Fisheries and Oceans Canada Pêches et Océans Canada
Science Sciences

Pacific Region

Canadian Science Advisory Secretariat
Science Advisory Report 2010/070

GUIDELINES FOR APPLYING UPDATED METHODS FOR ASSESSING HARVEST RULES FOR FRASER RIVER SOCKEYE SALMON (*ONCORHYNCHUS NERKA*)

Sockeye Salmon adult spawning phase. DFO website.

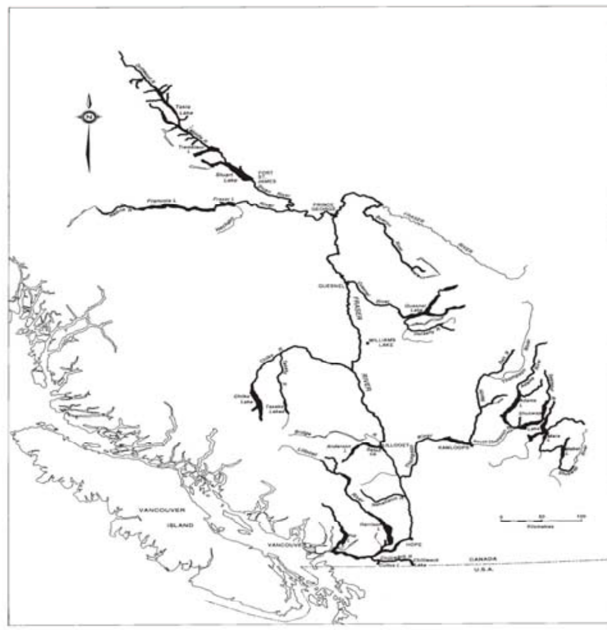

Figure 1: Sockeye Salmon spawning locations in South Western BC.

Context

The Fraser River Sockeye Spawning Initiative (FRSSI) has been an eight-year process to develop guidelines for setting annual escapement and exploitation targets for Fraser Sockeye Salmon stocks. The initiative began in early 2002, and has since evolved through a series of workshops and on-going feedback from stakeholders.

A quantitative modeling tool used to support the planning process was developed and reviewed by the Pacific Science Advice Review Committee (PSARC) in 2003. The model has evolved substantially since that time.

The simulation model supports the evaluation of alternative management strategies, such as target levels of total allowable mortality that change with run size. These management strategies shape pre-season fishing plans, guide in-season management decisions, and provide a reference point for post-season review.

In response to a request for science advice to guide upcoming planning processes for Fraser River Sockeye Salmon, an evaluation of the updated FRSSI model was conducted. Conclusions and recommendations for model extensions, future analyses, and considerations to guide model use are provided.

SUMMARY

- The Fraser River Sockeye Spawning Initiative (FRSSI) has been an eight-year process to develop guidelines for setting annual escapement and exploitation targets for Fraser Sockeye Salmon stocks. The initiative began in early 2002, and has since evolved through a series of workshops and on-going feedback from stakeholders.
- A quantitative modeling tool (FRSSI Model), used to support the planning process for Fraser River Sockeye Salmon, was developed and reviewed in 2003. The model has evolved substantially since. This assessment evaluates the assumptions and performance of the revised model.
- The FRSSI Model is intended as a formalized, quantitative tool for exploring the expected long-term performance of escapement strategies for Fraser Sockeye Salmon under a wide range of alternative assumptions (e.g. population dynamics, future changes in productivity).
- The FRSSI Model currently simulates 19 stocks of Fraser Sockeye Salmon forward for 48 years and applies different long-term escapement strategies chosen by the user. It tracks the performance of management groups as well as individual stocks, and is set up to explore many variations of management approaches that are applied on an annual basis: (1) fixed escapement, (2) fixed exploitation rate, and (3) varying total allowable mortality with run size. For each of these, the effect of overlap in return timing can be evaluated.
- The model allows users to confront a chosen strategy with a wide range of scenarios: (1) alternative spawner-recruit models, (2) alternative future patterns of productivity, (3) alternative assumptions about en-route mortality, and (4) alternative assumptions about pre-spawn mortality. All stocks within a management group are exposed to the same exploitation rate and environmental mortality.
- Use of the revised model [FRSSI (2010) Model] in support of Fraser River Sockeye Salmon planning is recommended. It was agreed that the alternative assumptions currently available in the FRSSI model establish reasonable bookends on plausible scenarios, and allow end-users to explore a comprehensive suite of “what-if” scenarios in a collaborative planning process.
- Recommendations for future analyses and model modifications include: (1) updated estimates of productive capacity for Fraser Sockeye Salmon lakes, (2) alternative future scenarios for en-route mortality, (3) development of a plausible suite of stock-specific future patterns in productivity due to differences in habitat and environmental conditions among stocks, (4) estimation of depensation thresholds and quasi-extinction thresholds for each of the Fraser Sockeye Salmon stocks, and (5) further analyses of alternative spawner-recruit models and their implications.

