dataset therefore includes not only core biological estimates but also metadata, flags, and explanatory fields designed to guide interpretation and appropriate use. The dataset relies on a division of responsibilities between Fisheries and Oceans Canada (DFO), which conducts spawning ground and juvenile assessments, and the Pacific Salmon Commission (PSC), which conducts in-season assessments of adult returns.

Spawner data are derived from an extensive spawning ground enumeration program coordinated by DFO and implemented in partnership with First Nations (Chapter C1). These data represent the best available estimates of spawning escapement for Fraser River sockeye and include estimates of total spawners, sex composition, spawning success, and effective female spawners (EFS). Effective female spawners refers to the estimated number of female spawners in a given brood year, adjusted downward to account for the proportion of eggs that were not successfully deposited, as determined from sampling on the spawning grounds. Juvenile production data, where available, include estimates of fry and smolt abundance by brood year. Spawning ground enumeration methods vary substantially among stocks and years. High-precision methods such as fences and sonar are used where feasible, particularly for higher-abundance stocks, while lower-precision visual surveys are used in other systems. Visual surveys require the application of expansion factors to estimate total escapement and are subject to greater uncertainty. Changes in funding, site access, and survey priorities over time have influenced which methods are applied to individual stocks, and users should recognize that data quality is not uniform across the dataset. Spawner data are aggregated to the production stock group level by PSC staff and, in limited cases, imputed for years when no enumeration occurred. Some spawners enumerated by DFO are excluded from the production dataset when fish cannot be assigned with sufficient confidence to a specific production stock group. Importantly, the spawner data used in the production dataset are not directly comparable with values reported in the New Salmon Escapement Database System (NuSEDS), which should not be used as a substitute for production data in assessment or forecasting contexts.

Recruit data represent estimates of the number of adult sockeye returning to the Fraser River to spawn, resolved by production stock group, return year, and age class using the Gilbert and Rich (1927) age notation. Recruitment estimation methods have evolved over time in response to changing assessment tools, environmental conditions, and improved understanding of in-river mortality. Historically, recruitment estimates were derived from spawning escapement and catch data, with post-season adjustments based on differences between upstream escapement estimates and observed returns. Since 2009, post-season recruitment estimates have been produced through a Run Size Adjustment (RSA) process (Chapter C6, DFO 2025). The RSA integrates spawning ground data, catch data, environmental information, and expert judgment to account for en-route mortality and biases in in-season estimates. Post-RSA recruitment estimates are considered the most reliable representation of true recruitment but are often unavailable for the most recent one or more return years due to the time required to complete the process. To address this lag, the dataset also includes in-season-based run size estimates, which are derived from Mission escapement estimates and seaward catches. Stock composition for in-season estimates depends on genetic stock identification from catch samples (Chapter B11). The ability to distinguish individual stocks varies among production groups due to limitations in current DNA methods. The in-season-based run size estimates provide timely but provisional information and are subject to greater uncertainty, particularly for stocks that are difficult to distinguish genetically. The dataset explicitly identifies the type of run size estimate used for each record to support appropriate interpretation. To allow users to assess whether in-season estimates for a given stock should be used with caution or avoided entirely, the dataset includes a stock identification quality indicator.

Age composition is a critical component of the recruitment estimates and determines how total returns are assigned back to brood years. Final age composition estimates rely primarily on scale and otolith samples collected on the spawning grounds (Chapter C2), supplemented by samples from test and commercial fisheries where necessary (Chapter B7). When sample sizes are insufficient, expert judgment and auxiliary information are used to gap fill missing data.

Results

The Fraser River sockeye production dataset is a comprehensive and evolving resource designed to support scientific assessment and management decision making. Its strength lies in the integration of multiple assessment programs into a consistent and transparent framework. However, users must recognize that data quality, uncertainty, and methodological consistency vary across stocks and years. Metadata fields, exclusion flags, and run size type indicators are essential tools for ensuring that the dataset is used appropriately and that conclusions drawn from it are scientifically defensible.

The production dataset is publicly available on the PSC website and distributed in two formats: a summary format and a detailed format. The summary format presents production stock information by brood year and provides a high-level overview consistent with historical production files. This format is simpler to interpret but cannot fully represent information that varies by return year or age class. As a result, some data, such as in-season-based run size estimates and detailed metadata, are excluded. The detailed format presents data at the cohort level, with each row representing a unique combination of production stock group, brood year, and age at return. This format includes the most up-to-date recruitment estimates, additional metadata fields, and in-season information, and allows for easy manipulation of the data in Excel or R. Because spawner data are repeated across age classes in this format, users must take care to avoid double-counting when summarizing or analyzing the data. The two data files are accompanied by detailed documentation of the production data, including descriptions of the data fields.

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C12. Data quality indicators

M.J. Hague, D. Brkic, and S. Wong

Summary

Advancements in genetic stock identification combined with management requirements for small, at-risk stocks have led to increasing demand for salmon data at a finer resolution. In response, Pacific Salmon Commission (PSC) staff constructed databases containing estimates of escapement, catch, run size, and passage at the same stream-level resolution as the spawning escapement time series. Storing data at the stream level allows estimates to be flexibly aggregated over a range of stock resolutions. While the finer resolutions allow biologists and managers to explore more complex questions, the data are inherently more prone to uncertainty and violations of underlying assumptions. The development of data quality indicators is an alternative approach for identifying and scoring the relative uncertainty across different datasets, particularly when they vary in resolution and/or underlying methodology used for data collection or processing. By pairing data requests with a corresponding set of quality indicators, the PSC aims to better inform end-users of the limitations of the data and to mitigate the possibility of inaccurate assessments based on known, but unquantified, data and assessment errors.

Introduction

Over time, advances in genetic stock identification (GSI) technology (Chapter B11), combined with real-time processing of samples collected from a suite of marine and freshwater test, commercial, and recreational fisheries (Chapter B7) have improved the quality and resolution of stock identification data used for managing Fraser River sockeye salmon (*Oncorhynchus nerka*) (Beacham et al. 2004). In parallel to these advancements, Canada has also developed an ever-increasing network of fisheries policies, guidelines, targets, and legal requirements (e.g., Tables 2 and 3 from Holt et al. 2020) that demand identification and assessment of salmon stocks at the scale of “conservation” unit (CU) or “designatable” units (DU). These regulations, paired with an increased number of Endangered CU listings by the Committee on the Status of Endangered Wildlife in Canada (Huang et al. 2021, DFO 2022), have driven the need for more conservative harvest management strategies and finer-scale stock resolution in the assessment of Fraser River sockeye.

In response to both data improvements, and shifting management requirements, PSC staff initiated a multi-year data management strategy beginning with the production and storage of finer stock-resolution catch time series (Dionne and Patterson 2018). This was subsequently followed by similar refinements to the data and modelling approaches used for post-season run reconstructions (Hague et al. 2023). While the PSC has historically disseminated post-season time series as “known” values, i.e., as point estimates with no associated uncertainty, increased requests and capacity to provide finer resolution time series drew attention to the recognised, but unquantified, variability in data quality across years, locations, and stocks. Even with the rigorous data checking protocols applied to catch, passage, and run size estimates stored within PSC databases (Dionne and Patterson 2018, Hague et al. 2023), the assumptions applied when generating finer resolution reconstruction data (Hague et al. 2023) still lead to inherent uncertainty in derived time series.

Uncertainty associated with data or estimates is often communicated using Bayesian probability distributions, frequentist confidence intervals, or discrete sensitivity analyses (Privitera-Johnson and Punt 2020). However, an alternative to these quantitative approaches for describing uncertainty is the development of "quality" classifications. Assigning "tiers" to different fisheries assessment and management systems, for example, is a global practice (Dichmont et al. 2016, Dowling et al. 2016, Benaka et al. 2021). Generally, a higher tier represents a more data limited system, and implies the need for more precautionary management (Dowling et al. 2016). While the exact structure and metrics used to define tier classifications vary across fisheries, Dichmont et al. (2016) recommend that classifications should consider both data quality as well as the quality of the assessment systems. The PSC applies a similar approach to documenting the uncertainty in "raw" and derived stock assessment time series associated with Fraser River sockeye salmon. By pairing data requests with a corresponding set of quality indicators, the PSC aims to better inform end-users of the limitations of the data and to mitigate the possibility of inaccurate assessments based on known, but unquantified, data and assessment errors (Chen 2003).

Methods

DATA SOURCES

Data were queried from the PSC Run Size, Fishing, and Escapement (RuFEs, Chapter C17) and the Daily Reconstructed Marine Abundance (DARMA, Chapter C18) databases.

DATA QUALITY INDICATORS

A standardised system for assigning data quality ensures all data users are provided the same context when evaluating the usefulness of a time series (Costanza et al. 1992). Data quality indicators can generally be grouped into one of two categories: (1) quality assurance (QA), or (2) quality control (QC). Campbell et al. (2013) classified QA metrics as "process oriented", and QC metrics as "product oriented". Quality assurance indicators relate to data sampling methodology and can be identified independently of the time series itself (Campbell et al. 2013). For example, Fraser sockeye run sizes from the early 1900s were estimated from cannery records, compared to current approaches requiring direct estimates of catch and escapement. Therefore, historical run size estimates are likely less certain than current assessments, even though it would be challenging, if not impossible, to directly quantify the historical uncertainty. In comparison, quality control indicators are calculated from the data themselves and may include metrics such as values out-of-range, frequency of missing data, or sample size. Expert knowledge was used to identify appropriate data quality indicators for catch, reconstructed marine abundances, and hydroacoustic estimates of fish passage for adult Fraser River sockeye salmon, and a flexible code base was developed to easily re-generate data quality assessments at different spatial, temporal and stock resolutions.

DATA QUALITY SCORE

To provide an overall assessment of data quality, indicators must be evaluated against some kind of categorical or numerical scoring system. For this purpose, the PSC has adopted a 5-tier sliding scale of data quality scores ranging from "Excellent" to "Do Not Use" (Table 1). Each score is assigned a corresponding colour ranging from red (poor quality) to green (high quality) which is displayed in the output in lieu of a number.

Table 1. *An interpretation of PSC data quality scores ranging from "do not use" to "excellent".*

Excellent	Data is of the highest quality, robust to changes in underlying assumptions and has been generated using current best practices.
Good	Data is of good quality and has been generated using current best practices. Some gap filling assumptions were applied to meet the requested data resolution.
Moderate	Data is of average quality and caution should be applied with drawing statistical inference from this data. Aggregating the data into coarser spatial, temporal or stock resolutions may be advisable.
Poor	Data quality is limited due to either the large number of assumptions required to produce the dataset, or because historical sampling methodology is more prone to error and uncertainty.
Do Not Use	While this timeseries can be generated, multiple assumptions and gap filling may have been required and/or the underlying sampling methods may be undocumented.

QUALITY ASSURANCE INDICATORS

Six different quality assurance metrics were identified to provide a general assessment of PSC data quality (Table 2): (1) data type, (2) stock resolution, (3) temporal resolution, (4) spatial resolution, (5) user specifications, i.e., disaggregation by gear, fishery, fishery user, (6) time periods as a proxy for major changes in sampling methodology. Table 2 provides an example of the QA indicators associated with a data request for daily marine catches at the Fraser sockeye management group level for years since 2013.

Table 2. *An example of quality assurance (QA) scores for a hypothetical catch data request at a daily resolution by RSA stock group and only including years since 2013.*

Data Type	Catch
Temporal Resolution	Daily
Stock Resolution	RSA Stocks
Spatial Resolution	Downsteam of Mission
User Specification	None
Time Periods	2009-Current

Overall Score	Moderate

In this example, the fine temporal scale of the data (daily) is a significant contributor to the overall assessment of "moderate" data quality. More data issues are typically associated with daily data, or data at a fine stock resolution, as a greater number of underlying assumptions are required to produce the estimates. If the request was modified to identify annual catches, for example, the data quality score would improve to "good".

However, the high-level quality assurance indicators only provide a generalised assessment of the requested data. Quality control indicators calculated directly from a time series are also required to highlight intra-annual and inter-annual variation within a given dataset and to explore the differences in relative data quality across stock groups.

QUALITY CONTROL (STOCK-SPECIFIC) INDICATORS

For each data type, a unique suite of metrics, indicators, thresholds, and weighting criteria were identified based on expert knowledge regarding unquantified sources of error and uncertainty in each dataset. The calculation of stock-specific data quality scores involves several steps:

1) Identify a suite of *n* quantifiable metrics (M_n) to describe the data (*D*). These can be derived from the raw time series, or relevant metadata.
2) Identify corresponding quality indicators (I_n) from the metrics. For example, if the data type is stock-specific catch, metrics might include both total catch, and catch by stock, while the indicator is the percentage of the stock in the catch, i.e. catch by stock/total catch).
3) Calculate the daily value of each indicator ($I_{d,n}$).
4) Derive a set of critical thresholds or bi-variate criteria associated with each indicator (T_n).
5) Compare the daily value of each indicator to its respective threshold to “flag” data points ($F_{d,n}$) as “high” ($F_{d,n}$ = 1) or “low” ($F_{d,n}$ = 0) quality, e.g.

$$\text{if } I_{d,n} > T_n \; then \; F_{d,n} = 1, else \; F_{d,n} = 0$$

6) The quality score (Q_n) for an indicator is calculated in one of two ways:
    a. Unweighted: Q_n is the proportion of days where $F_{d,n} = 1$

    $$Q_n = \frac{\sum_{d=1}^{Days} F_{d,n}}{days}$$

    b. Weighted: Q_n is the proportion of the data associated with “high” quality flags divided by sum of all the data. This approach will ensure that the score is weighted by the value of the data, and not just by the frequency of occurrence. Weighting prevents low quality data that may be associated with low catch or abundance days at the “tail” ends of run, from disproportionately impacting the overall quality score assigned to the time series.

    $$D_{flag,n} = \sum_{d=1}^{Days} D_d \cdot F_{d,n}$$

    $$Q_n = \frac{D_{flag,n}}{\sum_{d=1}^{Days} D_d}$$

7) Assign expert-based relative “weights” to each indicator, depending on how strongly they are thought to represent the overall data quality (W_n).
8) Calculate weighted average scores across all indicators to generate an overall data quality score for the time series.

$$Q = \frac{\sum_{n=1}^{N} Q_n \cdot W_n}{N}$$

9) Convert the numerical data quality estimate into the five-tier structure assigned to PSC data quality using the translations described in Table 1:

Table 1. *Conversion between relative quality control scores and the data quality descriptions defined in Table**.***

Quality Control (QC) Score	*Data Quality Description*
QC<20%	Do not use
20%≤QC<40%	Poor
40%≤QC<60%	Moderate
60%≤QC<80%	Good
QC>80%	Excellent

Results

The following results (Table 3) provide an example of quality control scores for annual estimates of sockeye catch (pooled over all fisheries) (2013-2023) at an intermediate stock aggregate resolution. These overall scores are weighted averages across the indicators provided in Table 4. In general, the quality of stock-specific catch estimates is most strongly influenced by the proportion of the stock in the catch. A detailed example of the scoring by performance metric and by year is provided for the Early Stuart stock in Table 4 and is available in more detail in the Appendix of Hague et al. 2023. In general, smaller stocks that have lower representation in the catch are assigned lower quality scores. Early Stuart is an exception as the temporal separation of this stock from other components of the run means that even when Early Stuart catches are low, they tend to comprise a higher percentage of the total catch on that day.

