Technical University of Denmark

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Thunberg, Eric; Holland, Dan; Nielsen, J. Rasmus; Schmidt, Jörn

Published in:
Proceedings of the Sixteenth Biennial Conference of the International Institute of Fisheries Economics & Trade

Publication date:
2012

Document Version
Publisher's PDF, also known as Version of record

Theme Session: Coupled Economic-Ecological Models for Ecosystem-Based Fishery Management: Exploration of Trade-offs Between Model Complexity and Management Needs

Eric Thunberg,[1] Dan Holland,[2] Rasmus Nielsen,[3] and Jörn Schmidt[4]

[1]NOAA Fisheries Office of Science and Technology, Economics and Social Analysis Division, Woods Hole, MA 02543

[2]NOAA Fisheries Northwest Fisheries Science Center, Conservation Biology Division, Seattle, WA 98112

[3] National Institute of Aquatic Resources, Technical University of Denmark, Charlottenlund Slot Jægersborg Allé 1, 2920 Charlottenlund, Denmark

[4] Cluster of Excellence, "The Future Ocean" "Sustainable Fisheries," Christian-Albrechts-Universität zu Kiel Department of Economics Wilhelm-Seelig-Platz 1, 24118 Kiel

Themes Session Description

Ecosystem based fishery management has moved beyond rhetorical statements calling for a more holistic approach to resource management, to implementing decisions on resource use that are compatible with goals of maintaining ecosystem health and resilience. Coupled economic-ecological models are a primary tool for informing these decisions. Recognizing the importance of these models, the International Council for the Exploration of the Seas (ICES) formed a Study Group on Integration of Economics, Stock Assessment and Fisheries Management (SGIMM) to explore alternative modelling approaches that bring the multiple disciplines of economics, ecology, and stock assessment into integrated ecosystem models. The theme session was designed to be an extension of a series of workshops and theme sessions organized by the SGIMM, but highlighted the economic component of coupled models.

Although economic and ecological systems are inherently complex, models are abstractions of these systems incorporating varying levels of complexity depending on available data and the management issues to be addressed. The objective of this special session was to assess the pros and cons of increasing model complexity to incorporate linkages between ecosystem components and processes. While more complex ecosystem models may provide greater insight into how management decisions and human actions propagate through the ecosystem and impact the value of ecosystem services, the resources and information required to develop and parameterize them is greater and these models tend to require trade-offs such as the inability to quantify uncertainty or model human behaviour as accurately as can be done with models of individual fisheries.

The theme session was organized as a moderated panel format representing a progression of economic-ecological models from less to increasingly complex. The panel was selected to represent a range of models from fully integrated, highly detailed and dynamic economic-ecological models such as Atlantis to models that may be less detailed or not fully dynamic or integrated. The special session focused primarily on management issues that are of a longer term strategic nature such as the implications of climate change, fundamental regime change, or the role of forage species in an ecosystem. Each panellist provided an overview of their model including the management questions the model was designed to address, the data and time requirements, as well as any lessons learned. The panellist presentations were followed by an open discussion among the panellists and the audience. The abstracts for each of the panellist presentation are provided below followed by a summary of the issues raised during the moderated discussion session.

A Coupled Model of the Gulf of Maine Lobster, Herring and Groundfish Fisheries- Dan Holland (Panellist) and Sigrid Lehuta

