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COLLABORATIVE DEVELOPMENT OF ESCAPEMENT STRATEGIES FOR FRASER RIVER SOCKEYE: SUMMARY REPORT 2003 - 2008

by

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The core development team consisted of:

- *DFO Policy & Management:* Paul Ryall, Les Jantz, Mark Saunders, and Wayne Saito (currently at BC MOE)
- *DFO Technical Team:* Al Cass, Jeff Grout, Ron Goruk, Ann-Marie Huang, and Michael Folkes
- *External Experts:* Gottfried Pestal (SOLV Consulting Ltd.), and Michael Staley (IAS Ltd.)

This report draws on materials developed over the full course of the initiative with contributions by all team members. Chapter 1 and Appendix 3 include sections modified from drafts provided by Jeff Grout and Wayne Saito in 2005.

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Note: Workshop participants were expected to comment constructively on intermediate results and to review the resulting recommendations prior to public consultation. Workshop participants repeatedly stated that they were involved purely as individuals with an interest in shaping the content of materials destined for public consultation, and that they were not attending as official representatives of any organization. For more details about the collaborative process refer to Chapter 2 and Appendix 4.

TABLE OF CONTENTS

ABSTRACT

Pestal, G, Ryall, P., and Cass, A. 2008. Collaborative Development of Escapement Strategies for Fraser River Sockeye: Summary Report 2003 – 2008. Can. Man. Rep. Fish. Aquat. Sci. 2855: viii + 84 p.

The Fraser River Sockeye Spawning Initiative (FRSSI) was a 6-year process to develop new guidelines for setting annual escapement and exploitation targets for Fraser sockeye stocks. In 2003 Fisheries and Oceans Canada (DFO) committed to reviewing the rebuilding plan which had been in place since 1987, and established a collaborative planning process to incorporate new information and implement emerging policies.

The technical groundwork was laid through the development of a simulation model which was refined over three years and six workshops, leading up to an intensive two-year planning exercise that merged the FRSSI model into a pilot implementation of the integrated management processes envisioned under the *Wild Salmon Policy*. The new escapement strategies were fully implemented in 2007, and updated through the 2008 pre-season planning process.

RÉSUMÉ

Pestal, G, Ryall, P., and Cass, A. 2008. Collaborative Development of Escapement Strategies for Fraser River Sockeye: Summary Report 2003   2008. (Projet collaboratif pour l’établissement de stratégies d’échappement concernant les stocks de saumon rouge du Fraser : Rapport des travaux 2003-2008). Can. Man. Rep. Fish. Aquat. Sci. 2855: viii + 84 p.

La Fraser River Sockeye Spawning Initiative (FRSSI) (traduction libre : Initiative de suivi du taux de reproduction du saumon rouge du Fraser) est une initiative d’une durée de six ans qui avait pour objet d’établir de nouveaux paramètres pour l’établissement des taux annuels d’échappement et d’exploitation des stocks de saumon rouge du Fraser. En 2003, Pêches et Océans Canada (MPO) a décidé de réexaminer le plan de rétablissement des stocks qui avait été mis en place en 1987 et d’établir un mécanisme de planification collaboratif pour que ce plan reflète les nouvelles informations à disposition ainsi que les nouvelles politiques.

La préparation technique du projet a consisté dans l’élaboration d’un modèle de simulation qui a nécessité trois ans de travail et six ateliers, pour aboutir à un exercice de planification intensif d’une durée de deux ans qui a permis d’intégrer la FRSSI à un projet pilote pour la mise en œuvre des processus de gestion intégrés prévus par la Politique concernant le saumon sauvage. Les nouvelles stratégies d’échappement ont été mises en œuvre en 2007 et ont été actualisées dans le cadre du processus de planification préparatoire de la saison 2008.

1. SETTING ESCAPEMENT TARGETS FOR FRASER SOCKEYE

This chapter summarizes the biology of Fraser sockeye, outlines the annual process for managing fisheries, and retraces the history of escapement planning for Fraser sockeye.

Introduction

The Fraser River is the greatest producer of sockeye salmon in British Columbia, with more than 200 distinct spawning populations using over 150 spawning areas. Many of the sockeye populations have recovered from very low levels in the early 1900s and historical evidence indicates that the Fraser River may have the potential to produce substantially larger sockeye runs than observed in recent decades.

Average annual abundance has increased from less than 7 million in the 1950s to 12 million in the 1990s, and 1993 saw a return of 23 million fish, the largest recorded since 1952. In recent years, however, average abundance dropped to about 7 million and several individual stocks have declined severely in abundance, constraining harvest opportunities in mixed-stock fisheries.

Fisheries and Oceans Canada (DFO) developed the *Rebuilding Plan* in 1987 to increase Fraser sockeye production. DFO achieved a steady increase in total spawning escapement over almost 20 years of implementation, despite the declining abundance and production observed since the mid-1990s. The overall exploitation rate has been drastically reduced, from an average 78% in the 1980s to an average 37% since 2000. The shift towards increased escapement and reduced exploitation rate was partly driven by the rebuilding objective, and partly by harvest constraints imposed to protect weak stocks such as Early Stuart and Cultus Lake sockeye within mixed-stock fisheries. This combination of factors was particularly pronounced in 2002, when additional concerns over potential in-river mortality due to behavioural changes and detrimental environmental conditions resulted in an overall exploitation rate of 27%. Late run sockeye had migrated into the river early since the mid 1990s, and had experienced particularly severe in-river mortality of 80-90% in the brood year (1998). However, Late run sockeye delayed their freshwater migration in 2002, in-river mortality was not as severe as expected, and a record number of sockeye migrated onto the spawning grounds while fisheries were heavily curtailed.

DFO initiated a review of the rebuilding strategy prior to the 2003 fishing season to address the growing concerns expressed by stakeholders and the recommendations from the 2002 Ministerial review of Fraser River sockeye fisheries. The mandate of the review process was to incorporate new information, integrate emerging policies such as the *Wild Salmon Policy* (WSP), and establish a formal framework for setting escapement targets. The *Fraser River Sockeye Spawning Initiative* (FRSSI) was the resulting 6-year participatory process to develop new guidelines for setting annual escapement and exploitation targets for Fraser sockeye stocks.

Population dynamics

<u>Life cycle of Fraser River sockeye</u>

The Fraser River system supports one of the largest sockeye salmon runs in the world, and a very rich data set has been collected, with catch data going back to the 1800s, and comprehensive assessment of the number of spawners on the grounds over the last 50 years. Escapement information for some populations dates back to the late 1930s.

Sockeye spawn in over 150 natal areas, from areas near the estuary to as far as 1,300 km upstream. Their spawning grounds include small streams, large rivers and lakes throughout Fraser River watershed (Figure 1). Juveniles generally rear in large lakes for one year as fry before migrating seaward as smolts, entering the Strait of Georgia and moving north along the continental shelf into the Gulf of Alaska. The majority of Fraser River sockeye rear in the Gulf of Alaska for two winters before returning to the Fraser River as 4-year old adults. The technical notation for this life cycle is 4_2, designating a total life span of four years, with the first 2 winters spent in the freshwater environment. A variable proportion of adults return as 5-year olds, and some males also return as smaller 3-year olds called *jacks*. Returning adults typically approach the North Coast of BC, and then migrate south to the Fraser River estuary.

Population dynamics is a general term used to describe the biological characteristics, environmental processes and human factors that determine a population's abundance, growth, reproduction and mortality. Biological characteristics include age at maturity, number of eggs per female, and fish size. Environmental processes such as river discharge and ocean temperatures also affect survival rates throughout the life cycle. Human factors include the effects of harvest and habitat alteration. Capturing these dynamics is critical to assessing a population's sustainability as an exploited resource, but the cumulative mechanisms causing observed patterns in abundance are poorly understood. We can replicate similar population behaviours with relatively simple models, but we don't know if the simple models fit for the right reasons.

Figure 2 shows a substantial decrease in exploitation rate since implementation of the Rebuilding Strategy in 1987, which achieved a steady increase in total escapement but failed to produce a lasting increase in total abundance. The rise and fall in total abundance is particularly pronounced when individual cycle lines are tracked. For example, Figure 2 highlights consecutive 4-yr generations from 1981 to 2005.

Increased escapements coincided with a period of declining productivity. Figure 3 summarizes production data for the 19 Fraser sockeye stocks which have been consistently enumerated on the spawning grounds and identified in catches, and illustrates the variability and uncertainty in productivity estimates. The majority of observations range from 1 to 20 recruits per spawner (R/S). Sockeye populations in the Fraser system are highly productive, with each spawner typically producing an average of 5 adult offspring that return to spawn (known as "recruits"). Production varies substantially among stocks and from one year to the next, and estimates are also subject to biases in escapement surveys, producing some extreme observations that may or may not reflect biological reality.

Larger total abundances could likely have been achieved from these increased escapements if productivity had remained stable at the levels observed in the 1970s and 1980s. However, spawner levels and resulting returns would have been much lower for many of the Fraser River sockeye stocks if pre-1987 exploitation patterns had been maintained in the face of reduced productivity.

Statistical methods have been developed to model the relationship between spawners and recruits (later referred to as SR models). For sockeye, these models typically calculate the expected number of 4yr old and 5yr old recruits produced by the spawners in each brood year, and combine these age classes into a projection of run size. SR models typically have 2 estimated parameters: productivity and capacity. Where additional data is available, more complex models can be developed to incorporate additional life stages (e.g. smolt abundance) or environmental factors (e.g. sea surface temperatures when young salmon first enter the ocean).

Models differ depending on the assumptions they make about:

- Productivity at low escapement (e.g. is there a point at which production levels fail to provide sufficient recruits to recover due to density-dependent predation, called the predator pit?)

- Productivity at large escapement (e.g. is there a pronounced decrease in productivity if escapement exceeds capacity, due to mechanisms such as competition for spawning locations?)

- Interaction between cycle lines (e.g. does a large escapement last year affect survival of this year's brood, due to mechanisms such as reduced food availability and increased predator abundance? Or does periodic large escapement increase long-term production due to increased marine nutrients released into the watershed by the carcasses?)

For many Fraser River sockeye populations we have a long time-series of SR data of more than 50 years, which is one of the most comprehensive data sets for fish populations anywhere in the world. Figure 4 shows two examples, and a stand-alone handout with the full data set is attached as Appendix 9.

However, even this rich data set has some issues that need to be carefully considered:

- Most of the available data are from a period when Fraser sockeye were fished heavily, and therefore give us a good picture of how much exploitation the stocks can handle and still recover, given the range of survival conditions they faced at the time. We don't have much information about Fraser sockeye when they are very abundant (i.e. prior to the Hell's Gate slide), because it hasn't happened very often since regular surveys began 50 years ago. Therefore we don't have a clear picture of how large the runs could get, and we don't have a good estimate of what population size would maximize long-term catch. Stating the same in more technical terms: the productivity parameter is relatively well defined in spawner-recruit models, but the capacity parameter is highly uncertain. This means that maximum sustainable exploitation rates are known with relatively good confidence, but the spawning escapement that maximizes sustainable catch is poorly known. This uncertainty needs to be considered in the management approach. A fixed escapement policy should perform better in a theoretical setting where good capacity estimates exist and stocks can be managed individually. However, fixed exploitation rate policies should perform better in settings like the Fraser River, where capacity estimates are highly uncertain and stocks are managed in aggregate due to practical considerations (Appendix 1).

- The available time series capture a very good picture of past population dynamics for abundant stocks, but recent environmental changes such as warmer rivers and unfavourable ocean conditions introduce additional sources of uncertainty.

- Some populations that are small and irregularly surveyed have been identified as potential conservation units under the Wild Salmon Policy. They can't be explicitly incorporated in the simulations because available data are not sufficient for fitting SR models, but the potential effect of alternative harvest strategies on these populations still needs to be considered in the planning process.

<u>Management groups, stocks, and conservation units</u>

271 individual groupings of spawning sockeye have been identified throughout the Fraser River watershed, each with a specific combination of spawning area (i.e. as stream or lake) and migration time. Not all of these groupings show persistent abundance of sockeye, but were observed at least once in the available assessment data. The Fraser watershed is vast (223,000 km^2) and the spawning migration

protracted (June to October), so that these spawning populations are aggregated for assessment and management purposes.

Spawning populations have been grouped into production units, called *stocks*, for the purpose of monitoring status, developing forecasts, and analyzing population dynamics. Stocks are identified based on the geographic location of spawning streams and rearing lakes, as well as the timing of adult migration. Most of the system's production is accounted for by a few large stocks or stock groups: Birkenhead, Weaver, Chilko, Quesnel, Stellako, Stuart (Early and Late), Adams and Shuswap.

Stocks are further aggregated into management aggregates based on similar migratory timing during their return from the ocean. These timing groups overlap to a varying degree each year, and discrete harvest of individual stocks or stock aggregates downstream of terminal areas is not possible for three of four timing groups. The aggregates are, in order of adult migration:

- *Early Stuart:* 7 individual groupings that spawn in the Takla-Trembleur lake system, arriving in the lower Fraser River from late June to late July;
- *Early Summer:* 74 individual groupings that spawn throughout the Fraser system, arriving in the lower Fraser River from mid-July to mid-August;
- *Summer:* 12 individual groupings that mostly spawn in the Chilko, Quesnel, Stellako and Stuart systems, arriving in the lower Fraser River from mid-July to early September;
- *Late:* 158 individual groupings that spawn in the lower Fraser, Harrison-Lillooet, Thompson and Seton-Anderson systems, arriving in the river from late August to mid-October.

Finer distinctions have been used in recent years. For example, early components of the Late run (a.k.a. Birkenhead-type lates) are managed differently from the later components which have experienced the bulk of en-route mortality (a.k.a. true lates).

The simulation model used for the Spawning Initiative incorporates 19 distinct stocks that capture most spawning populations and most of the annual sockeye production (98.6% of total Fraser run size on average). However, in some recent years *miscellaneous* stocks that are not covered in the model have contributed 30-40% of the Early Summer run size.

With the implementation of the WSP, the focus of salmon management is shifting to functionally distinct *conservation units* (CU). For Fraser sockeye, these CUs are generally based on rearing lakes and timing, with 251 individual groupings in 31 CUs. An additional 20 individual groupings are river-type sockeye which do not rear in lakes (e.g. spawners from the Harrison River/Widgeon Creek system), and these are grouped into 6 CUs. River-type sockeye start their migration to the ocean a year earlier than populations that rear in lakes, and can face very different environmental conditions as juveniles.

Public consultation on sockeye CUs continues at this time, and the methodology for delineating CUs has been peer-review through the *Pacific Science Advice Review Committee.* The full report is available as CSAS Research Document 2007/070 by Holtby, B and K Ciruna (2007). *Conservation Units for Pacific Salmon under the Wild Salmon Policy* will be posted on the CSAS website at http://www.dfo-mpo.gc.ca/csas/Csas/Home-Accueil_e.htm. A complete and up-to-date list of sites for all CUs is available at http://www-comm.pac.dfo-mpo.gc.ca/pages/consultations/wsp/CUs_e.htm.

<u>The question of cycles</u>

In addition to annual variation, Fraser sockeye also show strong cyclic fluctuations in total abundance, catches, and escapement. This cyclic pattern is largely driven by a few large stocks in the Summer group and the Adams River stock in the Late group. Of about 20 sockeye stocks in the watershed that are enumerated routinely, 8 exhibit persistent cycles with a consistent peak in abundance every four years. If this pattern is very pronounced it is referred to as *cyclic dominance*. In these cases the *dominant* cycle line is the sequence of years with run size persistently larger than the other cycle lines. The *sub-dominant* line has moderate abundance, and *off-year* lines tend to have extremely low abundance relative to the dominant and sub-dominant lines. The dominant cycle lines for different stocks do not necessarily coincide. For example, Figure 5 compares patterns in abundance for 3 stocks: Stellako shows no consistent pattern since the mid-1970s, but Quesnel and Adams follow pronounced 4-year cycles that peak a year apart.

Despite 50 years of study, there is still no scientific consensus on the cause of cyclic patterns in the abundance of Fraser sockeye, but recent research points to a combination of biological mechanisms and past harvest patterns. Various ecological hypotheses have been proposed, including interactions with predators, diseases, or parasites. Marine influences have been discounted because it is unlikely they could generate cycles where some stocks are dominant one year, and some stocks are dominant the next. Reduced food availability imposed by dominant cycle lines on off-cycle years is also unlikely since growth rates of highly cyclic Fraser sockeye are highest in off-cycle lines. Human impacts can perpetuate or increase the cyclic pattern in abundance: off-cycles have been consistently fished at higher relative rates than dominant and subdominant cycle lines. Some researchers have suggested that genetic factors, such as strongly inheritable age-at-maturity and age-dependent mortality, could maintain population cycles or at least slow the recovery of off-cycle lines, *in combination with high fishing mortality*. For more details, refer to the sources and related materials listed on p 44.

Understanding the causes of cycles in Fraser sockeye is extremely important for setting escapement targets. Provided there is no biological basis for the observed cyclic pattern, substantially larger run sizes should be possible on off-cycle years. This could be achieved by reducing the exploitation rate and increasing spawning escapements. However, if cycles are the result of biological interactions, then the potential for increased production may be much lower. Rigorous testing of the many hypotheses is only possible with adaptive, large scale experimentation to check whether larger escapements on off-cycle lines produce larger recruitment without significantly affecting the dominant cycle lines. This option has so far been avoided because of the potential for severe fishery disruptions associated with short-term reduction in catches from larger stocks co-migrating with smaller off-cycle stocks. However, it is possible that large benefits may be created in the longer term if off-cycle lines are capable of rebuilding to higher abundance, allowing for more stable harvest patterns.

DFO hosted a technical workshop to assess alternative models for explaining the observed cyclic dynamics of some stocks (Appendix 1). This workshop was a direct result of concerns raised by participants in the *Spawning Initiative*. The two main recommendations from the technical workshop were to change the escapement strategy to a fixed exploitation rate for run sizes above a certain threshold, and to use a more flexible model to calculate recruitment for all stocks based on the observed degree of interaction between cycle lines (i.e. Larkin model, see p. 28). Both of these recommendations were implemented in the application of the simulation model.

We will not be able, for quite some time, to determine conclusively whether stocks are inherently cyclic or not. However, the *Spawning Initiative* explicitly considers the relative importance of cyclic patterns in a given population's dynamics by modelling delayed-density interactions, and the simulation model was used to find escapement strategies that are as robust as possible to this uncertainty in population dynamics. As new models are developed that provide more insight into the life cycle of these stocks, they can be incorporated into the same planning framework.

The question of over-escapement

Another on-going debate concerns potentially detrimental influences of large escapements. The concern is that overall survival and growth of the offspring could be greatly reduced due to biological mechanisms such as competition (e.g. for spawning sites, prey, oxygen in the lake), disease outbreak, or increased predation.

The *Pacific Fisheries Resource Conservation Council* (PFRCC) investigated the issue and released a paper entitled "Does Over-escapement Cause Salmon Stock Collapse" in June 2004. The full paper is available at www.fish.bc.ca by searching for "escapement" in the *Report Finder*. The review was triggered by large spawning escapements to some sockeye populations in 2001 and 2002, which resulted in the largest total spawner abundance in the Fraser since the 1950s (Figure 2). The authors found declines in productivity at higher escapement levels, but no evidence of collapse, concluding that productive stocks should not suffer drastic reductions in recruitment as a result of management actions to protect weak stocks in mixed-stock fisheries. These conclusions were supported by observations in 2005 and 2006, when offspring from the 2001 and 2002 spawners returned in reduced, but substantial numbers despite an on-going decline in productivity (Figure 2 and Figure 3). However, individual stocks may have suffered pronounced delayed-density effects. For example, sockeye smolts migrating out of Quesnel Lake in 2004 were the smallest on record, resulting in severely reduced marine survival. These were the offspring of spawners in 2002, facing high densities at early life stages, but the observation may be confounded by low food availability in the lake at the same period.

The current management approach is based on the assumption that occasional large escapements likely reduce the efficiency of sockeye production in that year (i.e. smaller number of recruits per spawner), but do not cause stock collapses. Potential benefits of escapement spikes to individual systems include increased genetic diversity and transport of marine nutrients into distant watersheds.

Uncertainty around the effects of large escapements is closely linked to yearly variability in environmental, marine and freshwater conditions, as well as the large uncertainty in estimates of productive capacity for Fraser sockeye stocks.

Biological benchmarks

The productive capacity of Fraser River sockeye stocks is limited in the freshwater environment, either on the spawning grounds or in the rearing lakes. Several approaches have been used to estimate spawner capacity for individual sockeye stocks, including available spawning area, lake productivity, and numerical estimates of the capacity parameter from population models. For most stocks, however, such estimates are highly uncertain and vary depending on whether the population is thought to follow cyclic dynamics that constrain spawner abundance on off-cycle lines. For example, there is high uncertainty about the spawner capacity for the Quesnel system, with estimates of optimal spawner escapement ranging from 930,000 (based on lake productivity) to 2,400,000 (based on spawning ground capacity). Conversely, the spawner capacity for Chilko sockeye appears well defined with both methods producing estimates between 490,000 and 590,000 spawners. Estimates derived from spawner-recruit models are similarly sensitive to underlying assumptions (Table 1). Appendix 7 briefly summarizes research on the capacity of Fraser sockeye spawning habitat and rearing lakes, which will be integrated into the on-going implementation of the *Wild Salmon Policy*.

The productive capacity of Fraser sockeye stocks is not only uncertain, it is also highly variable. Environmental conditions fluctuate from one year to the next and biological mechanisms such as predation on juvenile salmon change in response to complex interactions throughout the watershed. Uncertainty and variability in productive capacity have important implications for the design of escapement strategies. The idea of managing towards an optimal abundance of adult spawners is equivalent to aiming for the bullseye (optimal escapement) in the fog (uncertainty) while the target is moving (variability). The task becomes even more challenging when multiple stocks, each with unique characteristics (unique bullseye), are managed in aggregate due to practical constraints. A more robust approach is to design escapement strategies that have a good chance of delivering some variable but sufficient amount of spawners for each of the individual stocks in most years. Rather than aiming for the bullseye, the escapement strategies should ensure that we don't miss the bigger target altogether. This can be formally expressed as a management objective, such as *"For each stock, avoid spawning abundances below which there is a high chance the population will collapse or result in low sustained future benefits - ecological, social, or economic"*.

To be useful in the planning process, the notion of low escapement needs to be more specifically defined through stock-specific benchmarks. The *Wild Salmon Policy* (WSP) offers a range of potential benchmark definitions that should be explored on a case-by-case basis (see pages 17 and 18 of the policy), but methods for identifying WSP benchmarks have not been finalized. In the meantime, the *Spawning Initiative* reviewed alternative approaches for setting biological benchmarks with workshop participants and settled on a robust combination using the smallest and largest value resulting from 5 different definitions of low escapement (Table 1).

Escapement benchmarks serve two distinct purposes. During the planning phase, these benchmarks provide a frame of reference for simulation output and help us compare alternative escapement strategies based on performance measures (e.g. probability that 4yr average escapement falls below the benchmark). However, these benchmarks are equally important for long-term performance monitoring.

Much of the debate around benchmarks focuses on trying to pin down the exact breakpoint between "enough sockeye spawners" and "too few sockeye spawners", but it is just as important to agree on the desired probability of staying above that breakpoint. It is a social choice to set an upper limit for the probability of low escapements, and to find a balance between this management objective and other considerations. The *Spawning Initiative* used several levels of public involvement to tackle this question (see Chapter 2), and identified management reference points designed to meet these benchmarks with a specified probability. Chapter 3 (page 30) contains a detailed discussion of the objectives and performance measures used to compare alternative escapement strategies. Appendix 6 includes a general discussion of the terminology used here (e.g. reference points, benchmarks, performance measures).

Management of Fraser sockeye

The Pacific Salmon Treaty

Management of Fraser River sockeye is highly complex due to many factors, including the predominance of different stocks in each year of the four-year cycle and the resulting variability in stock composition. There is also large, and often unpredictable, variation in the size of the returning run, migration timing of the different stocks, the extent of overlap among management groups, and the migration route around Vancouver Island.

Before 1985, the International *Pacific Salmon Fisheries Commission* (IPSFC) was responsible for managing Fraser River sockeye fisheries within the *Convention Area*, covering off-shore waters between the 48th and 49th parallels, areas off the southern tip of Vancouver Island (Juan the Fuca Strait, Puget Sound, southern Strait of Georgia), and the lower Fraser River. The catch taken within Convention waters was shared equally by Canada and the United States.

The Pacific Salmon Treaty, ratified in March 1985, replaced the IPSFC with the newly created *Pacific Salmon Commission* (PSC) and established the *Fraser River Panel* to manage fisheries within the Convention Area, now referred to as the *Panel Area.* In 1999, Chapter 4 of the Treaty dealing with Fraser sockeye and pink salmon was renewed through 2010 with several refinements, including a new harvest sharing arrangement that reduced the share of U.S. fisheries in Washington state to 16.5% of the total allowable international catch (TAC) by 2002 and new implementation guidelines that clarified the role of each country in the management process. The role of the Fraser River Panel is described briefly below. A detailed description is available at www.psc.org/about_org_panels.htm.

The Fraser River Panel is responsible for developing pre-season fishing plans, and for in-season management of Fraser River sockeye and pink salmon fisheries within the Panel area. Management plans for other stocks and species intercepted in non-Panel waters are the responsibility of the appropriate country. DFO is responsible for managing Canadian fisheries outside the Panel Area, but must coordinate its management actions with those of the Fraser Panel to ensure that escapement and international allocation objectives are met.

The Fraser River Panel directs the development of annual fishery regimes in accordance with the objectives of the Treaty. The Panel, guided by principles and provisions of the Treaty, establishes general fishing plans based on conservation concerns and harvest sharing of co-migrating sockeye stocks. The Panel's plans are based on a broad range of considerations including pre-season forecasts of abundance, escapement goals set by Canada, and international and domestic allocation of the TAC. The three main management objectives of the Fraser River Panel for sockeye fisheries are listed below in order of priority:

- achieve spawning escapement goals for sockeye and pink salmon stocks that are set by Canada or modified by Panel agreement;
- achieve international sharing of the TAC as per the Treaty or agreement of the parties; and
- achieve domestic allocation goals within each country.

The chief Canadian domestic objective is to achieve the target level of gross escapement into the river, which includes target spawning escapement, en-route mortality, and the anticipated catch in the First Nations fishery for food, social, and ceremonial purposes within the river. DFO sets the initial gross escapement goal, incorporating the pre-season forecast of run size, First Nations FSC requirements, and consideration for en-route loss due to environmental impacts. This goal may be revised several times during the fishing season, based on in-season estimates of actual run sizes, run timing, and in-river water conditions. For example, in years when water temperatures in the Fraser River exceed preferred migration temperatures, the gross escapement target may be increased to account for mortalities along the migration route and ensure spawning ground targets are met.

Annual fishing plans and allocations are based on a complex consultation and international negotiation process. Appendix 2 describes a simplified sharing formula developed for calculating social and economic indicators based on the catch trajectories produced by the Spawning Initiative model.

Due to on-going conservation concerns, Cultus Lake sockeye have been a particular management focus at each step of the annual planning cycle. DFO has undertaken a variety of actions to rebuild Cultus Lake sockeye. These include reductions in the fishery impact, enhancement efforts that produced additional numbers of fry and smolts to kick-start recovery using a captive brood technique, and habitat improvement techniques such as reduction in the abundance of predators in the lake.

Fisheries that target Fraser River sockeye

Stocks targeted for harvest are part of a large assemblage of sockeye populations that return to natal streams and lakes throughout the watershed. Returning adults approach the north coast of B.C., and then migrate south to the Fraser River estuary. They take one of two routes around Vancouver Island: the northern diversion through Johnstone Strait or the southern diversion along the west coast of Vancouver Island and through Juan de Fuca Strait. The *diversion rate*, the percentage of adults following the northern diversion, changes from year to year and has wide-reaching implications for fishery management.

Fisheries harvesting Fraser sockeye are also linked to those targeting pink salmon. Fraser River pinks follow a distinct two year cycle, with large numbers of adults returning in odd-numbered years. During these odd-numbered years, fisheries target both species, a situation that affects the geographic distribution of the fleets, fishing plans, and in-season considerations.

Before 1914, catches of Fraser River sockeye exceeded 20 million in the dominant cycle years. Between 1914 and 1949, sockeye runs were drastically reduced due to the combined effects of blockage to migration (Hell's Gate Canyon slide; dams across the Nadina, Nechako, Quesnel and Lower Adams rivers) and fishing pressure. Recovery of runs and catches was slow until the construction of fishways at Hell's Gate in 1945 and at other areas of difficult passage. These improvements were also coupled with more conservative management practices in recent years. Exploitation rates have been reduced to protect stocks that are less productive, less abundant, or both (Figure 2).

Fraser River sockeye are harvested in First Nations, commercial, and recreational fisheries in Canadian and U.S. waters. A brief overview of each fishing sector follows below. Appendix 3 contains a more detailed description.

First Nation fisheries for Fraser sockeye mostly take place throughout the waters around Vancouver Island and within the Fraser watershed, but small numbers are caught in waters around the Queen Charlotte Islands and along the Central Coast of B.C. The aboriginal catch has two main components: a fishery to meet food, social and ceremonial (FSC) needs and, more recently, a fishery in the lower part of the river that provides economic returns. Roughly 1 million Fraser sockeye have been harvested annually in FSC fisheries in recent years.