Table 3. *Average data quality for daily estimates of total sockeye catch, aggregated over all years (2013-2023) and all quality control indicators. Depending on the stock selected, data quality ranges from poor to excellent.*

Stock Group	Quality
13b Chilko (river + north lake)	
11 Late Stuart	
12 Stellako	
1 Early Stuart	
4a Nadina	
9 Harrison	
13a Early Chilko (south lake)	
14 Horsefly	
5a Gates	
17a Birkenhead+	
18a Late Shuswap	
3a Upper Pitt	
15 Mitchell	
2 Chilliwack	
8b Early Shuswap	
16b North Thompson	
19a Weaver	
16a Raft	
4b Bowron	
5b Nahatlatch	
18b Portage	
17b Big Silver+	
19b Cultus	
7 North Barriere	
8a Adams Lake	
6 Taseko	
10 Widgeon	
3b Alouette+Coquitlam	

Table 4. *Data quality by year and quality control indicators for daily estimates of total Early Stuart catch. SmStkMag = small stock composition magnitude (proportion of days where the percentage of the stock in the catch fell below a threshold and the daily stock specific catch was above a threshold percentage of the annual stock-specific catch); Missing = number of days with missing stock-specific catch data; SmStkFreq = small stock composition frequency (proportion of days where the percentage of the stock in the catch fell below a threshold); pGSI = the percentage of stock-specific catches on a given day that were derived from direct genetic sampling.*

Stock Group	Year	SmStkMag	Missing	SmStkFreq	pGSI	Overall
1 Early Stuart	2013					
1 Early Stuart	2014					
1 Early Stuart	2015					
1 Early Stuart	2016					
1 Early Stuart	2017					
1 Early Stuart	2018					
1 Early Stuart	2019					
1 Early Stuart	2020					
1 Early Stuart	2021					
1 Early Stuart	2022					
1 Early Stuart	2023					

Future Work

An R Shiny application is being developed that will be used to simultaneously generate data time series and accompanying data quality reports to help improve the efficiency and transparency with which the PSC responds to data quality requests. In the future, quality performance criteria will be developed for other data sets maintained at the PSC, potentially including age composition, productivity, and biological variables.

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C13. Test Fishing database

T. Sutherland

Summary

The Test Fishing Database is a centralized repository developed to support management and in-season assessment of Fraser River sockeye and pink salmon fisheries. It integrates data from both Panel and non-Panel water test fisheries, including information on fishing trips, catch, gear specifications, environmental conditions, and seal observations. Historical records from physical datasheets and legacy files were standardized and imported. New data are entered by Pacific Salmon Commission (PSC) staff in real time. The database also incorporates financial information, including charter rates, fish pricing, and fish ticket records, allowing accounting and finance staff to reconcile financial records with catch data. The database supports internal reporting, updates to the PSC website, and preparation of fishery summaries for the Fraser River Panel. Data can also be exported for analysis or reporting, providing a reliable, integrated tool for both in-season management and long-term program evaluation.

Introduction

The Pacific Salmon Commission (PSC) Secretariat Staff administer test fisheries within Fraser River Panel Area Waters (Panel waters) to collect in-season information on returning Fraser River sockeye and pink salmon (Chapter B1). Test fisheries in non-Panel waters, administered by Fisheries and Oceans Canada (DFO) in partnerships with A-Tlegay Fisheries Society and Yale First Nation, also support in-season assessments. These test fisheries collect a range of information, including fishing effort, catch and data on environmental conditions, that play a key role in informing run size estimation, stock assessment, and in-season management decisions. Test Fishing observers, referred to here as observers, record these data and submit them to the PSC office for analysis and long-term record-keeping. Observers also submit fish tickets from test fishing sales to support accounting and financial tracking.

Historically, test fishing data were maintained as physical datasheets and in multiple digital spreadsheet files, limiting consistency, accessibility, and analytical efficiency. The Test Fishing Database was developed in the early 2000s to provide a centralized repository for all Fraser Panel test fishery data. This centralized database improves data integrity and supports efficient querying, reporting, and analysis for both in-season decision-making and long-term program evaluation.

Database Structure and Function

The Test Fishing Database is a relational database system with a Microsoft Access front-end used to store, organize, and manage Fraser River test fishery data. As of January 2026, it uses a SQL Server backend; however, the underlying database infrastructure may change in the future.

Upon creation of the database, historical data from legacy records were standardized and imported into the database, ensuring consistency across years and fisheries.

The database is structured with multiple related tables that capture information on fishing trips and events, catch records, species composition, gear specifications, environmental conditions, and fisher and observer identifiers. Relationships among tables enable queries and integrated analyses of the various test fishery catch information.

In addition to test fishery catch and effort data, the database includes information on test fishery charter rates and fish pricing. This enables accounting and finance staff to cross-reference financial records with catch data and test fishery dates of operation, ensuring all catches are accounted for and allowing for efficient fiscal management.

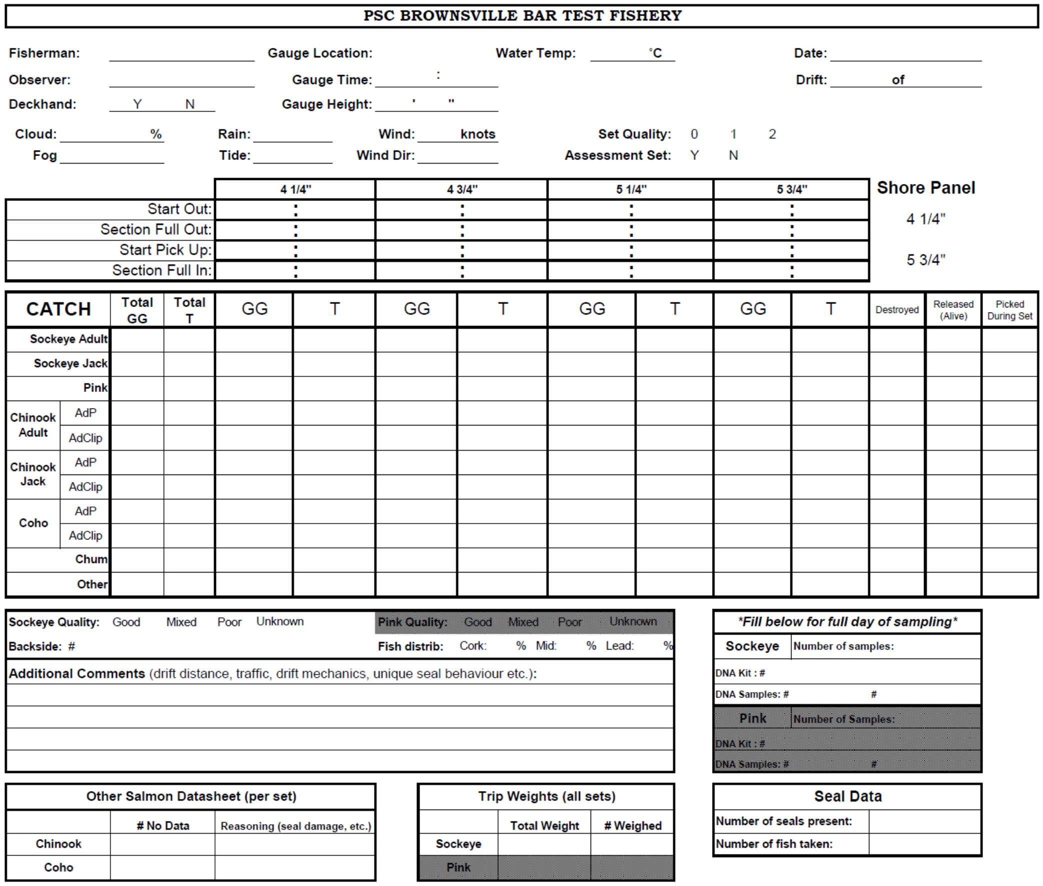
Data Sources

During each test fishing trip, observers record detailed catch and effort information by species for each set or event, along with relevant environmental conditions. Depending on the test fishery, these observations may include tide, weather, water temperature, the presence of seals or other predators, and any observed depredation. Observers also record information on the overall vertical distribution of fish catches throughout the net, as well as adipose clip status of all species caught. The specific test fishing data collected varies depending on the type of test fishery. Troll, marine gillnet, in-river gillnet, purse seine, and reefnet fisheries each use unique gear (Chapters B2 and B3), and their datasheets are tailored to capture the information most relevant to those fishing methods. Figure 1 provides an example of the datasheet for the Brownsville Bar in-river gillnet test fishery. Although not related to test fishing, the Test Fishing database also houses the daily passage data collected through observer counts at Hells Gate.

Fish sale data form another key component of the Test Fishing database. These records include the number of pieces and weights of fish sold, sale prices, and buyer information. Sale counts and catch counts are linked within the database to ensure that revenue associated with all retained and landed fish is fully accounted for. Some test fishing data collected by the test fisheries are stored outside the Test Fishing Database. For example, the collected scale, sex, and morphological measurement data on individual fish are stored in the Scale Database (Chapter C14) while DNA data are stored in the Database of Individual Nerka and Gorbuscha Salmon (DINGS, Chapter C16), managed by PSC staff.

Observers record test fishing information on physical datasheets and submit digital copies of the originals, typically photographs, for cross-referencing. They also submit the catch data through Fisheries and Oceans Canada's electronic logbook software (ELOG). ELOG submissions are sent electronically from remote locations to PSC staff email inboxes, where the data are reviewed and further processed and imported through an ELOG string processor into the Test Fishing Database. Once the ELOG data have been imported, office staff review and verify the information against the original physical datasheets to ensure accuracy.

Observers submit copies of fish tickets to confirm the sale of test fishing catches. The fish ticket information is entered into the database, allowing accounting staff to reconcile financial records with reported catch. The fish ticket information is also cross-referenced with the test fishing catches to ensure all fish are accounted for and to act as an additional data quality check.



PSC BROWNSVILLE BAR TEST FISHERY

Fisherman: ____ Gauge Location: ____ Water Temp: ____ °C Date: ____

Observer: ____ Gauge Time: ____ : ____ Drift: ____ of ____

Deckhand: Y N Gauge Height: ____ ' ____ "

Cloud: ____ % Rain: ____ Wind: ____ knots Set Quality: 0 1 2

Fog ____ Tide: ____ Wind Dir: ____ Assessment Set: Y N

	4 1/4"	4 3/4"	5 1/4"	5 3/4"
Start Out:	:	:	:	:
Section Full Out:	:	:	:	:
Start Pick Up:	:	:	:	:
Section Full In:	:	:	:	:

Shore Panel
4 1/4"
5 3/4"

CATCH		Total GG	Total T	GG	T	GG	T	GG	T	GG	T	Destroyed	Released (Alive)	Picked During Set
Sockeye Adult														
Sockeye Jack														
Pink														
Chinook Adult	AdP													
	AdClip													
Chinook Jack	AdP													
	AdClip													
Coho	AdP													
	AdClip													
Chum														
Other														

Sockeye Quality: Good Mixed Poor Unknown Pink Quality: Good Mixed Poor Unknown

Backside: # Fish distrib: Cork: % Mid: % Lead: %

Additional Comments (drift distance, traffic, drift mechanics, unique seal behaviour etc.):

Fill below for full day of sampling

Sockeye	Number of samples:
DNA Kit : #	
DNA Samples: #	#
Pink	Number of Samples:
DNA Kit : #	
DNA Samples: #	#

Other Salmon Datasheet (per set)

	# No Data	Reasoning (seal damage, etc.)
Chinook		
Coho		

Trip Weights (all sets)

	Total Weight	# Weighed
Sockeye		
Pink		

Seal Data

Number of seals present:	
Number of fish taken:	

Figure 1. *Blank datasheet used to record data collected from the Brownsville Bar test fishery to support in-season assessment of returning Fraser River sockeye and pink salmon.*

Outputs

The Test Fishing Database produces a range of outputs that support both internal PSC operations and public reporting. Internally, it produces reports used by biologists and the Fraser River Panel to inform in-season stock assessment and management. More specifically, the test fishing database calculates catch-per-unit-effort (CPUE) estimates using reported catch and effort data (Chapter B4) and provides the underlying data for species composition estimation (Chapter B19), daily run reconstruction (Chapter B21), in-season run size estimation (Chapter B23), Total Allowable Catch (TAC) calculations (Chapter B32) and the catch evaluation process (Chapter B34). These outputs are essential for ensuring timely and accurate assessment of Fraser River sockeye and pink salmon.

The database also produces daily in-season test fishing data summaries that are made available to the public through the PSC website. The same data stream also supports the PSC Shiny Application for in-season Fraser River sockeye and pink salmon data. This application allows users to visualize and compare in-season test fishing observations against data collected in previous years. Beyond catch and CPUE data from the different test fisheries, the application also contains test fishing data on length, weight and fish condition for both sockeye and pink salmon. In addition to operational and public reporting functions, the database also compiles end-of-season summaries used by the accounting team.

These summaries facilitate the determination of charter rates, fish value totals, and other financial metrics required for each test fishery's post-season financial accounting.

Future Work

Future improvements to the Test Fishing Database include incorporating and streamlining historical Hells Gate fish passage data, and improving data storage for other salmon species, such as Chinook, coho, and chum salmon. Having these other salmon data in the database in a queryable way will facilitate data quality and verification checks for DFO sampling requests. Data on other salmon species may include biological information such as length, weight, fin clip status, and sex.

C14. Hydroacoustic database

S.C. Madduri

Summary

The hydroacoustic database is a centralized, standardized system that consolidates Mission hydroacoustic data (Chapter B14) to support reliable in-season and historical assessments of Fraser River sockeye and pink salmon. The database integrates standardized hydroacoustic outputs, biological measurements, behavioural metrics, and records of Food, Social and Ceremonial (FSC) fisheries for all years since 2018, enabling streamlined analysis of salmon passage data. Built on a cloud-based SQL platform and supported by automated data-processing pipelines in Azure Logic Apps, Azure Data Factory (ADF), and Azure DevOps, the system ensures consistent, traceable, and timely data delivery to biologists. In addition to improving data accessibility and visualization workflows, the database lays the foundation for future integration with advanced modelling tools, including the species composition model currently under development (van Dam-Bates et al. 2025). This report describes the database design, data sources, workflows, outputs, and planned enhancements to further strengthen hydroacoustic assessment capabilities.

Introduction

Daily estimates of salmon passage at the hydroacoustic site in Mission, BC, form the backbone of in-season assessments for Fraser River sockeye and pink salmon. Although the hydroacoustic program has operated continuously since 1977, both the technologies used and data collected have changed substantially over time. Over the years, the Mission site has employed several different sonar systems, including split-beam, DIDSON, and ARIS, used in different configurations across years (Michielsens and Martens 2022). Mission hydroacoustic programs have also varied in terms of the areas assessed, i.e., offshore, and including the left and/or right bank, and the range-bin settings applied. To enable improved analysis of species composition using hydroacoustic data, a new consolidated and standardised Mission hydroacoustic dataset has been developed for all years going back to 2018, consisting of data from different hydroacoustic systems (splitbeam and imaging sonar), salmon lengths and behaviour statistics (e.g. speed, downstream ratio and distance from shore) as well as information on Food, Social and Ceremonial (FSC) fisheries conducted at the Mission site. Standardizing the Mission hydroacoustic data and storing it in a database has facilitated analysis of the data collected in-season and comparing and contrasting in-season data with historical estimates. The following sections describe the Mission hydroacoustic database, the structure, data and outputs, as well as work in progress.

Database Structure and Function

The hydroacoustic database has been implemented as an SQL database on Azure, providing a cloud-based, scalable solution and making the database readily accessible from both the Mission site, the office, and home office locations. The database is updated daily and interacted with heavily during the Fraser sockeye and pink salmon season (July to September), but use scales down substantially during the fall, winter, and spring. To automate the ingestion, transformation, and loading of data, a data-processing pipeline has been developed using Azure Data Factory (ADF), orchestrated by an Azure Logic App. The Logic App monitors a designated SharePoint directory and automatically triggers the ADF pipeline when new raw data files are uploaded, which also sends email notifications upon file arrival. ADF automatically retrieves the new inputs. Standardized formatting and QA/QC procedures are then applied, and the resulting validated outputs are loaded directly into the Mission database. This workflow ensures the timely and consistent availability of hydroacoustic data for analysis, consistent handling of both historical and in-season data and reduces the need for manual processing. The implementation of ADF has streamlined data management, reduced the potential for errors, and provides analysts and biologists with reliable, near real time access to updated information.

Azure DevOps is used as the central system for managing updates and deployments to the hydroacoustic database and its associated data pipelines. The database structure is maintained using SQL Server Data Tools (SSDT) which generate version-controlled files describing the database design. Automated build steps check that each proposed change is valid before being deployed, and the release process provides controlled promotion of updates with the option to roll database versions back if needed. For Azure Data Factory (ADF), all components, i.e., pipelines, datasets, and system connections, are managed using an infrastructure-as-code approach. This means that configuration details are stored in code, ensuring that deployments between environments are repeatable and well-documented. All ADF code and configuration files are stored and version-controlled in Azure DevOps, allowing the development team to track every modification and maintain consistent deployment practices. This approach also provides clear traceability of all data transformation steps and ensures that dataflows behave consistently. Automated Azure DevOps pipelines are used to validate, build, and deploy ADF assets, ensuring that updates are promoted in a controlled, auditable manner. Adopting the Azure DevOps strategy has resulted in a robust audit trail covering code changes, pipeline runs, and database updates. This has improved reproducibility, strengthened governance, and provided greater confidence in the reliability of the data processes that support the Mission hydroacoustic program.

