NOAA Technical Memorandum NMFS-SEFSC-760
doi:10.25923/4s2x-mt68

Report of the Southeast Trophic Ecology and Ecosystem Modeling Working Group

BY
DIONNE HOSKINS-BROWN, IAN ZINK, BRITTANY TROAST, MANDY KARNAUSKAS, SKYLER SAGARESE, AND MICHELLE MASI

U.S. Department of Commerce
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Southeast Fisheries Science Center
Miami, Florida 33149

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National Marine Fisheries Service
Southeast Fisheries Science Center
75 Virginia Beach Drive
Miami, Florida 33149

U.S. DEPARTMENT OF COMMERCE
Dr. Gina M. Raimondo, Secretary

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
Dr. Richard W. Spinrad, Under Secretary for Oceans and Atmosphere

NATIONAL MARINE FISHERIES SERVICE
Janet L. Coit, Assistant Administrator for Fisheries

AUGUST 2022

NOTICE

This report should be cited as follows:

Hoskins-Brown, D. L., Zink, I, Troast, B., Karnauskas, M., Sagarese, S, and Masi, M. 2021. Report of the Southeast Trophic Ecology and Ecosystem Modeling Working Group, NOAA Technical Memorandum NMFS-SEFSC NMFS-760, 42p. https://doi.org/10.25923/4s2x-mt68.

This report will appear on the SEFSC website at URL: https://www.sefsc.noaa.gov/

Copies may be obtained by writing:
Dionne Hoskins-Brown
NOAA Programs
Box 20467 Savannah State University
Savannah, Georgia 31404
dionne.hoskins-brown@noaa.gov

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Acronyms

CIE	Center of Independent Experts	NERTO	NOAA Experiential Research Training Opportunity
CSC	Cooperative Science Centers	NFWF	National Fish and Wildlife Foundation
DWH	Deep Water Horizon	NGOMEX	Northern Gulf of Mexico Ecosystems and Hypoxia Assessment
EBFM	Ecosystem-Based Fisheries Management	NMFS	National Marine Fisheries Service, also NOAA Fisheries
eDNA	Environmental DNA	NOAA	National Oceanic and Atmospheric Administration
EFH	Essential Fish Habitat	NRDA	Natural Resource Damage Assessment
EIS	Environmental Impact Statement	NWACS	Northwest Atlantic Continental Shelf
EPP	Educational Partnership Program	NWFSC	Northwest Fisheries Science Center
ERP	Ecological Reference Points	OST	Office of Science and Technology
ESA	Endangered Species Act	PEREC	Potomac Environmental Research and Education Center
EwE	EcoPath with Ecosim	PRD	Protected Resources Division
FEP	Fishery Ecosystem Plan	PRP	Programmatic Restoration Plan
FMP	Fishery Management Plan	PRSAIP	Protected Resources Stock Assessment Improvement Plan
FWC	Florida Fish and Wildlife Conservation Commission	QUEST	Quantitative Ecology and Socioeconomics Training (program)
FWRI	Florida Wildlife Research Institute	RESTORE	Resources and Ecosystems Sustainability, Tourist Opportunities, and Revived Economies
GAM	Generalized Additive Models	ROMS	Regional Ocean Model System
GMFMC	Gulf of Mexico Fishery Management Council	ROV	Remotely Operated Vehicle
GMU	George Mason University	RSMAS	Rosentiel School of Marine and Atmospheric Science
GoM	Gulf of Mexico	SAFMC	South Atlantic Fishery Management Council
GOMEMOw	Gulf of Mexico Ecosystem Modeling Workshop	SAIP	Stock Assessment Improvement Plan
GOMexSI	Gulf of Mexico Species Interactions database	SEAMAP	Southeast Area Monitoring and Assessment Program
HAB	Harmful Algal Bloom	SEDAR	Southeast Data, Assessment, and Review

HAIP	Habitat Assessment Improvement Plan	SEFSC	Southeast Fisheries Science Center
ICCAT	International Commission for the Conservation of Atlantic Tunas	SERO	Southeast Regional Office
IEA	Integrated Ecosystem Assessment	SFD	Sustainable Fisheries Division
IFAS	Institute of Food and Agricultural Sciences (University of Florida)	S-P	Surplus-Production
MICE	Model of Intermediate Complexity for Ecosystem	SSC	Scientific and Statistical Committee
MMPA	Marine Mammal Protection Act	SSIO	Student Scholarship Internship Opportunity (online system)
MSA	Magnuson-Stevens Act	TIG	Trustee Implementation Group
MSCA	Multispecies Statistical Catch-at-Age	TL	total length
MSE	Management Strategy Evaluation	ToR	Terms of Reference
MSIs	Minority Serving Institutions	U.S.	United States
MSVPA	Multispecies Virtual Population Analysis	USF	University of South Florida
NCSS	NOAA Fisheries Climate Science Strategy	UW	University of Washington
NEFSC	Northeast Fisheries Science Center	USVI	U.S. Virgin Islands
NEMoW	National Ecosystem Modeling Workshops		
NEPA	National Environmental Policy Act		

Executive Summary

On December 11-12, 2019, approximately 45 representatives from the NOAA Southeast Fisheries Science Center, NOAA Southeast Regional Office, NOAA Restoration Center, Gulf of Mexico Fisheries Management Council, Fish and Wildlife Research Institute, regional academic institutions, and non-governmental organizations convened to discuss strategies to inform priority management issues by increasing the application of ecosystem modeling. Through a combination of plenary presentations and discussion, management partners reviewed current priority management needs as the scientific community gave updates on current modeling capacity and data sources. In reviewing the existing databases, modeling approaches, and applications that have been made to date, it was clear that a robust foundation existed and that a number of successes have already resulted from past efforts. The group identified and worked through some of the bottlenecks that have prevented more frequent success in application. This included a lack of communication between practitioners and decision-makers, mismatched timescales between management decisions and model development, and data gaps.

