Proceedings of the Technical Expertise in Stock Assessment (TESA) National Workshop on 'Incorporating an ecosystem approach into single-species stock assessments', 21-25 November 2016, Nanaimo, British Columbia

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2017

PROCEEDINGS OF THE TECHNICAL EXPERTISE IN STOCK ASSESSMENT (TESA) NATIONAL WORKSHOP ON 'INCORPORATING AN ECOSYSTEM APPROACH INTO SINGLE-SPECIES STOCK ASSESSMENTS', 21-25 NOVEMBER 2016, NANAIMO, BRITISH COLUMBIA

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The Technical Expertise in Stock Assessment (TESA) group of Fisheries and Oceans Canada (DFO) held a national workshop on 'Incorporating an ecosystem approach into single-species stock assessments', in Nanaimo from 21st to 25th November, 2016. The workshop was chaired by Andrew Edwards and Rowan Haigh from the Pacific Region and Ross Tallman from the Central and Arctic Region. It was attended by 25 DFO participants and four external participants from Norway, the United States and local universities. There was a plenary session with two talks that gave an international overview, followed by 15 shorter talks from DFO participants. For the rest of the week participants worked in three break-out groups. The data-poor group primarily worked with the R package *DLMtool* (Data-Limited Methods Toolkit) to understand how *DLMtool* can implicitly incorporate ecosystem information. The data-rich group developed detailed recommendations for conducting a scoping exercise to determine where and how ecosystem factors could be incorporated into the advice-giving process. They also examined two case studies from the Gulf of St. Lawrence. The data-alternative group investigated Empirical Dynamic Modelling (EDM), a novel approach that empirically incorporates interactions among ecosystem variables to predict future populations, without making assumptions about the underlying processes.

The main recommendations for incorporating ecosystem factors into operational assessments are: (i) conduct a scoping exercise to understand how management outcomes might be improved, (ii) facilitate buy-in from stakeholders, and (iii) be aware of the potential pitfalls of mis-specifying an environmental relationship. The main recommendations for future research are to continue exploring and understanding *DLMtool* and the EDM approach. Participants contributed to an annotated bibliography of 44 Canadian examples that have already considered ecosystem effects in stock assessments, advice to managers or research. These Proceedings summarise the workshop, including talks, the work of the break-out groups (including case studies and the recommendations for scoping exercises), overall recommendations and the annotated bibliography. Finally, most of the talks and R code from the break-out groups are publically available at https://drive.google.com/drive/folders/0B5RDkOmwzCjnOXpNbVZtMHNWaTg and https://github.com/andrew-edwards/empirical-dyn-mod.

RÉSUMÉ

Edwards, A.M., Haigh, R., Tallman, R., Swain, D.P., Carruthers, T.R., Cleary, J.S., Stenson, G. and Doniol-Valcroze, T. (2017). Proceedings of the Technical Expertise in Stock Assessment (TESA) National Workshop on ‘Incorporating an ecosystem approach into single-species stock assessments’ 21-25 November 2016, Nanaimo, British Columbia. Can. Tech. Rep. Fish. Aquat. Sci. 3213: vi + 53 p.

Le groupe Expertise technique en évaluation des stocks (ETES) de Pêches et Océans Canada (MPO) a tenu un atelier national sur l’« intégration d’une approche écosystémique à l’évaluation du stock d’espèces individuelles », à Nanaimo, du 21 au 25 novembre 2016. L’atelier était présidé par Andrew Edwards et Rowan Haigh, de la Région du Pacifique, et par Ross Tallman, de la Région du Centre et de l’Arctique. 25 participants du MPO y ont pris part, ainsi que quatre participants externes de la Norvège, des États-Unis et des universités locales. L’atelier comprenait une séance plénière avec deux discussions permettant d’offrir un aperçu international, suivie de 15 discussions plus courtes des participants du MPO. Pendant le restant de la semaine, les participants ont travaillé en trois groupes de discussion. Le groupe sur les domaines sur lesquels on dispose de peu de données a travaillé avec *DLMtool* (outil de modélisation au moyen de données limitées), un progiciel R, afin de comprendre de quelle façon il peut intégrer implicitement les données écosystémiques. Le groupe sur les domaines sur lesquels on dispose de beaucoup de données a élaboré des recommandations détaillées pour la réalisation d’un exercice d’établissement de la portée visant à déterminer où et comment les facteurs écosystémiques pourraient être intégrés dans le processus de formulation d’avis. Les membres de ce groupe ont également examiné deux études de cas du golfe du Saint-Laurent. Le groupe sur les alternatives aux données a étudié la modélisation dynamique empirique, une nouvelle approche qui intègre de façon empirique les interactions entre les variables écosystémiques afin de prévoir les futures populations, sans formuler d’hypothèses au sujet des processus sous-jacents.

Les principales recommandations concernant l’intégration des facteurs écosystémiques aux évaluations opérationnelles sont les suivantes : (i) réaliser un exercice d’établissement de la portée afin de comprendre comment améliorer les résultats de la gestion, (ii) faciliter l’adhésion des intervenants, et (iii) être conscient des obstacles potentiels découlant de la mauvaise définition d’une relation environnementale. Les principales recommandations concernant les recherches futures consistent à continuer d’étudier et de comprendre *DLMtool* et la modélisation dynamique empirique. Les participants ont contribué à une bibliographie commentée de 44 exemples canadiens ayant déjà pris en compte les effets écosystémiques dans les évaluations des stocks, la formulation d’avis aux gestionnaires ou la recherche. Ce compte rendu résume l’atelier, notamment les discussions, les travaux réalisés par les groupes de discussions (y compris les études de cas et les recommandations en matière d’exercices d’établissement de la portée), les recommandations générales et la bibliographie commentée. Enfin, la plupart des discussions et le code R des groupes de discussions sont accessibles au public à l’adresse suivante
https://drive.google.com/drive/folders/0B5RDkOmwzCjnOXpNbVZtMHNWaTg et
https://github.com/andrew-edwards/empirical-dyn-mod.

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 issues such as providing advice in the interim years between full assessments, determining reference points under changing productivity regimes, and comparing methods for conducting flatfish stock assessments. The format of the present workshop, 'Incorporating an ecosystem approach into single-species stock assessments', was based on that of the March 2016 flatfish meeting, with 1.5 days of plenary talks followed by small break-out groups so that participants could work closely together to learn new tools, exchange code and ideas, and provide general guidance for the future. There were 25 DFO participants and four external participants.

Motivation for TESA to host this specific workshop came from the Government of Canada's general commitment to evidence-based decision making, DFO's mandate to take into account climate change when making decisions that affect fish stocks, and DFO's commitment to improve ecosystem-based advice for the management of Canadian fisheries.

A Terms of Reference (Appendix B) was developed to help guide the meeting, but not necessarily to constrain the meeting should interesting and productive avenues arise. The overall structure was to first get an impression of approaches taken in the U.S. North Pacific, Europe and then across Canada, through two talks by external speakers and 15 shorter talks by DFO participants. There were then presentations on the three proposed break-out groups:

(i) data-poor group: Tom Carruthers (University of British Columbia);

(ii) data-rich group: Doug Swain (DFO – Gulf Region);

(iii) data-alternative group: Andrew Edwards (DFO – Pacific Region).

Participants were free to choose which break-out group they wished to join; this worked well and resulted in groups of comparable sizes. The remainder of the week was devoted to working in break-out groups, with brief plenary summaries on Wednesday and Thursday mornings and Thursday afternoon, and a longer plenary discussion for most of Friday.

In the break-out groups the aforementioned presenters went into further details of their area and helped others apply them to their own data sets. The data-poor and data-alternative groups could directly use existing R packages, and the data-rich group used Automatic Differentiation Model Builder (ADMB) code from Doug Swain. The data-rich group also spent extensive time developing guidelines for what should be considered in a scoping exercise when determining if one should incorporate environmental factors into the advice-giving process (see below and Appendix E).

Overall, participants learnt a lot within their groups, and enhanced understanding during their own discussions. Specific recommendations arose from each group (see below), and some of the code will continue to be shared between participants (and other interested parties) through code-sharing repositories at https://drive.google.com/drive/folders/0B5RDkOmwzCjnOXpNbVZtMHNWaTg and https://github.com/andrew-edwards/empirical-dyn-mod, with some of the contributed presentations also available at the first of these websites.

Figure 1. Doug Swain giving a presentation at the Ecosystem Approach workshop.

Throughout the week, participants from all groups contributed examples of ecosystem effects being incorporated into Canadian stock assessments, advice to managers or research studies. The resulting tables in Appendix F contains 44 such examples, and provide a useful annotated bibliography of Canadian studies (including DFO assessments) that already consider ecosystem effects.

Four external participants attended. Two gave overviews of relevant work in the U.S. North Pacific (Paul Spencer, Alaska Fisheries Science Center, USA) and Europe (Daniel Howell, Institute of Marine Research, Norway). Tom Carruthers (University of British Columbia, Vancouver) gave an introduction to the R software package *DLMtool* (Data-Limited Methods Toolkit) for the data-poor group, and Dave Campbell (Simon Fraser University, Burnaby) contributed his valuable expertise to the data-alternative group for a day. All attendees are listed in Appendix C.

This document provides an overview of various aspects of the meeting.

2. INVITED PRESENTATIONS AND CONTRIBUTED TALKS

2.1. OVERVIEW FROM OTTAWA BY STEVEN SCHUT

After participants introduced themselves and reviewed the agenda, Steven Schut (DFO Science Advisor and National Capital Region co-ordinator for TESA) gave a short overview to explain the motivation for the workshop. Such motivation comes from the Government of Canada's general commitment to science-based decision making ("Decisions will be informed by scientific evidence ..." from the Speech from the Throne), the DFO Minister's Mandate Letter ("... take into account climate change, when making decisions affecting fish stocks and ecosystem management"), and DFO's commitment to "improve ecosystem-based advice for the management of fisheries in Canada's three oceans".

More specifically, the context for the workshop was inspired by themes such as:

- There is an increasing importance and urgency to incorporate consideration of ecosystem/environmental factors throughout government;
- Integration of ecosystem considerations is complex and must be undertaken strategically;
- DFO's Science Sector needs to demonstrate tangible progress in implementation of an ecosystem approach to management;
- Stock assessment is only one component of the required science;
- TESA can play a key role in advancing the incorporation of ecosystem drivers in, and linkages to, traditional quantitative stock assessment.

The talk ended with the reminder that there is a push within Government to make information freely available. In this spirit, most of the workshop materials (including most of the contributed talk and code used during the break-out groups) are available at the websites given above.

2.2. INVITED TALK BY PAUL SPENCER

Paul Spencer from the Alaska Fisheries Science Center, National Oceanographic and Atmospheric Association (NOAA, Seattle, USA), gave the first invited external talk:

Use of environmental and ecosystem information in single-species stock assessments – past and current work from the U.S. North Pacific.

Dr. Spencer works on groundfish stock assessments and his recent research includes estimating the vulnerability of Eastern Bering Sea stocks to climate change. His talk covered various subjects that he and his colleagues have investigated at the Alaska Fisheries Science Center. The main themes of his talk were:

1. *The environment can affect how fishing gear is sampling populations*. For example, for Yellowfin Sole (*Pleuronectes asper*) in the Eastern Bering Sea (EBS), there appeared to be higher survey catchability in warmer years, where

   survey catchability = gear efficiency x availability.

   This could have been due to effects on gear efficiency (fish might be less active in colder water) and/or availability (temperature may affect migration from spawning grounds to the survey area).

2. *The effect of the environment on recruitment*. For Eastern Bering Sea Walleye Pollock (*Theragra chalcogramma*), a statistical model was developed to relate recruitment to sea-

surface temperature and predator biomass. This was conducted outside of the assessment model, using the model's estimates of recruitment as data. Projections were conducted based on estimates of future increases in temperature (with warmer waters giving lower recruitment).

3. *The effect of the environment on medium and long-term ('strategic') advice*. Using the Walleye Pollock recruitment-temperature relationship, simulations were performed under different projected temperature increases to evaluate the effect of different management strategies. Evaluation criteria included: the number of years when spawning stock biomass (SSB) was below a certain level, the mean catch, the number of years when the fishery would be closed, and variability of catches between years. This work showed how deciding upon the best choice of management strategy depends on the management goals, and that assessment scientists can help identify implications of management strategies under changing climatic conditions.

4. *Incorporation of predation into single-species assessments*. For Gulf of Alaska Walleye Pollock in 2000, motivated by trends in abundance of predators such as sea lions, Arrowtooth Flounder (*Atheresthes stomias*) and Pacific Halibut (*Hippoglossus stenolepis*), empirical data on predation were fit in the assessment model. However, there were only limited diet data available for computation of 'predation per unit effort', with ≤3 years per species. Models with and without estimation of predation mortality were compared. This work provides a statistical methodology for estimating predation in a single-species model, and demonstrates how temporal variation in natural mortality can affect estimates of stock size and productivity. It was not clear how to reconcile the results with empirical estimates of natural mortality, and necessary assumptions were that natural mortality from other species was constant and that the catchabilities (and spatial overlaps) of predators were constant over time.

5. *Incorporation of predator-prey overlap and environmental variation in single-species assessments*. Recent work extended some of the above work on Walleye Pollock by: considering the spatial overlap of predators and prey, estimating temperature and predation effects within an assessment model, considering the effects of temperature on maximum consumption rates and on recruitment, and estimating functional responses within the assessment model. Such an approach is data intensive, requiring information on: spatial data on temperature and relative proportions of predators and prey, biomass and weight-at-age of predators, consumption by predators (including age composition of consumed prey), and metabolic parameters relating maximum consumption to temperature. Of three environmental process considered, the influence of temperature on recruitment was found to have the strongest effect on the dynamics of the stock.

6. *How complex do our models need to be*? A current Alaska CLIMate (ACLIM) project is investigating this, looking at climate-enhanced single-species models, three-species models, Ecopath, size-spectrum analyses and complex ecosystem models.

7. *In what conditions would multispecies models be desirable?* Multispecies models would be desirable when:

   - there are sufficient data (or information) available;
   - expert advice is not enough;
   - relationships are nonlinear and complex;
   - species are fully exploited;
   - pressures and impacts are high;
   - there is a high scope for the fishery to respond to management;
   - management is ready for an analysis of trade-offs.

In summary, Dr. Spencer concluded that:

- environmental variability and ecosystem processes affect many aspects of fish population dynamics and stock assessment;
- in many situations, single-species assessment models may be appropriate for management;
- ecosystem considerations can be incorporated into single-species assessment models, which may ease incorporation into management;
- the variability of input data relating to predation should be considered;
- we can distinguish between the effects on stock size and the effects on future productivity.

2.3. INVITED TALK BY DANIEL HOWELL

Daniel Howell from the Institute of Marine Research (Bergen, Norway) gave the second invited external talk:

Single-species advice in a multispecies world: the Barents Sea and beyond.

Dr. Howell works on single-species stock assessment and multispecies research. Here are the key points from his talk:

- Fish live in a complex, changing and interacting world. The question is how much of this complexity to consider when providing management advice on single species:
  - How much should we include?
  - How much *can* we include?
  - *Where* and *how* should we include it?
- There is a difference between models for assessments and for research:
  - A research model wants to be the *best available model* to examine a range of possibilities.
  - An assessment model wants to be the *simplest viable model*. Do not add complexity to a model just for the sake of it.
- Three requirements for including ecosystem effects into assessment modelling:
  - Strong and variable effects.
    - If an effect is weak then it does not matter and so need not be included.
    - If it is constant then it can just implicitly be part of natural mortality.
  - Need data to support the modelling.
  - Need an understanding of processes (not just correlations, as they tend to break down over time).
- Ecosystem considerations:
  - Europe: tended to focus on multispecies issues (as for most of the rest of this talk).
  - United States: more concerned with environmental drivers.
  - No clear answer as to why this difference occurs (key drivers, culture or just chance?).