The productivity and resilience of fisheries are subject to a multitude of dynamic and interrelated influences that arise from complex coupling of fish populations with the natural and human systems of which they are a part. With few exceptions, fisheries are managed independently, ignoring important natural and human linkages among them. The biological productivity, sustainability and consequently human benefits of ostensibly separate fisheries may be substantially increased if these linkages are better understood and if this understanding can be applied to management. The American lobster, Atlantic herring and Northeast multispecies groundfish fisheries in the Gulf of Maine are subject to an array of natural and human linkages, but these linkages have not been systematically studied. We use a range of bioeconomic models of varying complexity and realism to explore the implications that the linkages amongst these fisheries have for joint management. Our approach to studying and modelling the coupled system of fisheries is to build up from the knowledge base and models that are a legacy of the single-species approach to fisheries management that has prevailed to date, rather than attempt to construct original complex ecosystem models. While ecosystem models that attempt to characterize and quantify the overall food web in the ecosystem are useful in developing a qualitative understanding of the overall ecosystem, they are limited by major gaps in information and computational constraints. A fruitful middle ground is to build multi-fishery models incorporating single-species models that are connected by the important natural and human linkages among them.

Age-Structured Ecological-Economic Multi-Species Models for Baltic Sea Fisheries
Martin Quaas (Panellist), Rudi Voss, Jörn Schmidt, and Olli Tahvonen

Biologists have criticized traditional biomass models in fishery economics for being oversimplified. Biological stock assessment models are more sophisticated with regard to biological content, but rarely account for economic objectives. Recently, age-structured models of fish stocks have increasingly been used in fisheries economics, but applications have so far mainly been limited to single-species settings. Here, a multi-species age-structured optimization model will be presented for the Baltic that comprises the three economically most important stocks, cod, herring, and sprat, and the effects of predator-prey relationships between these stocks. The optimization model not only studies economically efficient management (using the Kaldor-Hicks criterion), but also studies distributional effects by studying Pareto-efficient allocations in the absence of compensation payments between fleets. It is shown that the distributional effects of economically efficient management can be large, and that, on the other hand, addressing distributional issues, or ecosystem considerations, can be very costly.

Decision-Support for Ecosystem-Based Fishery Management in the Context of Marine Spatial Planning: Regional Economic Impact Models, Model Outputs, and Tradeoff Measures - Porter Hoagland (Panellist) and Di Jin

The implementation of ecosystem-based fisheries management (EBFM) requires the development of new analytic tools to integrate environmental, ecological, and socio-economic data from various sources; to capture explicit interactions among ecosystem components; and to simulate and evaluate the effects of alternative management options. We are developing a computable general equilibrium (CGE) framework that models coastal and marine resource sectors linked to the output of a marine food web model. The framework can be used to examine the interactions among different components of a coastal economy and alternative realizations of the structure of a marine food web. We illustrate our framework with two examples from New England fisheries: (1) a basic model with five industry sectors, including agriculture, manufacturing, commercial fishing, seafood processing, and other (an aggregate of all other industries); and (2) an expanded nine-sector model, including four non-fishing sectors and five fishing sectors characterized by gear type: lobster (pot), trawl, scallop (dredge), gillnet, and other. The integrated framework can be used to develop “what-if” type policy simulations for many important issues faced by coastal and ocean managers (e.g., marine spatial planning and climate change impact assessments). Through comparative analyses, we show how economic and distributional tradeoffs among alternative policy options can be assessed by examining changes in metrics of interest to marine resource managers, including a measure of economic surplus.

Ecopath-Based Simulation and Optimization of Management Options for the Eastern Gulf of Mexico Reef Fish Fishery - Sherry Larkin (Panellist), Sergio Alvarez, Jake Tetzlaff, Mike Allen, Carl Walters, Bill Lindberg, and Bill Pine