During the interface between a diverse group of scientists and managers in the region, a number of areas of opportunity were identified. These opportunities included: improved bycatch analysis in fishing amendments, more robust responses to "crisis situations," multi-model approaches to inform key management questions, and linking ecosystem modeling into evaluations inherent in specific programmatic cycles. Given the time necessary to develop and tailor ecosystem models, examples of these programmatic cycles thought to be most promising included the 5-year programmatic evaluation associated with the Deepwater Horizon, the Trustee Implementation Group Restoration Planning Cycle and the Monitoring and Adaptive Management process, and the 10-year Environmental Impact Statement cycles.

A major theme of the workshop was improving communication, and one of the goals of the workshop itself was to assemble representatives from various agencies and institutions that may not typically engage. Ultimately, to improve the application of science in the region, scientists will need to gain a better understanding of policy issues, and managers and stakeholders will need a greater appreciation of model capabilities and limitations. Above all, the group recognized the necessity of having a "constancy of purpose" to make advancements in applications of ecosystem science to management. While the limitations of existing workloads and resourcing make it challenging to make progress, there is certainly room for improvement that can be facilitated by communicating better, coordinating activities, and leveraging resources. It was envisioned that the workshop would serve as one stepping-stone to help achieve this constancy, and continued opportunities are desired for critical evaluations and discussions on the improved transfer of ecosystem science to management.

Background

The strategic planning meeting of the Southeast Trophic Ecology Working group built on the extensive foundation of data collection and model development activities that have been conducted to date and that have advanced the outcomes from recent workshops relating to refining ecosystem model data inputs and management priorities. **The objective of this meeting was to create an action plan for the NOAA National Marine Fisheries Service (NMFS, also "NOAA Fisheries") Southeast Fisheries Science Center (SEFSC) and its collaborative partners to conduct ecosystem modeling in support of defined, high-priority resource management questions.**

Meeting Objectives:

- To familiarize the science and management community with how ecosystem models are used to support decision-making in different regions around the country
- To understand the wider context of priority management issues in the Southeast region
- To review the suite of modeling tools in the Southeast region available to address ecosystem-level questions
- To identify data gaps and limitations in funding, time, or expertise
- To discuss actionable ecosystem model outputs and chart a path forward to address priority issues

Structure of the Report

The workshop was held as two sessions: a Pre-Meeting Work Session (held on the afternoon of December 11th) and the Working Group Strategic Planning Meeting (held on December 12th). In order to achieve the above-mentioned meeting objectives, a number of presentations, discussions, and brain-storming sessions were held among the meeting attendees. Presentations were used to introduce different available modeling tools, identify science needs, gaps, and current limitations in the SEFSC and SERO, and provide examples of how different management questions have already been addressed within the Southeast region (and elsewhere) using ecosystem modeling approaches. The various discussion and brainstorming sessions also assisted with identifying science needs, gaps, and current limitations in the SEFSC and SERO while also bringing up other aspects of ecosystem modeling needs that may need consideration.

The report is presented in the order of the workshop agenda with outcomes, observations, and challenges as summarized in the workshop closing. General recommendations follow with an appendix of supporting materials. The major points of emphasis of each presentation were recapitulated, as were the question and answer session and general discussion that followed. Where appropriate, speakers, institutions, resources, and methods were identified in the discussion to guide the reader and provide context for additional reading.

Pre-Meeting Work Session
December 11, 2019

Opening Remarks
Mandy Karnauskas
Ecosystem Science Lead
Miami Laboratory
Southeast Fisheries Science Center (SEFSC)

Attendees were given a charge to consider these guiding questions throughout the workshop:

> How can the SEFSC work together and work smarter with collaborators and managers to be strategic about high priority issues?
>
> What are the Center's next steps?

Presentation: Applications of Ecosystem Models for U.S. West Coast Fisheries Management
Isaac Kaplan
Research Fishery Biologist
Conservation Biology Division
Northwest Fisheries Science Center (NWFSC)

On-ramps to federal, state, tribal, and treaty management were outlined using current ecosystem models of the oceanographic drivers affecting sablefish recruitment in northern California and the Tier I Environmental Impact Statement (EIS) for pacific groundfish harvest. Of the prevalent takeaways provided, progress was noted in assessing climate change impacts on model predictions and how this area was ripe for connecting to management.

Discussion:

Discussion ensued with questions about whether there were strategic processes where end-to-end models are appropriate to test scenarios. There are a host of applications and processes where end-to-end models would be appropriate, especially in the restoration context. It was emphasized that modeling should be conducted at the programmatic scale, and not just at the project scale. As an example, Economic Impact Statements (EIS) were mentioned as strategic 10-year documents on the potential impacts to a given area that set a broader scope than yearly quotas.

The next questions referred to how one can initiate and plan these end-to-end models and deal with potential outcomes. Indicator selection and discussions with various stakeholders on what indicators are important and what data are available were referred to as steps that would create a good starting point. When considering outcomes, there is a perception that ecosystem models lead to reductions in overall catch. This theory arises often when forage fish numbers are discussed, but this reduction depends on the objectives for other fisheries.

Presentation: From Qualitative to Quantitative: Use of Ecosystem Models in the Northeast

Sean Lucey
Fisheries Biologist
Resource Evaluation & Assessment Division
Northeast Fisheries Science Center (NEFSC)

Conceptual models were presented as critical tools for ecosystem-based fisheries management that can be used to describe the system, improve understanding, identify data gaps, and bridge multiple disciplines. They are used to structure State of the Ecosystem reports and identify indicators that can be turned into risk assessments. Main takeaways from this presentation were that models can range from simple to complex as well as qualitative to quantitative, that qualitative models help to narrow down what quantitative models need to be built, and that ecosystem models were beginning to inform management by testing strategies and creating multi-species reference points.

Discussion:

Discussion centered around working with data gaps and uncertainty in qualitative and quantitative models. Qualitative models allow one to estimate varying levels of an indicator to better understand how it would affect the system. Talking to fishermen can also help create estimates for some past data gaps, especially regarding diets. Similar processes can be used when describing uncertainties to managers. The division is currently working on uncertainty routines, however, information was given on a recent Southeast Data, Assessment, and Review (SEDAR) for menhaden in which the analysts were asked to adjust diets and present the outcome. Large adjustments to diets did not produce large effects in the overall model; this helped alleviate some of the concerns about the lack of diet data. Lastly, attendees posed questions on the process for having qualitative models assist quantitative models and what those objectives were. In the absence of specific objectives, work in the Resource Evaluation & Assessment Division has been based on current national legislation. There have been efforts to refine them into specific objectives through an iterative process of presenting indicators to management councils through their annual State of the Ecosystem reports.