Data Sources

The Mission hydroacoustic program has generated and stored a substantial amount of information over the years, and starting in 2023, a considerable effort was devoted to determining which data should be imported into a hydroacoustic database and at what level of resolution to support the hydroacoustic program and the subsequent use of the data for modelling and analysis, e.g., for species composition estimates. Going back to 2018, the database currently houses abundance- and sonar-related data from the different hydroacoustic systems at Mission alongside associated salmon lengths and behavioural information (speeds, downstream ratios and distance from shore), as well as records of FSC fisheries undertaken at the Mission site. Data are stored at hourly and daily resolutions and for different sections of the river (offshore versus different nearshore ranges, e.g. 0-10m, 10-20m). The standardization of the data prior to uploading into the database relates to adjustments that are made to the data to ensure underlying assumptions are the same. Years prior to 2018 are excluded from this database, given the differences in data collection protocols and the fact that standardization for those years is not possible to the same extent as for recent years.

Outputs

User access to the hydroacoustic database is managed through Microsoft Entra ID, a cloud-based identity and access management system. Using Entra ID, users can sign in with their existing organizational credentials, can connect to the database quickly through R and work with the data without requiring additional accounts or administrative steps. Alongside custom data access for users, the hydroacoustic database also contains a series of queries, views, and code that deliver the data in a structured and accessible format, enabling end users to generate summaries and visualizations in a repeated workflow. These visualizations can integrate information across multiple years and data sources, which previously would have been very difficult given that the data were spread across numerous, inconsistent spreadsheets. Because the tools are linked directly to the databases, data summaries and visual outputs can be updated almost in real time as new data are uploaded, requiring minimal additional effort from users while maintaining consistency and reliability. In addition to the output used to verify and analyse hydroacoustic data, the database is also used to integrate the various datasets needed for species composition estimates, including sonar outputs, biological (lengths and speeds) and environmental (distance from shore) information as well as test fishing and FSC fishing records.

Future Work

Although the hydroacoustic database has been fully developed and is operational, it has not yet been used for in-season assessments as of early 2026. Additional testing is planned for the 2026 season to ensure it can be applied effectively for in-season operations. Further work is also needed to expand automated data visualizations and summary tools, enabling more rapid and integrated analyses across years and multiple data sources with minimal additional effort from end users. Ongoing work is also focused on automating Logic Apps and Data Factory pipelines to handle each file and sheet independently, even when not all data arrive at the same time. This makes the process smoother and less dependent on manual coordination. Integration with the species composition model (van Dam-Bates et al. 2025) is actively underway, with the database being developed to ensure all necessary model inputs are accurate, timely, and easily accessible.

References

Michielsens, C.G.J. and Martens, F.J. Editors. 2022. Overview of pre-season and in-season assessment methods for Fraser River sockeye salmon. PSC Tech. Rep.: 49, 217 p.

van Dam-Bates, P., Wor, C., Potapova, A., Gautier, M., Hornsby, R., Hayward, K., Martens, F.J., Michielsens, C.G.J., Keizer, A. and Agha, M. 2025. Collaborative improvement of Lower Fraser species composition estimates. Southern Endowment Fund annual report, Vancouver.

C15. Scale database

J.E. Sellars

Summary

The PSC Scale Database contains detailed information on the origin and age of Fraser River sockeye salmon, beginning in 1912 when these attributes were first determined through scale analysis. Built in Microsoft Access, the database manages over a century of scale and otolith data. Over time, the metadata associated with the sockeye records has expanded to include attributes such as age, length, capture date, location, fishery, mesh size, and more. Biological data from the Scale Database can be automatically linked to genetic stock identification (GSI) data housed in the DINGS database (Database of Individual nerka and gorbuscha Salmon). Together, these systems form a powerful resource for storing, retrieving, and analyzing sockeye salmon records.

Introduction

The Pacific Salmon Commission (PSC) has a long history of collecting and maintaining sockeye (*Oncorhynchus nerka*) scales, otoliths, and associated metadata. This practice dates back to 1912, when biologists first discovered that the age and origin of salmon could be determined by analyzing the circuli patterns on their scales. In its earliest days, data collection consisted of handwritten notes. Over time, the PSC Scale Laboratory has continually modernized its archival methods in step with technological advancements. These methods have evolved from paper records to early digital formats, including Lotus 1-2-3 spreadsheets, Microsoft Excel, and, more recently, a relational database in Microsoft Access.

The Scale Database contains data from sockeye collected on the spawning grounds and caught in fisheries. Although spawning ground scale samples date back to 1912, commercial and test fishery samples have only been systematically collected and archived since 1977. Since 1991, between 15,000 and 51,000 sockeye scales have been analyzed annually to assess both freshwater growth patterns and age. The Scale Database was developed to streamline the storage and retrieval of these data, making them easily accessible for more in-depth analyses.

Database Structure and Function

The Scale Database is a relational database (Figure 1) featuring a graphical user interface (GUI) built in Microsoft Access (Figure 2). Historical data stored in Excel files have been standardised and imported in batches into the database, while recent data are entered throughout the season as they become available. The in-season data are merged with the field and sample data within an Excel application (Escala) that allows for data entry, data merging, error checking and summarising data, prior to uploading the file into the Scale Database. Users can export scale, otolith, and metadata in Excel format using the GUI interface.

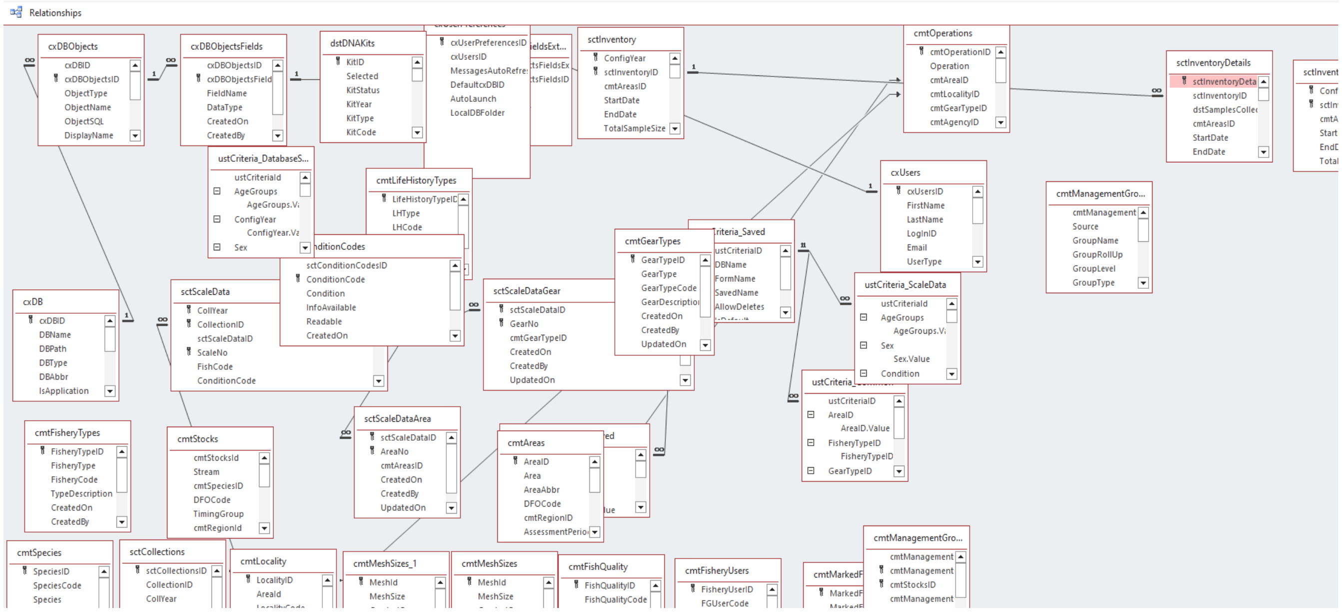


Figure 1. *A schematic illustration of the Scales relational table structure.*

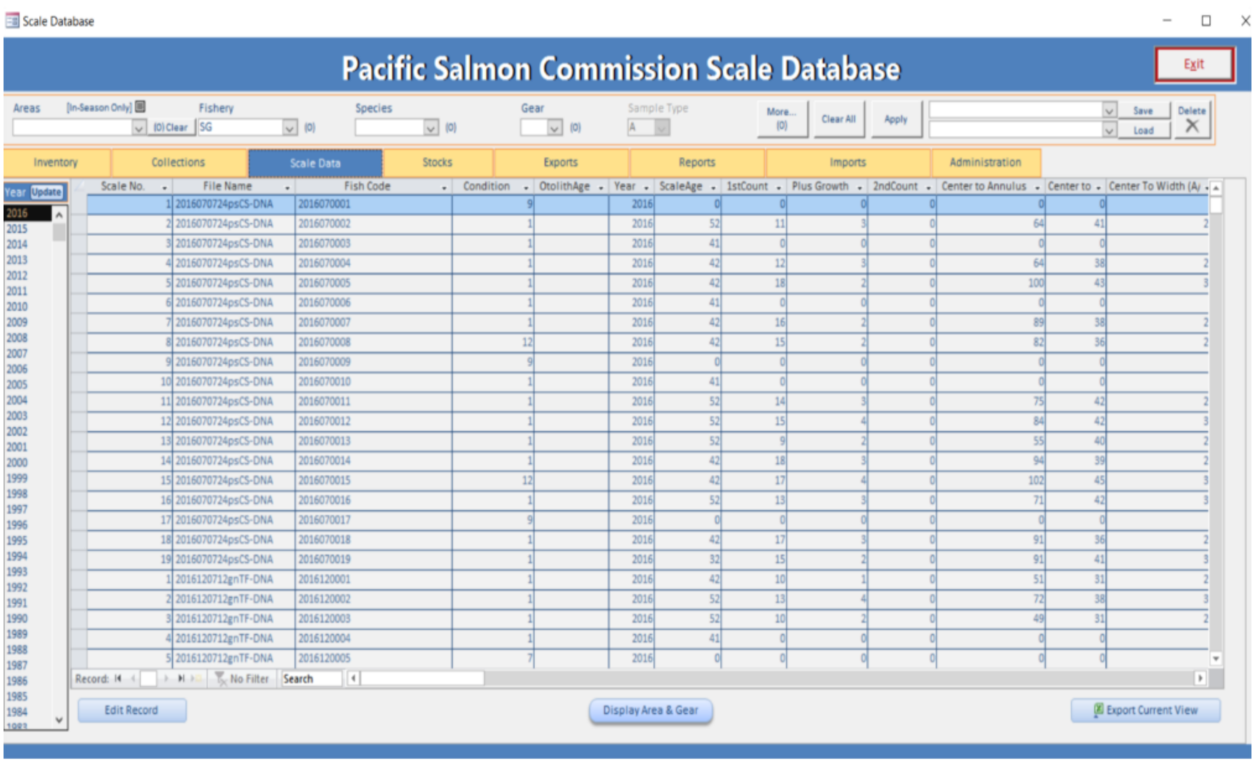


Figure 2. *This image shows the scale data within the database.*

Data Sources

Data for the Scale Database comes from different sources. All samples arriving in the lab are entered into the Scale Database inventory and linked to the corresponding sample in the Database for Sample Tracking and Reporting (D-STAR). Using a unique DNA identifier, scale and related metadata can be linked to match DNA results through DINGS (Database of Individual nerka and gorbuscha Salmon).

Table 1 shows the type of data in the database, and the source of the data.

Table 1. *Biological, scale, fishery and spawning ground data found in the Scale Database.*

DATA	SOURCE
Unique DNA identifier, sex, species, catch position, scale age, weights and lengths	Raw biological data on individual sockeye salmon, collected in the field
Catch date, fishing area, gear, type, shore panel, mesh size and user	Raw data from samples, collected in a fishery
Otolith age, fecundity	Raw data from spawning ground samples
Condition code, age, 1^{st,} and 2nd counts, plus growth, measurements of focus, 5^{th,} and freshwater annulus	Scale Analysis using a scale application in Image Pro Premier software
Measurements of centre to annulus, centre to 5th, marine growth	Calculated through Escala, an automated Excel application
Otolith age	Otolith analysis using Image Pro Premier software

Outputs

The user interface of the Scale Database contains eight main tabs. Table 2 shows these tabs and their functions within the database.

Table 2. *Eight user interface tabs associated with the Scale Database.*

COMPONENT	DESCRIPTION
Inventory	The collection metadata: area, catch date, fishery, gear, species, sample size, number associated with the collection, and who sampled, processed and analyzed the collection.
Collections	The list of filenames in a particular year. These include files that have been processed and/or analyzed only.
Scale Data	Metadata for every scale or otolith analyzed in a particular year.
Stocks	As of April 2025, this part of the database is not functional.
Exports	Allows data to be downloaded from the database, depending on what data fields are chosen.
Reports	A modified export field, allowing to quickly produce repeated data requests using a pre-set form.
Imports	Allows to upload data in the format produced by Escala which is an automated Excel application.
Administration	Table used by the database manager that allows to change data.

C16. Scale and otolith image library

C.E. Ball and J.E. Sellars

Summary

The Scale and Otolith Image Library is a curated collection of sockeye salmon scale and otolith images from the Fraser River Watershed. Since the late 1930s, Fraser River sockeye samples have been collected from both marine and river fisheries, as well as from the spawning grounds. These samples are analyzed and aged by staff at the Pacific Salmon Commission (PSC) Scale Lab to support stock identification and age determination. The Image Library documents variations in scale and otolith characteristics across different stocks, brood years, and life histories. It includes images from sockeye adults, jacks, and smolts, as well as scales from non-sockeye species. Serving as both a reference archive and a training resource, the Image Library captures patterns observed by analysts to support consistency and knowledge transfer.

Introduction

The Pacific Salmon Commission (PSC) maintains an extensive collection of sockeye salmon scales and otoliths dating from the 1930s to the present. Analysts in the PSC Scale Lab are responsible for aging and analyzing these samples to support in-season stock identification and to age fish caught in various fisheries and sampled on the spawning grounds. The resulting data are stored within the Scale database (Chapter C14). This database does not contain any actual scale or otolith images.

The Scale and Otolith Image Library is used to document the diverse patterns found in Fraser River sockeye scales across different stocks, brood years, and life histories. The library spans multiple years, with extensive coverage of images from 2017 to 2020. Noteworthy images from subsequent years are added as needed, while stock-specific anomalies are added annually. The library serves as a reference for interpreting complex or unusual traits and enables users to track recurring anomalies over time. These traits can be correlated with environmental conditions or life history events that influence scale development. The library also includes reference images of non-sockeye species, broadening its utility beyond sockeye analyses.

The Image Library is a valuable training and reference tool for onboarding new staff and supporting ongoing training of current analysts. It ensures consistency in aging difficult stocks and provides a shared resource for PSC staff. Additionally, it serves as a reference for external collaborators and third-party researchers.

Data

Images collected in-season focus on scales, aged and analyzed using an Olympus Upright Clinical Microscope and an Infinity 1 Digital Camera. An image of the scale is captured, stored, and analyzed using Image-pro premier software and the resulting scale measurements are stored in an Excel spreadsheet (Chapter B9). DNA comparisons are made and any anomalies between DNA and scales are highlighted for further review. The annotated images are added to the library.

Spawning ground samples consist of scales and otoliths. The scales are analyzed and aged, and the otoliths are aged. Images and notes are kept for post-season analysis. Upon completion of the spawning ground samples, the recommended notes and associated annotated images are put into the image library.

Each annotated image includes a descriptive text box in addition to markers highlighting key features. For example, annuli are marked when illustrating age, and arrows are used to indicate plus growth. Figure 1 shows an example of an annotated image.

