Proceedings of the Technical Expertise in Stock Assessment (TESA) National Workshop on 'Anadromous fish assessment methods', 20-24 November 2017, Moncton, New Brunswick

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2019

PROCEEDINGS OF THE TECHNICAL EXPERTISE IN STOCK ASSESSMENT (TESA) NATIONAL WORKSHOP ON ‘ANADROMOUS FISH ASSESSMENT METHODS’, 20-24 NOVEMBER 2017, MONCTON, NEW BRUNSWICK

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The Technical Expertise in Stock Assessment (TESA) group of Fisheries and Oceans Canada (DFO) held a national workshop on 'Anadromous fish assessment methods', in Moncton, NB from the 20th to 24th of November, 2017. The workshop was chaired by Kendra Holt and Ann-Marie Huang (Pacific Region) and Jamie Gibson (Maritimes Region). It was attended by 24 DFO participants from all 6 regions and three external participants from universities and the Pacific Salmon Commission. The first day-and-a-half of the workshop focussed on individual program presentations (~10 minutes each) given by most workshop participants, which established a basis for discussing common themes and challenges during the remainder of the workshop. Six extended presentations on advanced stock assessment methods that were of broad interest to participants were also given. Topics covered in extended presentations included in-season forecasting using Bayesian methods, life-stage specific population dynamics models, approaches to model selection, data-limited stock assessment methods, and biological reference point theory. In addition to presentations, two mini-workshops on advanced stock assessment methods were run at the meeting. These mini-workshops allowed participants to apply new methods to their data or example datasets. The first of these mini-workshops focussed on Bayesian approaches to stock assessment using OpenBUGS software, while the second focussed on data-limited (or data-poor) assessment methods such as Depletion Corrected Average Catch (DCAC) and Catch-MSY (maximum sustainable yield) models. A mix of plenary and small breakout group discussions were also used to explore common issues and possible solutions. Recommendations for future research included further exploration and application of modelling tools such as hierarchical Bayesian modelling and integrated life history models, which can be used to incorporate historical datasets with missing data or inconsistent sampling protocols into stock assessment advice. Recently developed data-limited assessment tools were also deemed useful for some stocks, but limitations in applying these tools to Pacific Salmon stocks were noted. These Proceedings include presentations, materials used in hands-on data workshops, and a list of recommendations for anadromous species stock assessment at DFO. Public materials are available at:
https://drive.google.com/drive/folders/1df9EmvlIWhjMr3MaLTkeQQEJRWCKO2i-

RÉSUMÉ

Holt, K., Huang, A-M., Gibson, J., and Davis, B. 2019. Proceedings of the Technical Expertise in Stock Assessment (TESA) National Workshop on 'Anadromous fish assessment methods', 20-24 November 2017, Moncton, New Brunswick. Can. Tech. Rep. Fish. Aquat. Sci. 3341: v + 35 p.

Le groupe Expertise technique en évaluation des stocks (ETES) de Pêches et Océans Canada (MPO) a tenu un atelier national sur les méthodes d'évaluation des poissons anadromes, à Moncton, au Nouveau-Brunswick, du 20 au 24 novembre 2017. L'atelier était présidé par Kendra Holt et Ann-Marie Huang (Région du Pacifique) et Jamie Gibson (Région des Maritimes). Vingt-quatre participants du MPO des six régions et trois participants externes d'universités et de la Commission du saumon du Pacifique y ont assisté. La première journée et demie de l'atelier était axée sur les présentations de programmes individuels (environ 10 minutes chacune) données par la plupart des participants à l'atelier, ce qui a permis d'établir une base pour discuter de thèmes et de défis communs pendant le reste de l'atelier. Six exposés détaillés sur les méthodes avancées d'évaluation des stocks qui présentaient un grand intérêt pour les participants ont également été présentés. Les sujets abordés dans les présentations prolongées comprenaient la prévision en cours de saison à l'aide de méthodes bayésiennes, les modèles de dynamique des populations selon les étapes de la vie, les approches de sélection des modèles, les méthodes d'évaluation des stocks limitées en données et la théorie des points de référence biologiques. En plus des présentations, deux mini-ateliers sur les méthodes avancées d'évaluation des stocks ont été organisés lors de la rencontre. Ces mini-ateliers ont permis aux participants d'appliquer de nouvelles méthodes à leurs ensembles de données ou à des exemples de données. Le premier de ces mini-ateliers s'est concentré sur les approches bayésiennes de l'évaluation d'un stock à l'aide du logiciel OpenBUGS, tandis que le second s'est concentré sur les méthodes d'évaluation limitées en données (ou peu documentées) telles que les modèles prises moyennes corrigées selon l'épuisement (Depletion-Corrected Average Catch [DCAC]) et prises-RMS (rendement maximal soutenu). Un mélange de discussions en séance plénière et en petits groupes a également été utilisé pour explorer les questions communes et les solutions possibles. Parmi les recommandations concernant les recherches futures, mentionnons l'exploration et l'application d'outils de modélisation tels que la modélisation bayésienne hiérarchique et les modèles intégrés du cycle biologique, qui peuvent être utilisés pour intégrer des ensembles de données historiques pour lesquels il manque des données ou dont les protocoles d'échantillonnage sont incohérents dans les avis d'évaluation des stocks. Des outils d'évaluation à données limitées récemment mis au point ont également été jugés utiles pour certains stocks, mais on a noté des limites à leur application aux stocks de saumon du Pacifique. Ces comptes rendus comprennent des présentations, du matériel utilisé dans des ateliers pratiques sur les données et une liste de recommandations pour l'évaluation des stocks d'espèces anadromes au MPO. Les documents publics sont disponibles à l'adresse suivante : https://drive.google.com/drive/folders/1df9EmvlIWhjMr3MaLTkeQQEJRWCKO2i

1. INTRODUCTION

The national committee on Technical Expertise in Stock Assessment (TESA) has had a mandate since 2009 to provide training within DFO (Department of Fisheries and Oceans Canada) and to hold workshops that have direct relevance to DFO's capacity to conduct stock assessment. Previous workshops have focused on topics such as incorporating an ecosystem approach into single-species stock assessments, determining reference points under changing productivity regimes, and comparing methods for conducting flatfish stock assessments.

The motivation for the current workshop, "Anadromous fish assessment methods", was based on the recognition that several common challenges arise in the assessment of anadromous species across Canada, and that biologists from the different DFO regions could benefit from sharing methods and expertise that has been developed within each region. For example, common challenges include how to assess total run size by in-season arrivals, the use of reference rivers for data-limited systems, the assessment of at-sea survival and growth, and consideration of hydro impacts. The workshop was intended to create an environment where assessment staff could discuss some of these issues, collectively brain storm about them, and try new methods with their data. The Terms of Reference used to guide the meeting is presented in Appendix A.

The workshop included 27 participants, of which 24 were from DFO. Among the DFO participants, all six DFO regions existing at the time were represented; Gulf, Quebec, Maritimes, Newfoundland & Labrador, Central & Arctic, and Pacific regions (Appendix B). External participants included Catherine Michielsens from the Pacific Salmon Commission, who led a mini-workshop on Bayesian stock assessment methods, and Guillaume Dauphin from the University of New Brunswick, who gave an extended presentation on hierarchical Bayesian models in population dynamics studies.

The structure of the workshop was kept flexible by the meeting co-chairs, with the agenda being revised over the course of the 5 days in response to input from meeting participants (Appendix C). The original agenda included two days of working in small break-out groups in which participants could work through specific ideas and/or challenges and try hands-on applications of new methods to data. Initial discussions at the workshop on how to divide into break-out groups however led to the decision to stay in a plenary format for the majority of the meeting so that everyone had the opportunity to participate in all aspects of the workshop. The resulting schedule included (i) individual program presentations (~10 minutes each) given by most workshop participants, (ii) six extended presentations on advanced stock assessment methods that were of broad interest, (iii) two methods workshops in which advanced assessment models were applied to example datasets by all participants, and (iv) a mix of plenary and small-breakout groups discussions of common issues and possible solutions.

Overall, participants expressed that they appreciated the exposure to a wide range of topics and felt that they were taking home ideas and tools that they could apply to their own work. Specific recommendations that arose from the workshop are summarized in Section 6. This document provides an overview of various aspects of the meeting.

2. INDIVIDUAL PROGRAM PRESENTATIONS

During the first 1.5 days of the workshop, most participants gave a brief (~10 minute) presentation related to their work. Presenters were told ahead of time that the presentations could be relatively informal, and were intended to give an overview of the different approaches and challenges faced in different regions. These presentations proved useful for establishing a basis for discussing common themes and challenges during the remainder of the workshop, as well as introducing participants to each other.

A summary of the assessment methods and programs presented by workshop participants is provided in Table 1.Time was provided at the workshop for each presenter to compile a brief written description of their talk and email it to the meeting co-chairs, which was an efficient way to compile Table 1.

Key themes identified during these presentations included the application of data-limited methods and benchmarks to stock assessment, consideration of time-varying productivity in forecasting, representing uncertainty in in-season management tools, challenges associated with using historical data sets collected using varying sampling methods and data quality over time, and the application of simulation testing to evaluate stock assessment and management approaches.

