Theme session G   2021

Beyond recruitment correlations: accounting for environmental change in single-species advice

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Background

There is growing legislative and policy demand for single-species fisheries management advice that accounts for environmental change (e.g., recent changes to Canada's Fisheries Act, NOAA Fisheries' Stock Assessment Improvement Plan, the European Marine Strategy Framework Directive). It is critical to develop scientifically defensible methods to account for environmental change in single-species assessments. While there has been extensive review of studies that incorporate environmental variables into stock-recruit relationships, there has been less work accounting for environmental effects on other aspects of stock productivity, such as growth and natural mortality. In addition, species distributional shifts may impact abundance indices and other data sources, or there may be a greater frequency of unexpected events. Single-species management advice should be robust to extra uncertainty arising from these types of impacts.

This session proposed to review advances in methods for incorporating environmental considerations into single-species stock assessment advice. This included:

1. Detecting and incorporating mechanistic hypotheses into stock assessments;
2. Mechanism-free assessment or forecasting approaches; and
3. Simulation studies to identify management procedures that meet conservation and fishery objectives and are robust to changes in stock productivity.

Session format

The session received 21 recorded talks, including a keynote presentation by Dr Anne Hollowed (Alaska Fisheries Science Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration), and five recorded poster presentations.

On September 7, 2021, a two-hour session was held on the virtual conference platform, attended by the conveners, the 26 presenters (panelists) and approximately 50 other participants. Based on the received talks and posters, the session was divided into five subsessions (Table 1):

Subsession 1. Keynote. Anne Hollowed: "Options for management of living marine resources under EBFM (ecosystem-based fisheries management) and nonstationary production scenarios".

Subsession 2. Mechanistic studies. Understanding patterns and mechanisms of changing distribution, condition and productivity under changing environmental conditions.

Subsession 3. Incorporating environmental effects into stock assessments. Forecasting and hindcasting approaches that account for environmental variables in stock assessment advice.

Subsession 4. Frameworks and Management Strategy Evaluation. Broad-scale approaches, frameworks, and testing performance and robustness to uncertainty, and communicating advice.

Subsession 5. General discussion.

The session was followed on September 9, 2021, by a 1-hour follow-up discussion that was attended by ten of the panelists.

Major Themes

The quality of the presentations and posters was high and generated discussion throughout the session. The breadth of the content of presentations exceeded the expectations of the conveners, with topics ranging from mechanistic studies evaluating the impacts of environmental change on fish populations, to sophisticated modelling studies, and new frameworks for evaluating risk and uncertainty in the face of environmental change. Many of the papers presented in the session had been published in 2020 or 2021, reflecting the rapid pace of development in this field of research.

The keynote presentation provided a long-term overview of the history of recruitment process studies and described a number of large interdisciplinary initiatives in the US, including the Alaska Climate Integrated Modeling project (ACLIM), and the NOAA Climate and Fisheries Initiative. Dr Hollowed's talk introduced a number of key themes that emerged throughout the rest of the session, including: the importance of developing multiple models at different spatial and temporal scales and with a range of complexity; the need to distinguish improvements in data fitting from evaluation of forecasting skill, where forecasting skill may be more effective for identifying mechanisms; the need to consider biological and social trade-offs that arise from accounting for climate change; the need for continued monitoring and improvement of mechanistic understanding; and the need to revisit management tools such as reference points, bycatch limits and system-level caps within a system of non-stationarity. The talk also underlined the critical need to develop platforms for consultation and communication with managers and fishery-dependent communities.

Subsession 2 included seven presentations on mechanistic studies that used observation, statistical and/or modeling techniques to evaluate the effects of temperature and other environmental effects (e.g., food availability and currents) on growth, recruitment and distribution of a broad range of marine fish and invertebrates, including scallops, shrimp, larval cod, anchovy and sardine, herring, and striped bass. For example, Giovanni Romagnoni described a modelling framework that coupled physical and biological processes to estimate larval transport of Atlantic cod in the North Sea. Jui-Han Chang described an environmentally and trophically linked species-distribution model showing the coupled impact of temperature and predator abundance on scallop distribution. Julie Gross made the point that predicting poor recruitment may be easier and more important than predicting good recruitment. Nicole Millette's study elucidated mechanisms linking temperature to copepod prey availability for striped bass. In keeping with the session theme, each talk commented on how the observed or predicted changes could be expected to impact management.