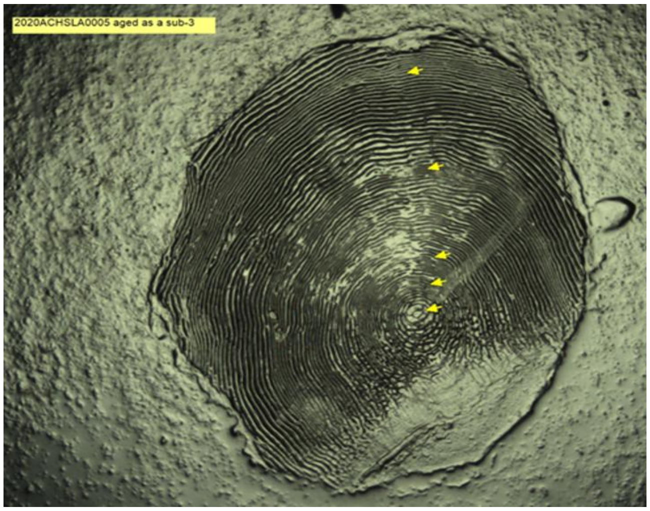


Figure 1. *Image of an annotated scale.*

The images in the database are curated to illustrate:

- Discrepancies between DNA results and scale characteristics,
- Unique patterns by stock or year (e.g., unusual ages, stress indicators, circuli counts),
- Common traits across stocks by cycle line,
- Features that are difficult to interpret, and
- Patterns from non-sockeye and non-salmonid species, collected opportunistically from PSC test fisheries and partner agencies.

Library structure

The library is housed in Windows 10 File Explorer folders on the Scale Lab's shared drive. Figure 2 shows the structure of the folders of the Images section of the library. Under the Image Library directory, the folder structure includes:

- Images – Organized by category and stock.
- Documents – Contains research papers and presentations on scale and otolith analysis.
- README – Provides an overview of the library contents and navigation guidance.
- To Do – Tracks ongoing projects and future additions.

Images are named using the individual fish's unique code from the Scale Database (Chapter C14). Magnification levels are indicated with suffixes (e.g., _a, _b, _c). To avoid duplication, shortcuts are used to reference the same image across multiple folders when relevant to different traits.

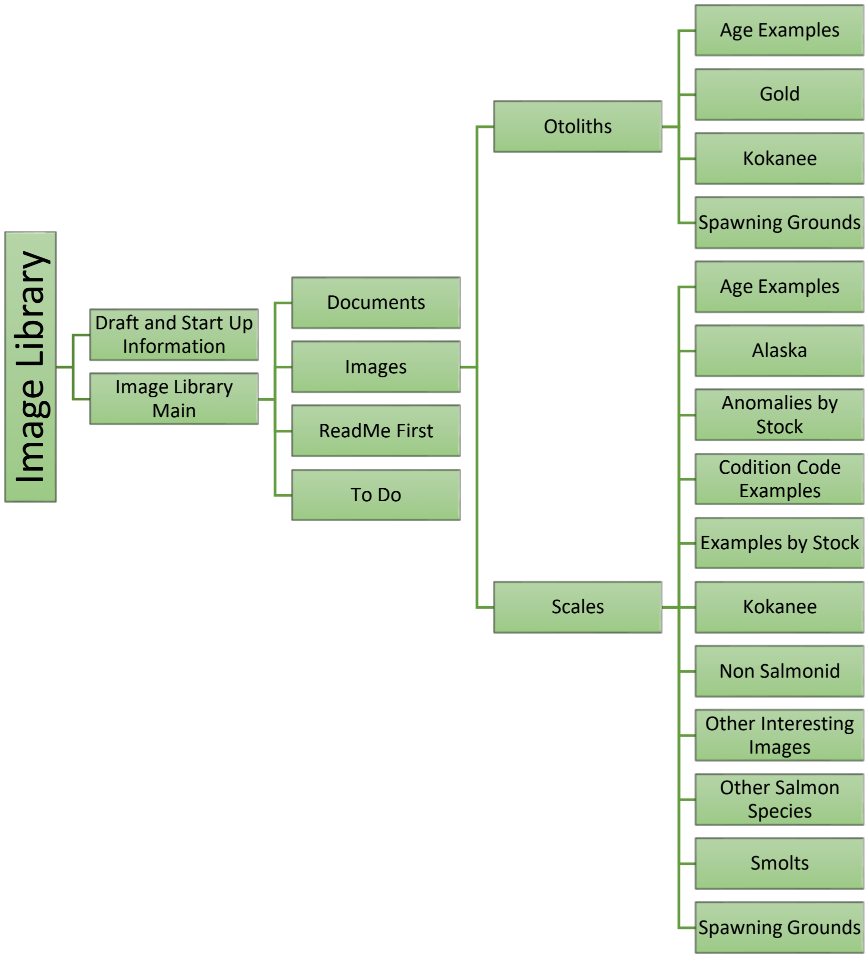


***Figure 2**. Image of the structure of the Image Library.*

Future Work

The library will continue to expand with new images, particularly those showing unusual patterns or showing discrepancies between scale and DNA results. While currently housed in Windows-based folders, the Scale Lab is actively exploring more user-friendly and accessible platforms for future implementation.

C17. DINGS: Database of Individual Nerka & Gorbuscha Salmon

A.M. Phung and S. Latham

Summary

The Database of Individual Nerka & Gorbuscha Salmon (DINGS) houses genetic stock identification (GSI) data for individual salmon (Chapter B11), matched to biological data stored in the Scales database (Chapter C15) and linked to sampling metadata stored in the Database for Sample Tracking and Reporting (DSTAR). DNA samples obtained from catches, escapements, and research projects by the Pacific Salmon Commission (PSC), Department of Fisheries and Oceans Canada (DFO), and other partners are sent to DFO's Molecular Genetics Laboratory for analysis (Chapter B11), and the resulting GSI data are subsequently sent to the PSC where they are compiled in DINGS. DINGS stores sockeye GSI data from 2003 to present and is a valuable tool for users to access size, age, and sex data of individual fish with matching estimates of stock of origin, enabling inquiries into historical trends of biological data by stock. Future effort will include incorporating individual pink salmon GSI and matching biological data in a similar fashion.

Introduction

The Pacific Salmon Commission (PSC) requires DNA samples from fisheries to apportion Fraser River sockeye salmon by stock and management unit through genetic stock identification (GSI, Chapter B11). The acquisition of DNA samples from fisheries and spawning grounds is co-ordinated by the PSC. DNA samples are sent to the Molecular Genetics Laboratory at the Department of Fisheries and Oceans Canada (DFO) in Nanaimo, where they are processed and analyzed, and then GSI results are provided to the PSC (Chapter B11). The GSI data are provided at a finer resolution than by management group, as this allows greater flexibility during data processing and analyses. In addition, detailed stock-level data are used for various technical Fraser River Panel purposes such as run size assessments, run reconstructions, forecasting, estimating migration timing and en-route mortality.

Before the creation of the Database of Individual Nerka & Gorbuscha Salmon (DINGS), GSI data were dispersed across numerous Excel files. This fragmented storage system hindered the integration of results across multiple years and complicated alignment with biological data. Manual matching of GSI and biological data such as size, sex and age was time-consuming and relatively prone to error. The establishment of the DINGS Microsoft Access database in 2014 streamlined this process by consolidating multi-year datasets and automating the linkage of GSI results with biological information. The DINGS database provides a centralized framework for storing and querying genetic stock information, supporting both in-season management decisions and post-season assessments that require GSI data and associated biological information.

Database Structure and Function

DINGS is a relational Microsoft Access database that efficiently stores and organizes data by relying on structured relationships among multiple tables (Figure 1). DINGS is also linked to other databases including the Scales database for biological data (Chapter C15), the Database for Sample Tracking and Reporting containing sample metadata (DSTAR), and the Common database that standardizes naming conventions across PSC databases. GSI data, processed and stored in Excel files, are imported into DINGS through the graphical user interface (GUI, Figure 2). Upon import into the DINGS database, the genetic stock assignments and probabilities are recorded for each individual fish. Concurrently, relevant sample and biological information stored in the other linked databases are automatically joined to GSI data during import. The DINGS database also supports the export of integrated datasets, including matching GSI data, scale data, biological data, and sample metadata. These data can be exported into Excel format for analysis, reporting or data sharing.

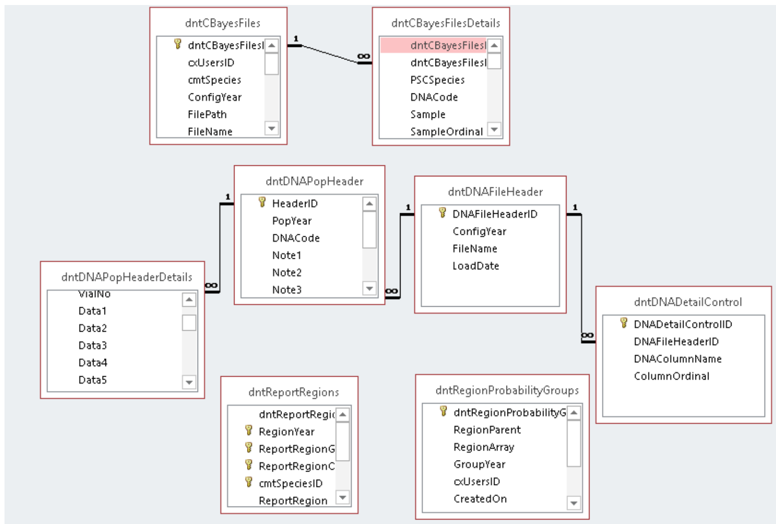


***Figure* 1.** *A schematic of the DINGS relational table structure. This database is also linked with several other databases not shown, including the Scales database for biological information, DSTAR for sample and shipping information, and the Common database containing common names used across the PSC databases.*

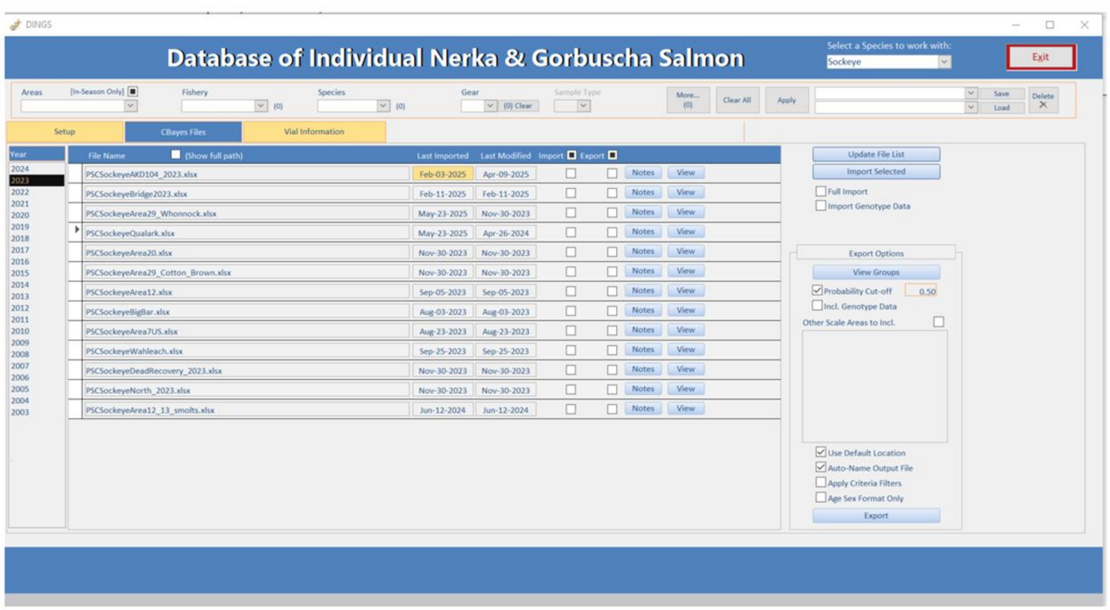


Figure 2. *The DINGS database interface. In this example, 2023 is selected for importing or exporting data.*

Data Sources

GENETIC STOCK IDENTIFICATION DATA

At DFO's Molecular Genetics Laboratory, sockeye DNA is extracted from samples and the genotype data are stored in text files which are subsequently analyzed using the program Cbayes to obtain stock estimates (Neaves et al. 2005, Chapter B11). Cbayes results are provided in Excel files containing multiple worksheets. For sockeye, the resolution of GSI data includes 50 Fraser stocks and 38 non-Fraser stocks, which correspond with DNA collection sites. The Fraser stocks are aggregated into 19 fine-scale reporting groups, and several coarse-scale reporting groups, including 4 management groups. Non-Fraser stocks are aggregated into 5 coarse-scale reporting groups. The GSI data are reported for both mixtures, as estimated stock proportions for a given sample, and for individuals, as Bayesian posterior probabilities of stock-of-origin assigned to each individual in the mixture. The individual probabilities are congruent with the mixture estimates. Sockeye GSI data from 2003 to present are stored in DINGS. In contrast, pink salmon genotypes are analyzed using the program ONCOR which outputs results in text files (Kalinowski et al. 2007). Due to differences in data formats, pink salmon microsatellite GSI data are not currently stored in DINGS but instead maintained in Excel files (2007 - present).

SAMPLE METADATA

Catch and shipping information are matched to genetic samples during the import of data into DINGS. DINGS is linked to tables in the Database for Sample Tracking and Reporting (DSTAR) which is used to track the shipment of samples to DFO's Molecular Genetics Laboratory. Metadata associated with DNA and scale samples are stored in DSTAR, including the catch date, catch location, and fishing gear used.

BIOLOGICAL DATA

When the user exports DINGS data, an Excel file is created containing estimated stock identities of individuals matched to their biological information from the Scales database (Chapter C15). Scale and otolith variables, fish age, sex, size, markings (e.g., for identification of hatchery-produced fish), and some catch information such as mesh size are stored in the Scales database, as well as the DNA identification number associated with individual fish. Scale variables include age and various digitized measurements of growth rings that reflect a fish's lacustrine residence as juveniles. An error checking process was built into the Scales database to identify problematic matches or duplicates with DNA samples through cross-checks against DSTAR.

Outputs

STOCK-SPECIFIC AGE, SEX, SIZE, SCALE VARIABLES

The DINGS data export for a given year is an Excel file that contains biological and scale data for each fish with probable stock assignments at two levels of stock resolution: 50 Fraser stocks and 19 Fraser stock groups used for in-season management by the Fraser River Panel. The DINGS data export is used in-season by biologists to produce stock-specific summaries and assess whether age, size, or scale variables are congruent with DNA results. For example, if a very large age 4_2 fish has extremely low scale growth and is assigned to the Nadina River stock with 80% probability based on DNA analyses, biologists may question the results. This is because Nadina-origin fish tend to be smaller and display higher freshwater growth, making the assignment biologically incongruent.

DINGS can also be queried with R (R Core Team 2025) to efficiently access large, multi-year datasets. This functionality allows users to examine stock-specific patterns over time across a variety of metrics, including sex composition, temporal trends in fish size, and comparisons of biological traits between fishery and spawning ground samples. Additional analyses can be performed as needed, and selected summaries are available in the PSC Biological Data App (Figure 3). Associating GSI data with other biological variables at the individual salmon level also facilitates robust data quality assessments. For example, if a sockeye exhibits a size or age that is highly unlikely for its assigned stock, the data record can be flagged and excluded from subsequent analyses.

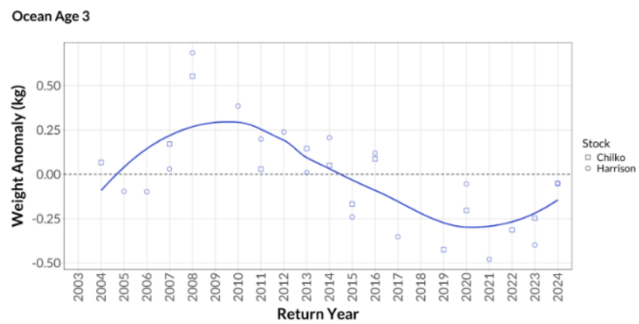


Figure 3. *Example of stock-specific DINGS data summarized and displayed in an R Shiny app (PSC Biological Data App) available on the PSC website.*

Future Work

Currently, DINGS only contains sockeye data. Historical pink salmon data are expected to be migrated into DINGS once a preferred software solution is identified for re-analyzing pink salmon mixture samples. In addition, a transition from microsatellite-based genotyping to single nucleotide polymorphism (SNP) genotyping is anticipated. These changes will require the development of new mechanisms and programming to accommodate the import of differently formatted genetic results into DINGS. Lastly, an additional data quality measure will be implemented to track individuals with dubious genetic stock identification and report an alternative stock identity, based on the combination of other available information such as age, size, scale characteristics, and the timing and location of catch.

