Improvements to Determining Post-Season Run Size for Fraser River Sockeye Salmon.

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The management of Fraser River sockeye salmon requires annual estimates of adult returns to determine both productivity and harvest rate. The purpose of this report was to make improvements to the overall process of generating these post-season run size estimates for all of the major Fraser River sockeye salmon populations, with specific emphasis on the in-river loss component. The post-season addition of in-river loss estimates to catch and spawning escapement are becoming an increasingly important contribution to run size calculations. To this end, the following is a summary of information and uncertainty on data sources and approaches used to estimate migration mortality. The primary focus of this work was to develop a preliminary decision framework to determine an estimate of the total number of returning sockeye that are not reflected in either catch or spawning escapement estimates.

Chapter One: Introduction to Run Size Determination

In order to sustainably manage sockeye salmon, reasonable estimates of adult returns and losses must be available throughout the planning cycle to guide decisions on harvest and escapement. As such, accurate pre-season, in-season and post-season estimates are important to the successful achievement of management objectives for the current season, and in determining objectives for future seasons. While pre-season estimates of adult returns are used to plan fisheries openings, in-season estimates are used to adjust harvest based on observed returns and actual migration conditions. Post-season, adult sockeye return estimates are used to assess whether harvest rate and spawning escapement were optimally balanced and to calculate the anticipated productivity and stock status of future returns.

Since 1992, the post-season returns for a given sockeye population have been calculated by adding estimates of spawning escapement, catch and in-river loss. The original rationale for including an in-river loss estimate was based on the observation that the estimated number of sockeye reaching natal spawning grounds was often different from the estimated potential, based on the number of sockeye passing through the lower Fraser River after adjusting for upstream catch; this discrepancy is referred to as the difference between estimates (DBE). Although it is understood that some portion of the DBE is due to inherent uncertainty and bias in the data producing this value, it also informs an estimate of en-route mortality from unaccounted sources. Currently, in-river loss estimates are evaluated using a post-season run size adjustment (RSA) that is designed to account for data-associated uncertainty and bias as well as estimates of en-route mortality; however, very little documentation exists to explain the procedures used to generate this RSA value.

Recent evaluations of the impacts of RSAs on post-season assessments indicate that this value can substantially alter our determination of abundance, productivity and exploitation for some sockeye stocks. For example, the inclusion of a high RSA when the true value is low leads to overestimates of productivity and underestimates of harvest rate, while the inclusion of a low RSA when the true value is high leads to underestimates of productivity and overestimates of harvest rate. Given the impact of post-season RSAs on stock status and the paucity of documentation, we undertook the process of developing a scientifically-defensible procedure for estimating stock-specific post-season RSAs that is agreeable to all data-contributing groups (i.e.

Pacific Salmon Commission (PSC); Fisheries and Oceans Canada (DFO) Resource Management, Science – Stock Assessment Division and Environment Watch Program). To begin, all sources of data and uncertainty currently incorporated into run size estimates were catalogued. Next, other potentially valuable information sources were evaluated for their use in future calculations, particularly in regards to progress towards migration mortality estimates that are independent of the DBE. Lastly, the 2009-2011 RSA values and key decision rationale were documented, including a framework and decision-making tree specifically developed for the RSA process. With this, we included a list of recommendations for improving future RSA evaluations. A detailed explanation of this project will be available in technical report format.

Chapter Two: Catalogue of Current Information for Post-Season Run Size Determination

Determining stock-specific post-season run size estimates requires the integration of data from sources throughout the Fraser River watershed and marine approach areas. More specifically, monitoring of marine and freshwater areas determine sockeye catch while spawner enumeration techniques estimate the number of sockeye escaping to reach natal spawning grounds. This report documents the information sources used to inform estimates of stock-specific post-season run size adjustments (RSA), focusing on the 2009-2011 process.

$$\text{Run size} = \text{spawning escapement} + \text{total catch} + \text{RSA}$$

The RSA was designed to account for uncertainty in data sources (i.e. catch and/or spawning escapement) and/or en-route mortality.

$$\text{RSA} = \text{RSA}_{\text{spawning escapement}} + \text{RSA}_{\text{catch}} + \text{RSA}_{\text{mortality}}$$

In most cases, the applied RSA was a derivative of the difference between estimates (DBE), as the DBE can provide a rough proxy for in-river loss. However, using this value effectively depends on accurate estimates of spawning escapement, total catch, and escapement through the lower Fraser River. This chapter provides a brief discussion of each of these three components.

