Report of the 4th National Ecosystem Modeling Workshop (NEMoW 4): Using Ecosystem Models to Evaluate Inevitable Trade-offs

Howard Townsend, Kerim Aydin, Kirstin Holsman, Chris Harvey, Isaac Kaplan, Elliott Hazen, Phoebe Woodworth-Jefcoats, Mariska Weijerman, Todd Kellison, Sarah Gaichas, Kenric Osgood, and Jason Link (editors)

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Benjamin Friedman, Acting NOAA Administrator

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Chris Oliver, Assistant Administrator for Fisheries

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Office of Policy, National Marine Fisheries Service
National Oceanic and Atmospheric Administration
1315 East-West Highway
Silver Spring, MD 20910

Or online at:
http://spo.nmfs.noaa.gov/tm/

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Executive Summary

The NOAA-National Marine Fisheries Service (NMFS) held its 4th National Ecosystem Modeling Workshop (NEMoW 4) on February 28-March 2, 2017 at the NMFS Southeast Regional Office in St. Petersburg, FL. Ten years ago, scientists and administrators at NMFS established the first NEMoW in response to needs to more formally review, evaluate, and project the ecosystem modeling efforts of NMFS. Since then ecosystem modelers around NMFS have routinely met at NEMoWs to share methodologies and discuss recent advancements in the field to improve ecosystem modeling for living marine resource (LMR) management. The general objectives of NEMoWs are: 1) to address broad questions of national interest for applied LMR-oriented EM, 2) to provide a forum for ecosystem modelers within NMFS to network and share information on ecosystem modeling advancements and best practices, and 3) to provide a vehicle to advanceecosystem modelingfor LMR within NMFS as it meets its mandates and obligations.

The theme of NEMoW 4 was "Using Ecosystem Models to Evaluate Inevitable Trade-offs" and focused on tools and best practices for addressing trade-offs in the context of living marine resource (LMR) management. Specifically, the ecosystem modeling community gathered to discuss common trade-offs across NMFS regions; tools for addressing trade-offs; and the management implications of trade-offs. The stated objective of this workshop was to evaluate best practices for using ecosystem models to address trade-offs inherent in ecosystem-based management of living marine resources.

Broadly, trade-offs associated with ecosystem-based fisheries management (EBFM) arise because of limited resources and interconnected resource production with an ecosystem. Energy (or biomass or production) flowing within an ecosystem is limited and desires for benefits and removals from the system are complex and multifaceted. As a result, objectives for maximizing benefits across multiple activities and management can rarely be accomplished simultaneously. For example, simultaneously achieving Maximum Sustainable Yield for all stocks in a region may not be feasible because of species interactions. Similarly, increased energy development might result in some loss or degradation of habitats, recreational areas, or fishing grounds, yet is often necessary to meet the nation's energy demand. Prior to implementation of EBFM, these trade-offs were implicit. As the nation moves forward with EBFM, the need to explicitly identify and address trade-offs arises.

As noted in the NMFS EBFM Road Map (hereafter referred to as the Road Map), accounting for trade-offs is a central tenet of EBFM. Moreover, the Road Map points out the need for modeling to capture essential ecosystem dynamics for understanding trade-offs. Ecosystem modeling is often used to address trade-offs associated with management actions – to support managers and stakeholders in understanding how living marine resource (LMR) management

actions aimed at a given stock/population or trophic level may affect other stocks/populations or the overall ecosystem structure. Additionally, other uses of ocean resources may affect LMRs or be affected by LMR management. Given biophysical constraints, trade-offs are inevitable. Ecosystem modeling can provide the ability to identify such trade-offs and explore potential management actions that meet society's needs in light of trade-offs. Largely based on the importance of trade-offs for EBFM and the need for ecosystem modeling in addressing trade-offs, the NEMoW Steering Committee determined that the use of ecosystem modeling for addressing EBFM trade-offs warranted further exploration. With support from the NMFS Science Board, the Steering Committee elected to hold a workshop focused on trade-offs.

During NEMoW 4, participants discussed the types of trade-offs, the tools for visualizing and communicating trade-offs, and the management implications of trade-offs. In addition, participants outlined the general categories and types of tools that have been used to explicitly account for trade-offs. The body of this report summarizes this discussion.

Key conclusions on best practices:

1) Stakeholder engagement is crucial.

2) Anticipating management needs can help to ensure modeling relevance.

3) Developing conceptual models is important.

4) Clearly communicating the results of a trade-off analysis is essential.

5) Using multiple models and visualization tools is ideal.

6) Trade-offs and synergies should be considered.

Four recommendations emerge from these conclusions:

1) High-level guidance on prioritizing and reconciling trade-offs across mandates (e.g., Magnuson-Stevens Act, Endangered Species Act, Marine Mammal Protection Act, National Environmental Protection Act) is needed.

2) Regular communication between scientists and managers is necessary to expedite NMFS's ability to address trade-offs.

3) Engagement of representatives from other disciplines (esp., social sciences) is needed to develop useful approaches for addressing trade-offs.

4) EM Toolbox development and implementation should continue.

Given copious calls for addressing trade-offs and ensuring modeling capacity for addressing trade-offs within the EBFM Roadmap, NEMoW 4 was quite timely and most attendees thought NEMoWs should persist and smaller, inter-sessional NEMoW working groups should be developed to focus on specific issues common to many regions. The NMFS is in a favorable position to apply ecosystem modeling to key LMR trade-offs. Doing so, will enable progress in ecosystem modeling and improve its utility for LMR management. While some development of expertise and technical capacity is still needed, a substantial foundation for NMFS exists.

Acknowledgements

The NEMoW 4 Steering Committee, on behalf of all NEMoW 4 participants, would like to thank the local host of the workshop, the Southeast Regional Office (SERO). We especially thank Steve Giordano, Kevin Owen and Becky Stanley for their efforts in setting up local arrangements, handling workshop logistics, and enabling a productive meeting.

We acknowledge the efforts of the invited speakers, and thank them for their participation. We had five participants from SERO who presented on the management and policy aspects of trade-offs and participated in the discussion. We appreciate the effort and participation of Dawn Davis (Habitat Conservation), Mike Jepson (Sustainable Fisheries), Bill Arnold (Sustainable Fisheries), Cynthia Meyer (Sustainable Fisheries), and David Bernhart (Protected Resources). We are grateful for the work they put into presenting and participating, and appreciate their perspectives.

In addition, we had five presenters discuss tools they have developed or used to visualize and communicate trade-offs. The presenters also led hands-on sessions to enable participants to begin using some of these tools. We appreciate the time and knowledge shared by: Isaac Kaplan (NWFSC), Andy Beet (NEFSC), Kelly Kearney (JISAO/AFSC), Jin Gao (JISAO/AFSC), and Chris Kelble (OAR/AOML).

We thank the NMFS Office of the Assistant Administrator and the NMFS Office of Science and Technology for partial funding support to help defray the costs of this workshop.

Finally, we thank the NMFS Science Board for their continued enthusiastic support.

Introduction

Ten years ago, scientists and administrators at NMFS established the first National Ecosystem Modeling Workshop (NEMoW) in response to the needs form more formal review, evaluation, and projection of the ecosystem modeling (EM) efforts of NMFS. Since then ecosystem modelers around NMFS have routinely met at NEMoWs to share methodologies and discuss recent advancements in the field in an effort to improve ecosystem modeling for living marine resource (LMR) management.

The general objectives of NEMoWs are: 1) to address broad questions of national interest for applied LMR-oriented EM, 2) to provide a forum for ecosystem modelers within NMFS to network and share information on ecosystem modeling advancements and best practices, and 3) to provide a vehicle to advance ecosystem modeling for LMR within NMFS. The specific objective for this 4th NEMoW (NEMoW 4) was to evaluate best practices for using ecosystem models to address trade-offs inherent in ecosystem-based management of LMRs.

To advance ecosystem modeling science for LMR management and with the stated objective of evaluating best practices for using ecosystem models to address trade-offs inherent in ecosystem-based management of living marine resources, NMFS scientists conferred for 3 days at NEMoW 4. This technical memorandum captures the essential points that emerged from that workshop.

NEMoW 4 was important for making continued progress in integrating across NMFS mandates and advancing EBFM. Incorporating ecosystem considerations into fisheries management is highlighted in the Magnuson-Stevens Fishery Conservation and Management Act. Similarly, incorporating ecosystem considerations is important for marine mammal and endangered species population assessment as required in the Marine Mammal Protection Act, the Endangered Species Act, and more broadly for cumulative effects under the National Environmental Protection Act. In addition, ecosystem connections are core for incorporation into the science for habitat management conducted by NMFS under multiple mandates. Accounting for trade-offs across these mandates is essential for NMFS; and ecosystem modeling approaches are indispensable for understanding the connections and explicitly accounting for the trade-offs in the resources addressed by these mandates.

Background

The topic of “using ecosystem models to evaluate inevitable trade-offs” was chosen as a theme for NEMoW 4 for many reasons. The major legislative mandates for NMFS require a movement towards various levels of ecosystem-based management; NOAA’s mission, vision, and policy statements continue to espouse an ecosystem approach; and the NMFS EBFM Road Map calls for explicitly addressing trade-offs among LMRs in making resource management decisions. In addition, many of these mandates require the use of best available science. Thus a need arises for ecosystem modeling to provide the best available science to inform NMFS in a variety of regulatory roles. As the NMFS ecosystem modeling effort matures among the regions, and more ecosystem models are developed. NMFS scientists must determine how to use modeling tools to provide the best available science for addressing and communicating trade-offs.

The format for NEMoW was designed such that NMFS Fisheries Science Centers (FSCs) could summarize their ongoing ecosystem modeling efforts generally and especially with respect to addressing trade-offs. These presentations 1) helped to provide invited speakers some context on approaches for dealing with trade-offs and 2) enabled idea-sharing among scientists from different regions. FSC presentations were followed by a plenary discussion on the common themes and novel applications of tools for trade-offs across regions and management contexts.

After the context-setting plenary discussion of regional applications, plenary presentations on the tools and implications were held.

The second set of plenary presentations provided background information on tools for visualizing and communicating trade-offs. Brief, overview demonstrations of 5 different types of tools were given. The overview presentations were followed by hands-on sessions, where participants met in smaller groups with presenters to receive instruction on how to use the tools. Time was allotted such that participants could receive instruction on 2-3 different tools. This hands-on session was then followed by breakout groups to discuss how the tools could be commonly used across NMFS FSCs and the need for additional tools.

The next set of plenary presentations was focused on implications of trade-offs in different management contexts – Sustainable Fisheries, Protected Resources, and Habitat Conservation. The format for this session was a panel discussion with five presenters giving overviews of the management trade-offs they face on a regular basis. This was followed by a response from a few participants who described modeling tools they have used for similar situations and a question and answer session with panelists and participants. This session was designed to help develop a shared understanding of the current ways Fisheries Management Councils (FMCs) and other regional management bodies are using ecosystem modeling to address trade-offs and what can be done to further support these groups with EM.

After the management panel discussion, fortified with information from the first days of the workshop, participants broke-out to discuss best practices for addressing trade-offs to advance EBFM goals. These best practices are described further below.

On the final day of the workshop, plans for development of a National Ecosystem Modeling Toolbox were presented and the utility of the Toolbox was discussed. Participants learned about the overall driving force for developing the toolbox and viewed a demonstration of the interface for models to be used in the toolbox. Afterwards, participants went into breakout groups to discuss the Toolbox plans, and then reconvened to share feedback.

This workshop was planned with a format to maximize interaction and discussion and to allow revisiting any particular topic from multiple perspectives, building upon the strength of having the NMFS ecosystem modeling community gathered from the different regions. The primary workshop objective was to address each of the workshop's Terms of Reference (TORs) such that we could explore common trade-offs, tools for addressing them, and management implications of trade-offs.

Terms of Reference (TORs)

Theme: Using Ecosystem Models to Evaluate Inevitable Trade-offs
Objective: Evaluate best practices for using ecosystem models to address trade-offs and synergies inherent in ecosystem-based management of living marine resources.

1) Update on current ecosystem modeling efforts underway at NMFS. Highlight ecosystem modeling that is geared towards addressing trade-offs and identifying commonalities.

2) Outline and review commonly encountered trade-offs in LMR and cross-sectoral management.

3) Outline and review common and novel tools for modeling and communicating trade-offs.

4) Discuss management implications of trade-offs.

5) Discuss National Ecosystem Modeling Toolbox and plan to ensure adequate tools are available for addressing trade-offs.

6) Summarize best practices for addressing trade-offs using EM.

Discussion Summary

ToR 1: Ecosystem Modeling efforts underway at each FSC

As pointed out in the opening remarks, over the past 10+ years NMFS has seen a considerable increase in the ecosystem modeling capacity at FSCs. The products of these ecosystem modeling groups are increasingly being used by FMC sand other management bodies. To help plan for future needs of EM-based information, participants had discussions on the current structure of FSC ecosystem modeling groups, how the groups are integrated with other programs and partners, how requests for EM-based information is received and processed, and how well these structures and processes were working.

All FSCs have some, at least informal, modeling group. Three FSCs have specific ecosystem modeling programs whereas 2 FSCs had ecosystem science programs with a modeling component. Others have an informal group of researchers participating in ecosystem modeling.

A few FSCs placed great value on proximity of staff/university to promote collaboration, but that this was not a necessity as regions with dispersed staff have managed to be successful. Specific mention was given to Integrated Ecosystem Assessment (IEA) work as an important way to bring people together for ecosystem modeling. A noted challenge – particularly for geographically dispersed staff - was a need to ensure that staff are not duplicating efforts. Communication is key and it often takes time to build relationships. There were multiple comments stressing interest in and the importance of building relationships between FSCs and NMFS Regional Offices (ROs).

In considering drivers of ecosystem modeling efforts, the discussion touched on recent NMFS initiatives (EBFM Roadmap, Climate Vulnerability, IEA, Management Strategy Evaluation (MSE) Workgroup), some FSC Directorates have begun to include cross-division ecosystem projects as priorities in Annual Guidance Memos, and project-based funding. There was discussion related to adding ecosystem modeling into performance plans to ensure that staff have a commitment to pursue research. Motivations for ecosystem modeling (specifically trade-off considerations) have changed over time as early works were often motivated by intellectual curiosity, whereas other recent examples have been regulatory or stakeholder driven. Attention was brought to recent work from a Knauss Fellow who has catalogued modeling efforts, software used, and ecosystem modeling applications. Along a similar line there is an MSE inventory Google sheet that was shared in the MSE presentation for Steering Committee members to review/update.

ToR 2: Trade-offs Addressed by Ecosystem Modeling within NMFS Regions

Workshop discussions ranged widely on the types of trade-offs being addressed by NMFS FSCs, effective methods for addressing trade-offs, and limitations to our abilities to effectively address trade-offs. The key points covered are described in this section.

Types of trade-offs

Though the discussion of the topic was not specifically organized around different levels of management (single-species, EAFM/EBFM, and EBM), what emerged from the workshop were discussions of trade-offs that can be thought of at different levels of management. The major types of trade-offs are outlined in Table 1.

Table 1. Classification of common LMR trade-offs by management level.

Management Level	Trade-off type	Examples
Single-Species Management	Fishery gear types	Limited space available for deploying mobile and fixed gear
	Between fisheries sectors	Limited resource to be shared among recreational, subsistence/cultural, commercial fishing interests
	Long-term vs. short-term outcomes	A desire to maximize yield at conflict with a desire for stable harvest level
	Aquaculture vs. wild fisheries	Aquaculture can supplement wild fisheries but also requires space and resources needed by wild fisheries
Ecosystem Approach to Fisheries Management/ Ecosystem Based Fisheries Management	Between target species	The single species trade-offs listed above also have to be considered across species.

	Between forage and the other components of the food web	Competition among recovering predators
	Ecosystem structure and functioning vs. desires for harvesting individual stock	Optimizing overall ecosystem yield vs. individual stock yield
Ecosystem-based Management	Fisheries vs. energy vs. water rights sectors	Dams for hydroelectricity or water management influence fish habitat and inshore life-cycle phases of some fish stocks
	Protected resources vs. fisheries	Gear interactions can affect protected resources
	Fisheries vs. tourism	Fisheries removal activities and locations of those activities influence the recreational tourism activities like snorkeling, kayaking, etc.
	Land use/coastal zone management vs. restoration/preservation for fisheries purposes	Coastal zone activities affect inshore fish habitats
	Energy development versus fisheries	Petroleum, wind and wave energy extraction may co-occur with fisheries grounds or may otherwise influence fisheries grounds
	Climate issues and living marine resource stocks/populations	

This table lists commonly occurring trade-offs that are addressed at FSCs and is meant to be illustrative, and not an exhaustive list. This simplifies some of the trade-offs discussion and generally focuses on the biophysical and economic constraints as their basis. As the level of complexity of management increases the number and complexity of trade-offs increases; for example, the trade-offs in single-species management contexts still exist for EBFM. As a result, ensuring appropriate systems for addressing trade-offs at single-species management levels is essential for good ecosystem-level management. Layered onto this are the management and governance issues as well as climate issues that have an impact on efforts to address trade-offs.