3. EXTENDED PRESENTATIONS

Prior to the workshop, the co-chairs developed a questionnaire in Google Forms that was distributed to participants to solicit feedback on what they hoped to get out of the workshop. As part of this questionnaire, participants were also asked to identify their level of expertise in several stock assessment topics, as well as whether they would be willing to provide an extended (40 minute) presentation or lead a hands-on analysis workshop on an advanced stock assessment topic.

A number of participants were then invited to give longer presentations based on their willingness and the interests of workshop participants. These presentations are summarized in Sections 3.1 to 3.6 below.

3.1. IN-SEASON ASSESSMENT OF FRASER RIVER SOCKEYE SALMON: THE VALUE OF SEAWARD DATA

Presenter: Catherine Michielsens

In-season assessment of Fraser sockeye (*Oncorhynchus nerka*) stocks relies on a time density model that can be fitted to different pieces of data representing absolute abundance estimates (e.g. reconstructed abundance derived from in-river hydro-acoustic estimates and catches) and relative abundance indices (e.g. test fishery CPUE data). Additional information can be incorporated within a Bayesian version of this model in the form of informative priors on run size, timing and spread of the run. Using 19 years of historical data, a retrospective analyses was run to evaluate the value of the different pieces of data at different times during the season by comparing the in-season run size against the ‘true’ post-season run size estimate. The average run size error is larger for models relying solely on in-river data compared to models relying on data collected in marine areas, even though the river data is of greater quality and less variable than the marine CPUE data. Only once the peak of the run is observed in-river (6 days after the peak has been observed in marine areas), does the model fitted to reconstructed abundance estimates outperform the model fitted to marine CPUE data. In case only marine CPUE data are used, the average run size error does not seem to decrease below 30%. This is due to the uncertainty in the catchability estimate.

Suggested reading / viewing:

The use of Bayesian methods to predict the number of returning Sockeye to the Fraser River (and, who will win the Stanley Cup!): https://www.youtube.com/watch?v=hKpb6Kn2B98

3.2. HIERARCHICAL BAYESIAN MODELS IN POPULATION DYNAMICS STUDIES: APPLICATION TO AN ATLANTIC SALMON POPULATION

Presenter: Guillaume Dauphin

The Allier River's Atlantic Salmon (*Salmo salar L*.) population presents unique features compared to other European populations. This population is characterized by a long distance freshwater migration to reach the spawning grounds (more than 700km from the Loire estuary to the first spawning grounds in the Allier River) as well as a prolonged marine life-stage for most of the individuals (2 to 3 years at sea). In addition, recent genetic studies have shown that the Allier population presents unique genetic characteristics in comparison to other French or European populations. For these reasons this population has a strong conservation value. Following declines in catch, important efforts have been undertaken. These efforts include fishery closures in 1994, the removal of dams or installation of fish passageways to facilitate salmon migration, as well as an intensive juvenile salmon stocking program have been undertaken. Despite these measures, the size of the population remains small in comparison to historical levels.

The model built during this study will bring together 35 years of heterogeneous data in a coherent framework while accounting for uncertainty. The results will show a retrospective estimation of the past abundance of Atlantic Salmon in three different spatial areas of the Allier River as well as the intergenerational renewal rate of the population. One of the main challenges of this modelling exercise is to incorporate the annual stocking data. The model will provide estimates of the contribution of the different categories of salmon life-stage stocked (egg, fry and smolt) over the time series considered. These results will provide useful information to managers to understand the impact of the different restoration program over the last decades in the Allier River and make decision about future programs.

Suggested reading:

Dauphin, G.J.R., Brugel, C., Hoffmann-Legrand, M., and Prévost, E. 2013. Estimating spatial distribution of Atlantic salmon escapement using redd counts despite changes over time in counting procedure: Application to the Allier River population. Ecol. Freshw. Fish, 22: 626-636.

Dauphin, G.J.R., Brugel, C., Legrand, M. and Prévost, E. 2017. Separating wild versus stocking components in fish recruitment without identification data: a hierarchical modelling approach, Can. J. Fish. Aquat. Sci. 74:7-1111.

Dauphin, G.J.R. and Prévost, E. 2013. Viability analysis of the natural population of Atlantic salmon (Salmo salar L.) in the Allier catchment. Indep. Tech. Report.

3.3. MODEL SELECTION & MULTIMODEL INFERENCE BY USE OF LENGTH-AGE GROWTH OF RINGED SEALS

Presenter: Xinhua Zhu

This presentation summarized an analysis of length-age growth models using model selection and multimodel inference (MMI). Eight models were structured to estimate growth patterns in standard length, round weight and girth-at-age of Ring Seals using data collected from yearling and older Ringed Seals collected in Nunavut and Hudson Bay between 1990 and 2015. Models were compared using the deviance information criterion (DIC) which is a model selection index representing model parsimony. DIC weights were also presented, which are used to weight estimates across different models (model-averaging or MMI). Results demonstrated that the von Bertalanffy growth model, which is commonly used, was not significantly supported by the datasets. In association with MMI, the best growth models were used to track the time-varying variation in kernel growth parameters, asymptote length and Brody growth rate, of the animals. Consequently, this sort of annual variation of growth characteristics partially results from adaptation to changing arctic regime such as the fluctuation of days of ice break-ups, temperature, and shifts of prey resources over geographic coverage of Nunavut and Hudson Bay, Canada.

Suggested reading:

Burnham, K.P. and Anderson, D.R. 2002. Model Selection and Multimodel Inference: A Practical Information-Theoretic Approach. New York: Springer.

Claeskens, G. and Hjort, N.L. 2008. Model Selection and Model Averaging. Cambridge University Press.

Panik, M.J. 2014. Growth Curve Modeling: Theory and Applications. Hoboken, New Jersey: John Wiley & Sons

3.4. DATA LIMITED ASSESSMENT OF ARCTIC CHARR IN NUNAVUT, CANADA

Presenter: Ross Tallman

Genus *Salvelinus* (Charrs) have low resilience to harvest. While Arctic Charr stock assessments are challenging, due to paucity of data and the high intra- and inter-stock variability in vital rates, there are now some methodologies that can assist in improving the quantitative nature of assessments. Productivity-susceptibility analysis (PSA) offers a methodology that utilizes the variability of Arctic Charr to analyze a large number of data-limited stocks for the vulnerability to fishing. An illustrative analysis of the vulnerability of 98 Nunavut Arctic Charr stocks was presented. A life history invariant surplus production methodology was paired with the PSA to estimate maximum potential production of stocks. For catch-based data limited methods, case studies were presented to show the use of Depletion-Based-Stock-Reduction Analysis, Catch-Maximum Sustainable Yield Methods, and a comparison of yield and data poor methods against a Bayesian analysis.

Suggested reading:

Dick, E.J., and MacCall, A.D. 2011. Depletion-Based Stock Reduction Analysis: A catch-based method for determining sustainable yields for data-poor fish stocks. Fish. Res. 110: 331-341.

Martell, S., and Froese, R. 2013. A simple method for estimating MSY from catch and resilience. Fish Fisheries Serie. 14: 504-514.

Roux, M.J., Tallman, R.F., and Lewis, C.W. 2011. Small-scale Arctic Charr *Salvelinus alpinus* fisheries in Canada's Nunavut: management challenges and options. J. Fish Biol.. 79:1625-1647.

Stobutzki, I., M. Miller, and Brewer, D. 2001. Sustainability of fishery bycatch: A process for assessing highly diverse and numerous bycatch. Environ. Conserv. 28: 167-181.

3.5. ESTIMATING LIFE STAGE SPECIFIC SURVIVAL RATES USING MATURITY SCHEDULE METHODS

Presenter: Gerald Chaput

Anadromous fishes provide opportunities for enumerating abundances at different life stages (for example smolts going to sea and adults returning from the ocean). These data can then be used to estimate return rates which are often used as proxies of survival rates. However, return rates are not equivalent to survival rates with the exception of stocks where adults mature and return exclusively at one single sea age. In all other situations, return rates are the product of survival rates and maturation rates. Maturity schedule methods that consider additional life history components, such as male and female abundances, provide an opportunity to disentangle survival rate from maturation rate processes under limited simplifying assumptions. Examples of the application of the maturity schedule to estimate the survival rates in the first and second years at sea and the probability of maturing after one year at sea of Atlantic Salmon were shown. Observations from a salmon population with a single dominant age at maturity were used to validate the assumption of similar survival rates of male and female salmon. Maturity schedule methods can be generally applied to species with multiple ages at maturity, given additional information on abundances of males and females at age.

Suggested reading:

Chaput, G., Caron, F., and Marshall, L. 2003. Estimates of survival of Atlantic salmon (*Salmo salar* L.) in the first and second years at sea. In Marine mortality of Atlantic salmon, *Salmo salar L*.: methods and measures. Edited by E.C.E. Potter, N.O. Maoileidigh, and G. Chaput. Can. Sci. Advis. Sec. Res. Doc. 2003/101. pp. 83–109.

Hoenig, J.M. and Hewitt, D.A. 2005. What can we learn about mortality from sex ratio data? A look at lumpfish in Newfoundland. Trans. Am. Fish. Soc. 134: 754-761.