Ecological and economic tradeoffs of recently proposed reef fish management actions were assessed using the Ecopath with Ecosim (EwE) and Ecospace software. The model has 70 biomass pools (e.g., detritus, primary producers, invertebrates, fish, dolphins, sea birds), including multiple age-classes of key species. After mass-balancing, the model was driven using observed fishing mortality from 13 fleets (4 recreational, 9 commercial) and foraging behaviour was adjusted to fit the model to historic abundance and catch trends. The mixed trophic impacts routine was used to identify the most influential groups in the system (i.e., recreational private boats, small mobile epifauna and sardines-herring). The initial simulation extended the status quo 20 years and examined the impact of: 1) rebuilding gag grouper, 2) reducing longline effort, 3) increasing baitfish harvests and 4) alternative closed areas. Results highlight changes in biomass through both competition and predation within the food web. Next, fishing effort is optimized to maximize a weighted four-criterion objective function (profit, jobs, stock size, and ecosystem structure). Tradeoff frontiers between profits and reef fish biomass arise. Results indicated the status quo of overfished gag grouper is sub-optimal but policies being considered should move the system closer to the frontier. Sensitivity analysis on the recreational and commercial prices reveals a stable frontier. Lastly, Ecospace predicts spillover effects from marine protected areas (MPAs) that benefit key species and fleets, however, negative effects of lost fishing grounds and subsequent concentration of effort occurs. Results indicate that MPAs would need to be relatively large in order to be effective at preventing overfishing.

Including human dimensions in integrated marine ecosystem models: Australian examples
Olivier Thébaud (Panellist), Beth Fulton, Trevor Hutton, Rich Little, Sean Pascoe, and Ingrid Van Putten

With international efforts to develop ecosystem-based management of ocean uses, there has been a growing call for the development of integrated assessment tools, including the design of models which can be used to identify possible futures and evaluate alternative management strategies. Along with this, there is increasing recognition that such models should include explicit representations of human behaviour and its drivers, as this is key to understanding the potential responses to economic, ecological and regulatory changes. The presentation will use examples from Australia to illustrate the diversity of approaches and domains of application in which such modelling can be developed, and discuss some of the key issues which need to be considered in developing these models. Examples will include whole-of-system models, such as Atlantis in the Australian South-East Fishery and multiple use applications of the In Vitro platform in North-Western Australia, as well as the highly spatial multi-species and multi-fleet Effects of Line Fishing Simulator in the Great Barrier Reef and Ningaloo Reef (Western Australia).

Session Discussion

The panel session and ensuing discussion was moderated by Rasmus Nielsen. The discussion session was structured in a way that all panellists had the chance to answer the questions posed by the audience to get a full range of views. The following provides a summary of the questions posed by the audience and panellist responses as recorded by the session rapporteur Jörn Schmidt. Panellist responses were recorded during the session. These responses were then sent to each panellist to assure that their comments were accurately recorded and to provide clarification. The panellist responses provided herein reflect this process.

Question 1: I was struck by the range, in which economics is included in the different models: what dictated the choice for the different models?

Porter Hoagland - Our modelling approach has a history, dating back to an early effort to develop an Input-Output (I/O) model to help understand the scale and distribution of economic impacts to New England coastal communities from the implementation of fishery management measures in the US Northeast Region. This kind of effort was called-for in the 1996 revision to the Magnuson-Stevens Act, known as the Sustainable Fisheries Act. Because of mathematical similarities to the marine food web models that were under development for the US Northeast fisheries, it was natural to try to link the I/O model to a food web, therefore creating a type of model that could help with ecosystem-based management. From this effort, we moved towards the development of a Computable General Equilibrium (CGE) model in order to be able to measure the welfare effects of either fishery management regulations or changes in the ecological system.

Sherry Larkin - A basic Ecopath model was already developed and mass-balanced so we were able to take advantage of previous model building efforts on the biological side. However, the role of economics in the broader Ecopath with Ecosim (EWE) platform is limited. It works similar to an I/O model, and the economic parameters are held constant even throughout long-run simulations. We have been able to further explore the use of optimizations that involve tradeoffs among four diverse objectives for the fishery and those have been well-received but it still suffers from the use of fixed parameters.

Dan Holland - The development was driven by the research interests of the scientists involved in the project and by funding possibilities. The project was designed in response to a call for proposals from the US National Science Foundation for interdisciplinary research on couple natural and human systems. The researchers felt that a middle ground approach, between single species models and foodweb models that focused on human and natural linkages between key fisheries would be a useful and novel way to improve understanding and management of these fisheries and a practical step toward ecosystem management that would also be appealing to the funding agency.