Spawning Escapement

Spawning escapement is an estimate of the number of sockeye salmon that successfully escaped all fisheries to reach their natal spawning grounds during a defined spawning enumeration period. The Stock Assessment Division of Fisheries and Oceans Canada is responsible for obtaining these estimates, which serve as targets for the primary objective of in-season management. The methods used to assess spawning escapement varies by population and depends on the pre-season estimate of run size and the physical attributes of the system. For populations whose expected spawning escapement is less than 75,000 spawners, low precision techniques, such as visual surveys, are typically used. However, when the expected spawning escapement is greater than 75,000 spawners, more precise methods (e.g. enumeration fence, Petersen mark-recapture method, dual frequency identification sonar) are typically employed. This section focuses on the methods used to enumerate sockeye salmon spawning ground escapement, as well as the uncertainty and potential bias associated with each technique.

Visual Surveys consist of a visual count of live and dead spawners and are designed to encompass an entire spawning area that is accessible by foot, boat, or aircraft. The frequency of assessment varies depending on the system. A fixed index expansion factor is typically applied to the counts to determine the total spawning ground escapement estimate and adjusted for the likelihood that not all fish were observed and/or present during the survey(s). Some typical sources of bias and uncertainty in visual surveys are due to individual observer variability, survey design effectiveness (e.g. frequency, completeness and timing), and poor environmental conditions at the time of survey.

Complete Census includes two distinct enumeration methods in which individual salmon are accounted for either as they enter their spawning grounds through a controlled fence opening, or as their carcasses are enumerated in a closed system (e.g. spawning channel). Common sources of bias and uncertainty in fence enumeration include interrupted or delayed fence operation, alterations in fish behaviour due to the fence's presence, and high abundance that overwhelms counting ability.

Petersen Mark-Recapture Method estimate salmon escapement by tagging and releasing a portion of the population as they migrate to their natal spawning grounds. As the spawning period progresses, the spawning ground and surrounding areas are combed to recover salmon carcasses, and the number of tagged and untagged carcasses are recorded. Based on the number of tagged sockeye that are released back into the population (*M*), the total number of sockeye carcasses recovered (tagged and untagged; *C*) and the number of tagged sockeye carcasses recovered (*R*), the population size (*N*) can be calculated using the following equation:

$$N = MC / R$$

Several assumptions can increase the uncertainty of the estimate; however, procedures are in place to make adjustments to the data (as required), and evaluate and account for potential biases.

Dual Frequency Identification Sonar (DIDSON) is a high precision enumeration technique in which migrating sockeye are detected by the reflection of acoustic waves transmitted by the DIDSON. The waves are converted to a computer image via the DIDSON unit, and the image is used to enumerate the number of fish. Typically, only a subsample of the collected data (e.g. the first 20 minutes of each hour) is used for fish enumeration. Potential sources of bias and uncertainty include inadvertent enumeration of non-target species, missed detection due to acoustic shadows or turbulent flows, and individual errors in fish enumeration from the image.

$RSA_{spawning\ escapement}$

The $RSA_{spawning\ escapement}$ component of an RSA value is the result of a bias adjustment to a stock-specific spawning escapement estimate that results in a difference of greater than 10% of the near final value. This component of the RSA value is designed to provide a more accurate estimate of spawning escapement to the stock-specific run size estimate that has not been reflected in the official spawning escapement data to date.

Catch

In the post-season, the number of Fraser River sockeye salmon captured in marine approach areas and the Fraser River watershed must be estimated in order to estimate total run size. Both the United States and Canada harvest sockeye salmon migrating through the coastal marine environment, with the Canadian commercial fishery extending into the lower portion of the

Fraser River. Canadian First Nation's and recreational fishing groups also participate in marine and freshwater harvest, with the latter occurring throughout the main stem Fraser River, smaller tributaries, and in some cases near the terminal spawning areas. Finally, fish caught as part of the PSC Panel-approved test fisheries also contribute to the total estimate of catch.