Hubley, P.B., and Gibson, A.J.F. 2011. A model for estimating mortality of Atlantic salmon, *Salmo salar*, between spawning events. Can. J. Fish. Aquat. Sci. 68: 1635-1650.

3.6. BIOLOGICAL REFERENCE POINTS

Presenter: Jamie Gibson

Biological reference points are metrics based on the biological characteristics of a fish stock and its fishery. They provide the link between stock assessment and management objectives, and are used to gauge whether management objectives are being achieved. They are fundamental for the assessment of fish stocks: abundance, biomass and fishing mortality values provided by an assessment are compared against the reference points to determine whether or not overfishing is occurring and whether or not the stock is in a depleted state.

Fisheries and Oceans Canada has adopted a precautionary approach (PA) to the management of fisheries (DFO 2006) which outlines the role of reference points for the management of Canadian fisheries. Stock status zones (“healthy”, “cautious” or “critical”) are delineated by the Limit Reference Point (LRP) defining the critical to cautious boundary, and an Upper Stock Reference (USR) defining the cautious to healthy boundary. The LRP ideally represents the stock status below which serious harm occurs to the stock and should be well above the level where the risk of extinction or extirpation is likely. The USR defines the point at which removals must begin to be reduced in order to avoid reaching the LRP. A Target Reference Point (TRP) may be defined in the DFO Decision-making Framework Incorporating the Precautionary Approach (DFO PA Framework; DFO 2009). It should be equal to or greater than the USR and represents a stock status goal that the management system is intended to achieve. A removal reference is also defined relative to the stock status zones as the maximum acceptable removal rate from all types of fishing and other human activities. This rate in each of the three zones (“healthy”, “cautious” or “critical”) should not exceed the removal reference in the healthy zone. The removal reference will vary depending on the stock’s location in each of the zones.

Biological reference points are typically related to the concept of maximum sustainable yield (MSY), including the fishing mortality rate (F_{MSY}) and biomass (B_{MSY}) that maximize the yield from the fishery. Although there are other approaches, a production model consisting of three components are often used to estimate these values. The first component is the stock-recruitment relationship, which models the density-dependent production of recruits as a function of spawner biomass. The second component is the spawner-biomass-per-recruit relationship, which models the lifetime production of spawner biomass by an individual recruit. The third component is the yield-per-recruit relationship, which models the yield produced by an individual recruit. Each model component is specifically tailored to the life history of the species or population being evaluated, as well as to the characteristics of its fishery.

Uncertainty in reference point development may be addressed in several ways. If there is insufficient information to parameterize the full model, proxies for MSY based on one model component are often used. For example, the reference point $F_{35\%}$ is the fishing mortality rate that reduces the spawner-biomass-per-recruit to 35% of its unfished level. Bayesian and decision-theoretic approaches have been shown to perform well when there is uncertainty in the underlying relationships or when data are noisy.

Suggested reading:

DFO. 2006. A Harvest Strategy Compliant with the Precautionary Approach. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep.2006/023.

Gibson, A.J.F., and Myers, R.A.. 2004. Estimating reference fishing mortality rates from noisy spawner-recruit data. Can. J. Fish. Aquat. Sci. 61: 1771-1783.

Mace, P. M., and Sissenwine, M.P.. 1993. How much spawning per recruit is enough? p. 101-118. In S. J. Smith, J. J. Hunt and D. Rivard [ed.] Risk evaluation and biological reference points for fisheries management. Can. Spec. Pub. Fish. Aquat. Sci. 120.

Michielsens, C.G.J., and McAllister, M.K.. 2004. A Bayesian hierarchical analysis of stock-recruit data: quantifying structural and parameter uncertainties. Can. J. Fish. Aquat. Sci. 61: 1032-1047.

Sissenwine, M. P., and Shepherd, J.G. 1987. An alternative perspective on recruitment overfishing and biological reference points. Canadian Journal of Fisheries and Aquatic Sciences 44: 913-918.

Examples of adapting the life-cycle-based production model to diadromous fish:

Gibson, A.J.F., and Myers, R.A. 2003a. Biological Reference Points for Anadromous Alewife (*Alosa pseudoharengus*) Fisheries in Atlantic Canada. Can. Tech. Rep. Fish. Aquat. Sci. No. 2468.

Gibson, A.J.F., and Bowlby, H.D. 2013. Recovery Potential Assessment for Southern Upland Atlantic Salmon: Population Dynamics and Viability. Can. Sci. Advis. Sec. Res. Doc. 2012/142.

4. WORKSHOPS

Two mini-workshops on assessment methods were run at the meeting, which allowed participants to apply new methods to their data or example datasets. Presentations, exercise descriptions, code, and sample datasets used for the data limited workshop are available to participants (and other interested parties) at: https://drive.google.com/drive/folders/1df9EmvlIWhjMr3MaLTkeQQEJRWCKO2i-

Those interested in Bayesian methods are encouraged to contact Dr. Catherine Michielsens at the Pacific Salmon Commission for future workshop dates.

Workshop topics and leaders were determined prior to the meeting based on feedback from the participant questionnaire. An overview of each of these workshops is provided below.

4.1. BAYESIAN METHODS: INTRO TO BAYES & BEYOND BASIC BAYES

This workshop, which was led by Dr. Catherine Michielsens from the Pacific Salmon Commission, was split into two parts: “Intro to Bayes” and “Beyond Basic Bayes”. Dr. Michielsens provided presentations linked to each of the two topics, as well as a set of hands-on exercises.

The “Intro to Bayes” session included an explanation of Bayes’ theorem and the principles of using prior information, as well as a comparison of Bayesian and frequentist statistics. A basic introduction to BUGS software and its syntax was also given. A brief explanation of Markov chain Monte-Carlo (MCMC) was given, including a description of convergence and convergence diagnostics. A simple linear regression exercise was used to introduce the group to Bayesian modelling, with step-by-step instructions provided on using WinBUGS (or OpenBUGS) to fit a linear regression model and assess convergence. Documentation for the exercise also included a list of suggested readings, and plots of discrete and continuous statistical distributions that may be useful for model specification.

The “Beyond Basic Bayes” session covered the principles of hierarchical models, and how to implement Bayesian hierarchical models. Examples of possible applications to challenges that came up during the workshop included estimating productivity for data-limited Arctic Charr stocks, or fecundity for Atlantic Salmon stocks. A multi-stock Ricker stock-recruitment analysis was used as an example during this session. Recursive Bayesian models, which allow parameters to vary over time, were also covered, with a Ricker stock-recruitment model with time-varying productivity used as an example.

A comparison of software used for Bayesian analysis was also provided, including WinBUGS, OpenBUGS, JAGS, and STAN. A basic example of a linear regression using STAN syntax was given. MCMC efficiency was discussed, including a comparison of Gibbs, Metropolis and No-U-Turn samplers.

To support topics covered in the “Beyond Basic Bayes” session, the following set of hand-on data exercises were provided by Dr. Michielsens that participants could use to further learn about the topics covered:

1 Stock-recruit analysis including time-varying productivity;

2. Hierarchical model structure using stock-recruit data;

3. In-season run size estimation using two different CPUE datasets;

4. Using WinBUGS, JAGS and Stan in combination with R;

5. Simple mark-recapture models using binomial, beta and Poisson distributions;

6. Using tagging data to estimate recapture probabilities; and

7. Using tagging data to estimate exploitation and abundance of fish.

Workshop participants were then given time within the workshop to try out the exercises that were most relevant for their assessment needs. As part of these exercises, participants were encouraged to adapt code to achieve exercise tasks, and apply to their own data if available. Dr. Catherine Michelsens and Dr. Guillaume Dauphin were available during this time to help with technical support / debugging as needed.

Group Discussion & Conclusions:

- Hierarchical Bayesian modelling tools are well-suited to salmon stock assessment work, in which there are intensively studied index streams that can be used to make inferences about non-index streams.
- Participants found this workshop very useful as an introduction to Bayesian topics. However, a multi-day workshop dedicated to Bayesian methods for anadromous assessments would be desirable for those seeking to apply them in their own stock assessments.
- Communication of results and uncertainty from Bayesian models takes some practice, but can be more intuitive to interpret for managers and interest groups than results from frequentist statistics.

4.2. DATA-LIMITED METHODS

This workshop was led by Ross Tallman and Samantha Fulton from the Central and Arctic Region of DFO. Data-limited (also called data-poor) methods were introduced as an innovative solution to the common problem of data deficiency. About 90% of worldwide fisheries are described as data limited. However, participants were cautioned not to use these methods as an excuse to collect fewer data, since they require many assumptions that can prove problematic. The application of the precautionary approach in data-limited situations is suggested.

The data workshop leads presented the theory and rationale behind two data-limited methods that have been applied to marine fish species: Depletion-corrected Average Catch (DCAC; MacCall 2009) and catch-MSY (Martell and Froese 2013).

MacCall (2009) states that “data-poor fishery analysis must often be content to simply estimate a yield that is likely to be sustainable.” DCAC is a data deficient method which only requires the total summed catch across years and an idea of the relative depletion, *M* (mortality), and the proportional relationship between F_{MSY} and *M*. By correcting for an underlying depletion through a windfall ratio, we can estimate a yield based on catch which is likely to be sustainable. Alternatively, Catch-MSY requires a time series of catch and an approximation of upper and lower bounds of *r* (resilience, see Musick, 1999), *K* (carrying capacity), and starting and ending biomass relative to B_0. Using a Schaefer production model, *r-K* pairs are randomly selected, and biomass is projected forwards through the time series of catch. *r-K* pairs which result in an unlikely final biomass are rejected, leaving you with a relatively small number of plausible *r-K* pairs given the catch data. The accepted *r-K* pairs can then be used to calculate management quantities such as MSY, B_{MSY}, and F_{MSY}.