Presentation: Progress on Implementing Ecosystem-Based Fisheries Management (EBFM) in the U.S. through the Use of Ecosystem Models and Analysis

Howard Townsend
Ecosystem Modeling Coordinator
Office of Science and Technology (OST)
Oxford Laboratory

Ecosystem models and analysis have been used in implementing EBFM and specific examples were described in this session. These included the Atlantic Herring Management Strategy Evaluation (MSE), Gulf of Alaska Pacific Cod Harvest, Mississippi River

Hydrodynamic and Delta Management Study, Hawai'i Coral Reefs, and Dynamic Ocean Management in the California Current Ecosystem. Best practices and recommendations for implementing ecosystem models that were based on past National Ecosystem Modeling Workshops (NEMoW) were also described and included developing and maintaining ecosystem modeling capacity and infrastructure, applying iterative communication with managers and stakeholders, ensuring periodic informal review throughout model building, using multiple models to address uncertainty in model structure and major ecosystem drivers, and implementing an MSE framework.

An additional, interactive process was outlined and offered for future efforts to develop and use ecosystem models in policymaking. First, the policy problem should be identified as well as the existing resource management process that will be used to address that problem. Next, the problem should be discussed so that scientists understand the policy issue and managers and stakeholders understand the capabilities of existing models. Then, initial modeling results should be shared and individuals should confer again to refine understanding on both sides and assess where additional scientific information and analyses are needed. Finally, management actions should be explored that would improve outcomes for natural resources and users under existing mandates. It was stressed that a constancy of purpose is needed in order to make progress.

Discussion was based on one of the examples provided during the talk (Dynamic Ocean Management in the California Current Ecosystem, or "EcoCast" tool) which incorporated tracking and satellite data and which moved toward using a seasonal ocean forecast to predict hot spots for fishing to reduce bycatch. Steph Brodie has a new publication out about this tool.

Discussion:

The implementation of models in the EBFM context fueled a general discussion. The first question focused on the genesis of the success stories, whether they were crisis-based or planned, and how future needs could be predicted. There was a mix of answers. In the case of the Herring MSE, money was made available for this type of modeling. "The Blob" case study, however, was a crisis situation in the sense that managers were aware of the environmental data. However, modeling was not initiated until the problem worsened. Use of Environmental Impact Statements (EIS) help to increase preparedness, especially in areas where ecosystem modeling could be used and where fisheries are not used to operating. EISs are used on larger spatial scales and are meant to address future issues as they arise. These are necessary as larger models (i.e. ATLANTIS) must be constructed in a way that makes them multipurpose as they take too long to construct to be usable in a crisis situation. Consequently, strategic planning is important for tool development.

Focusing on such strategic planning, the discussion moved to how modelers can best prepare to deal with future issues. The need for flexible models that can be repurposed for many issues arose because management decisions occur on shorter timescales than model development. While developing these models it is beneficial for modelers to consult as many managers and stakeholders as possible so the model will have the greatest utility. Adding in a new group later necessitates model validation and extends the timeframe for the model. Additionally, while creating models, developers should not think only about agency objectives, but those of the state they will be helping to inform (e.g., Coastal Louisiana Master Plan).

The conversation then turned to understanding local opportunities and bottlenecks regarding modeling in the southeast region. These opportunities included bycatch analysis in fishing amendments. Bycatch analysis tends to be a summary of the composition of bycatch instead of being an observation of what changes in bycatch and a consideration of alternatives. This presents an opportunity for routine representation of ecosystem modeling. Fund projects that promote multi-model approaches presents another opportunity. Bottlenecks identified included time to model completion, multi-model approaches, and classic issues like funding and staff limitations. Difficulties in model development include not only the time required for calibration and validation, but the time required to build trust in the model outputs. Rarely enough time is allowed for the model to go through a thorough review process. In the case of the Endangered Species Act (ESA), there is often limited resolution and time for the model to make meaningful conclusions. When implementing a multi-model approach, time should be allocated not only for individual model development but also for comparison among multiple teams and team predictions and consensus. This time must be designated in the project and allow for feedback outside the group. The Ocean Modeling Forum is a tool that modelers can use to communicate with other modelers and help bring together models already in existence. The last major group of challenges facing the Southeast involves classic bottlenecks including funding, staff, and dedicated time. The SEFSC seems to have less capacity to incorporate modeling into its activities than other Centers. This makes addressing the "constancy of purpose" point made by another attendee difficult to do, as any modeling is spotty and for only specific projects.

Working Group Strategic Planning Meeting
December 12, 2019

Opening Remarks
Mandy Karnauskas
Ecosystem Science Lead
Miami Laboratory
Southeast Fisheries Science Center (SEFSC)

The workshop opened with a welcome for the attendees and convener perspectives on EBFM. Strategic guidance documents from the Habitat Assessment Improvement Plan (HAIP), NOAA Fisheries Climate Science Strategy (NCSS), Stock Assessment Improvement Plan (SAIP), and Protected Resources Stock Assessment Improvement Plan (PRSAIP) all contain frameworks for incorporating ecosystem information into management advice, via the Integrated Ecosystem Assessment (IEA) and the Stock Assessment Process. Ideally, management bodies can receive advice at both the species and ecosystem level, which would allow them to make the required, often compartmentalized, management decisions in light of the broader ecosystem context. The agency is making incremental improvements to EBFM based on single-species models and framework and that EBFM is intended to be an evolutionary, not a revolutionary, approach. It was emphasized this informal workgroup could help advance the EBFM/EBM efforts in the region and help fulfill the evolving needs of the SEFSC to address ecosystem issues. Noting that the Magnuson-Stevens Act (MSA) as not being the only mandate relevant to EBFM, it was offered that there are National Environmental Policy Act (NEPA) and restoration activities to consider.