Subsession 3 included nine studies on incorporating environmental change into stock assessment models, where environmental change was assumed to impact a population-level process such as growth, natural mortality, or recruitment. Speakers used a range of

model-selection techniques to evaluate model fit under alternative mechanistic assumptions, and several evaluated whether including environmental variables in stock assessment changed or improved management advice. Notably, several studies found improved model fit with the inclusion of environmental variables but found little change in the resulting management advice. In some cases, this was because, in data-rich assessments, environmental variables may not have a major effect compared to other informative data sources such as age composition data (e.g., Paul Spencer's Alaskan pollock study), or high levels of survey coverage (e.g., Cameron Hodgdon's American Lobster study), which implicitly capture the effect. In some cases, there was not strong evidence for any single hypothesis, highlighting the need to investigate multiple model-selection techniques and alternative statistical assumptions about covariates (e.g., John Trochta's Pacific Herring study). However, it was noted that even if model fit wasn't greatly improved, there could still be large implications for management metrics such as reference points (e.g., Christine Stawitz' study on California Current Petrale Sole). Brian Stock gave a presentation on the Woods Hole Assessment Model (WHAM, see also publication), an open source state-space model that allows for the inclusion of environmental variables or mechanism-free time-varying parameters within the stock assessment. The surplus production in continuous time (SPiCT) model presented by Tobias Mildenberger also showed skill for estimating time-varying productivity that matched seasonal and decadal change from catch data and an index of abundance.

Subsession 4 included nine talks that described frameworks for accounting for environmental change in advice, including a management strategy evaluation (MSE) study by Brendan Connors, an end-to-end modeling study by Bernard Kuehn, that included a machine learning stage, a Canadian review and case-study based framework presented by Pierre Pepin, and two frameworks for adjusting target fishing mortality rates given ecosystem information. For the latter, Marie-Julie Roux described a risk equivalency framework, where the harvest control rule is adjusted according to the expected impact of an environmental factor on productivity. Daniel Howell described the "F_{eco}" framework, where target fishing mortality is adjusted within precautionary limits by a factor derived from a peer-reviewed ecosystem model.

Some major themes emerged from the General Discussion and the follow-up session. The talks and posters clearly illustrated the many options for choosing how to account for environmental change in single species advice (Table 1). Environmental drivers can be incorporated directly into stock assessments, modifying parameters that describe recruitment, growth, mortality or carrying capacity, and there is a wide range of model selection tools to help identify the best fitting model. However, many panelists identified forecasting skill, and the ability of models to provide advice that is robust to uncertainty, as more critical than obtaining more precise fits to data. The role of evaluating model fit in models that include environmental variables may be most valuable in identifying key mechanisms, and understanding the implications for forecasting skill and management metrics such as reference points. Panelists also underlined the need to develop management objectives with fishery-dependent communities and managers, and develop ways to clearly communicate additional uncertainty due to environmental change. Panelists highlighted the need for formalized decision-making frameworks to inform how environmentally enhanced forecasting approaches should be used in management advice, especially when presented in tandem with traditional single species approaches such as model-averaging.

A major discussion point in both the session and the follow-up meeting was whether reference points should be changed to reflect changes in productivity. Lowering biomass-based reference points to reflect lower productivity may have counterintuitive effects on perceived stock status (i.e., lower overfished thresholds, implying that fishing can continue at lower biomass levels). There was a general agreement that when productivity has changed, focus should be on identifying sustainable fishing levels and adjusting target fishing mortality accordingly, rather than adjusting biomass-based reference points. Panelists noted that if stock assessments are frequent enough, then changes in reference points due to environmental change should already be captured, without the need to explicitly account for environmental variables. However, it was also noted that assessments often become less frequent over time (e.g., if surveys become less frequent), and changes in parameter and reference point estimates are often not tracked from assessment to assessment (i.e., indicators that productivity is changing may be overlooked). Furthermore, it was noted that inclusion of environmental variables enables projections that account for environmental change.

Conclusions

The session showcased the wide variety of approaches being taken by scientists, as the need to incorporate environmental change into stock assessment advice becomes increasingly critical. Monitoring, statistical, and modeling studies to elucidate mechanistic links between environmental variables and the productivity and distribution of marine populations will all be critical components for improving the forecasting skill of models used for management advice. Direct incorporation of environmental variables into stock assessments is a rapidly growing field of research, with new open source modeling frameworks now available. The session underlined the importance of evaluating impacts of environmental change at multiple temporal and spatial scales and along a spectrum of model complexity. Whether and how to change reference points when productivity is changing is an open field of research, with some consensus growing on the need to focus on sustainable fishing mortality rates rather than changing biomass-based reference points. Communication with managers and stakeholders will be critical, especially communication of uncertainty and trade-offs. MSE approaches provide important tools for exploring the performance of alternative management procedures under environmental change and, critically, for identifying robust management procedures, even if mechanisms are unknown. MSE also provide a framework to facilitate identification of objectives and communication of risk and uncertainty. Risk assessment approaches that adjust fishing mortality based on estimated environmental effects may be an appropriate half-way point between advice based on single-species assessment and the outputs of more complex models.