The major *Canadian commercial fisheries* on Fraser sockeye are the troll fishery off the West Coast of Vancouver Island, purse seine, troll and gillnet fisheries in the Johnstone and Juan de Fuca Straits, and the gillnet fishery in the Fraser River. Smaller commercial catches of Fraser sockeye are taken within the Strait of Georgia. Before 1999, there was a significant seine and troll fishery west of the Queen Charlotte Islands, especially in years of high northern diversion when migration routes were more northerly and closer to the B.C. coast. The North Coast fishery on Fraser River sockeye was closed in response to the 1994 Fraser River Sockeye Review and the resulting recommendations for a more risk-averse management strategy given the uncertainty of run size estimates that early in the return migration. The commercial fishery on Fraser River sockeye has been a traditional economic mainstay, averaging 7 million fish in the 1990s, and a commercial harvest of more than 16 million in 1993. This is the largest commercial harvest since the early 1900's. Prior to the Hell's Gate slide, the largest commercial catch was an estimated total of 31 million sockeye in 1913. As stocks recovered from drastic declines in the 1920s and 1930s, the increase in total run sizes was followed by a steady increase in total catch since the late 1960s, and especially since 1985. Between 1981 and 1998, the total annual commercial catch averaged 7.7 million Fraser River sockeye. Between 1999 and 2002, in contrast, the total commercial catch of Fraser River sockeye declined to an average 1.2 million.

The principal *U.S. commercial fisheries* harvesting Fraser River sockeye are net fisheries (purse seine, gill net, and reef net) in Juan de Fuca Strait, the San Juan Islands area, and off Point Roberts. Some Fraser sockeye have also been taken in southeast Alaska. Since 2002 the U.S. share of the Fraser River sockeye catch has been limited to 16.5% of the total allowable catch, not including sockeye caught in southeast Alaska.

The Canadian recreational fishery for Fraser sockeye in tidal waters is relatively small and catches are low. However, the sport fishery in the non-tidal waters of the Fraser River between Mission and Hope has grown rapidly in size and effort since it began in 1996. Sockeye catches for the recreational fishery are much smaller than for other sectors (about 100,000 in recent high-abundance years), but are associated with significant economic benefits and are an important part of the coast-wide salmon harvesting opportunities for recreational anglers.

<u>Incidental catch of other stocks and species</u>

Incidental catch of other salmon in Fraser sockeye fisheries includes other Canadian sockeye stocks, pink salmon, summer chum, chinook, coho and steelhead, as well as passing U.S. stocks. Minor interception of fall chum stocks also occurs during the later sockeye and pink salmon fisheries. Most of the incidental catch is taken in Johnstone Strait, Juan de Fuca Strait and in the lower Fraser River.

Due to the four-year cycles exhibited by some Fraser sockeye stocks, fishing patterns vary each year depending on the timing and abundance of the dominant stocks. Consequently, the amount of interception of other stocks and species in these fisheries also differs from year to year. In recent years, some adjustments in fishing patterns and gear have been made to limit catches of other species, mainly coho and chinook salmon. The problem of harvesting non-target species like coho and chinook is common to all gear types. However, some seine and troll fisheries have demonstrated the ability to successfully release non-target species with high survival rates.

The catch of non-targeted stocks or other species has posed a major challenge in planning Fraser sockeye fisheries. Management actions to limit the harvest of chinook, coho, and steelhead in the major commercial fisheries include area and time closures, gear restrictions and non-retention. Time closures include reduction in the length of time spent fishing and elimination of early-season fisheries. Area closures, such as corridor closures and shoreline boundaries, focus on locations with high proportions of incidental species. Other actions aimed at conserving non-target species are non-retention of incidental species (e.g. in the commercial troll fishery), gear restrictions to allow immature salmon to escape (e.g. restricted mesh size for seine bunts) and use of "blue boxes" to revive and release live non-target fish.

Many of the First Nations fisheries in the Fraser River are also mixed-stock fisheries. While the exploitation rate in these fisheries is relatively low for most stocks, the cumulative impacts of all fisheries on individual stocks can be relatively high. First Nations effort has thus been limited in order to protect some of the early runs, such as Early Stuart and Cultus Lake sockeye and spring-run chinook stocks, as well as coho stocks during their fall migration up the river.

Towards a sustainable increase in Fraser sockeye production

The 1987 Rebuilding Strategy

DFO formed a Task Force in 1987 to develop a plan for increasing the average run size of Fraser River sockeye to at least 30 million fish. Specific objectives were to:

- maximize production from natural habitat, with enhancement where appropriate;
- identify effects of increased production on other species of salmon;
- identify uncertainties that could affect the outcome of alternative management strategies; and
- identify necessary changes to fishing patterns.

The DFO task force evaluated historical catches since 1894. They also looked at spawner-recruit relationships, spawning capacity and lake-rearing capacity. Like the *Fraser River Sockeye Spawning Initiative*, their work involved extensive computer modelling to develop and evaluate alternative rebuilding strategies. The Task Force concluded that it might be theoretically possible to build up Fraser sockeye to an average run size of 30 million or more, but recommended lower interim goals as more realistic and practical. This conclusion reflected uncertainty about the cause of the cyclic highs and lows in Fraser River sockeye returns and whether all years could be built up to the same extent (the questions about cyclic dominance persist today and are discussed on page 5). Low escapements for some stocks also raised doubts about the ability for all stocks to produce consistently at high levels. Thus a more cautious approach was adopted, with interim escapement goals for each of the main Fraser sockeye stocks that were expected to produce total average returns between 8 and 23 million fish, with a 16 million average across all cycle years. The Task Force felt it was too risky to try and achieve the same level of production across all four cycle years. Instead they recommended that exploitation rates should be reduced experimentally on the off-cycles for some stocks to learn about the mechanisms of cyclic dominance.

Evaluation criteria for rebuilding options included the net present value of the projected Canadian commercial catch over 40 years, the impact of harvest reductions in the first 4 years of implementation, and how rebuilding one stock would affect the other stocks. The Task Force's key findings and recommendations were:

- Fraser River sockeye production could be increased substantially on all stocks and cycle lines;
- Rebuilding would require reductions in harvest rates to 65-70% within four years (i.e. 10-15% percentage points less than historical levels of about 80%).
- It was considered too risky and impractical to manage for the same level of production on all cycle lines of a stock. However, additional reduction in harvest rates for some stocks on two of the four cycles should be used to learn about the mechanisms that cause cyclic dominance.
- Departures from the projected long-term rebuilding schedule were anticipated due to variability in marine and freshwater survival. Some stocks would proceed ahead of schedule and others would lag behind.

- Rebuilding should take 12-16 years with an adjustable escapement schedule that varies with run size. This approach would ensure sharing of the burden of rebuilding between users and the resource. In poor return years, escapement goals and catch should be lowered proportionately. In good years, the escapement goals and catch should increase. Occasional very large runs might allow placing more spawners on the grounds than provided for in the interim goal.

Based on these recommendations, an implementation plan for setting escapement targets was developed. The plan was the basis for Fraser sockeye management from 1987 to 2005. Using pre-season forecasts of adult returns, annual escapement plans were set within a range determined as follows:

- Set lower escapement targets for Early Summer, Summer and Late Run aggregates based on abundance of spawners in the brood year;

- The lower escapement target for the Early Stuart aggregate was fixed at 66,000, then increased to 75,000 after additional consultation in the late 1990s;

- Upper escapement targets on target escapement for all aggregates were based on a 65-70% cap on exploitation rate.

<u>Performance of the 1987 Rebuilding Strategy</u>

Since the implementation of the *Rebuilding Strategy*, the year-to-year management of Fraser sockeye has shifted away from a production-focused approach with exploitation rates of 70%-80% on abundant stocks to a conservation-focused approach. Exploitation rates have been reduced to protect stocks that are less productive, less abundant, or both (Figure 2).

The rebuilding strategy coincided with increasing stock productivity up to 1990, followed by declining productivity for the remainder of the time period (Figure 3). Greater benefits could likely have been realized if productivity had remained stable at the levels observed in the 1970s and 1980s. However, spawner levels and resulting returns would have been much lower for many of the Fraser River sockeye stocks if pre-1987 exploitation patterns had been maintained in the face of reduced productivity.

Escapement and catches of Fraser sockeye have been affected by many different factors over the 20 years since the 1987 Rebuilding Strategy was first implemented. Changes in marine productivity, concerns for weak stocks, and unforeseen issues such as high pre-spawn mortality in the Late Run aggregate have all contributed to the observed patterns of fishing and escapement. Some aggregates, like the Summer run, have increased considerably, but some individual stocks, like Cultus Lake, have become conservation concerns.

The Rebuilding Strategy also faced increasing criticism from First Nations, commercial harvesters and other interested groups. Some groups disagreed with the specified long-term and interim escapement goals, considering them too high or too low. The prescribed rate of rebuilding was also criticized as too slow or too ambitious. Others pointed out that managing for a strictly increasing rebuilding trajectory is unrealistic under changing productivity levels. Fundamental disagreements among groups also reflected different social and economic objectives, specifically regarding the trade-off between well-defined short-term implications and uncertain long-term benefits.

Response: the Fraser River Sockeye Spawning Initiative

DFO initiated a review of the rebuilding strategy in 2003 to address the growing concerns expressed by stakeholders and recommendations from the 2002 Ministerial review of Fraser River sockeye fisheries. The mandate of the review process was to incorporate new information, integrate emerging policies such as the *Wild Salmon Policy* (WSP), and establish a formal framework for setting escapement targets. Over the next 6 years DFO led a collaborative process, called the *Fraser River Sockeye Spawning Initiative* (FRSSI), and regularly brought together participants from First Nations, the commercial fishing industry, recreational fishing, environmental non-government organizations, and the provincial and federal governments.

The Spawning Initiative had four goals:

- Manage spawning escapement to ensure conservation while respecting social and economic values;
- Improve the existing consultation processes by focusing on proactive discussion of targets and operational guidelines, rather than reactive in-season decision making;
- Develop management reference points and a long-term strategy for managing Fraser River sockeye escapements;
- Develop processes for reviewing and modifying escapement strategies.

The WSP was finalized in 2005 and became one of the driving forces behind the final phase of the *Spawning Initiative,* shaping the development process as well as the technical analyses:

The WSP proposes an integrated planning process. The policy states that relative importance of social and economic factors in decision making depends on the status of conservation units (CU) and defines 3 status categories. Conservation and recovery efforts have the highest priority for CUs in the Red zone, but "*social and economic considerations will tend to be the primary drivers for the management of CUs in the Green zone*". The Spawning Initiative brought together diverse interests through an intense and sustained collaborative process to ensure that broad views are incorporated in every step of the development.

The modelling framework developed for the *Spawning Initiative* is consistent with the biological principles outlined in the WSP. For example, the stocks included in the simulation model closely match up with lake-based conservation units, and escapement strategies are evaluated based on the performance of individual stocks, not management groups. Unfortunately, there are only 19 stocks with sufficient escapement and return data to allowed incorporation into the simulation model. This presents an ongoing challenge for the operational aspects of the *Wild Salmon Policy,* and a coast-wide approach is under development for incorporating CUs with insufficient data into the planning and implementation of fisheries.

The escapement strategies developed under the *Spawning Initiative* retain many fundamental aspects of the 1987 Rebuilding Strategy. The new term *escapement strategies* has the same meaning as the familiar *escapement tables* of past years. These escapement strategies specify total allowable mortality and the resulting target escapements for a range of run sizes for each management aggregate. Target exploitation rates still vary with run size, and small, co-migrating stocks will be protected through constraints on mixed-stock exploitation rates.

Fundamental changes include:

- Escapement strategies for a given year are based on a target mortality rate, not on a fixed escapement target. Estimates of spawning capacity are highly uncertain for some stocks, and harvest strategies based on target mortality rates should be more robust to this source of uncertainty.

- Escapement strategies respond to run size, but do not change for different cycle years. Under the 1987 Rebuilding Plan, a different interim escapement goal was identified for each cycle line. Under the Spawning Initiative, off-cycle years in cyclic stocks are simply treated as an instance of low abundance, with the target mortality rate based on the shape of the escapement strategy (see Chapter 3).

- Escapement strategies specify total mortality rates, which when put into practice, need to take into account en-route and pre-spawn losses. The proportion of each run available for harvest, the target exploitation rate, is determined by deducting projected en-route and pre-spawn mortalities from the allowable total mortality.

- The requirement to stay above brood year escapement was removed to account for the fluctuating productivity of many stocks; and

- Escapement strategies are explicitly based on management objectives to account for conservation, cultural, social and economic values.

2. THE COLLABORATIVE PROCESS

This chapter describes the collaborative process that shaped the Spawning Initiative and summarizes the intensive planning workshops DFO hosted in 2006/2007.

Introduction

Under the Pacific Salmon Treaty, Fisheries and Oceans Canada (DFO) is responsible for setting escapement targets and harvest guidelines for Fraser River sockeye salmon. DFO recognizes the importance of comprehensive consultation prior to any fundamental changes in management practices, but it is not feasible to tie a full consultative process into the development phase of a complex technical analysis. As a practical compromise, DFO adopted an open and transparent collaborative process with extensive interaction between a core technical team and a large group of external reviewers. The core team developed a simulation model to test alternative escapement strategies and external reviewers participated in annual workshop series to guide the technical work. The results of each year's workshop series were then brought into full consultation through the *Integrated Fisheries Management Plan* (IFMP). Figure 6 shows major milestones in the *Spawning Initiative* and related processes.

Cultus Lake sockeye currently pose a serious conservation concern and constrain the allowable exploitation rate on co-migrating stocks. The recovery planning process for Cultus is distinct from the Spawning Initiative, but the two efforts have been closely coordinated. A simulation model was developed to test alternative recovery and harvest strategies for Cultus, and in 2006, DFO undertook a structured trade-off exercise to choose a suite of recovery actions. A technical report by Josh Korman and Jeff Grout has been peer-reviewed by *Pacific Science Advice Review Committee* (PSARC) and is available upon request from psarc@pac.dfo-mpo.gc.ca.

Four phases of development

The Spawning Initiative had 3 distinct phases:

- *Initial development* (2003-2005): The groundwork was laid through a series of six workshops in which stakeholders and experts reviewed the technical analyses, provided guidance for incremental refinement of the simulation model, and shaped the communications materials for broader consultation.

- *Wild Salmon Policy implementation pilot* (2006): A series of 3 workshops started off the 2006 pre-season planning process and brought escapement planning into the broader context of WSP implementation. The workshops were designed to test the decision process outlined in the WSP as well as the analytical tools developed during the first phase of the Spawning Initiative. Workshop recommendations were vetted through internal review and public consultation, leading up to the first implementation of new escapement guidelines based on target levels of total mortality.

- *Preferences and trade-offs* (2007): A second series of 3 workshops took place during the spring of 2007. Revisions and additions identified during the 2006 pilot had been incorporated into the Spawning Initiative model. These workshops were designed around a more structured planning exercise focused on capturing participants' preferences and exploring trade-offs among alternative escapement strategies.

- *Review and Revisions* (2008): Workshop participants provided feedback on the 2007 planning process and subsequent implementation through a questionnaire in the fall of 2007. This feedback formed the basis for model revisions and a streamlined planning process with one workshop in the spring of 2008.

Levels of participation

To encourage broad participation in the Spawning Initiative, DFO adopted an open and transparent process with six different levels of public involvement:

- A *working group* of fisheries managers and analysts performed the analyses. The working group first developed a computer model to help identify the most appropriate harvest policies and escapement targets for Fraser sockeye stocks. The model takes into account the biology of individual stocks and historical patterns of production. With this tool as a starting point, the focus of the working group shifted to eliciting feedback from stakeholders, revising the model accordingly, and communicating results to other participants.

- A *steering committee* of senior representatives from stakeholder organizations and DFO guided the working group through the initial development and ensured participation by their respective organizations.

- *Workshops* where 30-40 participants reviewed intermediate results, and provided recommendations for upcoming fishing seasons. DFO organized workshops to elicit feedback on both the conceptual approach and the technical details of the escapement strategies. These workshops were attended by First Nations, the commercial fishing industry, recreational anglers, environmental non-government organizations, provincial and federal agency staff, and staff from U.S. fisheries organizations. Workshop participants were expected to comment constructively on the intermediate results and to review the resulting recommendations prior to broad consultation. Participants' feedback helped DFO refine the proposed approach for managing spawning escapements prior to taking this initiative into broader consultation. Workshop participants repeatedly stated that they were involved purely as individuals with an interest in shaping the content of materials destined for public consultation, and that they were not attending as official representatives of any organization. First Nations participants also emphasized that the workshops did not qualify as consultation in the legal context of aboriginal rights.

- *Technical peer-review* of methods through the Pacific Science Advice Review Committee (PSARC). *Methods for Assessing Harvest Rules For Fraser River Sockeye Salmon* was published as Canadian Science Advisory Secretariat Research Document - 2004/025 and is available at www.dfo-mpo.gc.ca/csas/. Note that the model has evolved since then, as described in Chapter 3.

- *Annual pre-season consultation* on the resulting recommendations through established processes. For First Nations groups these processes include bilateral meetings with individual bands, tribal councils, watershed advisory processes and other established organizations. The recreational fishing community provided feedback through the Main Board of the Sport Fishing Advisory Board (SFAB) as well as the appropriate sub-committees. For the commercial fishing sector, the Commercial Salmon Advisory Board (CSAB) and gear-specific advisory processes were given opportunities to submit comments and suggestions. Representatives of non-harvest interests, such as researchers, environmental organizations, and other government agencies contributed through their established interactions with DFO managers.

- *In-season evaluation* of candidate escapement strategies in parallel with the previously established rebuilding plan during the 2005 season, pilot testing of new escapement strategies based on total allowable mortality in 2006, and full implementation of the new escapement strategies in 2007.

Steering Committee members and workshop participants provided valuable feedback during the initial development of the initiative, and helped shape the planning workshops of 2006/2007. The Spawning

Initiative evolved substantially in response to comments received from the Steering Committee, external working group members, and workshop participants. In particular:

- The timeline for the initiative was extended to allow for additional technical analyses, further refinement of the consultation materials, and additional work on on-going policy development (e.g. Wild Salmon Policy);
- More effort was dedicated to on-going communication to ensure productive participation;
- The technical analyses were scientifically reviewed through the PSARC process;
- Additional analyses were performed to address specific questions and concerns raised at the workshops.

From the very beginning, the working group recognized the challenges associated with involving stakeholders in the development phase of technical work, but the evolution of the model shows the clear benefits of this strategy.

Concerns raised by participants in the Spawning Initiative also served as focal points for sockeye research. For example, DFO hosted a science workshop to assess alternative models for explaining the observed cyclic dynamics of some stocks (Appendix 1).

2006 Planning workshops

Workshop structure

DFO hosted a series of facilitated workshops in the spring of 2006 which brought together two on-going initiatives: the Spawning Initiative and an implementation pilot for the Wild Salmon Policy. These two initiatives were a natural match for the intensive participatory process that unfolded over 3 months. The long-term escapement strategy being developed by the Spawning Initiative had to fit within the emerging requirements under the WSP, and the WSP implementation pilot was able draw on all the effort that had already been put into the Spawning Initiative by DFO and participants. The workshop series was highly productive towards both goals. In this way, the groundwork laid by the six previous Spawning Initiative workshops provided an essential foundation for piloting an approach to both long-term and immediate integrated strategic planning using Fraser River Sockeye as a focus.

The pilot process was implemented through a sequence of 3 workshops:

- The focus of the first workshop was to engage participants in the process, establish the format for subsequent discussions, and get a first sense of planning priorities.
- The second workshop was designed to build on the momentum from the first workshop, to elicit general views on management objectives and specific suggestions for indicators, and to get a first sense of the range of management actions proposed by participants.
- The third workshop was focused on developing a management strategy for 2006. Throughout most of the workshop, participants worked in small groups using interactive displays of alternative harvest rules, and discussed the immediate implications of choosing one or the other.

All three workshops followed the same structure, with a combination of presentations, facilitated discussion, and open circles where each participant commented on a specific question. The open circles proved highly effective in eliciting feedback and gauging participants’ opinions. All participants had to organize their thoughts and voice their views, but also had a dedicated and uninterrupted opportunity to address the entire group. In combination with issue-focused facilitation this approach shifted the dynamics of the meetings from heated debates among a few individuals to respectful and productive discussion among many. A detailed summary of the 2006 workshop series is available upon request.

Outcomes

Over the course of the three workshops, participants were able to develop a good rapport across a wide range of interests and backgrounds, making it possible to have a highly focused and specific discussion of alternative escapement strategies during the third workshop:

- Participants agreed to the Principles of Participation (Appendix 4), and showed great patience with the inevitable challenges that arose as part of a pilot process under great time pressure.
- Participants agreed that it is a priority to investigate bottlenecks in sockeye production (especially for Cultus Lake) and develop management plans that cover the full suite of recovery actions, not just short-term reductions in harvest.
- Participants came to agreement regarding the general structure of management objectives, and agreed on a set of practical considerations that should be incorporated.

During previous workshops, and during the 2005 pilot implementation of the new escapement strategies, workshop participants identified several areas for further work. Prior to 2006 implementation, the following revisions and extensions were implemented:

- *Expanded and updated stock dynamics:* Additional stocks were included for a total of 19.
- *Hosted a scientific review:* DFO hosted a science workshop to assess alternative models for explaining the observed cyclic dynamics of some stocks (Appendix 1). The two main recommendations from the science workshop were to use the Larkin model to calculate recruitment for all stocks, and to change the harvest rule to a fixed exploitation rate for most run sizes. Both of these recommendations were implemented for 2006 planning.
- *Cultus/Late Run:* A separate model was developed to assess recovery options for Cultus Lake sockeye.

Participants agreed with the conceptual changes that were made to the Spawning Initiative model:

- Apply a fixed exploitation rate (ER) across a wide range of run sizes, with a cut-off at which ER starts to be reduced (i.e. hockey stick harvest rule), provided that further work would be undertaken to explore cycle-specific harvest rules.
- Use Larkin model to simulate populations, provided that further analysis would be undertaken to investigate the implications for estimated productivity and related benchmarks.
- Express management objectives as a risk tolerance (e.g. 90% chance of achieving escapement benchmark on each component population)

Participants provided important insights into key areas of disagreement. Some important differences of opinion were:

- *Shape of the harvest rule at low run sizes:* Should there be some run size at which harvest stops, or should there be some baseline exploitation rate that allows harvests on overlapping aggregates?

- *Reliance on enhancement measures:* To what extent should the potential future benefits of enhancement be taken into account when planning fisheries for the short-term?

Participants provided wide-ranging recommendations for the 2006 Fraser sockeye escapement plans, and agreed on 3 candidate harvest rules that were brought forward into the pre-season consultation process as part of the 2006 *Integrated Fisheries Management Plan*. Stock-specific recommendations are listed in the 2006 Workshop Summary, which is available upon request from the Salmon Team Lead or the Regional Resource Manager – Salmon. Up-to-date contact information is included in the annual *Integrated Fisheries Management Plans* available at www-ops2.pac.dfo-mpo.gc.ca/xnet/content/MPLANS/MPlans.htm.

2007 Planning Workshops

Workshop structure

DFO hosted a series of facilitated workshops in the spring of 2007 to document participants' preferences and to explore trade-offs among alternative escapement strategies. This approach was the logical next step after the substantial effort that had gone into developing the analytical tools and establishing constructive lines of communication among regular workshop participants.

The 2007 planning workshops adapted the concepts of a structured decision process to address the logistical challenges of convening 30 participants and the inevitable time constraints of pre-season planning for sockeye fisheries:

- The workshop facilitator conducted in-depth interviews with individual participants to introduce the approach, compile suggestions for improvement over 2006, and build commitment towards the process.

- The first workshop was used to review technical developments since the previous year, introduce the concepts of structured decision making, and identify a draft decision table (i.e. a list of alternatives to be evaluated and a suite of performance measures to be used as the basis for comparisons).

- During the second workshop, participants explored the expected consequences of alternative escapement strategies and worked through a mock trade-off analysis to gain familiarity with the approach.

- The third workshop focused on a detailed analysis of trade-offs. The evaluations and comments provided during this workshop then shaped the draft escapement strategy included in the *2007 South Coast Salmon Integrated Fisheries Management Plan*.

The workshops followed the same basic structure as in 2006. This consistency was crucial because it helped participants over the learning curve associated with formal preference elicitation and quantitative trade-offs. Melding the free-flowing elements of facilitated discussion and open circles with the highly-structured sequence of formal trade-off analysis created some logistical challenges, and required careful coordination between the facilitator and the decision analyst.

Outcomes

Participants were able to build on the rapport established over the course of previous workshops and tackle the complex task of formal trade-off analysis as a cohesive group.

Most participants accepted the following scope for the structured decision exercise:

- Alternatives were framed as combinations of escapement strategies for the four main management aggregates, with an additional rule for Cultus Lake sockeye. Birkenhead sockeye are managed and simulated passively, exposed to the same exploitation rate as the Summer run stocks.

- Habitat and other recovery strategies at Cultus Lake were treated quantitatively and included in the definition of alternatives, but non-harvest issues elsewhere were treated qualitatively.

- Changes in catch allocation were outside the scope of this process.

- Fisheries locations were assumed to remain the same for the planning period.

Participants pointed out the following limitations of the process:

- The planning exercise did not explicitly address issues related to in-season implementation. Participants emphasized that escapement strategies need to be flexible for responding to surprises during in-season management, but accepted that the details of the in-season management were outside the scope of this process.

- Fraser River sockeye are experiencing a period of increasing environmental variability, which introduces additional sources of uncertainty into planning process and raises questions regarding the applicability of a simulation model based on past observations.

- Simulations for enhanced stocks produced unexpected results, and participants requested further analysis to explain the observed patterns in performance.

- Habitat quality is becoming an important factor in salmon rehabilitation. Several participants expressed that they would like to see habitat quality issues formally included in the analysis.

- Several participants expressed concern that escapement strategies based on 4 management groups would exclude important details about the individual stocks.

Participants worked through a preliminary evaluation of alternative strategies in the second workshop, and completed a more detailed trade-off analysis during the third workshop. These steps are described in more detail on pages 30 to 32.

Implementation

The 2007 planning process was a major milestone in the *Spawning Initiative*, with an emphasis on wrapping up the development of concepts and tools, and moving towards implementation. Accordingly, the 2007 workshops focused on trade-offs and preferences, and were organized to stimulate extensive discussion of alternative strategies and structured comparisons. Feedback received through the workshops helped shape the pre-season escapement plan for the draft IFMP in April 2007, which was reviewed in the regular advisory and consultative processes. A detailed information memo, summarizing the rationale for the proposed 2007 escapement plan, was circulated to support the consultations. The final 2007 escapement plan was released in July 22, 2007.

Escapement strategies developed under the Spawning Initiative functioned well in the complex management process during the 2007 season. Management actions were responsive to changes in run size and outcomes were consistent with DFO's management priorities:

- smooth transition from a continuous decrease in escapement level to a fixed escapement as run size decreases.
- severe reduction in total Fraser exploitation rate (to 10-15%) resulted in reasonable escapement levels being achieved despite the lowest observed return on all cycles since 1948.

However, the 2007 season only tested the upper and lower ranges of the escapement strategies (Figure 7), not the scenarios where commercial, recreational and full FSC fishing opportunities would have been permitted at less than 60% Total Allowable Mortality cap, but greater than the 2% minimum exploitation rate.

After the 2007 season workshop participants had an opportunity to provide written comments on the initiative and its implementation. Those who responded generally supported the intent of the process and recognized the considerable efforts and commitment by all participants. Respondents generally accepted the use of a simulation model to support a planning process and found the 2007 workshops a useful component of the pre-season planning process. However, respondents also expressed concern regarding the scope of the planning exercise and limitations of the current simulation model.

2008 Planning Workshop

<u>Workshop structure</u>

The planning process for 2008 was streamlined, building on the progress made during the 2007 workshop series. For this year, a draft set of options was discussed at a workshop in late January, followed by a more technical review session for additional analyses, leading up to the release of the proposed escapement strategy in the draft 2008 IFMP. After pre-season consultations, the final 2008 escapement plan was released in May.

The 2008 planning process focused on the challenges of adapting a long-term strategy to the particular circumstances of each year. Small changes in escapement strategy, that have little effect on long-term performance and trade-offs, can have substantial implications for fisheries planning in a given year. Pre-season expectations for 2008 created exactly that kind of scenario for Early Summers, which in turn affected the planned harvest pattern for Summers. DFO is exploring guidelines for annual adjustments to the long-term strategy, and considering the appropriate level of flexibility.

<u>Outcomes</u>

It is important to note that while the workshop participants were not able to identify one single option that was superior to all the others, their advice guided the Department's decision in crafting the draft 2008 Fraser River sockeye escapement strategy. For all these scenarios, Benchmark 2 was used as the interim benchmark level for avoiding low escapement (Table 3). Performance of stocks relative to these interim benchmarks is evaluated based on 4-yr average escapement to reduce the influence of a single very small or very large escapement (e.g. dominant line). On-going work by DFO Science under the *Wild Salmon Policy* will be used to refine these benchmarks prior to the 2009 planning process.

What worked well, and what needs to be improved

The collaborative process for the Spawning Initiative was highly successful. The development team and participants benefited from the intensive and sustained interaction, but organizing 13 workshops over 6 years required a substantial commitment of resources from DFO.

The core development team benefited from the regular feedback provided by workshop participants, who brought broader perspectives to the initial scoping of the initiative and patiently pushed for a more communications-focused approach to model development. Over the course of the initiative participants became increasingly familiar with the complexities of Fraser sockeye management and the technical jargon of simulation analyses, thereby setting the stage for productive debate of biological assumptions and different preferences.

Regular workshops with a fairly consistent mix of interests also provided participants the opportunity to establish personal rapport across the traditional boundaries of different interest groups, which created substantial spin-off benefits for the many participatory processes that are currently taking shape in the Pacific Region (e.g. Salmon Integrated Harvest Planning Committee).

Several elements were crucial for the successful development of the initiative. In particular, participants highlighted the following:

- Workshops were constructive because the Principles of Participation in Appendix 4 clearly defined the role of participants. Once they grew comfortable with providing feedback as individuals, rather than representing an interest group or organization, the emphasis shifted to jointly tackling fundamental questions and technical complexities.