A brief overview was given of the significant progress made to date. In 2017, Grüss et al. compiled best practices for the use of ecosystem models to inform EBFM in the Gulf of Mexico. Chagaris et al. (2018) identified seven management priorities for the region, and O'Farrell et al. (2017) reviewed 45 different ecosystem models that could be applied. In addition to the modeling frameworks, many tools to support ecosystem modeling exist; these included species distribution models, diet databases (e.g. Gulf of Mexico Species Interactions database, GOMexSI, and local ecological knowledge. Participants were charged to be active in their roles and provided with the objectives of the day which were to be active in their roles to: 1) Understand management issues, 2) Review modeling tools, 3) Identify gaps and limitations of current approaches, and 4) Identify "low hanging fruits", or potential advances that could be made given what is already being done.

Participant Goals

Participants contributed to an open dialogue in which attendees introduced themselves, responded to the opening remarks, and offered what they hoped to get out of the workshop. A complete participant list is provided in Table 1. Attendees described goals that focused on: 1) supporting their current research and modeling work on particular habitats and species (ex. Menhaden, south Florida estuaries, seagrasses, red tide, corals, shrimp, Barataria Bay, and the Gulf of Mexico); 2) expanding collaborations; 3) providing data for, expanding and validating current models; and 4) listening for management needs.

Integrating human dimensions and moving models into the management framework were also mentioned.

Panel I: Current Management Landscape in the Southeast U.S.

Presentation: Fishery Management in the Gulf of Mexico: An Overview of the Process and Summary of Ecosystem Efforts

Natasha Mendez-Ferrer
Fishery Biologist
Gulf of Mexico Fishery Management Council (GMFMC)

An overview was provided on the processes and ecosystem-based efforts toward fishery management in the Gulf of Mexico (GoM). The concept of the 8 regional management councils was introduced with further specifics on the Gulf Council. It has Fishery Management Plans (FMPs) for reef fish, shrimp, coral, red drum, and essential fish habitat (EFH) that covers 186,200 square nautical miles in the Gulf of Mexico. Because fish migrate over inter-jurisdictional boundaries, the Gulf Council manages spiny lobster and coastal migratory pelagics jointly with the South Atlantic Fishery Management Council (SAFMC). It has 17 voting members which include the regional administrator of NOAA Fisheries and directors of the five Gulf state marine resource management agencies. Eleven are appointed by state governors to represent the fishing industry. Four non-voting members from the U.S. Coast Guard, U.S. Department of Fish and Wildlife, and the Gulf States Marine Fisheries Commission serve supporting roles.

In reviewing the 10 National Standards of the Magnuson-Stevens Act, it was noted that there may be conflict between standards. For example, the objective to "minimize costs" may not be part of the best management of a fishery. Management changes are also triggered by the economy, social reasons, and changes in federal law. Consequently, the Council draws upon advisory bodies that include experts from state and federal agencies, academia, and the public. Once an issue is identified, it undergoes initial review that yields a full amendment. This engages the Advisory Panel and Scientific and Statistical Committee (SSC), moves to Council, and then up to Full Council. Attendees were encouraged to get involved with the Council to get to know each council's unique processes.

The MSA requires councils to integrate ecosystem considerations and minimize fishing impacts on the ecosystem. To support this, the act authorizes NOAA Fisheries to provide technical assistance to the councils so that regional EBFM programs can be developed. In the case of the Gulf Council, this involved a number of ecosystem-related activities, including workshops, comments on ecosystem-related NMFS products/policies, red tide considerations in red/gag grouper assessments and ecosystem committees (Council, SSC, and Technical). Guiding principles and best practices are also being considered for a Fishery Ecosystem Plan (FEP) that is in the early stages of development. FMPs have some ecosystem components. For example, some have EFH identified for each species and its life stages. Others use multi-species approaches, adjust harvest levels in response to the environment (e.g., red/gag low catch levels and red tide), or establish special fishing regulations in areas of particular importance (i.e., Marine Protected Areas and Habitat of Particular Concern). Management boundaries also can take ecosystem information into consideration, especially as it relates to migratory species.

The importance of the GoM Council hearing from stakeholders like those in attendance was emphasized. Current goals and priorities for ecosystem science involve developing predictive models to project fisheries productivity, assessing uncertainty in stock assessments, and improving single-species management. Additionally, they hope to evaluate the impacts of proposed management from an ecosystem perspective and improve stakeholder engagement. Participants were invited to get involved by applying to the SSC or participating in public meetings, contributing data for stock assessments, serving as reviewers, and providing comments.

Discussion

Initial questions asked how the Council was involved in fishery sampling on non-stock impacts of fishing, given the concern that no model can resolve issues related to "bad data." It was clarified that the Council provides advice but does not collect data. An attendee opined that priorities seemed misdirected because $100 million dollars was spent for reef restoration, but there was no monitoring of fisheries impacts on the ecosystem. It was offered that individuals could work with the state to get fishery-independent data, that funds from the National Fish and Wildlife Foundation (NFWF) and Deep Water Horizon (DWH) Oil Spill could be used to improve the lack of data. This was followed by noting that the 5 year cycle of research priorities presented an ongoing problem with resources. There are funds from DWH but they are allocated to "turn the dirt restoration", and even scientists in DWH have been hesitant to look at monitoring heavily. They have been considering outside the box methods, including obtaining fishery-independent data. It was recommended that this group share its priorities with the Council and the Science Center. However, someone acknowledged that there is slow movement to get momentum and that the public does not easily see the value of this so the work is a hard sell. Citizen science data were suggested as a tremendous opportunity to supplement data collection. The Gulf Council is engaging with citizen science right now via the "Something's Fishy" application. It was noted that, while citizen science initiatives can be powerful and useful, it is critical to ensure that there is a clear path for how the data are to be used and that participants do not lose interest.