R code providing examples of DCAC, Catch-MSY, and sensitivity analyses were provided by the workshop leads. Additional sample data sets with catch data for Fraser Sockeye, Atlantic Salmon, and Gaspereau River Alewife (*Alosa pseudoharengus*) were provided to the group by workshop participants. All participants were given time to work through the example code using the various data sets.

Group Discussion & Conclusions:

- The importance of the input values of *r*, *M*, and *K* was illustrated through sensitivity analyses on the various datasets. Similarly, the Alewife dataset highlighted that status estimates were highly sensitive to changes in a single year of catch data.
- Questions were raised about how these models deal with high variation in catch due to environmental effects and whether the surplus production model is suitable for relatively short-lived anadromous species with high levels of natural mortality. The group believed

that models that were more biologically appropriate for short-lived anadromous species should be explored using these types of frameworks.

- The question was raised of whether these data-limited methods can be justified when highly uncertain assumptions are required about *r*, *M*, and *K*, or whether DFO Science is better to just say "we don't know". The group generally agreed that using these methods is preferable to not providing advice, given that they at least provide a clear, transparent basis for decisions that need to be made one way or another.
- These methods did not seem suitable for stocks harvested in mixed-stock fisheries such as Pacific Salmon for several reasons, including:
    - We often don't have stock-specific catch for Pacific Salmon. Escapement data is more readily available at the stock level. Unfortunately, it is challenging to separate out harvest versus environmental drivers of escapement change.
    - Cyclic stock dynamics in the Fraser Sockeye population was identified as a major complicating factor that would render these analyses less accurate. The DCAC catch was way higher than the 2016 catch.

5. PLENARY DISCUSSIONS & BREAKOUT GROUPS

Three focal topics were identified for plenary discussion after the first two days of the workshop: (i) methods and terminology used to define reference points, (ii) tools and approaches for model selection, and (iii) how to deal with the limitations and challenges of using historical datasets of varying quality. In addition, two break-out groups were used to inform the model selection discussion. A summary of each of these discussions is provided in Sections 5.1 to 5.3 below.

5.1. REFERENCE POINTS (PLENARY)

This session focussed on identifying differences in terminology used among different regions within DFO when discussing reference points. The decision to add this discussion topic to the agenda was made early in the workshop when it became clear that terminology differed among regions.

Participants from the Pacific region described that they use the word "reference point" exclusively to refer to fishery reference points that define changes in the harvest control rule. Fishery reference points can be designed to incorporate both biological and socio-economic considerations. For example, the "Limit reference point" and "Upper stock reference", as defined in the DFO PA Framework, are considered fishery reference points (DFO 2009). Within the DFO PA Framework stock abundance is split into critical, cautious, and healthy zones delineated by these values (DFO 2009). When a population is in the healthy zone a particular removal rate will be used, which declines as the stock moves through to the cautious zone, and approaches zero (or very low) as the population declines towards the critical zone. In contrast, the term "biological benchmarks" are used when assessing population status under Canada's Policy for Conservation of Wild Pacific Salmon (also referred to as the Wild Salmon Policy; DFO 2005), and do not incorporate socio-economic considerations. Status relative to benchmarks may be re-assessed periodically, depending on generation time, and are taken into account when determining the shape and inflection points of the harvest control rule, but do not affect fisheries management directly. This differentiation between "fishery reference points" and "biological benchmarks" has been described by Holt and Irvine (2013).

Participants from other regions noted that such a differentiation between benchmarks and reference points is not generally made in their work, and that “reference points” was the term used for both.

A desire to make terminology consistent across DFO regions was expressed, and the benefits of having a separate terminology to reflect fishery decision-making based on socio-economic objectives was agreed upon.

5.2. MODEL SELECTION (PLENARY & BREAKOUT GROUPS)

This start of this discussion drew upon the material presented by Dr. Xinhua Zhu in his plenary presentation titled “Model Selection and Multimodel Inference (MMI)” (Section 3.3). Different options were explored for interpreting the results presented by Dr. Zhu. From DIC values an analyst can either select the “most parsimonious” model as indicated by DIC, or alternatively weight across models using model-averaging techniques. It was suggested that when using model averaging, a limited number of candidate models should be considered; for example, when DIC weights of zero are given for some models these models should not be included in model-averaged estimates.

Participants noted that when using model averaging to estimate parameters across models, such as animal growth, models must be nested (i.e., have the same structure and parameterization). However, if you’re looking at model predictions that are on the same scale across models (e.g., abundance forecasts), there is no need for models to be nested. The latter is particularly relevant to fisheries stock assessment to support management decisions. There was a consensus among the group that it is important to run different model forms that could illuminate relationships that weren’t seen before, but no consensus was reached by the group on whether a certain model-selection technique or model-averaging technique was best.

The importance of fitting alternative models with environmental co-variates was also discussed. Even if these models don’t turn out to be the “best”, they can highlight the conditions during which a certain environmental factor may become important, even if it hasn’t been historically important in all years. It was argued that model selection shouldn’t be solely based on an information criterion like DIC or AIC, and that multiple criteria be used, along with group discussion and expert opinion. It was argued that model averaging doesn’t necessarily make an estimate more “right”, and could possibly lead to a loss of information, as certain models may be “glossed over” that represent important relationships.

As an example of this point, Sue Grant presented a slide and explained how different forecasting models are presented in the annual Fraser Sockeye forecast. In this application no AIC-like model criterion is used. Instead models are ranked based on indicators of retrospective performance (how well they explain past population dynamics) and the top four models are presented with their associated uncertainty. This way managers can see the uncertainty across, and within, models at the same time. The forecast also includes qualitative caveats that communicate model assumptions in order to help managers identify models that are logical from a biological perspective.

At this point in the meeting, two break-out groups were established to further discuss topics related to model selection. The first group focussed on model selection methodology, as well as how to incorporate model uncertainty into management advice (Section 5.2.1). The second group focussed more broadly on the types of models available to solve specific challenges posed by participants in that groups (Section 5.2.2). At the end of the break-out group sessions, the workshop reconvened a plenary discussion to share break-out group results (Section 5.2.3).

5.2.1. Breakout Group 1: Model Selection Methodology

In this breakout group several issues surrounding model selection and presenting model uncertainty were discussed. The situation where different models produce very different outcomes was a focus, as this situation is hard for scientists to interpret, and hard to convey to decision-makers or managers. Notes from these discussions are as follows:

Quantitative model selection vs. biological plausibility

- There are currently two broad ways to select between models: (i) considering the biological plausibility of model parameters, and (ii) using quantitative model selection criteria (AIC, DIC, etc.). The most appropriate approach can vary on a case-by-case basis, and will depend on the intended application of the results. There may be cases where biological understanding could "trump" quantitative criteria.
- Data limitations and model assumptions must be considered when choosing among models, including how pre-treatment of the data may affect model outcomes.
- The steps taken in a model selection or model-averaging analysis requires subjective methodological choices, so the resulting choice may not be completely objective.

Presenting models and uncertainty to decision-makers or managers

- Presenting a suite of models can be overwhelming to managers. Furthermore, when presenting to managers it can be hard to have them consider the full range of uncertainty; there tends to be a focus on the point estimate, rather than the range of possible values.
    - Consistent messaging over time from multiple sources can help people understand and accept uncertainty, rather than just looking at median/mean estimate.
    - May be useful to educate scientists on providing advice in a more understandable way, and educate managers on interpreting uncertainty.
- There is a tendency to dwell on those years where the model did not perform well, and that led to unfavourable outcomes, rather than take estimated model uncertainty as the truth. Models don't often perform well over long time-frames, so years where the model fit poorly can generally always be pointed out. There is often a tendency for extreme events to influence someone's trust in a model.
    - Instead of just presenting models and weights, it may be useful to present models in the context of a biological narrative, i.e. if you assume productivity has increased you might expect X, if you assume it is decreasing, you might expect Y.

Integrating probability and risk into advice

- How can we convey risks associated with management decisions?
    - Rather than just presenting confidence intervals or posterior distributions around estimates it is useful to associate real risks/consequences to assuming a parameter is at the mean estimated level. For example, presenting possible outcomes if the parameters were actually at the extreme bounds of confidence intervals (i.e., if a population's abundance or productivity was currently at the lower confidence bound), and the risks associated with these extreme cases.
    - Important to connect probabilities to actions i.e., If you do X, you increase the risk of Y.

Management strategy evaluation (MSE) is a framework that can help to explain longer-term risks of short term actions.