- Workshops were designed around a carefully planned sequence of presentations, open circle discussions where each participant had one turn to speak, and small group discussions where participants from different backgrounds worked through specific tasks (e.g. review simulation results).

- Participants acknowledged the challenges of involving a large group in the development phase of a technical analysis, but indicated growing support as they saw how the model evolved in response to their feedback.

- It was not possible to completely isolate this development of a long-term escapement plan from the complexities of in-season planning and the particular issues that dominated each year’s planning cycle. However, the continued emphasis of long-term considerations served as very powerful incentive for constructive participation.

Participants were generally supportive of the overall process, but pointed out several areas for improvement:

- The Spawning Initiative was able to build considerable momentum and retain a consistent group of about 20 participants over the full 5-year period, with 30-40 people attending each workshop. However, participants at any one workshop did not necessarily reflect the full spectrum of interest groups in the region. In particular, additional First Nations participants would have been able to provide a more varied perspective on local issues.

- The timeline for each year's workshop series was very condensed due to logistical constraints, but participants would have preferred more time to review information materials prior to each workshop.

Most of the concerns and criticisms expressed by participants were not related to the process of the initiative, but to the content, such as biological assumptions (e.g. cyclic populations) and management approaches (e.g. management groups vs. conservation units, harvest patterns, benchmarks). Some, but not all, of these concerns could be addressed through model revisions and alternative simulation scenarios.

3. THE SIMULATION MODEL

This chapter describes the concepts used to design the simulation model, outlines the technical challenges encountered during development, briefly describes simulation scenarios used for the 2008 planning process, and concludes with a discussion of future extensions. We envision a scientific peer review of the technical aspects once additional modifications have been incorporated into the model.

Introduction

The model was developed to improve our understanding of the complex interaction between the population dynamics of individual stocks and escapement strategies that, due to practical constraints, are applied to groups of stocks. The model currently includes 19 stocks (i.e. production units delineated based on spawning site and timing), grouped into 4 timing aggregates for management purposes. Each model scenario applies a specified escapement strategy to a management group, based on a control rule that accounts for harvest as well as environmentally-induced mortality during the up-river migration. Simulations are projected 48 years into the future (i.e. 12 sockeye generations), starting with recent years escapement. Output from the simulations are used to track the performance of each individual stock.

The model allows us to investigate some of the complex questions that we face as part of the escapement planning process:

- *What is the appropriate balance between catch and escapement?*
- *How should this balance change at small (or large) run sizes?*
- *How should this balance change as run sizes fluctuate from year to year?*
- *How should this balance change when less abundant stocks are also caught in an aggregate?*
- *How should this balance change if escapement in recent years was large (or small)?*

Many considerations go into finding this balance. Some are technical in nature, while others are shaped by the preferences of participants and existing policies. Technical considerations include the dynamics of Fraser sockeye stocks, and how the stocks are expected to respond to different escapement strategies. Policy choices focus on trade-offs between different management objectives, such as:

> *Policy Choice 1: Trade-off between harvest benefits versus providing protection to individual stocks.*
>
> *Policy Choice 2: Trade-off between short-term and long-term benefits*
>
> *Policy Choice 3: Trade-off between stability in catch and maximizing opportunity*

The simulation model developed in this initiative allowed participants to explore these questions and choices in a structured, consistent, and transparent manner. In a workshop setting, the model was used to develop escapement strategies that explicitly incorporate a wide range of management objectives, to evaluate these escapement strategies through consistent, formal methods, and to compare their performance.

Cultus Lake sockeye currently pose a special management challenge as fisheries on abundant co-migrating stocks have to be reconciled with recovery efforts. A separate model has been developed for evaluating recovery options, and a separate planning process took place in 2006 (see page 15).

Escapement strategies (a.k.a. TAM rules, hockey sticks)

Escapement strategies developed under the *Spawning Initiative* are represented by a control rule that specifies total allowable mortality rate at different run sizes. The escapement strategies are designed around three fundamental considerations:

- Minimal or no fishing at very low run size (i.e. assessment only)
- Fixed escapement, resulting from reduced target mortality (i.e. reduced exploitation rates), at low run sizes to protect the stocks and reduce process-related challenges at this critical stage (e.g. uncertain run size)
- Fixed total allowable mortality rate at larger run sizes to ensure robustness against uncertainty in population dynamics (e.g. estimates of productivity and habitat capacity) and in-season information (e.g. run size).

The run size at which the strategy switches from a fixed mortality rate to fixed escapement is called the cut-back point, because it triggers a gradual cutting back in target mortality rate. The run size at which allowable mortality rate approaches zero (or some fixed minimum set aside for assessment) is called the no-fishing point.

This approach is equivalent to specifying a target escapement for each run size. Figure 7 shows an example, marked by arrows. If the total allowable mortality rate for a run size of 2 Million is 60%, then the corresponding target escapement is 800,000 and the available harvest is 1.2 Million minus a management adjustment which accounts for the difference between fish counted at Mission and fish counted on the spawning grounds. Appendix 5 explains the terminology in more detail.

The shape of escapement strategies has evolved substantially over the course of this initiative, from an s-shape curve with well-documented mathematical properties (up to 2006) to a simple hockey stick (2006), and finally a modified version of the hockey stick (since 2007). Specifically, the blade of the hockey stick from 2006 was bent to establish fixed escapement for over a range of run sizes followed by a fixed exploitation rate at larger run sizes.

DFO's *National Science Working Group* released a formal *Science Advisory Report* in 2006 describing the minimal requirements for harvest strategies to be compliant with the Precautionary Approach. The full science advisory 2006/023 is available at http://www.dfo-mpo.gc.ca/csas/Csas/status/2006/SAR-AS2006_023_E.pdf.

The escapement strategies developed under the Spawning Initiative are consistent with the requirements described in the science advisory. Specifically, the target mortality is reduced as abundance drops from a healthy to and cautious zone, and target mortality is minimal if abundance is critically low.

How the simulation model supports the planning process

The simulation model has been fully integrated into the annual management cycle for Fraser River sockeye since 2006. Figure 8 shows that the annual planning process is bracketed by two phases of public consultation, the *post-season review* in the fall and *pre-season planning* in the spring. Both of these consultations unfold as a combination of formal advisory processes (e.g. *Integrated Harvest Planning Committee),* bilateral meetings with First Nations, and townhall-style meetings with the general public (e.g. in coastal communities).

The timing of these processes is constrained by the amount of effort required before and after public involvement. It takes several months to compile even a preliminary summary of all the biological and fisheries data collected during each season and it takes several months to determine operational details of each year's fisheries once a draft escapement plan has been developed. This leaves a short 3-month window for the annual escapement planning process: A working group of analysts and managers updates and revises the simulation model based on the lessons learned from the previous season, and develops some preliminary escapement strategies for review. These are then evaluated in a multi-sectoral workshop setting. In 2006 and 2007 this review process consisted of three 2-day workshops with 30-40 participants (Chapter 2). The 2008 process was streamlined to a single 2-day workshop and a technical follow-up session.

Structure of the simulation model

Scope

The model simulates a group of stocks into the future and tracks the performance of different escapement strategies. An escapement strategy is expressed as a Total Allowable Mortality control rule (a.k.a. TAM rule, hockey stick) which specifies target mortality at different run sizes.

The model simulates stock-specific abundance and total mortality under uncertain and variable conditions, but does not include any explicit in-season management mechanisms. The escapement strategy is applied on an annual basis, all stocks within a management group are exposed to the same exploitation rate and environmental mortality, and catches are not taken in specific areas or fisheries.

Each simulated scenario is based on several important assumptions about the biology and behavior of Fraser sockeye stocks. For each stock, these assumptions include:

- Characteristics of the spawner-recruit model (e.g. spawning capacity, annual variability, cyclic interaction).
- Level of accuracy in implementing allowable mortality rates.
- Amount of non-harvest mortality during up-river migration.

The remainder of this section describes these model components in more detail.

The conceptual structure for a more detailed in-season management model is currently being developed, and that model will simulate how individual stocks or conservation units, each with their own timing, move through a sequence of fishing areas.

<u>From spawners to recruits – simulating the life cycle of Fraser sockeye</u>

Fraser sockeye stocks are simulated into the future based on the historical relationship between spawning escapement (i.e. number of adults in the brood year) and recruitment (i.e. number of 4 and 5 year old adults produced from that brood year). Recruitment is tracked in distinct year classes (i.e. age-structured model). The model approximates the full life cycle of these sockeye populations using the most consistent data available, but does not capture the dynamics of each individual life stage (e.g. egg-to-fry survival, juvenile migration).

Statistical methods have been developed to explain the relationship between spawners and recruits. For sockeye, these models typically calculate the expected number of age 4 and age 5 recruits resulting from each brood year, and combine these age classes into a projection of run size. SR models usually predict increasing production of recruits as the number of spawners increases, eventually levelling off or declining as high spawner abundances exceed the capacity of the environment to sustain the offspring (Figure 4).

SR models typically have 2 parameters, with more complex models requiring more. One of the parameters is the *productivity* parameter that determines the number of recruits per spawner at low abundance. The other parameter is the *capacity* parameter which reflects the maximum number of recruits that can be produced by available habitat and determines how big the stock is expected to grow in the absence of fishing. The productivity parameter describes the maximum sustainable exploitation rate for the stock, while the capacity parameter describes the spawning escapement that will maximize recruitment and the size of the catch. Knowledge of both parameters is important for management purposes.

Models differ depending on the assumptions they make about:

- Productivity at low escapement (e.g. is there a point at which production fails due to predators?)
- Productivity at large escapement (e.g. is there a pronounced decrease in productivity if escapement exceeds capacity?)
- Interaction between cycle lines (e.g. does large escapement last year affect survival of this year's brood?)

One benefit of simulation models, like the one used here, is that we can apply different SR models and evaluate their implications for management within a consistent framework. As new data and new hypotheses become available, they can be easily incorporated.

The approach for simulating population dynamics has evolved drastically over the course of this initiative:

- Prior to 2006, the model used two alternative population dynamics: The Ricker model, which assumed that all cycle lines are equally productive, and the Cycle Aggregate (CA) model which assumed that dominant/subdominant cycle lines were different, and independent, from the off-cycle lines. The CA model approximated cyclic patterns observed in some stocks, but did not capture any potential interactions between cycle lines.
- In the spring of 2006 DFO hosted a technical workshop to assess alternative models for explaining the observed cyclic dynamics of some stocks (Appendix 1). The two main recommendations from the

technical workshop were to use the Larkin model, which explicitly estimates the level of interaction between cycle lines, for all stocks, and to change the harvest rule to a fixed exploitation rate for most run sizes. Both of these recommendations were implemented starting with 2006 planning. All stocks are now simulated with the Larkin model to capture delayed-density effects on recruitment, and those with persistent cyclic patterns are modelled with stronger interactions between cycle lines (i.e. stronger delayed-density effects).

- Uncertainty plays a key role in the analysis. Model parameters for each stock are estimated from available time series of escapement and recruitment using a Bayesian approach. This is a common statistical procedure that allows a straightforward translation of uncertain population dynamics into uncertain outcomes for different management policies and resulting risks.

- The initial 12 stocks used in earlier versions of the model were selected based on the availability of long, consistent time series of escapement and recruitment data. Seven additional stocks with less data were incorporated into the model in 2006 to better reflect the diversity of stocks in the Early Summer aggregate and evaluate the effect of aggregate harvests on smaller stocks.

While these changes addressed long-standing concerns of workshop participants, they also introduced some substantial challenges for the remainder of the technical work. Specifically:

- How should benchmarks and harvest strategies take interaction between cycle lines into account?

- How can discrepancies between SR models be resolved (e.g. Larkin model produces higher productivity estimates)?

- How should the increased uncertainty for data-poor stocks be considered in the planning process?

Briefly, the proposed approach is to cap exploitation rate to address the potential bias in productivity estimates and to develop benchmarks and harvest rules that capture a 4-year sequence of escapements.

Accounting for additional complexity

Over the course of the Spawning Initiative workshops, participants consistently pushed for more detail in the model, and several additions to the core model were developed to approximate some of the mechanisms that will be more explicitly captured in the proposed in-season model:

- *Catch sharing:* The model does not simulate individual fisheries, but rather identifies an exploitation rate for a timing group, based on total abundance, the shape of the escapement strategy being tested, and environmental mortality. During the 2006 workshop series, DFO developed a rough sharing calculation that shows how total allowable catch (i.e. abundance * exploitation rate) would be shared across sectors and areas using the allocation formulas applied in recent years (Appendix 2).

- *Environmental conditions:* The model does not simulate environmental conditions at different life stages, but incorporates the cumulative effect as variability in recruitment, sampled from the available data to reflect the previously-observed range of survival conditions. The model does, however, explicitly simulate in-river mortality using the historical difference between Mission estimates (excluding in-river catch) and up-stream spawner estimates. This mortality is incorporated in two distinct steps: (1) to calculate the gross escapement to Mission necessary to achieve the target escapement to the spawning grounds as specified by the escapement strategy, and (2) to calculate the actual escapement to the spawning grounds for an actual escapement to Mission.

- *Overlap between timing groups:* The model currently can simulate individual stocks or groups of stocks managed as an aggregate. It can't simulate 4 timing groups at once while applying specific escapement strategies to each, and the catch trajectories produced by the model therefore reflect potential catch. For the 2007 planning process, the Working Group developed a simple calculation based on average peak timing and relative daily abundance of each aggregate to divide this potential catch into two components: (1) realizable catch in fisheries that are constrained by the overlap in timing, and (2) potential catch for fisheries that can harvest each timing aggregate selectively. Note: For the 2006 simulations catch trajectories were simply reduced by 25% to reflect the overlap.

- For *Cultus* sockeye a separate, more detailed, life history model has been developed to explore recovery options built around combinations of enhancement actions and escapement strategies. This model was used during a separate planning exercise in 2006, and tied in with the Spawning Initiative planning workshops in 2007 (see Chapter 2). For each of the candidate escapement strategies the Spawning Initiative model tracks the range and sequence of exploitation rates applied to Late run sockeye. The Cultus model then applies these exploitation rate trajectories to test their effect on Cultus under different enhancement scenarios. Under none of the options explored was the probability of extinction less than 25% at current levels of enhancement. The probability of extinction decreased to low levels only if enhancement levels were significantly increased. However, enhancement projects for Cultus sockeye remain unproven and are costly to implement. Survival data for Cultus hatchery releases from initial enhancement efforts are now becoming available and on-going analyses will shape the final recovery plans slated for completion in 2008.

Translating management objectives into performance measures

Escapement strategies for Fraser sockeye are designed to balance the fundamental objectives of (1) ensuring escapement and production for individual stocks and (2) accessing the catch-related benefits from productive stock groups. An important part of the planning process is to translate these fundamental objectives into more specific operational objectives and identify performance measures that can be used to compare simulation scenarios. The current policy context for the management of Fraser River sockeye is summarized at: http://www.pac.dfo-mpo.gc.ca/species/salmon/policies/default_e.htm. Appendix 6 includes a general discussion of the terminology used in this section (e.g. performance measures).

Quantitative performance measures are an attempt to capture the outcomes associated with different management objectives in a form that can be easily compared. Carefully chosen performance measures serve as a comprehensive summary of expected performance, but overly simplified summaries can miss important elements of the decision (e.g. long-term averages escapement hide important patterns in variability over time). A conservation objective could be expressed as "Avoid spawning abundances below which there is a high chance the population will collapse or result in low sustained future economic benefit". An economic objective could be expressed as "Avoid the catch level below which an industry can no longer remain viable".

The notions of low escapement and low catch can be quantified in many different ways, and the *Wild Salmon Policy* offers a range of potential benchmark definitions that should be explored on a case-by-case basis (see pages 17 and 18 of the policy). For the 2007 planning process, 3 alternative escapement benchmarks were considered, based on population dynamics and past observations (Table 1). Benchmarks for identifying low catch were based on feedback provided during the 2006 planning workshops.

These benchmarks provide a frame of reference for the simulation output, and are used in a variety of performance indicators (e.g. probability that 4yr average escapement falls below a stock-specific benchmark). For the 2007 escapement plan the department decided to adopt a cautious escapement benchmark selected as the highest value resulting from alternative benchmark definitions (Table 1).

Workshop participants tend to identify numerous variations of performance measures as potentially interesting, but it is not feasible to thoroughly compare a lot of performance measures across many potential alternatives. The facilitator then faces the challenge of helping participants identify a manageable suite of performance measures that still captures the most important considerations.

Participants and analysts worked through preliminary results over the course of the first two workshops and developed a shortlist of performance measures (PM) based on several considerations:

- PM should capture trade-offs between catch from aggregates and escapement for individual stocks
- PM should capture trade-offs between short-term reductions in allowable mortality rate and long-term harvest benefits.
- PM should capture trade-offs between the harvest that is available in mixed-stock fisheries (realizable harvest) and the harvest that could be available if each timing group could be harvested individually (potential selective harvest).
- PM should capture the range of expected outcomes
- PM should differ among the proposed options (i.e. should be sensitive to the change in escapement strategies)

The following specific performance measures were used for the trade-off analyses in the third workshop:

- Realizable mixed-stock catch over 48 years for each of the 4 timing groups (using the 75th percentile to reflect the lower end of the estimated range of values)
- Potential selective catch, also for each of the 4 timing groups, over 48 years and displayed as the 75th percentile.
- Total selective and mixed-stock catch over the first 8 years (using the 50th percentile to reflect the best estimate)
- Best estimate of total run size, averaged over 8 years and 48 years
- Probability that annual escapement or 4-year average escapement fall below the one of the escapement benchmarks in Table 1. Specific variations of these were picked based on the observed sensitivity to different management options.

<u>Choosing among alternative escapement strategies</u>

Once a comprehensive suite of performance measures has been identified, the emphasis shifts to filtering out any alternative strategies that are theoretically possible but clearly unreasonable. There are two approaches for eliminating unreasonable alternatives:

- *Optimization:* Filters many possible alternatives based on a few simple criteria.

- *Structured Comparison:* Compares a few candidate alternatives based on large number of criteria. This is how most fisheries models are used, and the comparison can be formalized through structured trade-off exercises.

The Spawning Initiative workshops used both of these approaches in sequence. First the Working Group used optimization techniques to develop a short list of candidate strategies that reflect alternative management priorities (*Avoid Low Spawners*, *Avoid Low Catch*). Workshop participants then used facilitated debates and structured trade-off exercises to provide feedback on the alternatives.

Participants worked through a preliminary evaluation of alternative strategies in the second workshop, and completed a more detailed trade-off analysis during the third workshop. The trade-off analysis combined two distinct methods for eliciting preference statements:

- Participants were asked to assign preference scores to different management objectives and performance indicators. This provided insight into *stated* preferences, highlighting criteria that participants felt should determine the choice of escapement strategy.

- Participants were also asked to assign preference scores to alternative options, where each option was a specific combination of escapement strategies for the four timing groups. This provided insight into *revealed* preferences (i.e. which option did participants actually prefer) and doubled as an opinion poll.

Briefly, the trade-off analysis showed that:

- Most participants were fairly consistent in their responses for the two elicitation methods, indicating that they had well formulated opinions and were comfortable with the process.

- Options that emphasized either conservation objectives or harvest objectives tended to polarize participants, receiving strong support from some while being strongly rejected by others.

- Options deliberately designed as a compromise weren't strongly rejected or endorsed, and established a middle-ground that served as a platform for 2007 pre-season planning.

It is important to note that while the workshop participants were not able to identify one single option that was superior to all the others their advice guided the Department's decision in crafting the 2007 Fraser River sockeye escapement strategy (Chapter 4).

<u>Model revisions for 2008</u>

A substantial amount of new technical work was completed in preparation for the 2008 planning process, in three categories:

- *Data Updates*: New escapement and recruitment data was included, and parameters for each stock's population model were updated.

- *Assumptions about the range of future outcomes*: The random variation associated with recruitment from a given escapement has been changed back to the way it was calculated up to 2006 (i.e. using transformed residuals calculated as normal (0,1) random deviation) A change was implemented for the 2007 planning process, but the technical team reverted to the original approach which results in a broader range of possible outcomes and is consistent with other DFO planning models (e.g. Cultus model by Korman and Grout, which was reviewed by PSARC in November 2007). This change has little effect on long-term average results, but some performance measures are highly sensitive. Specifically, very high and very low escapements more frequently occur in the simulated trajectories. At first glance this appears to be a purely technical consideration, but the implications for model results are drastic, as illustrated by the example for Late run sockeye on page 37.

- *Model Structure*: The model now includes the option to specify stock-specific escapement strategies (as in Figure 1), so that the total allowable mortality for a stock would be based on its individual abundance rather than aggregate abundance. This work was identified as a priority during the 2007 planning workshops, and provides the basis for future discussion. However, much work remains to be done to refine the concepts and tools, and it is important to clearly understand the capabilities of the model: The Spawning Initiative model does not distinguish where or how that allowable mortality is accessed, but rather helps evaluate how often we would face scenarios with very different target exploitation rates for the component stocks of an aggregate. Also, management adjustments are currently available for aggregates, not individual stocks. A detailed in-season model is needed to evaluate the feasibility of different fishery arrangements and assessment frameworks.

<u>Priorities for future model revisions</u>

The current Spawning Initiative model has proven sufficient to evaluate differences between major categories of escapement strategies for aggregates. For example, the model showed clear advantages of a strategy that responds to run size (Figure 1) compared to fixed escapement strategies or fixed exploitation rate strategies. The next step is to fine tune the model and the underlying assumptions.

The following priorities were identified during the 2008 planning process:

- Refine biological assumptions (correlation between stocks, correlation over time, capacity estimates, management adjustments, migration timing, population models, implementation error).

- Revise the model to run all 19 stocks concurrently, rather than one aggregate at the time, to better capture the constraints introduced by timing overlap between aggregates.

- Further explore the concepts and implications of stock-specific escapement strategies.

- Compile a technical report describing the revised model structure and assumptions, once the other changes have been implemented.

- Further assess the dynamics of stocks with spawning (e.g. Gates, Nadina), given their performance in the simulations.

- Assess robustness of control rules under plausible future climate change scenarios with varying productivity and capacity.

Other initiatives are also developing building blocks for a long-term escapement strategy. For example, on-going work under the *Wild Salmon Policy* will establish formal benchmarks to replace the interim escapement benchmarks listed in Table 3.

2007/2008 Simulation scenarios

Settings and assumptions

- The model includes 19 stocks grouped into 4 timing aggregates for management purposes.
- Population dynamics for all 19 stocks are simulated using the Larkin model, which explicitly estimates the level of interaction between cycle lines.
- Each model scenario applies a specified escapement strategy to a timing aggregate 48 years into the future, starting with recent years, and tracks the performance of each individual stock within the aggregate.
- The model does not distinguish the timing and location of harvests, and does not explicitly simulate alternative fishing plans.
- A minimum exploitation rate of 2% for assessment fisheries is applied every year.
- A cap of 60% total allowable mortality is applied every year for all stocks and aggregates.
- For the results presented here we assume that past observations cover the range and variability of productivity for these stocks. However, the model is set up to explore alternative assumptions about future productivity (e.g. 30% decline over 50 years).
- Overlap between timing groups was calculated based on run size, average peak timing, and average spread around the peak. Mixed-stock exploitation rate for each day was constrained by the smallest exploitation rate among those timing groups that contribute more than 10% of the abundance on that day, and realizable catch in mixed-stock fisheries was calculated based on these revised exploitation rates. For now, this calculation is applied after the fact to explore the magnitude of overlap under different combinations of escapement strategies. One of the priorities for future model revisions is to incorporate that calculation into the model.
- Simulations start with escapement data up to 2006, and population dynamics are estimated based on spawner and recruit data up to 2001 (due to the time-delay to compile and analyze recruitment data from age 3, 4, and 5 returns).
- Birkenhead sockeye were not included in the assessment of Late run escapement strategies, rather, Summer run escapement strategies were applied to Birkenhead, which reflects the passively managed nature of the Birkenhead component of the Fraser sockeye run.
- Harrison sockeye were considered separately, but due to the uncertainty in the population dynamics, introduced by the large 2005 escapement, and the inability to identify a separate management adjustment for Harrison, it was decided to continue to manage them with the other Lates. Work on these issues continues as new data becomes available.
- Cultus sockeye were considered separately based on the extensive recovery planning work completed in 2006 and 2007.

Candidate escapement strategies

The Working Group explored a wide range of escapement strategies and compared their performance using indicators that reflect the fundamental objectives of (1) ensuring escapement and production for individual stocks and (2) accessing catch-related benefits from the timing aggregates. Using several variations of these indicators to ensure robust conclusions, the Working Group re-evaluated the following options previously put forward during the 2007 planning process:

- *Option 1*: Reject all those escapement strategies that result in low catch from the aggregate with higher probability than some specified risk tolerance (e.g. Avoid low catch for the aggregate 7 out of 10 years). Among those strategies with sufficient probability of meeting the low catch requirement, choose the one that maximizes long-term average catch. Low catch benchmarks considered for this option are based on suggestions provided by participants during the 2006 workshop series.

- *Option 2*: Reject all those escapement strategies that fail to meet either Option 1 or Option 3, but with increased risk tolerance. Among those strategies that remain, choose the one that maximizes long-term average catch.

- *Option 3*: Reject all those escapement strategies that result in low escapement on individual stocks with higher probability than some specified risk tolerance (i.e. Avoid low escapement on each individual stock 8 out of 10 years). If a component stock fails to meet the risk tolerance for any of the escapement strategies (e.g. highly cyclic pattern), then reject all those escapement strategies that fail to minimize the probability of low escapement for that stock. Among those strategies with sufficient probability of meeting the low escapement requirement, choose the one that maximizes long-term average catch. Low escapement indicators considered for this option compare each year’s escapement and 4 year average escapement to two benchmarks that span a range of alternative definitions.

- *Option 4*: Same reasoning as for Option 3, but using a larger benchmark to identify low escapement.

Workshop participants reviewed updated results (due to model revisions described earlier) and reconsidered the rationale for choosing among the options in the face of specific circumstances expected for 2008. The major planning challenges for each aggregate are briefly discussed in the remainder of this section.

General observations

- No single performance indicator was informative across all 19 stocks or 4 timing groups.

- The performance indicators revealed many complex interactions between the effect of an escapement strategy on an aggregate of stocks and the resulting performance of individual components. For example, an escapement strategy that is intended to conserve individual stocks by cutting back on TAM at large run sizes may lead to quick increases in aggregate abundance, which in turn increases the average exploitation rate, and therefore slightly increases the probability of falling below the low escapement benchmark for some smaller component stock. Similarly, escapement strategies affect the degree of variability in escapement, both from one year to the next and in four year patterns (cyclicity), which can lead to performance trends that appear counter-intuitive at first glance.

- Any escapement strategy that results in substantial exploitation rates at low run sizes propagates or creates a cyclic pattern in run size, harvest, and escapement.

- *Early Stuart* is modeled as a single stock with strong cycle-line interaction. Escapement strategies with large cut-back points tend to build up off-cycle abundances and reduce peak abundance in dominant years, so that the stock builds up to a fairly stable abundance and escapement across all cycle years.

- The *Early Summer* aggregate is modeled as a mixture of 8 stocks, of which 3 exhibit strong cycle-line interactions and contribute the majority of the abundance (Nadina, Scotch, Seymour). For 4 of the 8 stocks considerably less data is available, with time series starting in the late 1960s (Fennel, Gates) or even in the 1980s (Scotch). This increases uncertainty in the population dynamics, and complicates interpretation of the simulation results.

- The *Summer* aggregate is modeled as mixture of 4 stocks. Late Stuart and Quesnel show strong 4 year cycles in past observations, while Stellako and Chilko show 2-year patterns (high-low-high-low) in the escapement sequence that should maximize run size for the individual stocks. Performance measures are strongly influenced by the extent to which the cyclic pattern is propagated.

- The *Late* aggregate is modeled as a mixture of 5 stocks, of which 1 exhibits strong cycle-line interactions and contributes most of the abundance (Late Shuswap). The performance of escapement strategies is very robust across a wide range of escapement strategies, because run size in most of the Late Shuswap dominant years is larger than the cut-back point (e.g. 2 Million) and in most of the "off" years, the run size is smaller than the no-fishing point (e.g. 500,000). As a result, the escapement strategy for Late run sockeye was modified to include a 20% ER floor (i.e. 20% exploitation rate at low run sizes).

<u>Simulation Results - Early Stuart</u>

Early Stuart is modeled as a single stock with strong cycle-line interaction. Figure 9 summarizes the simulation results.

Escapement strategies with high cut-back points (e.g. Option 4) tend to build up off-cycle abundances and reduce peak abundance in dominant years, so that the stock builds up to a fairly stable abundance and escapement. This implies that the estimated degree of cycle line interaction is not large enough to propagate the cyclic pattern in the absence of substantial exploitation rates in years with low abundance (i.e. off-cycle years).

Early Stuart sockeye have experienced poor returns in recent years, partly due to high en-route mortality as they migrate up the Fraser River. Many FRSSI participants and external advisors have raised the concern that this stock requires a high degree of protection. Accordingly, the escapement strategy selected for 2008 is Option 3, which has a low risk tolerance. For example, there is a less than 1 in 10 chance of not achieving BM 2, averaged over 4 years (--- dashed line in Figure 9).

<u>Simulation results - Early Summer</u>

The Early Summer aggregate is modeled as a mixture of 8 stocks, of which 3 exhibit strong cycle-line interactions and contribute the majority of the abundance (Nadina, Scotch, Seymour). For 4 of the 8 stocks considerably less data is available, with time series starting in the late 1960s (Fennel, Gates) or even in the 1980s (Scotch). This increases uncertainty in the population dynamics, and complicates interpretation of the simulation results. Figure 10 summarizes the simulation results.

Six of the eight stocks have a high probability (i.e. better than 9 out 10 years) of achieving BM 2 over the entire range of alternative escapement strategies (Bowron, Fennel, Gates, Raft, Scotch and Seymour).