Dr. Howell then gave seven approaches from Europe of how ecosystem considerations have been incorporated (or could be incorporated) into assessments:

1. Barents Sea Capelin (*Mallotus villosus*) was perhaps the first multispecies stock assessment model in the world (1990). It was recognised that there was a strong effect of predation by cod (and others) that needed to be considered. The cod abundance forecast came from the cod assessment, and consumption by cod came from historic stomach data. This worked due to a single strong effect and very good stomach data.

2. For some North Sea and Baltic Sea stocks, a multispecies model is run (and evaluated and approved by a working group) every three years. Predation mortalities are then used in single-species stock assessments for the next three years. This adds details into single-species assessments without adding too much complexity. However, it is somewhat inflexible and it can be too easy to add species *because you can* rather than *because you should*.

3. For Northeast Arctic Cod (*Gadus morhua*) extended survival analysis (XSA) is expanded by adding a 'fishing fleet' to account for cannibalism and the model is iterated until results are stable. A similar approach is used for cod predation on Haddock (*Melanogrammus aeglefinus*). This approach is not elegant, but somewhat generalisable.

4. A correlation had been found between age-3 cod and temperature (when the fish were spawned) in the Kola Section of the Barents Sea. The relationship could be used for projections, but with updated data (from 2007) it broke down completely. This is often the case for such correlations, and there was also no underlying mechanistic explanation.

5. A stochastic multispecies model was used in 2013 for the Baltic Sea to evaluate harvest control rules. There was backing from ICES and European Union fisheries managers, and several multispecies experts from around the world were involved. The model was used to examine trade-offs between the three main species: cod (the predator), and sprat and herring (the prey). However, the model spent most of its time in conflict about tuning single species outputs. And the managers ended up ignoring the results, probably because it required trade-offs to be made. The lesson was that you do need buy-in from managers.

6. It seems that we are not so good at modelling bottom-up effects. This can be very difficult to do in data-tuned models, though is possible in Ecopath and Atlantis (but these are not formally tuned to data). There is generally a lack of data.

7. Full multispecies models, such as Ecopath and Atlantis, can say something about overall trends, but are not tuned to data and cannot give quota advice. Models of Intermediate Complexity for Ecosystem assessments (MICE) are tuned to data and can give quota advice. However, such multispecies models are:

   a. understood by only a few people;

   b. time consuming to develop and tune;

   c. complex;

   d. difficult to check;

   e. and have many ways to introduce errors.

   Consequently they are not well-suited to a traditional annual assessment cycle.

The harvest control rule for capelin is in a sense multispecies. This is because there is a rule that there should be a 95% chance of there being >200,000 t left to spawn. Fishing occurs after the predation by cod (the rest of the fishery was closed to make this so), and so there is a clear objective to let the cod eat all they want and then allow catch on any surplus. Thus, the cod fishery is implicitly prioritised over the capelin fishery:

- yet this is not written down anywhere;
- but not doing this would effectively prioritise capelin;
- you cannot avoid prioritising between trophic levels.

Dr. Howell summarised his conclusions regarding including ecosystem effects into assessments as:

- decide what is *required* to include;
- decide what is *justified* to include;
- decide *where* in the advice process such inclusion will occur;
- decide the *simplest method* of including it;
- be *clear* about what you are doing;
- you need buy-in from stakeholders (including managers and scientists), and make sure that they understand and will use the resulting advice.

2.4. CONTRIBUTED TALKS

On the Monday afternoon (and Tuesday morning due to travel delays), fourteen contributed talks were given, each lasting ten minutes. Titles and authors are given in Appendix A; there were two unavoidable cancellations (Kim Hyatt and Adam Cook), with Adam Cook's work presented by Brad Hubley. A wide variety of subjects were covered, including:

- what is done by the North Atlantic Fisheries Organisation (NAFO) and the International Council for the Exploration of the Sea (ICES);
- use of Ecopath with Ecosim (not for tactical management, but to put single species in an ecosystem context);
- the physiological effects of water temperature, dissolved oxygen and pH;
- incorporating environmental effects and traditional ecological knowledge;
- including environmental and ecosystem information in probabilistic salmon forecasts, and using qualitative forecasts to help managers look at quantitative forecasts;
- incorporating information on ice conditions into assessments of seals by modifying survival in the population model – results helped convince managers of the need to incorporate such information in the advice;
- impacts of environmental drivers on dynamics/assessments of Snow Crab (*Chionoecetes opilio*) and pelagic fish stocks, including Greenland Halibut (*Reinhardtius hippoglossoides*) under changing prey and ice conditions and effects of oceanic regimes on Atlantic Herring (*Clupea harengus*);
- using time-varying productivity and natural mortality in assessment models;
- developing methods that account for the Bayesian outputs from a stock assessment model to conclude that there were no conclusive impacts of climatic and environmental variability on recruitment of Pacific Ocean Perch (*Sebastes alutus*), and therefore these do not need to be considered in upcoming assessments.

3. PLENARY TALKS TO DESCRIBE EACH BREAK-OUT GROUP

There then followed three 45-minute introductory talks, one by the leader of each break-out group:

(i) data-poor group: Tom Carruthers (University of British Columbia);

(ii) data-rich group: Doug Swain (DFO – Gulf Region);

(iii) data-alternative group: Andrew Edwards (DFO – Pacific Region).

Details about each group are given in the summaries below. Participants then split into three working groups. Participants chose which group they wished to be in, which fortuitously resulted in a fairly even split of numbers between the three groups.

Break-out groups worked from Tuesday afternoon until Friday, somewhat independently but with short plenary sessions on Wednesday and Thursday mornings to update the other participants. On Friday morning there was a presentation from each break-out group. This was originally planned for Friday afternoon but participants suggested moving these to Friday morning to allow participants to maybe incorporate others' thoughts within their own working groups.

Also on the Friday, Ross Tallman presented the table that participants had contributed to throughout the week, now finalised in Appendix F.

4. SUMMARY FROM DATA-POOR GROUP

Leads: Tom Carruthers, Ross Tallman, Rowan Haigh

Additional members: Kim Howland, Alida Bundy, Denis Chabot, Paul Spencer, Alex Hanke, Daniel Howell

4.1. SUMMARY

Tom Carruthers presented *DLMtool*, an R package for conducting management strategy evaluations (MSEs) of various management procedures (MPs) for data-limited fish stocks, and subsequent application of the MPs to data-limited stocks. Once the group had loaded the software and become familiar with the inputs for the MSE operating model (i.e., parameters defining the stock, fleet, and observation characteristics) and the structure of data objects, Dr. Carruthers provided a demonstration using a rockfish stock as an example. Multiple pre-programmed MPs were tested on the rockfish data to determine which MPs perform best using performance criteria such as stability in long term yield (LTY) and maintaining biomass above a reference level (e.g. $0.5B_{\mathrm{MSY}}$, half the biomass at the maximum sustainable yield). After the demonstration, the group decided to use an existing stock – Darnley Bay Arctic Charr (*Salvelinus alpinus*) – as a case study to explore *DLMtool*. Biological parameters and fleet dynamic inputs were taken from two source documents (Gallagher *et al.* 2017, Zhu *et al.*, 2017) and then reviewed by the experts in the group. These were then put into *DLMtool* to create an Operating Model of this "reference" situation. A suite of MPs were applied to this finalized reference case. Run results were assessed using visual tools designed for clients like NOAA and DFO.

Some participants were already familiar with *DLMtool* thanks to Dr. Carruthers' demonstration earlier in 2016. This was organised by TESA at the Pacific Biological Station, Nanaimo, BC, and broadcast to DFO participants across Canada via Webinar.

The group then discussed the best way to express ecosystem changes in terms that could be accommodated by the software. *DLMtool* does not use environmental or predator-prey relationships, but the effects of such variables on the "robustness" of the MPs can be assessed indirectly by taking into account their expected effects on parameters that are used by *DLMtool*, such as the growth rate or the mortality rate. Three climate-change scenarios were initially identified: (i) increasing von Bertalanffy growth rate K based on improved fish condition as ice cover recedes earlier in the year and water temperature warms up under climate change, (ii) increasing natural mortality (M) due to expansion northward of competitors/predators and less optimal conditions in rivers and lakes as permafrost is lost, and (iii) strongly increasing M. Other factors were identified but not run, and combinations of changing factors that should be considered were also not run (e.g. changes in the length at 50% maturity, the steepness of the stock-recruitment relationship or the amplitude of the stock-recruit curve). The reference case and the three EA scenarios were compared using a trade-off plot which relates P(LTY > half of the best fixed-F [fixed fishing mortality rate] yield) to P(B>0.5B_{MSY}), where B is the biomass. This comparison illustrated that certain MPs were sensitive to environmental changes; for example, projections for some MPs that indicated sustainable fishing in the reference case would suggest overfishing under climate-change scenarios. The group also explored application of the MPs to the real Arctic Charr data but did not have the opportunity to repeat the EA parameter changes done in the simulated data. Further details of the group's work are given in Appendix D, and code used in the workshop (plus Dr. Carruther's introductory talk) is available in the DLMtool/ folder of https://drive.google.com/drive/folders/0B5RDkOmwzCjnOXpNbVZtMHNWaTg.

4.2. COMMENTS

1. Even if the MP does not use explicit environmental effects, various input controls can be tweaked to approximate ecosystem effects and therefore the stock assessment can take them into account.
2. Use of *DLMtool* needs longer training to explore the tool responsibly.
3. There is no method to take into account changing responses (e.g. warming can increase the growth rate K up to an optimal temperature beyond which K then decreases).
4. The User Guide does not provide answers to all questions (e.g. definition of "amplitude" and how it should be parameterised).
5. It would be nice if the User Guide provided the list of all 86 MPs, along with a description of how they operate.

4.3. RECOMMENDATIONS

1. Add MPs that explicitly incorporate ecosystem effects and compare their performance to the pre-programmed data-limited MPs.
2. Clarify what the pre-programmed MPs actually do.
3. Provide longer training on using *DLMtool*.
4. Using a data-rich stock, take away data sequentially and see if the advice changes.
5. Choose a case study and work on it for a month to identify its potential and to formulate questions.
6. Approach the Quantitative Assessment Methods Section Head (Pacific Region) about *DLMtool*, to see if they can help take the lead (with TESA) in advancing DFO's use of *DLMtool*.

5. SUMMARY FROM DATA-RICH GROUP

Lead: Doug Swain

Additional members: Jaclyn Cleary, Steven Ferguson, Xinhua Zhu, Yanjun Wang, Paul Regular, Garry Stenson, Thomas Doniol-Valcroze, Stephane Plourde

The data-rich group spent extensive time developing detailed recommendations for conducting a scoping exercise to determine where and how environmental factors could be incorporated into the advice-giving process. The resulting guidelines highlight areas where environmental factors may improve the advice-giving process (and ultimately improve management outcomes), bearing in mind the distinction between hindcast assessments, short-term forecasts, long-term forecasts, and closed-loop simulations within a management strategy evaluation. It was stressed that while environmental factors may improve management outcomes, they do not always do so. Also, the process will be very stock specific. These guidelines are given in full in Appendix E.

The group also examined two case studies from the Gulf of St. Lawrence (see Appendix E for further details):

1. Including environmental effects into the Atlantic Herring assessment model. This was found to potentially improve short-term forecasts of fishable biomass.
2. Examining time-varying natural mortality in the Atlantic Cod assessment model, for which preliminary conclusions were that the current random walk model should continue to be used to assess stock status, but that a model specifically including Grey Seal (*Halichoerus grypus*) predation could be used to evaluate management options.

6. SUMMARY FROM DATA-ALTERNATIVE GROUP

Lead: Andrew Edwards

Additional members: Sue Grant, Carrie Holt, Brad Hubley, Jackie King, Mariano Koen-Alonso, Daniel Ricard, Elmer Wade and David Campbell

This group investigated Empirical Dynamic Modelling (EDM), a novel approach that empirically incorporates interactions among ecosystem variables to predict future populations. It does not require specification of equations (such as stock-recruitment equations) and thus does not make assumptions about underlying biological processes. Rather than attempting to incorporate an ecosystem approach into single-species stock assessments, EDM is an approach that can be used to analyse ecosystem influences on single (or multiple) species.

The EDM approach was previously applied to nine stocks of Fraser River Sockeye Salmon (*Oncorhynchus nerka*) with promising results (Ye *et al.*, 2015). An earlier study analysed sardine landings, anchovy landings and sea-surface temperature records from Californian waters, and introduced a technique to detect causality (rather than just correlation) in ecosystems (Sugihara *et al.*, 2012). The authors concluded that inverse correlations that sometimes occur between Pacific Sardine (*Sardinops sagax*) and Northern Anchovy (*Engraulis mordax*) landings are not a result of direct competition between the populations, but that both populations are directly influenced by sea-surface temperature. Recently, *Glaser et al.* (2014) analysed 206 time series of U.S. survey indices and landings, and used EDM to conclude that projections should only be made 1-2 years into the future. These three studies provided motivation for the EDM group, and the first two were explained in detail in the plenary talk, together with some of the theoretical background behind EDM.

Only half of the break-out group had previously heard of EDM, and so the group first went through much of the plenary talk again, and clarified several technical issues and areas of misunderstanding. In particular, an animation explaining some of the concepts behind EDM showed the Lorenz attractor, a well-known chaotic attractor, was only meant to be an example attractor that clearly demonstrates the idea of using time-lagged variables, it is not intrinsic to the EDM approach. Dr. Edwards had previously set up a private GitHub repository for sharing code (including a tutorial) and papers, which participants could easily download. This has now been expanded and made public, and will also likely document ongoing work; it is available at https://github.com/andrew-edwards/empirical-dyn-mod.

All participants also installed the *rEDM* R package (written by the lead authors of two of the aforementioned papers).

The group worked together through some of the vignette that came with the R package. The package has well-documented functions for implementing EDM, which enabled participants to advance rapidly. For example, during the first afternoon participants had generated a simulated data set of purely random data and verified that EDM did not concluded any spurious relationships, and also verified that it performed well with a purely deterministically-derived data set. Participants were given hand-outs of several papers, including Sugihara and May (1990) which was recommended to be read (if possible) before the Wednesday morning. The group leader then led everyone through the paper on Wednesday, since the paper slowly introduces several early concepts and takes a consistent approach to analysing several epidemiological, ecological and simulated data sets. David Campbell (Simon Fraser University) joined the group for the Wednesday, providing useful statistical input.

The group continued to work through the vignette, and then attempted to reproduce the results from the Sockeye Salmon paper. The original authors provided R code with that data, which was very helpful, though understanding was hard because of the lengthy functions in the code. Some of these over-wrote functions in the required *rEDM* package (since they were written specifically for the salmon analyses), keeping participants on their toes. Several results were faithfully reproduced; some minor results were slightly different to the published results, but not enough to affect conclusions (and were considered preliminary). Some participants attempted to extend the salmon results by using updated recent data. Preliminary conclusions were that the predictability was similar, but the best models changed, due to inclusion of alternative environmental variables to those in the original study. Given the short amount of time spent on this, these results were considered promising.

The group also examined Snow Crab data from Elmer Wade, for which EDM projected a future abundance surprisingly close to that estimated by the recent full stock assessment. Together the group figured out some of the subtleties with the data structures required by *rEDM* when using lagged data, as documented in the available code repository.

Overall, the group worked very effectively together (one participant exclaimed that she was having ‘the best time ever’). It worked very well to have a small focussed group learning something new that was outside of their usual area of modelling, especially as the EDM approach is potentially highly applicable to participants’ usual study systems.