Management and Governance

At the heart of management and governance issues is the fact that NMFS has responsibility for multiple mandates (e.g., MSA, MMPA, ESA, NEPA), which largely were developed prior to the advent of more holistic, ecosystem thinking in LMR management. As a result, when these mandates are taken as a whole they do not mesh together perfectly. For example, NEPA may call for protection of key habitats, but it does not take into account that a particular region may provide essential habitat for multiple stocks and some prioritization is necessary. MSA may allow for some of the flexibility needed to prioritize stocks, but policies for that mandate do not necessarily directly influence NEPA policies.

Emerging from these mandates, the governance structures such as FMCs and Regional Planning Bodies (RPBs) are also grappling with trade-offs. These management bodies face the trade-off between continuing to consider many single-species approaches versus tackling multiple goals/objectives within a broader EBM approach. FMCs are often configured to develop and implement fisheries management plans (FMPs) for single species or groups of related species so many of the EAFM/EBFM-related trade-offs cannot be adequately addressed. Development of ecosystem-based FMPs are necessary to address these trade-offs. With the adoption of the NMFS Ecosystem-based Fisheries Management policy, we are making progress towards implementing EBFM through MSA Fisheries Ecosystem Plans (FEP) and fishery related factors in MMPA Take Reduction Plans and ESA Recovery Plans.

FSCs and their ecosystem programs or groups, face choices when dealing with management trade-offs. FSCs have a mission to conduct research and monitoring to support the management, conservation, and sustainable use of LMRs in their regions. They have limited budgetary resources to conduct a broad array of surveys and research. They face decisions regarding how to allocate resources to develop tools for single-species and multi-species/ecosystem-based management. An additional type of tradeoff involves structural decisions in model formulation, i.e., the level of mechanistic complexity and the spatial resolution of modeling approaches.

The utility of using socioeconomic tools and approaches for helping to address management and governance concerns around trade-offs was discussed, and participants agreed that these approaches should be incorporated with ecosystem modeling to conduct trade-off analyses. These types of tools and approaches are necessary for understanding economic (revenue, jobs, etc.) and ecological trade-offs as well as non-economic trade-offs, e.g., cultural values, market vs. non-market valuation. Participants recommended an expanded (beyond quantitative modeling) workshop focused on trade-offs would be beneficial. Such a workshop would incorporate more participation from economists and other social scientists.

Climate

Besides being a part of a broad-scale trade-off, climate is an important driver that influences most of the trade-offs discussed at this workshop. Climate has direct impact on fisheries and other LMR issues in that warming oceans are causing distributional shifts in stocks and populations influencing the timing and location of human activities associated with harvest or other uses of these species. Climate-related distributional shifts then drive management and governance trade-offs as population centers move across jurisdictions.

In addition to direct impacts on LMR populations, climate has indirect impacts on LMR associated trade-offs. For example, changes in precipitation and land use associated with climate change can influence run-off and coastal habitats that are important for many LMR populations. So there is a need to address climate impacts on EBM-level trade-offs.

Methods for effectively addressing trade-offs

In the discussion of modeling activities to address trade-offs at the FSCs, a range of tools used and their effectiveness were discussed. Common modeling tools included Conceptual Models, Food Web and End-to-End Models as well as Spatial Modeling tools, and they have been effective at describing and quantifying trade-offs. IEAs and MSEs were identified as processes or frameworks that have been useful for identifying and addressing trade-offs.

Common modeling tools

Conceptual Models

Conceptual Models and related analytical tools, such as Quantitative Network Modeling, loop analysis etc., represent an approach to depict the interrelationships between the ecosystem's oceanographic, biological and socioeconomic components. The process involves a range of stakeholders, managers, and scientists tapping into their knowledge and perspectives on the ecosystem and drawing out key elements of the system (e.g., fisheries stocks, oceanographic drivers, industries that influence the ecosystem, governance/management). The stakeholders then draw arrows to illustrate their understanding of effects of one element on another and may additionally assign a semi-quantitative estimate of the size of the effect of one element on another. At a minimum this provides a visual hypothesis of the key ecosystem functions and ensures that a wide range of knowledge is brought to bear in the early stages of trade-off analysis and FEP development. When semi-quantitative magnitude of effect estimates are incorporated, perturbation analysis can be implemented to allow stakeholders to explore and identify unexpected outcomes from changes in ecosystem drivers or unintended consequences from management actions. When this approach is implemented, care must be taken to ensure that a wide range of participants are involved and to ensure stakeholders that the mental model is a hypothesis and not necessarily an entirely complete and accurate representation of the ecosystem interconnections.

Food web and end-to-end models

Food web models are mathematical representations of energy flows between key fisheries stocks, other LMR populations, the forage that support them, as well as the primary and secondary trophic levels essential to forage stocks. End-to-end models usually incorporate food webs as well as the other physical, biological and socioeconomic components of the focal ecosystem. These tools provide a useful quantitative summary of ecosystem functions and illustrate the biophysical constraints of an ecosystem. This quantification of an ecosystem allows exploration the effects of changing one component of the system on other components –e.g., will fishing a forage stock influence a marine mammal population. These tools can be used to assess a wide-variety of trade-offs and may help to elucidate trade-offs which had not been previously considered. A major advantage of this approach is that when properly implemented, it allows a full incorporation of the temporal and spatial dynamics of a system which facilitates a broad range of EBM actions to be considered. A disadvantage is that these can be time-consuming to develop because of the large quantities of data required for input and calibration. Currently, food-web and end-to-end models are primarily used to support strategic decision-making. Addressing uncertainty in input parameters and/or statistical parameter estimation using existing data for these models are areas of research that have been started, but require more emphasis across multiple regions. Developing methods for demonstrating that the short-term projections from these models are reliable is an area where additional investigation is needed. These models have value as data catalogs in that they rapidly identify data gaps. They also provide insights into cumulative effects, unintended consequences, and counterintuitive results. The challenge remains how to best use these in a management context.

Spatial tools

Spatial tools range from simple snapshot maps of species distributions based on survey data to more complex tools that incorporate temporal trends in spatial patterns by analyzing historical survey data and by incorporating oceanographic models. These are useful tools for identifying and reducing conflicts among users of ocean resources. In practice, these tools can facilitate the integration of multiple layers of GIS data for a particular ocean region where multiple resources are present. For example, spatial tools can use overlaid maps of major fishing grounds, shipping channels, conservation areas including wildlife migration routes, and ocean energy extraction sites to allow relevant stakeholders, managers, and scientists to identify areas of potential conflict and/or synergy and to propose appropriate management actions – consider trade-offs in management actions. As this overlay of information is concrete and visual, it facilitates clear discussion and can be useful for tactical decision-making and scenario modeling. When implementing this tool, care must be taken to consider the time horizons of the data used and the management action. This approach is adapted from terrestrial ecosystems which may be less dynamic than marine environments. Climate change induced shifts in fish and marine mammal populations may make historical maps of fishing grounds obsolete in a relatively short time. Although both qualitative and food web/end to end models are usually also spatial, these spatial tools are much more focused on basic data layers and presentation of thereof.

Common frameworks

Management Strategy Evaluations (MSEs)

MSEs are a key approach to exploring trade-offs. Most FSCs are using, developing or building capacity for employing MSE approaches. This involves the use of an operating model to simulate the biophysical components and anthropogenic drivers of the system and a management model to simulate the management procedures. MSE should be part of a full process, such as an IEA, involving the engagement, interaction and iteration with stakeholders to determine management objectives and performance measures. We primarily reviewed the potential to use ecosystem modeling within the analytical portion of MSEs, with simulations to evaluate a range of scenarios. The strength of this approach is that it enables sources of uncertainty to be identified and simulated. The biophysical model can be used to capture scientific uncertainty, and the management model can be used to capture outcome and implementation uncertainty. When used to simulate scenarios within the range of scientific and management uncertainties users will have a view of the range of outcomes of a management action. In addition, this approach can be used to explore improvements in research and monitoring that may help reduce uncertainty. By exploring a range of management scenarios in a modeling framework and reviewing the likely outcomes of each scenario, trade-offs among management alternatives are made explicit.

Integrated Ecosystem Assessments (IEA) framework

IEA is a framework to conduct scientific synthesis and transfer information to resource managers. IEA uses a stepwise approach (which include MSE) that defines and analyzes existing and future conditions as well as resource management objectives. For the stakeholder process of identifying objectives and developing a shared understanding of ecosystems, the IEA program uses a formal approach to defining objectives and conducting decision analysis. For the most part, formal stakeholder engagement is largely done with the assistance of other partners from other institutions. General objectives are taken from planning documents and can be refined within the stakeholder process. Regional applications are varied.

Workshop participants concluded that using the IEA framework to implement a range of modeling tools for MSEs can be an effective method for addressing trade-offs. This approach combines stakeholder involvement and insight with transparent, and objective modeling tools, to clearly illustrate and quantify the options available for managers given inevitable trade-offs. Often multiple solutions for decision-making in light of trade-offs can be identified, thus incorporation of socioeconomic tools for valuation are needed for a more meaningful set of results to help further winnow down the possibilities.

Limitations for addressing trade-offs

Though several tools and frameworks for addressing trade-offs have been employed across NMFS regions, FSCs face some challenges for addressing trade-offs. The limitations for addressing trade-offs at FSCs can be broadly classified as internal and external. Internal limitations are largely dependent on resources available for analytical staff to develop tools and for collaboration across institutional divisions. External limitations are largely driven by policy.

For FSCs that have mature ecosystem programs and ecosystem modeling groups, often the tools for addressing trade-offs are available. Once a trade-off of concern has been identified by an RO, an FMC, or an RPB, analytical staff can use available tools or parts of tools to begin a quantitative analysis of trade-offs. In this scenario, a trade-off analysis (e.g., MSE) can be completed relatively quickly. More ideally, specific tools would be developed for addressing specific trade-offs. In this case, additional time would be necessary for tool development. In the most ideal case, time and resources for a full stakeholder engagement process would be available. In this case, system components of concern to stakeholders but not obvious to modelers are incorporated, thus increasing the likelihood of adequate stakeholder buy-in. This buy-in is essential for moving towards operationalization of EBFM trade-off analyses and tactical decision-making based on these analyses. This full stakeholder engagement and trade-off analysis process may take 1-2 years for FSCs with mature ecosystem and modeling programs. Additional time may be necessary for FSCs that are in a capacity-building phase.

Apart from in-house limitations, engaging stakeholders and maintaining their engagement can be a limiting factor. Some FSCs have clear connections to ROs, FMCs, and RPBs to facilitate trade-off discussions and analysis. Others are dependent upon identifying critical trade-offs in the course of their research. In this case, considerable effort is necessary to identify and engage stakeholders so that FSCs can move from research on trade-offs to management applications. The IEA process can help with this engagement. Stakeholders engaged by IEAs are more than just managers, though who they are depends on the application, often there is not a “one-size-fits-all” approach to addressing and communicating trade-offs. In addition, even when a process for maintaining stakeholder engagement is in place, players change over time and the underlying environment can change as well. The dynamics of stakeholder groups and the environment makes the goals and objectives difficult to keep up with. A solution to a trade-off identified at one point in time may not be the optimal solution a few years later as the weightings and preferences for different management objectives may change with changes in stakeholder group composition over time. Similarly the changing environment may not make previous solutions feasible.

As stated previously, the mandates for which NMFS is responsible do not necessarily mesh perfectly. As a result, scientists at FSCs, in the course of their research, may identify interesting and important trade-offs; however, the lack of integration of mandates limits the solution space for resolving the trade-off. For example, some mandates have no-take policies; if a useful solution for a trade-off requires a small take, then that solution is not feasible. Consequently, issues that may be of interest to managers and stakeholders will not be addressed fully.

In summary, participants noted a range of limitations for addressing trade-offs. Internal limitations centered on the need for more time and resources at FSCs to thoroughly address trade-offs. Most FSCs have some capacity, but as EBFM becomes the norm, a need for more resources will arise. External limitations were focused on stakeholder issues and mandate issues. Once a trade-off analysis is completed and shared with management bodies and stakeholders, the work has just begun. Stakeholder groups are dynamic, so they will likely seek new solutions to trade-off problems. Similarly, the underlying ecosystem can change, and previous trade-off solutions may no longer be attainable. Finally, a given solution viewed under the lens of one NMFS mandate, may not be a feasible when polices under another mandate ae taken into account.

ToR 3: Tools for Visualizing and Communicating Trade-offs

A wide range of tools for visualization and communicating trade-offs were discussed. Tools included: 1) conceptual models used to build consensus and a shared understanding of focal systems, 2) software packages that enabled visualization of food web perturbation analysis, 3) spatial tools that help identify overlapping species distributions that may be the source of trade-offs and management conflicts, and 4) tools that allowed scenario exploration via graphs and animation. Detailed summaries of the visualization tools are given in Appendix A-3.

Virtually every FSC is using or developing conceptual modeling tools. Some FSCs developed these models in-house, relying primarily on the input of fisheries biologists, ecologists, oceanographers, and social scientists to outline and connect the essential components of focal ecosystems. Other FSCs worked with partners to develop a participatory process to develop conceptual models. In addition, a few FSCs worked with graphic designers to illustrate conceptual models. One advantage to conceptual models is that they can be readily converted into qualitative network models and used for exploring the impacts of perturbations on the system.

Spatial modeling tools, such as VAST (Vector Autoregressive Spatio-Temporal model) hold some promise for being useful across FSCs. A motivation for developing and applying spatial visualization modeling tools is that they can provide a unifying approach to support different groups that are working on stock assessments, habitat assessments, IEAs, etc. They can be used to quantify shared information among species, identify species with similar ranges, and help find correlations between species ranges with measured environmental variables. For trade-off analyses, multiple species distributions can be displayed and species interaction covariances can be modeled. In addition, the maps produce by these tools are helpful for stakeholder engagement, as maps are a familiar format and can convey complex information. The spatial modeling tool demonstrated has been used by many FSCs for a variety of ecosystems and could readily be used by other FSCs.

Often to convey trade-offs, modelers produce “horrendograms” (Figure 1), i.e., graphical representations of food webs. Marine food webs are typically visualized as network graphs—connected nodes with energy or biomass fluxes or exchanges. They get very complicated very quickly when all nodes and links are included; print and pixel space fills up quickly. Often the node placement is automated so the graphic may not permit useful grouping of associated guilds. These are often high information content graphics, which runs against the general idea of having something as a communication/information tool. Improvement of this approach is necessary. One tool, d3-foodweb, that improved upon this approach was demonstrated and can be readily used by FSCs with food web models.

Most FSCs have some type of Multi-species Production models in use or under development. A tool for using Multi-species Production model output that allows simple visualization of trade-offs between stocks under a range of harvest strategies was demonstrated. This tool could be re-implemented for use by other FSCs.

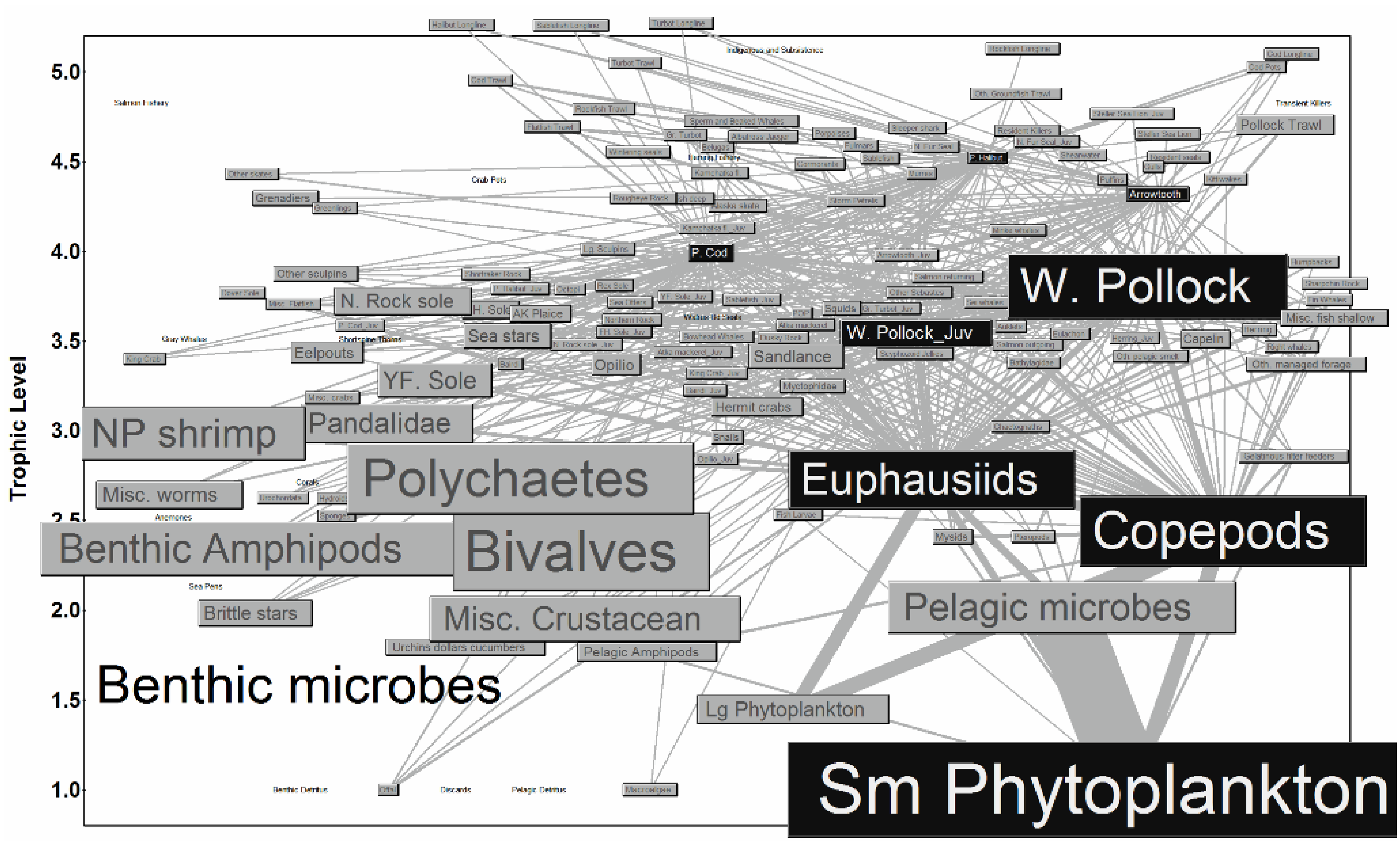

Figure 1. Example food web diagram, "horrendogram".