5.2.2. Breakout Group 2: How to Select a Modelling Approach

In this breakout group, participants outlined challenges they currently encountered in their assessment programs linked to data availability and quality, and the group brainstormed possible modelling tools or techniques they could consider given these limitations. Notes from these discussions are as follows:

Changes in survey methodology

- Challenge: How to develop a framework that allows comparison of abundance estimates before and after a change in assessment methodology. A participant identified a situation where mark-recapture methods were used historically to estimate Atlantic Salmon spawning abundance, but now a combination of snorkel surveys and recreational catch data are used, as an example of a change in methodology.
- Group recommendations: There are many examples of models that combine indices of abundance where the survey methods have changed through time. Many marine stock assessments have addressed this issue. For the Atlantic Salmon example above, a Bayesian integrated modelling approach has been developed that uses all data (recreational CPUE, snorkel abundance, periodic mark recapture surveys), and that explicitly considers the varying levels of uncertainty associated with each data type via weighting of the likelihoods in the model (e.g., Gibson and Bowlby 2009, Gibson et al. 2015). Using information about the life cycle of the species or population is helpful when determining how to link various indices together.

How to constrain estimation to realistic values given data limitations

- Challenge: Initial attempts at a more model-based assessment method that better represents uncertainty provides unrealistic results. A participant from Pacific region described how older area-under-the-curve (AUC) methods are used to estimate Pacific Salmon escapement from stream counts. Assessment biologists working on these stocks would like to switch to maximum-likelihood methods, but they seem to produce unrealistic estimates of escapement.
- Group recommendations: It was suggested that a Bayesian approach be used that could use priors to constrain values within a “realistic” range. Also, hierarchical models were also suggested, which could “borrow” information from other systems.

Using historical and incomplete data

- Challenge: How to infill historical and incomplete data. A participant brought up a scenario where a population of lake trout were overfished and are now commercially extinct, so catch data only exists historically. However, historic data is inconsistent in terms of spatial scale and effort and no log book program existed historically. Concerns about catch patterns changing over time such that local depletions cannot be traced in catch. However, evidence of local depletions exists within life history traits.
- Group recommendations: Look at catch rates now and then create historical scenarios that reconstruct effort as a series of sensitivity analyses.

  - Reconstruction scenarios could be based on qualitative anecdotal information such as number of fishers, number of vessels, interviews or traditional knowledge.
  - Leverage information that is known, such as where high abundance areas are, what abiotic factors affect distribution, etc.

Dealing with changes in abundance

- Challenge: A participant described a scenario where Ricker models were being fit to several populations over the last 20 years. Historical population levels were much higher than those seen today. How can historical data be used, despite changes in population levels?
- Group recommendations: Investigating whether the physical environment has changed, since that would be what controls capacity of each population. Suggests it might be possible to reconstruct historical carrying capacity. Habitat-based methods are used in lots of systems to estimate carrying capacity (e.g., Parken et al. (2006) for BC Chinook, other examples where rearing lake size is used to estimate Sockeye carrying capacity)

5.2.3. Model Selection Plenary Discussion

The follow-up plenary discussion on model selection focussed on linking model selection to fishery decision-making.

- Rather than focussing too hard on model selection techniques to identify a single “best model”, a better approach is to communicate the risk of choosing one model over another. Sensitivity analyses of key structural assumptions within a stock assessment model are one approach for communicating risks associated with different model selection decisions to managers.
- A more important exercise than standard model selection might be to ask: how are we using the model outputs to inform advice? More complex biological models may not be the best choice for stable, long-term management.
- Some of the individual presentations focused on management strategy evaluation (MSE). One individual pointed out that those presentations caused a shift in their thinking away from trying to come up with the best model and estimates given limited data, and towards trying to provide the best advice for fishery decision-making given these limitations. MSE provides an alternative method for model selection that focuses on management outcomes rather than statistical model fits.

5.3. HISTORICAL DATA (PLENARY)

The use of historical data was a recurrent topic in previous plenary and breakout discussions, so a decision was made to allow for a more detailed examination of this issue as a dedicated plenary topic. Some prominent questions that arose throughout the workshop included:

- I have discontinuous data with different gears and/or sampling techniques – how can I combine them to make a longer time series?
- Is it better to only use recent data that you have more confidence in, and leave out historical (more uncertain) data when doing stock-recruitment analysis?

- How can you use historical data in a current management context? Problems may arise if benchmarks are set according to historical population "potential", and current capacity and/or productivity is different than that seen historically.
- How can you deal with regime shifts during the data period?

Discussion points related to modelling tools that could be used to incorporate historical data were as follows:

- Level of confidence in data should be an important consideration when deciding how to use historical data.
  - If you have confidence in historical data it should be used. Integrated modelling techniques that allow incorporation of heterogeneous data, such as that described by Dr. Guillaume Dauphin in his extended presentation (Section 3.2) may be useful.
  - If confidence is low, one can try to account for this during model-fitting by allowing larger uncertainty for these data, and therefore affording them less weight. There is generally always some signal in a data set, and there should be reluctance to just "toss" anything out.
  - A state-space modelling framework can be useful for dealing with many of the mentioned issues.
- Data exploration is important. One should always look at time-varying covariates and look at changes in parameter values over time (e.g., productivity, reference points). Looking at residual errors over time can help identify periods where changes occurred. Pay attention to shifting baselines. "Normal" shouldn't just be based on what we remember or good data. It is important to question whether a population has the capacity to rebound from a current exploited/shifted state.

Our discussion of the challenges in incorporating historical data into stock assessment analyses highlighted the importance of providing context around data sets using metadata. Information about the design of sampling programs is important context for all datasets, and raw data cannot be handed over without this information. It was also noted that metadata is critically important if there is intent to carry out larger meta-analyses and collaborations across regions.

Additionally, values that are considered data are often not data at all; rather they are outputs of simple spreadsheet models that use infilling and unknown expansion factors. In such cases, analysts often aren't given the tools to be able to reproduce these "data" and trace their source back to raw data.

The following recommendations related to data and metadata storage were made by the group:

- DFO data reports are extremely valuable; time should be allocated to creating them.
- Automation of report making (using tools such as knitr/R Markdown) may be a way to reduce time required for data reports. It is then possible to format a document and "turn the crank" each year with much less effort than starting from scratch.
- Documenting models is also important and GitHub may be a useful tool for storing code and model documentation.
- To ensure that data aren't lost due to changes in technology, data should be stored in flexible file formats (e.g., csv files). This point also applied to model code.
- Need to make sure raw data isn't thrown out once estimates are made. Both the raw data and the analysis or grooming of the raw data should be maintained and documented.

- Depending on the context, using previously derived estimates can be fine and can save considerable work in re-doing necessary analyses and data tidying; however, the underlying data and analysis assumptions should not be lost.

6. OVERALL SUMMARY AND RECOMMENDATIONS

Having an assessment training workshop based on models suited to anadromous life histories was useful. The suite of challenges faced in assessments tends to be specific to this life history, which are typically only observed during their freshwater life history stages.

Incorporating historical datasets into current stock assessment advice was identified as a major challenge for anadromous species assessment programs throughout DFO given often patchy coverage and/or unknown or inconsistent sampling methodology dispersed over multiple spawning sites. This workshop exposed participants to modelling approaches that could assist with this challenge, including hierarchical Bayesian modelling (HBM) and integrated models, and included a mini-workshop in which participants were able to set-up and run an HBM stock-recruitment analysis in OpenBUGS. HBM is particularly suited to multi-stock (or multi-stream) stock assessments, which is often the case for anadromous species, because it allows information from data-rich indicator streams to be shared with data-limited streams.

For some species, historical datasets are lacking altogether, or deemed unreliable. In these cases, data-limited stock assessment tools may be a better alternative than making management decisions in the absence of science advice. Two types of data-limited assessment methods were explored by workshop participants in a mini-workshop: DCAC and Catch-MSY.

Several participants noted that a significant benefit of this workshop was the opportunity to connect and network with salmon stock assessment staff from various DFO regions. These connections have the potential to improve collaboration and knowledge sharing in the future, and could strengthen CSAS review processes by drawing from a broader range of participants and reviewers.

The main recommendations regarding anadromous species stock assessments at DFO are:

- Further exploration and application of modelling tools such as HBM and integrated life history models that can be used to incorporate historical datasets with missing data or inconsistent sampling protocols into stock assessment advice.
- Improved documentation of current data collection programs, possibly through the Canadian Data Report of Fisheries and Aquatic Sciences series, is needed to ensure that future stock assessment work has an appropriate level of metadata available. Automation of report writing using tools such as knitr/R Markdown could improve the efficiency of this work.
- While data-limited methods such as DCAC and Catch-MSY require substantial assumptions, these methods are preferable to not providing science advice. However, challenges were identified in applying these methods to Pacific Salmon at the workshop. Application of these methods to Pacific Salmon stock assessment is not recommended at this time.
- More clarity and standardization of the terminology used to describe different types of reference points and benchmarks would improve communication of methods and approaches among regions. The Wild Salmon Policy and the DFO PA Framework use different terminology, which has led the Pacific Region to develop a clear delineation between “biological benchmarks” and “fishery reference points” that is not used elsewhere.

- Develop a networking platform or working group that facilitates long-term collaboration among DFO scientists and biologists working on anadromous species stock assessment.

7. LITERATURE CITED

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Table 1. Overview of assessment methods and programs presented by workshop participants.