Nadina and Pitt don't achieve BM 2 with a similarly high probability, but show some gradual improvement as the escapement strategy shifts to a higher cut-back point (e.g. from Option 1 to Option 5). However, this marginal improvement comes at the cost of a substantial decrease in long-term average catch, as well as a substantial increase in the probability of falling below annual catch targets. Balancing these different considerations, DFO chose Option 2 as the long-term escapement strategy for Early Summer, which was also adopted last year. DFO is working on guidelines for the degree of annual flexibility associated with this long-term strategy, due to the substantial implications of forecast uncertainty for 2008 fisheries planning (e.g. difference between TAM under Options 2 and 3 at low end of forecast).

Simulation Results - Summer

The Summer aggregate is modeled as mixture of 4 stocks. Late Stuart and Quesnel show strong 4 year cycles in past observations, while Stellako and Chilko show weaker cycle line interactions. Performance measures are strongly influenced by the extent to which the cyclic pattern is propagated. Birkenhead is modeled passively by applying Summer exploitation rates. Figure 11 summarizes the simulation results.

Three of the four stocks have a high probability (i.e. better than 9 out 10 years) of achieving BM 2 over a the entire range of alternative escapement strategies (Chilko, Quesnel and Stellako). Late Stuart doesn't achieve BM 2 with a similarly high probability, but shows some gradual improvement as the escapement strategy shifts to a higher cut-back point (e.g. from Option 1 to Option 3 and beyond). However, this marginal improvement comes at the cost of a substantial decrease in long-term average catch, as well as a substantial increase in the probability of falling below annual catch targets. Balancing these different considerations, DFO chose Option 1 as the long-term escapement strategy for the Summer aggregate, which is slightly modified from 2007 based on updated simulation results.

Simulation Results - Late run

The Late run aggregate is modeled as a mixture of 5 stocks (L. Shuswap, Weaver, Portage, Harrison and Cultus), one of which exhibits strong cycle-line interactions and contributes most of the abundance (Late Shuswap).

Figure 12 shows that the performance of escapement strategies is very robust across a wide range of cut-back points, because run size in most of the Late Shuswap dominant years is larger than the largest cut-back point (e.g. 2 Million) and in most of the "off" years the run size is smaller than the lowest point at which the strategy switches to the exploitation rate floor of 20% (e.g. 500,000). The performance of escapement strategies is much more sensitive to the chosen minimum exploitation rate, as shown in Figure 13.

This modification from the 2007 plan was explored for two reasons:

- The strong cyclic pattern driven by one stock poorly reflects the dynamics of other stocks in the aggregate. The need for a modified strategy in off-cycle years was identified during the 2007 planning process, due to the timing overlap with Summer run sockeye and the associated implementation constraints on most fisheries.

- Management of the Late run aggregate benefits from consistency with the recovery strategy for Cultus Lake sockeye.

Portage, Weaver and Late Shuswap achieve the escapement benchmark with a fairly high probability if the exploitation rate floor is low:

- better than 8 out of 10 years if ER floor is less than 15%.
- better than 7 out of 10 if ER floor is less than about 20%. While this risk tolerance is not as stringent as the criteria applied to the other aggregates, it is still consistent with previous departmental risk assessments.

This was considered acceptable in the context of the revised assumptions about the range of future recruitment, which produce a much broader range of possible outcomes and increase the simulated frequency of low escapements. Figure 14 shows simulation results for the same scenarios as Figure 13, but using a narrower range of future outcomes. In particular, fewer years with low outcomes translate into in a much lower probability of falling below the stock-specific escapement benchmarks, which indicates less risk for a given escapement strategy. Also note that a wider range of outcomes produces more contrast in performance across different escapement strategies (i.e. steeper gradient in the performance indicators from left to right. For example, with transformed residuals, the difference between a 5% ER floor and a 25% ER floor is about a 5% higher probability of Late Shuswap, Weaver, or Portage falling below their individual escapement benchmarks (Figure 14). For untransformed residuals the same comparison shows about 20% higher probability (Figure 13).

There is no clear-cut choice between these options, but the Working Group chose to use the untransformed residuals for 2008 planning simulations to remain consistent with other models used for Pacific Salmon, such as the Cultus model. Accordingly, DFO chose Option 1 as the long-term escapement strategy for the Late aggregate, with a 20% floor on exploitation rate to address cyclic patterns and timing overlaps.

Harrison and Cultus were simulated as part of the Late run, but also considered separately, as described in the next section.

<u>Special Considerations – Birkenhead, Harrison, and Cultus</u>

Birkenhead sockeye have distinct population dynamics and migration behavior. While they were managed as part of the Late run aggregate prior to 2002, they did not exhibit the same elevated pre-spawn or en-route mortality as the rest of the Late run aggregate and consequently, they are now passively exposed to the same exploitation rate as the Summer run aggregate. In simulations, the long-term distribution of escapement is only slightly affected by the choice of escapement option for the Summer run aggregate. In fact, there is a better than 9 out of 10 chance that escapements will exceed the benchmark every year (90% of escapements larger than tip of the lower whisker in Figure 15).

Harrison sockeye present a particular management challenge, and the option of developing an individual escapement strategy for Harrison was explored during the planning workshop. However, the approach for 2008 is to continue managing Harrison as part of the Late run aggregate. Three key considerations shaped this decision:

- It is difficult to interpret the large escapement in 2005, with almost 10 times more spawners than the largest previously observed escapement. This introduces large uncertainty into the SR model for this stock, and makes it difficult to judge the long-term implications of alternative escapement strategies.
- Simulations showed that Harrison tends to perform poorly under any of the Late run escapement options *if the population dynamics for Harrison follow the pattern of production estimated from data up to 2001, and under the same level of en-route mortality as other Late run stocks.*

- Simulations showed that Harrison cannot sustain exploitations rates resulting from any of the Summer run escapement options *if the population dynamics for Harrison follow the pattern of production estimated from data up to 2001, and under the same level of en-route mortality as other Late run stocks.*

For Cultus sockeye a separate, more detailed life history model has been developed to explore recovery options built around combinations of enhancement actions and escapement strategies. This model was used during the 2006 planning exercise, and has been directly tied in with the FRSSI model results.

For each of the Late run escapement options, the FRSSI model tracks the range and sequence of exploitation rates applied to Late run sockeye. The Cultus model then applies these exploitation rate trajectories to test their effect on Cultus under different enhancement scenarios. Under none of the options explored was the probability of recovery greater than 30% at current enhanced levels. If enhancement levels were significantly increased, the probability of recovery increased and the probability of extinction decreased to very low levels. However, enhancement effects for sockeye remain unproven and are costly to implement.

The 2008 plan for Cultus sockeye is a target exploitation rate of 20%, just as in 2007. This was selected due to:

- a low 2008 forecast of 5,000 sockeye, which is the same as the 2007 forecast,
- high uncertainty in the forecast,
- unpredictable long-term responses to predator removal.

4. 2007-2010 ESCAPEMENT PLAN FOR FRASER SOCKEYE

This chapter lists the guiding principles for setting escapement targets, summarizes the specific strategies for 2007 by management group, and outlines next steps in the development process.

Guiding principles

The main product of the *Spawning Initiative* is a long-term approach for setting escapement targets for Fraser sockeye, built around the following guiding principles:

- Fraser sockeye escapement is managed in 4 groups (Early Stuart, Early Summer, Summer, Late)
- Escapement strategies for each management group are designed to protect component stocks and stabilize total harvest across all sectors.
- Annual targets for each management group are based on escapement strategies that specify target levels of total mortality across different run sizes.

To achieve a balance between conservation at low abundance and harvest at higher abundance, the strategies specify:

- No fishing at very low run size, except for stock assessment.
- Fixed escapement and declining total allowable mortality at low run sizes (to protect the stocks and reduce process-related challenges at this critical stage (e.g. uncertain run size)
- Fixed total allowable mortality rate of 60% at larger run sizes. This cap on mortality serves two purposes: It ensures robustness against uncertainty (e.g. estimates of productivity and capacity, changing run-size estimates) and protects stocks that are less abundant, less productive, or both.
- The exact shape of the escapement strategy for each management group (i.e. the run sizes at which it changes from no fishing to fixed escapement, and then to fixed mortality rate) is selected based on simulated performance and reviewed in public consultation.
- Candidate escapement strategies are compared based on their performance relative to biological and socio-economic indicators.
- Biological indicators reflect the intent of the *Wild Salmon Policy* and the *Science Advisory Report* describing the minimal requirements for harvest strategies to be compliant with the Precautionary Approach. Biological indicators emphasise comparisons to stock-specific escapement benchmarks (e.g. How often does the 4-yr average escapement fall below the benchmark?).
- Stock-specific escapement benchmarks need to be robust against uncertainty in escapement data, parameter estimates (e.g. capacity), and alternative definitions. The Spawning Initiative explored a range of alternative benchmarks, using the largest and smallest value to bookend the performance measures (Table 1).
- Socio-economic indicators focus on stability in total harvest (e.g. How often is the realizable harvest less than 1 Million fish?).

2008 Escapement strategies by management group

The escapement plan for 2008 has been modified from 2007, but there are no substantial changes in strategy for the Early Stuart, Early Summer, and Summer groups. The strategy for Late run has been revised as explained below. These escapement strategies for 2008 are identified by the bolded blue line in Figure 9 to Figure 12.

The plan for 2008 includes some changes compared to 2007, because of revisions in the underlying simulation model and additional consideration of practical challenges:

- *Early Stuart*: The abundance forecast of 35,000 is substantially below average for this cycle line, and the strategy for this year is to maximize escapement from this low run size. The long-term strategy, as adopted in 2007, is to reduce total allowable mortality at run sizes below 270,000, with minimal allowable mortality at run sizes below 108,000.

- *Early Summer*: The aggregate abundance forecast of 288,000 for the eight stocks in the simulation model is about half of the average for this cycle line, with 6 of the 8 components stocks expected to return below average. The strategy for this year, as adopted in 2007, is to reduce total allowable mortality at run sizes below 300,000, with minimal allowable mortality at run sizes below 120,000. The implications of this long-term strategy for 2008 fishing plans will be strongly influenced by in-season run-size estimates over the forecast range.

- *Summer*: The aggregate abundance forecast of 1.8 Million is about a third below the average for this cycle line, with 2 of the 4 component stocks expected to return below average. The selected strategy for this year, slightly modified from 2007, is to reduce total allowable mortality at run sizes below 1.3 Million, with minimal allowable mortality at run sizes below 520,000.

- *Late*: The aggregate abundance forecast of 705,000 is just under the average for this cycle line, but this aggregate presents several unique management challenges that influence the choice of strategy (e.g. Cultus recovery planning, early migration and in-river mortality, mix of stocks). The strategy for this year, modified from 2007, is to reduce total allowable mortality at run sizes below 1 Million, with an exploitation rate floor of 20% at run sizes below about 500,000. This change was implemented to (1) address the strong cyclic pattern driven by Late Shuswap, historically the most abundant of the component stocks, and (2) allow consistency with the Cultus escapement strategy.

- *Birkenhead*: The abundance forecast of 238,000 is near the average for this cycle line. The stock is managed passively and exposed to Summer run exploitation rates.

- *Harrison*: The abundance forecast of 47,000 equals the long-term average. The approach for 2008 is to continue managing Harrison as part of the Late run aggregate. It is not currently feasible to develop a separate escapement strategy for Harrison because production from the large 2005 escapement has not been observed and large pre-spawn mortalities in recent years add additional uncertainty to the long-term evaluation of alternative strategies.

- *Cultus*: The abundance forecast is 5,000, and the approach, as in 2007, is a fixed exploitation rate of 20%.

Review process and timelines

The new approach was implemented for the 2007 fishing season, updated for 2008, and will be fully reviewed as part of the 2010 post-season review, after a complete 4-year cycle of sockeye escapements.

The specific escapement strategies for each management group will continue to be reviewed annually as part of the post-season review process, and modifications will be considered during the pre-season planning process.

The following steps are planned leading up to the 2009 fishing season:

- *Questionnaire:* Workshop participants will get an opportunity to comment on all aspects of the initiative. DFO will circulate a questionnaire in November 2008 requesting feedback regarding the guiding principles of the new escapement plan, the strategies for each management group, and the collaborative process.

- *Analyses and model revisions:* The simulation will continue to evolve as additional mechanisms are incorporated. One of the priorities identified by workshop participants in January 2008 is to review the biological assumptions in the simulation model.

- *Pre-season planning:* The planning process will begin once the final post-season estimates of abundance, escapement, and catch are available sometime in December 2008.

- *Workshop:* DFO is planning to host a workshop in January 2009 to review model revisions and explore escapement strategies based on pre-season forecasts.

- *Preliminary escapement plan for 2009:* A draft escapement plan will be developed based on workshop feedback and included in the draft 2009 Integrated Fisheries Management Plan, which will go through public consultation during April and May of 2009.

Escapement strategies for Fraser sockeye will be reviewed as emerging policies are finalized and new information becomes available. Areas for on-going research and development include:

- Finalize conservation units (CU) for Fraser sockeye.

- Finalize status benchmarks under the Wild Salmon Policy (WSP).

- Complete an initial assessment of Fraser sockeye CUs relative to WSP status benchmarks.

- Develop an in-season model for evaluating alternative assessment and management strategies.

- Complete a framework for prioritizing stock assessment projects for Fraser.

SOURCES AND RELATED MATERIALS

Materials available online

Cass A, Folkes M, and G Pestal (2004) *Methods for Assessing Harvest Rules for Fraser River Sockeye Salmon* was published as *Canadian Science Advisory Secretariat Research Document - 2004/025* and is available at www.dfo-mpo.gc.ca/csas/. Note that the model has evolved since then (Chapter 3), and an updated technical report is planned for 2009.

Fisheries and Oceans (2006). *A Harvest Strategy Compliant With The Precautionary Approach*. CSAS Science Advisory Report 2006/023 is available at http://www.dfo-mpo.gc.ca/csas/Csas/status/2006/SAR-AS2006_023_E.pdf.

Fisheries and Oceans (2006) *Canada's Policy for Conservation of Wild Pacific Salmon* is available at http://www-comm.pac.dfo-mpo.gc.ca/publications/wsp/default_e.htm.

Holtby, B and K Ciruna (2007) *Conservation Units for Pacific Salmon under the Wild Salmon Policy*. CSAS Research Document 2007/070 will be posted on the CSAS website at http://www.dfo-mpo.gc.ca/csas/Csas/Home-Accueil_e.htm.

Korman J and J Grout (2008) *Cultus Lake Sockeye Population Viability Analysis* has been peer-reviewed by *Pacific Science Advice Review Committee* (PSARC) and is available upon request from psarc@pac.dfo-mpo.gc.ca.

Walters C, LeBlond P, and B Riddell (2004) *Does Over-escapement Cause Salmon Stock Collapse?* is available at www.fish.bc.ca by searching for “escapement” in the *Report Finder*.

Fraser River Action Plan (1995) *Sockeye Salmon* is available at www.dfo-mpo.gc.ca/Library/187444.pdf

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Bodtker KM, Peterman RM, and MJ Bradford (2007) Accounting for Uncertainty in Estimates of Escapement Goals for Fraser River Sockeye Salmon based on Productivity of Nursery Lakes in British Columbia, Canada. North American Journal of Fisheries Management 27:286-302.

Cass AJ, and CC Wood (1994) Evaluation of the depensatory fishing hypothesis as an explanation for population cycles in Fraser River sockeye salmon (*Oncorhynchus nerka*). Canadian Journal of Fisheries and Aquatic Sciences 51:1839-1854.

Ricker WE (1950) Cyclic dominance among the Fraser River sockeye. Ecology 31: 6-26

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Schnute JT, Cass AJ, and LJ Richards (2000) *A Bayesian decision analysis to set escapement goals for Fraser sockeye salmon*. Canadian Journal of Fisheries and Aquatic Sciences 57: 962-979

Shortreed KS, Hume JMB, and JG Stockner (2000) *Using Photosynthetic Rates to Estimate the Juvenile Sockeye Salmon Rearing Capacity of British Columbia Lakes.* Pages 505-521 in Knudsen EE, Steward CR, Macdonald DD, Williams JE, and DW Reiser, editors. *Sustainable Fisheries Management: Pacific Salmon*, CRC Press, Lewis Publishers, Boca Raton, Florida.

FIGURES

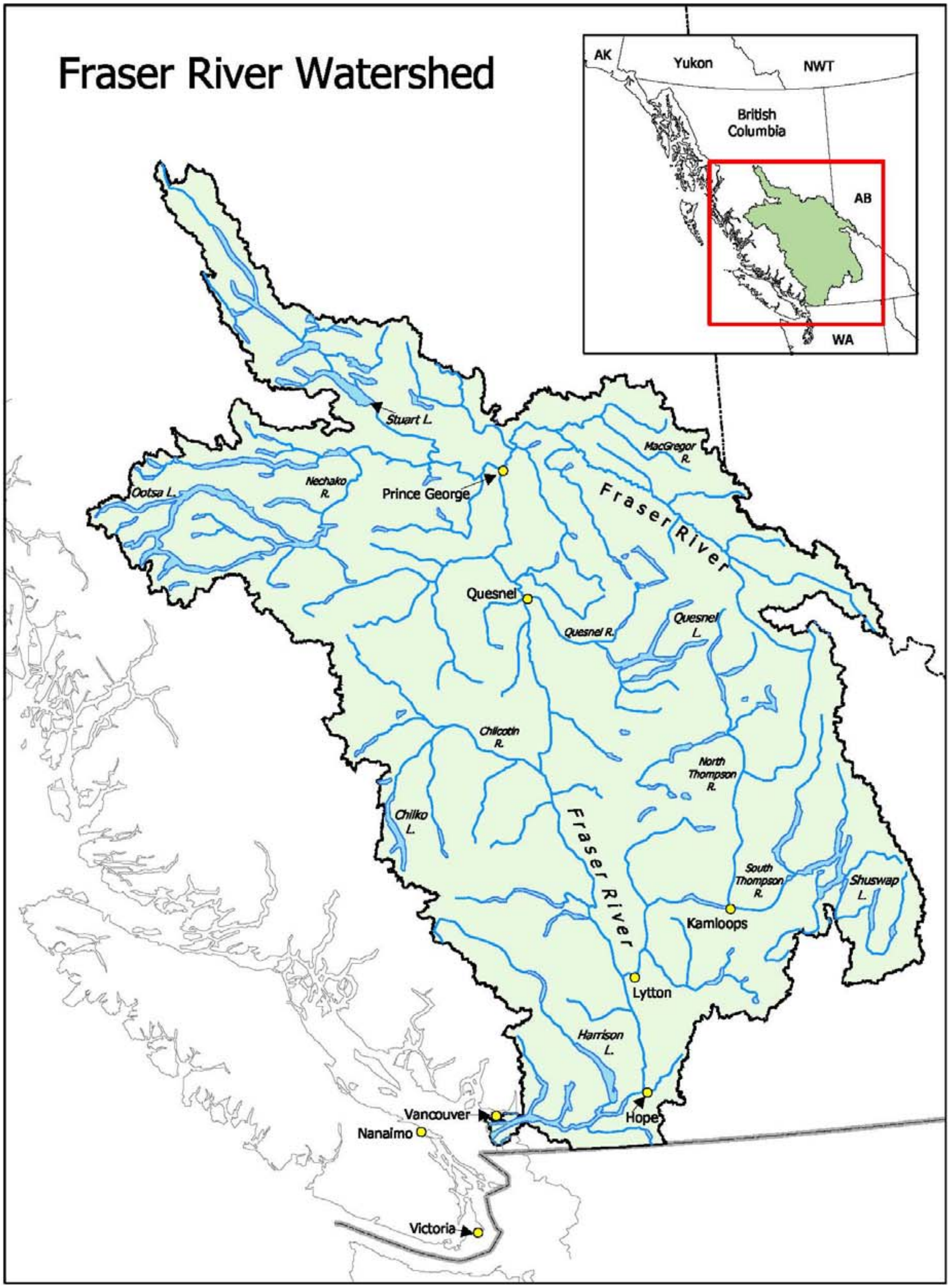

Figure 1: Fraser River watershed and major sockeye rearing lakes.
(Map provided by the Pacific Salmon Commission)

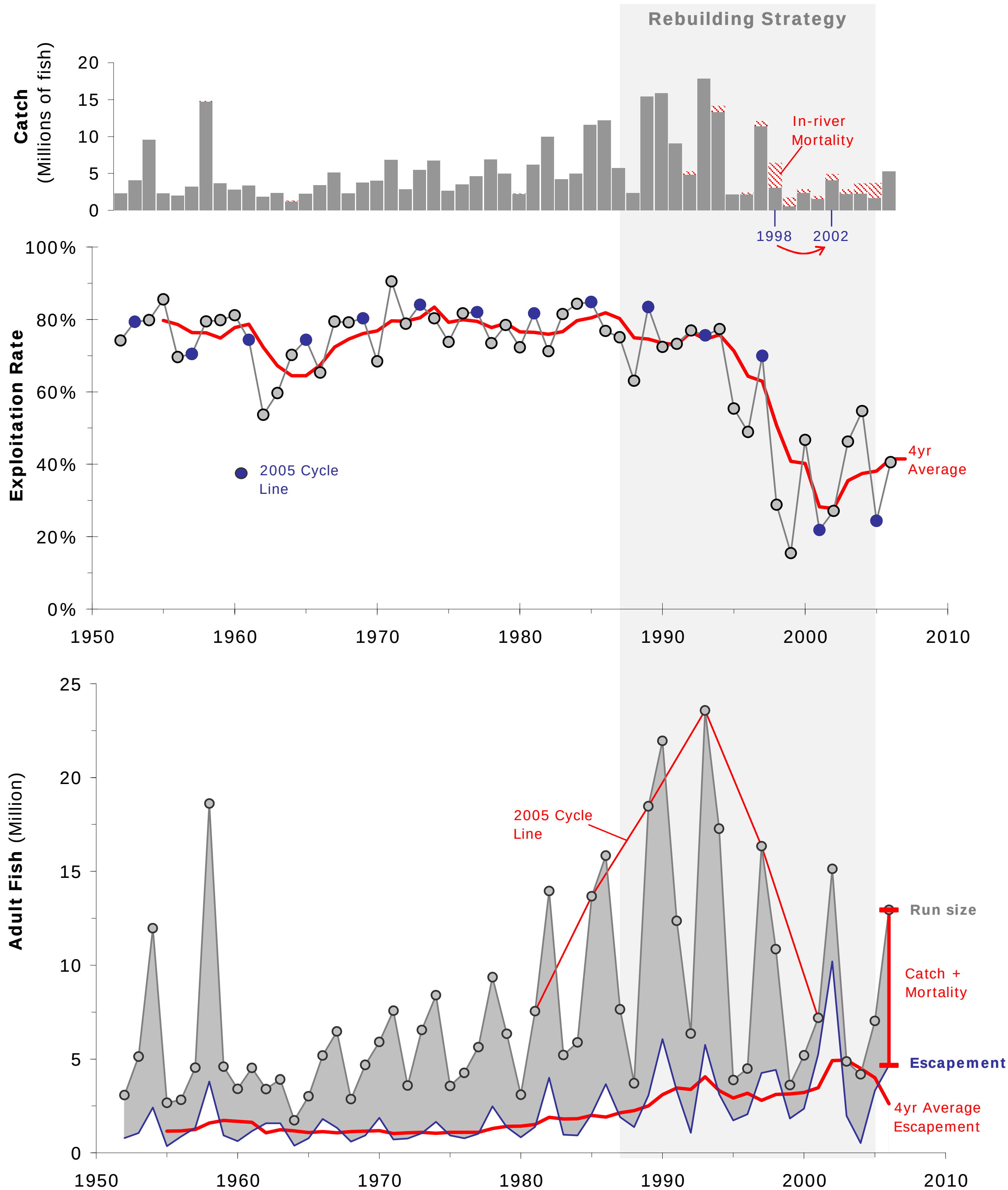

Figure 2: Patterns in Fraser sockeye catch, exploitation, abundance, and escapement.

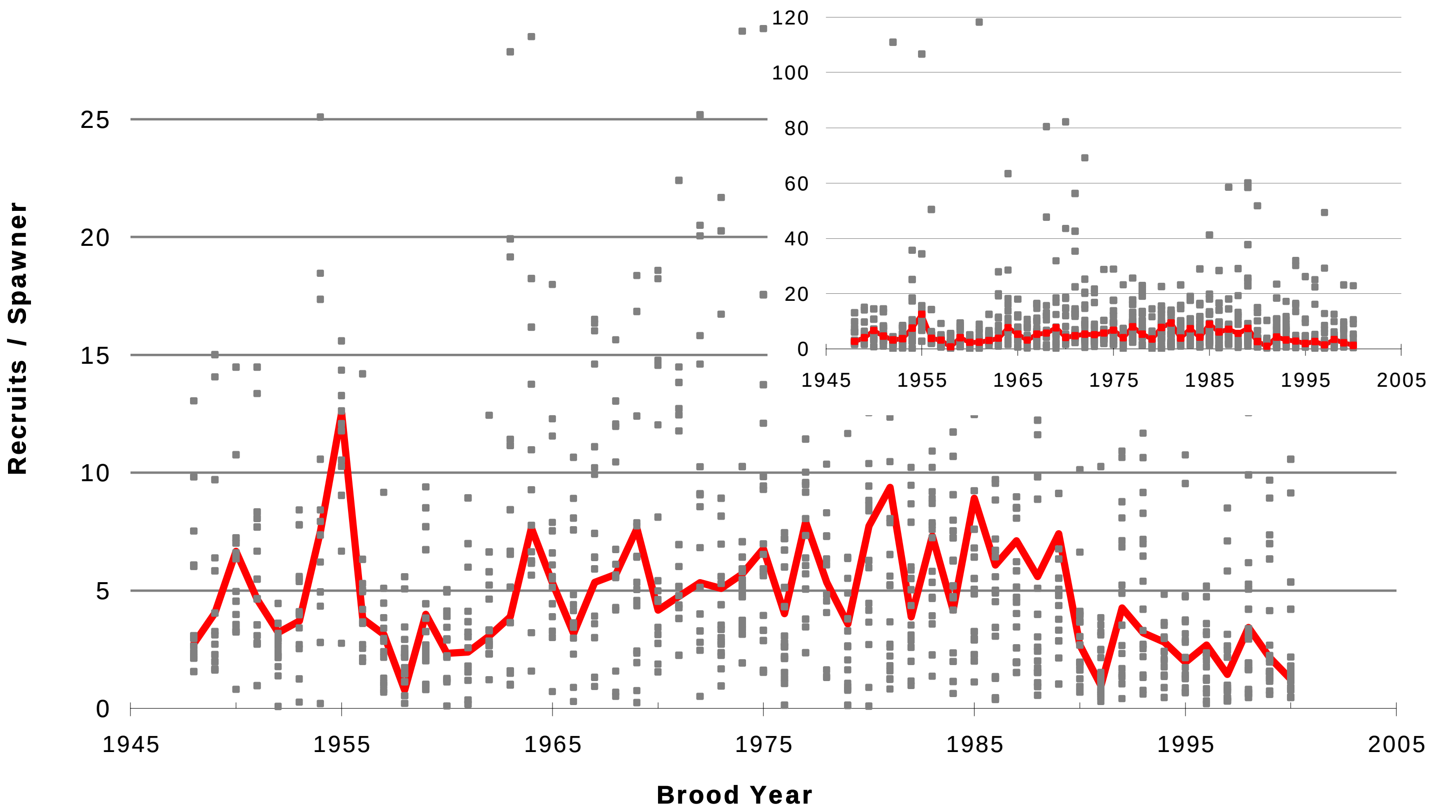

Figure 3: Patterns in productivity for 19 Fraser sockeye stocks.
Note that the main plot excludes very large observations, which are emphasized in the insert. The red trend line tracks average productivity weighted by relative contribution to total escapement, so that larger stocks have stronger pull on the average. Productivity in the 1990s was only about a quarter to half of the productivity in the 1980s.