All FSCs have time series data on multiple species. Most have food web or end-to-end models. One tool, virtual ecosystem scenario viewer (VES-V), being implemented allows visualization through video-game-like animation. Scenarios run through ecosystem models or for MSEs can be visualized and compared side-by-side in a virtual ecosystem to allow an engaging view of trade-offs.

In addition to the visualization tools presented other useful tools and approaches were discussed. Participants pointed out that the Habitat model toolbox at SWFSC could be used by multiple FSCs. Similarly Regional Ocean Modeling System (ROMS) and satellite data combined with ecosystem models can be used to make spatial predictions and look at trade-offs based on spatial and temporal overlap of species and associated human activities. The idea of using Pareto fronts, which is commonly used in economics to evaluate trade-offs, was brought up as a useful approach for communicating trade-offs, but many participants were unfamiliar with this tool.

Though these tools are useful for illustrating trade-offs, some concern arose that they may be too simple and mask underlying uncertainty. Though many efforts to deal with uncertainty in ecosystem modeling have been undertaken, visualizing the uncertainty is another issue. In quantifying it well, modelers may, at times, run the risk of users losing confidence in model predictions. But uncertainty is real and needs to be communicated. Often the model narrows down uncertainty in the output when there is a high uncertainty in the input. In addition, the aim of many of these tools is to simplify and clarify information, whereas adding information on uncertainty will make the visualization more complex and less clear. Participants recommended sub-workshops and getting outside advice to help deal with visualizing uncertainty in trade-offs. Participants also recommended 1) risk assessment frameworks, which may be the best way to express ecosystem outputs, 2) focus on confidence rather than uncertainty, and 3) drawing from outputs of previous NEMoWs focused on uncertainty.

A need to share visualization tools and modeling tools across FSCs was discussed. Participants emphatically felt GitHub and R package development were necessary approaches for enabling sharing. It is the industry standard, and it is accepted by Commerce. Sharing tools is necessary to conserve time and personnel resource and ensure efficiency. Participants also recognized that just keeping websites updated is difficult, so tool-sharing is likely even more difficult. FSC IT resources are limited (hardware infrastructure and people) which limit modeling capabilities.

In addition to software-based approaches for sharing visualization tools, people-based approaches for tool-sharing were highlighted. Rotational assignments that allowed modelers from one FSC to spend time working with modelers in other FSCs will facilitate tool sharing. In addition, training programs or webinars would facilitate exchange. Similarly cross-FSC working groups focused on specific tool types would be beneficial.

Across FSCs there were many lessons learned about communicating trade-offs from recent engagement with FMCss, review panels, etc. Some of the major lessons include:

1) Review panels are often not accustomed to evaluating ecosystem models, so common ToRs are needed for the different model types that review panels might encounter.
2) Communication is critical; best practices for how to use ecosystem model output in management decision making are needed.
3) Ecosystem models cannot be modified on the fly during a review meeting, as is often done with less complex models during review. People leave reviews with many questions. A different process from the “accept/reject” stock assessment process is needed.
4) Align model use with review and consider bias/variance trade-offs. “All models are wrong, but some are useful.” The key question for ecosystem, multispecies, stock assessment, or other models is: Is this model good enough for its intended use? Considering a model’s demonstrated strengths and weaknesses, will managers make better decisions with it than with what they had before (which may be nothing).
5) More use of formal tools for eliciting management objectives is necessary. Social scientists involvement is needed at the beginning of a trade-off analysis and stakeholder process. An MSE position at FSCs could be the person who knows how to deal with stakeholders, understands these communication methods, and assists with eliciting objectives. These tools are critical to making the modeling relevant.
6) As more FSCs begin to use conceptual and qualitative models; guidelines on using these approaches to inform management are needed.
7) There is a need to more thoroughly apply new methods to explore/visualize trade-offs better. Specifically these tools can be used to narrow down management options to facilitate a more productive discussion.
8) Most participants felt that involving economists and social scientists into these processes would be highly beneficial.

In summary, the tools to illustrate trade-offs are often different than the tools to do the modeling, because the tools to illustrate trade-offs have to engage people. There are analytical tools to calculate trade-offs, but visualizations to illustrate and communicate the trade-offs is necessary. In addition, tools are needed to quantify linkages between ecosystem components and across disciplines from ecology to social sciences.

There is a range of tools to calculate trade-offs. Conceptual modelling approaches, like Mental Modeler, might be the most user friendly. They can be used to illustrate concepts from more complex models or they can be used to engage stakeholders to form a basis for more quantitative approaches. Other models, such as ATLANTIS, are mostly for scientists and need additional tools to help with visualization and communication of model outcomes.

ToR 4: Management Implications of Trade-offs

Several management and policy staff from SERO served on a management panel and talked about management issues they focus on. They discussed how EMs are used to help address those issues. The topics covered by the management panel ranged from Parrotfish species interactions influencing coral development to bycatch management in the face of climate change. In cases where EMs were not used, the management panel discussed how EMs might be useful. Summaries of the Management Panel presentations are provided in Appendix A-4.

The Management Panel Session of NEMoW 4 was invaluable. While RO and FSC staff sometimes work together on a specific project, the interactions are often narrowly focused, formal, and with tight deadlines looming. This session offered science and management staff an opportunity to take a step back and consider the bigger picture purpose of our work and how best to accomplish it. During this session, modelers were able to gain a better understanding of how ROs interact with FMCs and RPBS, so that they can bring EM-derived information to the table to enlighten discussions about trade-offs. In turn, RO staff were able to find out more about the processes with FSCs for developing, testing and applying EMs for trade-offs.

During the course of the discussion, it became apparent that FMCs are interested in ecosystem modelling but often do not know how or what exactly to ask for. Similarly, scientists have the models and tools but don't know how or who to ask for what the FMC needs. This is not necessarily the case for all FSC-RO-FMC/RPB interactions in every region, but this illustrates the need for improved understanding of FSC, RO, and FMC processes.

One way that a trade-off issue appropriate for ecosystem modeling application is brought to a FMC is through "options papers". In this case, a stakeholder brings up an issue to an FMC. The NMFS RO staff and FMC staff come up with a scoping document that eventually becomes a list of actions with alternatives (no analysis), also known as an "options paper". EMs and MSEs can be an approach to analyzing the alternatives in the paper, and informing the FMC of the trade-offs associated with each alternative. Participants agreed that codifying and communicating this type of approach for FSC-RO-FMC interactions could improve the application of EMs for trade-off analysis.

Further discussions on how FSCs can facilitate the use of EMs for trade-off analysis were centered on understanding, access, and timing. Many RO and FMC staff are not familiar with the suite of ecosystem modeling tools available. Similarly, management and policy staff do not have many contacts at FSCs, so they are unable to initiate discussions and plans to get ecosystem modeling projects started. Even if they are able to get projects started, often the timelines for developing and implementing a model do not coincide well with management needs for information to inform management decisions.

Management and policy staff felt more information on models would be helpful. They would benefit from a list of tools noting capabilities each tool has. Knowing a model exists does not equate to knowing what its capabilities are. Management and FMC members may be aware of the tools in the toolbox but might not realize that a model is capable of answering their questions of interest. In addition to a tool list, identifying experts who could be available to discuss the tools would be beneficial.

A tool list with identified experts as points of contacts would also improve access to modelers. Not every program has equal access to people with appropriate expertise. This also seems to highlight a lack of communication between scientists and end users (management and communication staff), but also among scientists. Regularly scheduled (bi-monthly, quarterly) conference calls/web meetings between scientists can help facilitate this communication among scientists across FSCs, regions, and programs. Questions that may otherwise go unaddressed may get new life and answers as a result of such communication.

Often managers have a short time window for research/analysis to address trade-offs and explore management options. In some cases, tools that at least partially address the issues are in place at FSCs. These tools can be used as a preliminary step to help bound the breadth of the problem with the recognition that additional tool refinement may be necessary. Most management issues are considered in an adaptive management loop (at least implicitly). Recognition of this loop and making model refinement an explicit part of the loop should help with some timing issues. Gaps identified in the modeling phase of the loop can inform management staff about research and data needs.

In summary, to ensure that 1) FSCs are able to be responsive to management needs for trade-off analysis and 2) RO staff are aware of modeling capabilities at FSCs, the following are necessary:

- A standardized approach for raising an issue, e.g., options papers,
- A list of tools and their capabilities available across the FSCs and regions,
- A list of modelers and their expertise, and
- Regular conference calls or webinars for EBFM-related RO and FSC staff.

ToR 5: Ecosystem Modeling Toolbox for addressing Trade-offs

EMs are an essential approach for addressing EBFM/EBM trade-offs, and NMFS personnel have developed and applied a variety of ecosystem modeling approaches. Thus the need for an Ecosystem Modeling Toolbox to organize and make NMFS's ecosystem modeling efforts more efficient has arisen. During the workshop, participants heard about the overall plans to create an NMFS Ecosystem Modeling Toolbox and saw a demonstration of the toolbox interface. A summary of the presentation is given in Appendix A-5. Afterwards, participants discussed the utility of the toolbox as well as its pros and cons. The information from this discussion will help guide the development of the toolbox.

Generally, the Ecosystem Modeling Toolbox - i.e., a central repository where modeling platforms can be accessed – was seen to have numerous potential benefits. The drawbacks associated with the toolbox were generally focused on the fact that ease of model use sometimes allows users to use tools without sufficient in-depth thinking and planning. The major pros and cons of the Ecosystem Modeling Toolbox are listed in Table 2.

Table 2. Pros and cons of developing and implement a NMFS Ecosystem Modeling Toolbox.

Pros	Cons
All tools in one central location makes clear what tools are available	Graphical user interface may promote use without thought
Improves the replicability and reviewability of model applications	May limit or constrain new development and innovation of new modeling platforms
Reduce time spent by modelers on development and maintenance of modeling platforms/software	Could cause users to convert the issue to be modeled to fit existing model instead of building model for purpose
Facilitates modularity of code	
Increased use of models	
Increased transparency	
Transferability to new applications	
Could attract managers as users, too	

Potentially decreases model development time so management applications can be produced more rapidly	
Facilitates cross-region comparisons with the same model type	
Facilitates the use of multiple models for a system	

The discussions about the pros and cons resulted in participants generating a number of overall recommendations for toolbox development and ecosystem modeling review. These recommendations are listed below.

Recommendations for Ecosystem Modeling Toolbox development and review procedures.

- The toolbox should have an overview of all the tools with documentation and a capabilities section in plain language for managers. The overview should include information on the model inputs and outputs, example applications, and an interactive list to search by data type for what models/modules can be used. The metadata and modules should be well documented and described.

- Overall, the toolbox should have a forum for questions and answers. The questions and answers on what models to use and how to use them should be separated from programming issues (bug reports and software improvement suggestions).

- Common language, code standardization, and shared application programming interface (api) of exchanging data to ensure that code modules will work together across models.

- Model modules should be accessible by researchers so that they can be re-used and recombined to create new model modules. The modules would be in a library of functions that can be called. This will ensure interchangeability and consistency across models.

- Must be open source and cross platform (Linux, Mac OS, and Windows) tools.

- Visualization tools should be available too. Visualization tools should be developed in cooperation with visual information specialists and should use interactive visualizations.

- A library of functions one can call for interchangeability and consistency across models (e.g. predation mortality functions used across Multi-species Statistical Catch-at-Age and length-structured Multi-Species models, recruitment functions).

- Models and modules should be developed collaboratively with programmers and modelers. This will require some programming assistance for modelers. Assistance could come in multiple forms. Specify best practices for code development to submit to the toolbox. Coding workshops for researchers — e.g., best practices, how to develop code for models, — coding boot camps.

- Modules might include:
    - Input data handling modules
    - Data fitting modules
    - Sensitivity analysis module
    - Modules for fitting diet data (Dirichlet vs other options, and how to deal with diet data).
    - Visualization modules

- GitHub is a commonly used approach for shared software development that is endorsed by the Department of Commerce and should be used for the toolbox.

- To facilitate model review for applications by FMCs and other management and planning bodies, a multi-level review is necessary. The model code should be reviewed to ensure the code does what it is purported to do. A review of the model theory/platform is required to ensure that the model platform makes sense for the application. Finally, the model application has to be reviewed to ensure the data and parameterization are the best available science. Additional levels of review that need to be incorporated include: model performance/simulation and calibration/tuning.

- The toolbox will require collaborative work on the part of modelers at FSCs, who would like to contribute to this beneficial NMFS enterprise-wide endeavor. Incentives for FSC modelers are more regionally based or are based on publications. Alignment of incentives is necessary to ensure the success of toolbox development.

- The toolbox should include connections to third-party modeling platforms (e.g., Atlantis and EwE). NMFS should still review and validate these platforms to ensure they are doing what they say they are doing before applying them.

- Modules should have the ability to link to other models (e.g., climate, oceanographic, and socioeconomic) that are not part of the toolbox. Many other models have useful inputs for EMs or can use the outputs from EMs. Ideally other models could be dynamically linked.

- The toolbox needs a single person to serve as POC/Owner to push or update code. There should be some redundancies/planning to minimize disruptions when personnel move on and there is no accountability or ownership.

- The toolbox should include or be complemented by archived model outputs. For instance point to model output that is archived under Public Access to Research Results (PARR), so that these can be used as inputs into other ecosystem models (Example: ESRL climate projection portal). Document model output and version. The National Centers for Environmental Information (NCEI) and PARR require this type of archiving, but archived data are fragmented across the country.

Conclusions

The overarching conclusion from the participants of NEMoW 4 was that NMFS has many of the ecosystem modeling and visualization tools needed to proceed with and advance trade-off analysis. A number of FSCs have had some success working with FMCs and other management and planning bodies in identifying trade-offs associated with different management options. Participants identified the best tools to use for dealing with and visualizing different types of trade-offs. They recognized our current limitations in our abilities to deal with trade-offs and considered approaches to overcome these limitations. A general approach for dealing with trade-offs is not one-size-fits-all, but provides a framework for beginning to deal with the complex array of trade-offs that arise in EBFM and EBM.

A general approach for dealing with trade-offs includes:

1) Early involvement of the range of stakeholders associated with the issue.
2) Developing a model (or ideally multiple models) that capture the key dynamics of the issue.

3) Using the model in an MSE (or MSE-like) approach for evaluating options.
4) Clearly communicating the trade-offs and management options.
5) Re-evaluate the issue in an adaptive management cycle as needed.

As we move forward with trade-off analysis for LMR management, modelers are advised to follow the best practices listed below. In addition, the recommendations listed below will facilitate the improvement in scientific advice for LMR management.

Best Practices

1) Stakeholder engagement is crucial.
   Engage FMCs, other management bodies, and stakeholders early and often. FMCs need an answer and need to know they can defend it. Early engagement should also include clear identification of management goals and objectives. This will likely require work with sub-committees or work with the RO instead. This will be helpful in defining and refining the spatial and temporal scale at which the trade-off applies.

2) Anticipating modeling needs can help to ensure management relevance.
   Management timelines are often tight, which may preclude full engagement or the ability to use the ideal model for addressing a trade-off. FEP prioritized list of research (and other relevant planning documents) can be useful for helping to stay ahead of modeling needs. Some development of research models may be helpful for demonstrating some options to FMCs.