Presentation: SERO Ecosystem Modeling Needs

Mike Jepson, Branch Chief, Social Science Branch, SERO
Nick Farmer, Branch Chief, Species Conservation Branch, SERO
Steve Giordano, Environmental Compliance Program Manager, SERO

This group presentation detailed the major priorities in the areas of Sustainable Fisheries and Economics, Protected Resources, and Restoration. The Sustainable Fisheries Division's (SFD) main objective is "to maintain fish stocks important to commercial, recreational, and subsistence fisheries at sustainable levels and increase long-term economic and social benefits." A summary of the Fishery Management Council process with respect to SFD set the foundation for discussion of the Division's top management issues in 2019. These were 1) the delegation of management of the red snapper private angler component to the states, 2) island-based fishery management plans in the Caribbean, 3) the implementation of electronic for-hire programs in the Gulf and South Atlantic, and 4) fishery disaster responses. The Division prepared a list of ecosystem issues important to management, which were:

- Shifting stock distribution due to climate change (with a need to coordinate across Councils)
- Degradation of coral reefs in the Florida Keys and the Caribbean
- Increased frequency of catastrophic weather events and effect on fisheries and fishing communities
- Effects of sea-level rise on fishing communities
- Effects of ocean acidification
- Effects of artificial structures on fish populations and habitat
- "Multispecies Maximum Sustainable Yield" tradeoffs
- Stopgap & advanced recruitment forecasting
- Impacts of red tide
- Predictions of fisheries effort shifting

It was noted that a number of activities were underway to address the above needs, including the development or revision of FEPs in different regions, the formation of a workgroup to address climate-related species distribution shifts, and climate vulnerability assessments.

The Protected Resources Division (PRD) reviewed its activities and mandates. The division is responsible for the protection, conservation, and recovery of marine and anadromous species listed under the ESA, as well as managing take and evaluating status of marine mammals under the MMPA. Each mandate had different aspects that could be informed by ecosystem modeling activities. For example, under the ESA, a species may be listed as threatened or endangered due to certain factors including modification of habitat, disease or predation, the inadequacy of regulations, or other manmade factors. A recent status determination for the dwarf seahorse (NMFS SEFSC 739) demonstrated a need for disentangling multiple ecosystem factors. In this case, seagrass coverage, harmful algal blooms, cold events, and harvest were all thought to affect population viability. As another example, protected species take could be better estimated with the increased use of species distribution models. These models might also help managers provide better project design criteria that avoid interactions with listed species by identifying seasonal windows or spatial areas with reduced risk. A multi-layer ecosystem modeling approach was taken by Nick and his colleagues to evaluate the impact of continued authorization of oil and gas exploration activities on the behavior, reproduction, and survival of sperm whales (Farmer et al 2018). The Division suggested a priority list of ecosystem modeling needs:

- Species distribution models (incorporating spatio-temporal environmental drivers, ensuring adequate monitoring to support rare-event species distribution or habitat suitability models)
- Red tide mapping and assessment of vulnerability

- Climate change vulnerability assessment (including cold snap mortality)
- Habitat degradation/restoration connections to recovery, including impacts to forage base
- Interactions between fisheries and protected resources, including reducing bycatch risk (e.g., sawfish) and balancing NMFS missions (removals for harvest vs. forage base for recovery; dolphins versus menhaden example)

The panel closed with a synopsis of activities and priorities regarding Habitat Conservation and Restoration. It reminded attendees that the mission of Habitat Conservation is to "protect, conserve, restore, and create habitats and ecosystems vital to self-sustaining populations of living marine resources under our stewardship." Habitat Conservation also has the mandate to review and advise on the enhancement of fishery habitat via a wide range of legislative authorities. Similarly, Habitat Restoration is mandated to restore habitats that have been destroyed by natural or anthropogenic effects. Steve pointed out that the "big gorilla" in the room in terms of Gulf restoration is the DWH oil spill, the settlement of which has injected nearly $21 billion into funding for associated damages. These resources are awarded via the Programmatic Restoration Plan (PRP), a complex governance structure employing a Comprehensive Integrated Ecosystem Restoration Portfolio and which uses a science-based adaptive management framework. An overview of the Trustee Implementation Group Restoration Planning Cycle and the Monitoring and Adaptive Management process emphasized steps in which ecosystem modeling could be informative. This included the following activities:

- Restoration planning, design, implementation, and evaluation
- Multi-scalar project and programmatic monitoring and adaptive management
- Coordination of restoration actions in the context of multiple restoration programs to assess and avoid conflict and maximize synergy
- Provide information to help determine the effects of complex, large-scale ecosystem restoration actions to inform environmental compliance responsibilities
- Improve understanding of trophodynamics in GoM - direct and indirect effects of restoration on key species
- Evaluate the combined impacts of restoration projects on GoM food webs and productivity
- Evaluate benefits (e.g., secondary and tertiary production) from coastal habitat production
- Evaluate climate change impacts on resources to be restored, and how to incorporate in planning

The presentation continued with an example of a major restoration project that was informed by a variety of ecosystem modeling approaches: the proposed Barataria Bay sediment diversions project which is intended to address rapid land loss in coastal Louisiana. The state's Coastal Master Plan looks at many stressors that will impact the LA coastline and there are many different types of restoration going on at any given time. Thus, understanding and measuring the synergistic effects will be difficult. The IEA decision support framework is being used at a smaller scale to inform management on the smaller scale of Barataria Bay. Due to a number of project timeline issues, ecosystem models are being used at the adaptive management stage of this project. However, it would be ideal to use ecosystem models upfront to inform projects or programs at their very early stages. The benefits of predictive modeling can help managers understand how individual actions will permeate through the ecosystem. Finally there is a need to address the large amounts of money dedicated to restoration, particularly given that the funds are largely supporting "turn the dirt" projects and not science initiatives. Because no single program can cover all of the needs, it will require the different agencies and divisions to break down barriers and work together to optimize restoration efforts.

The presentation concluded with a summary of cross-divisional ecosystem information needs. Many of the priority management questions that could be informed by ecosystem models were fleshed out in a recent workshop and published (Chagaris et al. 2019). Other ecosystem information needs include:

- Spatio-temporal information on species distributions
- Trophic studies
- Species vulnerability assessments
- Climate change vulnerability index for fishing communities
- Studies on the effects of hurricanes on species distribution, abundance, and affected fishing communities
- Evaluations of the effects of climate change and other events not related to fishing (i.e. red tide) on stock status
- Quantifying intermittent and chronic non-fishing sources of mortality (i.e. red tide, hurricanes, habitat loss)
- Understanding environmental effects on recruitment variability and prediction of year class strength

There was discussion during and following the presentation on the issue of timescales for development of ecosystem models. Because the plan is to carry out DWH programmatic evaluations on a five-year cycle, this approach is could be potentially conducive to the development of ecosystem models to assist in those evaluations. It was noted that in other processes (e.g., NEPA, ESA) timing would be more limited. Additionally, some infrastructure projects are being expedited into a two-year window and it would be difficult to develop a model to inform management within that time frame.