6.1. RECOMMENDATIONS

The EDM approach is worth pursuing further; for example it does seem to be capturing some underlying dynamics of the salmon populations. The group was keen to continue working together, and participants established new collaborations that have already been mentioned in proposals for funding. The *rEDM* package was easy to use, but, as ever, this means that users need to be diligent in understanding what it is doing (behind the scenes). Finally, the group warned that there is still a need to have a firm understanding of environmental mechanisms (even though these are not detailed in equations for EDM), and not to jump to conclusions purely based on the EDM results.

7. PLANNING OF WORKSHOP

As a potential aid to planning similar workshops in the future, brief logistical details are given here. The idea of the workshop came from the national TESA group, and the Terms of Reference was gradually narrowed to focus the workshop on the single idea of incorporating ecosystem effects into *single-species stock assessments.* The venue was established and booked, and external speakers invited early, which was particularly important because they were coming from the United States and Norway. Rowan Haigh established a Google Forms questionnaire to establish interest from potential DFO participants. Questions included what species people worked on, what computational tools and population models they use, and what would be a provisional title for their presentation. This was invaluable in ensuring that the resulting participants would be suitable for the workshop, and be very engaged (since the success of such a workshop relies on active participation, rather than a few people teaching everyone else). Only two deliverables (this Proceedings and an online repository of talks and code) were required, to minimise workload of participants, and to make the most of the time for participants to work together and share practical ideas and computer code.

8. OVERALL SUMMARY AND RECOMMENDATIONS

8.1. SUMMARIES FROM EXTERNAL SPEAKERS

Both external speakers were asked to provide some summary points at the end of the meeting. Daniel Howell’s remarks included:

1. It appears that DFO has the data, the people, the tools and the desire to do something useful in this context;
2. He probably wouldn't get such buy-in if he tried to run the same kind of meeting in Norway;
3. Be clear about what you are doing, why, and where in the advice process it fits, and don't just present the numbers;
4. Data-rich and data-poor stocks can have different needs for environmental drivers. Data-poor may want them as a proxy for missing fisheries information. But they do fit into the same overall framework;
5. Marine mammals vs. fish – both live in the ecosystem but have very different underlying biology, especially around reproduction;
6. Could develop *DLMtool* into a Data Rich Tool. *DLMtool* is very good (unusually good!) at looking at structural uncertainty (choice of model, management regime) rather than just effects of noise in the data;
7. Need to check what happens if you are wrong. Suppose you code in some environmental relationship but it is not true. There is a need to test if this model mis-specification is worse than not including such a relationship, especially if it could go catastrophically wrong – a small potential improvement at the cost of potentially being very wrong does not seem smart;
8. Do not over-promise what you will deliver (or do not promise what you cannot deliver).

Paul Spencer noted that comparable US workshops would be more like a conference of ~100 people rather than having interactive groups exchange ideas. The present workshop was great in having the break-out groups where people worked together on detailed problems. There was communication between ecosystem-analysis people and stock assessment people – often those groups do not interact well. He was impressed that DFO is thinking about how to incorporate ecosystem information into assessments, and clearly thinking about it first without just jumping into doing lots of coding. He noted that the plenary talks were varied and impressive, and covered a wide range of topics.

One note of caution is that the stock-assessment process can often focus on what goes into a model or is left out, but not everything useful can be quantified and put into a model. For example, management approaches such as seasonal and spatial closures can be useful approaches, but hard to quantify in a model that has coarse temporal (e.g. annual) and spatial (e.g. coastwide) scales.

Dr. Spencer encouraged the use of *DLMtool*, as it helps us to think about what models can and cannot apply for a given situation, as well as requiring managers and stakeholders to articulate objectives. Finally, continually trying to improve the data will help, especially since stock-assessment models that fit the noise and not the signal can do more harm than good.

8.2. OVERALL RECOMMENDATIONS

The main recommendations for assessment scientists considering how to incorporate ecosystem information into a single-species stock assessment are:

1. Conduct a scoping exercise to identify how environmental factors could be included, focussing on what could be expected to improve management outcomes. This can be based on the guidance from Appendix E that is relevant to the specific stock.
2. Have buy-in from stakeholders (including managers and scientists) to make sure that they will understand and use the resulting advice. Including ecosystem information in an assessment may result in a different type of advice than they are used to.
3. Be aware that if an environmental relationship is correctly specified in a model then this still might only lead to a small potential improvement in the resulting management advice. But if the relationship is mis-specified then it could potentially lead to very misleading/incorrect advice. This could be tested if possible, which may conclude that it is not be prudent to include the relationship.

The main recommendations regarding further research and exploration are:

1. Approach the Section Head (Robyn Forrest) of the Pacific Region's Quantitative Assessment Methods Section about advancing DFO's use of *DLMtool*. *Already done – Tom Carruthers has been contracted to adapt DLMtool for some of DFO's needs (specifically for COSEWIC-listed Pacific groundfish). He also received Partnership Funding to customise performance metrics and operating models for BC groundfish species. An extended three-year Partnership proposal to advance DLMtool for a broad set of Canadian fisheries is currently under review. Furthermore, TESA is contracting Dr. Carruthers to give a five-week course (one hour per week) on DLMtool via Webinar in October/November 2017.*
2. The EDM approach can implicitly include ecosystem effects and so is worth pursuing further. It needs to be tested and understood more fully before applying to operational stock assessments.

9. REFERENCES FOR MAIN TEXT

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APPENDIX A. AGENDA

Technical Expertise in Stock Assessment (TESA)

National Workshop

AGENDA

Incorporating an ecosystem approach into single-species stock assessments

Nov 21-25, 2016

Malaspina Room, Coast Bastion Hotel, Nanaimo BC
Break-out rooms: Malahat & Dunsmuir

Chairs: Andrew Edwards, Ross Tallman, and Rowan Haigh

DAY 1 – Monday, Nov 21

Time	Subject	Presenter
0900	Introductions, Review Agenda & Housekeeping	Chairs
0910	TESA Overview – NCR perspectives	Steven Schut
0920	Review Terms of Reference Objectives: (i) participants, (ii) Ottawa Meeting products	Chairs
0930	Use of environmental and ecosystem information in single-species stock assessments – past and current work from the U.S. North Pacific	Paul Spencer (AFSC, USA)
1030	***Break***	
1050	Going beyond single-species management: experience from across the Atlantic	Daniel Howell (IMR, Norway)
1150	Further questions for Paul or Daniel	Participants
1200	***Lunch Break***	
1300	*Talks by Participants (10 min talk, 5 min discussion)*	*Name (region*)*
1300	1. The NAFO Roadmap towards implementing an Ecosystem Approach to Fisheries: the role of single-species stock assessments	Mariano Koen-Alonso (N&L)
1315	2. How ICES uses multiple single-species assessments to obtain the available harvest trade-offs in mixed fisheries	Daniel Ricard (G)
1330	3. Using Ecopath with Ecosim to put single species assessments into an ecosystem context	Alida Bundy (M)
1345	4. A quick overview of the effects of water temperature, dissolved oxygen and pH on the physiology of water breathers, and why it matters for stock assessment	Denis Chabot (Q)
1400	5. Data limited methods incorporating environmental effects and a traffic light system that uses traditional knowledge	Ross Tallman (C&A)

Time	Subject	Presenter
1415	6. Quantitative and qualitative approaches for including environmental and ecosystem information in probabilistic salmon forecasts	Sue Grant (P)
1430	7. Incorporating environmental conditions into assessments of seals	Garry Stenson (N&L)
1445	***Break***	
1500	8. Snow Crab assessment and environmental drivers	Brad Hubley (M)
1515	9. Impact of environmental factors on pelagic fish stock dynamics	Stéphane Plourde(Q)
1530	10. A warming ocean, an expanding halibut fishery, a declining beluga whale subsistence hunt, and shifting intra-guild predation with a new top forage fish – harbinger of a future Arctic?	Steve Ferguson (C&A)
1545	11. Using GCM and RCM outputs with local-area "tuning" to produce climate-and-salmon stock impact scenarios for applied management advice	Kim Hyatt (P)
1600	12. Stock assessment tools and scripts for applying a variety of techniques to specific problems	Adam Cook (M)
1615	13. Recent approaches that incorporate environmental effects: oceanographic regimes acting on recruitment in an Atlantic herring population model	Thomas Doniol-Valcroze (Q)
1630	14. Incorporating an ecosystem approach into single-species stock assessments: population models with time-varying components of productivity	Doug Swain (G)
1645	15. A Bayesian framework for investigating impacts of climatic and environmental variability on recruitment of Pacific Ocean Perch	Andrew Edwards (P)
1700	Adjourn for the Day	

*C&A = Central & Arctic, G =Gulf, M = Maritimes, N&L = Newfoundland & Labrador, P = Pacific, Q = Québec

DAY 2 – Tuesday, Nov 22

Time	Subject	Presenter
0900	Review Agenda & Housekeeping Review Day 1 (comments from externals)	Chairs
0930	Demo data-poor model – *DLMtool* w/ potentially 85+ methods	Tom Carruthers
1015	***Break***	
1030	Demo data-rich model – SCA for S. Gulf of St. Lawrence cod	Doug Swain
1115	Demo data-alternative model – Empirical Dynamic Modelling	Andrew Edwards
1200	***Lunch Break***	
1300	Work in break-out groups	Groups
1430	***Break***	
1500	Work in break-out groups	Groups
1630	Brief summary of progress Discussion on how to proceed on Day 3	Participants
1700	***Adjourn meeting***	

DAY 3 – Wednesday, Nov 23

Time	Subject	Presenter
0900	Review Agenda & Housekeeping Review Status of Day 2 Insights/advice from external participants on directions we might pursue given the presentations and the break-out groups	Chairs, Externals
0915	Work in break-out groups	Groups
1030	***Break***	
1045	Work in break-out groups	Groups
1200	***Lunch Break***	
1300	Work in break-out groups	Groups
1430	***Break***	
1500	Data-poor group – summary of progress	Group member
1530	Data-rich group – summary of progress	Group member
1600	Data-alternative group – summary of progress	Group member
1630	General discussion on how to proceed on Day 4	Chairs, Participants
1700	***Adjourn meeting***	

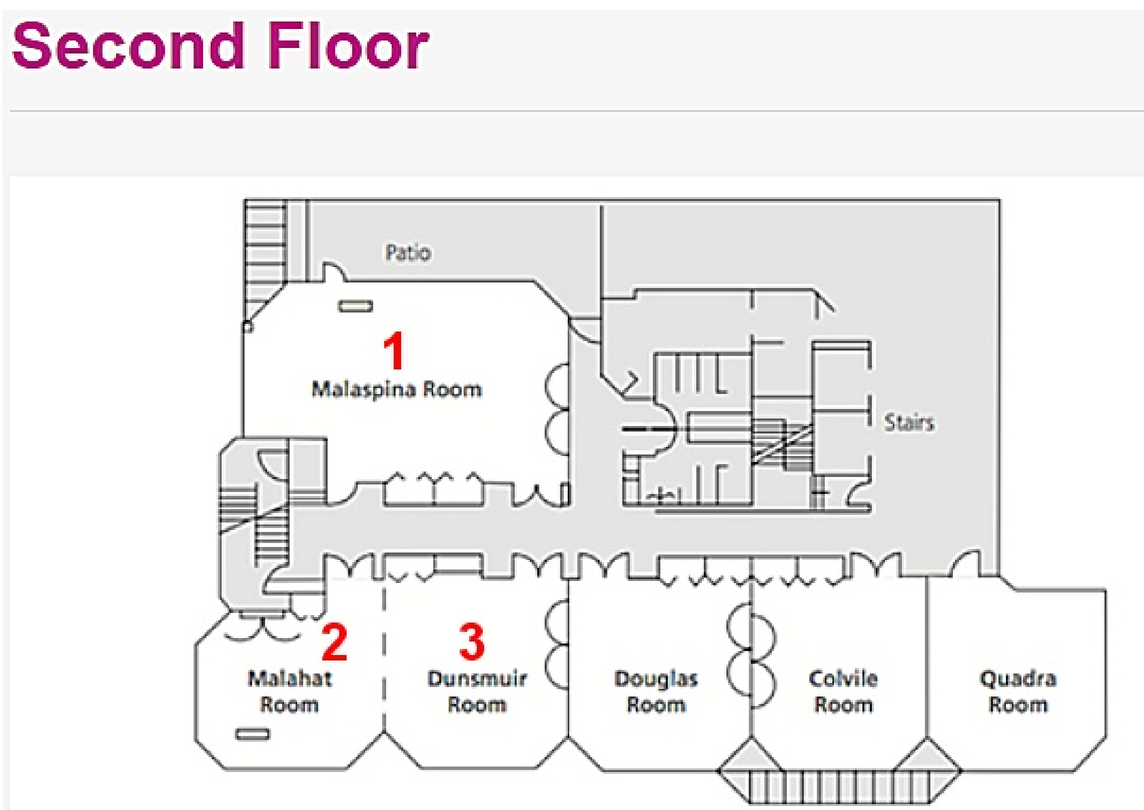
DAY 4 – Thursday, Nov 24

Time	Subject	Presenter
0900	Review Agenda & Housekeeping Review Status of Day 3	Chairs
0915	Work in break-out groups	Groups
1030	***Break***	
1045	Work in break-out groups	Groups
1200	***Lunch Break***	
1300	Work in break-out groups	Groups
1430	***Break***	
1500	Work in break-out groups	Groups
1630	Evaluation/insights from Daniel Howell	Daniel Howell
1700	***Adjourn meeting***	

1800	**Group Dinner at Firehouse Grill (7 Victoria Rd)**	**Everyone**

DAY 5 – Friday, Nov 25

Time	Subject	Presenter
0900	Review Agenda & Housekeeping Review Status of Day 4	Chairs
0915	Work in break-out groups	Groups
1030	***Break***	
1045	Work in break-out groups	Groups
1200	***Lunch Break***	
1300	Data-poor group – final presentation	Group member
1345	Data-rich group – final presentation	Group member
1430	***Break***	
1500	Data-alternative – final presentation	Group member
1545	Evaluation/insights from Paul Spencer	Paul Spencer
1615	Meeting wrap-up Assign tasks (if any) Identify deliverables Flag future directions for this kind of work in DFO Solicit an overall evaluation from the group	Chairs
1700	***Adjourn meeting***	



APPENDIX B. TERMS OF REFERENCE (ENGLISH AND FRENCH)

Incorporating an ecosystem approach into single-species stock assessments

Committee on Technical Expertise in Stock Assessment (TESA) National Workshop

25-26 November 2016
Nanaimo, BC

Chairs: Ross Tallman (FWI, Winnipeg), Rowan Haigh (PBS, Nanaimo)

Context

The incorporation of ecosystem approaches (EAs) into decision making has been a primary goal of fisheries management organizations across the globe for at least 20 years. However, it is rare to find examples of how it is being applied operationally with respect to influencing advice regarding exploitation of a single stock. Some ecosystem approaches attempt to deal with the whole ecosystem at once in a large multispecies modelling network but rarely is that approach used to provide species-specific harvest advice, even if those approaches are useful in terms of providing overviews of the whole ecosystem and interactions among components.

Single-species assessment approaches still provide the backbone of advisory products for fisheries management, and there has been little reduction in the reliance on this kind of advice even with strong policies advocating an ecosystem approach to marine management. This said, single species do not exist in isolation from the rest of the ecosystem, and single-species population models rely on inputs and fitted parameters that are closely linked to other components of the ecosystem and environment. For example bottom-up processes may influence growth and subsequently weight-at-age, which is an important input to age-based assessments. Likewise, predation is usually an important part of natural mortality. Environmental factors such as water temperature or zooplankton production likely affect recruitment rate. Logically, there are parameters in single-species assessments where hypotheses about the ecosystem and environment can be mechanistically or statistically included; therefore, advice in the single-species context can be conditioned upon plausible hypotheses about the ecosystem and environment. This indirect but very operational methodology could be seen as a means of implementing aspects of the ecosystem approach that could influence harvest advice on specific populations.