3) Developing conceptual models is important.
   Conceptual models can help with stakeholder engagement if a participatory modeling approach is employed. Conceptual models facilitate work across scientific disciplines (e.g. oceanography, ecology, economics, and anthropology) that is necessary for full tradeoff analysis under EBFM/EBM. Conceptual models can help guide the development of quantitative models to be used in an MSE or other trade-off analysis.

4) Clearly communicating the results of a trade-off analysis is essential.
   Visualizations of model output/trade-off analysis requires simplicity in presentation but also the ability to include uncertainty. This can be a difficult balance to achieve. Limiting the number of trade-offs under discussing can help. When expressing changes in the ecosystem under different management conditions, results relative to status quo conditions provides a baseline that simplifies results. Interactive tools and maps are more engaging forms of communication.

5) Using multiple models and visualization tools is ideal.
   Multiple models are necessary for dealing with the uncertainty associated with model structure. Assessing trade-offs in a variety of model types may provide greater assurance and consensus on likely outcomes to management actions. Multiple visualization tools are necessary for engaging a diverse array of stakeholders.

6) Trade-offs and synergies should be considered.
   Addressing trade-offs is a central tenet of EBFM and EBM. Trade-offs imply losses associated with management decisions. However, many management options may result in unexpected gains in other ecosystem components or management sectors. Clearly identifying unexpected gains will help stakeholders be aware of long-term optimization of and stability in ecosystem goods and services

Recommendations

In developing the list of best practices for addressing trade-offs, participants identified steps that could be taken with NMFS and the FSCs. The major recommendations are outlined below.

1) Guidance on prioritizing and reconciling trade-offs across mandates (e.g., MSA, ESA, MMPA, NEPA) is vital.
   For example, some mandates have no-take policies; if a useful solution for a trade-off requires a small take, then that solution is not feasible. Consequently, issues that may be of interest to managers and stakeholders will not be addressed fully. Because overlap in NMFS's mandates exists, a higher-level, nationwide effort to address trade-offs associated with multiple mandates is needed. Modelers can identify trade-offs in the ecosystem but may have limited options for solutions to trade-off problems because of a lack of clarity among mandates.

2) Regular communication between scientists and managers should expedite NMFS's ability to address trade-offs.
   Regular, topical conference calls between ecosystem modeling staff at FSCs and EBFM/EBM staff at ROs will foster collaboration and cooperation. Increased awareness of trade-off issues and tools to address them will promote engagement and co-ownership of management solutions to trade-off issues.

3) Engagement of representatives from other disciplines will help to develop useful approaches for addressing trade-offs.

Social scientists are needed for participatory model development and stakeholder engagement. Programmers and communications experts can provide input on development and improvement of visualization tools. Economists can help translate trade-offs associated within biophysical constraints of ecosystems into meaningful socioeconomic indicators. A future interdisciplinary workshop on trade-offs would be valuable.

4) EM Toolbox development and implementation should continue.
The tool box provides a standardized code base for modeling tools that will facilitate peer review and uptake by regional management as well as use by partner agencies and academics. Modelers should be supported to be actively engaged in toolbox development. They are essential for development, documentation and testing of tools. They will benefit from improved use and review of tools. Training on programming (a coding boot camp) will be worthwhile for initiating this engagement.

Appendix A -Abstracts and Summaries of Plenary Presentations

A-1: Summary of Introduction and Opening Remarks

Dr. Jason Link, NMFS Senior Scientist for Ecosystem-based Management and Dr. Kenric Osgood, NMFS Office of Science and Technology, Marine Ecosystems Division Chief kicked off the meeting with some opening remarks. They reviewed the progress and capacity building that has occurred for NMFS ecosystem modeling efforts over the past 10+ years. They set the stage for why ecosystem modeling is important in NMFS, and where future ecosystem modeling efforts will be headed.

Jason Link began by welcoming all participants from NMFS FSCs, ROs, and other NOAA line offices, as well as invited guest observers and speakers.

Link highlighted that this workshop (and the NEMoW series) is a key part of the ongoing NMFS EBFM efforts. Link reviewed the general objectives of the NEMoWs and provided some historical background on the origin of NEMoWs, why NEMoWs are still needed, and what we aimed to achieve at NEMoW 4.

He outlined some of the key accomplishments for supporting NMFS EBFM efforts that sprang from NEMoWs and related efforts. These outcomes include:

- Went from 1 out of 7, to now 5 out of 6 FSCs having formal ecosystem modeling groups or capacity
- Demand, interest, and need for MSEs
- Driving multidisciplinary connections & discussions
- More LMR assessments quantitatively including ecosystem factors
- Recognized need for systematic and cumulative impact evaluations
- Served as a core element of EBFM discussions and Ecosystem Program Reviews
    - New Ecosystem Modeling Coordinator
    - New MSE FTEs
- Driving some NOAA-wide modeling discussions

He noted the forces driving the need for more and better ecosystem modeling efforts within NOAA.

- We manage 5-10% of the world's oceans.
- We are a mandate driven science agency.

- Mandates include MSA, ESA, MMPA, and NEPA.
- As we continue to try to meet our mandates in a changing ocean, there are commonalities and efficiencies we can gain from adopting a more coordinated, ecosystem-approach that addresses issues across mandates.

He noted the national, state, and international regions in which we are implementing or supporting implementation of EBFM and EBM.

- 8 Fisheries Management Councils (Northeast, Mid-Atlantic, South Atlantic, Caribbean, Gulf of Mexico, Pacific, North Pacific, West Pacific)
- 4 Marine Fisheries Commissions (Atlantic, Pacific, Gulf, Great Lakes)
- 3 SRGs (Pacific, Atlantic, Gulf, plus MMC)
- 150 Estuaries – Local & State Partners
- 11 LMEs (Antarctic, Beaufort, Chukchi, Eastern Bering Sea [Aleutians], Gulf of Alaska, California Current, Insular Pacific/Hawaiian, Gulf of Mexico, SEUS, NEUS, Caribbean)
- 7 main RFMO/RMOs –(**CCAMLR**, CCAS, **IPHC, IWC, ICCAT**, NASCO, NAFO, WECAFC, **ITTAC**, PSC, NPAFC, WCPFC, **AIDCP**, **IOTC**, IOSEA, IAC, ACAP, CBD, CITES, UNFSA, COFI; quota setting bodies bolded)
- 8 IEA Regions (California Current, Pacific Islands-Kona, Alaska Complex, Gulf of Mexico, NE Shelf, Southeast Shelf, Caribbean, Great Lakes),

Given the broad range of mandates, depth of knowledge needed, and expansive geographic coverage that NMFS is involved in, ecosystem modeling is essential to covering the bases. Providing scientific advice on individual stocks, populations, and issues on a single-sector basis will not be possible.

He offered some direction to cover these bases. He stated that ecosystem modeling will be increasingly necessary for implementing Management Strategy Evaluations, Trade-off evaluations, and ecosystem-level reference points. This will require standardized tools and operational use of EMS.

Osgood followed Link's remarks. He discussed the Ecosystem Program Reviews of the FSCs and the Office of Science and Technology Marine Ecosystems Division. He noted that ecosystem modeling was integral to the Ecosystem Programs at most FSCs.

In addition, Osgood discussed the NMFS EBFM Policy and the EBFM Road Map. He highlighted the ecosystem modeling aspects of the Road Map and the importance of dealing with trade-offs in these NMFS EBFM efforts.

A-2: Extended Abstracts on Ecosystem Modeling efforts at NMFS Fisheries Science Centers

Alaska Fisheries Science Center Ecosystem Modeling Efforts

Food web modeling

Scientists with the (AFSC) Resource Ecology and Ecosystem Modeling (REEM) program previously developed mass-balance food web models of large marine ecosystems (LME) in Alaska, including the eastern Bering Sea, Gulf of Alaska, and Aleutian Islands. These food web models are updated frequently and are used regularly in fishery management advice in annual Stock Assessment and Fishery Evaluation (SAFE) reports. Recently, this suite of models was expanded with the completion of a model of the Chukchi Sea. Using the same food web modeling framework, the researchers focused on a set of network metrics to draw comparisons with nearby subarctic ecosystems—the eastern Bering Sea and Gulf of Alaska, and a more distant Arctic ecosystem, the Barents Sea.

The Chukchi Sea is a seasonally ice-covered, peripheral sea of the western Arctic Ocean. It lies north of the Bering Strait off the northwestern coast of Alaska. Comparison of the network metrics highlights distinctions that lead to the eastern Chukchi Sea having the lowest total production/biomass (P/B) ratio of the systems examined; the P/B of the nearby eastern Bering Sea was about double that of the eastern Chukchi Sea. In practical terms, this characteristic implies that the eastern Chukchi Sea is fundamentally different from the adjacent eastern Bering Sea – they have roughly comparable total biomass density but the total production of the Chukchi Sea is 45% that of the eastern Bering Sea. Thus, the standing biomass in the Chukchi Sea is not expected to be highly resilient to commercial fishing or other high-mortality events such as that which might be expected following a large-scale oil spill. Further research into the production of species/functional groups and their response to extraction or disturbance could be useful for evaluating the impact of future fisheries on the food web and predicting response to potential environmental disturbances related to energy extraction.

Multispecies statistical modeling

REEM modelers continue to develop so called “Models of Intermediate Complexity for Ecosystem assessments” (MICE; Plagányi et al. 2014). These include the CEATTLE bioenergetics-based multispecies statistical catch at age model for the EBS (Holsman et al. 2016) and a newly funded application of CEATTLE to the Gulf of Alaska (development to begin Fall 2017). These models have multiple applications including for evaluating potential climate driven changes to fish and fisheries in Alaska. For example, model runs have been completed for the Bering Sea using a $10km^2$ Regional Ocean Modeling System (ROMS) model coupled to a Nutrient-

Phytoplankton-Zooplankton (NPZ) model to produce detailed hindcasts for the period 1970-2012 and forecasts using IPCC scenarios through 2040. As part of an integrated climate-change modeling project (ACLIM), these results drive a climate-driven Multispecies Statistical Model (CEATTLE) for use in a management strategy evaluation of three groundfish species from the Bering Sea (walleye pollock, Pacific cod, arrowtooth flounder). First, ROMS model results modulate bioenergetics, food supply, growth, recruitment, and species overlap (i.e. functional responses and predation mortality) as fit in CEATTLE using hindcast-extracted time series. Then the model is applied to downscaled IPCC climate projections via a ROMS and NPZ model projection of temperature, circulation, and zooplankton abundance. Results of model simulations have helped REEM scientists understand and predict how future climate driven changes to the system may impact predation and fishery harvest limits.

For this approach, recruitment estimates were first derived from a multi-species stock assessment models (CEATTLE) fit to historical survey and fishery data. The model was run in multi-species mode, where each species is linked through a predation sub-model, as well as in single-species mode, where no predation interactions occur. This produced a time-series of spawning stock biomass and recruitment from the multi-species and single-species models. ROMS model estimates for mean water column temperature and spring and fall zooplankton biomass were then used as covariates on a Ricker stock recruitment curve, such that:

$$log(\hat{R}_{p,y}) = \log(\alpha_{R,p} \cdot SSB_{p,y-1}) - \beta_{R,p} \cdot SSB_{p,y-1} + \beta_{Z,p}^{spr} \cdot Z_y^{spr} - \beta_{Z,p}^{fall} \cdot \left(\delta_{p,1,y}^{fut} \big/ Z_y^{fall} \right) + \varepsilon$$

Where $\hat{R}_{p,y}$ is estimated recruitment in year *y* for species *p*, $SSB_{p,y-1}$ is the spawning stock biomass from the multi-species model, Z_y^{spr} and Z_y^{fall} are the total spring and fall zooplankton biomasses predicted from the ROMS/NPZ model for the Bering Sea, $\delta_{p,1,y}^{fut}$ is the ration of the youngest age class for each species, and $\alpha_{R,p}$, $\beta_{R,p}$, $\beta_{Z,p}^{spr}$, $\beta_{Z,p}^{fall}$ are parameters of the recruitment function fit through maximum likelihood to recruitment from the multi-species model ($R_{p,y}$) such that $\varepsilon \sim N(0, \sigma^2)$. Model estimates were compared via AIC and top models for each species were selected for use in projections of the multi-species model under future climate scenarios from ROMS/NPZ projections based on down-scaled IPCC climate model scenarios (Fig. 1; Holsman et al. in prep).

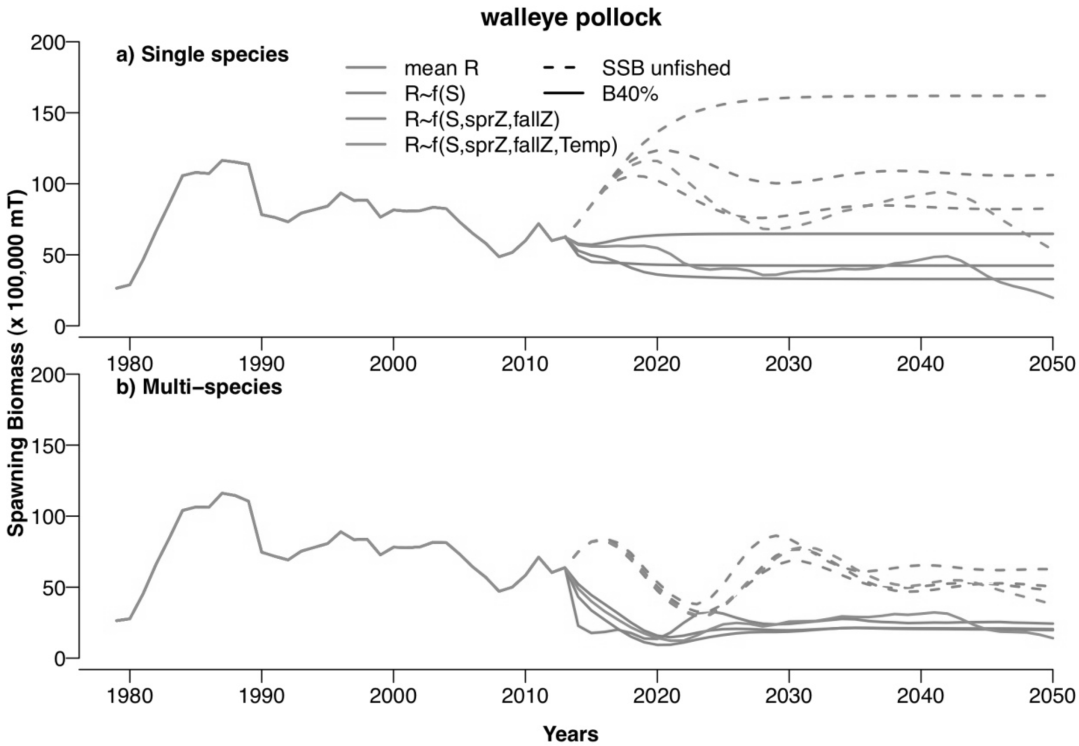

Figure 1. Projected spawning stock biomass for walleye pollock predicted from single (a) and multi-species (b) modes of CEATTLE under various recruitment relationships and no harvest ("SSB unfished"; dashed line) or harvest that yields 40% of SSB on average during the last five years (2045-2050) of the projection (B40%; solid line).

Size spectrum modeling

A species-specific size spectrum model is being developed for the Eastern Bering Sea through modifying the MIZER R package to include climate-driven changes to species interactions and overlap. This model is being fit to observed diet matrices for the EBS, and will then be used to project climate driven changes to food webs in the EBS using methods similar to those outlined for the multispecies CEATTLE model above.

End to end modeling

The Forage and Euphausiid Abundance in Space and Time (FEAST) model is a length based, spatially explicit bioenergetics model that comprises the fish portion of the vertically integrated model of the North Pacific Research Board's Bering Sea Integrated Ecosystem Program (BSIERP). The vertical model itself contains 5 modules: climate, oceanography (ROMS), lower trophic levels (NPZ), fish, and fisheries (FAMINE). FEAST models 14 fish species linked to 5 zooplankton groups (Fig. 2) and 20 fisheries specified by sector, gear and target species. Species include walleye pollock, Pacific cod, arrowtooth flounder, salmon, capelin, herring, eulachon, sandlance, myctophids, squids, shrimp, crab, epifauna, and amphipods; these have a two-way interaction with six groups from the Nutrient - Phytoplankton - Zooplankton (NPZ) module: small copepods, oceanic/shelf copepods, oceanic/shelf euphausiids, and benthos. Temperature and advection estimates from the physical oceanography portion (ROMS) are used in the fish bioenergetics and movement components. The model has a spatial resolution of approximately 10 Km and will be run both with past climate (1970-2010 hindcast) and three different climate projections stemming from three different climate models. In addition, FEAST is the "real world" model to be used in a Management Strategy Evaluation for walleye pollock and Pacific cod, two of the main commercial groundfish in the Bering Sea.