References

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R Core Team. 2025. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

C18. RuFEs: Run Size, Fishing, and Escapement database

S. Wong and M.J. Hague

Summary

The Pacific Salmon Commission (PSC) Run Size, Fishing, and Escapement (RuFEs) Database houses daily Fraser River sockeye salmon catch and passage, annual spawning escapement, and run size adjustment (RSA) data by stock, accessible through a Microsoft Access interface that provides access to SQL Server hosted data. Catch data consists of fishery-specific catch records for sockeye and Kokanee from Fraser-directed fisheries in the marine approaches (below Mission) and in the Fraser River (above Mission). The database contains stock-specific catch information for 50 different Fraser River sockeye stocks (Chapter C3). Annual spawning escapement data includes stream- and sex-specific spawning escapement estimates (Chapter C1) as well as the number of jacks and fish taken for brood stock. Run size adjustments (RSA) are post-season corrections to annual catch, spawning escapement, and in-river natural mortality estimates used to generate annual post-season run sizes estimates (Chapter C6). Differences between estimates (DBEs, Chapter C8), that underly the selection of Management Adjustments (Chapter B25), are also calculated and maintained in the database. In addition to providing a secure historical data repository, algorithms within RuFEs also automate dis-aggregation and aggregation of data at different spatial, temporal, and stock resolutions.

Introduction

The Pacific Salmon Treaty, Article XIV(b) states that each party must make catch, effort, and related data for all Fraser sockeye salmon (*Oncorhynchus nerka*) stocks available to the Commission (PST 2025). For Fraser River sockeye salmon, PSC staff are responsible for producing and maintaining stock-specific time series of historical catch and Mission passage estimates (Chapter C3). The catch data are used in conjunction with Fisheries and Oceans Canada (DFO) spawning escapement data (Chapter C1) and Run Size Adjustment (RSA) estimates (Chapter C6) to produce post-season estimates of annual post-RSA run size. The Mission passage estimates, in conjunction with catch above Mission and spawning escapement estimates, are also used to produce annual differences between estimates (DBEs, Chapter C8).

Historically, catch, passage, RSA, and DBE data were stored at a fixed stock resolution in a combination of Excel workbooks, an Access database, and printed, published volumes. In 2014, PSC staff created the Run Size, Fishing, and Escapement (RuFEs) database as the official post-season repository for catch, Mission passage, and DBE time series. Copies of DFO spawning escapement time series are also stored in RuFEs to enable internal calculations of run size and DBEs, and to re-aggregate data into different stock resolutions. Over the years, the historical time series were extended backwards as well as iteratively updated with new information. In 2023, the database structure was expanded to include run size adjustments (RSAs), allowing the database to provide post-season, stock-specific, post-RSA run size estimates. Currently, the database holds records from 1893 onward. However, data available and resolution decreases further back in time. Because the RuFEs import process partitions original catch and RSA records into a stream-level granularity based on spawning ground proportions, data can be explored at multiple stock aggregations.

The migration of data into the RuFEs database provides a standardised and secure repository for historical time series but also improves the ability for biologists and managers to explore the data, in particular through the data publicly available on the PSC Pacific Salmon Run Size App (PSC 2025) and the Fraser River Panel Annual Report Data App (PSC 2026). This flexibility provided by RuFEs allows staff to expediently fulfill data requests to inform conservation and fisheries management processes, thereby upholding the commitment to make PSC data more accurate, transparent, and accessible (PSC 2024a and 2024b). The following sections focus on the database structure, data sources, and outputs associated with the RuFEs database.

Database Structure and Function

RuFEs is a relational database (Figure 1) with a SQL Server back end and a Microsoft Access-based graphical user interface (GUI) front end (Figure 2). Historical data stored in Excel files are first standardised into a database import format. The Access GUI is used to import annual time series of daily stock-specific catch and Mission passage estimates as well as annual escapement and RSA estimates. Upon import, the catch, passage, and RSA data are partitioned into stream-level resolution, i.e., to match the resolution of the escapement time series, before being stored in the SQL Server tables. Newly imported data are run through a series of quality control and quality assurance routines to identify any errors, e.g., estimates which are out of range, missing values, or errors introduced during the stock partitioning or re-aggregation processes, and to ensure data integrity.

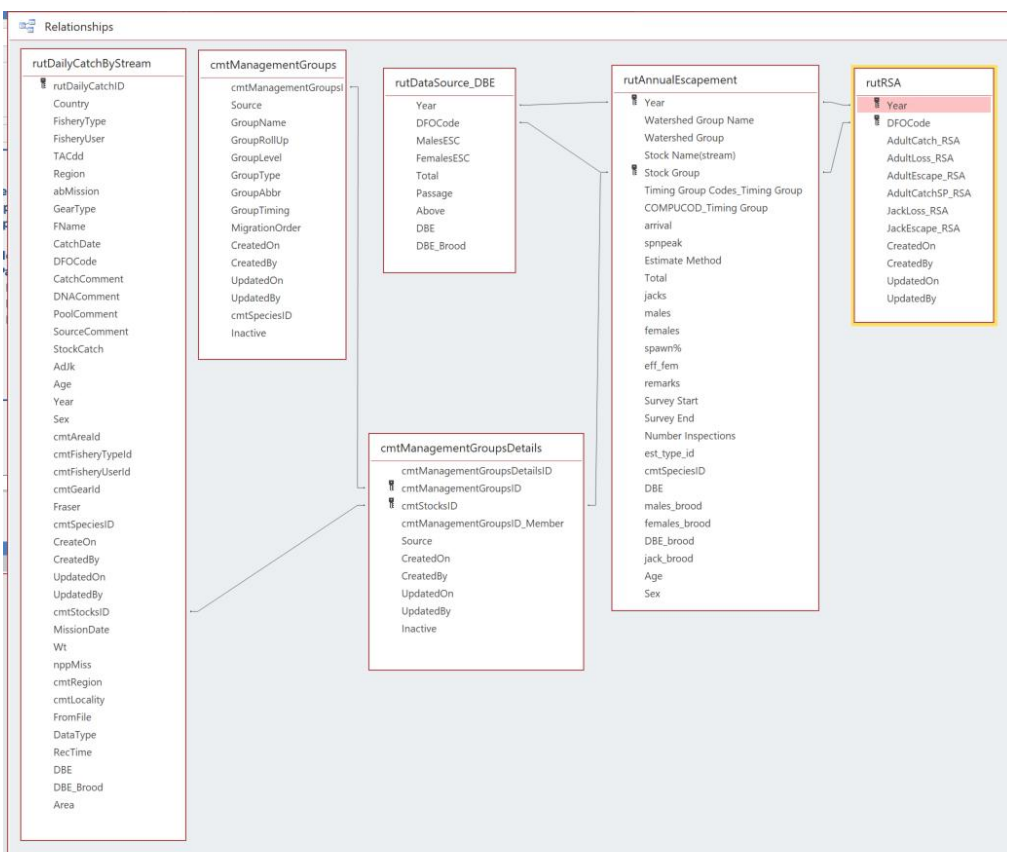

Figure 1. *A schematic illustration of the RuFEs relational table structure.*

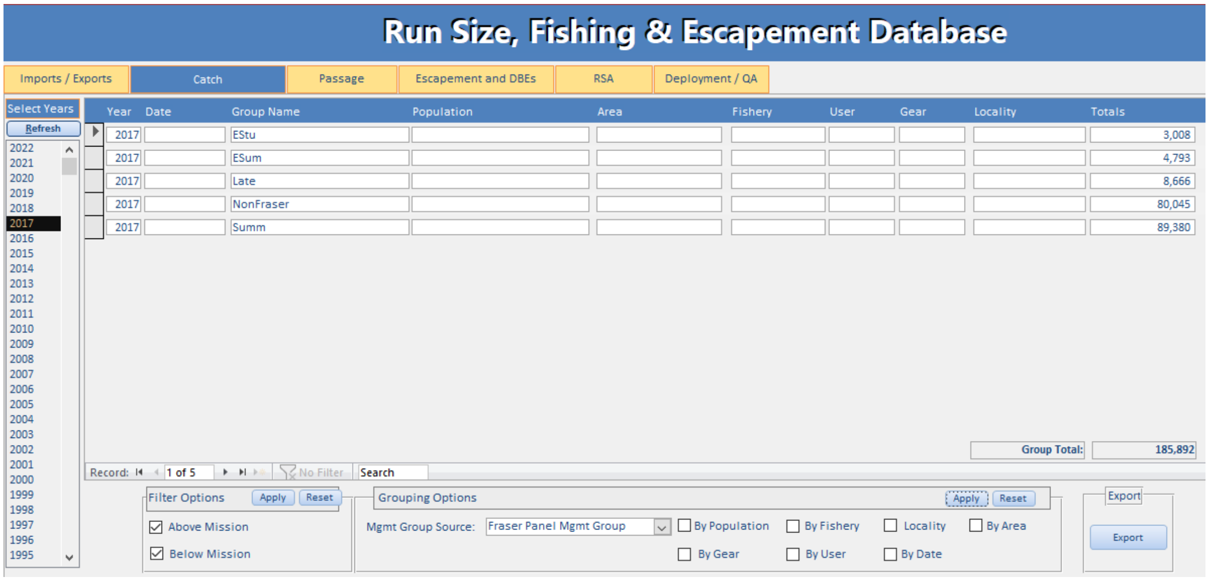

Figure 2. *The RuFEs graphical user interface. In this example, 2017 Fraser River sockeye catch, both above and below Mission, is aggregated at the Management Group level.*

Data Sources

CATCH

Raw estimates of sockeye catch by date, area, user, and gear are provided to the PSC by Canada and the United States. Metadata describing each catch record is also entered according to standardised conventions to ensure transparency across all PSC databases. These harmonized metadata fields, covering attributes such as location, fishing gear, fishery type, fishery user, country, and multiple temporal resolutions, provide a common structure that supports robust data aggregation.

PSC staff combine the raw data with estimates of stock proportions to create stock-specific catch time series (Chapter C3). For years prior to 2003, stock proportion estimates were derived from scale analyses (Chapter B10). Since 2003, genetic stock identification (GSI) has been applied to produce more finely resolved stock-specific catches for approximately 50 different stock groups (Chapter B11). All catch data are further disaggregated to match the stream-level of the DFO escapement database (Chapter C1) based on spawning ground proportions. For stock groups without spawning ground enumerations (either un-enumerated, or non-Fraser), catch and passage values are divided equally amongst component stocks. The relational table structure then allows the re-aggregation of the stream-level data into a variety of standardised stock aggregates, including Fraser Panel management groups (MGs), conservation units (CUs), and genetic stock identification baseline groups (Chapter B11). While the data are not intended to be analysed at a stream resolution due to the large number of assumptions required to partition the data, storing the data this way provides users with flexibility to group stocks into larger, custom aggregates**.**

MISSION PASSAGE

Since 1977, the PSC and its predecessor, the International Pacific Salmon Fisheries Commission (IPSFC), have operated a hydroacoustic salmon enumeration program in the lower Fraser River near Mission, BC (Chapter B14). The program generates daily passage estimates at Mission which, when combined with seaward catch data, provide in-season run size estimates. Stock composition estimates derived from scale or DNA samples collected in downstream fisheries are applied to the Mission passage estimates.

Consistent with the treatment of catch data, the RuFEs database extends the same proportional stock-level scaling to the stream level.

SPAWNING ESCAPEMENT

Spawning escapement data are imported from a file containing DFO NuSEDS (New Salmon Escapement Database System) data (Chapter C1). This file is provided by DFO and contains sex-specific spawning escapement, jack numbers, and total spawning escapement estimates, from 1938 onward. Raw Fraser River sockeye salmon spawning escapement estimates are updated annually from the most recent version of the DFO NuSEDS database. DFO also provides terminal brood stock removal data, which RuFEs uniquely identifies to give users the option of including or excluding these values in total spawning escapement estimates. Table 1 summarises deviations from the DFO estimates in the RuFEs database to account for years with un-enumerated systems and/or re-assignment of strays to their original spawning population.

Table 1. *PSC adjustments to the DFO spawning escapement data obtained from NuSEDS.*

Year	DFO Stock Name	DFO Management Group	Fraser Panel Stock	Fraser Panel MG (2015)	Comment
2002	Horsefly R.	Summer	Horsefly R.	Summer	Not enumerated. PSC estimate: 1,963,020 adults.
2002	Birkenhead R.	Summer	Birkenhead R.	Summer	Not enumerated. PSC estimate: 189,446 adults.
2005	Mitchell River	Summer	Mitchell R.	Summer	Not enumerated. PSC estimate: 553,111 adults.
Various	Various	Various	Various	Various	Small un-enumerated populations in a given year (post-1996), which have been enumerated in other years, are treated as zero under the assumption that they were not assessed due to low expected returns.
Various	Cayoosh Cr.	Summer	Horsefly/ Chilko	Summer	Presumably Summer-run strays (if not Early Summer Gates or Late-run Portage); should put in Horsefly in 2013/14 cycles and Chilko 2015/16 cycles
Various	Seton Cr.	Summer	Horsefly/ Chilko	Summer	Presumably Summer-run strays (if not Early Summer Gates or Late-run Portage); should put in Horsefly in 2013/14 cycles and Chilko 2015/16 cycles
Various	Upper and Lower Seton Channel	Summer	Horsefly/ Chilko	Summer	Presumably Summer-run strays (if not Early Summer Gates or Late-run Portage); should put in Horsefly in 2013/14 cycles and Chilko 2015/16 cycles
Various	S. End Chilko L.	Early Summer	Chilko	Summer	Re-classified as Summer run
Various	Harrison Lake	Late	Harrison	Summer	Re-classified as Summer run
Various	Hawks Cr., Williams Lake R., Baezaeko R., Euchiniko R.	Summer	Horsefly	Summer	Have been assigning to Quesnel (Mitchell 2010, Horsefly 2013/14)
Various	Bridge R.	Summer	Horsefly/ Chilko	Summer	Presumably Summer-run strays (if not Early Summer Gates or Late-run Portage); should put in Horsefly in 2013/14 cycles and Chilko 2015/16 cycles
Various	Yalakom R.	Summer	Horsefly/ Chilko	Summer	Presumably Summer-run strays (if not Early Summer Gates or Late-run Portage); should put in Horsefly in 2013/14 cycles and Chilko 2015/16 cycles.

RUN SIZE ADJUSTMENTS

Since 2009, Fraser River sockeye salmon post-season run size estimates have been calculated as catch plus escapement plus “Run Size Adjustment” (RSA, Chapter C6). The RSAs are expert-based corrections that account for assessment errors in catch and escapement estimates as well as natural mortality, primarily during the adult freshwater migration. Annual RSA estimates are applied separately to marine and lower river catches, in-river catches above the Mission hydroacoustic site, spawning escapement, and to represent adult natural mortality within the Fraser River. They are produced for 28 Fraser River stock groups and applied separately by age. The age-resolution is not included in RuFEs but is applied in external calculations of stock productivity (Chapter C11).

Derived Outputs

Raw RuFEs data are also used to calculate multiple values critical for fisheries management, including differences between estimates (DBEs), run size, and exploitation rates. While DBEs are calculated and stored within RuFEs, run size and exploitation rate are calculated externally.

Spawning escapement, river catches above Mission, and Mission passage are used to calculate differences between estimates, or DBEs. The DBEs refer to the numerical differences calculated between spawning escapement estimates and estimates of Mission passage minus upstream catch (Chapter C8). Historical DBEs are used for pre-season (Chapter A3) and in-season modelling (Chapter B25) of management adjustments (MAs). The MAs are deducted from run size estimates to inform total allowable catch. Mission 50% migration dates derived from the daily passage estimates are also used as inputs in DBE forecast models (Chapter B27), and in calculations of migratory delay for some Fraser River sockeye salmon stocks (Chapter B22).

For Fraser River sockeye salmon, post-season estimates of run size are derived from the summation of catch, escapement, and an additional value representing a combination of assessment errors and natural mortality (Chapter C6). Prior to the installation of the Mission hydroacoustic program, run size in most years was simply the sum of catch and escapement. However, expert judgement was applied in some isolated cases to adjust for losses during the adult spawning migration in years of extreme environmental conditions. From 1977 to 2008, the additional value is represented by the DBE. From 2009 to current, the correction is represented by the RSA.