Objectives

The objectives of this science framework discussion are to:

1. Explore methods for operationally incorporating the ecosystem approach into single-species stock assessments and advice.
2. Provide at least one concrete example of how it could be implemented in Canada:
   a. Show impacts on advice with and without the ecosystem approach included;
   b. Provide methods and a code repository for computational tools.
3. Format:

a. 5-day workshop where methods are explored and applied in specific cases;
b. Short presentations by participants on their methods for incorporating ecosystem factors into existing stock assessments;
c. Presentations by external participants on EA methods used in other jurisdictions;
d. 4 break-out groups which will examine methods for incorporating environment and ecosystem variables in stock assessments of different complexity:
    i. Data poor (e.g. index based methods);
    ii. Data moderate (e.g. delay-difference);
    iii. Data rich (e.g. catch at age);
    iv. Simulation as a tool for including an ecosystem approach in stock assessment.
e. DFO science participants from all regions across Canada providing analysis;
f. External participants.

Expected Publications

- A proceedings report (CSAS document or Canadian Technical Report of Fisheries and Aquatic Sciences).
- A repository to share code, data and presentations explored at the meeting.
- A compilation of assessments in Canada which already incorporate external stock factors.

Participation

- DFO Science – Stock Assessment Experts
- DFO Science – Ecosystem Modelling Experts
- DFO Resource Management Representatives
- External Experts

Intégration d'une approche écosystémique à l'évaluation des stocks par espèce

Atelier national du groupe d'expertise technique en évaluation des stocks (ETES)

Du 21 au 25 novembre 2016
Nanaimo (Colombie-Britannique)

Présidents : Ross Tallman (Institut des eaux douces, à Winnipeg), Rowan Haigh (Station biologique du Pacifique, à Nanaimo)

Contexte

Depuis au moins vingt ans, les organisations vouées à la gestion des pêches se donnent comme objectif d'incorporer l'approche écosystémique aux processus décisionnels. Cependant, les exemples d'application opérationnelle d'une telle approche se font rares, surtout lorsqu'il est question de déterminer l'influence des avis sur l'exploitation d'un stock. Certaines approches écosystémiques tentent de considérer l'écosystème tout entier dans une modélisation d'un large réseau de relations plurispécifiques. En revanche, de telles approches sont très peu utilisées pour fournir des avis sur la pêche d'une espèce même si elles ont l'avantage de fournir une vue d'ensemble de l'écosystème et des interactions entre les différentes composantes.

Les approches à l'évaluation par espèce servent toujours de fondement aux documents scientifiques pour la gestion des pêches. La dépendance à ce genre d'avis a peu diminué même si certaines politiques prônent l'adoption d'une approche écosystémique à la gestion des ressources marines. Cela dit, aucune espèce n'existe indépendamment de son écosystème, et les modèles de population par espèce sont fondés sur des intrants et des paramètres adaptés qui sont étroitement liés à d'autres composantes de l'écosystème et de l'environnement. Par exemple, les approches ascendantes pourraient influencer la croissance et, par le fait même, le poids selon l'âge; il s'agit là d'une donnée importante pour les évaluations fondées sur l'âge. De même, la mortalité naturelle est habituellement due en grande partie à la prédation. Des facteurs environnementaux, tels que la température de l'eau et la production de zooplancton, ont sans doute une influence sur le taux de recrutement. Logiquement, il y a des paramètres dans des évaluations par espèce où des hypothèses sur l'écosystème et l'environnement peuvent être incluses statistiquement; ainsi, les avis visant une espèce en particulier peuvent être influencés par les hypothèses plausibles sur l'écosystème et l'environnement. Une telle méthodologie, opérationnelle quoique indirecte, pourrait servir à la mise en oeuvre de certains aspects de l'approche écosystémique qui influenceraient les avis sur la pêche de certaines populations.

Objectifs

Les objectifs de ce cadre scientifique sont les suivants:

1. Explorer les méthodes pour intégrer, de façon opérationnelle, l'approche écosystémique dans les évaluations des stocks et avis par espèce.
2. Fournir au moins un exemple concret de comment ça pourrait être mis en oeuvre au Canada:
    a. Démontrer l'incidence sur l'avis selon si l'approche écosystémique est intégrée ou non;
    b. Fournir les méthodes et un dépôt de code pour les outils de calcul.

3. Format:
    a. Atelier de cinq jours où les méthodes sont explorées et appliquées à des cas précis;
    b. Courtes présentations des méthodes utilisées par les participants pour incorporer les facteurs écosystémiques dans leurs évaluations de stocks existantes;
    c. Présentations par les experts externes des approches écosystémiques utilisées dans leur pays;
    d. Quatre groupes de discussion pour examiner les méthodes utilisées pour incorporer des variables environnementales et écosystémiques dans l'évaluation de stock de complexité différente :
        i. Pauvre en données (ex : méthode basée sur des indices)
        ii. Modérée en données (ex : modèle à différences retardées)
        iii. Riche en données (ex : capture à l'âge)
        iv. Simulation comme un outil pour inclure une approche écosystémique dans l'évaluation de stock.
    e. Analyses effectuées par des participants du Secteurs des sciences du MPO de partout au Canada;
    f. Participants externes.

Publications prévues

- Un compte-rendu (document du Secrétariat canadien de consultation scientifique ou rapport technique canadien des sciences halieutiques et aquatiques)
- Un dépôt pour partager les codes, les données et les présentations utilisés lors de l'atelier.
- Une compilation des évaluations effectuées au Canada qui tiennent déjà compte des facteurs externes qui influencent les stocks.

PARTICIPATION

- Secteur des sciences du MPO – Experts en évaluation des stocks
- Secteur des sciences du MPO – Experts en modélisation des écosystèmes
- Représentants de la Division de la gestion des ressources du MPO
- Experts externes

APPENDIX C. LIST OF PARTICIPANTS

Table C.1. List of participants attending the Ecosystem Approach Workshop in Nanaimo, British Columbia.

DFO Region	Name
C&A	Steven Ferguson
C&A	Xinhua Zhu
C&A	Ross Tallman
C&A	Kimberly Howland
GULF	Doug Swain
GULF	Elmer Wade
GULF	Daniel Ricard
MAR	Alex Hanke
MAR	Yanjun Wang
MAR	Brad Hubley
MAR	Alida Bundy
NL	Paul Regular
NL	Mariano Koen-Alonso
NL	Garry Stenson
PAC	Andrew Edwards
PAC	Jaclyn Cleary
PAC	Carrie Holt
PAC	Jackie King
PAC	Sue Grant
PAC	Rowan Haigh
QC	Thomas Doniol-Valcroze
QC	Denis Chabot
QC	Stephane Plourde
External	Daniel Howell
External	Paul Spencer
External	Tom Carruthers
External	Dave Campbell
PAC	Robyn Forrest
NCR	Steve Schut

The above participants attended the workshop (the final four could only attend for one or two days, the remainder participated for the full week).

APPENDIX D. *DLMTOOL* CASE STUDY – ARCTIC CHARR

D.1. DATA-LIMITED MODEL OVERVIEW

Tom Carruthers presented *DLMtool*, an R package for conducting management strategy evaluations (MSEs) of various management procedures (MPs) for data-limited fish stocks, and subsequent application of the MPs to data-limited stocks.

Extract from DLMtool User Guide (Carruthers and Hordyk 2016)*:*

"An MSE is usually comprised of three key components:

1. an *operating model* that is used to simulate the stock and fleet dynamics,
2. an assessment method and harvest control rule model (interchangeably referred to as *management procedures*, or *management strategies*) that use the simulated fishery data from the operating model to estimate the status of the (simulated) stock and provide management recommendations (e.g. a total allowable catch (TAC) or effort control), and
3. an *observation model* that is used to generate the simulated observed data that would typically be used in management (i.e., with realistic imprecision and bias).

The management recommendations by each management procedure are then fed back into the operating model and projected forward one time step. The process of simulating the population dynamics of the fishery along with the management process that feeds back and impacts the simulated fish population is known as *closed-loop simulation*."

D.2. WORKSHOP OPERATING MODEL

Once the data-limited break-out group had loaded the software and became familiar with the inputs for the MSE operating model (i.e., parameters defining the stock, fleet, and observation characteristics) and the structure of data objects, Tom provided a demo using a rockfish stock as an example. Multiple pre-programmed MPs were tested on the rockfish data to determine which MPs perform best using performance criteria such as stability in long term yield (LTY) and maintaining biomass above a reference level (e.g. $0.5B_{\mathrm{MSY}}$ – half of the equilibrium biomass that would support the maximum sustainable yield).

After the demo, the group decided to use an existing stock – Darnley Bay Arctic Charr (*Salvelinus alpinus*) – as a case study to explore *DLMtool*. Biological parameters and fleet dynamic inputs were taken from two source documents (Gallagher et al. 2017, Zhu et al., 2017, respectively) and then reviewed by the experts in the group. These were then put into *DLMtool* to create an Operating Model of this "reference" situation. A suite of MPs were applied to this finalized reference case. Run results were assessed using visual tools designed for clients like NOAA and DFO. A summary of progress made is presented here. This will help potential users of *DLMtool* appreciate how it works, understand the workflow involved, and how environmental effects can be implicitly incorporated. Results are provisional and not intended as advice.

The components of the operating model depicted in Figure D.1 include:

1. A csv file containing the parameters for the stock object (`Stock_Charr.csv`) used by the operating model (OM).
2. A csv file containing the parameters for the fleet object (`Fleet_Charr.csv`) used by the OM.
3. A generic observation model was used to generate fishery data subject to moderate levels of precision and bias and used in the OM.

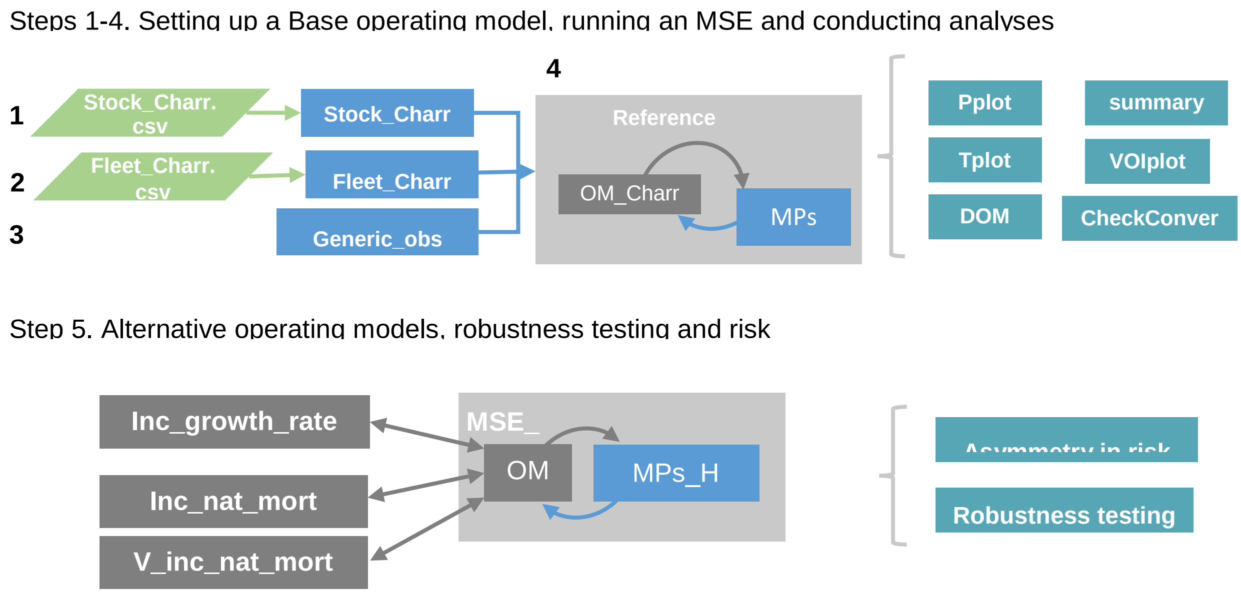


Figure D.1. The process followed by the data-limited break-out group. An operating model comprises three objects – stock parameters, fleet parameters, and observation error.

4. The stock, fleet and observation models were combined in a single operating model and the MSE run for all MPs.

5. Scenarios for various ecosystem processes were specified including increasing growth and natural mortality rate.

D.2.1. Stock dynamics

The Stock object contains all the information relating to the fish stock that is being modelled. Details of data that make up a stock object appear in Table D.1 and the parameter values used appear in Table D.2.

Typically the performance of management procedures is most strongly determined by longevity and stock productivity (natural mortality M), resilience to fishing (steepness h), stock level (depletion D), non-stationarity in productivity (recruitment auto-correlation AC, but also Kgrad), length at maturity (L50, L50_95), and the variability in recruitment (Perr). [Note that M, h etc. refer to abbreviations used in the code rather than to mathematical symbols, and so are not italicised].

However, there are no general rules. For example,

- if an MP is selected based on its ability to achieve certain biomass levels and the fish is short-lived (high M) and has high recruitment variability (Perr) then the starting level of stock depletion (D) may have little bearing on performance over a 50 year projection;
- the influence of length at maturity is entirely determined by the length-selectivity of fishing and may be unimportant if it is always well below the length at which individuals become vulnerable to fishing;
- none of the parameters above will be important if performance is related to avoiding low stock sizes and 60% of a viscous stock is found in a reserve (Frac_area_1 = 0.6, Prob_staying > 0.98).

Table D.1. Guide (Stock_guide.csv) for filling out the file Stock_Charr.csv. CV is coefficient of variation.

Row	Parameter	Description
1	Name	The name of the stock
2	maxage	The maximum age of the fish
3	R0	Unfished recruitment level
4	M	Natural mortality rate
5	Msd	Interannual variability in mortality rate (log-normal CV)
6	Mgrad	Gradient in natural mortality rate (%/y)
7	h	Steepness of the stock recruitment curve
8	SRrel	Functional form of the stock recruitment curve
9	Linf	Maximum length
10	K	Maximum growth rate (von Bertalanffy growth)
11	t0	Theoretical age at length zero (von Bertalanffy growth)
12	Ksd	Interannual variability in maximum growth rate (log-normal CV)
13	Kgrad	Gradient in maximum growth rate (%/y)
14	Linfsd	Interannual variability in maximum length (log-normal CV)
15	Linfgrad	Gradient in maximum length (%/y)
16	recgrad	Gradient in recruitment strength (%/y)
17	a	Length-weight parameter a ($W=aL^b$)
18	b	Length-weight parameter b ($W=aL^b$)
19	D	Current level of stock depletion (spawning biomass now relative to unfished)
20	L50	Length at 50% maturity (same units as Linf)
21	L50_95	The length interval from 50% maturity to 95% maturity (same units as Linf)
22	Perr	Process error: the interannual variability in recruitment (log-normal CV)
23	AC	Auto-correlation in recruitment
24	Period	The duration of recruitment regimes
25	Amplitude	The fractional increase / decrease in recruitment strength
26	Size_area_1	Fraction of habitat in area 1 (a potential marine reserve)
27	Frac_area_1	Fraction of habitat in area 1
28	Prob_staying	Probability of individuals remaining in an area between time steps
29	Source	Where did all these parameters come from (what document)?

Table D.2. Parameters for the stock object (Stock_Charr.csv), in this case, Darnley Bay Arctic Charr.