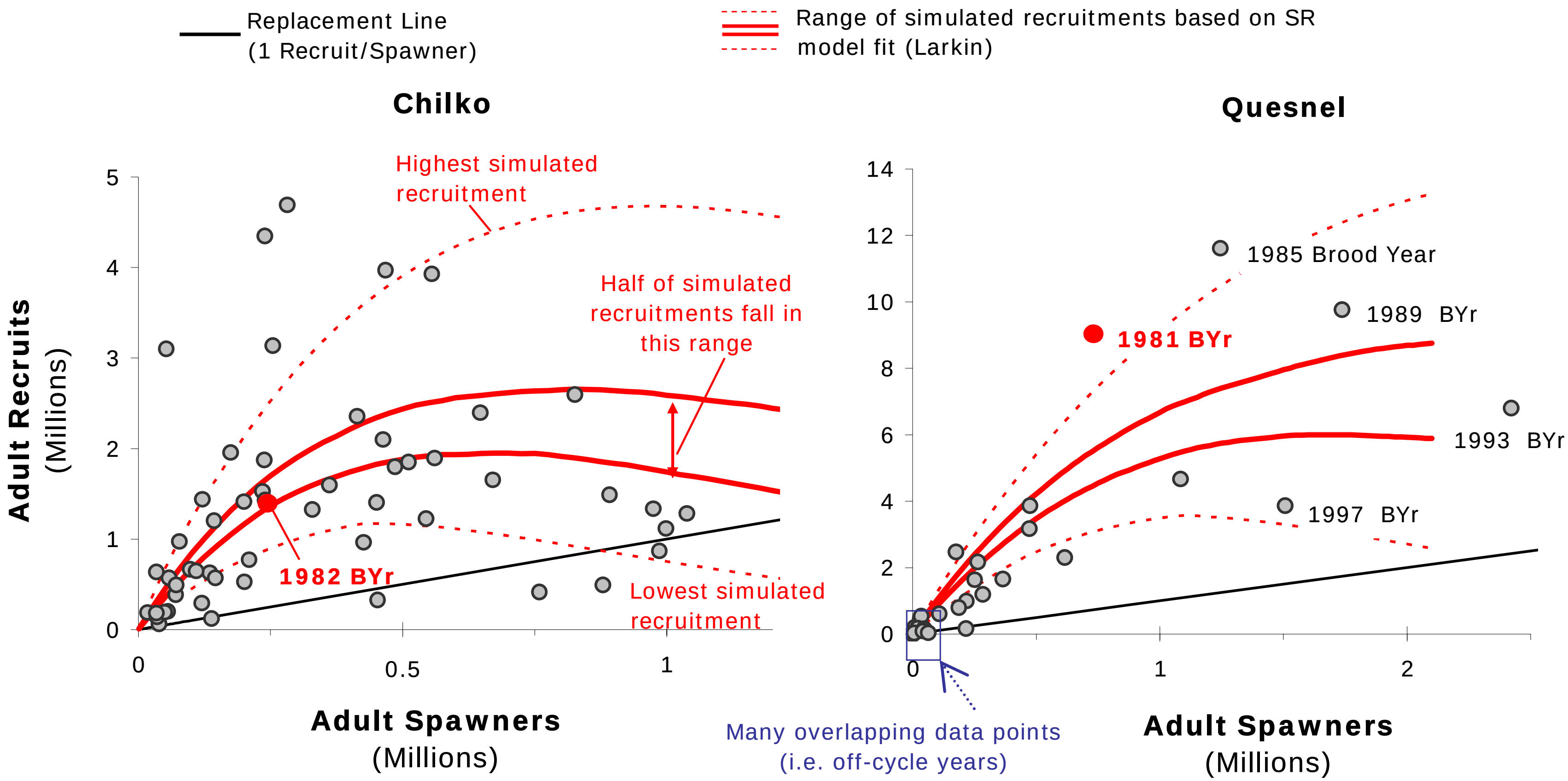

Figure 4: Relationship between spawning abundance and recruitment for 2 Fraser sockeye stocks.
Recruitment is simulated using the Larkin model (p.28), which incorporates delayed-density effects of spawning abundance in the three preceding years. The solid and dashed curves show how expected recruitment changes for different spawning abundances *in a given brood year*, but the shape of the red curves changes *depending on the spawning abundance in the three previous years.* Recruitment curves shown are for two highly productive brood years: the dominant Quesnel cycle in 1981, and the 1982 brood year for Chilko. Note that the range of simulated recruitments reflects only uncertainty in parameter estimates for the Larkin model. When simulating the dynamics of these stocks forward in time, random variation is included to reflect year-to-year variability in recruitment. For both stocks the majority of spawning abundances fall on the lower end of the observed range, introducing larger uncertainty in simulated recruitment produced by large escapements. This is particularly pronounced for Quesnel sockeye, which have exhibited a consistent cyclic pattern. A stock must produce at least 1 recruit per spawner to maintain a stable abundance in the absence of fishing and in-river mortality (i.e. replace parent abundance).

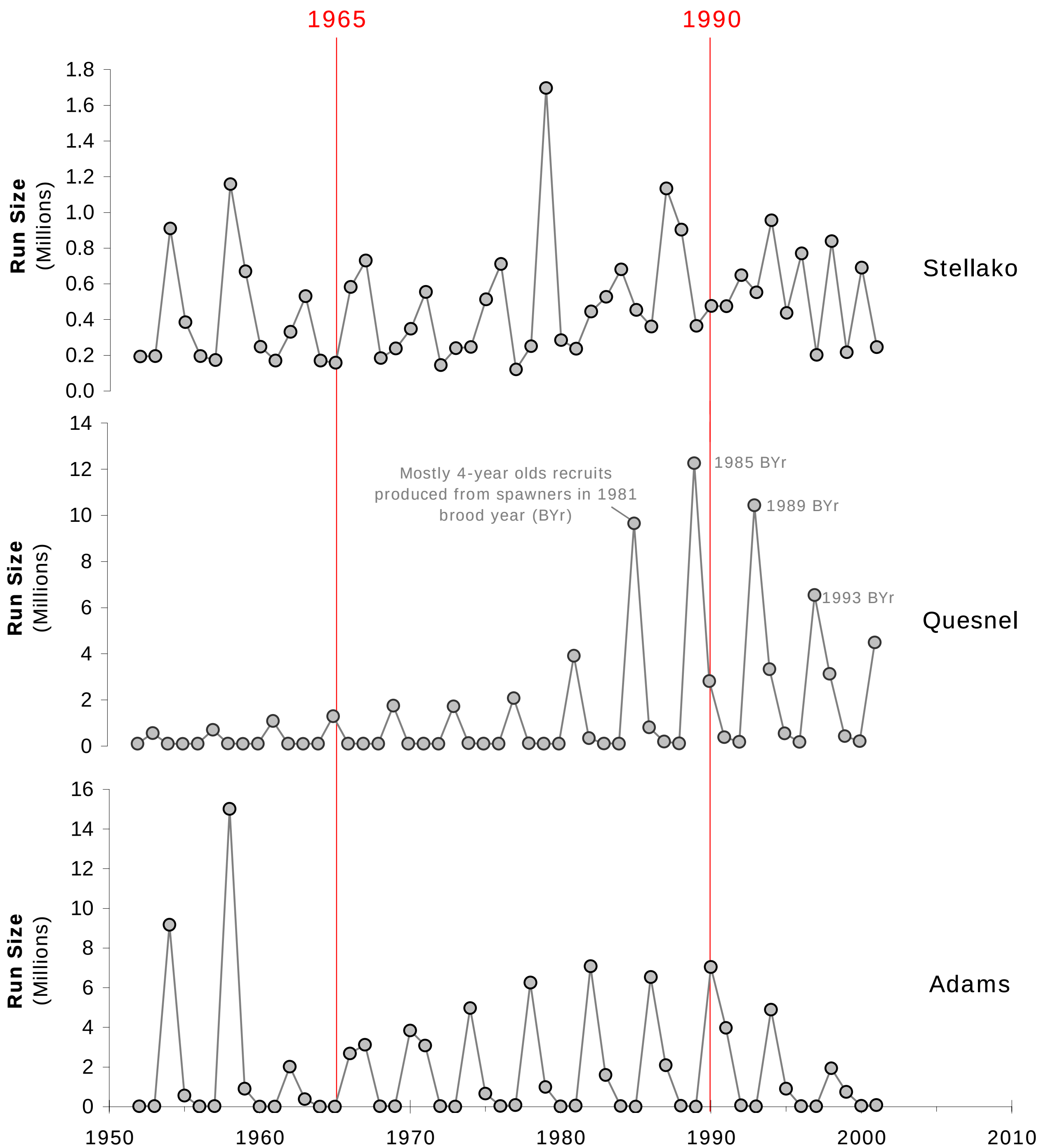

Figure 5: Patterns of abundance for 3 Fraser sockeye stocks.
Large run sizes for Quesnel labelled by brood year in this figure match the points highlighted in the Spawner / Recruit plot (Figure 4). Also note that the time series starts *after* a severe collapse of the Quesnel system due to the Hell's Gate slide in 1913, other blockages to migration, and high fishing pressure. The stock began rebuilding after fishways were completed in the 1940s.

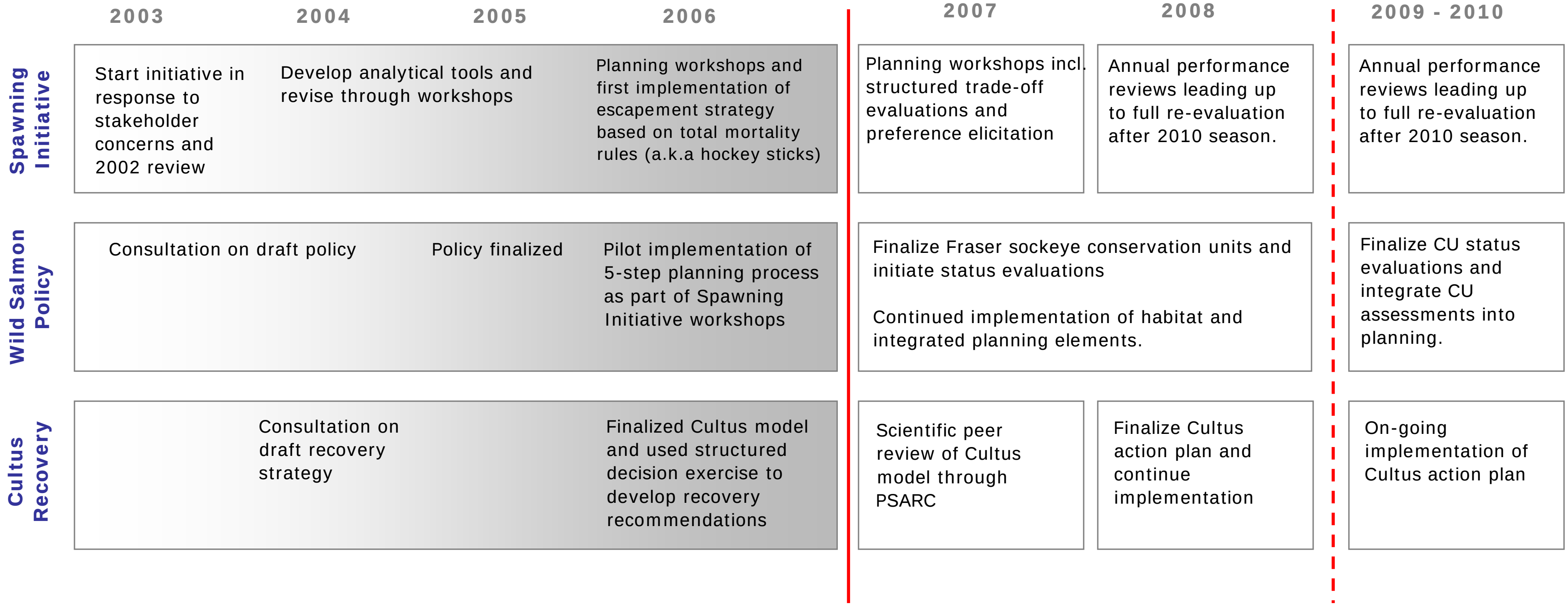

Figure 6: Timeline of the Spawning Initiative and related processes.

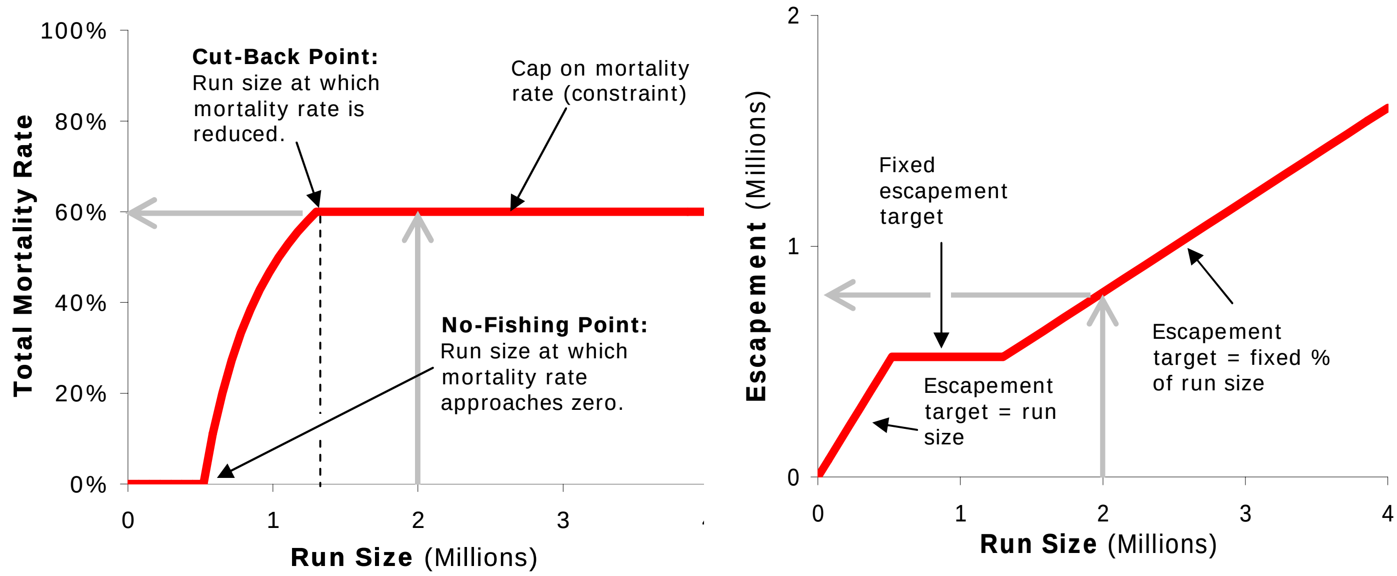

Figure 7: Total Allowable Mortality (TAM) rule and corresponding escapement strategy for the Summer aggregate in 2008.

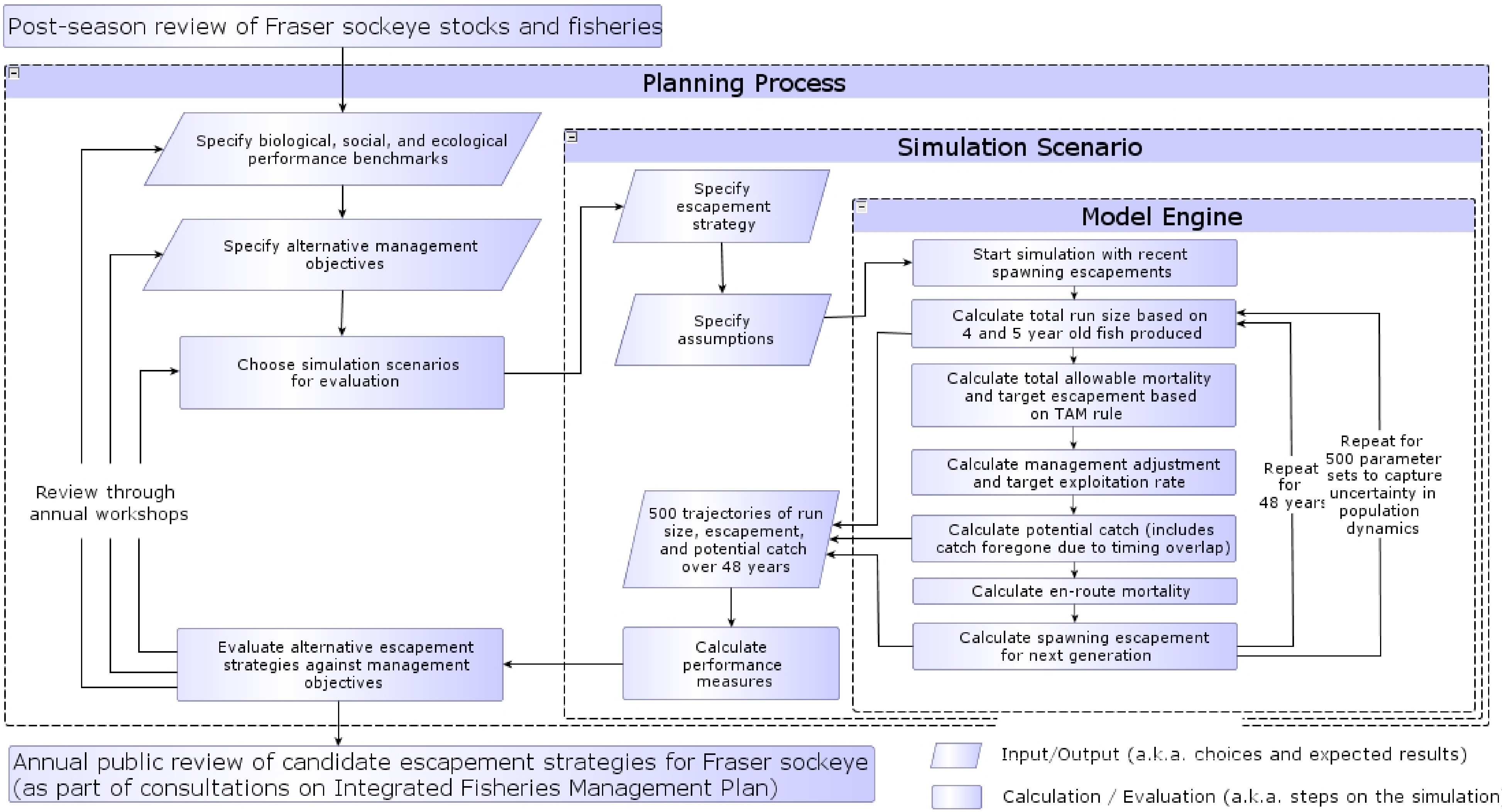

Figure 8: Information flow in the planning process and simulation model

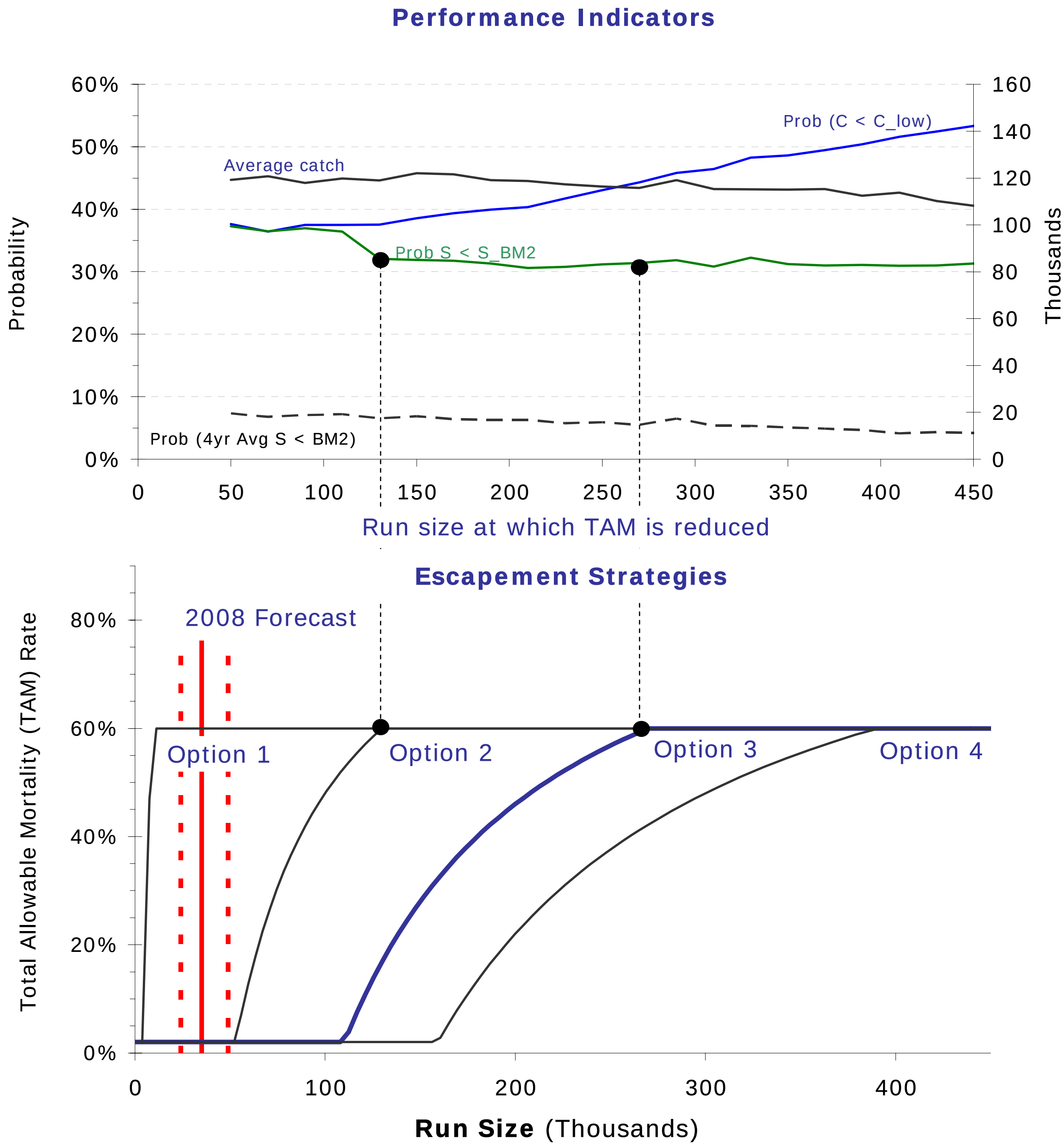

Figure 9: Sample simulation results and options for Early Stuart sockeye.

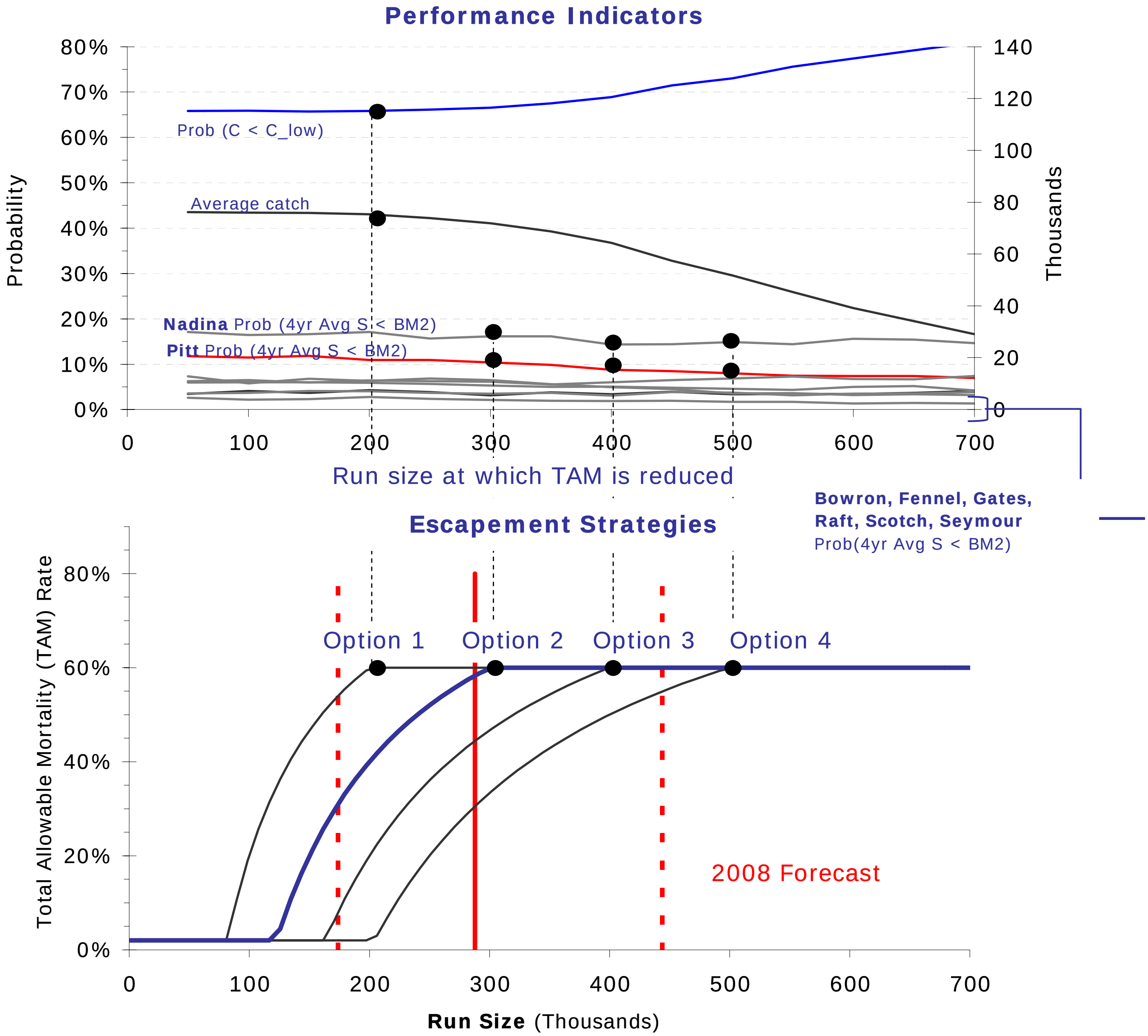

Figure 10: Sample simulation results and options for Early Summer sockeye

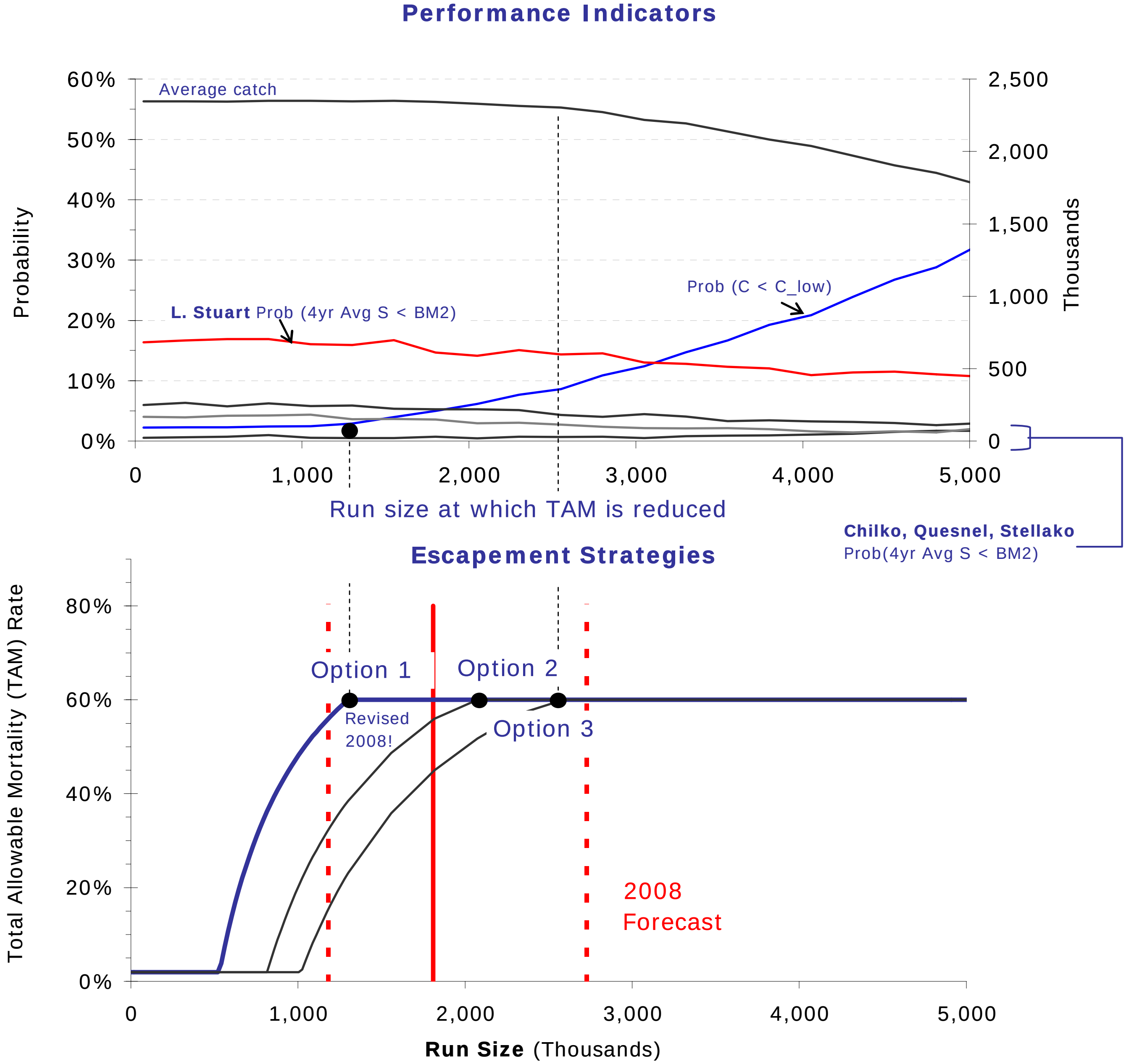

Figure 11: Sample simulation results and options for Summer sockeye

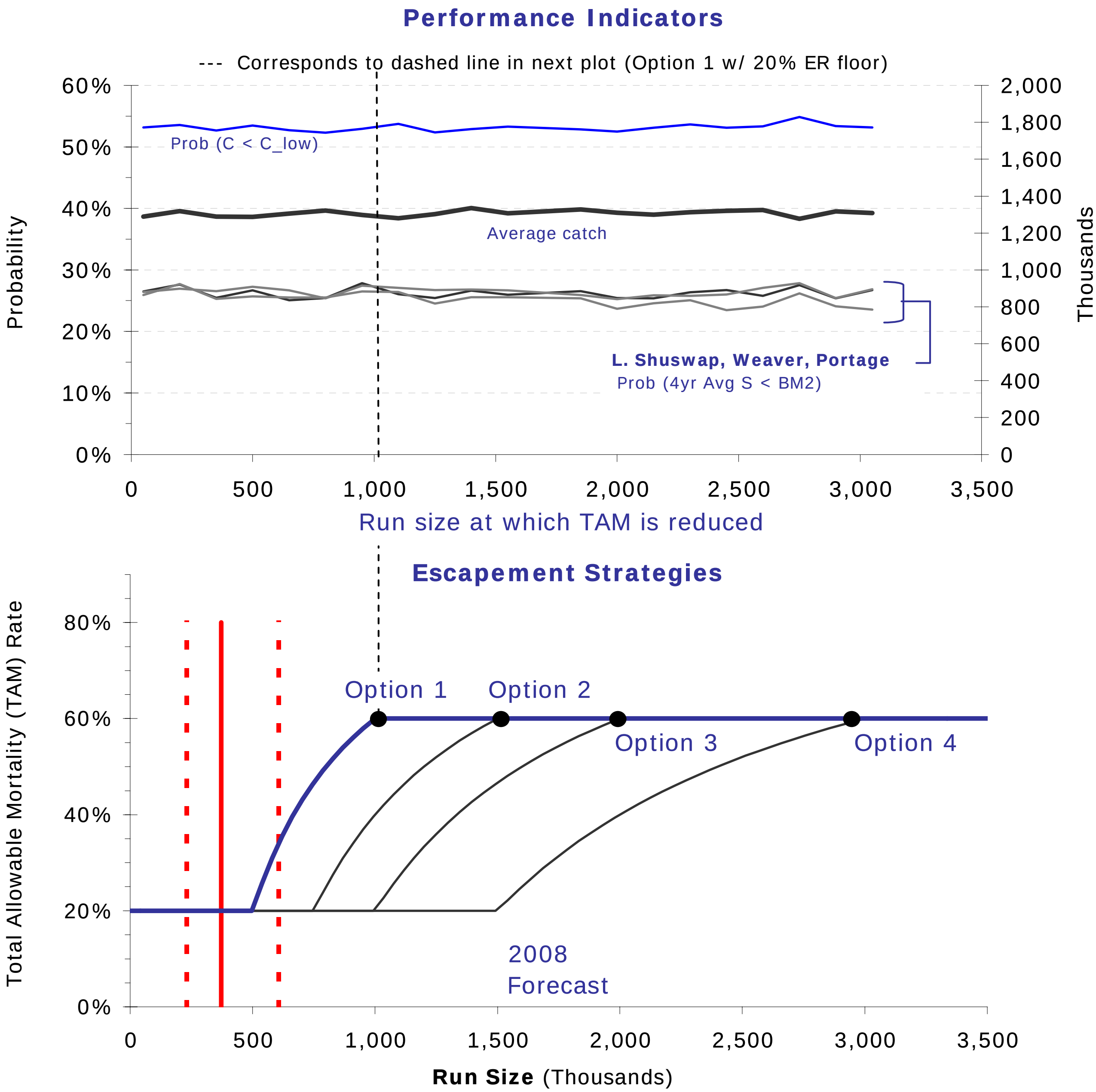

Figure 12: Sample simulation results and options for Late sockeye (using a 20% ER floor)