As indicated, various sources of catch information must be integrated in order to determine the total number of Fraser River sockeye salmon harvested. Two essential components of determining catch estimates are fisheries monitoring and catch reporting. The relative contribution of each of these components varies by fishery.

Fisheries Monitoring involves non-harvesters (i.e. fisheries officers, fisheries guardians, and dedicated catch monitors) placed on boats or landing sites who monitor and record fishing effort and catch information. Additional catch and effort information can also be gathered through visual surveys (e.g. overflights) and interviews (i.e. phone, dockside or streamside).

Catch Reporting is done by harvesters, fish buyers, or contracted third party monitors. These individuals report harvest verbally, electronically, or in writing. The data provided by these methods typically classify catch by species. However, stock-specific catch information is required for the determination of individual run sizes for each of the forecasted stocks. Because of this, stocks are apportioned to catch based on DNA and/or scale samples collected from test and commercial fishing vessels or extrapolated from the relative proportion of stocks observed on the spawning ground.

Given the multitude of catch sources, a major source of uncertainty in catch reporting is associated with validation of the catch numbers themselves. Additionally, several sources of bias and uncertainty are associated with generating the stock-specific catch estimates including the challenge of covering a large geographical area, estimating unreported catch, inaccuracies in DNA stock assignment, and extrapolation of stock composition between locations. A more rigorous discussion of the uncertainty associated with generating catch estimates is documented in the Cohen Commission of Inquiry into the Decline of Sockeye Salmon in the Fraser River 2012 final report.

RSA_{catch}

The $\boldsymbol{RSA_{catch}}$ component of an RSA value is the result of known or expected bias adjustments to a stock-specific catch estimate that results in a difference of greater than 10% of the original value. This component of the RSA value is designed to provide a more accurate estimate of catch to the stock-specific run size estimate that has not been reflected in the official catch estimate to date.

Lower River Escapement Estimates

The lower river escapement estimate is defined as the estimated number of adult sockeye salmon that have reached the hydroacoustic site at Mission during their homeward spawning migration. While data collected from the hydroacoustic system is a component of the lower river escapement estimate, catch numbers and stock identification from test fisheries in both the marine approach and lower Fraser River areas are also be integrated into this estimate. The relative contribution of each of these data sources to the lower river escapement estimate is variable and depends on the quantity and quality of the available information.

Mission Hydroacoustic Facility

The Mission hydroacoustic facility has been operating since 1977 to provide near real-time estimates of fish escaping the commercial fishery and migrating through the lower Fraser River past Mission. Importantly, the data collected at this hydroacoustic site is used to estimate salmon abundance. Similar to the DIDSON, the sonar technology at Mission introduces uncertainty or bias due to issues with fish detection (i.e. non-target species enumeration and missed detection) and inaccuracies in the applied expansion factor. Furthermore, catch data from test fisheries are used to assign species and stock-specific escapement estimates to the abundance information, introducing additional sources of uncertainty.

Test Fishery Data

In-river test fishing data collected from Whonnock and Cottonwood in the lower Fraser River) are used to determine species and stock-specific lower river escapement estimates based on the abundance estimates at Mission. The stock composition information can be weighted towards a particular test fishery depending on the quality of data available (e.g. sample size, location, gear, effort). In years of pink salmon returns, the hydroacoustic facility typically shuts down late in the season due to high abundance; when this occurs, both of these test fisheries provide the lower river escapement estimates. Uncertainty and bias can be introduced from both the data collected from the test fisheries and the application of this information in assigning species and stock-specific escapements to the Mission abundance estimate.

$RSA_{mortality}$

$RSA_{mortality}$ component of the RSA value is the number of fish that are estimated to have died during the upstream migration (i.e. Mission to spawning grounds). Post-season, the DBE is calculated by subtracting in-river catch and lower river escapement estimate from the spawning escapement estimates. Historically, this DBE value is treated synonymously with the post-season $RSA_{mortality}$ value to provide an overall estimate of en-route mortality. It is important to understand that the DBE integrates data and associated uncertainties from each of the sources discussed above, and thus its value reflects this as well as potential en-route mortality. Chapter 3 describes in more detail the other potential sources of biological information that can be used to provide an estimate of $RSA_{mortality}$ that is more independent of DBE.