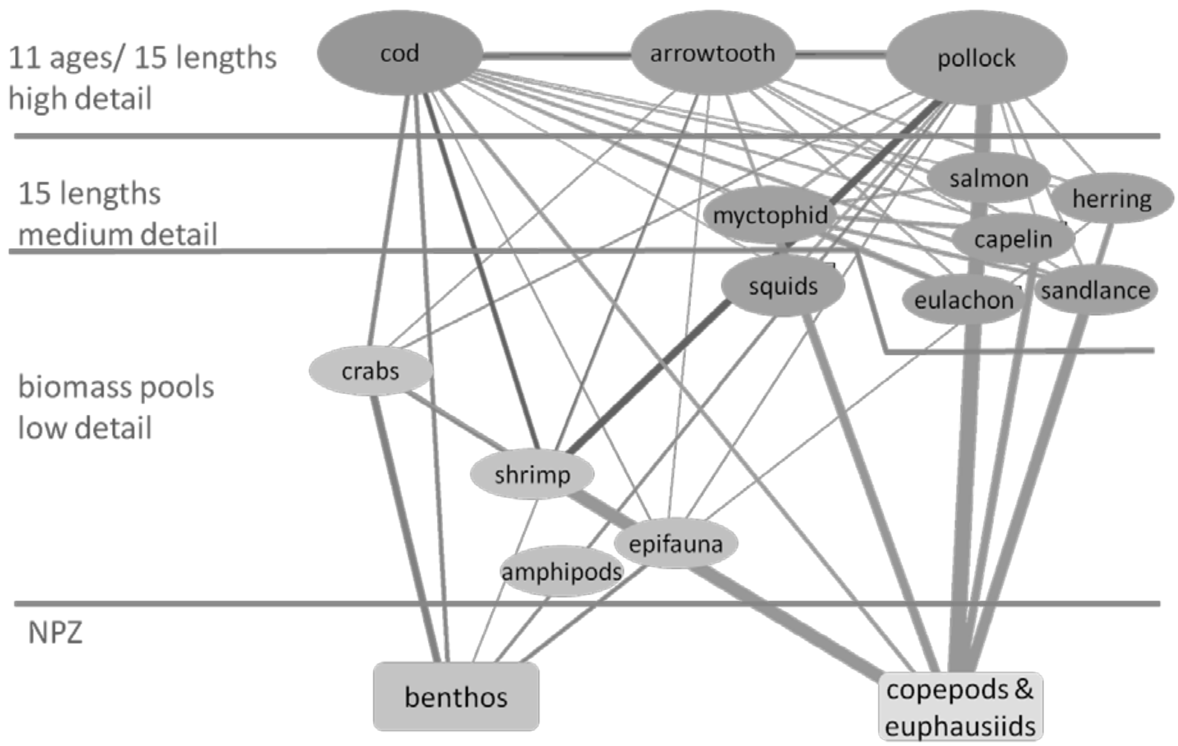

Figure 2. Food-web underlying FEAST, showing level of detail for the groups modeled. Lines depict trophic flows, line thickness is proportional to magnitude of flow.

Qualitative Network Models (QNM; i.e., dynamic conceptual models)

Qualitative network models allow for rapid evaluation of the sensitivity of species to direct and indirect interactions, and human or climate driven changes to a system. QNMs are being developed for the whole ecosystem in the Gulf of Alaska and for blue king crab in the EBS. For the EBS model, expert opinion through stakeholder meetings was used to develop the BKC based web and to evaluate potential management actions that might help promote recovery of BKC.

Individual-based modeling

Groundfish recruitment in the Gulf of Alaska is thought to be controlled by physical processes (i.e. climate and transport) and biological processes (i.e. growth and predation) experienced between offshore spawning sites and the end of the young of year (YOY) stage. As part of the North Pacific Research Board's Gulf of Alaska Integrated Ecosystem Research Program (GOAIERP), AFSC modelers are using a Regional Ocean Modeling System (ROMS), a Nutrient-Phytoplankton-Zooplankton (GOANPZ) model, and Individual-Based Models (IBMs) to examine recruitment mechanisms and derive indices related to recruitment for five ground fish species; arrowtooth flounder, walleye pollock, Pacific cod, Pacific Ocean perch, and sablefish. The work will also incorporate the indices into the existing Ecosim model of the Gulf of Alaska to explore the consequences of recruitment variability on the GOA ecosystem and fisheries. Indices produced, and conclusions about the effects of physical and biological processes on the GOA ecosystem under different physical regimes will aid in the management of these important fish stocks.

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Northeast Fisheries Science Center Ecosystem Modeling Efforts

The NEFSC is heavily involved in IEA efforts that employ models which range from single species to ecosystem level models. Recent applications have included qualitative models to explore trade-offs between IEA objectives, production models to explore marine mammal-fishery trade-offs and risk-value trade-offs in multispecies fisheries, the exploration of multispecies management trade-offs using structured models, food web models used for forage fish trade-offs, and end to end models for climate scenario trade-offs.

Qualitative models are a relatively new tool that we've used at the NEFSC. We developed Georges Bank, Gulf of Maine, and Middle Mid-Atlantic Bight conceptual models using Mental Modeler (Gray et al. 2013). In each case ecological/fishery, climate, and socioeconomic submodels were developed around focal components and then merged into one large model. The conceptual models facilitated work as an interdisciplinary IEA team (DePiper et al. 2017). Two alternative scenarios were created to explore differences in climate over time, and two management strategies' implications were explored by increasing or decreasing the strength of pelagic and groundfish fisheries. The results were best interpreted as a likely increase or decrease in other components of the system rather than quantitative results. QPress is another software package which was used to take the Georges Bank and Gulf of Maine models created by Mental Modeler, and run further analyses. The results are expressed in terms of number of simulations which resulted in a positive or negative change for each node in the model. In general, these qualitative models can be used in understanding a system, communicating the important connections in an ecosystem to managers or stakeholders, and exploring trade-offs of management actions.

A simple aggregate group production model was used to explore trade-offs between management objectives related to fisheries (yield, biomass of target species) and marine mammals (overall biomass). Losses to marine mammals occurred through interactions with fisheries (ship strikes, bycatch and removal of prey). A simple set of scenarios explored different levels of fishing on the three groups in the model (forage fish, flatfish and gadids). Sensitivity analyses were performed to test assumptions related to human interactions with marine mammal groups and marine mammal dependence on prey in the model. These sensitivities showed that the most important parameter in the model with regard to marine mammals meeting their target biomasses was direct human interactions. This further resulted in an update to the model using better estimates of fishery interactions with the marine mammal groups (Smith et al. 2015).

The NEFSC is also exploring a set of management procedures which focus on trade-offs at the species, aggregate, and ecosystem, as part of a prototype analysis for Georges Bank. The first management procedure is to set an overall cap on ecosystem removals based on total productivity of the system. Next, functional groups of species will be defined, and each will be assigned a maximum removal amount. Third, each species/stock will be assigned a minimum stock size threshold below which it can't be fished. And finally, the species mix will be optimized using a method such as the bio-economic portfolio analysis example described below. The benefits of this approach would be fewer catch limits while allowing for greater flexibility for the fisheries.

One management procedure study explored trade-offs between species biomass, yield and revenue using Hydra (a length structured multispecies/multifleet model). One of the primary findings was that for the set of species in the prototype Georges Bank analysis, 50% of the averaged historical effort achieved 86% of historical yield but also achieved the highest revenue in the simulation while not driving any species below its biomass floor. When 100% historical effort was applied, three species were driven below their biomass floors, yield was at 94%, but revenue was only 68% of maximum. Further, while yield continued to rise through 150% of the historical effort, it was the lower value groups (planktivores and elasmobranchs) which continued to have higher yield while the higher value groups (benthivores and piscivores) exhibited lower yield thus resulting in an overall lower revenue due to the species mix caught in the model (Gaichas et al. 2017).

An ongoing management procedure study used a simple multispecies production model (Kraken) as an operating model with catches set by biological constraints and portfolio analysis optimization. The 10 species from the Georges Bank prototype study were used. The operating model was loosely based on historical survey and catch time series, and included competitive interactions and predation. It calculated the biological constraints (species floor and aggregate group ceiling) and current biomass for each time step. The portfolio analysis optimization routine determined the catch on each species by minimizing the variance on the catch subject to the biological constraints (Jin et al. 2015). The results can then be compared to the historical levels of revenue, yield and biomass.

Further brief examples of ecosystem level tradeoff analyses completed at the NEFSC were reviewed. Examples include forage fish work that examined the effects of decreasing forage fish biomass on the other species in the Northeast U.S. Large Marine Ecosystem. The effects of climate change (temperature and ocean acidification) on different functional groups and fishery metrics have been explored using Atlantis (Nye et al. 2013; Fay et al. 2017). Finally, visualization tools have been developed which can more easily show trade-offs across the ecosystem given changes in fishing, or other scenarios. These studies are a first step in developing an MSE and risk assessment framework which incorporates fishery management council objectives into models and analyses devoted to exploring the trade-offs in the system.

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Southwest Fisheries Science Center Ecosystem Modeling Efforts

The SWFSC carries mandates over a number of species and guilds including Coastal Pelagics, Highly Migratory species, Demersal species, Anadromous species, Invertebrates, Marine Mammals, and Marine Turtles. This requires a diversity of approaches from statistical to mechanistic to mass-balance based approaches. SWFSC has no formal modeling division although significant effort occurs within the Environmental Research and Fisheries Ecology Division often tied in as part of Integrated Ecosystem Assessment efforts. Following from the ecosystem review, the SWFSC is making multiple strides towards improving modeling at the center with the creation of a Management Strategy Evaluation position to focus on Albacore Tuna and a SWFSC modeling forum led by ERD that would unite modeling efforts across the center. Below are examples of modeling efforts completed or underway.

Both ERD and the Marine Mammal and Turtle division are using statistical habitat models to look at species distribution relative to anthropogenic threats and human activities (Forney et al. 2012, Hazen et al. 2013, Maxwell et al. 2013, Redfern et al. 2013, Hazen et al. 2016, Eguchi et al. 2017). These include generalized additive mixed models, boosted regression tree models, and Bayesian approaches at understanding species-habitat relationships, and using these relationships to predict habitat in space and time. These tools assume maintenance of the relationships to allow persistence through time and require ongoing validation when operationalized.

Dynamic energy budgets and stochastic dynamic approaches can be used to model physiological response to changing environmental conditions, such as for salmon adjusting to water temperature and stream flows (Pike et al. 2013, Lindley 2015, Holsman and Danner 2016). These models can focus on first-principles to provide a mechanistic approach to habitat and survival. These also can be generalized as physical-biological models that couple physics to lower trophic levels to understand how environmental conditions translate to ecosystem productivity (Jacox et al. 2015, Jacox et al. 2016). Conceptual models have been used to understand complex processes such as salmon ocean survival to understand how oceanic processes translate to growth and survival (Wells et al. 2016). Mass-balance models were developed for the California Current by John Field originally (Field et al. 2006), and have been expanded by academic researchers to look at finer resolutions and different environmental forcings (Koehn et al. 2016). Mass-balance approaches for the California Current are largely outside the SWFSC presently.

Finally, the outlier but also a promising approach is to use non-frequentist approaches including Bayesian population models and empirical dynamic programming where data sets are lacking or to understand population fluctuations as a function of their previous state in addition to extrinsic forcing (Deyle et al. 2013, Moore and Barlow 2013, Munch et al. 2016).

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Pacific Islands Fisheries Science Center Ecosystem Modeling Efforts

The Pacific Islands Fisheries Science Center (PIFSC) has a number of ecosystem modeling efforts addressing trade-offs and synergies in living marine resource management. These efforts include but are not limited to trade-off analyses for a number of coral reef ecosystems using several modeling platforms, continued development of models for the pelagic longline fishery, downscaling of climate model output to island scales, and conceptual modeling of ecosystem services by the West Hawaii Integrated Ecosystem Assessment (IEA). Additionally, PIFSC continues to devote resources to improving communication of the trade-offs identified by this research. These and other modeling and communication efforts are summarized below.

Trade-off analyses for coral reef ecosystems

The Guam Atlantis Coral Reef Ecosystem Model was completed (Grafeld et al. 2016; Weijerman et al. 2015; 2016a; 2016b; 2016c). This model was built based on discussions with Guam resource managers which identified both a number of land- and marine-based management strategies for evaluation as well as metrics for measuring their effectiveness. Results showed that none of the selected management strategies could prevent the decline of corals under future climate change, but that reducing stressors such as land-based pollution sources could postpone the onset of climate change impacts by about a decade. Further work quantified the trade-offs between conservation and extraction through examining the impacts of management strategies on recreational fishermen and dive tourists.

Similar trade-off analyses were conducted using an Ecopath with Ecosim model (EwE) as well as the Coral Reef Scenario Evaluation Tool (CORSET). EwE was used for a case study of Puako by the West Hawaii IEA. This study evaluated the effectiveness of alternative management strategies identified by State managers to reverse the declining trend in coral reef resources. These strategies were evaluated under two future climate change scenarios and measured three indicators for ecosystem services: 1) ecosystem structure and resilience, 2) potential dive tourism, and 3) the coral reef fishery. CORSET was used for a case study in Maui Nui, examining local management strategies for ecosystem services under global climate change impacts. Papers on these two analyses are in preparation.

Data from over 30 CMIP5 global climate models were downscaled for coral reefs to evaluate the timing of annual severe bleaching conditions across the globe (van Hooidonk et al. 2016). Results showed that reefs in the Pacific Islands are expected to experience annual bleaching beginning between 2035 – 2045, highlighting the importance of accounting for changing environmental conditions in future management strategies.

Modeling efforts for protected species and protected areas

Several modeling efforts have examined both protected species as well as waters in protected areas such as the Marine National Monument encompassing the Northwestern Hawaiian Islands (NWHI). An EwE model evaluated ecosystem structure and energy flows for two sub-populations of Hawaiian monk seals in the NWHI. This model also included climate variability (PDO) and anthropogenic (fishing and other mortalities) forcings to determine drivers of monk seal population trends and identify potential management actions for recovery. A paper summarizing this work is in preparation.

PIFSC's marine turtle research program is working to include climate change impacts in their Population Viability Analyses for Hawaiian green sea turtles. This work uses output from CMIP5 climate models to project changes to sand, sea surface, and air temperatures. These temperatures are then used in calculations for temperature dependent sex ratios and egg mortality rates. Understanding how nesting beaches may change in the coming decades is critical for protected species management. For example, it allows for evaluation of trade-offs between turtle population impact and fishery impact when setting limits on incidental takes. A paper summarizing this work in is preparation.

Additional, Wren et al. (2016) examined larval reef fish connectivity in the Hawaiian Islands using ocean circulation and dispersion models. Their results showed a greater flux of larval reef fish from the main Hawaiian Islands to the NWHI than vice versa as well as a great deal of self-recruitment. Insight into reef fish connectivity may be used to address trade-offs between environmental impact and human use in the Hawaiian Islands.

Network and conceptual modeling

The importance of social networks to information sharing in the Hawaii-based longline fishery was highlighted by Barnes-Mauthe et al. (2013) and Barnes et al. (2016). Using the example of reducing shark bycatch, they showed how synergies can be harnessed to improve information dissemination. Additionally, the West Hawaii IEA has completed conceptual modeling to identify locally relevant ecosystem drivers and pressures and their respective impact to ecosystem state and the delivery of ecosystem services. The results from this modeling lay the groundwork for identifying trade-offs between management strategies as well as between natural-social relationships (Harvey et al. 2016).

Models in early development

Two modeling efforts for evaluating trade-offs are in the early stages of development. The first is an Atlantis model for the main Hawaiian Islands. This model will focus on questions surrounding monk seals and coral reef ecosystems. The second is an integrated size- and species-based model for the ecosystem supporting Hawaii's pelagic longline fishery. This model will provide abundance at size for a number of species and allow for evaluation of species-specific trade-offs involving fishing effort and climate impacts.

Communicating trade-offs

PIFSC is actively working to improve the communications of our research results. In addition to maintaining our use of traditional communication avenues (e.g., scientific journals, technical memoranda, Council interaction), we are also pioneering several new efforts. A number of staff recently participated in communications training through COMPASS (Communication Partnership for Science and the Sea, www.compassonline.org). This training brought scientists together with print and radio journalists for a two-day workshop. PIFSC also holds a weekly Newsroom gathering for 30 minutes each Wednesday morning. Staff brainstorm on communication ideas (topics, outlets, key messages) for a different topic each week. Finally, staff are increasingly holding targeted practice sessions to prepare communications with specific audiences, such as Council meetings or media interviews.

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Southeast Fisheries Science Center Ecosystem Modeling Efforts

The NMFS Southeast Fisheries Science Center (SEFSC) covers three regions – the US Gulf of Mexico (GoM), the Southeastern US Atlantic (hereafter South Atlantic), and the US Caribbean. The SEFSC has personnel based at multiple laboratories ranging from NC to TX (Beaufort, NC; Miami, FL; Panama City, FL; Stennis & Pascagoula, MS; Lafayette, LA; and Galveston, TX). The SEFSC coordinates with three Fishery Management Councils (Gulf, South Atlantic, and Caribbean), two Marine Fisheries Commissions (Atlantic States and Gulf States), and highly migratory species and international management entities.