Rudi Voss - The development was clearly driven by the personal background of the people involved. The start was to overcome the hesitation of biologists to include economic considerations into their models. To ease the communication, especially with stock assessment scientists, the model was structured in a similar way as the stock assessment models (e.g. age structured), also using the same input data.

Olivier Thébaud - The starting point was the need to answer specific questions, which people asked. The move came partly from biologists, and the development was also driven by the background of the people involved.

Question 2: Coming from live-stock economics: There is still a lack of integration of real feedback from the economic system to the ecological system. Any ideas how to tackle this?

Porter Hoagland - The CGE model that we have developed is fundamentally a static representation of the economy. We use biomass inputs from linked ecological models to assess the economic effects. There are a few CGE models that have been designed to allow dynamic feedbacks. The incorporation of feedbacks is mostly a task for future research, but the development of reliable CGE approaches will be difficult due to model complexity and the practical aspects of model balancing.

Sherry Larkin - In the EWE model it is possible to restrict landings by certain sectors, for example, by requiring that the harvest be profitable, which would then affect fishing effort on certain species. The group is looking for possibilities to incorporate endogeneity in the prices and costs in the optimization and simulation routines where the biology and economics interact but has no progress to report at this time.

Dan Holland -The group wants to build in feedbacks, but wants to concentrate on micro-scale feedbacks. The feeling is that a full-feedback model will unreasonably increase the uncertainty, because medium or even long term projections of economic behaviour are highly uncertain and would add disproportionately to the uncertainty, which is already inherent in ecological models.

Rudi Voss Totally agrees with Dan, especially with respect to the high uncertainty of ecological models and the difficulty to perform sensitivity analyses due to high computational demands of complex ecosystem models.

Olivier Thébaud - The incorporation of full feedback also depends on the use of the model, e.g. in Australia some people want to develop feedback models for strategic outlook taking into account interactions between multiple sectors of the economy, including those related to the mining boom, and the ecosystem.

<u>Question 3</u>: Some of the ecological models used for the coupled approach are highly complex and the need for at least multispecies models is clear. However there might be the risk of not including important species within the ecosystem, especially if they are not of commercial value: Is there a susceptibility of the models to different degrees of complexity?

Rudi Voss - For some regions, e.g. the Baltic Sea, there are already different models with different degrees of complexity available. A working group within the International Council for the Exploration of the Sea (ICES) has used a set of different models with the same input data (where possible) to explore the uncertainty around the different models (ensemble modelling approach). However a challenge is the hesitation of the political side to adopt this approach. They still go for the single model approach.

<u>Question 4</u>: Another perception is that there is national or international pressure already there, but institutions are not well prepared to step beyond single stock assessments and advice.

Porter Hoagland - It would be interesting to use one economic model to assess different levels of the aggregation of species. One could initialize the model with historic data to get an idea of whether it is sensitive to alternative species aggregations. Preliminary results from our CGE framework reveal that welfare estimates can differ when assessing increases (due to fishery regulations) in the biomass of two species independently in comparison to assessments of such changes simultaneously. This result is due undoubtedly to the current structure of the CGE framework.

<u>Question 5</u>: If you want to use the models, you need to evaluate the robustness of the model: how do you approach this?

Dan Holland - Both the Ecopath and the Atlantis models are tuned with time series data. However, when the models are forced with dramatic changes in the system to explore the reaction a real validation or even sensitivity analysis is difficult, because of the high computational demands of running the models and the fact that scenarios and outcomes are typically outside the range of historical data with which to validate.

Olivier Thébaud - Agree with respect to Atlantis. It is not possible to perform a full sensitivity analysis, thus one has a look at the major assumptions and explore potential outcomes of selected scenarios, as well as try to get the processes right. It would be interesting to develop ensemble-modelling approaches for economic process models, but he is not aware of an existing study.