Parameter	Lower	Upper	Details	Description
Name			Darnley Bay Arctic Charr	Stock name
maxage	18		Age structure diagram, page 55 Biological document	Maximum age for simulation calculations
R0	1000		MSE is scale-less so R0 is arbitrary	Unfished recruitment
M	0.232	0.348	0.29 +/- 20% Page 15 Modelling document	Instantaneous natural mortality rate
Msd	0	0.1	+/- 20%, ie minor interannual variability but consider robustness Table 9 page 30 of Biological document	CV controlling degree of inter-annual variability in M among years (e.g. 0.1 is a CI of ~ 0.8 - 1.2)
Mgrad	-0.1	0.1	Gradients in M are minor but consider robustness	% yr^{-1} slope in natural mortality rate
h	0.75	0.95	Figure 34, page 78 of the Modelling document	Steepness of the stock recruitment
SRrel	1		Beverton-Holt stock-recruitment	Beverton-Holt stock recruitment
Linf	760.5	799.5	Average of male+females (812, 748) +/- 2.5%, page iv of the Modelling document	von B. (von Bertalanffy) Linf
K	0.171	0.189	+/- 5% page iv of the Modelling document	von B. K

Parameter	Lower	Upper	Details	Description
t0	0	0	Not specified, zero length at age zero	Theoretical age at length zero
Ksd	0.01	0.02	Minor changes in growth rate K among years (consistent with stock assessment assumptions)	CV controlling degree of interannual variability in von B. K
Kgrad	-0.25	0.25	Minor possible future trajectory in growth rate K (consistent with stock assessment assumptions)	% yr^{-1} slope in growth rate K
Linfsd	0.01	0.02	Minor changes in maximum length among years (consistent with stock assessment assumptions)	CV controlling degree of interannual variability in von B. K
Linfgrad	-0.1	0.1	Minor possible future trajectory in Linf (consistent with stock assessment assumptions)	% yr^{-1} slope in maximum length
recgrad	0	0	No slope in recruitment (this slot is currently unused in *DLMtool* 3.2.2 (but will feature in 3.2.3)	% yr^{-1} gradient in recruitment
a	1.39E-05		Page 10 of the Modelling document	W=aLb
b	2.98		Page 10 of the Modelling document	W=aLb
D	0.2	0.6	Fig 36, page 80 (Modelling document) puts SSBmsy/SSB0 at just under 0.2 and Fig 37, page 81 puts current SSB around 1-3 times SSBmsy	Current SSB relative to SSB0
L50	544.78	610.08	Linf*(1-exp(-K*8)): min age at maturity is 7 or 8 (Page 9 of the Modelling document). Robustness: seems high	Length at 50% maturity
L50_95	31.204	35.535	Assuming age at 95% maturity is 8 and 9 respectively (corresponding with L50 for 7 and 8)	Length interval between 50% and 95% maturity
Perr	0.3	0.6	Eyeballing Figure 31, page 75 of the Modelling document	Process error, sigma R
AC	0.7	0.8	Weak lag-1 autocorrelation	Lag 1 autocorrelation
Period			Not specified, no recruitment regime shifts	The duration of recruitment regime shifts
Amplitude			Not specified, no recruitment regime shifts	The magnitude of recruitment regime shifts
Size_area_1	0.5	0.5	Currently not used in v3.2.2	Size of area 1
Frac_area_1	0.5	0.5	Even stock distribution (a mixed stock)	Fraction of habitat in area 1
Prob_staying	0.5	0.5	As likely to stay as leave (a mixed stock)	Probability of staying in area 1
Source			Multimodel assessment of population production and recommendations for sustainable harvest levels of anadromous Arctic Charr from the Hornaday River, Northwest Territories	Zhu et al. 2017

D.2.2. Specifying fleet parameters

While the Stock object contains all the information relating to the fish stock that is being modelled, the Fleet object is populated with information relating to the fishing fleet and historical pattern of exploitation (Table D.3). Values used for the fleet targetting Darnley Bay Arctic Charr appear in Table D.4.

The trajectory in fishing mortality rate described by EffLower and EffUpper is the key determinant of whether the stock is currently subject to overfishing or underfishing, depending of course, on the level of stock depletion D specified in the Stock object (Stock@D).

Similarly, the length selectivity of fishing interacts with the length at maturity to determine whether the stock is subject to growth (catching fish that are too small) or recruitment overfishing (catching fish that are fecund).

Table D.3. Guide (Fleet_guide.csv) for filling out the file Fleet_Charr.csv.

Row	Parameter	Description
1	Name	The name of the fleet
2	nyears	The number of historical years of fishing prior to today
3	Spat_targ	The level of spatial targetting (currently disabled)
4	Fsd	Interannual variability in fishing mortality rate (or effort)
5	qinc	Average annual increase in fishing efficiency (%/y)
6	qcv	Interannual variability in catchability (for projections)
7	EffYears	Vertices (years) describing the historical trend in fishing effort (relative effort)
8	EffLower	Lower bound on historical effort (relative effort) corresponding with EffYears
9	EffUpper	Upper bound on historical effort (relative effort) corresponding with EffYears
10	SelYears	<time varying selectivity> Vertices (years) describing historical shifts in length selectivity (if applicable)
11	AbsSelYears	<time varying selectivity> Alternative year names for plotting corresponding with SelYears
12	L5	<constant selectivity> The length at 5% vulnerability
13	LFS	<constant selectivity> The length at 100% vulnerability
14	Vmaxlen	<constant selectivity> The vulnerability (fraction) of the largest fish
15	L5Lower	<time varying selectivity> a time series of lower bounds for L5 corresponding with SelYears
16	L5Upper	<time varying selectivity> a time series of upper bounds for L5 corresponding with SelYears
17	LFSLower	<time varying selectivity> a time series of lower bounds for LFS corresponding with SelYears
18	LFSUpper	<time varying selectivity> a time series of upper bounds for LFS corresponding with SelYears
19	VmaxLower	<time varying selectivity> a time series of lower bounds for Vmaxlen corresponding with SelYears
20	VmaxUpper	<time varying selectivity> a time series of upper bounds for Vmaxlen corresponding with SelYears
21	isRel	Is selectivity relative to length at maturity (i.e. are L5 and LFS a fraction) or absolute (e.g. cm)

Table D.4. Parameters for the fleet object (Fleet_Charr.csv), in this case, Darnley Bay Arctic Charr.

Parameter	Lower	Upper	Details	Description
Name			Darnley Bay Arctic Charr	
nyears	46		1969-2013 Modelling document	Historical years of fishing
Spat_targ	1	1	Not currently used in v3.2.2	Spatial targetting of the fleet
Fsd	0	0	Don't need this as we have annual F estimates	Extra-EffLower/EffUpper trend interannual variability in effort
qinc	-0.1	0.1	Minor changes in fishing	% yr^{-1} changes in

Parameter	Lower	Upper	Details	Description	
			efficiency as per stock assessment	catchability	
qcv	0.05	0.1	A guess at the possible variability in fishing efficiency among years	Interannual variability in catchability	
EffYears	1	2	3	4	5
EffLower	0.2074	0.2722	0.2722	0.2722	0.2852
EffUpper	0.3852	0.5056	0.5056	0.5056	0.5296
(cont'd)	6	7	8	9	10
	0.4148	0.2593	0.4407	1.0111	1.0824
	0.7704	0.4815	0.8185	1.8778	2.0102
(cont'd)	11	12	13	14	15
	1.3741	1.2704	1.8148	0.7519	2.1778
	2.5519	2.3593	3.3704	1.3963	4.0444
(cont'd)	16	17	18	19	20
	1.5167	1.9315	0.8296	0.5185	1.1148
	2.8167	3.587	1.5407	0.963	2.0704
(cont'd)	21	22	23	24	25
	1.1148	0.8815	0.8037	0.8167	0.7259
	2.0704	1.637	1.4926	1.5167	1.3481
(cont'd)	26	27	28	29	30
	1.0111	1.9444	1.2963	1.1407	1.063
	1.8778	3.6111	2.4074	2.1185	1.9741
(cont'd)	31	32	33	34	35
	0.8491	0.7259	0.7778	0.5639	0.5898
	1.5769	1.3481	1.4444	1.0472	1.0954
(cont'd)	36	37	38	39	40
	0.7778	0.4148	1.063	0.538	0.2593
	1.4444	0.7704	1.9741	0.9991	0.4815
(cont'd)	41	42	43	44	45
	0.6481	0.363	0.337	0.3565	0.4537
	1.2037	0.6741	0.6259	0.662	0.8426
SelYears	NA		Not specified, constant selectivity	Years corresponding with shifts in selectivity	
AbsSelYears	NA		Not specified, constant selectivity	Labels for years (graphing only)	
L5	450	490	Based on Figure 7 Page 39 of Biological document	Length at 5% vulnerability	
LFS	580	620	Based on Figure 7 Page 39 of Biological document	Length at full selection	
Vmaxlen	0.95	0.95		Vulnerability of longest fish (dome shapedness)	
L5Lower	NA			Time varing length at 5% vulnerability	
L5Upper	NA			Time varing length at 5% vulnerability	
LFSLower	NA			Time varying length at full vulnerability	
LFSUpper	NA			Time varying length at full vulnerability	
VmaxLower	NA			Time varying vulnerability of longest fish	
VmaxUpper	NA			Time varying vulnerability of longest fish	
isReloooo	0		FALSE	Is vulnerability	

Parameter	Lower	Upper	Details	Description
				parameterized in terms of a fraction of length at maturity (isRel =1) or in absolute terms (e.g. cm)

D.2.3. Specifying observation error model parameters

The final component for the Operating Model is the Observation object (Table D.5). This object contains all the information relating to how the fishery information is generated inside the model. There are a number of built-in Observation objects in the *DLMtool*, and for this exercise we used the ‘Generic_obs’ object (see *DLMtool* User Guide).

In general, at least one of these data sources are used by each of the MPs in *DLMtool* which means that increasing the bias or imprecision in a particular data source can strongly determine the performance of one or more MPs.

In this simulation exercise we used the pre-built Observation model ‘Generic_obs’. Alternative models to consider include ‘Perfect_Info’ (ideal situation), ‘Precise_Unbiased’ (accurate and precise) and ‘Imprecise_Biased’ (bad quality data).

Table D.5. Guide (Observation_guide.csv) for filling out a file Observation_Charr.csv; however, we use a built-in Observation object called ‘Generic_obs’.

Row	Parameter	Description
1	Name	Name of the observation model
2	Cobs	Error in annual catch observations (expressed as a lognormal CV)
3	Cbiascv	Extent of possible biases in catches (expressed as a lognormal CV)
4	CAA_nsamp	The number of catch-at-age observations
5	CAA_ESS	The effective sample size of annual catch-at-age observations
6	CAL_nsamp	The number of catch-at-length observations
7	CAL_ESS	The effective sample size of annual catch-at-length observations
8	CALcv	The degree of variability in the length composition at age
9	Iobs	Error in annual relative abundance indices
10	LenMcv	Extent of possible biases (EPB) in length at maturity estimates
11	Mcv	EPB in natural mortality rate
12	Kcv	EPB in maximum growth rate parameter
13	t0cv	EPB in growth parameter t0 (theoretical age at length zero)
14	Linfcv	EPB in maximum length
15	LFCcv	EPB in length at first capture
16	LFScv	EPB in length at full selection
17	B0cv	EPB in unfished biomass
18	FMSYcv	EPB in FMSY (fishing mortality rate at maximum sustainable yield)
19	FMSY_Mcv	EPB in ratio of FMSY to natural mortality rate
20	BMSY_B0cv	EPB in BMSY relative to unfished biomass
21	ageMcv	EPB in age at maturity
22	rcv	EPB in intrinsic rate of increase
23	Dbiascv	EPB in depletion (spawning biomass relative to unfished)
24	Dcv	Error in annual estimates of stock depletion
25	Btbias	EPB in estimates of current absolute stock size
26	Btcv	Error in annual estimate of stock size
27	Fcurbiascv	EPB in estimates of current fishing mortality rate
28	Fcurcv	Error in estimates of current fishing mortality rate
29	hcv	EPB in estimate of recruitment compensation (steepness)
30	Icv	Error in annual relative abundance index

Row	Parameter	Description
31	maxagecv	EPB in assumed maximum age
32	Reccv	EPB in recent recruitment strength
33	Irefcv	EPB in index at maximum sustainable yield
34	Crefcv	EPB in MSY
35	Brefcv	EPB in BMSY
36	beta	Parameter controlling hyperstability / hyperdepletion in a relative abundance index

D.3. MSE – REFERENCE CASE

Management strategy evaluations (MSEs) were run using all available management procedures (MPs) that the data supported using the *DLMtool* function `runMSE`, with 96 simulations projected out for 42 years with a 5-year assessment interval. A function called `DFO_plot` was used to display trade-offs among yield and biological performance metrics (Figure D.2). As the

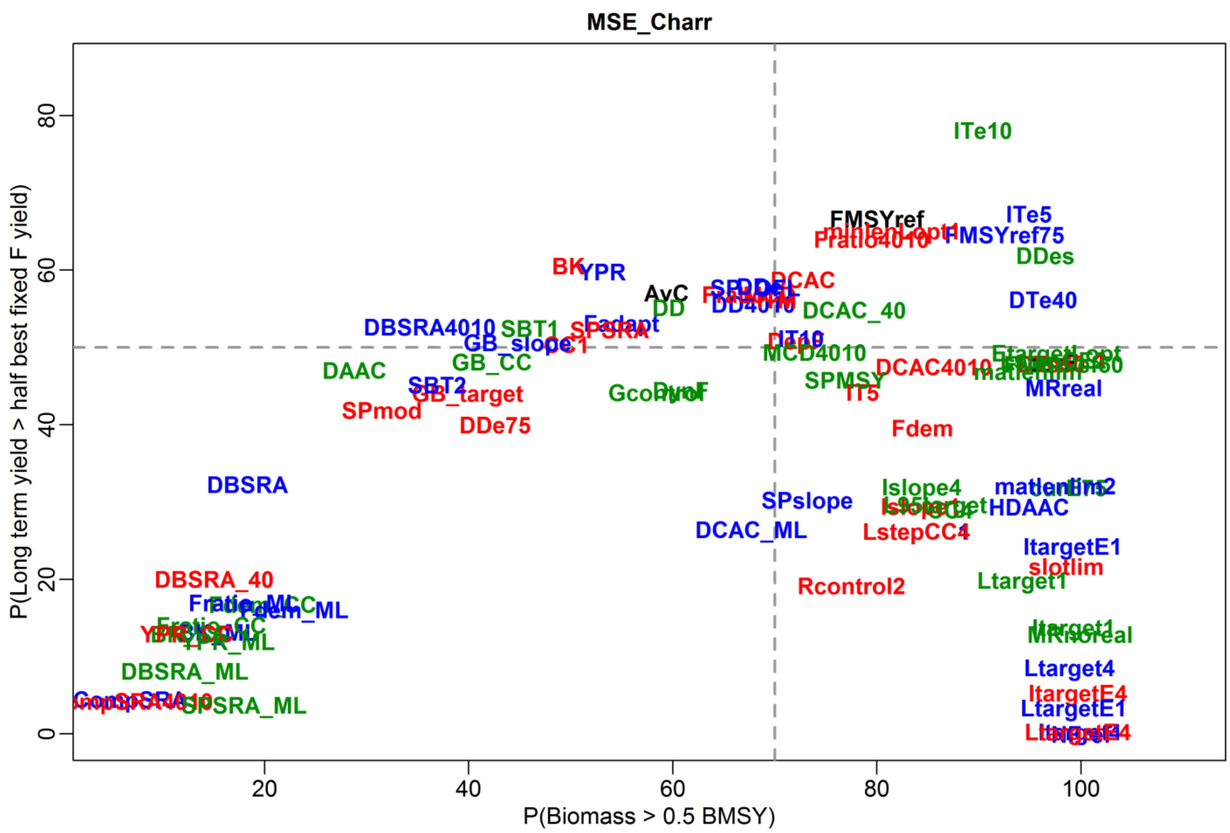


Figure D.2. The trade-off between biological (relative to $0.5B_{MSY}$) and yield (probability of getting a good yield) for all management procedures.