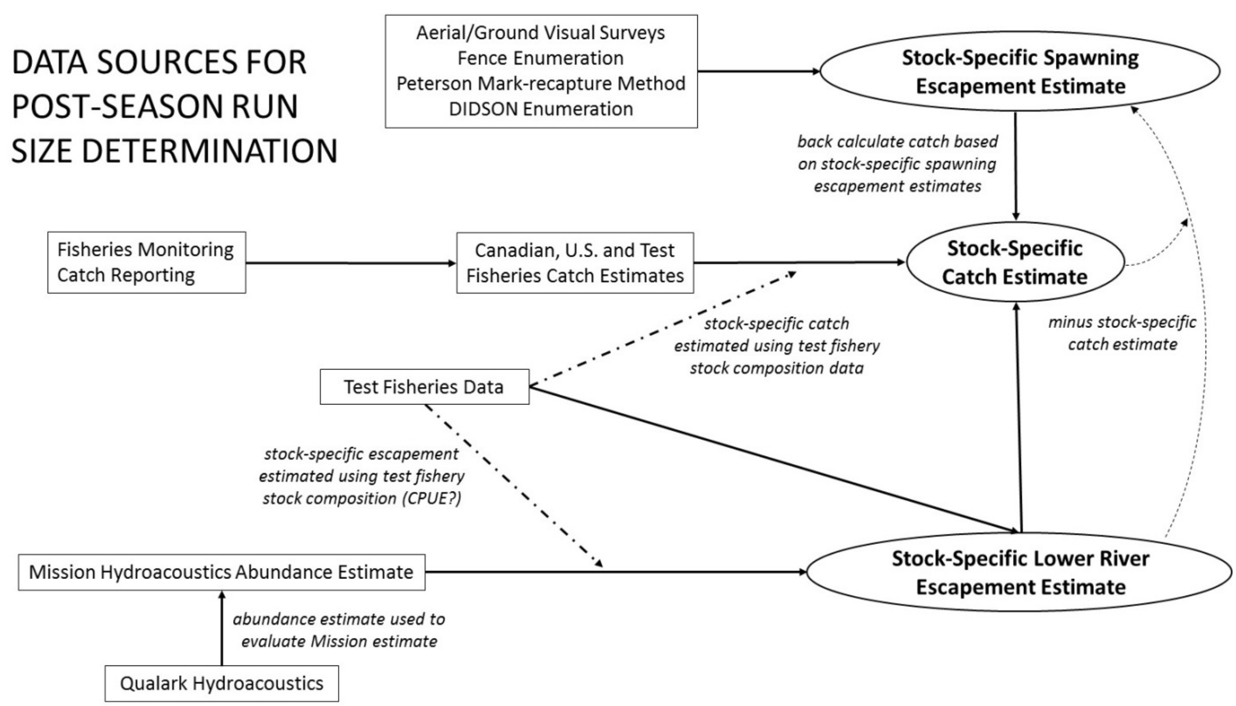

Figure 1. Concept map of the connections between data sources used in determining post-season run size estimates.

Data Integration

Each method used to collect data for the post-season determination of run size introduces some level of uncertainty into the estimate. However, further uncertainty develops as the data are integrated into a useable format. For example, post-season run size estimates are evaluated for the major sockeye salmon stocks, but the data attained from these sources are not consistently produced at that level of organization (e.g. run timing vs. individual stocks). Therefore, data sources are integrated to produce the information needed to make these informed decisions. Figure 1 illustrates the complexity of the integration between these data sources that are available.

Chapter Three: Use of Biological Information in Assessing Migration Mortality

Fraser River sockeye salmon are exposed to myriad of physical and biological stressors during their return upstream migration. As such, the relative importance of each of these stressors needs to be considered when determining a scientifically-defensible post-season estimate of en-route mortality. To evaluate the strength of the scientific evidence connecting individual stressors to en-route mortality, we conducted a review of the current literature on migration mortality in Fraser River sockeye salmon. The information collected was used to catalogue both current and potential new sources of information related to en route mortality, as well as construct different methods to quantify en route loss. The mortality estimate approaches explored to generate an $RSA_{mortality}$ from this review were based on weight-of-evidence, river entry timing, and thermal physiology.