Questions arose about the monitoring of restoration progresses and whether funding being put towards monitoring is sufficient to detect change. A participant noted that the TIG allocations include monitoring funds, and that under NRDA restoration, each project includes monitoring as a part of its funding. Additionally, there is monitoring across the Gulf states that allows for measuring the DWH program as a whole. Queries if the requisite power analysis has been done to understand what level of monitoring is sufficient and whether there are provisions for long-term monitoring at the project level were answered with variation. In many cases it depends on the project itself, as they have different timelines for monitoring, but that DWH as a whole has a 20-30year time frame for monitoring. Another question raised was the geographic scales over which monitoring should be focused in order to achieve maximum effectiveness.

When an attendee pointed out the need to know initial conditions for parametrizing models and for understanding the context of restoration, discussion acknowledged the challenges of determining baseline conditions within ecosystems that are heavily impacted and modified (such as the Gulf). There are many issues with fishery-independent monitoring in the region, that not all current monitoring activities were necessary, and that there has been a push to get funding for the types of monitoring that are lacking. The Restoration Center has been working with Monitoring and Adaptive Management (MAM) to accomplish a project on habitat mapping across the Gulf. This was a major gap that existed before the oil spill that is now being filled.

Panel 2: Ecosystem modeling in the Southeast Region: Tools and Applications

Presentation: Evaluating the State of Ecosystem Modeling in the Gulf of Mexico: Tools and Applications

Elizabeth A. Babcock
Associate Professor
University of Miami Rosenstiel School of Marine and Atmospheric Science, Department of Marine Biology and Ecology

Having convened the January 2016 Gulf of Mexico Ecosystem Modeling workshop (GOMEMOw), Beth Babcock gave an overview of its results as well as the ongoing work in her laboratory. Similar to this gathering, ecosystem modelers, empiricists, non-governmental employees, and fishing industry representatives convened to collect data, discuss models in use, identify critical data gaps in GOM ecosystem models, and get insights from fishing industry representatives.

Beth reviewed the status and needs of ecosystem modeling in the Gulf of Mexico related to ecosystem-based fisheries management and restoration activities from O'Farrell et al (2017). Of the 45 models reviewed, most (58%) were whole system or aggregated models or extensions of single-species models (22%). The remaining models were dynamic multispecies or coupled and hybrid model platforms (both 7%), conceptual/qualitative (4%), or biogeochemical-based end to end models (2%). Most of the study areas were located in Florida (38%) or in the U.S. GOM (22%). Models were stage, age, or size-structured, individual-based, trophodynamic, trophodynamic/age, or trophodynamic/stage-structured, or other.

In August 2016, a working group convened to align current ecosystem modeling efforts in the GOM with ecosystem-based fisheries management and restoration needs and provided recommendations (Gruss et al 2017):

- Model development should be driven by management questions
- Use more conceptual/quantitative models
- For tactical use (e.g. fishery management, restoration) model scale must be appropriate
- Complex ecosystem models are currently most useful for strategic questions
    - Complement simpler models
    - Management strategy evaluation

Additionally, a number of proposed best practices were shared: 1) identifying priority management questions, 2) using scenarios as simulation experiments, 3) enhancing the calibration and validation processes of ecosystem models, 4) conducting sensitivity and uncertainty analyses with ecosystem models, 5) ensuring transparency, 6) improving communication between ecosystem modelers and stock assessment scientists, empiricists, managers, resource users, or other stakeholders, 7) documenting ecosystem modeling efforts, and 8) maintaining ecosystem models and codes.

The priority management questions that need to be addressed relate to how the status of the gag stock would be improved by restoring the seagrass beds of the West Florida Shelf; how stock assessments can be improved by: considering environmental influences on fish recruitment; conducting MSE studies to assess the effectiveness of harvest control rules during anticipated future conditions under climate change; mitigating the lionfish invasion; and examining the effects of water and sediment diversion due to restoration. Emphasis was placed on the need for ecosystem models to do a better job of accounting for forage fish, and explicitly representing habitat effects. They also need to demonstrate the capabilities to capture future conditions under climate change, simulate the cumulative impacts of multiple management measures, and include or inform socioeconomic considerations. Lastly, ecosystem models also need better data on diets and fish distributions.

Providing the West Florida Shelf Harmful Algal Bloom EcoPath with Ecosim (EwE) model as an example, the presentation showed how diet data from the GoMexSI database (14,989 samples across 43 predatory fish species) for the West Florida Shelf was used to fit the model (Perryman et al 2020). Collaborators found that updating the diet data had a larger impact than elevated Harmful Algal Bloom (HAB) mortality, demonstrating that up to date empirical diet data are important.

Discussion

Noting that environmental stressors generally have strong bottom-up effects, an attendee queried if the lower trophic level species were being well incorporated. The response was that a lot of the models are fish predator/prey models and improving the lower levels should be a priority. Another question was posed about whether independent analysis of the model (without the data) had been performed to test its efficacy and sensitivities. In particular, there was interest in knowing the sensitivity to the diet matrix. Validation and model checking had been discussed, and sensitivity and jitter analyses were acknowledged as being worthwhile and important to focus on moving forward, including how they respond to perturbation.

There was also interest in the diversity of the diet and whether it had been less diverse historically or whether the change observed was due to sampling or ecological changes across the time period. There is not much diet data before the overfishing era and techniques have become more sophisticated. Researchers are considering models that rely less on diet and more on plausible predator/prey combinations. When questions were presented about ways to qualify the quality of the data being input to the models, discussion revealed that many tools are available to evaluate the plausibility of the model but that diet data can be unreliable. Modelers may need to focus on how to evaluate the quality of the data being input. Another attendee offered that the GoMexSI data for some species is largely generated by the FWC gut lab so some of the data on diet is being influenced by Florida sampling and the increase in sample size. Bias for the west Florida shelf is apparent in many larger Gulf of Mexico models.