INTRODUCTION

The FRSSI model is intended as a formalized, quantitative tool for exploring the expected long-term performance of escapement strategies for Fraser Sockeye Salmon under a wide range of alternative assumptions (e.g. population dynamics, future changes in productivity). The model is simply a thinking aid, a consistent way of linking and tracking some of the many considerations that are debated during the annual planning process. Alternative options and assumptions can be easily explored through a series of “what if?” scenarios. This process works best in a collaborative setting, but the inevitable complexities create substantial communication challenges in multi-stakeholder workshops.

The FRSSI model currently simulates 19 stocks of Fraser Sockeye Salmon forward for 48 years and applies different long-term escapement strategies chosen by the user. It tracks the performance of management groups as well as individual stocks.

The model is set up to explore many variations of management approaches that are applied on an annual basis: (1) fixed escapement, (2) fixed exploitation rate, (3) varying total allowable mortality with run size. For each of these, the effect of overlap in return timing can be evaluated.

The model allows users to confront a chosen strategy with a wide range of scenarios: (1) alternative spawner-recruit models, (2) alternative future patterns of productivity, (3) alternative assumptions about en-route mortality, and (4) alternative assumptions about pre-spawn mortality. All stocks within a management group are exposed to the same exploitation rate and environmental mortality. The model does not consider differing catches for specific areas or fisheries.

Alternative escapement strategies, applied on an annual basis and for all stocks within a management group, are exposed to the same exploitation rate and environmental mortality. Therefore, the current model is not set up to address the following: (1) in-season management strategies, such as approaches for dealing with uncertain and changing forecasts, (2) alternative fishing plans, such as the timing and location of harvests, (3) catch sharing across sectors or areas, or (4) annual adjustments to escapement strategy.

The FRSSI model is designed as a big-picture model to address long-term management questions such as, “What types of strategies tend to be robust to uncertainty in population dynamics?” It does not address operational questions such as, “What is the optimal fishing plan for next week, given the latest estimates of abundance, timing, and management adjustments?”

Given this intent, the FRSSI model does not attempt to explicitly incorporate all known biological mechanisms. However, there are other planning processes, with their own models, that deal with these biological mechanisms in more detail.

ANALYSIS

Biological Sub-Model

Spawner–Recruit Data

The primary data used to analyze the population dynamics of Fraser Sockeye Salmon are estimates of annual spawning abundances (escapement), and estimates of their adult progeny that are caught in fisheries, perish during upriver migration, or survive to spawn. Escapement is estimated directly using systematic surveys of the spawning population. Estimates of catch, migration mortality, and escapement are combined to estimate the total abundance of returning sockeye salmon in a given year.

The simulation model currently includes 19 stocks. For 12 of these stocks, escapement and catch by brood year have been routinely measured since 1948. Early in the FRSSI process, another seven stocks, with shorter time series of available data, were added to better reflect the mixed-stock challenges of management resulting from different productivities among stocks and uncertainty in parameter estimates from spawner-recruit models. Together, these 19 stocks account for 98% of the long term average annual run size and escapement, ranging from 89 to 100% of the total run and 87 to 100% of the escapement.

Spawner–Recruit Models

Statistical methods have been developed to model the relationship between spawners and recruits, later referred to as SR models. For Sockeye Salmon, these models typically calculate the expected number of 4-year old and 5-year 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 two 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).

Alternative models differ in the assumptions they make about:

- Inherent productivity (i.e. recruits / spawner at low abundance)
- Depensatory mortality at low spawner abundances - for example, due to the constant take by predators from a declining population of salmon.
- Compensatory reduction of productivity at high spawner abundances - for example, due to competition for spawning locations.
- Interaction between cycle lines. Large escapement in a given year may result in decline in survival of the following year's brood due to mechanisms such as reduced food availability and increased predator abundance. Alternately, periodic large escapements may increase long-term production due to increased marine nutrients released into the watershed by the carcasses.

Of the 19 Sockeye Salmon stocks in the watershed that are enumerated consistently, eight exhibit persistent cycles, with a consistent peak in abundance every four years. When this pattern is 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.