Sherry Larkin - As mentioned in the presentation, we approached the model building process with the need for the model to pass a credibility test, expose they key underlying issues, address how the model could be useful to management and become an operational tool. This was accomplished by holding a series of workshops for scientists (economists, ecologists and biologists) and policy makers. These workshops were invaluable for ground-truthing some of the inputs and ensuring the outputs were reasonable. We were also able to use some of the system summary statistics (e.g., primary production, total system throughput, ascendency, etc.) to compare our EWE model with others that have been developed for other regions. A validation might be difficult for some of the data for the economic models because sufficient data is not always accessible for all the sectors that may need to be modelled. However, the model could be used to identify the parameters that (when changed) produce significant changes in results (i.e., sensitivity analysis). The benefit of such an analysis is that the results can be used to identify were future data collection efforts should be improved; these models take a lot of data and resources are scarce so we see this as a valuable use for these models.

Question 6: What about societal or economic scenarios or regimes? Are the time scales or dynamics similar and what are the time scales of the models?

Olivier Thébaud - You can for example consider this at the process level, e.g. technical changes or changes related to expected future trends in global market. One example of this is the Northern Prawn fishery where changes in future input and output price levels have been factored into the evaluation of possible strategies towards achieving Maximum Economic Yield.

Dan Holland - The time scale can be different in different models and one has to be aware that there is not a single generic model which fits all purposes, but specific models are built for answering specific questions.

Question 7: How are you planning to incorporate non-market values?

Porter Hoagland -In theory, we could incorporate non-market economic values into the CGE framework, and the diagram in our presentation indicates that such values might be incorporated naturally into consumer utility functions. Note that the existing linkage to the ecological model assumes that fish yields are an unpriced input to the production of seafood. Assigning a price to the harvest of fish implies that the production function at the front end of the CGE model would need re-specification, possibly requiring a change in its constant elasticity of substitution form, and leading to a necessary rebalancing of the model. David Finnoff and John Tschirhart at the University of Wyoming have been working along these lines, incorporating, for example, protected species in what they refer to as a "general equilibrium ecosystem model" for Alaska's Bering Sea.

Sherry Larkin - It is possible to give species, which are not commercially exploited (e.g., seabirds and dolphins), a non-market value in Ecopath. When entered as non-market values, the values are included in calculations of the total value of the ecosystem. However, these non-values are not considered in the optimizations that evaluate tradeoffs between various fishery objectives (even the ones designed to capture social values and ecosystem strength).

Rudi Voss - It is possible to build in constraints, e.g. a minimum stock size of a prey species for sea birds or marine mammals.

Olivier Thébaud - It is possible to calculate the shadow values associated with the protection of species or areas with no commercial value, using the model, and then to use these values in assessing the performance of alternative management strategies.

Question 8: Given the complexity of the models and results, it is more and more difficult to communicate the results, but there is increasing space for interpretation and discussion. How to deal with this?

Sherry Larkin - They had stakeholder discussions on the model inputs and results (including those designed to capture uncertainty in the point estimates) and it was obvious which graphs and tables were most confusing and which were most important and helpful. That process was extremely helpful in being able to better communicate what the model can and cannot do. With respect to what the model cannot do, or which it is not suited to addressing, that was our biggest challenge. For example, the model should not be used to address allocation issues between fishing fleets due to the use of total values based on fixed parameters (versus marginal values that would be a better tool for determining the movement of use between sectors).

Dan Holland - They have not tried so far to get in discussions with stakeholder, but it is well understood that communicating uncertainty is an important issue.

Olivier Thébaud - As the models tackle increasingly complex systems and multiple-use issues, there is a need to communicate simulation outcomes across a growing range of dimensions, taking into account uncertainty and potentially diverging views on what is important to consider. There is a need to invest research efforts in this part of ecological-economic modelling as well.