Species	Region	Presenter	Presentation Summary	Methods highlighted
Dolly Varden Arctic Charr	C & A	Xinhua Zhu	As salmonid fisheries have developed in the arctic, community members have expressed concerns about sudden decreases of fisheries catches. Through data exploration, we identified that there are a number of issues related to the quality of dataset, such as outliers, zero catch, autocorrelation, and temporal variation of environmental variables. Incorporated with these uncertainties, model selection and multi-model inference (MMI) have been adopted to standardize catch per unit effort (CPUE), resulting in the inclusion of hurdle and zero-inflated negative binomial models. MMI was applied to model parameters of three candidate models: depletion-based stock reduction analysis (DBSRA), surplus-production model and statistical catch-at-age model (SCA). Through this exercise, we strongly recommended the use of model selection and MMI to maximize the capacity of community-based monitoring information collected.	Model selection & multi-model inference Data-limited methods
Arctic Charr	C & A	Ross Tallman	Arctic Charr fishery assessments are challenging because of the geographical scale and the physical isolation of the North, the multitude of stocks, the expense and complexity of monitoring within a land claim area, all resulting in a paucity of data. To handle the problem, fisheries are classified into 5 types: national priority stocks (8 stocks); regional priority stocks (6); remaining commercial stocks (187); emerging-exploratory (~20 and increasing); food security (unknown) with expectation of data collection and assessment scaled for each. Other than the national priority stocks, stock assessments are likely to rely on data-limited models, such as catch-based, productivity-susceptibility, and landscape correlated estimators and indicators of stock health.	Stock classification and prioritization for stock assessment Assessment methods for northern stocks
Dolly Varden Arctic Charr	C & A	Kimberly Howland	Formal DFO Canadian Science Advisory Processes and renewal of an Integrated Fisheries Management Plan (IFMP) with stock assessment advice and overarching guidelines for management are conducted on a 5-year cycle. Scientific assessments are based mainly on population abundance estimates obtained through mark-recapture studies that are conducted anywhere from every 1-3 years. Harvest control rules, formalized in the IFMP are to maintain the catch below 5% of the most current population abundance estimate for the fishable component of a	Mark-recapture Alternative data sources Data-limited methods

			given stock. Given the variance around abundance estimates, additional indicators of stock abundance (e.g., size and age structure, recruitment, proportion of spawners, local harvester observations) are also taken into consideration for setting harvest levels. Where there are sufficient data stock assessment modelling (surplus production, DBSRA, SCA) has been conducted to corroborate estimates of abundance and sustainable harvest levels. The current assessment approach appears to work well in the context of co-management and has led to recovery and current stability in populations that were previously depressed through a combination of overharvest and possible environmental effects.	
River Herring	MAR	Mark Billard (Acadia University)	Several types of catch curve models and statistical catch-at-age models are tested using data simulated from a forward-projecting age-structured population dynamics model for Alewife in the Margaree River, Nova Scotia. Stock assessment model performance is assessed under a variety of different levels of exploitation, variability in recruitment/age-at-maturity, sample sizes, and with and without including previous spawning history data. Performance metrics such as percent bias and interquartile spread are used to assess model performance. Results of model performance will be incorporated into a framework for assessing river herring in the Maritimes Region	Simulation testing Catch curve analysis Statistical catch-at-age models
River Herring	MAR	Jamie Gibson	Maritimes Region’s Emerging River Herring Assessment Program Alewife (*Alosa pseudoharengus*) and blueback herring *(Alosa aestivalis*) are diadromous species of fish that are collectively referred to as River Herring. River Herring return to many of the river systems in Nova Scotia and Southwest New Brunswick and are fished together as “gaspereau”. The fishery is geographically widespread, with fishing practices and gear types that differ among rivers, and is managed primarily through effort controls. Within the Maritimes Region, the status of river herring stocks has not been regularly assessed. Towards the goal of developing an on-going monitoring and assessment program, an assessment framework was undertaken to provide an overview of: 1) the spatial scale for assessment and identification of stock units; 2) reference points against which status could be evaluated; 3) monitoring methods; 4) analytical methods; and 5) research recommendations, taking into account DFO’s PA Framework for fisheries management (DFO 2009).	Catch curves Multiple stocks Life history-based catch-at-age models

			River herring have a high degree of fidelity to natal rivers, therefore the populations of each species in individual rivers are considered to be discrete. Reference points are well developed for alewife and are defined on two axes: one that identifies whether overfishing is occurring, and one that identifies whether abundance is in the critical, cautious or healthy zones. Reference points for blueback herring have not been developed. Monitoring and assessment approaches differ depending whether data are fishery dependent or independent. With fishery-dependent data only, in the short term, status can only be assessed relative to fishing mortality reference levels, whereas in the longer term, statistical catch-at-age (SCA) models, which are well developed for at least alewife, can be used to estimate both abundance and mortality rates enabling status evaluations on both axes. Research that helps to: (1) apportion landings from mixed-stock fisheries to specific stocks; (2) improve our understanding of how other human activities affect stocks (e.g. efficiency of fish passage facilities, survival at dams, increased habitat via reservoir construction); and (3) test the effectiveness of assessment models, is anticipated to significantly improve advice within DFO's PA Framework (DFO 2009).	
Atlantic Salmon	Gulf	Guillaume Dauphin	Electrofishing is a commonly used technique to assess freshwater fish population abundance and in many programs, there has been a shift in the sampling methodologies towards less laborious techniques. These new techniques usually only provide an index of abundance and require calibration with other sampling methods such as successive removal to be used for absolute abundance estimation. Using data for juvenile Atlantic Salmon collected in 400 sites sampled over 21 years in two large Canadian river catchments (Miramichi and Restigouche) with a unique original sampling protocol, the hierarchical Bayesian model that we developed allowed the identification of significant effects of effort, day of sampling, area of the site, and catchment on the relationship between the single pass index of abundance and the fish densities. This illustrates the importance of carrying out a calibration exercise on a regular basis. Our work indicates that calibration relationships can change over time, even under controlled sampling protocols, and that these directional changes in important components of the sampling procedure can bias the estimate of population abundance and misinform the understanding of population dynamics.	Sampling methodology Bayesian hierarchical modelling

Atlantic Salmon	MAR	Alex Levy	An overview of Atlantic Salmon assessments in the Southern Upland and Eastern Cape Breton of DFO's Maritimes Region was provided. The Southern Upland and Eastern Cape Breton Atlantic Salmon designatable units (DUs) have been assessed by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) as Endangered and are under consideration for listing under the Species at Risk Act (SARA). Monitoring, generally consisting of counts and mark-recapture experiments, is conducted annually on index populations to estimate abundance/juvenile densities relative to reference values to provide advice to DFO clients and external stakeholders on the status of salmon resources and for use in assessing the recovery potential of these at-risk populations.	COSEWIC/SARA Mark-recapture Recovery potential analysis
Atlantic Salmon	Gulf	Ross Jones & Sarah Tuziak	Evaluation of the status and trends of Atlantic Salmon in the Inner and Outer Bay of Fundy (IBoF and OBoF, respectively) regions is based on abundance monitoring of parr, pre-smolt, smolt and adult returns on a number of index populations. Conservation and assessment projects for these 'endangered' populations are currently focused on two rivers in the IBoF region (i.e. Big Salmon and Gaspereau) and two rivers in the OBoF region (i.e. Tobique and Nashwaak), which rely greatly on established partnerships with local First Nation communities and conservation groups. Assessment challenges are usually associated with estimating total abundance from partial counts of returning adults (e.g. dive surveys, counting fences), pre-smolts/smolts (i.e. rotary screw traps and surface bypasses) and parr (i.e. electrofishing surveys). Within the IBoF DU we assess returns to index populations using actual fish counts through swim surveys (Big Salmon) and hydrodam fish passage (Gaspereau), however for a number of other IBoF rivers we rely on estimates using historical data sources, such as previous program-related fish releases (unfed fry, parr, smolt, adults) and electrofishing surveys. These return estimates are based upon data derived (e.g. survival rates) from the Big Salmon River, as it has the most robust dataset and we are able to trace the origin of our returns through genetics. Using this model our preliminary IBoF adult salmon abundance estimate is 78 fish.	Integrating multiple data sources Genetics Abundance estimation
Atlantic Salmon	N & L	Nick Kelly	Assessment of Atlantic Salmon in the Newfoundland and Labrador Region	