Table 1. Session G agenda.

Speaker	Title
CONVENERS	Welcome and introduction
Subsession 1. KEYNOTE	
Anne Hollowed (NOAA)	Options for management of living marine resources under EAFM, EBFM and non-stationary production scenarios.
Subsession 2. SUMMARIES: MECHANISTIC STUDIES	
Andy Boens (IFREMER Nantes)	The decrease in size-at-age of anchovy and sardine in the Bay of Biscay and its interpretation
Jui-Han Chang (NOAA)	Forecasting future range of sea scallops using a trophically-linked species distribution model: Will climate change constrain scallop distribution in the Mid-Atlantic Bight?

Hsiao-Yun Chang (U. of Maine)	Thermal niche and temperature effects on northern shrimp (Pandalus borealis) at different life stages in the oceanographically variable Gulf of Maine
Julie Gross (VIMS)	Predicting bad recruitment in striped bass and its implications for stock projections
Susan Kenyon (U. of Aberdeen)	Intra and interannual variability in the fat content of mature North Sea herring (Clupea harengus) as revealed by routine industry monitoring
Nicole Millette (VIMS)	Control of striped bass recruitment in spring by winter water temperature through temperatures effect on development time of copepod
Giovanni Romagnoni (U. of Oslo)	Cross-scale influence of larval transport and temperature on recruitment dynamics of North Sea cod (Gadus morhua) populations
Subsession 3. SUMMARIES: INCORPORATING ENVIRONMENTAL EFFECTS INTO STOCK ASSESSMENTS	
Margit Eero (DTU Aqua)	Accounting for productivity change in stock assessment and advice for the Eastern Baltic cod
Cameron Hodgdon (U. of Maine)	A framework to incorporate environmental effects into stock assessments informed by fishery-independent surveys: a case study with American lobster (Homarus americanus)
Tobias Mildenberger (DTU Aqua)	Time-variant productivity in biomass dynamic models on seasonal and long-term scales
Paul Spencer (NOAA)	Statistical evaluation of a climate-enhanced single-species assessment model for eastern Bering Sea walleye pollock
Tim Miller/Christine Stawitz (NOAA)	Incorporating temporal changes in fish growth into stock assessments using statespace models
Brian Stock (Ocean Associates, Inc.)	The Woods Hole Assessment Model (WHAM): a state-space age-structured stock assessment framework that can include environmental effects on population processes
Xiaozhuo Tang (MUN)	Identify regime shifts in stock-recruitment relationships using hidden Markov model
Thomas Teears (NC State University)	Estimation of recruitment variation using cohort-specific von Bertalanffy growth coefficients: stock assessment implications
John Trochta (IMR Norway)	A framework for incorporating and evaluating environmental hypotheses using Bayesian stock assessments
Subsession 4. SUMMARIES: FRAMEWORKS AND MANAGEMENT STRATEGY EVALUATION	
Brendan Connors (Fisheries and Oceans Canada)	Incorporating harvest – population diversity trade-offs into harvest policy analyses of salmon management in large river basins
Juliette Champagnat (Agrocampus Ouest Rennes)	How essential fish habitats impact population productivity and resilience
Robyn Forrest (Fisheries and Oceans Canada)	Incorporating ecosystem considerations into single species advice: Four challenges for Pacific Canadian fisheries
Daniel Howell (IMR Norway)	Ecosystem advice in a precautionary world
Christian Kiaer (DTU Aqua)	Predicting the "unpredictable": experiences with forecasting North Sea sandeel recruitment
Bernard Kuehn (Thuenen Institute for Sea fisheries)	An end-to-end machine learning framework for linking spatio-temporal environmental information to fish recruitment
Pierre Pepin (Fisheries and Oceans Canada)	Adopting an ecosystem approach to fisheries management: changing fisheries science in Canada one step at a time
Pierre Pepin/Susan Thompson (Fisheries and Oceans Canada)	A suite of case studies to inform the development of a framework for the implementation of an ecosystem approach to fisheries management in Canada
Marie-Julie Roux (Fisheries and Oceans Canada)	Risk equivalency: a general approach to account for environmental considerations in scientific advice for fisheries