The SEFSC pursues major programs in the areas of stock assessment, programs to support stock assessments (including fishery-independent and -dependent surveys), socioeconomics / human dimensions, protected species research and monitoring, and applied fisheries and habitat research. The SEFSC has staff assigned to support each of these activities. The SEFSC does not have a coordinated organizational structure for ecosystem science.

Major SEFSC ecosystem activities include an Ecosystem Status Report (ESR; see http://www.aoml.noaa.gov/ocd/ocdweb/ESR_GOMIEA/) and Integrated Ecosystem Assessment (IEA; see https://www.integratedecosystemassessment.noaa.gov/regions/gulf-of-mexico/index.html) for the GoM. The GoM ESR was completed in 2013 and updated in 2017. Initial steps in pursuit of a South Atlantic ESR are also underway.

Aside from the activities listed above, SEFSC ecosystem activities are predominantly project-based and grant-funded. Recent or ongoing modeling efforts that include ecosystem components, and in which SEFSC personnel are project leads or participants, include:

- Single-species individual-based models (IBMs) or bioenergetics models including environmental effects
    - Leo, Minello et al. GoM brown shrimp production dynamics
    - Adamack et al. (including Rozas and Minello): use of a Bayesian bioenergetics modeling approach to predict the effects of freshwater diversions on juvenile brown shrimp growth and production
    - Rose et al. nutrient / hypoxia / MS River diversion effects on shrimp, menhaden and red snapper
- Multi-species IBMs including species interactions and environmental effects
    - Gruss et al. GOM OSMOSE : An OSMOSE model was built for the West Florida Shelf and focused specifically on economically important fisheries in the snapper-grouper complex. Several manuscripts were published, including a management strategy evaluation simulation to understand whether current

management practices are robust to episodic natural mortality events (e.g., such as those produced by red tides).

- Multi-species production modeling (K. Craig and K. Shertzer)
- Food-web / trophic mass-balance models
    - Ainsworth et al. GoM Atlantis: An “end-to-end” (bacteria to apex predators) Atlantis model was built for the GoM which includes age structure, larval transport, space limitation, habitat, nutrient and waste cycling, and detailed fisheries accounting. Several methodological papers have been published which detail the diet studies, biomass distributions, and larval transport models that served as inputs. The model has been applied to consider effects of stressors such as Mississippi river hypoxia and the Deep Water Horizon oil spill, and to test harvest control rules in the GoM.
    - Sagarese et al. northern GoM: a mass-balanced Ecopath model (“nGoM Ecopath”) which integrated ecosystem stressors, indirect effects of fishing (e.g. bycatch), and predator-prey dynamics. Mixed trophic impact analysis revealed species including snappers, groupers, pelagic coastal piscivores, oceanic piscivores, cephalopods, and dolphins as critical top-down predators. Bottom-up effects were identified for juvenile groupers and mackerels, which benefited from high production of invertebrates and small fishes. Network analysis revealed detrimental effects of red tides on sharks, skates and rays, and demersal coastal invertebrate feeders such as black drum, as well as adult red and gag grouper. Pelagic coastal piscivores and mobile epifauna imposed the largest influence on ecosystem structure as keystone predators. The nGoM Ecopath model using the dynamic module Ecosim can help guide restoration efforts through the evaluation of multispecies responses to management actions and identification of ecosystem trade-offs.
    - De Mutsert et al. wGOM (LA shelf) Ecospace
    - ASMFC menhaden work: SEFSC scientists are involved in Atlantic menhaden work being completed and led by the Atlantic States Marine Fisheries Commission (ASMFC). Specifically, Atlantic menhaden have a broad spatial range and overlap with various predators and environments, which has led to managers become interested in ecosystem reference points. Historically, ecosystem functions were addressed through the use of a Multi-species Virtual Population Analysis, which produced a time and age varying natural mortality rate that was then used in the stock assessment. Currently, ASMFC is working toward ecosystem reference points for management use whereby stakeholders have defined goals and objectives. Several model types are currently being considered including a single species model, multi-species surplus production

models, and multi-species statistical catch at age models. Several multi-species models, along with the single species assessment, are planned to go to review in 2019.

Northwest Fisheries Science Center Ecosystem Modeling Efforts

Trade-offs between natural, social, and economic systems, via qualitative network models
Qualitative network models may offer insight into the complex trade-offs related to social and natural systems. Qualitative network models (such as Melbourne-Thomas et al. (2012)) and related approaches are now being applied by multiple Science Centers. These methods are useful for data-poor systems, and are derived from loop analysis methodology, where "links" in a food web are representated qualitatively (i.e., signs of −, 0, +). Monte Carlo approaches can address uncertainty in the strength of these links, and can be used to test simple management scenarios. At the NWFSC, Harvey et al. (2016) built qualitative network models for the California Current based on conceptual diagrams developed with the IEA program. NWFSC staff have contributed to similar approaches in Willapa Bay and Puget Sound (Reum et al. 2015).

Trade-offs regarding competition between recovering predators and protected prey
Recovery of marine mammals, especially pinnipeds, has been a success stemming from the Marine Mammal Protection Act (and in some cases also from the Endangered Species Act). However, this also has led to trade-offs among marine mammals (e.g. sea lions and seals versus killer whales), and between marine mammals and recovery of fish stocks. For the Puget Sound/Salish Sea region in Washington State and southern British Columbia, Chasco and colleagues from NWFSC (2017) modeled predation of Chinook salmon *(Oncorhynchus tshawytscha*) by killer whales (*Orcinus orca*), and recovering populations of California sea lions (*Zalophus californianus*), Steller sea lions (*Eumetopias jubatus*), and harbor seals (*Phoca vitulina*). Chasco and colleagues applied a suite of marine mammal bioenergetics models to estimate a ~10 fold increase in total biomass of Chinook salmon consumed by pinnipeds from 1970-2015. Converting from juvenile salmon (which are often consumed by harbor seals) to 'adult equivalents', by 2015 pinnipeds consumed an amount of Chinook salmon equivalent to that consumed by killer whales, and 2x greater than fisheries catches. These trade-offs are not unique to the Pacific Northwest; for instance similar trade-offs between mammals and fish stocks have been identified in the NE US (Smith et al. 2015).

Trade-offs: harvest of forage fish versus predator populations
NWFSC scientists have participated in several recent studies that identify trade-offs between abundance of forage fish and their predators. For forage fish on the West Coast (including Pacific sardine *Sardinops sagax* and Northern anchovy *Engraulis mordax*), abundance of these forage fish is influenced by fishing but is also strongly driven by recruitment of juveniles, likely influenced by oceanographic conditions. In a case study that was included in the Ocean Modeling Forum (http://oceanmodelingforum.org/), NWFSC scientists and colleagues explored effects of sardine and anchovy depletion on predators using a multi-model framework (as

suggested by previous NEMoW participants, (Townsend et al. 2014). The modeling approaches included an Atlantis model (Kaplan et al. 2017), MICE (Punt et al. 2016), and Ecopath (Koehn et al. 2016). The multi-model approach identified results that were robust across models (e.g. brown pelicans as vulnerable to forage fish depletion) and reasons for divergence between models (e.g. taxonomic resolution, age structure, and density dependence influencing model predictions).

Trade-offs: energy development versus fisheries

Trade-offs between energy development and other marine uses (including fisheries) were a common theme among regions; on the West Coast this may in the future involve development of wave energy. Plummer and Feist (2016) applied a wave energy model (Kim et al. 2012) to identify the economic value of potential wave energy sites; this was dictated both by wave energy and by proximity to the electrical grid. One novel aspect of the approach of Plummer and Feist (2016) was to estimate overlap between wave energy sites and other marine uses. These included fishing but also shipping lanes and designated marine conservation areas. This analysis identifies the trade-offs between multiple marine uses that are inherent in marine planning, including for the energy sector which rarely been the focus of NEMoW discussions.

Trade-off: business-as-usual global change versus fisheries

Increasing CO_2 concentrations and subsequent global warming and ocean acidification pose threats to fisheries production that are now being addressed by NWFSC scientists. Marshall et al. (2017) studied impacts of ocean acidification projections for the 2060s on California Current living marine resources and fisheries. The analysis linked global models from NOAA OAR GFDL (ESM2M) to a Regional Ocean Modeling System (ROMS), and then to an Atlantis ecosystem model. Ocean acidification (pH) from ROMS was directly used to drive survival of calcifying species and other groups, following a recent meta-analysis by Busch and McElhany (2016). The projections also identified predators, such as some groundfish and sharks, that were vulnerable due to loss of prey caused by ocean acidification. Highly vulnerable fisheries included state-managed invertebrate fisheries, as well as federally managed groundfish fleets. The work echoes recent results regarding potential impacts of ocean acidification for the Northeast US (Fay et al. 2017).

Haltuch et al. (in prep) and Tolimieri et al. (in review) provide insights into how future ocean conditions may affect sablefish (*Anoplopoma fimbria*) fisheries. Tolimieri et al. (in review) have worked with the Pacific Fishery Management Council to re-evaluate ecosystem drivers of sablefish recruitment, improving the skill of previous statistical predictors of recruitment (Schirripa and Colbert 2006). Ongoing work includes using global climate models to predict future ocean conditions and subsequent changes in recruitment and the effectiveness of management strategies.

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Management Strategy Evaluation Workgroup Efforts

As Management Strategy Evaluation is one of the major approaches used within NMFS for evaluating EBFM and EBM strategies, scientists from all FSCs are working together in a national MSE Workgroup. Dr. Sarah Gaichas from the NEFSC gave a brief update on the MSE efforts of the workgroup.

The NMFS Vision for MSEs is:

> "A national MSE capability with complementary expertise at each Center to advance the science and utilization of Management Strategy Evaluations to inform management decisions across NMFS that can be applied to fisheries management, protected resources, habitat, ecosystem and economic issues."

To move forward with this vision, each FSC has been supported to hire staff charged with steering the FSCs' MSE efforts. Most FSCs have either filled the position or are in the process of doing so.

The workgroup has representatives from each center. They have completed an inventory of MSE projects completed or underway at each of the centers.

As a reminder, Gaichas emphasized that the key elements of MSE (from Smith 1994) are:

i. **M**ultiple objectives are addressed
ii. **U**ncertainty is characterized
iii. **S**takeholders are involved
iv. **Trade-off**s are evaluated

A few examples of MSE efforts in progress with the Councils were highlighted. Those include:

1) Global change and U.S. west coast sablefish recruitment - using sea level indices from Global Climate Models to explain variability in sablefish recruitment.
2) New England Atlantic Herring MSE— developing herring ABC control rules that consider herring's role as forage within the ecosystem
3) Alaska Climate Integrated Modeling Project - integrating multiple models for multimodel inference on harvest and climate, linked to socioecological objectives end points.

A-3: Summary of Visualization and Communication Tools Session Presentations

Overview of Tools Session

The Tools Session was scheduled for 1:30 - 5:30 on Tuesday, February 28. For this session, Tool Experts were asked to give a 10-15 minute presentation on their tool- the focus being on how the tool is used to visualize trade-offs. After that, 2 rounds of breakout sessions were held for the hands-on session. This gave an opportunity for the participants to use the tool. The leads provided some example data that participants used for tinkering with the tool. Alternatively, the leads worked with participants to load the participants' own data/model output into the tool and use that for exploring the tool. There were two 1-hour sessions for hands on work. This allowed participants to have an opportunity to explore multiple tools.

The Tool Experts were asked to cover the following in their presentations:
- Background on why and how the tool was developed,
- Give some specific examples of the types of trade-offs the tool can be used for, and
- Briefly show output and features of the tool - including types of input data the tool uses and outputs of the tool

During the hands-on session, Tool Experts worked with participants to install tools, load example data sets (or data sets that participants bring), and helped participants explore and navigate features of their tools.

The following tools were used for this session:

- Virtual Ecosystem Scenario Viewer - Isaac Kaplan
- Multi-species Viewer - Andy Beet
- D3 Foodweb - Kelly Kearney
- Species Distributions/VAST - Jin Gao
- Conceptual Modeling - Chris Kelble

Summaries of the tools

VES-V - Isaac Kaplan

Virtual Ecosystem Scenario Viewer (VES-V) – Software for Visualizing the Results of Ecosystem Modelling Outputs

Download from VES-V website https://www.st.nmfs.noaa.gov/ecosystems/EBFM/ecosystem-modeling

VES-V visually illustrates the responses of virtual marine ecosystems to a range of living marine resource management scenarios. Visualizations can help many audiences see the potential for widespread application of models in our work managing marine resources. This tool will facilitate stakeholder engagement and input for exploring future trade-off scenarios in marine resources management decisions for our nation's large marine ecosystems.

The main purpose of this tool is to demonstrate how we can better present and visualize marine ecosystems, their marine resources, and their collective responses to a range of disruptions. VES-V can be directly linked to and utilize output files from ecosystem models such as Atlantis, MS-PROD, or EwE to explore different marine management scenarios. VES-V is designed to handle a wide range of model outputs and data, such that survey time series or even multiple stock assessment outputs could also be used to populate this virtual ocean world.

Versions available for PC, Mac, Linux, Microsoft Surface , and (iPhone) IOS. Demo visualizations for the Northeast US, Gulf of Mexico, and California Current are pre-loaded.

Users can add additional time series from any ecosystem model, stock assessments, or monitoring data (e.g. relative abundance trends from trawl surveys or visual surveys). Users can add time series in a simple CSV format with values representing relative annual abundance of each species. Documentation is provided in \NOAA_VES-V_Docs, "Quick Start Guide" and "Using Your Own Scenarios".

Multi-species Viewer - Andy Beet

Kraken Visualization Software

With an eye towards using an ecosystem based approach to fisheries management, the Kraken Visualization tool demonstrates the effects (or trade-offs) of altering fishing pressure on groups of species and how this in turn propagates through the system. The Kraken Visualization tool was designed primarily to engage stakeholders and help aid in understanding the trade-offs of increasing or reducing fishing effort in an interconnected multispecies ecosystem.

The underlying multispecies model is of a Lotka-Volterra type and has been named in house as Kraken. It consists of species growth, species interaction (predation and competition) and species catch. It should be noted that the underlying data used to demonstrate this tool, up to this point, are artificial and should not be considered a representation of the real world. The demo version illustrates a system of ten species split into four functional groups all interacting with each other in varying degrees.

This tool was developed by Robert Gamble and others and is currently maintained by Rob. It is coded in C++ and requires a data rich input file. There isn’t any official documentation or user guide. The only available version is for windows and there have been some issues running this tool on 64 bit machines. Software will be available during the hands on session

EwE Food Web Graphics - Kelly Kearney

d3-foodweb

Food web diagram layout algorithm. The "tool" side of it is still a work in progress, and I'm hoping to get some feedback from others about how they might want to use it (including adding things like Ecosim-ish food web perturbation visualizations).

It's a D3 (https://d3js.org/) plugin designed to create both static (for print) and interactive (for web) food web diagrams for complex, Ecopath-style food webs. Its development was motivated by my desire to turn the typical illegible, spaghetti-knot/birds'-nest/ink-blob food web diagram into something slightly more legible and information-dense.

Code is on GitHub.
 Main tool: https://github.com/kakearney/d3-foodweb
 Supporting foodwebgraph Matlab toolbox: https://github.com/kakearney/foodwebgraph-pkg
 ecopath_matlab toolbox: https://github.com/kakearney/ecopath_matlab-pkg

Types of data and software needed
I've set up some online tools to demonstrate the main capabilities (link forthcoming at the workshop). To play with these and the example food webs I'll provide, users just need an internet connection and a web browser. Any browser, any OS.

To do more hands-on experimentation with their own data, users will need a bit more:

- data: an Ecopath model. Can accept data from any flavor of Ecopath... Ecopath with Ecosim (.EwEmdb), Rpath (.csv files), EwE-F (text files), or ecopath_matlab (ecopathmodel object).

- Matlab R2015b or later, for preprocessing calculations and file setup.

- If starting with an EwE6 database file, will need a way to import the .mdb file to Matlab. See note for below details.

- For offline use of the web tool, it's helpful to have either a web browser that allows cross-origin requests (e.g Firefox), or even better, the ability to run a local web server (e.g. python offers a very simple command for this).

To import .mdb files to Matlab:
 * Linux: mdbtools

The mdbtools source code can be acquired from GitHub: https://github.com/brianb/mdbtools. Instructions to compile from source are included in the download.

* MacOS: mdbtools

Ports of mdbtools are available through either Homebrew or MacPorts. Install either Homebrew or MacPorts if you don't already have them on your system, then run:

brew install mdbtools   <-- from Terminal, Homebrew

port install mdbtools   <-- from Terminal, MacPorts

* Windows: pyodbc python module plus ODBC driver

On Windows, first check your computer to make sure you have the MS Access driver installed (the driver list is buried in the Control Panel... search ODBC Data Sources as a quick way to find it). You need the 'Microsoft Access Driver (*.mdb)'. Next, you need python 3.x. There are many options for downloading and installing python if you don't already have it; I personally like the Anaconda Python distribution (https://www.continuum.io/downloads) for scientific use. Finally, download and install the pyodbc module; easy installation can be done via pip:

pip install pyodbc   <-- from Command Prompt

or via conda, if you use Anaconda Python

conda install pyodbc <-- from Command Prompt

My mdbexport.py script also requires the csv and os modules; these are installed automatically with most common python distributions.