Atlantic Salmon	Gulf	Gerald Chaput	A hierarchical mark-recapture model has been developed to estimate the returns of Atlantic Salmon to two branches of the Miramichi River, New Brunswick. The model uses data on catches, marks, and recaptures of previously marked salmon, which are collected at index trapnets in the estuary of the Miramichi River. The consistent placement of the trapnets and the standardization of the experimental protocols provide the necessary experimental conditions for implementing a hierarchical model structure that draws information from all years to make inferences on annual abundances of returning adults. The parameters of interest include estimates of the capture efficiencies of the index trapnets which, when combined with the catches of upstream migrating salmon, provide estimates of abundance of salmon to the two main branches of the river.	Mark-recapture Hierarchical modelling
Pacific Salmon	Pacific	Sue Grant	The goals of the State of the Salmon program are to (1) Identify and present patterns in salmon time series (common and divergent patterns); to achieve this goal we will apply novel and existing analytical approaches to communicate and compare large amounts of salmon data, and (2) to determine the factors that contribute to these salmon states; to achieve this goal we will link salmon trends to Regional climate and local factors (e.g. landslides, forecast fires, predator-prey dynamics). State of the Salmon Program Deliverables include in-season reporting/updates; post-season State of the Salmon Report; interactive data visualization tool to compare patterns in salmon stocks across the Pacific Region. The key to this program is collaboration and integration across regional salmon and ecosystem experts Fraser Sockeye are used as a case study to develop approaches to compare salmon characteristics across stocks and species. Although these stocks share common ecosystems in some cases (i.e. marine distribution), there will be many differences among stocks in the freshwater habitats they experience during spawning and rearing, and also their smolt and adult migration timing, and exact distribution in the Northeast Pacific Ocean. There may also be differences between stocks in regards to their life-history characteristics, physiology, etc. All these differences contribute to differences observed in their productivity time series. Since the 1950's to present over the 19 stocks, there are periods of higher productivity (1970s to mid-1990s brood year) and lower productivity (mid-1990's to 2005 brood years), but there are also differences between individual stocks and these patterns. In recent years, 2005-2012 brood years, productivity has been more variable across stocks, with less synchrony. In the last two years,	Time series analysis Changes in productivity Large-scale patterns of abundance

			although overall returns have been poor, productivity is variable across stocks. Through comparisons of productivity patterns between stocks, mechanisms influencing the population dynamics of stocks can be explored. Annually, DFO Pacific hosts a Canadian Science Advisory Secretariat (CSAS) process to integrate scientific information across research and monitoring programs through all life-history stages of Fraser Sockeye. This includes research on upstream Fraser River migration conditions (temperature and discharge) for adults in the late summer and fall, adult escapements and condition on the spawning grounds, lake food-web dynamics and fry monitoring, smolt outmigration (relative abundance and condition), and juveniles in the Strait of Georgia, as well as younger age classes returning the previous year (jacks). Integration of this research attempts to improve our understanding of Fraser Sockeye stocks' population dynamics.	
Pacific Salmon	Pacific	Mike Hawkshaw	The management biologist’s role is to provide both tactical and strategic advice to management to support fisheries decision making. Day-to-day work includes attending meetings and assisting with consultations, providing TAC calculations for specific stocks, and helping with allocation decisions. In addition to the day-to-day work, I build in-season planning tools (to optimize in-season management), conduct stock-recruit analyses, and make catch (or bycatch) predictions, and build models for run-size estimation and reconstruction. I presented three examples of novel analyses I was developing to support science and management of Fraser River salmon stocks: (1) a stock-recruitment analysis of a data-limited pink stock; (2) using Hurdle modelling to estimate rates of low-frequency by-catch events (3) a mixture-model-based method for estimating run timing and abundance of data deficient Lower Fraser River coho stocks. Shareable code can be accessed through GitHub: https://github.com/mikehawkshaw	Stock-recruitment analysis By-catch modelling (hurdle modelling) Mixture modelling
Pacific Salmon	Pacific	Diana McHugh	Estimates of escapement are based on periodic visual surveys in many river systems on the west coast of Vancouver Island. Systems are short, clear, and flashy, precluding the use of many estimation options, including fences and mark-recapture using carcass recoveries, due to high rates of predation and flushing during high water events. Swim surveys are used to be able to utilise brief weather windows to obtain counts and provide a better idea of species composition than bank walks. Area Under the Curve	Survey methodology Integrating multiple data sources Area under the curve methods

			(AUC) methods are used to translate periodic counts into escapement estimates. AUC estimates require assumptions about observer efficiency and survey life. Radio-tagging projects in recent years have been used to corroborate some of the values used for Chinook and ancillary information, such as time of first freshet, observations of behavior, and environmental conditions inform the final estimates.	Radio-tagging
Pacific Salmon	Pacific	Brittany Jenewein	An in-season run size prediction model is used to estimate abundance returning to the mouth of the Fraser River for both Chinook and Chum Salmon. The main data inputs are the Albion test fishery daily catches and the escapement, or total run size, estimates derived post-season by stock assessment. Models generally perform well, but uncertainty is quite high and efforts to reduce uncertainty are focused on adding data from other test fisheries and environmental covariates, and evaluating different options for priors. Steelhead are considered in the management of Chum Salmon fisheries because they are co-migrating species, and an exposure model has recently been developed for fishery planning to meet the strategy of protecting 80% of the steelhead run from Fraser River commercial gillnet fisheries. The model is still under development and consultations with the Province of BC are forthcoming to review both the model and steelhead conservation strategy.	In-season run estimation
Chinook Salmon	Pacific	Erin Porzst	A CSAS paper is currently in progress that describes straying of hatchery Chinook in Southern BC. The objectives are to describe the percent and magnitude of hatchery fish that stray, the spatial extent of straying, any trends, whether certain release strategies are associated with higher rates of straying, and the hatchery (local and stray) contribution to sampled rivers in BC. The recovery of hatchery marked fish in escapement samples are used to assess first generation straying, with the hatchery marks being either coded wire tags (CWT) or thermal marks. Preliminary results from the west coast of Vancouver island (WCVI) show that sea pen releases tend to have higher stray rates, and that estimates of straying and hatchery contribution are biased low when using only CWT data as opposed to thermal mark data. Preliminary results also show that there is a high hatchery contribution to many river systems on the WCVI, and that hatchery fish are present in many rivers without a hatchery associated with them.	Hatchery straying CWT Marking Thermal Marking

Chum Salmon	Pacific	Brooke Davis	Status assessments for Chum Salmon (*Oncorhynchus keta*) under the Wild Salmon Policy (WSP) have been limited, in part because recruitment time-series required to calculate stock-recruitment based benchmarks are not consistently available. Alternative benchmarks have been proposed for data-limited Conservation Units (CUs) using percentiles of the observed spawner abundance time-series. However, these benchmarks have not been evaluated against stock-recruitment benchmarks currently used to assess status on abundances for data-rich CUs under the WSP. Using retrospective and simulation analysis, with southern BC Chum Salmon as a case study, we found that percentile benchmarks generally align or are more precautionary than traditional stock recruitment models. However, percentile benchmarks (as well as data-rich benchmarks) perform poorly when harvest rates are high, and productivity is low. We have made recommendations that different percentiles can be used for different harvest rate/productivity combinations, and that caution should be taken when applying both types of benchmarks in high harvest rate/low productivity situations.	Stock-recruitment modelling Data-limited methods Simulation modelling Bayesian hierarchical modelling
Pacific Salmon	Pacific Salmon Commission	Catherine Michielsens	Statistical model selection criteria are not designed to detect possible biases in the model parameters and tend to favor time-varying Ricker models as they fit the data better. However, time series with limited data at low spawner abundances provide insufficient information to estimate time-varying productivity parameters. Even in time series where data were available at low abundances, distinguishing between variability in a stock's productivity parameter versus its capacity parameter is challenging without independent information on those parameters. This can result in biological benchmarks and reference points that are unreliable.	Model selection Stock-recruitment modelling Changes in productivity
Sockeye Salmon	Pacific	Ann-Marie Huang	Since the early 2000s, Fraser Sockeye escapement options have been evaluated in a process consistent with management strategy evaluation practices. The model (not MSE-consistent) and process continue to evolve with feedback from the process. One of the recent stock-recruitment (SR) model issues to be raised is the issue of the impact of SR model choice (Ricker vs. Larkin) on the behavior of stocks that are not clearly cyclic or non-cyclic over the long term (48 years). The question posed to the group at the end of the presentation was "How do you present/summarize a lot of outputs and include information on uncertainty to managers and interest groups in a way that is useful, informative, and can be taken into account	Management strategy evaluation (MSE) Stock-recruitment modelling Presenting uncertainty

			by people making decisions (as opposed to having uncertainty ignored or outputs dismissed because of wide uncertainty bounds)?”	
Chinook Salmon	Pacific	Kendra Holt	Work is being initiated by DFO Canada to develop a Management Strategy Evaluation (MSE) for Southern BC Chinook salmon stocks. MSE is an approach to decision-making that involves assessing the consequences of a range of management procedures and presenting them in a way that shows the trade-offs in performance across a range of conflicting objectives. Initial consultations with managers, First Nations, and stakeholders have identified two aspects of decision-making that an MSE should seek to evaluate: (1) the impacts of fishery-, place-, and time-specific changes in harvest on management performance and (2) the impacts of changes in hatchery production on management performance. In this talk, I provided an overview of MSE methodology, some background context on southern BC Chinook Salmon stocks and fisheries, and then presented our two-stage plan to develop an MSE for southern BC Chinook.	Management strategy evaluation (MSE)

APPENDIX A. TERMS OF REFERENCE (ENGLISH)

TESA annual workshop activity

Anadromous fish assessment methods workshop

Dates

20-24 November 2017 (4-days)

Location

Moncton, NB

Chairs

Jamie Gibson (Bedford Institute of Oceanography, Dartmouth)

Ann-Marie Huang (Lower Fraser River Area Office, Vancouver)

Kendra Holt (Pacific Biological Station, Nanaimo)

Participants

- Primarily DFO Science assessment staff working in anadromous fish stock assessment
- Possibly assessment specialists working in provincial agencies and universities
- Possibly invited external experts

Context and purpose

This workshop is intended to address issues related to assessment of anadromous fish in Canada. The workshop will focus on how different species and stocks are assessed across regions, which should be representative though not extensive. There are common issues that arise in many anadromous assessments, such as how to assess total run size by in season arrivals or how to represent run size and acceptable fishing mortality on rivers with little or no direct run count data based on reference rivers. Assessment of sea survival and growth is challenging for highly migratory populations yet can completely dominate run size estimates. Data availability will be a primary determinant of why and how certain methods are applied for assessment, while in some cases specific regional expertise in particular methods may be an important reason why certain kinds of methods are applied to some stocks. Equilibrium population modelling has also been used to provide scenario assessments to inform on possible management interventions. In addition, simulation modelling within management strategy evaluations are being developed to inform decisions on monitoring, assessment and management, for some stocks and species, and may be useful more broadly.