Annual exploitation rates are also calculated from RuFEs data as total landed catch divided by total post-season run size. At this time, exploitation rates only refer to landed catches and do not include the impact of the mortality associated with sockeye being caught and subsequently released (release mortality). When run sizes are small, the uncertainty associated with all post-season run size components, i.e., spawning escapement, catch and RSA, is generally large, requiring caution when generating stock-specific exploitation rates (DFO 2025).

Future Work

RuFEs is continually updated with new annual data. In the future, the database may be expanded to include estimates of sockeye release mortality estimates, as well as catch and Mission passage data for Fraser River pink salmon. To facilitate the use of more stock-specific estimates, RuFEs data exports in the future will be accompanied with data quality indicator information, meant to identify and score the relative uncertainty associated with the generated data (Chapter C12).

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C19. DARMA: Daily Reconstructed Marine Abundance database

S. Wong and M.J. Hague

Summary

The Pacific Salmon Commission (PSC) Daily Reconstructed Marine Abundance (DARMA) Database houses time series of post-season reconstructed daily marine abundances for Fraser River sockeye salmon starting in 2003. The database uses a SQL Server back-end with a Microsoft Access interface. Prior to import into DARMA, abundances for stock aggregates are reconstructed to a variety of locations along key marine approach routes using information from test fisheries, Mission hydroacoustic passage, and landed catch (Chapter C4). Upon import into DARMA, abundances are partitioned into a stream-level resolution, allowing users to aggregate stream-level data into a variety of standardised stock aggregates such as Fraser River Panel management groups and Wild Salmon Policy conservation units (CUs). Reconstructed abundances from DARMA are used to calculate important metrics of migration behaviour, including median migration timing to key marine approach areas and northern diversion rates through Johnstone Strait. DARMA is a valuable tool that allows users to flexibly aggregate data to different spatial, temporal, and stock resolutions as well as export data for data requests or use in further analyses.

Introduction

The Pacific Salmon Commission (PSC) Secretariat Staff are responsible for developing and applying run reconstruction models for Fraser River sockeye salmon (*Oncorhynchus nerka*, Cave and Gazey 1994) and archiving their results (Hague et al. 2023, Chapter C4). Within these reconstruction models, stock-specific daily marine and lower river catches are added to daily escapement estimates from the PSC Mission hydroacoustic facility (Conrad et al. 2019, Chapter B14) to reconstruct the salmon run in marine areas. In turn, the marine abundance data produced from these reconstructions can be used to provide post-season estimates of marine timing (date at which 50% of a run passes a location) and diversion rate (percentage of adult salmon migrating around Vancouver Island via Johnstone Strait instead of Juan de Fuca Strait), as required under the terms of the Pacific Salmon Treaty (PST 2025). Traditionally, reconstruction models were updated during the fishing season and then used to produce annual time series of catchability, marine timing, diversion, and spread (the number of days required for 95% of the run to pass a location) (Hague et al. 2023). However, the underlying data and decision rules used to derive these abundance estimates were not routinely re-evaluated post-season and the files used to store the data varied in structure and stock resolution over time.

In 2018, a new reconstruction model was developed which allowed analysts to update in-season reconstructed estimates using a complete suite of post-season information (Hague et al. 2021, 2023). Compared to the in-season approach, the new "MR100" post-season process (Chapter C4) uses a finer stock resolution, standardised and transparent fish movement assumptions, and a clear set of decision rules for assigning fish abundance to the northern or southern approach around Vancouver Island. As a result, the MR100 model produces a more robust and standardised time series of daily marine abundances than analysed in-season. The data and model assumptions underlying the creation of the post-season marine reconstructed abundance time series are described in more detail in Chapter C4 and in Hague et al. (2021, 2023). Concurrent with the development of the new model was the creation of a database in 2022 to house the resulting time series and associated metadata.

The DARMA database not only provides a standardised and secured repository for these data but also improves the flexibility to aggregate and explore the data at various stock aggregation levels. This flexibility provided by DARMA allows staff to expediently fulfill increasingly frequent data requests to inform conservation and fisheries management processes, thereby upholding the commitment to make PSC data more accurate, transparent, and accessible (PSC 2024a and 2024b). The following sections focus on the database structure, data sources, and outputs associated with the daily reconstructed marine abundance (DARMA) database.

Database Structure and Function

DARMA is a relational database (Figure 1) with a Structured Query Language (SQL) server back end and a Microsoft Access front end graphical user interface (GUI) (Figure 2). Historical data stored in Excel files are first standardised into a specified format for import. Users then utilise the Access GUI to import annual time series of daily reconstructed abundances and catch. Upon import, the data are partitioned into a stream-level resolution, the finest possible resolution, before being stored in the SQL tables. Time series of stream-level run reconstructions are generally of poor quality due to the number of underlying assumptions required. However, by storing the information at this resolution, data can easily be extracted from DARMA at various stock aggregations such as Pacific Salmon Treaty management groups or Wild Salmon Policy conservation units (CUs, Huang et al. 2021, DFO 2022). Like other PSC databases, DARMA also includes relevant metadata using standardised naming conventions for fishing areas, gears, and stock groupings to provide a common structure that supports robust data aggregation.

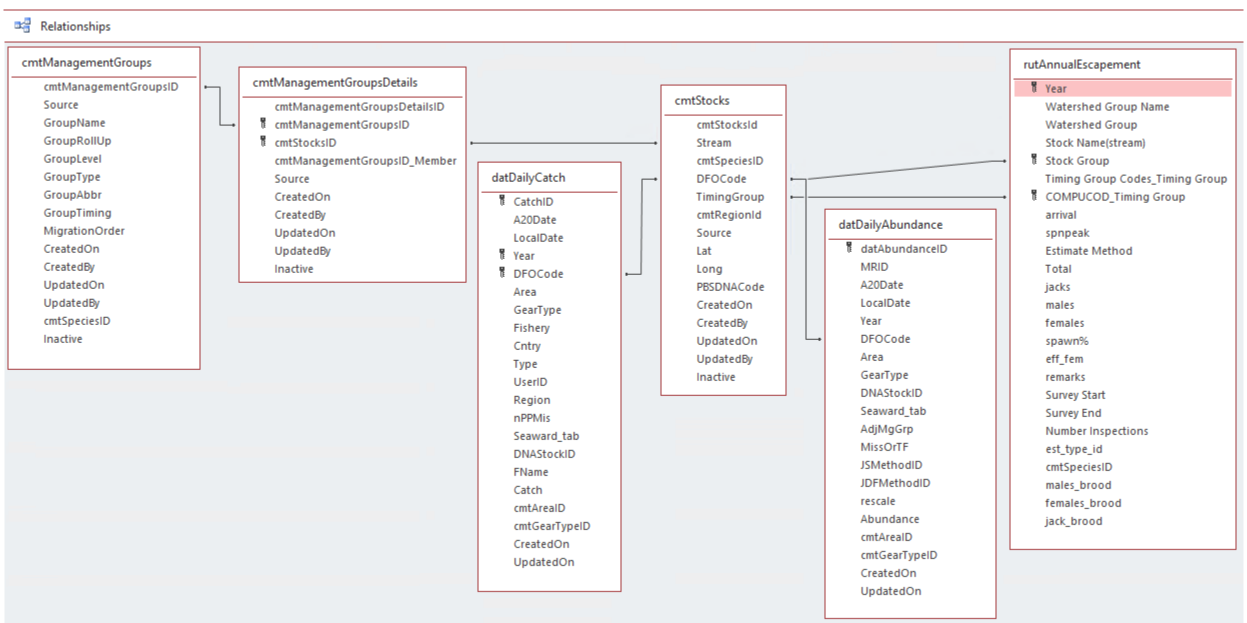

Figure 1. *A schematic illustration of the DARMA relational table structure.*

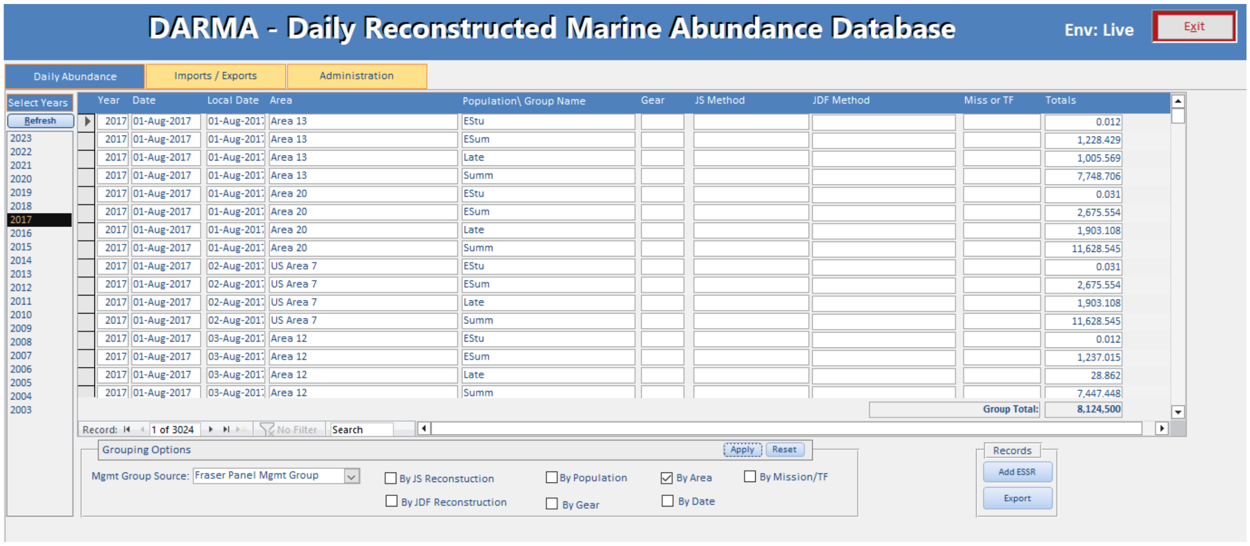

__Figure 2.__ The DARMA database interface. In this example, Fraser River sockeye abundances in 2017 are grouped by area and are aggregated at the Fraser Panel management group level.

Data Sources

Three main data types are imported into DARMA (Figure 1) from the MR100 marine reconstruction model files:

1) Stock-specific daily reconstructed abundances at key index locations (Figure 3).
2) Stock-specific daily reconstructed catches by fishery for fisheries seaward of Mission.
3) Meta-data associated with data sources and methodology used to derive marine abundances (Chapter C4).

Similar to the MR100 files, data stored in DARMA extends back to 2003. In addition, DARMA also links to spawning escapement tables in the RuFEs database (Chapter C18) to disaggregate imported data to the stream-level, matching the resolution of the DFO escapement database (Chapter C1).

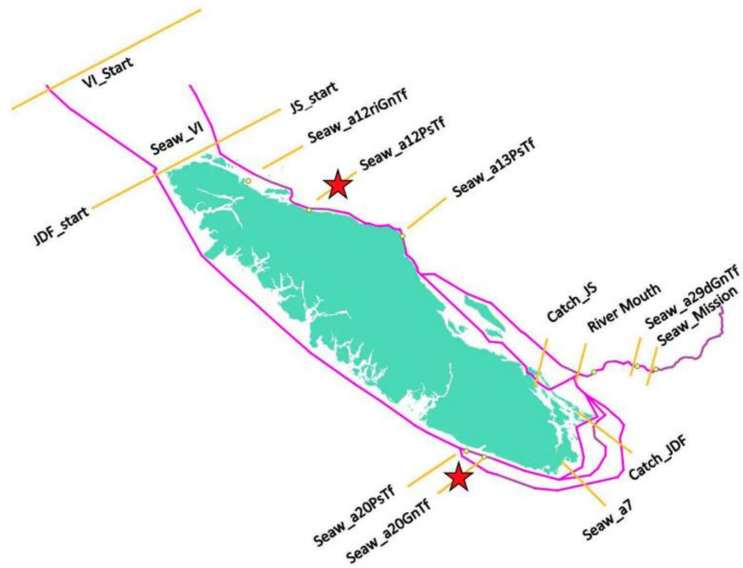

Figure 3. *Locations of reconstructed time series generated by the MR100 marine reconstruction model (Hague et al. 2021, Chapter C4). Red stars reference the Area 12 and Area 20 fishing areas, respectively.*

Storing data in a structured, relational database improves data integrity, accessibility, and security. To help validate the imported records, a series of quality control and quality assurance (QA/QC) protocols have been developed in R statistical software (R Core Team 2025). The QA/QC checks ensure that database totals match those in the original flat files, and that catch records housed in RuFEs and DARMA are consistent – ensuring data integrity.

Derived Outputs

Prior to the development of the MR100 reconstruction files and the DARMA database, the PSC only reported marine reconstructions at an aggregate stock-level. Median migration timing estimates were available for a mixture of stock aggregates, but diversion rate was only recorded for total Fraser River sockeye salmon. The ability of DARMA to provide daily abundances at multiple key locations along each migration route around Vancouver Island for various levels of stock aggregation has led to the development of new historical time series of migration timing, northern diversion rate (Hague et al. 2023, Wong et al. 2026) and spread that can be used to refine pre-season forecasts and priors used during in-season stock assessments (Chapter B23). The resulting time series of timing and diversion by management group are publicly available on the Fraser River Panel Annual Report Data App (Figure 4, PSC 2026). Because DARMA only extends back to 2003, migration timing and diversion estimates prior to 2003 are available but at a coarser resolution and users should be aware of the more uncertain nature of earlier estimates. Further details about the methods used to derive timing and diversion rates estimates prior to 2003 can be found in the documentation associated with the Annual Report Data App.

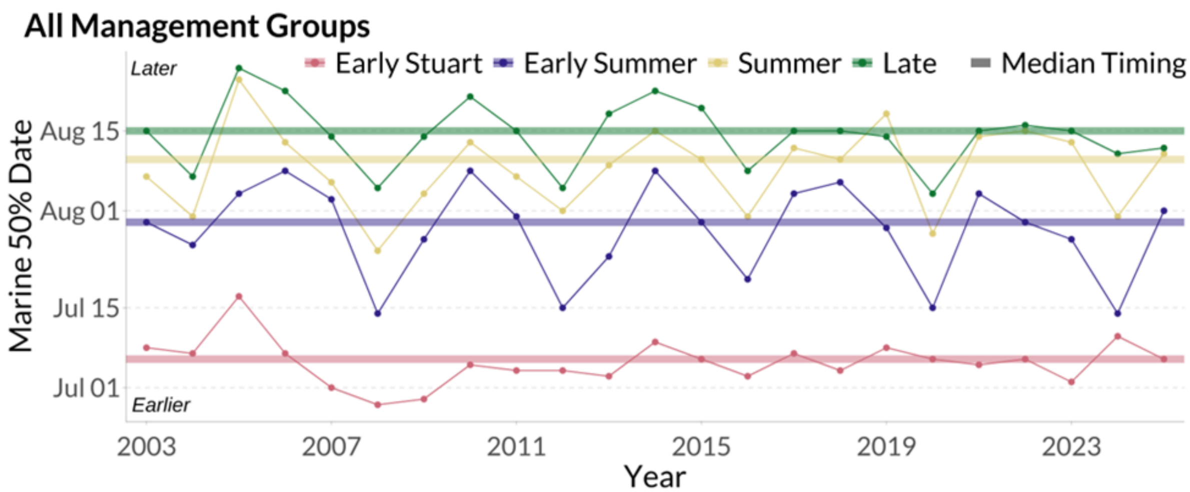

Figure 4. *Marine migration timing for Fraser River sockeye salmon, defined as the date when 50% of the returning run has migrated past the purse seine test fishing locations in Juan de Fuca and Johnstone Strait. Horizontal lines indicate the median timing across years for the different Fraser River management groups (PSC Annual Report Application 2026).*

In addition to the stock-specific daily reconstructed abundances produced by the MR100 files for pre-defined locations along different marine migration routes to the Mission hydroacoustic site (yellow lines in Figure 3), users can also query DARMA to extract stock-specific daily catch estimates aggregated across different fishing areas to produce stock-specific daily reconstructed estimates at an even finer spatial resolution. The improved spatial and stock resolutions will help improve the assessment of fishery- and area-specific harvest rates as well as in-season fishery proposal assessments (Chapter B34).