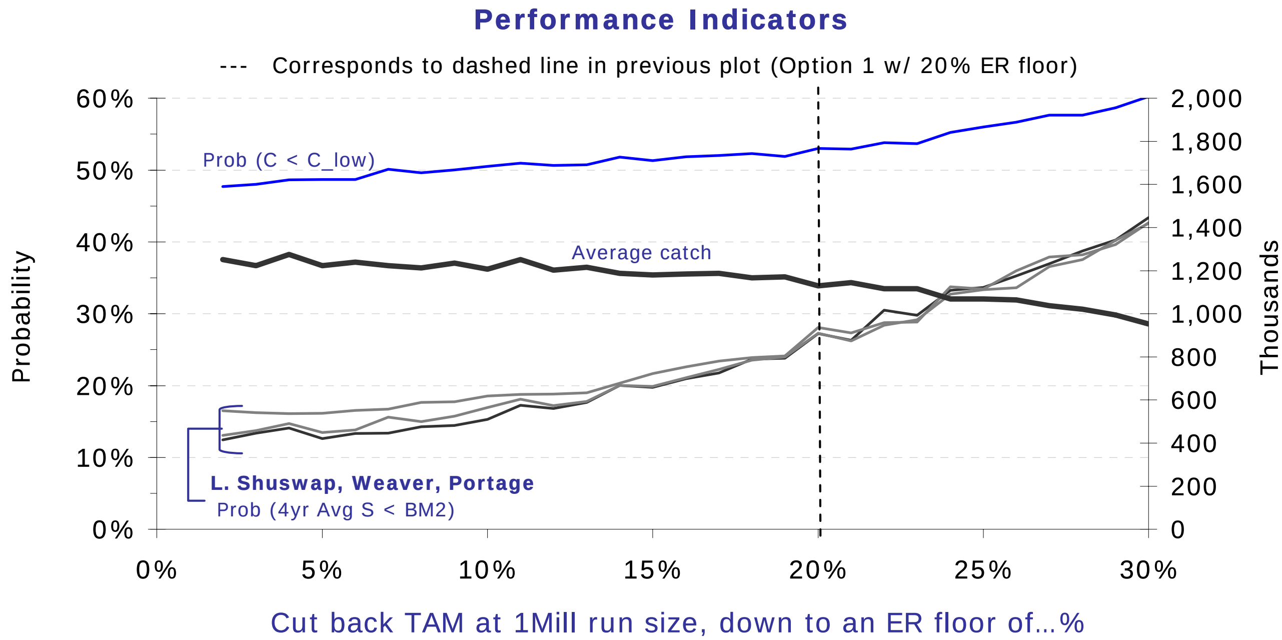

Figure 13: Effect of changing ER floor for a given Late run TAM rule (Option 1)

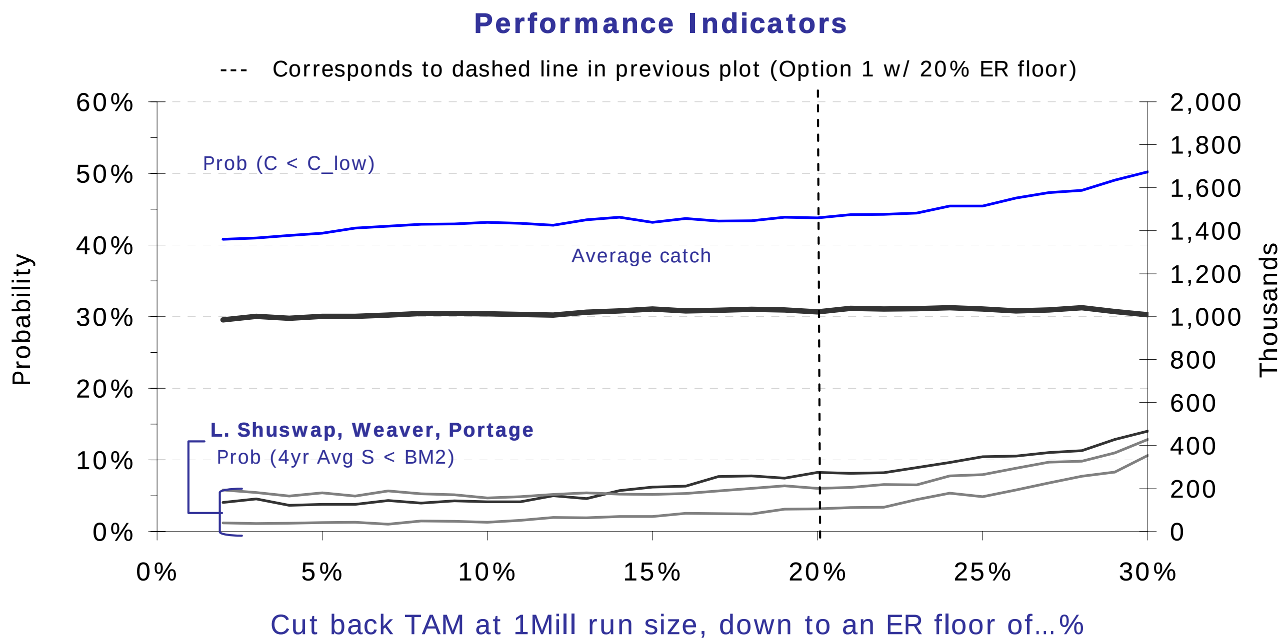

Figure 14: Effect of changing ER floor for a given TAM rule (Option 1) with alternative assumption about plausible range of future outcomes.

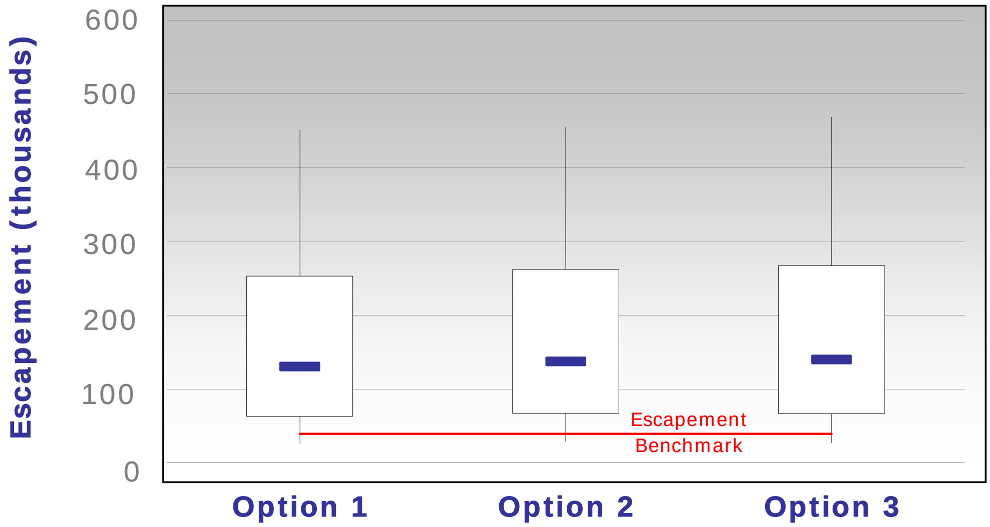

Figure 15: Response of Birkenhead escapement to alternative Summer run strategies

TABLES

Table 1: Summary of escapement, capacity, and planning benchmarks for 19 Fraser sockeye stocks

Production benchmarks were calculated as a proportion of the spawner abundance that maximizes recruitment estimated with median Larkin parameters (20% or 40%, adults or log of adults). Performance evaluations take into account annual escapement and 4-year average escapement relative to the two alternative values for the low escapement benchmark (i.e. BM1, BM2).

	Escapement Summary (up to 2004)					Production BM Range for 4 alternative definitions		Potential Conservation Reference Point	2007 Low Escapement BM Lowest and highest of Production BM and Conservation RP	
Stock	**Smallest**	**75p**	**Median**	**25p**	**Largest**	**Min**	**Max**	Smallest observed 4yr average	**BM 1**	**BM2**
E. Stuart	1,500	21,000	39,500	122,900	688,000	24,100	50,300	10,200	10,200	50,300
Bowron	800	3,100	6,800	13,300	35,000	2,500	4,900	3,000	2,500	4,900
Fennell	<100	1,400	5,700	9,100	32,300	1,100	2,200	500	500	2,200
Gates	<100	2,000	4,700	8,400	86,300	1,100	3,500	1,500	1,100	3,500
Nadina	1,000	2,400	5,900	14,300	173,800	2,000	5,700	5,800	2,000	5,800
Pitt	3,600	12,700	18,000	36,500	131,500	3,400	6,800	11,200	3,400	11,200
Raft	500	2,600	6,100	8,700	66,300	2,500	5,200	2,600	2,500	5,200
Scotch	100	2,200	4,600	14,800	101,300	900	4,000	2,200	900	4,000
Seymour	1,300	5,700	13,400	44,600	272,000	9,500	19,000	9,100	9,100	19,000
total	7,300	32,100	65,200	149,700	898,500	23,000	51,300	35,900	22,000	55,800
Chilko	17,300	109,600	239,900	544,400	1,037,700	66,400	132,900	164,500	66,400	164,500
Late Stuart	<100	5,700	21,600	157,100	1,363,800	39,100	78,300	29,500	29,500	78,300
Quesnel	<100	300	8,500	263,000	3,062,200	41,100	154,500	7,800	7,800	154,500
Stellako	15,800	42,100	79,300	138,000	371,600	22,700	45,400	37,000	22,700	45,400
total	33,100	157,700	349,300	1,102,500	5,835,300	169,300	411,100	238,800	126,400	442,700
Birkenhead	11,900	30,700	48,900	78,600	335,600	19,700	39,300	23,200	19,700	39,300
Cultus	100	1,900	10,300	17,600	47,800	3,700	7,300	1,900	1,900	7,300
Harrison	300	3,800	8,200	17,100	45,600	2,000	4,100	3,600	2,000	4,100
Portage	<100	1,100	3,600	8,200	31,300	100	1,200	1,300	100	1,300
Weaver	3,200	16,700	34,700	45,400	267,300	8,600	17,800	14,500	8,600	17,800
L. Shuswap	600	3,600	12,800	1,133,400	5,216,800	111,100	222,100	320,500	111,100	320,500
total	4,200	27,100	69,600	1,221,700	5,608,800	125,500	252,500	341,800	123,700	351,000

25% of escapements were smaller than this number

Table 2: Draft 2008 Fraser River sockeye escapement plan (In 1000s of fish; at mid-point of forecast range)

Stock Group	Run Size Estimate of forecasted stocks	Run Size Reference Points		Total Mortality Rate Guidelines	Total Allowable Mortality at Run Size	Escapement Target at Run Size	Management Adjustment (a)		Exploitation Rate after MA	Cycle year adult escapement estimates 1988	1992	1996	2000	2004
Early Stuart	35	-	108	0%	0%	35	69%	24	0%	180	66	88	90	9
		108	270	0 - 60%										
		270		60%										
Early Summer		-	145	0%						218	102	363	574	157
	349	145	364	0 - 60%	58%	145	41%	59	41%					
		364		60%										
Summer		-	520	0%						745	635	1,412	1,650	272
		520	1,300	0 - 60%										
	1,810	1,300		60%	60%	724	5%	36	58%					
				0%						167	186	56	14	38
Birkenhead and Birkenhead-type Lates (b)				0 - 60%										
	331			60%	60%	132			60%					
true-Late	374	-	503	20%	20%	299			20%	61	80	143	25	54
(excl. Birk. Type)		503	1,005	20 - 60%										
		1,005		60%										
Cultus	5								20%	1	1	2	1	0
Sockeye Totals	2,899 *Est. Return*					1,336		120		1,371	1,070	2,064	2,354	529

a) Management adjustments (MAs) are added to the escapement targets to correct for the actual differences between Mission and upstream abundance estimates over all years. This approach makes no prior assumption about environmental conditions because we don't yet know whether conditions will be favourable or unfavourable in 2008. We expect that the MAs will be revised to take into account an environmental conditions during the inseason management period.

b) Birkenhead type Lates include returns in the miscellaneous non-Shuswap component of the forecast returning to natal spawning areas in the Harrison-Lillooet systems (excluding Harrison and Weaver).

APPENDICES

Appendix 1: Workshop to assess cyclic population dynamics

A science workshop was held at UBC Feb 7-8, 2006, to review hypotheses, models and management implications for cyclic populations of Fraser River sockeye. This section summarizes the workshop discussions. Complete proceedings are available at www.dfo-mpo.gc.ca/csas/Csas/Proceedings/2006/PRO2006_004_E.pdf.

The workshop was hosted by DFO as part of the Fraser River Sockeye Spawning Initiative and pilot Fraser sockeye WSP implementation project. About 25 experts from BC and Alaska attended the meeting. The workshop was successful in that there was consensus among participants on this long-standing issue on the following points:

Some stocks clearly display a pronounced 4-year cycle in population abundance. There is evidence based on recent ecological modeling that delayed-density interactions are a biological reality. Although the precise mechanisms are not known, high densities of juvenile sockeye appear capable of over-cropping zooplankton in rearing lakes. The evidence shows that the effect can carry-over into succeeding years resulting in reduced juvenile body growth in low abundance years and increased vulnerability to size-mediated predation of sockeye by in-lake predators.

There is high uncertainty in the degree of delayed-density interaction. Some lakes have shown a 2-year (high-low) periodicity with high interaction between two adjacent years (i.e. Chilko and Nadina sockeye). Other lake systems, especially the "big-three" - Shuswap, Quesnel and Stuart lake populations -show a 4-year pattern (dominant-subdominant-low-low) with carry-over into the third and fourth year following the dominant cycle.

High fishing pressure is a prerequisite of population cycles. Reduced exploitation rates have resulted in the break-down of cycles in some lakes (i.e. Quesnel Lake, Bowron Lake and cyclic Bristol Bay sockeye). One explanation for recovery of low abundance years is the filling in of low-cycles by age-5 recruits from preceding dominant brood lines when fishing is relaxed.

Statistical models (Larkin multiple regression model) are the best models for assessing the delayed-density effects compared to ecological models that incorporate fish growth and predation terms given the uncertainty in the data.

A particular important conclusion for the resource management of Fraser sockeye is that the maintenance of cycles is not necessary and is difficult to implement in mixed-stock fisheries. Cycles will persist under high exploitation (i.e. Adams) and break-down when fishing pressure is reduced (i.e. Quesnel).

Participants agreed that a fixed-exploitation policy is superior over a wide range of populations, objectives and conditions compared to a fixed escapement policy. It is robust to uncertainty about whether population dynamics are cyclic or non-cyclic and to uncertainty in habitat capacity estimates. There is, however, a need to develop a contingency plan at low abundances to reduce exploitation rates and avoid conservation risks.

Meeting participants concluded that a fixed escapement policy is only superior in very limited management situations. It is only "optimal" for single-stock management where habitat capacity estimates are well known, the population size is known at the time of harvest and implementation error is small.

Given the strong evidence for delayed-density ecological processes in sockeye rearing lakes, meeting participants endorsed the need for research and monitoring programs to better understand the ecosystem of freshwater rearing systems.

Specifically for the Spawning Initiative Model, the recommendation was to drop the “Cycle-Aggregate” model from consideration, because it treats dominant/subdominant and off cycles as fundamentally different and independent. The Larkin model is more appropriate.

Appendix 2: Simplified sharing rule for Fraser sockeye

This appendix describes a simplified version of the current allocation calculations for Fraser Sockeye. The simplified rule was developed during 2006 planning workshops to calculate socio-economic indicators from simulation output. The simulation model produces trajectories of total catch, and the simplified rule is used to calculate indicators for different sectors (e.g. expected average commercial catch over 12 years). No attempt was made to anticipate potential future changes in allocations, fishing locations, or management practices.

All calculations are for Total Allowable Catch (TAC).

1. Determine **Total Allowable Mortality** based on run size and escapement strategy (Figure 7)

2. Calculate **Target Exploitation Rate** based on total allowable mortality – expected en-route mortality

2. Calculate **Target TAC** based on run size * target exploitation rate

3. To get **Realizable TAC**, deduct proportion of Target TAC foregone due to overlap in run timing and other constraints. For 2006 planning, this deduction was 25%. For 2007, deductions were based on the degree of overlap and difference between target exploitation rates for the timing groups.

4. To get **Canadian TAC**, deduct US share calculated as (Realizable TAC – 400,00 Aboriginal Exemption) * 16.5%

5. To get **Economic TAC**, deduct First Nations FSC harvests from Canadian TAC

- Marine = 250,000 (or 25% if Canadian TAC < 1 Million)
- Upper River = 300,000 (or 30% if Canadian TAC < 1 Million)
- Lower River = 450,000 (or 45% if Canadian TAC < 1 Million). If Economic TAC > 0, then 75% of this harvest is for Economic Opportunity, otherwise it is all for FSC.

6. To get **Commercial TAC**, deduct 3.7 % of Economic TAC for FN Economic Opportunity (Lower River) and 5% of Economic TAC for Recreational Share, up to 150,000.

7. Commercial TAC is shared as follows:

- If Commercial TAC < 5 Million, then 48% Area B, 14.5% Area D, 26.5% Area E, 0% Area G, and 11% Area H
- If Commercial TAC > 5 Million, then 43% Area B, 13.5% Area D, 25.5% Area E, 8% Area G, and 10% Area H

Appendix 3: Description of Fraser sockeye fisheries

This appendix includes short descriptions of the fisheries that target Fraser sockeye. Detailed maps of salmon management areas and Commercial Salmon Licence Areas are available at www.pac.dfo-mpo.gc.ca/ops/fm/fishmgmt_e.htm.

West Coast Vancouver Island (WCVI) Troll Fishery

The West Coast Vancouver Island troll fishery (Licence Area G) is geographically the first fishery to intercept Fraser River sockeye salmon in the course of their return migration. A fixed share of the total allowable catch (TAC) for commercial fisheries is allocated to these fisheries identified for these fisheries when the total commercial TAC exceeds 5 Million (see simplified sharing rule in Appendix 2). In the past, the troll fishery has been a significant harvester of Fraser sockeye stocks in years of high sockeye abundance combined with a low northern diversion rate. Major catches of Fraser sockeye in the WCVI troll fishery are taken in late July to mid-August, with the largest catches consistently in the Adams cycle years. The largest troll catch in this area occurred in 1986, with a total harvest of 1.6 million. Areas 20 to 22, on the southern end of Vancouver Island, have been closed for several years to protect coho stocks, and in recent years this fishery has not had a significant harvest of Fraser sockeye.

Johnstone Strait - Sabine Channel Fishery

The Johnstone Strait - Sabine Channel fishery (Statistical Areas 11-16 and 27) has been the major Canadian harvester of Fraser sockeye in the last 15 years, with catches increasing since the late 1970s. In 1993, a record 8.7 million Fraser sockeye were taken. The Sabine Channel fishery has been closed in recent years to protect coho and Sakinaw Lake sockeye.

The Johnstone Strait summer fishery is directed primarily at the dominant Fraser sockeye stocks (and pink stocks in the odd years) approaching the Fraser River via the northern route. Consequently, the catch in this fishery is highly dependent on the diversion rate of these stocks. All three gear types (seine, gillnet and troll) operate in the Johnstone Strait fishery, which encompasses Statistical Areas 11, 12 and 13, and is managed as a unit. These areas typically open simultaneously except when there are specific closures to protect local stocks.

The current fishing pattern for the Johnstone Strait fishery was established between 1978 and 1986, in consultation with harvesters. Management actions are designed to reduce the incidental catch of non-target stocks and species, and include reduction of fishing times, area closures, fishing gear restrictions and, in some cases, non-retention. Since fishing in Johnstone Strait is dominated by net gear, troll management actions have historically been dictated by concerns for meeting allocation targets between the competing commercial gear of purse seine, gill net and troll. Consequently, trolling in Johnstone Strait may depend on catch ceilings or allocations within the troll group. Since 1998, fishing time and catches have been drastically reduced due to conservation of species of concern coupled with relatively poor Fraser River sockeye production.

The Sabine Channel gill net and seine fishery is located in the Strait of Georgia between Texada and Lasqueti Islands (Area 16). The fishery has historically targeted surplus Fraser sockeye and pink salmon prior to their entering the Fraser River. The management goal for the Sabine Channel fishery is to increase the interception of Fraser River stocks without increasing the incidental harvest of other stocks migrating through Johnstone Strait. The fishery is currently managed simultaneously with the Johnstone Strait fishery and consists largely of seine catches. Fishing times are generally limited to less than three days a week, and are more commonly between 12 hours and one day a week. In recent years no fisheries have been permitted, due to conservation concerns for coho stocks and Sakinaw Lake sockeye.

Juan de Fuca Strait Fishery

The Juan de Fuca Strait net fishery operates in a portion of Statistical Area 20 (Area 20 east of Sheringham Point, as well as Area 19, are closed to commercial salmon fishing). The Juan de Fuca Strait fishery is directed at Fraser sockeye and pink stocks approaching the river via the southern route. Historically, both seines and gillnets are used, with seines taking the majority of the catch. Catches of Fraser River sockeye in this fishery have fluctuated considerably over the years, with a maximum of 3.4 million fish recorded in 1989 and 1990.

Management of the Juan de Fuca fishery requires close coordination with the U.S. net and Fraser River fisheries, a task that falls to the Fraser Panel of the Pacific Salmon Commission. The Juan de Fuca fishery is highly efficient, and openings and closures are carefully conducted to ensure that enough sockeye are available for the U.S. and Fraser River fisheries and that the international allocation commitment, as set by the Treaty, is fulfilled. Although the incidental harvest of non-target stocks is unavoidable, management actions are taken to reduce by-catch. These actions include adjusting the number and timing of vessels, relocating the fleet to avoid chinook and coho encounters, closing fisheries inside a 30 fathom shoreline contour to reduce catch of juveniles and non-salmonids, brailing and regulating seine net bunt sizes to conserve juvenile salmon. Since 1998 gill net openings have not occurred and purse seine openings have been reduced in order to ensure impacts on Upper Fraser coho stay within conservation limits.

Strait of Georgia and Fraser River Fisheries

The Strait of Georgia fishery includes Areas 17-18 and Area 29 (including the tidal waters of the Fraser River). This fishery is directed at Fraser River sockeye and odd-year pink stocks, and is primarily a gill net fishery, with occasional troll and seine fisheries. The inside troll fishery in the Strait of Georgia historically targeted chinook and coho salmon, and was not a major harvester of sockeye or pink salmon.

The gillnet fishery fished in the area since the mid-1860s, with the establishment of the first canneries. Total commercial catches of Fraser River sockeye in the Strait of Georgia fishery averaged fewer than one million during the 1960s and 1970s, but reached a record high of 3.4 million fish in 1990.

The Fraser River fishery harvests salmon that migrate from both the northern and southern approach routes. It is managed by the Fraser Panel of the Pacific Salmon Commission in conjunction with the Juan de Fuca and the U.S. net fisheries. DFO also ensures there is a coordinated approach with Fraser River First Nation fisheries. Early-run sockeye are harvested primarily by gill nets from the mouth of the river to Mission, 80 km upstream. Late-run stocks are harvested either in the River or off the mouth of the River in shallow areas of the estuary.

Although the Fraser River fishery is directed mainly at large, productive sockeye and pink stocks, interception of minor sockeye stocks, chinook, chum, coho and steelhead also occurs. Management actions for this fishery have aimed primarily at reducing interceptions of declining coho salmon and steelhead. Changes in management include reduction in total fishing days, elimination of openings when these species are present, and restrictions on net size and hang ratio.

First Nations Fisheries

Fraser River sockeye are of paramount importance to First Nations in the Fraser River watershed and in marine areas, and support the largest native fisheries on the South Coast. Catches are taken throughout the Fraser watershed as well as outside areas, primarily Johnstone Strait. Annual in-river sockeye catches have increased substantially since the mid-1970s, with the average estimated catch at 633,000 fish between 1999 and 2002. First Nations catch in the Fraser River recorded in 1997 was 1,075,000 sockeye. The Fraser River sockeye catch for First Nations food fisheries outside the Fraser River occurs primarily in Johnstone Strait, Juan de Fuca and off the mouth of the Fraser River. This fishery has been relatively low in harvest amounts historically but has been increasing in recent years. In 2002, the catch outside the Fraser reached 264,000.

Gear and fishing methods vary greatly throughout the areas. Fisheries in marine areas mainly use gill net and purse seine. In the lower Fraser River below Hell’s Gate salmon are harvested using either drift or set gill nets. Further upstream, dip nets, set nets, weirs and gaff are used. In recent years, fish wheels have also been used in a number of areas along the Fraser River in an attempt to harvest sockeye, but mainly for collaborative assessment projects.

Food, social, and ceremonial requirements of First Nations, and treaty obligations to First Nations, have first priority in salmon allocation after conservation needs are met. Since 1992 the lower Fraser River First Nations have had the opportunity to sell a portion of their catch.

Recreational Fishery

The recreational fishery on Fraser sockeye has been minor, representing less than 1% of the total catch. Historically, the majority of the marine sport catch has been taken in the southern portion of the Strait of Georgia, with minor catches in the Johnstone and Juan de Fuca Straits. However, in very recent years, sport fisheries for sockeye have grown significantly in the non-tidal portion of the lower Fraser River, reaching a catch of 128,000 sockeye in 2002.

U.S. Fisheries

There are three U.S. fisheries on passing Fraser sockeye and pink salmon in Washington State waters in the Fraser Panel Area: on the U.S. side of Juan de Fuca Strait, on Salmon Banks (San Juan Islands), and off Point Roberts. These fisheries use gill nets, seines, and reef nets, but not troll gear.

Interception of Fraser River sockeye has also been identified in Alaskan District 104 fisheries, reaching catches up to 270,000 fish in 1990. Between 1999 and 2002, U.S. catches of Fraser sockeye averaged 309,000 in the Panel Area and 17,000 in Alaskan waters.

U.S. fisheries in Washington State waters are managed by the Fraser Panel of the PSC, in conjunction with Area 20 and the commercial fisheries in the Gulf of Georgia and Fraser River. The overall success of the United States fisheries is greatly affected by the amount of fish that migrate via the southern Juan de Fuca route versus the northern Johnstone Strait route. In years of high water temperature a greater number of the returning sockeye migrate through Johnstone Strait in comparison to Juan de Fuca. This requires increased fishing time in United States waters in order for their fishermen to meet their agreed upon Treaty share. Management objectives for the U.S. fisheries include meeting escapement requirements, securing the U.S. share of the Fraser River sockeye and pink catch as specified in the Pacific Salmon Treaty, and domestic catch allocations. The three U.S. fisheries are briefly described below.

The U.S. Juan de Fuca fishery harvests only modest numbers of sockeye as a result of most fish migrating along the Canadian side of the Strait. The Salmon Banks fishery is diffuse, with no set fishing pattern as migration routes of these sockeye tend to vary. However, catches are substantially greater than in the Juan de Fuca fishery because a higher abundance of Fraser sockeye migrate through the area in comparison to the Juan de Fuca fishery area. The Point Roberts fishing area receives limited numbers of migrating sockeye, mainly due to these stocks already being harvested in the Salmon Banks fishery. The fleet directs its initial effort on fish migrating throughout the Point Roberts area (Area 7A). Later in the season the fleet then moves to form a line along the Canadian border in order to target on sockeye holding off the mouth of the Fraser River. In some instances, the area off the west side of Point Roberts is closed in order to protect delaying fish which may move back and forth across the International Boundary.

Appendix 4: Principles of participation

The following principles of participation are offered as a guide to deliberations. They will be reviewed at the beginning of Workshop 1 and modified if the meeting directs.