Despite 50 years of study, there is still no scientific consensus on the cause of cyclic patterns in the abundance of Fraser River Sockeye Salmon, but recent research points to a combination of biological mechanisms and past harvest patterns (e.g. Ricker 1997, DFO 2006b). Hypotheses include interactions with predators, diseases, and parasites in freshwater. 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.

Other Biological Mechanisms

En-route Mortality:

Since the early 1990s there have been, with increasing frequency, large differences between estimates (DBE) of Sockeye Salmon in the lower Fraser River measured at the hydro-acoustic site at Mission, B.C, and estimates of the population at the spawning sites plus in-river catch above Mission (often termed en-route mortality). The discrepancies potentially arise from a number of different sources, including: estimation error, unreported catch, and en-route mortality from adverse environmental conditions (e.g. Macdonald et al. 2010). Discrepancies are evaluated post-season, and if they are concluded to be real, the DBE is incorporated into the recruitment data used in the spawner-recruit dataset.

Patterns in Productivity:

A recurring concern raised by participants in the FRSSI workshops relates to assumptions about future productivity of Fraser Sockeye Salmon stocks. Any forward simulation using parameters estimated from observed data implies that the range of future outcomes (e.g. recruits per spawner at a given abundance of spawners) resembles the range observed in the past. The FRSSI model includes two options for exploring assumptions about future productivity: (1) an abrupt and persistent loss of productivity across all stocks, or (2) a stock-specific pattern over time.

Harvest Sub-model

The purpose of the FRSSI model is to explore the expected long-term performance of different escapement strategies for Fraser Sockeye Salmon under a wide range of alternative assumptions (e.g. population dynamics, future changes in productivity). During the annual management cycle, escapement strategies guide the annual balance sought between catch and abundance of spawners, as run sizes vary from one year to the next and among stocks. In the model, these strategies are specified as quantitative control rules that prescribe a target level of exploitation rate for each management group. Three types of escapement strategies are currently available in the model:

Fixed escapement	Strategy is to catch everything in excess of stock-specific target escapement plus a buffer for en-route mortality. Exploitation rate increases with run size, up to some optional cap (e.g. 85%).
Fixed exploitation rate	Strategy is to catch same proportion every year, regardless of run size or en-route mortality.
Total Allowable Mortality (TAM) Rule	TAM changes with run size. Target exploitation rate is adjusted based on en-route mortality.

TAM rules are designed around three fundamental considerations: (1) The total allowable mortality rate is capped at larger run sizes to ensure robustness against uncertainty in population dynamics (e.g. capacity estimate), changing in-season information, and differing productivity among component stocks; (2) A minimum fixed escapement threshold is established at low run sizes to protect the stocks against extirpation and reduce challenges related to the complex in-season management process at this critical stage (e.g. uncertain run size); and, (3) A fixed, minimum exploitation rate is established to allow for test fishing and to account for some incidental harvest in fisheries targeting more abundant co-migrating stocks or species even at very low run sizes.

The application of escapement strategies to each of the four management groups is constrained by their overlap in run timing. Timing overlap is simulated based on long-term average migration timing through Statistical Area 20 (i.e. in a mixed-stock fishing area). Two alternative approaches for approximating the constraints imposed by timing overlap are included in the model: (1) based on a timing window around the migration peak, or (2) based on contribution to daily abundance. In both cases, the intent is to reflect the implementation challenges introduced by escapement strategies that tend to result in widely differing target exploitation rates for the four management groups. If the same fixed exploitation rates are chosen for all management groups, there is no overlap constraint.

CONCLUSIONS AND ADVICE

Application of the FRSSI model for Fraser River Sockeye Salmon planning is endorsed. It was concluded that the alternative assumptions currently available in the FRSSI model establish reasonable bookends on plausible scenarios and allow users to explore a comprehensive suite of “what-if” scenarios in the collaborative planning process.