Presentation: A Tale of Two Spills: DWH Spill and IXTOC-I spill

Cam Ainsworth
Associate Professor
University of South Florida

This presentation focused on research comparing the ecosystem impacts of the Deep Water Horizon (DWH) and the IXTOC I oil spills. The spills were largely similar but differed in the depth at which they occurred. Fish data were validated against ROV data for density and body size. Modeling showed that it was more common for the IXTOC spill to have a "chaotic recovery" to a stable state. This was attributed to how the oil was dispersed, how it made its way through the system, and timing. In both oil spills there was a disproportionate effect on juvenile fishes. Of note was the observation that oiled marine snow enriched the detritus-based food web before toxicity levels were met. Generalized Additive Models (GAM) predicted the depth of ~40 species in the water column and will be used to identify spawning locations and settlement for mesopelagics in pelagic food web.

Discussion

A slide with tilefish data led to an inquiry into the indices for recruitment used for this study and whether there was any ground-truthing. The number of "new age" individuals was used; sometimes fish from the first few years of age were included. These approaches more accurately represent recruitment and juvenile survivorship. An attendee asked about the overlap of oil with larval fish to understand recruitment effects, but this was considered a small impact so it was not included in the overall model. There was also interest in the spatial distribution of impacts of oil spills. The Madison Swanson Marine Protected Area (MPA) appeared to be one of the areas that was hardest hit.

When asked about biomass differences between runs with and without oil, effects were described as occurring distant from the wells because mobile species come in contact with the well but spend time in many other polygons skewing the impact to those areas. Someone also contributed that biomass is seasonal near the area of the DWH spill. If species that were present during the spill were removed, they should have a larger ecosystem impact because of double loss from direct mortality and the secondary loss of reproductive capacity. Fecundity is a function of body size in the Atlantis model. One of the problems with the model is that it predicts a large impact on pelagics that was not represented in tuna catches. No oil avoidance was included in the model and would explain the tuna result differences and other large pelagic losses.

Very good data on fisheries closures can be obtained and were included in the model but they did not have a big impact because of the short timeline and spatial aspect of closures. Questions about a relationship to the Louisiana shelf damage allowed the clarification that the goal was not to establish quantitative estimates of damage and that the objective was more relative.

Presentation: Ecosystem Modeling for Fisheries Management in the Southeast Region

Dave Chagaris
Research Assistant Professor
University of Florida IFAS Nature Coast Biological Station

The many challenges managers face and the considerations that accompany the use of ecosystem models were outlined and developed for discussion. First, there needs to be an awareness of when to use precaution and whether stock assessment parameters need to be adjusted. Then models need to help explain and forecast population fluctuations. In response, managers need to be able to evaluate how policies will perform under environmental change, how they will affect other species, and whether single species targets can be achieved simultaneously.

Moving to modeling efforts in the Southeast and focusing on a recent effort to integrate information on ecosystem stressors and predator-prey interactions into fisheries assessment and management for the GoM, the group was updated on a three-year project funded by the NOAA RESTORE Science Program as a decision-support tool priority. The group consists of a modeling team (Sagarese, Lauretta, de Mutsert, Ahrens, Nuttall, Vilas, Mahmoudi, Walters, and Steenbeck) and a team of end-users (Farmer, Vanderkooy, Kilgour, Schueller, Estes, Guyas, Townsend, and Frazer) who are redesigning three models: the West Florida Shelf EwE, U.S. Gulf-wide EwE, and NGOMEX.

The West Florida Shelf EwE (adapted from Okey et al 2002) has 83 functional groups and 18 fishing fleets. A novel red tide application in Ecospace included spatial overlap, bloom duration and severity, sub-lethal effects (foraging capacity), avoidance, and food web effects (Chagaris et al 2015; Chagaris et al 2017). Direct mortality is under development and is expected to be completed by February 2020. They are incorporating red tide capability into Ecospace and consider this is a more precautionary approach to management because stock projections assume that the allowable catch is dependent on red tide mortality. This is attributed to the lower survival of juveniles and below-average recruitment. The effects of multiple stressors (ex. DWH, lionfish, recreational fishing, and indirect/direct food web effects) on biomass in the Northern GoM were described with DWH as an example. Results based on ROV survey data suggest that the region's recovery after the DWH oil spill may have been greater without lionfish, particularly species that are target prey items for the invasive species. Data that showed red drum spawning output and recruitment recovering more slowly in the eastern Gulf than in the west.

The timeline of the development of Ecological Reference Points (ERP) for Atlantic Menhaden was provided. While this effort began in 2010 using a Multispecies Virtual Population Analysis (MSVPA), this work was not completed until 2015. In February 2015, an Ecosystem Management Objectives workshop was held and led to the development of a Surplus-Production (S-P) model, a Multispecies Statistical Catch-at-Age (MSCA) analysis, and an EwE model between 2015 and 2017. Capping this effort was the development of the Northwest Atlantic Continental Shelf (NWACS) Ecosim full model that incorporated 61 model groups representing a larger set of menhaden predators (Buchheister et al. 2017). This led to a reduced model, the NWACS Model of Intermediate Complexity for Ecosystem (MICE) assessment, in which only 17 groups were used to develop the ERPs. The ERPs were based on a menhaden-striped bass tradeoff. The SEDAR Technical Review was performed in November 2019 and the final product was slated to be presented to the Management Board in February 2020. Future work will continue to focus on environmental forcing, MSE, and Ecospace.

The presentation concluded with an overview of data and research needs in the areas of trophic ecology, fisheries, and operations that would support ongoing work.

Discussion:

Opening questions addressed whether the MICE modeling suggested that striped bass would remain unaffected if menhaden fishing levels increased and what application there was to specific models. While talk affirmed that conservative fishing was occurring, if examined from a single species point of view, current fishing still may be too high. With respect to different models, he offered that models that include a lot of information that is not directly connected to certain management questions can slow down the review. There was interest in knowing whether it had been difficult to be explicit about their management decisions in a multi-species context in the Gulf since the Council doesn't have state jurisdiction like in the Atlantic states. Gulf-wide telemetry was suggested to determine if spatially explicit mortality was as anticipated. It also may help ground-truth red tide and hypoxia mortality and assist in being prepared for other natural events.