Intent of the Workshops

1. To share experience and learn from dialogue among participants;

2. To understand and respect the diversity of perspectives brought to the table;

3. To build working relationships; and

4. To identify areas of common ground, of differences and the various underlying reasons.

Participation

Participants in the discussion have been selected to reflect a range of values, interests, and experience and to share these with other participants and DFO. They are invited in their personal capacity and not as representative of any organization or interest. There is no expectation that participants will report back to or seek approval from any organization of interest. Further, participation is not to be seen as an endorsement by any participant of DFO decision-making or any specific outcome.

Report

A summary report of the meeting will be prepared and distributed to participants for review before being finalized. The report will include a list of participants as well as these Principles of Participation.

No specific attribution of any comment made by any participant will be referenced in the report of the meeting, unless specifically requested by a participant.

Provided by Tony Hodge, Anthony Hodge Consultants Inc, Victoria BC

Modified from Glenn Sigurdson, CSE Group, SFU Centre for Dialogue, Vancouver BC

Appendix 5: Jargon used in stock assessment

Estimates of total abundance, catch, exploitation rate and spawner abundance are derived from information gathered by DFO and the Pacific Salmon Commission (PSC).

Total abundance is the sum of all fish caught in fisheries plus those arriving at the spawning grounds, including in some instances fish thought to have died along the migratory route in the Fraser River (en-route loss). The PSC provides in-season estimates of total abundance for each sockeye stock aggregate based on several methods that include catch per unit effort data from test fisheries, abundance estimates from a hydro-acoustic counting facility at Mission, and stock identification data to determine which stocks the catches came from. These in-season estimates of total abundance are used for planning sockeye fisheries but are generally not used to produce the final estimate of total abundance for each stock, unless data on spawner abundance or catches is insufficient to derive an estimate of abundance after the fishing season is over. However, in-season estimates of total abundance are sometimes used to estimate en-route losses in some stocks (e.g. unreported harvest or mortality that occurs between the lower Fraser River near Mission and terminal spawning areas). En-route losses are calculated as the difference between the gross escapement at Mission minus the upstream catches and abundance of spawners in spawning areas. En-route losses are added to catches and spawner abundance to determine total run size in situations where poor environmental conditions such as high flows or water temperatures indicate substantial mortalities.

Catch of each stock is determined based on samples collected from fisheries. Catches of Fraser River sockeye are monitored by the countries and reported to PSC staff. PSC staff then use unique scale characteristics or DNA stock identification methods to determine how much each individual stock contributed to the catch.

Spawner abundance is estimated directly in terminal areas for each stock. Spawner abundance is estimated by DFO using a two-tiered system where the method selected for a particular stock is based on its forecast return for any given year. For stocks with small expected returns (less than 75,000), a variety of stock-specific estimation methods are used, including visual surveys. For stocks with larger expected returns (more than 75,000), abundance is estimated using enumeration fences and mark-recapture studies. Not all spawning populations within a stock are surveyed annually.

Exploitation Rate (ER) is the proportion of each stock caught in all fisheries and is calculated by dividing the catch by the total abundance. More specifically, the exploitation rate is calculated as

$$ER = \frac{Catch}{Abundance} = \frac{Catch}{Catch + Mortality + Escapement}$$

Total Mortality Rate (TM) is the proportion of adult fish from each stock to fail to return to the spawning grounds, excluding natural levels of predation. Specifically, total mortality rate is calculated as

$$TM = \frac{Catch + Mortality}{Catch + Mortality + Escapement}$$

where Mortality = estimated en-route mortality.

The new escapement strategies specify a target level of total mortality. Fishing plans are developed and adjusted to achieve this Total Allowable Mortality given estimates of expected en-route mortality.

SR models use the number of recruits produced by the spawning population from each brood year. How is this number derived? The PSC uses annual data about total abundance, spawner abundance and age composition data (determined from ring patterns in scales and otoliths) for each stock to determine the number of recruits produced by a parental spawning population. For example, in any given year the total abundance of any individual sockeye stock is composed of age 3, 4 and 5 fish produced by spawners 3, 4 and 5 years earlier. In other words, the total run in any year is composed of recruits from 3 different sets of spawners. However, when we do SR analysis we wish to know the total number of recruits produced by a single year’s spawners (i.e. the brood year). Using age data, PSC staff is able to allocate which fish in the total run came from each brood year. The total recruits for each brood year’s spawning population can then be determined by adding up the age 3, 4 and 5 year old fish.

Appendix 6: Jargon used in performance evaluation

This appendix includes a brief explanation of the jargon used by analysts when discussing the performance of escapement strategies, both in forward-looking simulation and in hindsight after implementation.

The approach for comparing escapement strategies is identical to the steps used by testers of consumer products, such as refrigerators. Testers must understand what consumers expect from the product, identify relevant measures of performance, determine how each product scores for each performance measure, and finally find a meaningful balance among the performance measures to arrive at an overall evaluation.

Step 1: Management objectives

Objectives describe the desired end-results of the management process, but should be clearly defined up-front.

The first question faced by product testers is: "What matters to people when they choose a refrigerator?" The most fundamental *objective* is that the fridge needs to keep food reliably at a safe temperature. Assuming that new fridges sold in Canada meet the required safety standards, the attention of testers can shift to secondary *objectives* such size and affordability.

Managing Fraser River sockeye is a lot more complex than buying a fridge, and needs to incorporate a wide range of biological, social, and economic considerations. The current policy context for the management of Fraser River sockeye is summarized at: http://www.pac.dfo-mpo.gc.ca/species/salmon/policies/default_e.htm

The *Spawning Initiative* picked out one element of the annual management process, the development of a long-term strategy for setting annual escapement targets, and focused on the balance between two fundamental objectives:

(1) ensuring escapement and production for individual stocks, and

(2) accessing the catch-related benefits from productive stock groups.

An important part of the planning process is to translate these fundamental objectives into performance measures that can be used to compare simulation scenarios.

Step 2: Performance Measures (a.k.a. indicators)

Performance measures are clear numerical descriptions that reflect the general intent of management objectives, can be consistently evaluated, and can be easily compared.

Performance measures likely to be considered by people looking at refrigerators include more specific aspects of general objectives such as size and affordability. Some interesting *performance measures* that relate to the size of the fridge include width, height, storage capacity, and required floor space. The general objective of affordability can be similarly captured by a suite of *performance measures* including retail price, warranty coverage, average energy use over 1 year (kWh/yr), and estimated maintenance costs over ten years.

Performance measures considered in the *Spawning Initiative* reflect more specific aspects of the general biological, social, and economic objectives. Some interesting biological *performance measures* are long-term average escapement, long-term average run size, year-to-year variability in escapement, escapement trend over next 12 years, and the lowest projected escapement over 48 years. Each of these performance measures can be calculated for individual stocks (e.g. Chilko), for the four management groups (e.g. Early Summer), or the total Fraser system.

Participants in a collaborative process tend to identify numerous variations of *performance measures* as potentially interesting, but it is not feasible to thoroughly compare a lot of performance measures across many potential alternatives. The facilitator then faces the challenge of helping participants identify a manageable suite of performance measures that still captures the most important considerations.

Step 3: Benchmarks

Benchmarks are specific levels of a performance measure that establish a meaningful context for a broader audience.

Performance measures are raw numbers, and often only the specialists have a good sense of what those numbers really mean. For a general audience the numbers still need be put into a bigger picture, and benchmarks establish the context that is necessary to grasp the bigger picture.

For example, product testers could pick an energy use of 300 kWh/yr as a benchmark for identifying fridges that are very energy efficient, or specify a storage capacity of 8 cu ft as a benchmark for separating the fridges into “small” and “large”.

Applying the same concept to Fraser sockeye, we need to choose benchmarks to quantify the concepts of “low escapement” and “low catch”. For example, the benchmark for low escapement could be set at 20% of the escapement that maximizes adult recruitment. This type of benchmark is called a relative benchmark, because it is calculated based on the spawner-recruit model, and is therefore relative to assumptions about the stock dynamics. Relative benchmarks are different for each stock, and for different spawner-recruit models. Absolute benchmarks are based on independent considerations. For example, spawner abundance could be considered “low” if it is less than 10,000. Stock-specific benchmarks used in the *Spawning Initiative* are described in Chapter 1.

The distinction between *benchmarks* and *performance measures* can become blurred in practice, when we construct *performance measures* that are calculated relative to a *benchmark* (e.g. probability that 4yr average escapement falls below a stock-specific benchmark).

Note that early draft materials distributed for the Spawning Initiative used the term "management reference points" to describe these benchmarks, which was inconsistent with the technical definition of reference points. Management reference points directly trigger management actions. Thus, changes in variables (e.g. run size) that cross a management reference point cause changes in management actions (e.g. fishery closure). Benchmarks only affect management actions indirectly, by altering the performance evaluation of alternative escapement strategies. For example, the escapement strategy for Summer run sockeye in 2007 specified a management reference point of 1.5 Million, which triggered a switch from a total allowable mortality of 60% to a fixed escapement target of 600,000 spawners. This trigger point was chosen to ensure that individual stocks in the Summer group had a good chance of achieving at least their low escapement benchmark. If a stock-specific benchmark is increased, then the corresponding trigger points also need to be adjusted.

Step 4: Balancing considerations

Whether we are choosing a refrigerator or an escapement strategy for Fraser sockeye, the final decision requires careful weighing of each alternative and its characteristics (i.e. performance relative to benchmarks).

The decision process for the refrigerator purchase might unfold along the following lines: "We need a fridge large enough for a family of 4, but with a height less 170 cm to fit under the built-in cabinetry. Of the fridges in our price range that meet these requirements, we'll get one that is energy efficient and has low expected maintenance costs."

This example illustrates two important points, which are equally applicable to more complex decision processes, such as developing escapement strategies for Fraser sockeye:

For each step in the deduction there is a corresponding performance measure (e.g. height) and a clear benchmark (e.g. 170 cm).

The final decision is based on a combination of hard constraints (e.g. must be less than 170 cm high) and trade-offs, such as the balance between certain and uncertain considerations (e.g. retail price vs. expected maintenance costs), and the balance between short-term costs and long-term benefits (e.g. higher retail price vs. better energy efficiency).

Individual customers will each bring their own set of priorities, focus on different performance measures, and pick their own benchmarks. However, product testers can try to anticipate the most typical suite of performance measures, set some broadly applicable benchmarks, and summarize each of the tested products in a simple summary rating (e.g. 1-5 stars)

The decision process for choosing escapement strategies is conceptually the same. Once a comprehensive suite of performance measures was identified, the emphasis shifted to filtering out any alternative strategies that were theoretically possible but clearly unreasonable. There are two approaches for eliminating unreasonable alternatives:

- *Optimization:* Filters many possible alternatives based on a few simple criteria.
- *Structured Comparison:* Compares a few candidate alternatives based on large number of criteria. This is how most fisheries models are used, and the comparison can be formalized through structured trade-off exercises.

The Spawning Initiative workshops used both of these approaches in sequence. First the Working Group used optimization techniques to develop a short list of candidate strategies that reflect alternative management priorities. Workshop participants then used facilitated debates and structured trade-off exercises to provide feedback on the alternatives. This approach follows the same logic as first discarding all fridges from consideration that are too small or too high, and then weighing the remaining fridges based on a trade off between retail price and energy efficiency. As for the fridge example, participants considered the balance between different categories of considerations (catch from aggregate vs. sustainability of individual stocks), and the balance between immediate costs and potential long-term benefits (e.g. reductions in realizable harvest in first 8 years of implementation vs. expected increase in average harvest over 48 years).

Appendix 7: Estimating optimal escapement for Fraser sockeye stocks

The productive capacity of Fraser River sockeye stocks is limited in the freshwater environment, either by available spawning habitat or by available lake rearing habitat. Several approaches have been used to estimate productive capacity for individual sockeye stocks, including available spawning area, lake productivity, and numerical estimates of the capacity parameter from population models.

This appendix briefly summarizes three key publications relating to the productive capacity of Fraser sockeye stocks. Each of these analyses differed in scope and methodology from the others, and the results are not easily comparable. One particular challenge is dividing lake-based estimates of capacity into estimates of optimal escapement for different stocks that rear in the same lake (e.g. Early Stuart vs. Late Stuart).

A synthesis of capacity estimates will be integrated into the on-going implementation of the *Wild Salmon Policy.*

Fraser River Action Plan – Fraser River Sockeye (1995)

This DFO report includes two appendices with capacity estimates:

- Estimated spawning ground capacity for 19 Fraser sockeye stocks, based on usable spawning area and optimum spawning densities in 4 bio-geoclimatic zones.
- Estimated sockeye rearing capacity in 18 lake systems of the Fraser River watershed, based on two separate analyses: the relationship between fry survival and rearing conditions, and the relationship between adult production and photosynthetic rate of the lakes. Photosynthetic rate measures the amount of CO_2 consumed in a given volume of lake over a given amount of time, which serves as a proxy for the amount of algae in the water, which in turn indicates how much food is available at the very bottom of the food web.

Note: The estimates in this DFO report were developed for management purposes at the time, and were not scientifically peer-reviewed.

Using Photosynthetic Rates to Estimate the Juvenile Sockeye Salmon Rearing Capacity of British Columbia Lakes (2000)

The methods for developing capacity estimates based on the photosynthetic rate (PR) of rearing lakes were refined over several years, and are documented in a series of peer-reviewed publications. The most recent refinement of the approach, published in 2000, lists estimates for all BC sockeye nursery lakes where PR data are available, including 5 large lake systems in the Fraser watershed.

Shortreed KS, Hume JMB, and JG Stockner (2000) *Using Photosynthetic Rates to Estimate the Juvenile Sockeye Salmon Rearing Capacity of British Columbia Lakes.* Pages 505-521 in Knudsen EE, Steward CR, Macdonald DD, Williams JE, and DW Reiser, editors. *Sustainable Fisheries Management: Pacific Salmon*, CRC Press, Lewis Publishers, Boca Raton, Florida.

Accounting for Uncertainty in Estimates of Escapement Goals for Fraser River Sockeye Salmon based on Productivity of Nursery Lakes in British Columbia, Canada.

This most recent analysis of capacity and optimal escapement for Fraser sockeye stocks used a Bayesian approach to formally track uncertainty from input data to capacity estimates and combine information from three different sources:

- Photosynthetic rate models
- Spawner - Juvenile models
- Spawner - Recruit models

The paper includes estimates of escapement that maximizes adult recruitment for 6 lake systems in the Fraser watershed, and for two stocks in the Stuart system (early versus late).

Bodtker KM, Peterman RM, and MJ Bradford (2007) Accounting for Uncertainty in Estimates of Escapement Goals for Fraser River Sockeye Salmon based on Productivity of Nursery Lakes in British Columbia, Canada. North American Journal of Fisheries Management 27:286-302.

Appendix 8: Pull-out summary of spawner and recruit data for Fraser sockeye

FRASER SOCKEYE PLANNING WORKSHOPS - DATA REFERENCE

Note: These are the time series used in the FRSSI model. Data provided by Al Cass (DFO - Nanaimo)

To provide comments or corrections, please contact **Gottfried Pestal** (gpestal@solv.ca)

	Early Stuart			Early Summer			
Year	Spawners	Recruits	R/S	Spawners	Recruits	R/S	
1948	19,979	198,153	9.9	94,833	266,323	2.8	
1949	582,228	1,030,708	1.8	48,458	121,708	2.5	
1950	59,104	241,087	4.1	73,660	266,812	3.6	
1951	60,423	173,645	2.9	92,432	271,390	2.9	1951-1960
1952	29,925	88,572	3.0	89,124	166,315	1.9	
1953	154,036	540,597	3.5	45,546	132,760	2.9	
1954	35,050	155,482	4.4	62,901	167,573	2.7	
1955	2,159	27,456	12.7	41,350	321,279	7.8	
1956	25,020	107,428	4.3	50,615	129,965	2.6	
1957	234,850	1,219,035	5.2	42,076	90,927	2.2	
1958	38,807	102,352	2.6	113,809	57,350	0.5	
1959	2,670	20,835	7.8	107,498	147,170	1.4	
1960	14,447	74,127	5.1	40,544	67,741	1.7	
1961	198,921	254,331	1.3	29,522	153,202	5.2	1961-1970
1962	26,716	73,653	2.8	88,315	118,634	1.3	
1963	4,607	92,222	20.0	118,158	366,311	3.1	
1964	2,390	38,889	16.3	23,178	266,618	11.5	
1965	23,045	416,779	18.1	22,338	77,336	3.5	
1966	10,830	83,040	7.7	58,254	121,372	2.1	
1967	21,044	339,270	16.1	57,533	298,061	5.2	
1968	1,522	10,412	6.8	40,946	349,125	8.5	
1969	109,655	1,370,633	12.5	42,279	96,888	2.3	
1970	32,578	179,544	5.5	24,443	80,098	3.3	
1971	95,940	430,503	4.5	62,414	375,325	6.0	1971-1980
1972	4,657	32,207	6.9	38,410	354,420	9.2	
1973	299,892	1,346,407	4.5	35,558	136,721	3.8	
1974	39,518	143,156	3.6	72,946	187,508	2.6	
1975	65,752	223,826	3.4	125,183	639,150	5.1	
1976	11,761	31,834	2.7	72,345	231,069	3.2	
1977	117,445	761,122	6.5	34,882	216,147	6.2	
1978	50,004	72,650	1.5	95,176	128,278	1.3	
1979	92,746	107,696	1.2	179,290	202,736	1.1	
1980	16,939	63,491	3.7	61,058	250,404	4.1	
1981	129,457	350,095	2.7	74,321	182,538	2.5	1981-1990
1982	4,557	27,803	6.1	84,592	160,565	1.9	
1983	23,867	187,709	7.9	83,032	321,351	3.9	
1984	45,201	239,403	5.3	94,701	383,637	4.1	
1985	234,219	1,205,936	5.1	35,589	293,622	8.3	
1986	28,584	145,883	5.1	197,678	397,312	2.0	
1987	148,194	525,912	3.5	157,770	372,258	2.4	
1988	179,807	379,236	2.1	151,288	543,673	3.6	
1989	384,799	1,137,707	3.0	52,062	143,843	2.8	
1990	97,035	166,096	1.7	395,524	412,817	1.0	
1991	141,119	143,951	1.0	228,410	203,408	0.9	1991-2000
1992	65,617	100,366	1.5	66,909	520,389	7.8	
1993	687,967	1,813,936	2.6	72,873	359,347	4.9	
1994	29,831	29,024	1.0	154,227	374,988	2.4	
1995	122,856	189,580	1.5	136,316	245,468	1.8	
1996	87,570	462,438	5.3	273,409	1,049,994	3.8	
1997	265,697	145,595	0.5	71,022	176,959	2.5	
1998	32,570	29,478	0.9	174,688	362,820	2.1	
1999	24,532	30,628	1.2	89,567	213,496	2.4	
2000	89,747	132,370	1.5	405,355	597,567	1.5	
2001	170,906			229,936			
2002	24,637			342,034			
2003	13,166			149,304			
2004	9,281			97,733			
2005	98,537			169,427			
2006							

Percentiles	Early Stuart Spawners	Recruits	R/S	Early Summer Spawners	Recruits	R/S
10%	4,637	29,708	1.25	35,577	101,237	1.35
25%	23,045	74,009	2.02	48,458	142,063	2.06
50% Median	**39,518**	**145,739**	**3.69**	**74,321**	**223,608**	**2.71**
75%	117,445	357,380	5.66	136,316	360,215	4.06
90%	213,040	1,100,049	12.04	209,971	411,267	7.61

Note: These are the time series used in the FRSSI model.

Year	**Summer** (excl. Birkenhead) Spawners	Recruits	R/S	**Late** Spawners	Recruits	R/S	
1948	686,485	1,862,366	2.7	49,264	110,689	2.2	
1949	301,383	2,740,709	9.1	20,661	84,819	4.1	
1950	168,570	1,163,574	6.9	1,334,353	9,475,902	7.1	
1951	198,804	1,185,072	6.0	173,349	710,904	4.1	
1952	526,188	1,915,031	3.6	50,944	65,349	1.3	
1953	719,235	2,856,658	4.0	36,095	100,689	2.8	
1954	181,924	1,993,042	11.0	2,080,898	15,215,962	7.3	1951-1960
1955	180,551	2,120,238	11.7	95,417	1,214,762	12.7	
1956	686,335	2,690,398	3.9	19,625	53,365	2.7	
1957	925,063	2,591,080	2.8	27,017	65,381	2.4	
1958	257,837	688,627	2.7	3,329,861	2,157,469	0.6	
1959	550,655	2,648,049	4.8	211,045	463,197	2.2	
1960	468,114	1,140,411	2.4	36,757	28,731	0.8	
1961	780,788	2,185,646	2.8	57,342	27,221	0.5	
1962	221,919	1,615,877	7.3	1,191,209	2,876,604	2.4	
1963	1,140,330	1,856,835	1.6	203,040	3,279,493	16.2	
1964	271,232	2,058,227	7.6	13,882	94,371	6.8	1961-1970
1965	654,220	3,161,515	4.8	37,064	263,759	7.1	
1966	321,928	1,212,417	3.8	1,378,000	4,096,577	3.0	
1967	267,943	2,524,998	9.4	924,018	3,337,967	3.6	
1968	445,318	2,518,572	5.7	37,656	220,869	5.9	
1969	578,152	3,896,037	6.7	79,236	478,805	6.0	
1970	197,531	952,218	4.8	1,563,410	5,875,821	3.8	
1971	187,387	1,146,293	6.1	307,109	909,369	3.0	
1972	604,901	2,671,148	4.4	37,625	430,088	11.4	
1973	563,264	3,122,235	5.5	49,621	420,114	8.5	
1974	169,487	1,013,970	6.0	1,222,845	7,194,960	5.9	1971-1980
1975	390,006	3,359,175	8.6	215,240	1,337,635	6.2	
1976	515,437	1,845,972	3.6	54,446	322,465	5.9	
1977	693,445	5,680,395	8.2	62,535	374,453	6.0	
1978	223,562	1,915,500	8.6	1,981,989	10,340,277	5.2	
1979	557,395	2,163,603	3.9	415,898	1,801,826	4.3	
1980	541,082	4,749,382	8.8	67,758	400,433	5.9	
1981	1,033,371	11,570,971	11.2	53,128	299,723	5.6	
1982	360,227	2,388,320	6.6	3,336,987	10,746,226	3.2	
1983	455,275	2,640,336	5.8	276,032	2,346,407	8.5	
1984	515,647	1,358,836	2.6	47,575	720,633	15.1	1981-1990
1985	1,632,448	15,735,710	9.6	37,301	109,330	2.9	
1986	563,241	8,539,846	15.2	2,378,530	10,579,346	4.4	
1987	477,641	5,340,665	11.2	706,494	4,284,344	6.1	
1988	635,989	4,362,598	6.9	46,884	548,918	11.7	
1989	2,409,006	18,395,899	7.6	24,468	994,002	40.6	
1990	1,580,333	7,115,937	4.5	3,656,341	8,181,247	2.2	
1991	1,255,740	1,918,107	1.5	1,328,386	963,198	0.7	
1992	634,621	2,885,065	4.5	57,969	787,772	13.6	
1993	4,431,333	14,802,545	3.3	77,356	664,653	8.6	
1994	1,280,367	4,502,689	3.5	1,418,308	3,373,840	2.4	
1995	917,131	1,704,023	1.9	478,212	1,130,965	2.4	1991-2000
1996	1,411,681	3,260,889	2.3	111,174	514,475	4.6	
1997	3,455,648	5,226,367	1.5	27,519	355,723	12.9	
1998	2,286,630	6,081,965	2.7	1,417,471	7,541,890	5.3	
1999	1,277,676	2,611,575	2.0	394,110	1,056,633	2.7	
2000	1,647,641	1,945,695	1.2	11,811	111,993	9.5	
2001	4,041,280			37,227			
2002	3,802,124			5,365,170			
2003	993,179			426,170			
2004	270,384			21,488			
2005	2,454,632			512,807			
2006							
Percentiles 10%	198,295	1,167,874	2.10	25,997	86,729	2.20	
25%	321,928	1,900,482	3.21	37,633	316,780	2.77	
50% Median	**563,264**	**2,558,039**	**4.81**	**103,296**	**754,203**	**5.27**	
75%	1,140,330	4,012,677	7.36	869,637	2,977,326	7.17	
90%	2,335,580	7,012,540	9.62	2,011,662	7,507,197	12.63	

Note: These are the time series used in the FRSSI model.

Early Summer Components

Year	Bowron Spawners	Bowron Recruits	Bowron R/S	Fennell Spawners	Fennell Recruits	Fennell R/S	
1948	25,205	80,266	3.2				
1949	22,283	62,746	2.8				
1950	16,146	74,998	4.6				
1951	21,731	103,443	4.8				1951-1960
1952	18,645	43,296	2.3				
1953	13,277	75,576	5.7				
1954	10,515	66,264	6.3				
1955	9,350	96,912	10.4				
1956	6,994	37,746	5.4				
1957	12,011	41,966	3.5				
1958	14,843	18,112	1.2				
1959	29,247	61,854	2.1				
1960	7,620	17,729	2.3				
1961	7,449	28,148	3.8				1961-1970
1962	6,286	21,321	3.4				
1963	25,141	214,288	8.5				
1964	1,500	27,507	18.3				
1965	2,659	17,799	6.7				
1966	2,470	22,249	9.0				
1967	31,695	206,370	6.5	916	15,201	16.6	
1968	3,611	43,543	12.1	954	15,015	15.7	
1969	3,872	17,211	4.4	52	881	16.9	
1970	1,305	15,826	12.1	9	740	82.2	
1971	25,497	124,507	4.9	1,293	16,226	12.5	1971-1980
1972	4,138	16,971	4.1	1,931	28,398	14.7	
1973	4,558	10,662	2.3	205	1,106	5.4	
1974	1,850	19,160	10.4	140	536	3.8	
1975	29,700	170,075	5.7	4,005	70,646	17.6	
1976	2,250	7,112	3.2	4,090	21,358	5.2	
1977	2,500	15,396	6.2	355	9,130	25.7	
1978	3,141	40,627	12.9	107	2,230	20.8	
1979	35,000	29,984	0.9	15,565	14,229	0.9	
1980	2,894	45,170	15.6	8,437	35,970	4.3	
1981	1,170	16,532	14.1	2,076	3,947	1.9	1981-1990
1982	1,647	5,277	3.2	1,132	10,828	9.6	
1983	6,451	38,132	5.9	4,977	38,250	7.7	
1984	10,461	50,591	4.8	11,021	47,064	4.3	
1985	6,395	19,177	3.0	1,598	31,826	19.9	
1986	3,118	21,198	6.8	6,024	34,206	5.7	
1987	11,071	22,460	2.0	16,633	76,448	4.6	
1988	12,780	13,050	1.0	26,927	48,647	1.8	
1989	2,534	12,842	5.1	3,988	19,454	4.9	
1990	7,860	31,849	4.1	11,862	22,812	1.9	
1991	4,920	50,948	10.4	20,554	11,894	0.6	1991-2000
1992	2,560	12,869	5.0	9,139	48,671	5.3	
1993	1,184	20,467	17.3	7,546	41,439	5.5	
1994	4,380	10,849	2.5	5,919	12,987	2.2	
1995	34,417	27,350	0.8	11,245	36,747	3.3	
1996	8,176	27,297	3.3	32,279	13,312	0.4	
1997	4,811	5,185	1.1	9,000	4,056	0.5	
1998	4,751	15,259	3.2	8,741			
1999	8,238	13,258	1.6	5,697	12,441	2.2	
2000	13,440	25,379	1.9	10,155	55,364	5.5	
2001	5,842			5,721			
2002	8,770			7,198			
2003	6,752			9,087			
2004	836			2,718			
2005	1,730			5,399			
2006							

Percentiles	Bowron Spawners	Bowron Recruits	Bowron R/S	Fennell Spawners	Fennell Recruits	Fennell R/S
10%	1,769	12,847	1.67	186	1,331	1.09
25%	2,894	16,861	2.73	1,446	10,828	2.19
50% Median	**6,395**	**23,920**	**4.70**	**5,548**	**15,714**	**5.27**
75%	11,071	43,358	6.72	9,087	36,359	13.63
90%	25,283	74,645	12.12	15,195	48,659	18.78

Note: These are the time series used in the FRSSI model.