The overall goal of the workshop is to create an environment where anadromous fish assessment staff can come together to discuss issues commonly encountered in their assessments, collectively brain storm about them and try new methods with their data at the workshop. The intention is for analysts to bring data to the workshop to apply those methods with support from other participants. The result is more robust science delivery based on shared experiences and knowledge and an increased vitality in applying new methods and better understanding of potential assessment approaches.

Workshop structure (TBD)

- presentations on individual stock assessments, methods and challenges
- presentations and testing of equilibrium population model approaches and scenario analyses
- discussion of common issues and exploration of methods in anadromous assessment
- breakout group application of methods

Workshop products

- Proceedings document (Can Tech Report) – not a CSAS activity
- A table summary of anadromous fish assessments by participants
- Code and data repository

APPENDIX B. LIST OF PARTICIPANTS

Region/Affiliation	Name	Notes
Acadia University	Mark Billard	
Gulf	Cindy Breau	
MAR	Jeremy Broome	
Gulf	Michel Biron	Day 1 only
Gulf	Gerald Chaput	
Gulf	Guillaume Dauphin	
Pacific	Brooke Davis	
C & A	Samantha Fulton	
MAR	Jamie Gibson	Co-Chair
Pacific	Sue Grant	
C & A	Kimberly Howland	
Pacific	Mike Hawkshaw	
Pacific	Ann-Marie Huang	Co-Chair
Pacific	Kendra Holt	Co-Chair
Gulf	Ross Jones	
Pacific	Brittany Jenewein	Rapporteur
N & L	Nick Kelly	
MAR	Alex Levy	
Gulf	Sophie LeBlanc	
Pacific	Diana McHugh	
Pacific Salmon Commission	Catherine Michielsens	
QUE	Pedro Nilo	
Pacific	Erin Porzst	

MAR	Dustin Raab	
C & A	Ross Tallman	
Gulf	Sarah Tuziak	
C & A	Xinhua Zhu	

APPENDIX C. AGENDA & REVISIONS

The draft agenda distributed to participants was as follows. Tentatively set break-out group topics were Bayesian approaches to stock assessment, data-limited assessment tools, and development of reference points and benchmarks.

Technical Expertise in Stock Assessment (TESA)
National Workshop
DRAFT AGENDA

Anadromous Fish Assessment Methods Workshop

November 20-24 2017 - Moncton

Day 1 – Monday, November 20

Time	Subject	Presenter
900	Welcome	co-chairs
	- Intro to TESA	Daniel R.
	- review agenda/workshop structure	
	- housekeeping	
	- getting presentations onto computer	
	- workshop report	
	- ID rapporteurs for the day	
	- group social/dinner plans?	
915	Group Intro	ALL
930	Individual Program Presentations	
	Fraser sockeye population dynamics, forecasts, and status	Sue G.
	Comparing candidate benchmarks for the Wild Salmon Policy	Brooke D.
	Straying of hatchery Chinook in Southern BC.	Erin P.
	Are Fraser Pink Salmon Data Limited?	Mike H.
1030	break	
1050	Individual Program Presentations (cont'd)	
	Assessment methods for Chinook, chum, and steelhead in the Fraser River	Brittany J.
	Assessment of Northern Dolly Varden Char	Kimberly H.
	Inner and Outer Bay of Fundy Atlantic salmon assessments	Ross J.
	Assessment of Atlantic Salmon in the Newfoundland and Labrador Region	Nick K.
	Acoustic tracking of small numbers of Atlantic salmon against a backdrop of severe marine mortality: working outward from rivers on tractable problems.	Dave H.

1200	lunch	
1300	Individual Program Presentations (cont'd) Southern Upland and Eastern Cape Breton Atlantic Salmon Assessments	Alex L.
	Miramichi Atlantic salmon assessment model	Gerald C.
	Quantitative assessment of anadromous salmonid population dynamics in Arctic: indicators, model selection and uncertainties	Xinhua Z
	Estimating juvenile Atlantic salmon abundance from electrofishing data	Guillaume D.
	Escapement based on periodic visual surveys: A brief overview of the Area Under the Curve method based on snorkel surveys and why we use it in isolated, flashy, but relatively short and clear systems.	Diana M.
	Big and small, wide and narrow: stock assessments of coregonids, salmonids and ecological change in the Arctic	Ross T.
1440	break	
1500	Individual Program Presentations (cont'd) Maritimes Region's emerging River Herring assessment Program	Jamie G.
	Simulation testing of stock assessment models for anadromous River Herring	Mark B.
	Accounting for time-varying productivity in stock-recruit relationships to inform benchmarks and status	Catherine M.
	Developing a Management Strategy Evaluation for Chinook Salmon in Southern British Columbia	Kendra H.
	Evaluating long term escapement strategies for Fraser Sockeye: process, models, and a cacophony of outputs	Ann-Marie M.
1620	organize breakout groups: - topics/scheduling - "Beyond Basic Bayes" - Catherine - Data limited(?) - RossT, Xinhua, Kim - Statistical Catch at Age models - Jamie - group lead(s) + list of things covered in each breakout group - any plenary topics? - don't need people to choose topics, yet	co-chairs/ALL
1700	adjourn for the day	

Day 2 – Tuesday, November 21

Time	Subject	Presenter
900	Daily organization/Agenda Review - breakout group ideas - ID rapporteurs for the day	co-chairs/ALL
910	In-season assessment of Fraser River sockeye salmon and the value of seaward data	Catherine
1010	break	
1030	ICES Atlantic Salmon assessment model	Gerald
1130	Atlantic salmon population dynamics models utilizing several data sources	Guillaume
1230	lunch	
1330	Use of sex-ratio and maturity information for estimating at-sea survival	Gerald
1350	Statistical catch-at-age/life cycle models for River Herring and Atlantic salmon	Jamie
1430	Data limited methods for assessing Arctic Char in Canadian Arctic	Ross T.
1530	break	
1545	Benchmarks & Reference Points	Jamie Sue Ann-Marie
1645	Plan for tomorrow - have breakout groups ID'd - preliminary indication of interest in groups - breakout group day/time assignments	co-chairs/ALL
1700	adjourn for the day	

Day 3 – Wednesday, November 22

Time	Subject	Presenter
900	Daily organization/Agenda Review - round robin - thoughts? - group "sign up" - ID group rapporteurs (not group leader)	co-chairs/ALL
945	breakout groups (3.25hr = 3hr + 15min break)	breakout
1230	lunch break	
1330	breakout groups (3.25hr = 3hr + 15min break)	breakout
1645	Plenary - International Year of the Salmon - where/when to meet up for dinner/restaurant directions	co-chairs/ALL
1700	adjourn for the day	

Day 4 – Thursday, November 23

Time	Subject	Presenter
900	Daily organization/Agenda Review - round robin - thoughts? - group "sign up" - ID group rapporteurs (not group leader)	co-chairs/ALL
945	breakout groups (3.25hr = 3hr + 15min break)	breakout
1230	lunch break	
1330	breakout groups (3.25hr = 3hr + 15min break)	breakout
1645	Plenary - DLMtools TESA workshop & anadromous fish assessments - Incorporating climate change into assessments	co-chairs/ALL
1700	adjourn for the day	

Day 5 – Friday, November 24

Time	Subject	Presenter
900	Daily organization - workshop report	co-chairs
910	breakout group report backs (~15min/group)	group rapporteurs
1015	break	
1030	breakout group report backs (cont'd)	group rapporteurs
1130	round robin - thoughts/takeaways	ALL
1155	closing remarks	co-chairs
1200	adjourn meeting	

Revisions were made to the agenda throughout the workshop based on feedback from participants. The decision was made to run most of the sessions and workshops as plenaries as participants were reluctant to chose among workshop topics.

The resulting schedule was as follows:

Day 1	
Morning	• Welcome & introductions (including review of TESA and workshop terms of reference) • Individual program presentations
Afternoon	• Individual program presentations
Day 2	
Morning	• Individual program presentations
Afternoon	• Extended presentations • Group discussion of structure for days 3 & 4
Day 3	
Morning	• Extended presentations • Plenary session: Reference points
Afternoon	• Mini-workshop: Basic Bayes & Beyond Basic Bayes
Day 4	
Morning	• Break-out groups: Model selection
Afternoon	• Mini-workshop: Data limited methods
Day 5	
Morning	• Plenary session: Historical data
Afternoon	• Meeting summary • Identification of recommendations