Specific conclusions and recommendations related to the design and use of the FRSSI model include:

- Simulating spawners and recruits for 19 stocks is the most detailed practical level of biological resolution in the population dynamics. While additional life history stages (e.g. smolts) or additional mechanisms (e.g. ocean conditions during first entry) could be incorporated for some stocks, this could not be consistently applied across all stocks. Estimating population dynamics for smaller population groups (e.g. conservation units) is not currently feasible, because recruitment estimates are not available at that resolution.
- Comparison of alternative SR model fits (e.g. the nature of cycle interactions) should be based on a combination of biological plausibility and statistical performance measures. The Deviance Information Criterion (DIC) is recommended as the main measure of statistical fit.
- Bayesian parameter estimates are useful to characterize the uncertainty in population dynamics. However, the implications of up-front assumptions need to be carefully considered (e.g. constraints on parameters describing capacity and cyclic interactions).
- Given the scope and intent of the model, the other biological mechanisms are adequately approximated by the current suite of alternative assumptions (i.e. en-route mortality, pre-spawn mortality, depensation, timing overlap).
- The model can be used to test a wide range of alternative forms for annual management strategies (i.e. fixed exploitation rate, fixed escapement, TAM rule) applied to the four Fraser River Sockeye Salmon management groups. Some participants recommended stock-specific or CU-specific management strategies, but the model is set up to simulate the current management system. The model is easily extendable to stock-specific management strategies, but this would require stock-specific assumptions about patterns of en-route mortality.
- The FRSSI model provides a wide range of options to explore, but the resulting flexibility increases the burden of choosing scenarios in the collaborative planning process. Science advice should be sought regarding the most plausible scenarios (e.g. future productivity) and key sources of uncertainty.

Recommendations for further analyses to inform FRSSI model simulations and improve model performance:

- Update current estimates of productive capacity for Fraser Sockeye Salmon lakes to inform parameter estimates for spawner-recruit models (i.e. prior assumption about capacity parameter).
- Develop alternative sample distributions for en-route mortality (e.g. based on climate change scenarios).
- Develop a plausible suite of stock-specific future patterns in productivity and test alternative spawner-recruit models and their implications.
- Develop estimates of depensation thresholds and quasi-extinction thresholds for each of the Fraser Sockeye Salmon stocks.
- Perform a full forward evaluation of 2010 TAM rules under all combinations of assumptions in the updated model (e.g. all identified variations of spawner-recruit models).
- Complete a retrospective analysis of FRSSI TAM rule performance ("What would have likely happened if 2010 TAM rules had been used since 1987, given observed recruitment patterns?").

SOURCES OF INFORMATION

Banneheka, S.G., Routledge R.D., Guthrie, I.C., and Woodey, J.C. 1995. Estimation of in-river fish passage using a combination of transect and stationary hydro-acoustic sampling. Can. J. Fish. Aquat. Sci. 52: 335-343

Cass, A., Folkes, M., and Pestal, G. 2004. Methods for assessing harvest rules for Fraser River sockeye salmon. DFO Can. Sci. Advis. Sec. Res. Doc. 2004/025.

DFO 2006a. A harvest strategy compliant with the precautionary approach. DFO Can. Sci. Advis.Sec. Sci. Advis. Rep. 2006/023. Available at http://www.dfo-mpo.gc.ca/csas/Csas/status/2006/SAR-AS2006_023_E.pdf.

DFO 2006b. Workshop to assess population dynamics of cyclic Fraser River sockeye and implications for management.

Pestal G., Huang, A.M., Cass, A., and the FRSSI Working Group. 2010. Updated methods for assessing harvest rules for Fraser River sockeye salmon (*Oncorhynchus nerka*).). DFO Can. Sci. Advis. Sec. Res. Doc. 2010/nnn.

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.

Ricker, W.E. 1997. Cycles of abundance among Fraser River sockeye salmon (*Oncorhynchus nerka*). Can. J. Fish. Aquat. Sci. 54: 950.968

FOR MORE INFORMATION

Contact: Ann-Marie Huang
Resource Management
Fisheries and Oceans Canada
100 Annacis Parkway, Unit
Delta, BC V3M 6A2

Tel: 604-666-6033
Fax: 604-666-7112
E-Mail: Ann-Marie.Huang@dfo-mpo.gc.ca

This report is available from the:

Centre for Science Advice (CSA)
Pacific Region
Fisheries and Oceans Canada
Pacific Biological Station
3190 Hammond Bay Road
Nanaimo, BC V9T 6N7

Telephone: 250-756-7208
Fax: 250-756-7209
E-Mail: CSAP@dfo-mpo.gc.ca
Internet address: www.dfo-mpo.gc.ca/csas-sccs

ISSN 1919-5079 (Print)
ISSN 1919-5087 (Online)

La version française est disponible à l'adresse ci-dessus.

CORRECT CITATION FOR THIS PUBLICATION

DFO. 2011. Guidelines for applying updated methods for assessing harvest rules for Fraser River sockeye salmon (*Oncorhynchus nerka*). DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2010/070.