Species Distributions/VAST - Jin Gao

VAST (from https://github.com/James-Thorson/VAST)

- Is an R package for implementing a spatial delta-generalized linear mixed model (delta-GLMM) for multiple categories (species, size, or age classes) when standardizing survey or fishery-dependent data.
- Builds upon a previous R package SpatialDeltaGLMM (publicly available here), and has unit-testing to automatically confirm that VAST and SpatialDeltaGLMM give identical results (to the 3rd decimal place for parameter estimates) for several varied real-world case-study examples
- Has built in diagnostic functions and model-comparison tools
- Is intended to improve analysis speed, replicability, peer-review, and interpretation of index standardization methods

Background

- This tool is designed to estimate spatial variation in density using spatially referenced data, with the goal of habitat associations (correlations among species and with habitat) and estimating total abundance for a target species in one or more years.
- The model builds upon spatio-temporal delta-generalized linear mixed modelling techniques (Thorson Shelton Ward Skaug 2015 ICESJMS), which separately models the proportion of tows that catch at least one individual ("encounter probability") and catch rates for tows with at least one individual ("positive catch rates").
- Submodels for encounter probability and positive catch rates by default incorporate variation in density among years (as a fixed effect), and can incorporate variation among sampling vessels (as a random effect, Thorson and Ward 2014) which may be correlated among categories (Thorson Fonner Haltuch Ono Winker In press).
- Spatial and spatiotemporal variation are approximated as Gaussian Markov random fields (Thorson Skaug Kristensen Shelton Ward Harms Banante 2014 Ecology), which imply that correlations in spatial variation decay as a function of distance.

Requirement

You will need to install TMB prior to arrival, and confirm that it is working.

· I recommend following the directions at https://github.com/nwfsc-assess/geostatistical_delta-GLMM/wiki/Steps-to-install-TMB

· If you do not get “313.4137” at the end of the testing script at that page, please email jin.gao@noaa.gov.

· Please install VAST following instructions from https://github.com/James-Thorson/VAST. Examples of data requirement and output can be found at https://github.com/James-Thorson/VAST/tree/master/examples.

Conceptual Modeling - Chris Kelble

Mental Modeler

Mental Modeler is a decision-support software intended to help individuals and communities understand the impacts associated with environmental change and develop mitigation strategies to reduce unwanted outcomes by capturing, communicating and representing knowledge. Through a multi-step process based in Fuzzy-logic Cognitive Mapping (FCM), Mental Modeler allows groups of stakeholders to come together and easily develop semi-quantitative models of environmental issues which: (1) define the important components relevant to a community, (2) define the strength of relationships between these components and (3) run "what if" scenarios on these models to determine how the system might react under a range of possible conditions. Through iterative modeling, Mental Modeler was developed to help stakeholders' pool and represent collective knowledge and test ideas about their assumptions in "real time" workshop sessions.

It is accessible via mentalmodeler.org   Anyone can sign-up to get a test account.

A-4: Summaries of Management Panel Presentations

Overview of Management Panel

The Management Panel was scheduled for 11 AM - 3:30 on Wednesday, March 1. For this session we asked panel members to present briefly (10-15 minutes) on the types of management trade-offs they have to deal with on a regular basis. For example, will a proposed habitat action have the potential to be beneficial for one fish stock or protected resource population while also having potential negative effects on another stock or population? Will a new protected area be beneficial for fishers who folks on one stock/stock complex but excludes another group from their favorite fishing grounds?

In the Management Panel presentations, presenters were asked to cover the following points:
- Who they are and what they do - help give participants a sense of what they do on a regular basis, what policies and mandates they deal with,
- Give some specific examples of the types of trade-offs they have to consider in their work,
- Discuss their experience using models/model outputs (especially multi-species/ecosystem models) for helping to make decisions about pertinent trade-offs. Or if they haven't had much experience (because no models are available), what types of models and tools might help them with their work?

Dawn Davis (Habitat)

Management implications in using ecosystem models for evaluating trade-offs: a case study with diversions

Ecosystem models are being used to evaluate the effects of large-scale Mississippi River diversions on the fishery resources in Barataria Bay and Breton Sound, LA. LA is experiencing a coastal crisis where large areas of the coast have been lost. Some of the land loss is caused by the construction of levees preventing the flow of nutrients and sediment from the river into the adjacent marsh. Sediment diversions are one restoration strategy proposed to reduce the land loss rate by reconnecting the river to the basin. The State of LA has operated small scale freshwater diversions but not sediment diversions at such a large scale. Before constructing such a project, research and modeling was needed to inform on the effects to the ecosystem. NMFS had requested ecosystem modeling to inform on the effects and trade-offs with Essential Fish Habitat.

There are 2 paths for evaluating diversions: Mississippi River Hydrodynamic and Delta Management Study (MS Hydro) and the LA Coastal Master Plan. The Master Plan through the

State of LA is a suite of coastal restoration and protection projects, including diversions, evaluated for the whole coast. A computer-based decision support software system using optimization was used to identify alternatives with the criteria of building the most land and reducing the most flood risk. The ecosystem model used for Master Plan: Ecopath with Ecosim and Ecospace model (EwE) is a food web model that accounts for effects of environmental changes, fishing, and predator-prey interactions. Nineteen habitat suitability indices (HSIs) provide estimates of a variety of aquatic and terrestrial species habitat.

MS Hydro is a federal feasibility study with USACE and State of LA. This study evaluated a combination of 4 large-scale sediment diversions by connecting hydrodynamic models to ecological and fisheries ecosystem models. A similar EwE model was used as with the Master Plan and a second ecosystem model, Comprehensive Aquatic Systems Model (CASM), was chosen for evaluating bioenergetics-based growth in an aquatic food web.

The trade-off is to find a restoration strategy that minimizes adverse impacts to living resources but also maximizes land building and wetland health. Results from the MS Hydro study show the average salinity from April-June in the Barataria and Breton Basins for no diversion and the Mid-Barataria diversion scenario. The entire Barataria Bay turns completely fresh for the duration of diversion operations. Here we start having to think about trade-offs. The Diversion is building land but what is it doing to fisheries biomass? Not only do we need to consider the low salinity effect on fish and shellfish species but the effects these low salinities have on dolphins. Dolphins are protected under the MMPA. Dolphins exposed to freshwater can become sick or may be displaced, and any of these actions would be considered a 'take'. Takes are prohibited (with certain exceptions) under the MMPA. Based on these results, the State of LA and USACE had to reassess the operation plans.

The State of LA proposes to make changes to the operation plans, in direct response to the MMPA concerns. Given the complexity of modeling fishery ecosystems and the remaining uncertainties, the NMFS believes the current versions of the EwE and CASM models need more work before they are reliable predictors of fish and shellfish responses to diversion operations. However, we do believe the general trends reported in the modeling results can be informative when used along with expert opinion to help interpret the potential effects of diversions on fisheries biomass. Howard Townsend recommended for evaluating fishery biomass responses from the ecosystem models by focusing on species with high goodness of fit statistics and similar (significant) relative change in biomass between the two models. These species represent the most reliable of species' responses to evaluate.

The trade-offs that NMFS has considered so far are spatial, temporal, reversibility, and species. At the spatial scale, NMFS decided to look at biomass responses on a basin level scale. Short (5 years) and long term (50 years) temporal scales should be evaluated. Reversibility expresses the likelihood that the ecosystem, when the diversion is running, will return to its original state if the diversion ceases. This can pertain to diversion operations. Dolphins can be adversely affected by long term diversion operations; perhaps, changing the operation regime can reduce the salinity effect on them. State of LA wants to optimize diversion operations by maximizing sediment to water ratio efficiency. Operation regimes can be used under adaptive management. NMFS decided to focus on evaluating biomass responses for a few key species that are most affected by salinity changes.

NMFS is still in the early stages of deciding on trade-offs when dealing with diversions. NMFS will need to make some hard decisions on trade-offs in terms of species importance and the amount of uncertainty that is acceptable in the models. A continued dual ecosystem model approach is recommended along with additional model improvements in development and further data collection. NMFS has provided a list of recommendations on how to improve the EwE and CASM models. The results from the ecosystem models will inform the alternatives and trade-offs on EFH for NEPA documents and adaptive management.

Mike Jepson (Sustainable Fisheries)

Recent work on incorporating human dimensions into the Gulf IEA has been encouraging and hopefully will continue to further a more complete Integrated Ecosystem Assessment. Through this process, it quickly becomes apparent that many trade-offs are intrinsic within the model. With my focus on fisheries, we see trade-offs between sectors, within sectors, between fishing communities and many more. Although there are many trade-offs, by incorporating human dimensions it becomes more a transparent process and can better inform the management process.

a. Social scientists are pretty qualitative
b. In Council process, social impact assessment is different from ecological or fisheries impact analyses
c. A lot of social science data is at an individual or household scale, but the needs of Councils are often at different scales (e.g., finer temporal scale but broader spatial scale). Social scientists are trying to revisit their approaches to better fit Council needs, IEA needs, etc.

d. Incorporating human dimensions into ecosystem models remains a challenge, in part because models are not readily for this, and in part because the social scientists themselves aren't always trained in modeling or quantitative methods

Bill Arnold (Sustainable Fisheries)

The coral reef ecosystem is the foundation of fisheries in the U.S. Caribbean region, which includes Puerto Rico and the U.S. Virgin Islands. That complex ecosystem is an ideal candidate for ecosystem-based management, which has as a primary requirement the ability to model ecosystem structure and function. To date, data necessary to populate any form of ecosystem model is not available. Despite this process limitation, some ecosystem-based fishery management (EBFM) is being applied in the region. The best example of EBFM in the region is the management of parrotfish and other grazers to ensure adequate availability of suitable settlement substrate for Acroporid corals. Within the context of available information and guidance regarding the definition and distribution of critical settlement substrate, harvest of surgeonfish and parrotfish has been substantially reduced from historic levels. Additionally, harvest of the three largest parrotfish species (midnight, blue, and rainbow) is now prohibited. Moreover, the Caribbean Fishery Management Council (Council), the entity responsible for managing fisheries in federal waters of the U.S. Caribbean, remains responsive to additional information that would guide further adjustments to grazer harvest rates. But effective management of fisheries or the resources upon which they depend requires a more complex approach than simply closing the fishery. Instead, management decisions must be science-based to the greatest degree possible. Thus, the Council requires data upon which to rationalize their decisions.

U.S. Caribbean fisheries appear to be on a downward trajectory during the last 40+ years. Attributing that trajectory to overfishing is a simple but naïve and incomplete explanation. Many factors have contributed to the decline in U.S. Caribbean fisheries, not the least of which is the decline of corals and the associated ecosystem upon which the fishery resources depend. Bleaching, acidification, and the drastic reduction in abundance of Acroporid corals have combined to reduce stony coral coverage. Nearshore and onshore development activities have reduced the abundance of mangroves and seagrasses, essential nursery habitats for coral reef and associated fishery species. Nutrification has increased the scope of growth for algal species that compete with corals for the hard substrate that serves as essential settlement substrate for Acroporid and other corals. These losses have reduced the ecosystem's carrying capacity for harvested fish and invertebrates. As a result, although harvest has contributed to reductions in abundance, the fisher should not be held solely responsible for the depleted state of these resources. Nor should they, with or without management constraints, be expected to pay the full price for rebuilding these resources. That is a common and simple approach, but it's counterproductive because it alienates a user group with perhaps the greatest interest in protecting the resource.

Due at least in part to the continuing attribution of resource depletion to "overfishing", local governments in the U.S. Caribbean and throughout the Caribbean basin have become resistant to cooperative management. Government representatives participate in the process and may be fully engaged, but they continue to maintain regulations in local waters that are not compatible with federal regulations applicable in exclusive economic zone waters. This discontinuity between state and federal management reduces the practical enforcement of such regulations. The areal extent of federally managed waters in the U.S. Caribbean is vast, especially relative to the availability of enforcement agents. Thus, on-the-water enforcement required to ensure adherence to federal regulations in the federal fishing zone is difficult at best. Shoreside enforcement is more viable, but not if regulations differ and the source of harvest cannot be ascertained. As the Council moves from species-based to island-based fisheries management, state governments will of necessity assume a more prominent role in regional management. The Council recognizes this increased need for cooperative management, and is convening a state/federal workshop to address these issues and identify possible solutions.

Cynthia Meyer (Sustainable Fisheries)

Councils want to do ecosystem modeling but don't have a clear pathway for ecosystem modeling; hard for Councils to reach out, communicate, and get estimates on a timeline for when things will be ready. *Models should include timelines!!!*

- Model inputs are going to be necessary as part of NEPA process, but it's largely lip service in terms of how model inputs get used
- Coordination required between scientists and managers because lawsuits are likely to result from these types of decisions
- NEPA documents are segue to broader fisheries management at Council level; uptake of ecosystem models into EBFM
- There does need to be an explicit adaptive management loop, not just something that you talk about but an actual identified adaptive mgmt. loop for iterative application and improvement of models

In general, the Councils have been supportive of integrating ecosystem based approaches and modeling; however, there are logistical challenges to applying the models to the management actions. Some challenges include:

- knowing what models are available
- getting in contact with the modelers and requesting information
- coordinating the timelines for the modeling efforts and the development of the management actions for the Fishery Management Plans.

Better coordination between the modelers at the science FSCs and the plan coordinators at the regional offices (possibly including the Council staff) would aid in the application of the available models and requests for future modeling efforts.

Ecosystem level analysis is necessary in the FMP development as a requirement in the Cumulative Effects Analysis for the NEPA. Often, this analysis remains qualitative and very high level for potential impacts of climate change and ecosystem connectivity.

David Bernhart (Protected Resources)

At SERO, Protected Resources (PR) issues largely center on cetaceans (right whales, sperm whales, dolphins). However, there are some ESA species like sea turtles, corals, Johnson seagrass, sturgeons, and elasmobranchs. Trade-offs are largely encountered under ESA section 7 consultation process. A few particular issues of current concern are Right whales, Johnson's seagrass, and sturgeon.

Most known right whale nursery areas are in shallow, coastal water of the US Atlantic Coast. Right whales issues are based on risk trade-offs (though not necessarily informed by data) in right whale management and Army Corps activities in nursery habitats. Currently, we are "managing around a status quo" rather than on a more informed basis. Ecosystem modeling approaches may help to inform management issues.

Johnson's seagrass is the first and only marine plant to be listed under the ESA. Johnson's seagrass was listed as threatened due to its limited geographic range and habitat loss. It is endemic to SE Florida coast. It reproduces vegetatively, and it is opportunistic and tolerant of many conditions. It seems to tolerate disturbances, yet is still a fringe species. Many conflicts arise in the coastal zone. Hyperstability of the status quo may not be the best thing for this species. Little modeling work has been done to evaluate trade-offs associated with this seagrass and coastal zone activities.

Gulf sturgeon has designated critical habitat along the northern Gulf of Mexico. Many restoration efforts are underway all along this region, but that restoration is geared toward many uses—not just sturgeon (sand/mud habitat) but also habitat for, say, oyster reefs. There are science gaps for estimating trade-offs here. To better evaluate habitat-related trade-offs, there is a need to know how sturgeon use different habitats—mangroves (refuge?), shoals (feeding?), etc., and what the relative values of those habitats are.

Shortnose sturgeon are typically large, long-lived fish that inhabit a great diversity of riverine habitat, from the fast-moving freshwater riverine environment downstream to the offshore marine environment of the continental shelf. They are benthic feeders and do not appear to make long distance offshore migrations. In the Southeast, the Savannah River Port has been deepened over time to accommodate larger cargo ships. This has moved shortnose sturgeon foraging habitat further and further up river. So SERO and its partners must also manage for spawning habitat. The Army Corps has requested trade-off of spawning habitat over foraging habitat, with the assumption that spawning habitat is more critical than the foraging habitat, and that sturgeon are more resilient to loss of foraging habitat than spawning. Again, these decisions are not being informed by modeling.

Additional Management Panel Discussion

Apart from the main conversation on management implications of trade-offs summarized in the body of this report, several brief, important conversations about management and ecosystem modeling arose. Though these were not topics central to the workshop theme, they were significant ideas. The kernels of these ideas are captured here so that they might be used as fodder for future discussions and workshops.

Question to panel: Forget about funding, timing, etc., if you could have a one model to answer one issue what would it be?

> Caribbean Islands: Parrotfish; how one group of species interacts with another group of species, to facilitate habitat development.
>
> SEFSC: Freshwater diversions (e.g., Mississippi delta) to rebuild marshes and habitat. With respect to diversions and EFH, dolphins may be the species to focus study/modelling on.

Follow-up question to panel: No managers mentioned ACLs vs. PBR? Why is that?