The literature review identified over 80 primary publications relating mortality in adult Fraser River sockeye salmon to physical and biological stressors encountered during their upstream migration. The majority of the publications were published in the past 10 years and either examined the impact of thermal experience on migration success or the high mortality associated with early river-entry (particularly for the Late-run sockeye populations). Overall, the review identified run timing, stock, sex, and fish maturity as the main biological variables influencing migration success while run timing, temperature, and discharge were noted as the key physical factors. Several new sources of information were also identified during the literature review which could prove useful in future mortality evaluations including water quality, density dependence, body size, body energy, disease, fishing impact, and cumulative effects. A biological checklist was developed to provide current update of the relevant information that would be available post-season for generating a biologically defensible mortality estimate.

The biophysical information checklist provides a list of key factors to consider, where the information is available, and prioritization of information. The two main factors to consider first are water temperature and discharge based on their historic relationship with in-river loss for Fraser sockeye. The main factor is stock-specific migration timing. Timing is important for both determining more detailed environmental exposure risk as well as the direct link with timing and mortality for late-run stocks. Finally, a list of secondary biophysical information needs to be compiled annually. This information includes carcass observations, fish condition, related research (e.g. tagging, holding studies), and fishing (both catch and effort information).

In order to evaluate the impact of the key identified factors, the en-route mortality experienced by stocks in 2009-2011 seasons was estimated using several different approaches. These approaches ranged from qualitative (i.e. weight-of-evidence) to more quantitative (i.e. thermal physiology and the Weaver Creek timing-model) analyses and utilized different physical and biological factors in their evaluation. For example, the weight-of-evidence approach focuses on both the overall and relative impact of timing, temperature, and discharge on migration mortality based on the proportion of the total run exposed to adverse migration conditions (thresholds defined by the literature). Conversely, the thermal physiology model uses stock-specific aerobic scope parameters and simulated temperature exposure in order to generate a post-season estimate of temperature-based mortality. Finally, the Weaver Creek timing-based model uses the historic relationship between entry timing into the Harrison River and survival to the spawning grounds in order to estimate migration mortality. To do this, a daily abundance estimate of the number of Weaver fish passing Mission is applied to a survival curve in order to generate a weighted survival estimate for the Weaver Creek population as a whole. A comparative evaluation of each model was considered in the 2009-2011 decision-making process and contributed to the recommendations proposed in future integrations (outlined in Chapter Four).

Chapter Four: 2009-2011 Run Size Adjustments Decisions and Future Recommendations

Through the concerted efforts of all data-contributing groups, an initial structure for the transparent and documented process of determining post-season, stock-specific, run size adjustments has been developed. The resultant framework for the RSA process, the decisions and general rationale behind the 2009-2011 values, and any recommendations or adjustments to future evaluations are presented below.

The framework developed involved follows the sequence of steps outline below. The $RSA_{spawning\ escapement}$ and RSA_{catch} adjustments (described in Chapter 2) were determined prior to the $RSA_{mortality}$ component. The first step in the stock-specific $RSA_{mortality}$ estimate was to determine if a meaningful DBE existed. If not, then no $RSA_{mortality}$ was used. If yes, then the environmental conditions were considered to determine whether the DBE was a reasonable estimate of en-route mortality. If yes, the DBE was applied as the $RSA_{mortality}$. If no, then the next step was to consider abundance and/or stock bias in the lower river escapement estimate used to calculate the DBE. If a potential stock identification bias existed, then the DBE was redistributed across relevant stocks based on relative spawning ground escapement composition. If there was no indication of biases, then other sources of information were evaluated to determine a $RSA_{mortality}$ value (e.g. biological checklist - migration biology research, historic DBE information, timing-based models; see Chapter 3). It was agreed that with the growing availability of scientific information on salmon migration survival, future processes should not center on the DBE.

Four main recommendations arose from the 2009-2011 RSA work that will improve both the process and estimates for future determinations of RSA. First, we recommend a clear list of the data that each contributor is responsible for collecting and presenting for the purpose of post-season run size calculations. Second, we recommend consistent development and updates of current and new sources of biological information for input in the assessment of migration mortality. Third, we recommend a revised step-by-step decision processes that integrates the data sources in a manner that is not dependant on the DBE. Lastly, we recommend developing detailed and transparent documentation of the decisions made leading up to the annual stock-specific RSA values. A pending technical report will provide further details for all Chapters.