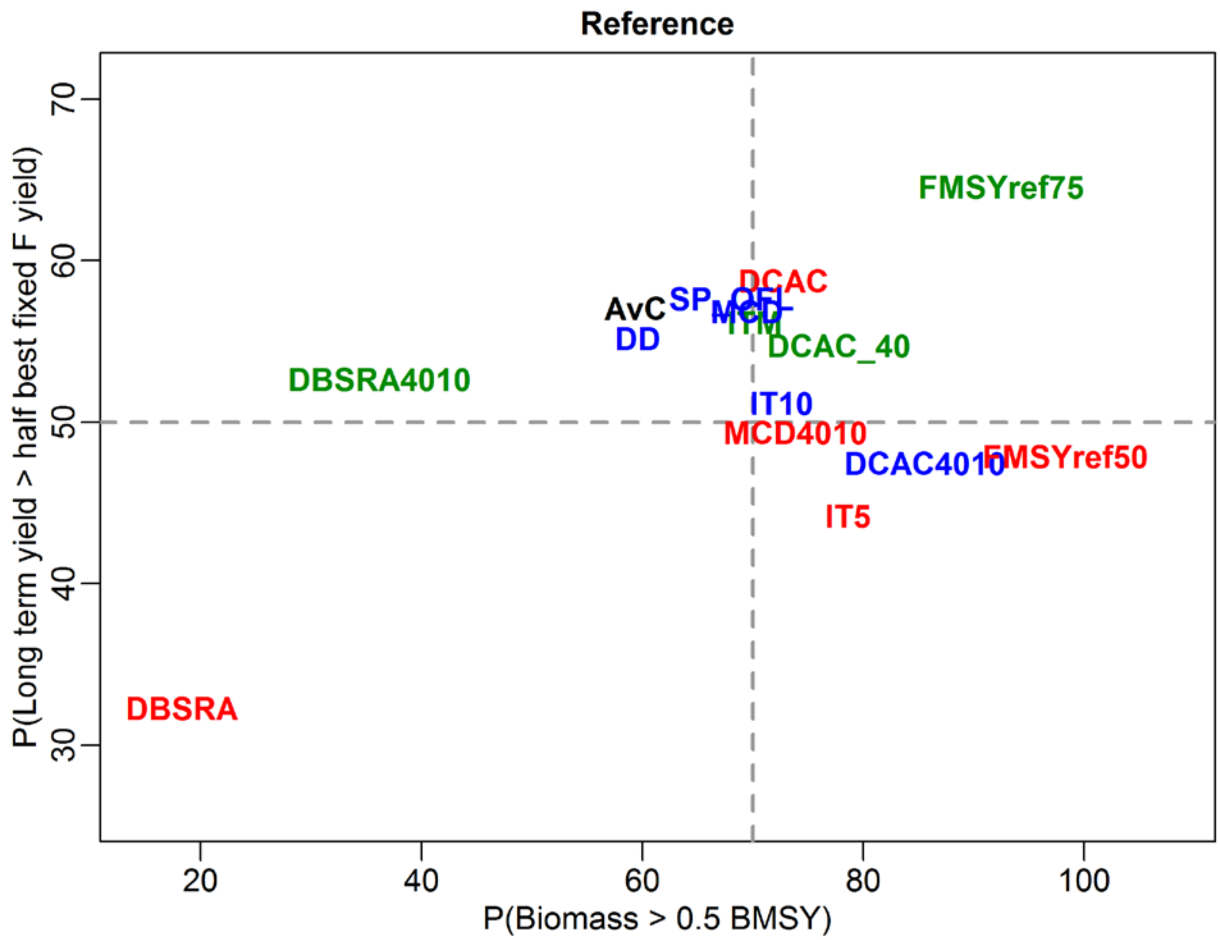


Figure D.3. The trade-off between biological (relative to 0.5B_{MSY}) and yield (probability of getting a good yield) for a subset of MPs that satisfy yield and over-fishing criteria.

possibilities were too many to realistically consider, the MPS were subset to those with:

- long-term yield > 60,
- the fraction of simulations where the [average annual variability in yield is less than 10%] is greater than 50%,
- probability of over-fishing < 50%.

In addition to this subset, several MPs (`"DD", "DBSRA", "DBSRA4010", "SP_OFL"`) were explicitly included regardless of the performance restrictions above. The results appear in Figure D.3 and form the reference set for this stock.

D.4. MSE – INCORPORATING ECOSYSTEM EFFECTS

The group discussed the best way to express ecosystem changes in terms that could be accommodated by the software. *DLMtool* does not use environmental or predator-prey relationships, but the effects of such variables on the “robustness” of the MPs can be assessed indirectly by taking into account their expected effects on parameters that are used by *DLMtool*, such as the growth rate or the mortality rate, etc. Three climate-change scenarios were initially identified:

1. increasing growth rate (von Bertalanffy) K based on improved fish condition as ice cover recedes earlier in the year and water temperature should warm up under climate change;
2. increasing natural mortality M due to expansion northward of competitors/predators and less optimal conditions in rivers and lakes as permafrost is lost; and
3. strongly increasing M.

Other factors were identified but not run, and combinations of changing factors should be considered but were not run (e.g. L50 – change in length at 50% maturity, h – steepness, amplitude of stock-recruit curve).

The reference case and the three EA scenarios were compared using a trade-off plot which relates P(LTY > half of the best fixed-*F* yield) to P(B>0.5B_{MSY}). This comparison illustrated that certain MPs were sensitive to environmental changes (Figure D.4); for example, projections for some MPs that indicated sustainable fishing in the reference case would suggest overfishing under climate-change scenarios. The group also explored application of the MPs to the real Charr data but did not have the opportunity to repeat the EA parameter changes done in the simulated data.

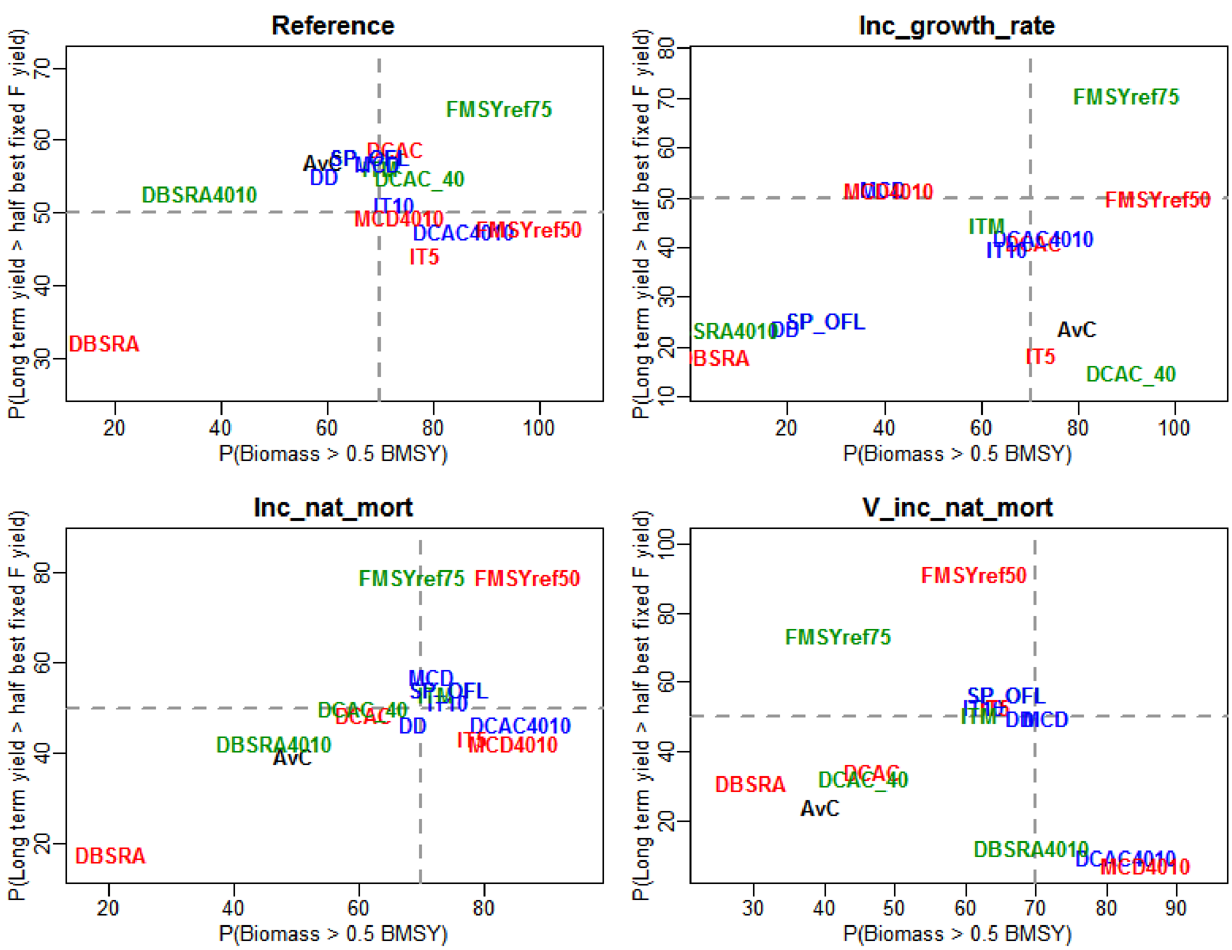


Figure D.4. A comparison of trade-off plots for the various ecosystem scenarios.

D.5. WORKSHOP OUTCOME

D.5.1. Comments from the group

- Even if the MP does not use explicit environmental effects, various input controls can be tweaked to approximate ecosystem effects and therefore the stock assessment does take them into account.
- Use of *DLMtool* needs longer training to explore the tool responsibly.
- There is no method to take into account changing responses (e.g. warming improves growth rate K for a while, but past optimal temperatures, further increases reduce K).
- User Guide does not provide answers to all questions (e.g. definition of “amplitude” and how it should be parameterised).
- It would be nice if the User Guide provided the list of all 86 MPs, along with a description of how they operate.

D.5.2. Recommendations

- Add MPs that explicitly incorporate ecosystem effects and compare their performance to the pre-programmed data-limited MPs.
- Clarify what the pre-programmed MPs actually do.
- Provide longer training on using *DLMtool* (e.g. one-week FAO workshop). [This is being implemented through TESA as five one-hour lectures by Dr. Carruthers over five weeks starting in October 2017, to be broadcast across DFO via Webinar].
- Using a data-rich stock, take away data sequentially and see if the advice changes.
- Choose a case study and work on it for a month to identify its potential and formulate questions.
- Approach the Pacific Region’s Quantitative Assessment Methods section head about *DLMtool* to see if they can either assume the lead on this directly or assign tasks (via workplans).

D.5.3. Additional *DLMtool* features desired

- Sex-specific population characteristics.
- Ontogenetic habitat shifts.
- Changes in condition factor (weight-length relationship).
- Slope in recruitment.
- Life-stage specific population characteristics.
- A plot illustrating simulation conditions (the real operating model dynamics).

D.6. REFERENCES

Carruthers, T.R., and Hordyk, A. 2016. *DLMtool*: Data-Limited Methods Toolkit. . R package version 3.2.2. (Accessed November 24, 2016)

Gallagher, C.P., Howland, K.L., and Harwood, L. 2017. Harvest, catch-effort, and biological information of Arctic Char (*Salvelinus alpinus*) collected from subsistence harvest monitoring programs at Hornaday River, Lasard Creek, and Tippitiuyak, Darnley Bay, Northwest Territories. DFO Can. Sci. Advis. Sec. Res. Doc. 2016/108. v + 81 p.

Zhu, X., Gallagher, C.P., Howland, K.L., Harwood, L.A., and Tallman, R.F. 2017. Multimodel assessment of population production and recommendations for sustainable harvest levels of anadromous Arctic Char, *Salvelinus alpinus (L.)*, from the Hornaday River, Northwest Territories. DFO Can. Sci. Advis. Sec. Res. Doc. 2016/116. v + 81 p.

APPENDIX E. ISSUES TO CONSIDER AND CASE STUDIES FROM THE DATA-RICH GROUP

This Appendix was primarily written by the following members of the data-rich group: Thomas Doniol-Valcroze, Garry Stenson, Jaclyn Cleary and Doug Swain.

E.1. ISSUES TO CONSIDER WHEN THINKING OF INCORPORATING ECOSYSTEM FACTORS IN SINGLE-SPECIES STOCK ASSESSMENTS

When deciding if one should incorporate ecosystem (physical or biological) factors into the advice-giving process, one should conduct a scoping exercise to identify where and how environmental factors could be included. This exercise should focus on what could be expected to improve management outcomes. This Appendix attempts to give guidance on this scoping exercise, highlighting areas where environmental factors may improve the advice-giving process, bearing in mind the distinction between hindcast assessments, short-term forecasts, long-term forecasts, and closed-loop simulations within an MSE process. It should be stressed that while environmental factors may improve management outcomes, they do not always do so. We also stress that the process will be stock specific, with the choice of what to include or exclude being dictated by the particular circumstances of each stock. A general overview of questions to be considered is given in Figure E.1. Although the guidance here has been written for data-rich stocks, a similar process is likely to be appropriate for data-poor stocks.

Before an ecosystem effect can be explicitly incorporated in a stock assessment model, its effect on a model parameter (e.g. catchability, rates of recruitment, natural mortality or individual growth) needs to be identified, ideally including its functional form. When an ecosystem factor is thought to have an important impact on productivity but its quantitative relationship with a component of productivity has not been determined (e.g. the effect of biomass of a key prey species on predator productivity [1]), it may be possible to include it in a qualitative way in management advice. Thus, research on ecosystem effects on population productivity is needed to explicitly incorporate effects of particular ecosystem factors in stock assessment. This research is likely to become increasingly important as ecosystems change rapidly in the face of climate change. Ecosystem considerations may also be important in determining management objectives (e.g. biomass targets for forage fishes), but this issue is beyond the scope of this discussion.

The break-out group on data-rich stocks identified a series of issues that should be considered when thinking of incorporating environmental factors in single-species stock assessments.

1. Definition of data-rich:
   a. For the purpose of this working group, we define data-rich fish assessments as those stocks with appropriate data to feed an age- and/or length-structured assessment model.
   b. Other species groups (e.g. marine mammals, invertebrates) may use different definitions.
2. What situations could suggest the need to include environmental variables in the assessment?
   a. Retrospective patterns in the assessment suggest model mis-specification (i.e., there are missing elements in the model).
   b. Poor fit of the model to the data (e.g. mortality in the case study below on cod [2], ice-related mortality of harp seal pups [3,4]).
   c. High unexplained variation (e.g. case study below on recruitment in [5,6]).