Early Summer Components

Year	Gates Spawners	Gates Recruits	Gates R/S	Nadina Spawners	Nadina Recruits	Nadina R/S	Pitt Spawners	Pitt Recruits	Pitt R/S	
1948							55,380	122,720	2.2	
1949							9,290	19,336	2.1	
1950							40,061	146,275	3.7	
1951							37,837	120,302	3.2	1951-1960
1952							48,899	71,842	1.5	
1953							18,673	25,060	1.3	
1954							17,624	51,052	2.9	
1955							17,950	164,010	9.1	
1956							32,094	66,855	2.1	
1957							12,335	28,018	2.3	
1958							10,381	16,135	1.6	
1959							15,731	61,732	3.9	
1960							24,510	33,248	1.4	
1961							11,158	100,761	9.0	1961-1970
1962							16,580	56,764	3.4	
1963							12,680	142,668	11.3	
1964							13,756	190,600	13.9	
1965							6,966	38,984	5.6	
1966							20,842	75,904	3.6	
1967							10,282	66,869	6.5	
1968	7,466	78,774	10.6				16,988	105,494	6.2	
1969	569	3,724	6.5				25,073	61,083	2.4	
1970	54	154	2.9				6,642	54,555	8.2	
1971	343	7,721	22.5				15,452	215,185	13.9	1971-1980
1972	5,079	128,433	25.3				13,412	122,884	9.2	
1973	608	13,241	21.8	12,874	73,208	5.7	11,895	29,165	2.5	
1974	49	1,413	28.8	3,355	20,017	6.0	20,581	134,067	6.5	
1975	1,516	18,486	12.2	10,605	306,965	28.9	39,920	65,218	1.6	
1976	11,516	70,185	6.1	993	7,247	7.3	36,525	105,297	2.9	
1977	1,978	20,020	10.1	9,871	131,677	13.3	13,852	34,007	2.5	
1978	215	1,058	4.9	1,626	31,164	19.2	24,786	34,749	1.4	
1979	2,831	15,902	5.6	37,288	101,368	2.7	37,542	38,214	1.0	
1980	17,103	77,848	4.6	1,689	21,368	12.7	17,101	16,905	1.0	
1981	3,039	17,352	5.7	11,583	76,744	6.6	25,327	34,057	1.3	1981-1990
1982	614	6,340	10.3	1,519	6,775	4.5	8,708	18,228	2.1	
1983	4,882	26,556	5.4	17,020	149,699	8.8	16,852	62,031	3.7	
1984	16,835	136,133	8.1	3,920	24,917	6.4	15,797	75,589	4.8	
1985	3,039	125,622	41.3	8,355	46,853	5.6	3,560	23,182	6.5	
1986	2,349	21,000	8.9	2,125	20,838	9.8	29,177	39,998	1.4	
1987	6,347	26,150	4.1	22,242	191,020	8.6	13,637	21,965	1.6	
1988	31,211	309,753	9.9	4,931	57,739	11.7	37,747	61,077	1.6	
1989	12,208	47,315	3.9	2,905	18,687	6.4	16,037	18,103	1.1	
1990	3,961	14,902	3.8	3,580	15,078	4.2	12,202	9,626	0.8	
1991	5,953	21,630	3.6	35,812	57,679	1.6	22,500	33,940	1.5	1991-2000
1992	25,494	183,794	7.2	4,453	104,704	23.5	9,129	100,553	11.0	
1993	12,233	88,913	7.3	5,555	65,413	11.8	22,835	98,175	4.3	
1994	2,196	70,317	32.0	1,148	34,707	30.2	9,500	34,390	3.6	
1995	7,181	21,489	3.0	13,415	65,492	4.9	5,500	52,998	9.6	
1996	86,303	197,354	2.3	23,719	533,189	22.5	50,077	161,913	3.2	
1997	3,659	11,851	3.2	6,322	2,612	0.4	35,798	98,322	2.7	
1998	4,675	3,636	0.8	2,406	4,344	1.8	76,888	133,965	1.7	
1999	2,827	65,655	23.2	6,877	19,072	2.8	35,961	24,686	0.7	
2000	69,782	88,011	1.3	173,818	240,491	1.4	42,638	41,744	1.0	
2001	8,393			36,660			131,481			
2002	1,503			1,237			90,280			
2003	6,415			2,347			78,229			
2004	6,549			18,971			60,942			
2005	29,355			34,572			62,047			
2006										

Percentiles	Gates Spawners	Gates Recruits	Gates R/S	Nadina Spawners	Nadina Recruits	Nadina R/S	Pitt Spawners	Pitt Recruits	Pitt R/S
10%	479	3,654	2.88	1,530	7,105	1.75	9,226	19,862	1.17
25%	2,033	13,241	3.88	2,406	19,781	4.40	12,680	33,767	1.54
50% Median	**4,675**	**21,560**	**6.32**	**5,939**	**46,853**	**6.43**	**17,950**	**58,921**	**2.81**
75%	9,174	78,311	10.44	15,218	95,212	11.76	35,961	98,880	5.75
90%	25,494	132,283	24.26	35,192	191,020	22.48	54,423	134,057	9.16

Note: These are the time series used in the FRSSI model.

Early Summer Components

Year	Raft Spawners	Raft Recruits	Raft R/S	Scotch Spawners	Scotch Recruits	Scotch R/S	Seymour Spawners	Seymour Recruits	Seymour R/S	
1948	10,359	63,337	6.1				3,889	29,658	7.6	
1949	6,113	39,626	6.5				10,772	25,617	2.4	
1950	6,404	45,539	7.1				11,049	161,081	14.6	
1951	8,544	47,645	5.6				24,320	68,695	2.8	
1952	15,617	51,177	3.3				5,963	11,156	1.9	
1953	7,904	32,124	4.1				5,692	44,870	7.9	
1954	9,988	50,257	5.0				24,774	432,402	17.5	
1955	5,079	60,357	11.9				8,971	309,325	34.5	1951-1960
1956	9,037	25,364	2.8				2,490	12,737	5.1	
1957	6,860	20,943	3.1				10,870	11,959	1.1	
1958	10,214	23,103	2.3				78,371	189,334	2.4	
1959	10,210	23,584	2.3				52,310	175,560	3.4	
1960	5,513	16,764	3.0				2,901	8,697	3.0	
1961	7,293	24,293	3.3				3,622	25,649	7.1	
1962	7,613	40,549	5.3				57,836	170,350	2.9	
1963	8,683	9,355	1.1				71,654	113,939	1.6	
1964	5,177	48,511	9.4				2,745	18,498	6.7	
1965	6,624	20,553	3.1				6,089	34,707	5.7	1961-1970
1966	6,244	23,219	3.7				28,698	141,170	4.9	
1967	1,279	9,621	7.5				13,361	219,687	16.4	
1968	8,089	106,299	13.1				3,838	22,108	5.8	
1969	5,537	13,989	2.5				7,176	14,617	2.0	
1970	4,462	8,823	2.0				11,971	223,705	18.7	
1971	801	11,686	14.6				19,028	133,969	7.0	
1972	11,048	57,734	5.2				2,802	56,465	20.2	
1973	2,714	9,339	3.4				2,704	24,381	9.0	
1974	2,383	12,315	5.2				44,588	247,377	5.5	
1975	2,609	7,760	3.0				36,828	221,634	6.0	1971-1980
1976	8,665	19,870	2.3				8,306	18,384	2.2	
1977	617	5,917	9.6				5,709	55,279	9.7	
1978	2,493	18,450	7.4				62,808	261,195	4.2	
1979	1,758	3,039	1.7				49,306	135,215	2.7	
1980	5,418	51,611	9.5	107	1,532	14.3	8,309	52,838	6.4	
1981	815	8,610	10.6	18,952	25,296	1.3	11,359	26,268	2.3	
1982	2,992	3,742	1.3	4,709	109,375	23.2	63,271	505,718	8.0	
1983	2,780	4,051	1.5	239	2,632	11.0	29,831	268,723	9.0	
1984	19,086	46,730	2.4	409	2,613	6.4	17,172	35,843	2.1	
1985	3,637	4,421	1.2	3,385	42,541	12.6	5,620	43,244	7.7	1981-1990
1986	2,095	3,013	1.4	26,624	257,059	9.7	126,166	823,036	6.5	
1987	1,436	3,820	2.7	2,089	30,395	14.6	84,315	441,906	5.2	
1988	19,851	50,087	2.5	1,060	3,320	3.1	16,781	10,843	0.6	
1989	1,647	11,292	6.9	7,236	16,150	2.2	5,507	18,809	3.4	
1990	630	2,583	4.1	83,388	315,967	3.8	272,041	279,168	1.0	
1991	464	1,490	3.2	9,954	25,827	2.6	128,253	100,908	0.8	
1992	8,236	67,345	8.2	2,156	2,453	1.1	5,742	13,917	2.4	
1993	5,047	33,113	6.6	8,359	11,827	1.4	10,114	8,716	0.9	
1994	1,712	27,483	16.1	73,180	184,255	2.5	56,192	172,547	3.1	
1995	1,040	27,227	26.2	14,772	14,165	1.0	48,746	66,022	1.4	1991-2000
1996	46,592	112,687	2.4	4,609	4,242	0.9	21,654	40,294	1.9	
1997	6,093	52,394	8.6	3,085	2,539	0.8	2,254	2,194	1.0	
1998	7,198	12,596	1.7	35,981	193,020	5.4	34,048	213,648	6.3	
1999	6,979	52,032	7.5	4,093	26,352	6.4	18,895	133,795	7.1	
2000	66,292	106,411	1.6	3,765	40,167	10.7	25,465	58,038	2.3	
2001	32,498			2,449			6,892			
2002	18,369			101,269			113,408			
2003	10,040			5,089			31,345			
2004	5,611			783			1,323			
2005	28,645			4,163			3,516			
2006										

Percentiles	Raft Spawners	Raft Recruits	Raft R/S	Scotch Spawners	Scotch Recruits	Scotch R/S	Seymour Spawners	Seymour Recruits	Seymour R/S
10%	1,183	3,866	1.63	559	2,539	0.96	2,861	12,115	1.15
25%	2,609	9,351	2.44	2,229	3,320	1.41	5,742	23,813	2.26
50% Median	**6,093**	**22,023**	**3.39**	**4,163**	**20,723**	**3.46**	**13,361**	**62,030**	**4.54**
75%	8,683	47,862	7.41	11,159	41,354	10.16	44,588	195,413	7.05
90%	18,656	57,200	10.47	43,421	190,391	13.79	74,341	278,124	9.62

Note: These are the time series used in the FRSSI model.

Summer Components

Year	Chilko Spawners	Chilko Recruits	Chilko R/S	L. Stuart Spawners	L. Stuart Recruits	L. Stuart R/S	
1948	670,622	1,654,244	2.5		327		
1949	58,247	571,003	9.8	107,752	1,526,554	14.2	
1950	17,308	187,983	10.9	5,843	39,090	6.7	
1951	98,315	665,674	6.8	4,364	63,644	14.6	1951-1960
1952	485,585	1,799,904	3.7	35	3,887	111.1	
1953	200,691	528,558	2.6	368,634	1,549,542	4.2	
1954	34,296	636,547	18.6	5,470	137,815	25.2	
1955	121,167	1,438,974	11.9	7,582	51,316	6.8	
1956	646,906	2,396,538	3.7	913	46,102	50.5	
1957	138,464	120,511	0.9	531,108	1,329,010	2.5	
1958	120,104	291,933	2.4	23,619	54,005	2.3	
1959	463,060	2,099,156	4.5	8,225	7,325	0.9	
1960	426,546	964,857	2.3	2,396	9,590	4.0	
1961	39,101	64,296	1.6	410,887	777,920	1.9	1961-1970
1962	77,713	974,191	12.5	18,643	45,024	2.4	
1963	998,231	1,116,906	1.1	3,222	12,024	3.7	
1964	238,272	1,874,731	7.9	1,816	3,041	1.7	
1965	35,335	140,915	4.0	214,943	1,124,200	5.2	
1966	209,619	772,105	3.7	9,027	73,805	8.2	
1967	174,715	1,956,680	11.2	1,629	16,332	10.0	
1968	413,862	2,357,108	5.7	389	31,299	80.5	
1969	70,902	385,793	5.4	207,014	1,622,780	7.8	
1970	135,388	628,421	4.6	14,978	70,520	4.7	
1971	145,990	571,260	3.9	1,535	65,527	42.7	1971-1980
1972	560,767	1,895,516	3.4	7,341	18,766	2.6	
1973	55,675	201,994	3.6	214,230	663,965	3.1	
1974	109,563	646,245	5.9	14,190	49,540	3.5	
1975	199,739	1,413,397	7.1	14,229	196,849	13.8	
1976	361,752	1,597,193	4.4	2,898	3,339	1.2	
1977	49,539	192,317	3.9	146,459	1,357,637	9.3	
1978	143,402	1,203,661	8.4	12,738	78,748	6.2	
1979	234,924	1,526,845	6.5	31,918	6,854	0.2	
1980	467,812	3,970,297	8.5	946	21,440	22.7	
1981	34,360	182,108	5.3	249,494	2,033,901	8.2	1981-1990
1982	239,903	1,432,199	6.0	16,758	60,796	3.6	
1983	329,220	1,325,694	4.0	2,246	17,912	8.0	
1984	452,618	327,106	0.7	1,228	14,522	11.8	
1985	71,435	493,215	6.9	274,621	3,499,874	12.7	
1986	281,771	4,692,771	16.7	28,715	816,297	28.4	
1987	239,601	4,349,335	18.2	6,472	379,087	58.6	
1988	254,668	3,137,460	12.3	7,117	207,234	29.1	
1989	53,039	3,101,966	58.5	575,697	5,306,868	9.2	
1990	825,837	2,596,079	3.1	189,079	388,754	2.1	
1991	1,037,737	1,283,236	1.2	76,860	107,033	1.4	1991-2000
1992	511,267	1,852,267	3.6	19,513	135,399	6.9	
1993	555,226	3,929,559	7.1	1,363,826	3,760,174	2.8	
1994	450,745	1,404,652	3.1	76,462	115,440	1.5	
1995	544,364	1,224,376	2.2	34,362	132,071	3.8	
1996	974,349	1,335,629	1.4	62,991	1,024,328	16.3	
1997	985,827	868,458	0.9	907,652	370,610	0.4	
1998	879,095	493,209	0.6	138,397	277,684	2.0	
1999	891,567	1,490,993	1.7	61,574	143,563	2.3	
2000	758,941	416,330	0.5	454,397	858,113	1.9	
2001	668,783			351,515			
2002	382,814			34,498			
2003	609,173			36,647			
2004	91,903			81,962			
2005	535,967			293,124			
2006							
Percentiles 10%	51,639	194,252	1.14	1,582	7,778	1.53	
25%	109,563	519,722	2.58	5,843	37,142	2.39	
50% Median	**239,903**	**1,214,019**	**4.01**	**19,513**	**92,891**	**4.97**	
75%	535,967	1,857,883	6.95	189,079	692,454	12.06	
90%	847,140	3,051,377	12.28	385,535	1,530,352	29.05	

Note: These are the time series used in the FRSSI model.

Summer Components | **Passively managed with Summer**

Year	Quesnel Spawners	Quesnel Recruits	Quesnel R/S	Stellako Spawners	Stellako Recruits	Stellako R/S	Birkenhead Spawners	Birkenhead Recruits	Birkenhead R/S	
1948	100	618	6.2	15,763	207,177	13.1	83,787	191,990	2.3	
1949	30,664	463,409	15.1	104,720	179,743	1.7	70,504	237,158	3.4	
1950	398	2,014	5.1	145,021	934,487	6.4	64,440	214,749	3.3	
1951	49	413	8.4	96,076	455,341	4.7	21,296	173,801	8.2	1951-1960
1952	184	562	3.1	40,384	110,678	2.7	47,041	213,941	4.5	
1953	107,776	604,343	5.6	42,134	174,215	4.1	42,491	118,877	2.8	
1954	299	10,692	35.8	141,859	1,207,988	8.5	18,213	146,171	8.0	
1955	63	180	2.9	51,739	629,768	12.2	14,553	228,353	15.7	
1956	78	1,115	14.3	38,438	246,643	6.4	49,754	251,198	5.0	
1957	216,969	989,724	4.6	38,522	151,835	3.9	14,536	42,835	2.9	
1958	1,863	3,385	1.8	112,251	339,304	3.0	15,166	86,069	5.7	
1959	65	165	2.5	79,305	541,403	6.8	26,159	225,156	8.6	
1960	292	1,469	5.0	38,880	164,495	4.2	36,838	130,133	3.5	
1961	283,937	1,196,316	4.2	46,863	147,114	3.1	31,681	84,468	2.7	1961-1970
1962	1,078	7,257	6.7	124,485	589,405	4.7	26,369	74,421	2.8	
1963	83	956	11.5	138,794	726,949	5.2	48,893	330,206	6.8	
1964	254	2,812	11.1	30,890	177,643	5.8	48,908	311,035	6.4	
1965	364,557	1,652,928	4.5	39,385	243,472	6.2	16,230	123,803	7.6	
1966	1,753	7,434	4.2	101,529	359,073	3.5	20,116	216,335	10.8	
1967	119	1,750	14.7	91,480	550,236	6.0	39,876	411,254	10.3	
1968	699	428	0.6	30,368	129,737	4.3	57,947	253,589	4.4	
1969	251,025	1,634,350	6.5	49,211	253,114	5.1	37,382	690,379	18.5	
1970	1,368	20,339	14.9	45,797	232,938	5.1	30,656	562,013	18.3	
1971	171	747	4.4	39,691	508,759	12.8	24,629	292,244	11.9	1971-1980
1972	93	856	9.2	36,700	756,010	20.6	54,516	471,597	8.7	
1973	262,955	2,170,386	8.3	30,404	85,890	2.8	56,653	165,326	2.9	
1974	4,459	22,351	5.0	41,275	295,834	7.2	119,637	633,482	5.3	
1975	97	1,713	17.7	175,941	1,747,216	9.9	61,538	105,133	1.7	
1976	53	1,233	23.3	150,734	244,207	1.6	77,305	563,748	7.3	
1977	474,400	3,864,815	8.1	23,047	265,626	11.5	23,845	384,881	16.1	
1978	8,524	196,546	23.1	58,898	436,545	7.4	94,782	609,424	6.4	
1979	511	6,011	11.8	290,042	623,893	2.2	60,988	394,123	6.5	
1980	274	2,446	8.9	72,050	755,199	10.5	78,613	477,078	6.1	
1981	727,691	9,069,092	12.5	21,826	285,870	13.1	49,023	261,609	5.3	1981-1990
1982	34,146	539,452	15.8	69,420	355,873	5.1	119,738	1,752,826	14.6	
1983	2,117	40,379	19.1	121,692	1,256,351	10.3	44,029	775,080	17.6	
1984	844	6,189	7.3	60,957	1,011,019	16.6	40,245	434,360	10.8	
1985	1,244,293	11,613,966	9.3	42,099	128,655	3.1	11,905	216,306	18.2	
1986	175,578	2,468,956	14.1	77,177	561,822	7.3	335,630	1,184,529	3.5	
1987	20,483	176,581	8.6	211,085	435,662	2.1	164,849	977,898	5.9	
1988	6,502	26,563	4.1	367,702	991,341	2.7	166,591	865,447	5.2	
1989	1,737,091	9,764,806	5.6	43,179	222,259	5.1	29,334	1,109,139	37.8	
1990	471,497	3,170,188	6.7	93,920	960,916	10.2	166,773	224,957	1.3	
1991	46,259	153,593	3.3	94,884	374,245	3.9	293,626	116,115	0.4	1991-2000
1992	5,862	29,213	5.0	97,979	868,186	8.9	185,908	94,662	0.5	
1993	2,421,210	6,802,981	2.8	91,071	309,831	3.4	244,954	560,370	2.3	
1994	615,165	2,300,539	3.7	137,995	682,058	4.9	39,234	57,043	1.5	
1995	215,729	163,717	0.8	122,676	183,859	1.5	40,003	150,889	3.8	
1996	41,178	87,470	2.1	333,163	813,462	2.4	56,474	72,644	1.3	
1997	1,506,837	3,861,851	2.6	55,332	125,448	2.3	50,317	27,025	0.5	
1998	1,083,497	4,665,521	4.3	185,641	645,551	3.5	296,503	601,622	2.0	
1999	186,367	790,637	4.2	138,168	186,382	1.3	49,019	80,738	1.6	
2000	62,739	36,066	0.6	371,564	635,186	1.7	14,470	62,168	4.3	
2001	2,869,623			151,359			44,450			
2002	3,062,151			322,661			189,445			
2003	269,316			78,043			310,960			
2004	9,831			86,688			38,386			
2005	1,449,851			175,690			53,546			
2006										
Percentiles 10%	89	644	2.54	34,376	148,058	2.08	17,420	75,684	1.49	
25%	299	1,948	4.18	42,134	213,290	3.05	30,656	122,572	2.89	
50% Median	**8,524**	**27,888**	**5.61**	**79,305**	**366,659**	**5.01**	**48,893**	**226,755**	**5.32**	
75%	269,316	1,305,825	11.18	137,995	637,777	7.31	77,305	497,901	8.62	
90%	1,326,516	3,864,519	15.71	195,819	951,643	11.42	187,323	766,610	16.10	

Note: These are the time series used in the FRSSI model.

Late Components

Year	Cultus Spawners	Cultus Recruits	Cultus R/S		Harrison Spawners	Harrison Recruits	Harrison R/S	Late Shuswap Spawners	Late Shuswap Recruits	Late Shuswap R/S	Period
1948	12,746	39,076	3.1		26,162	43,283	1.7	10,356	28,330	2.7	
1949	9,055	37,489	4.1		8,000	25,650	3.2	3,606	21,384	5.9	
1950	29,928	101,664	3.4		33,044	29,830	0.9	1,271,381	9,316,321	7.3	
1951	12,677	170,570	13.5		17,145	18,078	1.1	143,498	522,030	3.6	1951-1960
1952	17,833	44,265	2.5		25,794	4,633	0.2	7,317	16,451	2.2	
1953	11,543	63,172	5.5		21,030	7,552	0.4	3,472	29,571	8.5	
1954	22,036	63,564	2.9		28,800	8,651	0.3	2,026,693	15,107,801	7.5	
1955	25,922	275,674	10.6		5,595	80,836	14.4	63,859	853,876	13.4	
1956	13,718	36,232	2.6		2,586	9,714	3.8	3,321	7,419	2.2	
1957	20,375	27,988	1.4		3,793	35,140	9.3	2,809	2,206	0.8	
1958	13,324	47,366	3.6		14,701	4,480	0.3	3,297,045	2,080,873	0.6	
1959	47,779	52,080	1.1		27,868	31,079	1.1	134,826	374,607	2.8	
1960	17,640	23,020	1.3		17,210	3,357	0.2	1,907	2,333	1.2	
1961	13,396	5,954	0.4		42,773	11,550	0.3	1,150	6,996	6.1	1961-1970
1962	26,997	35,483	1.3		8,162	19,678	2.4	1,144,115	2,751,141	2.4	
1963	20,303	134,623	6.6		22,258	37,548	1.7	158,468	3,051,092	19.3	
1964	11,067	69,246	6.3		2,202	7,274	3.3	604	17,280	28.6	
1965	2,455	19,606	8.0		15,034	12,130	0.8	2,087	24,312	11.6	
1966	16,919	40,514	2.4		32,646	12,577	0.4	1,280,308	3,937,025	3.1	
1967	33,198	102,785	3.1		20,548	28,976	1.4	844,896	3,116,378	3.7	
1968	25,314	42,418	1.7		5,379	4,220	0.8	3,686	20,783	5.6	
1969	5,942	5,031	0.8		14,959	5,152	0.3	5,985	27,967	4.7	
1970	13,941	44,947	3.2		12,666	20,855	1.6	1,524,303	5,376,623	3.5	
1971	9,128	48,028	5.3		3,790	23,176	6.1	289,908	680,439	2.3	1971-1980
1972	10,366	30,023	2.9		1,346	810	0.6	4,192	43,396	10.4	
1973	641	669	1.0		3,060	5,425	1.8	3,794	63,843	16.8	
1974	8,984	29,082	3.2		16,920	34,205	2.0	1,133,390	6,822,230	6.0	
1975	11,349	108,087	9.5		5,987	56,177	9.4	173,139	1,017,404	5.9	
1976	4,435	6,109	1.4		5,130	1,184	0.2	4,780	13,049	2.7	
1977	82	1,457	17.8		2,246	7,982	3.6	12,510	93,025	7.4	
1978	5,076	69,111	13.6		19,717	34,177	1.7	1,886,464	8,777,336	4.7	
1979	32,031	108,244	3.4		45,615	10,425	0.2	298,825	1,491,217	5.0	
1980	1,657	4,639	2.8		5,092	977	0.2	2,498	21,794	8.7	
1981	256	965	3.8		3,193	5,403	1.7	10,293	9,466	0.9	1981-1990
1982	16,725	17,948	1.1		9,189	24,681	2.7	3,019,935	8,995,429	3.0	
1983	19,944	95,903	4.8		4,239	9,995	2.4	211,338	1,963,237	9.3	
1984	994	9,106	9.2		1,267	1,569	1.2	4,335	33,071	7.6	
1985	424	2,102	5.0		5,097	10,713	2.1	1,288	4,319	3.4	
1986	3,256	10,278	3.2		7,265	3,927	0.5	2,263,497	10,451,143	4.6	
1987	32,184	65,836	2.0		5,228	42,702	8.2	616,538	3,894,013	6.3	
1988	861	7,726	9.0		1,544	1,823	1.2	5,007	8,076	1.6	
1989	418	10,741	25.7		2,934	13,075	4.5	563	12,858	22.8	
1990	1,860	24,531	13.2		4,515	67,746	15.0	3,619,499	7,408,932	2.0	
1991	20,157	17,455	0.9		15,000	33,655	2.2	1,255,210	829,908	0.7	1991-2000
1992	1,203	2,150	1.8		313	3,363	10.7	12,816	18,404	1.4	
1993	1,063	1,600	1.5		3,258	2,284	0.7	1,366	14,671	10.7	
1994	4,399	2,435	0.6		9,515	20,219	2.1	1,352,332	2,514,354	1.9	
1995	10,316	14,200	1.4		16,618	48,276	2.9	418,915	764,791	1.8	
1996	2,022	1,497	0.7		15,379	4,486	0.3	12,179	44,944	3.7	
1997	88	634	7.2		1,418	70,070	49.4	1,072	31,409	29.3	
1998	1,959	5,951	3.0		4,496	44,978	10.0	1,340,479	6,899,486	5.1	
1999	12,392	10,360	0.8		8,577	77,400	9.0	340,549	702,099	2.1	
2000	1,227	70	0.1		4,343	3,850	0.9	831	1,418	1.7	
2001	515				15,309			4,330			
2002	5,149				41,542			5,216,828			
2003	1,939				8,259			374,840			
2004	52				2,106			2,991			
2005	193				388,605			21,113			
2006											
Percentiles 10%	479	1,518	0.85	10%	2,164	2,499	0.27	1,335	7,550	1.47	
25%	1,657	5,953	1.38	25%	3,793	4,596	0.59	3,606	18,123	2.24	
50% Median	**9,128**	**23,776**	**2.97**	**50%**	**8,162**	**11,132**	**1.67**	**21,113**	**233,816**	**4.15**	
75%	16,919	49,041	5.67	75%	16,920	31,723	3.37	844,896	2,573,551	7.50	
90%	25,557	93,237	9.49	90%	28,241	47,946	9.37	1,942,556	6,891,760	13.20	

Note: These are the time series used in the FRSSI model.

Late Components

Year	Weaver Spawners	Weaver Recruits	Weaver R/S	Portage Spawners	Portage Recruits	Portage R/S	
1948							
1949					296		
1950					28,087		
1951				29	226	7.8	
1952							
1953				50	394	7.9	
1954				3,369	35,946	10.7	1951-1960
1955				41	4,376	106.7	
1956							
1957				40	47	1.2	
1958				4,791	24,750	5.2	
1959				572	5,431	9.5	
1960					21		
1961				23	2,721	118.3	
1962				11,935	70,302	5.9	
1963				2,011	56,230	28.0	
1964				9	571	63.4	
1965	16,507	204,403	12.4	981	3,308	3.4	1961-1970
1966	16,784	75,454	4.5	31,343	31,007	1.0	
1967	21,351	85,709	4.0	4,025	4,119	1.0	
1968	3,191	152,402	47.8	86	1,046	12.2	
1969	51,387	409,882	8.0	963	30,773	32.0	
1970	8,627	376,645	43.7	3,873	56,751	14.7	
1971	4,002	141,914	35.5	281	15,812	56.3	
1972	21,531	342,703	15.9	190	13,156	69.2	
1973	38,163	269,481	7.1	3,963	80,696	20.4	
1974	55,076	268,531	4.9	8,475	40,912	4.8	
1975	21,590	143,140	6.6	3,175	12,827	4.0	1971-1980
1976	39,059	295,026	7.6	1,042	7,097	6.8	
1977	40,087	232,768	5.8	7,610	39,221	5.2	
1978	60,754	1,355,323	22.3	9,978	104,330	10.5	
1979	35,852	139,784	3.9	3,575	52,156	14.6	
1980	56,711	361,547	6.4	1,800	11,476	6.4	
1981	33,531	267,384	8.0	5,855	16,505	2.8	
1982	267,271	1,498,847	5.6	23,867	209,321	8.8	
1983	32,764	240,414	7.3	7,747	36,858	4.8	
1984	39,269	627,311	16.0	1,710	49,576	29.0	
1985	28,727	68,199	2.4	1,765	23,997	13.6	1981-1990
1986	90,221	42,659	0.5	14,291	71,339	5.0	
1987	45,724	219,920	4.8	6,820	61,873	9.1	
1988	38,404	510,599	13.3	1,068	20,694	19.4	
1989	12,653	761,714	60.2	7,900	195,614	24.8	
1990	12,131	629,081	51.9	18,336	50,957	2.8	
1991	25,966	66,585	2.6	12,053	15,595	1.3	
1992	40,931	756,383	18.5	2,706	7,472	2.8	
1993	51,909	480,578	9.3	19,760	165,520	8.4	
1994	42,792	710,266	16.6	9,270	126,566	13.7	
1995	24,488	265,721	10.9	7,875	37,977	4.8	1991-2000
1996	78,172	377,566	4.8	3,422	85,982	25.1	
1997	15,175	195,740	12.9	9,766	57,870	5.9	
1998	45,358	573,833	12.7	25,179	17,642	0.7	
1999	26,328	257,545	9.8	6,264	9,229	1.5	
2000	4,141	94,934	22.9	1,269	11,721	9.2	
2001	13,923			3,150			
2002	86,698			14,953			
2003	36,192			4,940			
2004	15,052			1,287			
2005	90,814			12,082			
2006							

Percentiles	Weaver Spawners	Weaver Recruits	Weaver R/S	Portage Spawners	Portage Recruits	Portage R/S
10%	11,781	80,582	3.96	50	553	1.40
25%	16,784	150,087	5.42	1,062	7,191	4.79
50% Median	**34,692**	**267,384**	**7.98**	**3,575**	**24,374**	**8.13**
75%	45,541	462,904	15.96	8,331	55,212	14.65
90%	72,947	719,489	37.10	14,754	87,817	36.82