> ACLs, not used because considered a little too big to wrap heads around. How ACLs are interacting with each other (31 species + PR).

ACLs may be a symptom of the system and the problem as opposed to being part of a solution to the problem. If we can manage the system so that we can improve habitat and overall system productivity, the ACLs may be increased as a result. Reducing ACLs as a tool might provide a meaningful result, but there could also be compliance issues with respect to accurate catch reporting, potentially nullifying the management action. The ACLs may be a legal mandate but they might not be an effective driving force (or tool) for managing the system.

Question to panel: With respect to spatial models of expected species distributions do you see uses for that in identifying or predicting hotspots and does that fit your needs?

Managing bycatch. Lots of recent changes (recent years) in observed species distributions; in the face of ongoing change; are existing spatial modeling tools able to keep up and/or reliably predict species distributions.

Question to Panel: How do you on a daily basis deal with mandates/forms to assess a project (short-term focus). Is there a mechanisms to deal with short-term vs. long-term trade-offs?

These decisions have not been made, but we can pull into the discussion. ESA constraining? (seems flexible)

Must use best available scientific information….but we must come to a conclusion even with best available science is pretty awful. Major source of tension between RO and Science Center. We like models because it looks more like best available science. It is imperative to decide, makes us make decisions. We could approve a short-term negative consequence for a long-term positive consequence that is "reasonably certain to occur". But you can't trade injury now for a promise in the future, unless you know that you will get result.

Follow-up question to panel: How much capacity/willingness is there for fishing fleets to endure short-term hardships to help secure long-term gains?

This is a part of rebuilding plans. Landings reductions are typically a part of rebuilding plans. In the Gulf of Mexico this also has to be balanced against recreational fishing needs.

Question to panel: Can mgmt. respond to anticipated climate change impacts?

If it's an important part of the problem (future outlook) they have to take that into account.

Question to panel: Are there management implications or trade-offs that have been neglected by ecosystem modelling or that you would like to see a model used for?

Ecosystem Models could have big cumulative impacts support to NEPAs. Communication opportunities with manager and modeler to ensure the cumulative impacts are accounted for. This could segue to applying ecosystem modeling to wider fishery management. This will raise awareness for Councils and they may take ecosystem modeling more seriously in the future.

EM could inform spatial shifts in populations driven by climate change. If Council sees priority they may support 1-2 year ecosystem modeling development

One difficulty in applying EMs and trade-off analysis is that many Councils and management bodies are often reacting to crises at hand. Even though EBFM is a reality, it is difficult to draw attention from crises when stakeholders are very vocal.

A-5: Summary of Ecosystem Modeling Toolbox Presentation

NMFS uses a wide variety of analytical and modeling tools to provide the best available scientific information to LMR managers. A spectrum of models can be used for LMR management – from traditional single sector/species models to more complex, end-to-end models such as Atlantis models. Many of the tools are used on an operational basis as a part of a dynamic cycle of management aimed at preserving and protecting ocean resources and ecosystems. They provide scientific advice to decision-makers on the current health and future trends of fish stocks and their fisheries, marine mammals and other protected sources, and ecosystem interactions and structure. These tools also offer the technical basis for setting annual fishery harvest levels (through quotas and catch limits) and other fishery management measures. In addition, they are the technical basis for management strategy evaluation.

More specifically, ecosystem models have seen increased used within NMFS and its partners over the past decade. The primary reason to use EMs is to establish of a transparent connection between single species and ecosystem-based advice in a stock assessment, protected resources assessment, or IEA context. They are being used: 1) as operating models for Management Strategy Evaluation and skill assessment, 2) as one of many models for multiple model inference in an effort to reduce uncertainty attributable to model structure, and 3) as a framework for risk assessment and trade-off evaluation.

To date NMFS has primarily worked to improve the development and applications of ecosystem models and coordinate efforts among FSCs via NEMoWs. The next steps in improving NMFS ecosystem modeling efforts is outlined in the NMFS EBFM Road Map. A major step outline in the Road Map is the "Development of an EBFM analytical toolbox that includes ecosystem modeling tools and best practices; data-poor qualitative and semi-quantitative tools; and related decision support tools." The objective of the Toolbox is to support National-scale technical activities important to maintaining & improving the EBFM analytical enterprise through development, maintenance, availability, standardization, testing, and user support for EBFM analytical tools. In short, the Toolbox should enable modelers to spend more time operating and applying models by reducing time spent on development and maintenance.

NMFS has supported the development of other toolboxes, so staff associated with Ecosystem Modeling Toolbox will look to coordinate with other efforts and to ensure synergies and efficiencies are capitalized on. To facilitate utilization and review of the operational and commonly used models, NMFS has developed web-accessible modeling toolboxes that allow users to download software for creating a wide range of analytical tools and models for different uses. For fisheries science and stock assessments, the NOAA Fisheries Toolbox, NFT, (http://nft.nefsc.noaa.gov/) provides a suite of models that can be used for fisheries stock assessments and fisheries data analysis. NFT provides the modeling software with a standardized GUI format and a calculation engine (using C++ and ADMB). The software is maintained and supported by the Office of Science and Technology. To support the protection, conservation, and recovery of marine mammals and endangered/threatened marine life under their responsibility, NMFS has developed the National Protected Species Toolbox, NPST, (https://www.st.nmfs.noaa.gov/npst).

The current plan for the Ecosystem Modeling Toolbox is to employ a structure that is a hybrid between the NPT and NPST. The NFT is a collection of software programs which can be used in fishery stock assessments. Each program is a stand-alone Windows desktop application and combines a sophisticated graphical interface with an independent calculation engine. The NPST provides access to a variety of modeling and statistical tools. These tools are developed and maintained by individual NMFS FSCs. THE Ecosystem Modeling Toolbox will have at least two separate compartments. One compartment will be similar to the NFT, a collection of software programs with graphical user interfaces hosted at a central site for broadly used tools that have been thoroughly reviewed. The other compartment will be similar to the NPST - collection of links to tools at NMFS FSCs in development and review.

As the NFT and NPST have some similar needs as the Ecosystem Modeling Toolbox, personnel from each toolbox effort will coordinate to increase efficiencies. For example, each toolbox effort likely has some similar operations such as data handling and statistical optimization routines that can be dealt with using common, shared modules. Similar procedures for code review can be developed and shared across efforts.

The expected benefits of the Ecosystem Modeling Toolbox (and benefits of toolbox coordination) include:

1) Standardized code base for modeling tools that will facilitate peer review and uptake by regional management
2) Improved ease of use that will expedite model development and use of multiple models
3) Increased used by partner agency and academics

Appendix B – Agenda

Day 1 - February 28, 2017

8:30-9 - Welcome , Introduction, Layout plans for NEMoW 4. Overview and Welcome (**Andy Strelcheck, Jason Link, and Kenric Osgood**)
9-10:30 – Center presentations and MSE update (ToR 1)
NEFSC
SEFSC
SWFSC
NWFSC
PIFSC
AKFSC
MSE Workgroup
10:30-11:00 - Break
11:00-12:00 - Questions and plenary discussion on ToR 2 (common Trade-offs) based on Center updates.
12:00-1:30 - Lunch
1:30 - 3:30 – Hands on session ToR 3 (Tools for modeling and communicating) – NMFS and Invited Experts present on tools and methods for communicating trade-offs.

Tools to be discussed and explored are listed below. A brief presentation on the tool will be given. Afterwards participant will break into groups and have an opportunity to use the tools with some guidance from the leads listed below. Time is allotted for 2-3 rounds of hands-on sessions, so participants will have an opportunity to explore a few different tools.

- VES-V - Isaac Kaplan
- Multi-species Viewer - Andy Beet
- EwE Graphics - Kelly Kearney
- Species Distributions/VAST - Jin Gao
- Conceptual Modeling - Chris Kelble

3:30-4:00 - Break
4:00-5:30 – Continue Hands-on session
5:30 - Adjourn

Day 2 - March 1, 2017

8:30-9 - Recap Day 1, Layout plans for Day 2
9-10 – Breakout groups address ToR 3.
10-10:30 – Summary and plenary discussion on ToR 3
10:30-11:00 - Break
11:00 -12:00 – Presentations on ToR 4 (Management implications and need)

- Dawn Davis (Habitat),
- Mike Jepson (Sustainable Fisheries),
- Bill Arnold/Cynthia Meyer (Sustainable Fisheries),
- David Bernhart (Protected Resource)

12:00-1:30 - Lunch
1:30-2:30 - Management Panel Discussion Q&A (ToR 4) - Steering Committee highlights examples of ecosystem modeling used to deal with trade-offs in Council setting or with other management bodies
2:30-3:30 – Summary and plenary discussion on ToR 4
3:30-4:00 - Break
4:00-5:00 - Breakout group on best practices for addressing trade-offs (ToR 6)
5:00-5:30 – Plenary discussion on best practices for addressing trade-offs - products/manuscripts
5:30 - Adjourn

Day 3 - March 2, 2017

8:30-9 - Recap Day 2, Layout plans for Day 3
9-10:00 Presentation on plans for National Ecosystem Modeling Toolbox (ToR 5) (Howard Townsend & Ron Klasky)
10:00-11:00 - Questions and breakout discussion on National Ecosystem Modeling Toolbox
11:00 -12:00 - Summary and group discussion on Toolbox
12:00-1:30 - Lunch
1:30-2:15 - Breakout groups meet to summarize and plan tech report and other products.
2:15-3:00 - Reconvene plenary; Breakout groups give status update and submit electronic copies of outlines and notes. Final discussion
3:00 - Adjourn

Appendix C – Participants List

Participant Name	Program Office, Division, and Branch	E-mail
Jason Link	AA	jason.link@noaa.gov
Ronald Klasky	AA/S&T	ronald.klasky@noaa.gov
Andy Whitehouse	AKFSC	andy.whitehouse@noaa.gov
Kelly Kearney	AKFSC	kelly.kearney@noaa.gov
Kerim Aydin	AKFSC	kerim.aydin@noaa.gov
Kirstin Holsman	AKFSC	kirstin.holsman@noaa.gov
Jin Gao	JISAO	jin.gao@noaa.gov
Andrew Beet	NEFSC	andrew.beet@noaa.gov
Charles Perretti	NEFSC	charles.perretti@noaa.gov
Ryan Morse	NEFSC	ryan.morse@noaa.gov
Samuel Chavez	NEFSC	samuel.chavez@noaa.gov
Sarah Gaichas	NEFSC	sarah.gaichas@noaa.gov
Chris Harvey	NWFSC	chris.harvey@noaa.gov
Isaac Kaplan	NWFSC	isaac.kaplan@noaa.gov
Raphael Girardin	NWFSC	raphael.girardin@noaa.gov
Chris Kelble	OAR	chris.kelble@noaa.gov
Justin Hospital	PIFSC	justin.hospital@noaa.gov
Mariska Weijerman	PIFSC	mariska.weijerman@noaa.gov
Phoebe Woodworth-Jefcoats	PIFSC	Phoebe.Woodworth-Jefcoats@noaa.gov
Howard Townsend	S&T	Howard.Townsend@noaa.gov
Kenric Osgood	S&T	kenric.osgood@noaa.gov
Rebecca Shuford	S&T	rebecca.shuford@noaa.gov
Amy Schueller	SEFSC	amy.schueller@noaa.gov
Kevin Craig	SEFSC	kevin.craig@noaa.gov
Todd Kellison	SEFSC	todd.kellison@noaa.gov
Bill Arnold	SERO	bill.arnold@noaa.gov
Cynthia Meyer	SERO	cynthia.meyer@noaa.gov
David Bernhart	SERO	david.bernhart@noaa.gov
Dawn Davis	SERO	dawn.davis@noaa.gov
Denise Johnson	SERO	denise.johnson@noaa.gov
Linda Atwell	SERO	linda.atwell@noaa.gov
Michael Jepson	SERO	michael.jepson@noaa.gov
Nick Farmer	SERO	nick.farmer@noaa.gov
Steve Giordano	SERO	steve.giordano@noaa.gov

Matthew Supernaw	SERO/ST	matthew.supernaw@noaa.gov
Elliott Hazen	SWFSC	elliott.hazen@noaa.gov
Steve Lindley	SWFSC	steve.lindley@noaa.gov
Robert Wildermuth	UMASS/SMAST	rwildermuth@umassd.edu
Cameron Ainsworth	USF	ainsworth@usf.edu
Michelle Masi	USF	mbonewit@mail.usf.edu

Appendix D – Steering Committee

AKFSC	Kerim	Aydin	Kerim.Aydin@noaa.gov
	Kirstin	Holsman	Kirstin.Holsman@noaa.gov
NWFSC	Chris	Harvey	Chris.Harvey@noaa.gov
	Isaac	Kaplan	Isaac.Kaplan@noaa.gov
SWFSC	Toby	Garfield	Toby.Garfield@noaa.gov
	Elliott	Hazen	Elliott.Hazen@noaa.gov
PIFSC	Phoebe	Woodworth-Jefcoats	Phoebe.Woodworth-Jefcoats@noaa.gov
	Mariska	Weijerman	Mariska.Weijerman@noaa.gov
SEFSC	Mandy	Karnauskas	Mandy.Karnauskas@noaa.gov
	Todd	Kellison	Todd.Kellison@noaa.gov
NEFSC	Rob	Gamble	Robert.Gamble@noaa.gov
	Laurel	Smith	Laurel.Smith@noaa.gov
S&T	Kenric	Osgood	Kenric.Osgood@noaa.gov
S&T	Howard	Townsend	Howard.Townsend@noaa.gov
AA	Jason	Link	Jason.Link@noaa.gov

Appendix E – Breakout Group Questions for TOR and Summary Discussion

TOR 1: Update on current ecosystem modeling efforts underway at NMFS centers/offices/labs. Highlight ecosystem modeling that is geared towards addressing trade-offs and identifying commonalities.

Discussion Questions:

- What are the common trade-offs across regions, which are currently being addressed by ecosystem modeling?
- What have been the effective methods for addressing the trade-offs?
  - Models
  - Engagement with managers and stakeholders
- What are the limitations for addressing trade-offs?
- How is ecosystem modeling organized in your region, and what is "best practice" for addressing needs and priorities related to MSE, EBFM Roadmap, MSE, and guidance from 2016 NMFS Ecosystem Science Reviews? :
  - Does your center have a formal ecosystem modeling group?
  - Do you have an informal modeling group in a larger Ecosystem Program or Division?
  - Do the ecosystem modeling groups incorporate folks from other Divisions or Programs (e.g., Pop Dyn/Stock Assessment, Protected Species, Habitat)?
  - Are the ecosystem modeling projects driven by funding (e.g. stock assessment of commercial important species for Council).
  - Does the structure work well or can it be improved, and if so, how?

TOR 2: Outline and review commonly encountered trade-offs in LMR and cross-sectoral management.

Discussion Questions:

- What are the common trade-offs across regions (including those for which models are lacking)?
  - Are the regions mostly dealing with trade-off within fisheries and LMR management or across sectors (i.e., LMR and energy, transportation, etc.)?
  - Are there trade-offs between legal mandates (Magnuson, ESA, MMPA, NEPA)?
- Are there novel trade-offs that have not been addressed yet in all regions, but we should prepare for and learn about from case studies?

- Are the IEAs being applied in similar ways across regions to deal with trade-offs?
- Are MSEs being applied in similar ways across regions to deal with trade-offs? When is formal 'closed loop' MSE most useful, versus scenario-based projections?

TOR 3: Outline and review common and novel tools for modeling and communicating trade-offs.

Discussion Questions:

- Are there tools all centers are using regularly?
- Are there new tools (not demo-ed at the workshop) that could be used more broadly by the Centers?
- What are some ways to ensure we share tools across Centers?
- How do these tools quantify uncertainty?
- Have multi-model approaches been applied, and how?
- Are there lessons learned with respect to visualization and communication, from recent engagement with Fishery Councils, review panels, etc.?

TOR 4: Discuss management implications of trade-offs.

Discussion Questions:

- How are councils, Regional Offices, and other management bodies using ecosystem modeling to consider trade-offs?
- How can Centers facilitate the use of ecosystem modeling for addressing trade-offs?
- Ecosystem modeling of global change may suggest trade-offs between fisheries and future CO2 emissions. How do we present these trade-offs, who do we present to, and under what framework (e.g. Regional climate Action Plans, USGCRP, ICES/PICES…).
- Are there management implications and trade-offs that have been neglected by ecosystem modeling (habitat restoration?)

TOR 5: Discuss National Ecosystem Modeling Toolbox and plan to ensure adequate tools available for addressing trade-offs.

Discussion Questions:

- What are the pros and cons of the toolbox?
- Will the toolbox be useful for facilitating peer review of EMs?
- What are the priorities for tools to be developed?

TOR 6: Summarize best practices for addressing trade-offs using EM.

Discussion Questions:

- What are the best practices to ensure we adequately address trade-offs?
- How do we best engage councils and other management bodies to address trade-offs?
- What visualization tools can be used to engage management and policymakers?
- What papers/articles can we prepare to demonstrate and evaluate best practices for addressing trade-off?