Future Work

DARMA is continually updated with new annual data. To facilitate the use of more stock-specific estimates, DARMA data exports in the future will be accompanied with data quality indicator information, meant to identify and score the relative uncertainty associated with the generated data (Chapter C12).

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Glossary of terms

Aboriginal Fishery Exemption (AFE): A number of sockeye that are reserved for First Nations fisheries for the purposes of management and calculating the Total Allowable Catch (TAC).

Abundance: The number of fish or the size of a stock.

Acoustically measured fish length: Fork length measurements from the fish's nose to the fork of its tail using ARIS fish images.

Acoustic blind zone: Area from which the return echoes are excluded from the recording by an echo sounder system.

Acoustic ensonified zone: Areas from which the return echoes are recorded by an echo sounder system.

Acoustic ping: Transmission of a single or a group of acoustic pulse(s).

Adipose-clipped (ADC): A salmon that is missing an adipose fin without notable scarring. Hatcheries mark released smolts by removing their adipose fin.

Adipose-damaged (ADD): A salmon that is missing its adipose fin with notable scarring and may or may not be a hatchery clipped fish.

Adipose fin: A small fleshy fin without rays found on the back behind the dorsal fin of some teleost fishes such as salmon.

Age group: Age is expressed as a two-digit code using the Gilbert and Rich nomenclature, e.g., 4_2 (Clutter and Whitesel 1956). The first number represents the total age at maturity, representing the number of years from egg deposition to spawning and the subscript or second number denotes the age at which the sockeye migrate to sea, i.e. the number of winters spent in fresh water as a juvenile.

All Citizen fishery: Refers to a type of fishery in the U.S., as opposed to U.S. Tribal fisheries.

Allele: Alternative forms of a gene inherited from each parent.

Anal fin: The median, unpaired, ventrally located fin that lies behind the anus.

Annulus: A distinct zone of closely spaced (thin) circuli on a scale, indicating a marked reduction in growth rate, interpreted as a period of winter growth.

Area 20 date: An index of marine migration timing, assuming the entire run migrated through Canadian fishery management Area 20 in Juan de Fuca Strait.

ARIS: Adaptive Resolution Imaging Sonar hydroacoustic equipment used to count passing fish.

Azure Data Factory (ADF): A cloud-based data integration service designed to orchestrate and automate data workflows. It is used to collect, transform, and deliver data, ensuring that insights are readily accessible for analytics and decision-making.

Azure DevOps: A cloud-based platform that provides integrated tools for software development teams. It includes everything needed to plan work, collaborate on code, build applications, test functionality, and deploy to production.

Azure Logic Apps: A cloud service provided by Microsoft that simplifies and automates workflows across applications and services.

Azure SQL database: A fully managed, cloud-based relational database service powered by the Microsoft SQL Server engine. It handles routine database management tasks, such as patching, automated backups, scaling, security, and high availability, allowing users to focus on data and application development rather than infrastructure.

Baseline: See genetic baseline.

Bayesian: Statistical method based on Bayes' theorem which specifies how prior probability distributions and data interact in the generation of estimates.

Brood year (BY): The year in which an individual fish was spawned.

C&S: Ceremonial and Subsistence. This is a type of fishing conducted by Tribes in the U.S.

Catch per unit of effort (CPUE): A relative measure of the abundance of the target species.

Caudal fin: Often called the tail fin. It provides the main power for forward movement of the fish.

Cbayes: A Bayesian genetic stock identification (GSI) method and software used to estimate the proportional stock composition of mixed-stock salmon samples. Cbayes is commonly applied to aggregate genetic samples from fisheries or test fisheries to produce stock-specific composition estimates.

Circuli: Fine, concentric bony ridges formed on a fish scale around the focus, deposited incrementally as the fish grows. The spacing between circuli reflects the growth rate, with wider spacing indicating faster growth and narrower spacing indicating slower growth.

Coefficient of variation (CV): Statistical measure of the dispersion of data points around the mean.

Conservation Unit (CU): Group of wild salmon sufficiently isolated and evolutionary distinct from other groups that is very unlikely to recolonize naturally within an acceptable time frame if extirpated.

Cycle line: A sequence of years associated with a cohort of Fraser sockeye, based on the assumption that the dominant portion of returning spawners mature at age 4. A cycle line consists of every 4th year. For example, the 2024 cycle line includes return years 2012, 2016, 2020 and 2024.

Cyclic dominance: A characteristic abundance pattern in Fraser River sockeye in which one year in a four-year cycle exhibits persistently large abundance (the dominant year), followed by a slightly lower abundance in the subdominant year, and very low low abundances in two off-cycle years.

DARMA database: The Daily Reconstructed Marine Abundance (DARMA) database houses time series of post-season reconstructed daily marine abundances for Fraser River sockeye salmon starting in 2003.

Database: An organized collection of data that is stored, managed and accessed electronically, allowing users to efficiently retrieve, update and analyze information.

Data pipeline: An automated system that ingests raw data from various sources, transforms it, and moves it to a destination, typically a data lake or warehouse, for analysis.

Delay: Number of days salmon will delay in the Strait of Georgia during their migration to the Fraser River.

Demonstration fishery: A Canadian commercial fishery designed to test particular gear configurations or explore the feasibility of harvests either in non-traditional areas or by non-traditional gear. A limited number of licenses are typically issued to permit these fisheries.

Density dependence: Stock-recruit dynamics whereby a large number of spawners are thought to have a negative effect on productivity such that subsequent recruit numbers are reduced.

Designatable Unit (DU): For salmon, a DU represents a group of populations that is both discrete (separated from other groups by genetic, geographic, ecological, or behavioural factors) and significant to the species' evolutionary legacy, such that its loss would result in an irreplaceable reduction in the species' diversity. DUs are the fundamental units used by COSEWIC to assess extinction risk and inform conservation and recovery planning in Canada.

DIDSON: See Dual-Frequency Identification Sonar.

Difference between estimates (DBEs): Difference between spawning escapement (SE) and potential spawning escapement (PSE) (DBE=SE-PSE). Note that jack spawners are excluded from the calculation.

DINGS database: The Database of Individual Nerka & Gorbuscha Salmon (DINGS) houses genetic stock identification (GSI) data for individual salmon matched to biological data stored in the Scales database.

Discharge: Volumetric flow rate of water.

Discriminant function analysis: A statistical procedure that classifies unknown individuals into a certain group and indicates the probability of the classification.

District 104 (D104): A commercial fishing district in Southeast Alaska.

Diversion rate (Northern diversion rate): Proportion of the salmon run that migrates through Johnstone Strait (northern approach) as opposed to Juan de Fuca Strait (southern approach).

Dorsal Fin: A median fin along the back of the fish which is supported by rays.

Dorsal hump: Distinct hump often developed by male salmon prior to spawning.

DSTAR: The Database for Sample Tracking and Reporting (DSTAR) is an inventory of biological samples collected by the PSC and other agencies, and is the main tool used by PSC staff for in-season tracking of sample collections and shipments.

Dual-Frequency Identification Sonar (DIDSON): A high-definition acoustic camera that produces near-video-quality images underwater, even in conditions with zero visibility or high turbidity.

Early Stuart run: Earliest of the four Fraser River sockeye management groups. This group spawns in the Takla–Trembleur Lake system.

Early Summer run: Sockeye management group that returns to the Fraser River after the Early Stuart run timing group and prior to the Summer run.

Economic Opportunity (EO) fishery: Commercial Fraser River First Nations fishery in the Lower Fraser River.

Echosounder: The topside, land-based component of the hydroacoustics system that provides power, data transfer, and signal processing to the submerged transducer.

Effective Female Spawners (EFS): An estimate of the number of female spawners that successfully contribute eggs to reproduction, calculated as the total number of female spawners multiplied by a measure of average spawning success. Spawning success is derived from subsampled females and reflects the proportion of eggs deposited before death.

El Niño Southern Oscillation: Inter-annual climate variability event in the Pacific Ocean that occurs every two to seven years and persists for less than 2 years, characterized by coupled variations in sea surface temperature and sea level pressure.

En route loss: The loss of a salmon from the calculation of post-season run size due to unaccounted catch, release mortality or natural mortality.

En route mortality: The mortality of adult salmon from the marine approach areas to the spawning grounds.

EWatch: The DFO Environmental Watch (EWatch) program that provides PSC mangers with scientific advice and environmental data to assess the impact of different environmental factors on the migration success of Pacific salmon in fresh water.

Escapement (SE): Spawning escapement of adult male and female spawners as well as jack spawners (precocious males, typically age-3), as estimated through assessment programs conducted on the spawning grounds or projected from other data when such programs are not conducted. Note that for the estimation of differences between estimates, jack spawners are excluded from the escapement.

Expansion line (EL): Inverse of the catchability coefficient, which indicates the extent to which a stock is susceptible to fishing.

Exploitation rate (ER): The proportion of a fish stock or population removed by fishing. Exploitation rate is stock-wide, whereas harvest rate is fishery-specific.

Fecundity: The total number of eggs present in a female salmon's ovaries prior to spawning, commonly used as a measure of reproductive potential.

Final TAC run size: The Fraser sockeye run size adopted at the last in-season Fraser River Panel meeting that determines the United States share of the TAC.

Fish density: Number of fish per unit volume (fish m^{-3}).

Fishery-induced Mortality (FIM): Outdated term formerly used by the Fraser River Panel to describe mortality resulting from the capture, handling and release of salmon in fisheries. As of 2026, the Fraser River Panel uses the narrower term of Release Mortality in its reports.

Fishery Planning Model: A pre-season simulation model that allows the Fraser River Panel to evaluate the impacts of various fishery options on the achievement of management objectives, given pre-season expectations such as abundance, stock composition, migration timing, diversion rate, spawning escapement targets, management adjustments and catch objectives.

Fishing-Related Incidental Mortality (FRIM): Refers to any mortality that occurs as a result of an encounter with fishing gear that is not included in the retained catch estimates, such as drop-off (i.e. drop-out, depredation, escape and avoidance mortality), and release mortality (i.e. on-board, or post-release mortality).

Fish flux: Number of fish passing through a unit area per unit time (fish sec^{-1} m^{-2}).

Focus: The central area of a salmon scale formed at the onset of scale development, shortly after the fry has absorbed its yolk sac. The focus represents the earliest stage of scale growth, from which circuli are subsequently deposited outward as the fish grows.

Fork length: Length from the fish's nose to the fork of its tail.

Food, Social and Ceremonial (FSC) fishery: Non-commercial First Nations fishery.

Forecasted Stock: One of 27 Fraser River sockeye stocks for which annual run size forecasts are generated. Timeseries of stock recruit data are available for 20 of the forecasted stocks, while 7 stocks relay solely on historical timeseries of escapement data.

Fraser River Panel (FRP): Responsible for the in-season regulation of fisheries in Southern BC and Northern Puget Sound targeting Fraser River sockeye and pink salmon.

Fraser River Sockeye Spawning Initiative (FRSSI): A multi-year collaborative planning process by DFO to develop a long-term escapement strategy using a simulation model that allows for the evaluation of the performance of different escapement strategies through the application of different harvest control rules. In addition, it explores the robustness of these strategies to different key sources of uncertainty such as possible alternative population dynamics and future patterns of productivity.

Fraser River Technical Committee (FRTC): Technical Committee that supports the work of the PSC Fraser River Panel.

Freshwater zone: The area on the salmon scale that represents the time the fish spent in freshwater.

Fry: Juvenile freshwater life history stage when salmon have emerged from the gravel, completed yolk absorption, and are less than a few months old.

Gear: Equipment used to fish.

Genetic baseline: A systematically collected and curated reference dataset of genotypic information from known breeding populations, used to assign individuals from unknown or mixed-stock samples to their population, stock, or management group of origin through genetic stock identification (GSI).

Genetic differentiation: A measure of how different two populations are genetically based on what alleles they share.

Genetic profile (or multilocus genotype): A composite of genotypes from different locations within the genome.

Genetic stock identification (GSI): A molecular technique used to estimate the composition of mixed-stock fisheries by comparing the genetic markers of unknown individuals to a reference baseline of known population stocks.

Genotype: Genetic make-up at a particular location of the genome that is composed of alleles inherited from the two parents.

Gilbert-Rich age notation: Method to describe the age of a salmon (Clutter and Whitesel 1956). Age is expressed as a two-digit code, e.g., 4_2. The first number represents the total age at maturity, representing the number of years from egg deposition to spawning and the subscript or second number denotes the age at which the sockeye migrate to sea, i.e. the number of winters spent in fresh water as a juvenile.

Gillnet (GN): A fishing net which is hung vertically such that fish attempting to swim through the net are entangled by their gills.

Harvest Rate: The proportion (often expressed as a percentage) of the available abundance of fish during a defined time period in a specified fishing area that is retained in a fishery. Harvest rate is specific to the combination of gear type, location, timing, and regulatory conditions under which the fishery operates. Harvest rate is fishery-specific, whereas exploitation rate is stock-wide.

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

Hells Gate: Narrow canyon located approximately 209 km upstream from the mouth of the Fraser River that presents migration challenges for Pacific salmon due to high water velocities, turbulence, and constricted flow.

Hydroacoustics: Technology involving sonars to detect fish in the water.

Hydroacoustic data: an index of abundance of fish produced by acoustic equipment

Hydroacoustics database: The hydroacoustics database integrates standardized hydroacoustic outputs, biological measurements, behavioural metrics, and records of Food, Social, and Ceremonial fisheries from 2018 onwards.

Hypural plate: A wide, fan-like plate onto which the caudal fin rays are attached.

Individual transferable quota (ITQ): A fisheries management tool to allocate proportions of the total available catch to individual fishers or companies. These quota shares confer long-term harvesting rights and can be bought, sold or leased, allowing for transferability among participants while maintaining an overall catch limit for the fishery.

In-River mortality: Natural and anthropogenic mortality of adult salmon within the Fraser River, between Mission and the spawning grounds.

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

In-season-based run size: Run size based on the abundance estimates at Mission plus downstream (i.e., seaward) catches. In-season-based run size estimates can be generated immediately after the fisheries management season and represent in-season knowledge and information that may not be appropriate for certain kind of post-season analyses.

Integrated Fisheries Management Plan (IFMP): DFO document to communicate on the planning of fisheries and their management to DFO staff, co-management boards and other stakeholders.

International Pacific Salmon Fisheries Commission (IPSFC): International Commission formed in 1937 between governments of Canada and the United States for the protection, preservation and extension of the sockeye and pink salmon fishery of the Fraser River. The IPSFC was dissolved in 1985 following the signing of the Pacific Salmon Treaty.

Jack: A male salmon that spawns after spending a year or two less in the sea than most individuals of its species.

Kalman filter model: A state-space stock-recruitment model describing the relationship between the number of spawners and recruits while allowing key population parameters, most commonly productivity, to vary through time.

La Niña: Inter-annual climate variability event characterized by anomalous cool sea surface temperature and low sea level pressure.

Larkin model: A stock-recruitment model that extends traditional density-dependent frameworks by incorporating delayed density-dependent effects across successive brood years. In the Larkin model, recruitment in a given year is influenced not only by the abundance of parent spawners but also by spawner abundance in previous brood years. These delayed effects are commonly interpreted as resulting from food depletion, habitat alteration, or increases in pathogens or predators in response to large abundances of spawners.

Late run: One of the four Fraser River sockeye management groups, returning last to the Fraser River.

Lateral Line: A sensory organ of fishes which consists of a canal running along the side of the body and allows perception of low frequency vibrations and pressure differences.

Local adaptation: A population that has evolved characteristics to survive and reproduce in specific local environmental conditions.

Locus (plural Loci): A location in the genome.

Low Abundance Exploitation Rate (LAER): The purpose of managing a sockeye management unit in a LAER situation is to permit by-catch of that stock group in fisheries directed at other management units or species with available surpluses, e.g. Fraser River pink salmon. The application of a LAER for a management unit has the effect of limiting the exploitation rate (ER) of that group to a small amount, e.g., 10% or 20%.

Lower Fishery Reference Point: Run size below which no directed fisheries are allowed on Fraser River Sockeye Salmon; only incidental harvest, directed at co-migrating stocks is permitted. This incidental harvest needs to remain well below the Low Abundance Exploitation Rate (LAER).

Management Adjustment: An in-season estimate of the additional fish required to be added to a spawning escapement target for the purpose of increasing the likelihood of achieving the escapement target.