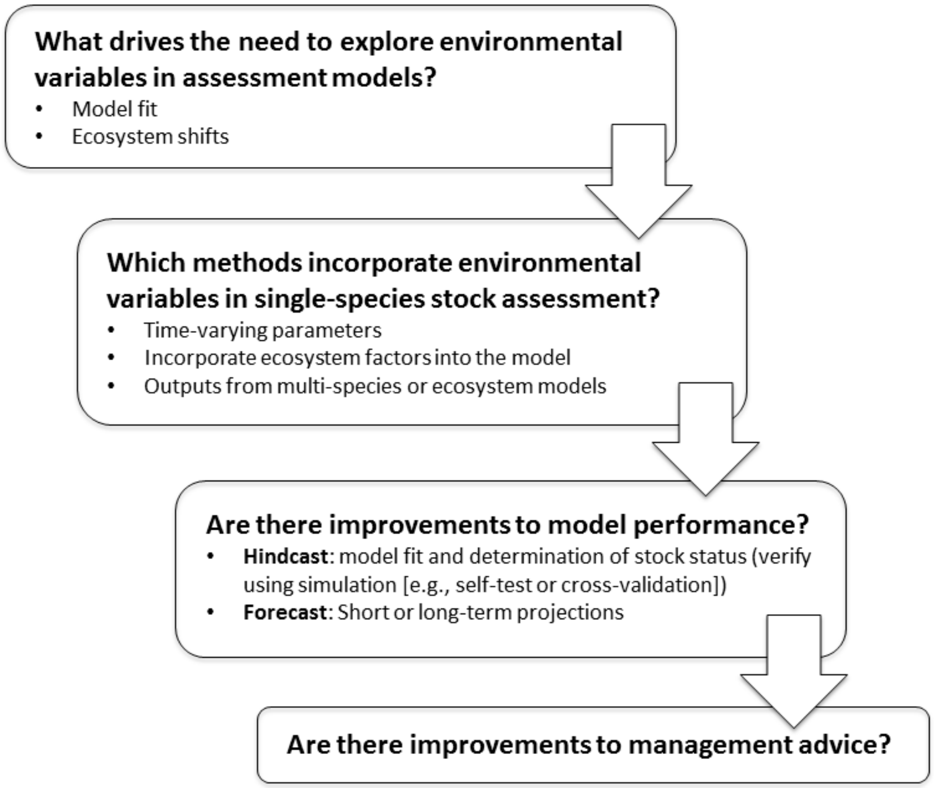


Figure E.1. Diagram outlining questions to consider when incorporating ecosystem effects into data-rich stock assessment models.

d. Indication of past, current or future shift in ecosystem conditions (e.g. regime shifts, climate change).

e. Caveat: there are situations for which environmental factors are not expected to improve the assessment or are not relevant.

3. What environmental factors should be considered for inclusion in assessments?

a. Physical factors:

i. Physical factors are often proxies for biological factors (e.g. water temperature acting on herring recruitment via food), but sometimes act directly on population parameters (e.g. seal pup mortality due to ice conditions [3]).
ii. Physical factors often have the advantage of being available for long time periods and/or over broad geographic scales.
iii. Physical factors often have models available for future projections.

b. Biological factors:

i. Biological factors generally have a more direct influence on population dynamics and thus relationships are easier to understand.
ii. Biological factors are usually available for shorter time periods and/or are more local in geographic scale, which can limit their usefulness in assessments.

    iii. Biological factors may be harder to project into the future.

  c. Considerations for the use of physical and biological factors:

    i. Factors need to vary in magnitude or frequency over time (the effects of a constant factor may already be included implicitly in the current assessment).
    ii. Factors should have an effect that is strong enough to impact management outcomes.
    iii. Factors should have a signal-to-noise ratio strong enough to tease them apart from background noise.
    iv. Factors should ideally be linked to population dynamics by hypothesized mechanisms to avoid spurious correlations.

4. How do environmental factors influence population dynamics?

  a. Environmental factors may act on recruitment either via parental effects or via impacts on early life-stages.

  b. Environmental factors may act on natural mortality either via bottom-up (e.g. starvation) or top-down (e.g. predation) processes.

  c. Environmental factors may influence individual growth (e.g. temperature, food), which in turn may impact recruitment and mortality. However, in some cases, growth is incorporated into the assessment directly.

  d. Environmental factors may act on phenology, dispersal and distribution.

5. Approaches for including environmental effects in single-species assessments:

  a. Growth, natural mortality or recruitment may be incorporated in the assessment model as time-varying parameters in order to acknowledge unspecified environmental effects (in the absence of known mechanisms).

    i. Time-varying parameters should be used when biologically justifiable and doing so improves the assessment (e.g. time-varying natural mortality in 4T cod [2]).
    ii. Time-varying growth is included implicitly when annual empirical weight-at-age data are included in the assessment.
    iii. Time-varying catchability (*q*) could be considered when environmental factors may have changed survey or gear catchability (but should not be assumed in the absence of other indications).
    iv. Time-varying recruitment is implicit in many hindcast assessments.
    v. There may be other indicators (e.g. body condition) that support the use of time-varying parameters.
    vi. Caveats: this approach does not explain underlying causes; projections can be made based upon the assumption that past conditions reflect future variations but without any predictive mechanism.

  b. If sufficient data are available, physical or biological variables can be related directly to growth, recruitment or natural mortality in the assessment.

    i. This approach generally requires hypotheses explaining the ecological mechanisms linking the environmental factor under consideration to population dynamics (e.g. case-studies [2-5]).
    ii. This approach generally involves estimating coefficients to quantify the effects of environmental factors on model parameters (e.g. average recruitment, recruitment deviations, von Bertalanffy growth parameters, direct mortality or functional responses of predators to prey).

iii. Prior knowledge may inform the estimation of those coefficients.
iv. The functional form of the relationship should reflect the underlying ecological mechanism, which may be assumed or estimated. This relationship may be linear or nonlinear (e.g. Generalised Additive Models [GAMs], polynomial relationships) but there is a trade-off between model complexity and the number of parameters that must be estimated.
v. The environmental factors may be incorporated individually or can be combined, either within the model or externally (e.g. through principal component analysis). However, combined effects should represent interpretable environmental components.
vi. The use of proxies to describe environmental impacts on biological parameters will often result in greater uncertainty than the use of factors more closely linked to stock dynamics.
vii. Factors that are considered, and the way in which they are incorporated, will differ depending on whether they are used in hindcasting or forecasting.

c. If environmental factors are included in the assessment, simulations should be carried out to test the robustness of the results, including testing the impacts of mis-specified environmental impacts.

6. Does including environmental data improve the assessment/ advice process?

a. Hindcast (assessment):

i. Including environmental factors may resolve retrospective patterns in the assessment.
ii. Including environmental factors may improve fit and provide better estimation of other parameters.
iii. Including environmental factors may be useful to improve credibility of the assessment and its acceptance by stakeholders.
iv. Including environmental factors may improve understanding of processes impacting population dynamics (which will lead to better forecasts).

b. Forecast:

i. Stock-specific considerations and the type of advice requested will have a high bearing on the usefulness of environmental factors in forecasting.
ii. When short-term projections are used for quota settings, environmental factors may not be necessary (e.g. late recruitment into fishery). However, there are cases for which environmental factors have a strong and immediate impact (e.g. highly variable predation in Northeast Arctic cod, river conditions for salmon), and thus environmental factors will have to be included in short-term forecasting.
iii. Environmental factors are more likely to be needed for long-term projections. Some situations where environmental factors must be considered in projections include:

I. When there are known trends in an environmental factor to which the system is known to respond.
II. When inclusion of environmental factors is required to ensure the model is working in a realistic way and includes key processes (e.g. annual ice mortality has a direct impact on the accuracy of seal abundance projections [3]).
III. When understanding mechanisms can inform alternate scenarios for plausible projections (e.g. alternate temperature regimes under global warming models).

7. Environmental drivers can be qualitatively considered in quantitative forecasts if the relationships among variables are not fully specified and cannot be included quantitatively (e.g. forecasts of recruitment for Fraser River Sockeye Salmon [7,8]).
   a. In some cases, it may be desirable to include environmental factors directly in the Harvest Control Rules (e.g. water temperature impacts on salmon). In other cases, the effect of the environment may already be included implicitly via environmental factors in the short-term forecasts.
   b. The benefits of including environmental factors is case-specific and may vary depending on the situation even within the same stock (e.g. impact of cannibalism at low vs. high biomasses of older cod).
   c. In all cases, the utility of including environmental factors to provide management advice should be tested (e.g. MSE, management procedure evaluation).
8. Environmental factors may be incorporated at several steps within closed-loop simulation to evaluate management procedures:
   a. Environmental factors may be needed in the operating model to realistically simulate the system and to test a number of scenarios that cover the range of likely outcomes.
   b. Environmental factors may be needed in the simulated assessment to evaluate the utility of including these factors in meeting management objectives.
   c. Environmental factors may also be considered in the harvest control rules, e.g. using different HCR under different environmental conditions.

E.2. CASE STUDY 1 – INTEGRATING THE EFFECTS OF ENVIRONMENTAL VARIABILITY INTO THE GULF OF ST. LAWRENCE 4R HERRING ASSESSMENT MODEL [5, 6]

- 4R herring stock assessment (fall spawning component):
  - Data-rich: catch-at-age composition from fishery data (1965-2015), 11 acoustic surveys (1991-2015)
- Rationale for including environmental effects in the assessment model:
  - In the Gulf of St. Lawrence, recent studies revealed that changes in zooplankton dynamics mediated by variations in bottom-up forcing at different temporal scales could be key drivers of the productivity of Atlantic Herring stocks.
  - Due to the lack of a stock-recruitment relationship in the 4R herring assessment model, yearly variation in recruitment was totally unexplained.
- Working hypothesis: strong recruitment episodes that support fisheries for several years may depend on high abundance of key copepod prey during specific time windows
- Environmental factors:
  - Physical factors (1971-2012): multivariate factors based on multiple physical indices.
  - Biological factors (1990-2012): multivariate factors describing abundance and phenology variations of key zooplankton community components.
  - Variability in the biological factors were largely explained by physical factors acting at different time scales.
- Independent analysis (GAMs):

- o Variations in biological factors (zooplankton abundance, composition and phenology) explained a large part of the variability in observed herring annual recruitment, whereas SSB was not a significant driver.
  - o The analyses described the functional form of the relationships between biological factors and recruitment, including nonlinear effects suggesting an optimal window in zooplankton timing.
  - o Therefore, the results confirmed the assumed underlying ecological mechanism and supported the inclusion of environmental factors in the assessment model.

- Inclusion of environmental factors in the assessment model:
  - o Environmental variables were included in a statistical catch-at-age model (Stock Synthesis 3) as factors acting on average recruitment via a single estimated coefficient.
  - o Run 1 included a physical factor representing low-frequency variations over 1971-2012 as a proxy of biological factors found to be influential for herring recruitment.
  - o Run 2 included average values of this physical factor over different periods determined by time-series analyses, thus representing different levels of stock productivity regimes.
  - o Run 3 included a biological factor that integrated effects acting at low and high frequencies, shown to be closely associated to herring recruitment over 1990-2012.

- Results from preliminary analyses:
  - o Run 1 showed that inclusion of physical factors (1971-2012) reduced the amount of unexplained variability in the stock-recruitment relationship compared to the assessment model without environmental effects.
  - o Run 2 estimated average recruitment levels specific to different periods characterized by contrasted physical conditions, yet the fit was similar to Run 1.
  - o Runs 1 and 2 were not able to explain years of very high recruitment.
  - o Run 3 explained a higher proportion of the variability in recruitment and better matched years of observed high recruitment.

- Improvements of the assessment model due to inclusion of environmental factors:
  - o Hindcasting: better understanding of processes impacting population dynamics and decreased unexplained variability in recruitment.
  - o Forecasting: improving estimates of recruitment in recent years (for which no catch data are available) might improve short-term forecasts of fishable biomass.

E.3. CASE STUDY 2 – TIME-VARYING NATURAL MORTALITY OF ATLANTIC COD IN THE SOUTHERN GULF OF ST. LAWRENCE [2]

The talk (14swainTimeVaryingM.pptx) and some code for this case study are available from https://drive.google.com/drive/folders/0B5RDkOmwzCjnOXpNbVZtMHNWaTg.

1. Severe residual and retrospective patterns indicated non-stationarity and model misspecification. Independent analysis indicated that natural mortality (*M*) had increased between the 1970s and the 1990s.
2. Models incorporating age-group-specific random walks in *M* estimated a strong increasing trend in M of fish aged five years and older but not in younger fish. This change in model structure eliminated the residual and retrospective problems.
3. Simulation tests indicated that the model could reliably recover the true values of *M* in both a self test and a cross test using constant *M*. This strong performance reflected strong

contrast in the fishery (a long period of high fishing mortality followed by a long period of very low fishing mortality).

4. The random walks in *M* incorporated ecosystem effects in the assessment model and the advice. However, the ecosystem factors causing this non-stationarity were unidentified.
5. A suite of hypotheses were examined as possible causes of the increasing *M*. Unreported catch (1986-1992) and poor fish condition (density dependence or harsh environmental conditions, in combination with early maturation) may have contributed to increases in *M* in the 1980s and early to mid 1990s, but subsequent increases appeared to be primarily due to predation by grey seals.
6. The population model was modified to incorporate a functional response for predation by grey seals on 5+ cod. Natural mortality due to other sources was incorporated in the model using a time-varying informative prior. The model fit the data well in the 1990s and 2000s when predation by grey seals was the main source of natural mortality, but not as well as the random-walk model in the 1970s and 1980s when other sources of natural mortality were more important than in the later period.
7. The revised model was used to forecast future cod biomass under various scenarios of future seal abundance. The projection performance of this revised model should be evaluated by fitting to a subset of the data and then projecting over the remaining observed years, given the observed catch and seal abundance.
8. The random walk model will continue to be used to assess stock status, but the model incorporating grey seal predation using a functional response may be used to evaluate management options.

E.4. REFERENCES

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APPENDIX F. EXAMPLES OF CANADIAN SINGLE-SPECIES STUDIES THAT CONSIDER ECOSYSTEM EFFECTS

Table F.1. Examples of when ecosystem information has been incorporated into Canadian stock assessments, advice to managers and/or research studies. The examples presented here are not an exhaustive list but gleaned from the workshop participants' knowledge. Ecosystem effects are defined as ecological factors external to the stock and fishery that have a significant effect on the dynamics of the stock. For example, these could be as simple as the addition of a temperature effect on the growth parameters in a dynamic model, as moderately complex as considering key predator-prey relationships, or as complex as applying a full ecosystem model in the assessment. Our discussions led to determining that there are three categories of how ecosystem effects are currently considered in stock assessments. The first situation is where ecosystem effects are in the model of stock dynamics and applied in the advice. The second is where ecosystem effects are in the model but are not currently part of the advice. In these cases the assessor has strong reasons to believe that an ecosystem effect is important to the stock dynamics but the knowledge of the effect on the dynamics may not yet be well enough understood to enter into the advice. Finally, there may be ecosystem effects not incorporated mathematically in the assessment model but that qualitatively have an effect on the advice. DFO Regions are: G=Gulf, Q=Quebec, P=Pacific, NL=Newfoundland and Labrador, CA=Central and Arctic.