Management Strategy Evaluation (MSE): A simulation model to test different potential harvest control rules to achieve the management objectives.

Management Unit (MU) or group: Aggregates of sockeye salmon stocks that are used by the Fraser River Panel for the management of Fraser River sockeye: Early Stuart, Early Summer, Summer, and Late run sockeye.

Marine growth: Growth of the fish during their time in saltwater.

Markov chain Monte Carlo (MCMC): Algorithm used in Bayesian analyses to approximate the posterior probability distribution by random sampling.

Mark-recapture: A scientific method to estimate the total abundance, migration patterns, and survival rates of salmon populations.

Maximum likelihood estimation (MLE): Statistical method to estimate model parameters, given the observed data.

Maximum sustainable yield (MSY): The largest average catch that can be removed from a stock over an indefinite period under existing environmental conditions.

Median: 50^{th} percentile of the distribution.

Microsatellite: A genetic marker characterized by repeating sequences of DNA where number of repeats are used to characterize alleles.

Migration date or 50% date: Dates when half (50%) of the total run would have passed a location.

Migration timing: See Migration date.

Miscellaneous stock: A stock forecasted by DFO without a spawner-recruit relationship, given a lack of recruit data of sufficient length.

Mission-based final run size: Run size based on post-season daily reconstructed abundance estimates derived by adding daily estimates of seaward catches to the daily abundance estimates at Mission.

Mixture analysis: A statistical modeling technique used to identify, characterize, and estimate the properties of underlying, unobserved subpopulations within a larger, heterogeneous data set.

Multivariate method: A statistical method that uses more than one independent variable in the analysis.

Natal fidelity: Tendency of organisms to return to their birthplace to reproduce.

Nearest-neighbor method: A spatial statistical approach to predict missing values based on observations in neighboring areas.

Non-directed/targeted: Fish caught incidentally by fisheries targeting other species.

Non-retention: In fisheries where one species is targeted but by-catch of a second species is expected, regulations may specify that the fish of the second species be released, not retained. Non-target species that are released are assigned gear-specific release mortality rates (see release mortality), that are accounted for along with landed catches in estimates of total exploitation rates.

Northern Diversion rate: See Diversion rate.

Offset: See Timing offset.

Otolith: Bony structure found in the inner ear of salmon, used to age fish.

Pacific Decadal Oscillation (PDO): Atmospheric and oceanic index used to describe the inter-decadal variability in the climate of the North Pacific Ocean.

Pacific Salmon Commission: Regional Fisheries Management Organization (RFMO) overseeing the Pacific Salmon Treaty (PST) between Canada and the United States.

Pacific Salmon Treaty: Bilateral agreement between Canada and the United States addressing the conservation and allocation of Pacific salmon.

Panel Area Waters: Geographical area defined under the Pacific Salmon Treaty in which Fraser River sockeye and pink salmon management is subject to provisions of the Treaty.

Passage: The count or estimated number of salmon that migrate through a defined geographic area or monitoring point within a defined time period, commonly reported at regular intervals, e.g., the daily passage of salmon past the Mission hydroacoustic site.

Pipeline: See Data pipeline.

Planning Inter-Panel Workshop on Genetics (PIPWOG): An ad hoc workgroup of GSI practitioners and technical committee members assembled to address issues regarding the estimation and communication of harvests of Fraser River sockeye stocks in Alaska's District 104 fishery.

Plus growth: A zone on a salmon scale representing freshwater growth that occurs after the formation of the final freshwater annulus and before entry into the marine environment. Plus growth is characterized by circuli of intermediate spacing. The extent and appearance of plus growth are highly variable among Fraser River sockeye stocks and reflect differences in juvenile life history and migration timing.

Polymerase chain reaction (PCR): a molecular biology method to create many copies of targeted parts of the genome to allow further genetic analyses.

Post-season run size: A stock-specific run size determined post-season currently based on spawning escapements, catch estimates, and en route mortality. The value also includes corrections for estimated biases in spawning ground escapement and catch data.

Potential Spawning Escapement (PSE): Predicted abundance of Fraser River sockeye salmon on the spawning grounds based on Mission escapement minus in-river catch upstream of Mission and assuming no en route mortality.

Pre-season run size forecast: A quantitative estimate, developed prior to the fishing season, of the total number of salmon expected to return to spawn in a given year, typically stratified by stock, management group, and/or geographic region.

Pre-spawn mortality: Mortality of salmon that successfully migrate to the spawning grounds but die before releasing any eggs, resulting in no direct reproductive contribution.

Principal component analysis: A statistical method to summarize a set of variables that are correlated (e.g., scale data) by creating synthetic variables called principal components that are linear combinations of the original variables. Principal components are not correlated with each other and satisfy the independence assumption in many statistical methods.

Principal component scores: Transformed variable values after principal component analysis.

Prior (prior probability distribution): A probability distribution that express the information about a parameter before any observed data. Priors may be based on historical observations, theoretical expectations, etc.

Productivity: The ability of a salmon population to sustain itself, often defined as the number of adult fish produced per spawner.

Purse Seine (PS): A net that can be drawn into the shape of a bag using the line along the bottom of the net like the drawstring of a purse.

Quality Assurance (QA): A proactive, systematic approach to maintain high data standards throughout its lifecycle, ensuring data is accurate, complete, consistent, and reliable for its intended use. The emphasis is on preventing defects before they occur through policies, standards, and continuous process improvement.

Quality Control (QC): A reactive, process-oriented practice centered on assessing actual data outputs against predefined quality rules and expectations. QC involves detecting, correcting, and managing data defects, such as missing values, duplicates, or invalid formats, by performing checks and validations on datasets before data usage.

Reconstruction: See run reconstruction.

Recreational fishing (sport fishing): Non-commercial fishing as a leisure activity or to provide food for personal consumption.

Recruit: A salmon that survives to maturity is considered a “recruit” from its parent generation, or brood year.

Recruits per spawner (R/S, RS): A measure of productivity of a population or stock. The number of salmon surviving to maturity per each adult salmon that successfully spawned in the freshwater spawning grounds.

Reef net (RN): A net suspended between two boats. The net is anchored for stability.

Release Mortality: Mortality associated with the release of caught fish due to stress of capture or handling.

Resorption: The physical wearing down of the scales from the environmental stress of moving from marine waters to freshwater waters. It makes the scale difficult to age as the perimeter of the scale is worn away.

Return year: The year in which an individual salmon returns to freshwater with intent to spawn.

Ricker model: Model describing the density-dependent population dynamics between the number of spawners and recruits.

rubias: An open-source R package for genetic stock identification. rubias is increasingly used in salmon assessments as a flexible and transparent framework for DNA-based stock identification, simulation, and evaluation of assignment performance.

RuFEs database: The Run Size, Fishing and Escapement (RuFEs) database houses daily Fraser River sockeye salmon catch and Mission passage estimates, annual spawning escapement, and run size adjustment (RSA) estimates by stock.

Run reconstruction: A scientific analysis used to estimate the total abundance and migration timing of salmon stocks by working backward or forward from observed data. Forward reconstructions predict daily escapement into the river or to the spawning grounds based on marine daily abundance estimates while backward reconstructions add marine and lower river daily catches to daily escapement estimates to reconstruct daily abundances in marine areas.

Run size: The total number of returning adult salmon prior to being impacted by fisheries en-route to the spawning grounds.

Run Size Adjustment: A post-season adjustment to run size based on post-season evaluations of factors influencing en route mortality and biases associated with spawning escapement and catch estimates.

Run Size Adjustment (RSA) stock: Twenty-eight Fraser Sockeye stocks that are annually assessed post-season for adjustments to the stock-specific run size estimates.

Run timing: See migration date.

Run timing group: One of four Fraser River sockeye management group characterized by different timing of their migration to the Fraser River: Early Stuart, Early Summer, Summer and Late run.

Scale: A small, thin, overlapping plate that grows continuously on the skin of a fish and act as external, flexible and protective armour.

Scale database: The Scale database contains detailed information on the origin and age of Fraser River sockeye salmon beginning in 1912.

Scale and otolith image library: The scale and otolith library is a curated collection of sockeye salmon scale and otolith images from the Fraser River watershed and documents variations in scale and otolith characteristics across different stocks, brood years, and life histories. It serves as a reference archive and training resource.

Scale pattern analysis: The examination of growth patterns on salmon scales, based on the spacing and arrangement of circuli, to determine fish age and infer life-history characteristics such as freshwater and marine residence. Scale pattern analysis is routinely used for aging salmon and for identifying population or stock origin based on characteristic growth signatures.

Set net: Gillnet anchored in position rather than drifted.

Shiny app: An interactive web application built using the Shiny framework for the R programming language. It enables users to explore data, perform analyses, and visualize results through a web browser using interactive controls and graphics, without requiring users to write or understand code.

Single nucleotide polymorphism (SNP): a genetic marker with alleles that differ at a single nucleotide base.

Single Stock FSC (SSFSC): FSC fisheries for individual Fraser sockeye spawning populations that may be considered if the projected number of spawners is expected to exceed the freshwater productive capacity of the system.

Smolt: A juvenile life-history stage of salmon following the fry stage when the young salmon are typically rearing in lakes or rivers In late winter, juveniles undergo smoltification, a suite of physiological and morphological changes that prepare them for marine life. Smolts typically migrate downstream to marine waters in spring.

Spawner: Adult salmon that successfully migrate from marine environments to freshwater spawning grounds and have the opportunity to reproduce, after avoiding natural mortality and harvest.

Spawning Escapement (SE): See Escapement.

Spawning Escapement Plan: The pre-season management framework that specifies how many Fraser River sockeye salmon must be allowed to escape fisheries and reach the spawning grounds in order to meet conservation and rebuilding objectives. The plan is developed under Canada's obligations to the Pacific Salmon Treaty (PST 2025) and is derived through the Fraser River Sockeye Spawning Initiative (FRSSI).

Spawning escapement target (SET): Target for total adult spawning escapement for each spawning population as defined each year by Canada's Spawning Escapement Plan.

Spread: Number of days encompassing 95% of a stock's migration.

Spring growth: A zone on a salmon scale representing freshwater growth that occurs after the final freshwater annulus has formed and immediately prior to marine entry. Spring growth is characterized by circuli of intermediate spacing, narrower than early marine circuli but wider than typical winter circuli. The presence and extent of spring growth are highly variable among Fraser River sockeye stocks and reflect differences in juvenile rearing conditions and migration timing.

Stock: A genetically distinct population of salmon, spawning at similar times and location.

Stock assessment: Use of statistical and mathematical calculations to estimate fish abundance as well as the impact of fisheries management decisions on fish abundance.

Summer run: One of the four sockeye management groups returning to the Fraser River after the Early Summer run and prior to the Late run.

Target strength (TS): A decibel measure of the acoustic backscattering cross-section of a target relative to 1 m^2. Target strength is used in hydroacoustic analyses as an index of acoustic target size.

Test fishing: A fishery conducted by management agencies to determine the abundance and/or stock and age composition of returning adult salmon.

Test fishing database: Houses test fishing related data including information on fishing trips, catch gear specifications, environmental conditions, seal observations, charter rates, fish pricing, and fish ticket records.

Time-density model: In-season run size assessment model that allows to estimate run size and migration timing based on the proportion of the migration on a given date.

Timing offset: Difference in migration timing.

Transect sampling: Sampling from a mobile platform along pre-set routes.

Transducer: A piezoelectric device usually built from certain types of ceramics that transforms electrical energy to mechanical energy and vice versa. In other words, an acoustic transducer converts electric signal into an acoustic signal via vibrations of a ceramic element, and then receives the incoming sound wave and converts it back into an electric signal.

Troll (TR): Fishing by trailing a baited line along behind a boat.

Total Allowable Catch (TAC): The number of sockeye and pink salmon available to be caught after spawning and the expected catch in Panel-authorized test fisheries have been subtracted from the run size.

Total Allowable Mortality (TAM): The maximum allowable mortality for each Fraser River sockeye salmon management group and run-size level as specified in Canada's Spawning Escapement Plan. Total Allowable Mortality includes fishery removals (retained catch) and en route mortality, represented by the Management Adjustment (MA).

Total Allowable Mortality (TAM) cap: Maximum amount of Total Allowable Mortality.

Univariate method: A statistical method that examines the relationship between a response variable and a single independent (explanatory) variable.

Visual survey: A non-invasive, cost-effective monitoring method used to estimate the abundance, distribution, and spawning behavior of salmon populations. Observers count live spawners and carcasses, either on foot, by boat, or by helicopter.

Whatman Sheet: Filter paper used for drying and preserving DNA samples.

Acronyms and abbreviations

A#	Area #
ADF&G	Alaska Department of Fish and Game
AC	All Citizens
ADF	Azure Data Factory
AFE	Aboriginal Fishery Exemption
ARIS	Adaptive Resolution Imaging Sonar
BEST	Bivariate ENSO Timeseries
BY	Brood year
CI	Confidence Interval
COSEWIC	Committee on the Status of Endangered Wildlife in Canada
CPUE	Catch per unit effort
CU	Conservation Unit
CV	Coefficient of variation
cyc	Cycle line
D104	District 104
DBE	Difference between estimates
DIDSON	Dual-frequency Identification SONar
DFA	Discriminant Function Analysis
DFO	Fisheries and Oceans Canada
DU	Designatable Unit
Ei	Entrance Island
EFS	Effective Female Spawners
EL	Expansion Line
EO	Economic Opportunity
ER	Exploitation rate
ESSR	Excess salmon to spawning requirements
EWatch	DFO Environmental Watch
F	Fishing mortality
FIM	Fishing-induced mortality
FN	First Nations
FPM	Fishery Planning Model

FRP	Fraser River Panel
FRTC	Fraser River Technical Committee
FSC	Food, Social and Ceremonial
GAM	General Additive Model
GAMM	Generalized Additive Mixed-effects Model
GLM	Generalised linear model
GN	Gill net
GSI	Genetic Stock Identification
GUI	Graphic user interface
HCR	Harvest control rule
HR	Harvest rate
HSM	Hope Statistical Model
IFMP	Integrated Fisheries Management Plan
ITQ	Individual transferable quota
IPSFC	International Pacific Salmon Fisheries Commission
JD	Julian date
JS	Johnstone Strait
JTC	Joint Technical Committee
LAER	Low abundance exploitation rate
LDA	Linear discriminant analysis
LFRP	Lower Fishery Reference Point
LRP	Limit Reference Point
M	Natural mortality
MA	Management Adjustment
MAE	Mean Absolute Error
MEF	Mid-eye fork length
MRE	Mean Raw Error
MSE	Management Strategy Evaluation
MSY	Maximum Sustainable Yield
MU	Management Unit
MCMC	Markov chain Monte Carlo
MEF	Mid-eye fork length
NEPSTAR	North East Pacific Salmon Tracking and Research

NOAA	National Oceanic and Atmospheric Administration
ONI	Oceanic Niño Index
OSCAR	Ocean Surface Current Analysis Real-time
p50	50^{th} percentile (similar for p10, p25, p75, p90)
PBS	Pacific Biological Station
PCA	Principal components analysis
PCR	Polymerase chain reaction
pDBE	Proportional Difference between estimates
PDO	Pacific Decadal Oscillation
PED	Passage estimate difference
PI	Probability Interval
Pi	Pine Island
pMA	Proportional Management Adjustment
POF	Postorbital fork length
POH	Postorbital hypural length
POM	Princeton Ocean Model
PS	Purse seine
PSC	Pacific Salmon Commission.
PSE	Potential Spawning Escapement
PST	Pacific Salmon Treaty
QA	Quality assurance
QC	Quality control
R	Recruits
REF	Retrospective Evaluation Framework
RMSE	Root mean square error
RN	Reef net
RS	Recruits per spawner
RSA	Run size adjustment
SARA	Species at Risk Act
SCAM	Shape constrained additive models
SE	Spawning escapement
SET	Spawning escapement target
SID	Stock Identification

SNP	Single nucleotide polymorphism
SOG	Strait of Georgia
SOI	Southern Oscillation Index
SSS	Sea surface salinity
SST	Sea surface temperature
TAC	Total Allowable Catch
TAM	Total Allowable Mortality
TF	Test Fishery
Tr	Tribal
TR	Troll fishing
TS	Target Strength
UFRP	Upper Fishery Reference Point
WDFW	Washington Department of Fish and Wildlife
WSP	Wild Salmon Policy