Region	Species	Scientific Name	Stock	Primary Author	Year	Type of Stock Assessment	Ecosystem Effects in Model BUT not Considered in Advice	Ecosystem Effects in Model and Advice	Not in Model but Ecosystem Effects Influence Advice	Ref.	Status
G	Atlantic Cod	*Gadus morhua*	Southern Gulf of St. Lawrence	Douglas Swain	2015	Virtual Population Analysis (VPA), Statistical Catch at Age (SCA)		Time Varying M		1	In assessment
G	Atlantic Cod	*Gadus morhua*	Southern Gulf of St. Lawrence	Douglas Swain	2015	Virtual Population Analysis (VPA), Statistical Catch at Age (SCA)		Predation by Grey Seals		1	Under consideration
Q	Beluga	*Delphinapterus leucas*	St. Lawrence	Stéphane Plourde	2014	Status of the St. Lawrence beluga population			Description of different environmental variables (physical, potential preys) as an index of habitat quality. Considered in SAR	2, 3	In assessment
Q	Atlantic Mackerel	*Scomber scombrus*	Gulf of St. Lawrence	Stéphane Plourde	2014	Stock assessment of Atlantic Mackerel stock	Effects of physical and biological (zooplankton) on mackerel stock productivity		Description of different environmental variables (physical, biological)	4, 5	Under consideration
Q	Atlantic Herring	*Clupea harengus harengus*	4R	François Grégoire	2014	Stock assessment of 4R Atlantic herring stock	Environmental model (GAM) used in replacement of the stock VPA that was not good enough for the stock assessment		Effects of physical and biological (zooplankton) on stock productivity; effect of F, productivity and potential predation by seals on SSB	6	In assessment

Region	Species	Scientific Name	Stock	Primary Author	Year	Type of Stock Assessment	Ecosystem Effects in Model BUT not Considered in Advice	Ecosystem Effects in Model and Advice	Not in Model but Ecosystem Effects Influence Advice	Ref.	Status
Q	Beluga Whale	*Delphinapterus leucas*	St. Lawrence	Rob Williams	2016	PVA with the programme Vortex to predict responses of St. Lawrence beluga to environmental changes and anthropogenic threats to orient effective management actions.		Simulations made with Vortex incorporated an enviromental model (GAM) estimating the effect of summer SST, sea ice and prey availablity on newborn mortality		7	In assessment
Q	Blue Whale	*Balaenoptera musculus*	Eastern Canadian waters	Stéphane Plourde	In press	Identification of habitats important to the blue whale in the Northwest Atlantic	Krill habitat model developed to produce a spatial layer of the probability for a high krill density to occur (Significant Areas of Krill, SAKs)	Significant Areas of Krill (SAKs) described using the krill habitat model were used as a key information to identify habitats (regions) important for the blue whale		8, 9	In assessment
P	Salmon	*Oncorhynchus*	Fraser Sockeye and Pink	Sue Grant	Annual	Pre-season Return Forecast; stock-recruitment models		Fraser Discharge and SST in SOG; carrying capacity and delayed density dependent mechanisms		10	In assessment
P	Salmon	*Oncorhynchus*	Fraser Sockeye	Hao Ye	2015	Pre-season return Forecast using Empirical Dynamic Models	Fraser Discharge and SST in SOG; carrying capacity and delayed density dependent mechanisms			11	Under consideration
P	Salmon	*Oncorhynchus*	Fraser Sockeye	Sue Grant	Annual	Fraser Sockeye Forecast Supplement: qualitative information			Compilation of research and monitoring of Fraser sockeye from spawning grounds, lake ecosystems, fish health, smolt, ocean etc.	12	In assessment
P	Salmon	*Oncorhynchus*	Fraser Sockeye	Sue Grant	Every four years	Fraser Sockeye stock status; using abundance stock-recruitment metrics		Use of time varying productivity to set abundance Sgen and Smsy benchmarks;		13	In assessment

Region	Species	Scientific Name	Stock	Primary Author	Year	Type of Stock Assessment	Ecosystem Effects in Model BUT not Considered in Advice	Ecosystem Effects in Model and Advice	Not in Model but Ecosystem Effects Influence Advice	Ref.	Status
P	Salmon	*Oncorhynchus*	Fraser Sockeye	Michael Folkes	Annual	Fraser Sockeye Run Timing and Diversion Forecasts; models with environmental variables		Use of marine environmental variables to make predictions			In assessment
P	Salmon	*Oncorhynchus*	Fraser Sockeye	Gottfried Pestal	2011	In-season fisheries management: models to predict upstream migration loss/mortality and total allowable catch, etc.		Use of time varying productivity to test relative performance of different management strategies		14	In assessment
P	Salmon	*Oncorhynchus*	Fraser Sockeye	Merran Hague	2007	En-route loss estimates of migration for in-season fisheries management		Use of freshwater river conditions to predict en-route upstream migration mortality		15	In assessment
G	White Hake	*Urophycis tenuis*	Southern Gulf of St. Lawrence	Douglas Swain	2015	Virtual Population Analysis (VPA) Statistical Catch at Age (SCA)		Time-varying *M*		16	In assessment
G	Winter Skate	*Leucoraja ocellata*	Southern Gulf of St. Lawrence	Douglas Swain	2016	Statistical Catch at Length		Time-varying *M*		17	In assessment
G	Winter Skate	*Leucoraja ocellata*	Southern Gulf of St. Lawrence	Douglas Swain	2016	Statistical Catch at Length		Predation by Grey Seals			Under consideration
G	Yellowtail Flounder	*Limanda ferruginea*	Southern Gulf of St. Lawrence	Tobie Surette	2016	Statistical Catch at Length		Time-varying *M*		18	In assessment
G	American plaice	*Hippoglossoides platessoides*	Southern Gulf of St. Lawrence	Daniel Ricard	2016	Virtual Population Analysis (VPA)		Time-varying *M*		19	In assessment
M	Snow Crab	*Chionoecetes opilio*	CFA 20-24, 4X	Jae Choi	2015	Zero-inflated habitat abundance model with surplus production dynamics	Explicit habitat and abundance models incorporate multiple ecosystem variable (i.e. bottom temperature, substrate, species composition)				
M	Lobster	*Homarus*	LFA 41	Adam Cook	2016	Primary (abundance) and contextual (ecosystem) indicators			Ecosystem indicators		

Region	Species	Scientific Name	Stock	Primary Author	Year	Type of Stock Assessment	Ecosystem Effects in Model BUT not Considered in Advice	Ecosystem Effects in Model and Advice	Not in Model but Ecosystem Effects Influence Advice	Ref.	Status
M	Surfclam	*Spisula solidissima*	Banquereau	Brad Hubley	2016	Spatial surplus production	VMS density as a proxy for suitable habitat				
G	Snow Crab	*Chionoecetes opilio*	Southern Gulf of St. Lawrence	Elmer Wade	2012	Direct estimate and delay difference model	Geostatistics (kriging with external drift) using depth as a proxy for bottom temperature			20	In assessment
G	Snow Crab	*Chionoecetes opilio*	Southern Gulf of St. Lawrence	Joel Chasse	In progress		Development of habitat index based on temperature and depth to incorporate directly in assessment method			21	Under consideration
M	Swordfish	*Xiphias gladius*	North Atlantic	SCRS	2012	ASPIC, SS3 and BSP2	Trends in three climate indices relate to trends in CPUE and this provoked discussions on where to account for the environmental variability (model or catch rate standardization)			22	In assessment
P	Chinook Salmon	*Oncorhynchus tshawytscha*	Southern British Columbia (multiple stocks, or Conservation Units)	Gayle Brown	2014	Stock Status Assessment based on multiple criteria, including stock-recruitment based benchmarks		Regime shifts in productivity resulting in revised biological benchmarks of status		23	In assessment
NL/Q	Harp Seal	*Pagophilus groenlandicus*	NW Atlantic harp seals	Mike Hammill	2015	Age-structured model		Mortality due to ice conditions; annual, age specific reproductive rates		24	In assessment
Q/M	Grey Seal	*Halichoerus grypus*	Canadian grey seals	Mike Hammill	2016	Age-structured model		Mortality due to ice conditions, changes in juvenile survival		25	In assessment
NL	Northern Shrimp	*Pandalus borealis*	SF6	Mariano Koen-Alonso	2016	Survey based			Estimations of consumption by predators, and correlations with environmental factors have been used to assess stock productivity.	26	In assessment

Region	Species	Scientific Name	Stock	Primary Author	Year	Type of Stock Assessment	Ecosystem Effects in Model BUT not Considered in Advice	Ecosystem Effects in Model and Advice	Not in Model but Ecosystem Effects Influence Advice	Ref.	Status
NL	Capelin	*Mallotus villosus*	2J3KL	Frances Mowbray	2016	Survey based			Estimations of consumption by predators, prey availability, and status of the fish community have been factored in to assess stock status.	27	In assessment
NL	Snow Crab	*Chionoecetes opilio*	2J3KLNOPs	Darrell Mullowney	2016	Survey based complemented with statistical models			Correlations with thermal habitat, and estimations of consumption by predators have been factored in to assess stock status.	28	In assessment
NL	Cod	*Gadus morhua*	2J3KL	Alejandro Buren	2016	Age-structured model	Modelling results on the drivers of the stock, estimations of food consumption, diet composition, and status of the fish community were presented at the assessment.	Variable *M* in model, but no formal link with known mechanisms.		29	In assessment
NL	Cod	*Gadus morhua*	3Ps	Rick Rideout	2016	Age-structured model			Estimations of food consumption, diet composition, and status of the fish community have been considered to evaluate stock status.	30	In assessment
NL	Cod, shrimp and Snow Crab	*Multispecies*	2J3KL	Pierre Pepin	2014	Multiple analyses (models, survey-based indices, estimations of food consumption, etc)		Integration of information to produce short-term stock prospects taking into account ecosystem interactions.		31	In assessment

Region	Species	Scientific Name	Stock	Primary Author	Year	Type of Stock Assessment	Ecosystem Effects in Model BUT not Considered in Advice	Ecosystem Effects in Model and Advice	Not in Model but Ecosystem Effects Influence Advice	Ref.	Status
Q	Atlantic Cod, Greenland Halibut, Northern Shrimp	*Gadus morhua, Reinhardtius hippoglossoides, Pandalus borealis*	Esturay and northern Gulf of St. Lawrence	Christine Stortini	2016		Species distribution model parameterized with present distribution and used with projections of temperature and dissolved oxygen data for 2040-2050 to evaluate impacts on distribution and biomass of these three species			33	Under consideration
CA	Arctic Charr	*Salvelinus alpinus*	Cumberland Sound	Ross Tallman	2016	Index-based and/or Surplus Production Model moving to age-structured model			Change in juvenile growth related climate change and stock-potential large change in productivity due to switch of ecotype		Under consideration
CA	Arctic Charr	*Salvelinus alpinus*	Cumberland Sound	Ross Tallman	2016	Index-based and/or Surplus Production Model moving to age-structured model			Change in forage species in Charr diet due to range extension of Capelin affecting growth		Under consideration
CA	Beluga Whale	*Delphinapterus leucas*	Cumberland Sound	Steve Ferguson		Potential Biological Removal			Change in Forage species in Beluga Diet due to range extension of Capelin		Under consideration
CA	Arctic Charr	*Salvelinus alpinus*	Cambridge Bay	Xinhua Zhu	2014	CPUE and macroscale climate variables	Regression for simulation of missing values of CPUE versus NAO, AOI, SST and other variables				Under review
CA	Arctic Charr	*Salvelinus alpinus*	Darnley Bay	Xinhua Zhu	2016	CPUE standardization versus environmental variables as well as DB-SRA, SPM and SCA	CPUE versus water level, color, debris, temperature, and Julian date, which greatly impact seasonal migration of population between coastal marine and freshwater systems		Ecosystem variables		Under review

Region	Species	Scientific Name	Stock	Primary Author	Year	Type of Stock Assessment	Ecosystem Effects in Model BUT not Considered in Advice	Ecosystem Effects in Model and Advice	Not in Model but Ecosystem Effects Influence Advice	Ref.	Status
CA	Dolly Varden	*Salvelinus malma malma*	Rat River	Xinhua Zhu	2016	CPUE standardization versus environmental variables as well as DB-SRA, SPM and SCA	CPUE versus water level, color, debris, temperature, and Julian date, which greatly impact seasonal migration of population between coastal marine and freshwater systems				Under review
CA	Arctic Charr	*Salvelinus alpinus*	Nunavut	Marie-Julie Roux	2012	Productivity-Susceptibility	Productivity-Susceptibility of Arctic Charr data poor stocks across Nunavut			32	In assessment
M	Atlantic Cod	*Gadus morhua*	Eastern Georges Bank	Yanjun Wang	2013	Virtual Population Analysis (VPA)		Time-block varying M		34,35	In assessment
P	Pacific Ocean Perch	*Sebastes alutus*	Queen Charlotte Sound	Rowan Haigh	Subm.	Statistical catch-at-age model			Unable to detect impacts of climatic and environmental variability on recruitment, so no such influences in model.	36	Under review

Table F.2. References cited in Table F.1 (column 'Ref') of Canadian studies that incorporate ecosystem effects.

ID	Reference
1	Swain, D.P., Savoie, L., Cox, S.P., and Aubry, E. 2015. Assessment of the southern Gulf of St. Lawrence Atlantic cod (*Gadus morhua*) stock of NAFO Div. 4T and 4Vn (November to April), March 2015. DFO Can. Sci. Advis. Sec. Res. Doc. 2015/080. xiv + 137 p.
2	Plourde, S., Galbraith, P., Lesage, V., Grégoire, F., Bourdage, H., Gosselin, J.-F., McQuinn, I., and Scarratt, M. 2013. Ecosystem perspective on changes and anomalies in the Gulf of St. Lawrence: a context in support to the management of the St. Lawrence beluga whale population. DFO Can. Sci. Advis. Sec. Res. Doc. 2013/129. v + 30 p.
3	DFO. 2014. Status of beluga (*Delphinapterus leucas*) in the St. Lawrence River estuary. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2013/076. 17p.
4	Plourde, S., Grégoire, F., Lehoux, C., Galbraith, P.S., and Castonguay, M. 2014. Effect of environmental variability on the Atlantic Mackerel (*Scomber scombrus* L.) stock dynamics in the Gulf of St. Lawrence. DFO Can. Sci. Advis. Sec. Res. Doc. 2014/092. v + 30 p.
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6	DFO. 2014. Assessment of the West Coast of Newfoundland (Division 4R) herring stocks in 2013. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2014/056. 14p.
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9	DFO. 2016. Habitats important to the blue whale in the Northwest Atlantic. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2016/nnn.
10	Grant, S.C.H., Michielsens, C.G.J., Porszt, E.J., and Cass, A.J. 2010. Pre-season run size forecasts for Fraser River sockeye salmon (*Oncohrynchus nerka*) in 2010. Can. Sci. Advis. Sec. Res. Doc. 2010/042: vi + 125p.
11	Ye, H., Beamish, R.J., Glaser, S.M., Grant, S.C.H., Hsieh, C., Richards, L.J., and Schnute, J.T. 2015. Equation-free mechanistic ecosystem forecasting using empirical dynamic modeling. Proc. Nat. Acad. Sci. 112: E1569-E1576.
12	DFO. 2015. Supplement to the pre-season return forecasts for Fraser River Sockeye Salmon in 2015. Can. Sci. Adv. Sec. Sci. Response 2015/028: 49 p.
13	Grant, S.C.H. and Pestal, G. 2012. Integrated biological status assessments under the Wild Salmon Policy using standardized metrics and expert judgement: Fraser River Sockeye Salmon (*Oncorhynchus nerka*) case studies. Can. Sci. Advis. Sec. Res. Doc. 2012/106: v + 132 p.
14	Pestal, G., Huang, A., and Cass, A. 2011. Updated methods for assessing harvest rules for Fraser River Sockeye salmon (*Oncorhynchus nerka*). Can. Sci. Advis. Sec. Res. Doc. 2011/133: vii + 175 p.

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16	Swain, D.P., Savoie, L., and Cox, S.P. 2016. Recovery potential assessment of the Southern Gulf of St. Lawrence Designatable Unit of White Hake (*Urophycis tenuis* Mitchill), January 2015. DFO Can. Sci. Advis. Sec. Res. Doc. 2016/045. vii + 109 p.
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18	Surette, T., and Swain, D.P. 2016. The Status of Yellowtail Flounder in NAFO Division 4T to 2015. DFO Can. Sci. Advis. Sec. Res. Doc. 2016/058. x + 74 p.
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20	Wade, E., Moriyasu, M., and Hébert, M. 2014. Methods and models used in the 2012 assessment of the snow crab (*Chionoecetes opilio*), stock in the southern Gulf of St-Lawrence. DFO Can. Sci. Advis. Sec. Res. Doc. 2013/113. v + 50 p.
21	Chasse, J, Wade, E., Marcil, J., (In progress). Temperature preference and a habitat index for adult male and female snow crab, *Chionoecetes opilio*, in the Southern Gulf of St. Lawrence, Canada.
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25	Hammill, M.O., C.E. den Heyer, and W.D. Bowen. Submitted. Harvest advice for Northwest Atlantic grey seals. Under review as a DFO Can. Sci. Advis. Sec. Res. Doc.
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28	DFO. 2016. Assessment of Newfoundland and Labrador (Divisions 2HJ3KLNOP4R) Snow Crab. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2016/013. 22p.
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