LUNCH

Presentation: Using Coupled Ecosystem Modeling to Evaluate Nutrient and Hypoxia Reductions on Living Marine Resources

Kim de Mutsert
Associate Director, Potomac Environmental Research and Education Center (PEREC)
George Mason University

Examples of how ecosystem models can be used to evaluate management actions, including the development and refinement of management tools, and their impacts on living marine resources are needed to demonstrate how ecosystem modeling can be leveraged by NOAA NMFS/SERO. This presentation focused on a case study that used ecosystem modeling to investigate the impacts of the "Gulf of Mexico Hypoxic Zone" on living marine resources. More specifically, the notion of impacts included the consideration that fish avoidance of low oxygen areas should be considered in stock assessments and fishing regulations and whether these reductions in available fish habitat should impact catches of specific species.

The case study included two modeling scenarios: 1) status quo (100% current nitrogen and phosphorus inputs) and 2) nitrogen and phosphorous reductions which were previously computed that reduced the hypoxic zone to 5000 km^2 or less. The model incorporated physical aspects from Regional Ocean Model System (ROMS) models and a spatially explicit foodweb, fish growth, habitat quality, and fisheries aspects within the EwE and Ecospace framework. End products included management models and predictive tools, fisheries landings and revenue, estimates of essential fish habitat, and species-specific production. The study found that reducing hypoxia had small positive effects on fisheries species of ecological and economic interest and, despite reductions in bottom-up food web energy flow, the nutrient reductions had a small net effect on living marine resource biomass.

Discussion

It was noted that this modeling scenario could be expanded - for example, the planned Louisiana sediment diversions should increase wetland uptake of nutrients and thus reduce their coastal loading. This aspect could be modeled, but would require linkage of estuarine/terrestrial models to the offshore model. Another avenue could include consideration of climate scenarios and impacts on hypoxic zones.

There was a query about how species-specific oxygen relationships are modeled. Currently, implicit in the model is a decision about the slope/shape of these relationships, which were derived from monitoring data. In addition, experimental work could be conducted to supplement the distribution data. Sensitivity analyses could also be used to determine how changes in slope/shape alter the outcomes. The modeling framework could be considered from a bioenergetics point of view.

There was also interest in the interactions between hypoxia and the fishing fleet. The fleets are very specific in what species they target. They go where the fish are located. Consequently, fleets can be observed concentrating on the edges of the hypoxic zone. When looking at basin scale and population-level impacts of perturbations (oil spill, hypoxia etc.), one can see small overall impacts but it was questioned whether these models can be used to determine community or local level impacts that could be more severe. This information is essential when the model is being set up because those details need to be considered from the beginning of model design. For example, grid size or group by regions of interest could be altered based on spatial scale of questions being investigated. Without consideration of the smaller scale impacts, GoM-wide output may not be useful to management. From some perspectives, small scales may provide the ability to see large impacts, but as a whole, ecosystem modeling aims to describe the habitat as a whole.

Presentation: Challenges to Implementing EBFM in the Gulf of Mexico (Understanding the Trophic Role of Gulf Menhaden)

Skyler Sagarese
Research Ecologist
Sustainable Fisheries Division
SEFSC

The Ecosystem Modeling to Improve Fisheries Management in the Gulf of Mexico project is a 3-year program funded through the NOAA RESTORE Act Science Program (https://restoreactscienceprogram.noaa.gov/projects/fisheries-ecosystem-models). The goal of this project is to integrate information on ecosystem stressors and predator-prey interactions into the assessment and management of fisheries in the Gulf of Mexico. The project is largely focused on gag grouper (*Mycteroperca microlepis*) and gulf menhaden (*Brevoortia patronus*) as target species, but has relevance to other species and stressors of interest to managers and stakeholders (Chagaris et al. 2019). Ecosystem models are being updated for use as decision support tools for the West Florida Shelf (e.g., Chagaris et al.

2015), the U.S. Gulf of Mexico (e.g., Sagarese et al. 2017), and the northern Gulf of Mexico (e.g., de Mutsert et al. 2016). Anticipated products include an index of menhaden predation mortality as well as an assessment of hypoxia and red tide mortality.

Both the U.S. GoM and the northern GoM models have relevance for Gulf menhaden, the former in terms of the contribution of menhaden to higher trophic level organisms throughout the Gulf, and the latter due to its spatial extent focused on key menhaden habitat and coastal species. Both models were developed using EwE, with the northern GoM model extended into Ecospace. Gulf menhaden age classes from age-0 through ages 4+ are explicitly incorporated in each model, which has required consideration of predators of each age class for parameterizing the diet matrix. Despite efforts to review and conduct a meta-analysis of the available information (Sagarese et al. 2016), a number of assumptions were still required to quantitatively allocate age-specific menhaden predation mortality. Data collection and additional research are needed to better understand predation on menhaden, including investigating diet data from juvenile life stages of predatory fishes and predation in inshore waters where juvenile menhaden are abundant. Other critical data gaps that exist in the Gulf that are relevant to menhaden include bycatch in the purse seine fishery. In the U.S. Gulf of Mexico model, bycatch and dead discards from the Gulf menhaden purse seine fishery were allocated based on the only available studies (>20 years old). There is no observer program for this fishery so there is no data to derive empirical estimates.

Discussion: Data Gaps in Trophic Ecology and Ecosystem Modeling

Multiple data providers attended and gave brief summaries of their programs, identified major gaps, and answered questions regarding the programs.

- The "Gut Lab" at the FWRI (led by Kevin Thompson) is one of the major providers of data in the Southeast region. The region has seen an increase in ecosystem modeling and it spurred gut analysis to support models. FWRI initiated its programs in 2005 to support this need and is now the largest gut content effort in the Gulf of Mexico. The Lab generates critical diet data for many of the West Florida Shelf ecosystem models. Data collection started with inshore samples but is now primarily based on SEAMAP. Adult specimens experience barotrauma when collected at depth so the major gap in data collection is for adult reef fishes. This is unfortunate because this suite of species is often of primary interest to many studies. The Gut Lab has three employees and has the capacity to look at guts from other states and partners, but lacks funding to do this systematically. FWRI has not been doing genetic gut content analysis; this would require changing field protocols and increase the difficulty of data collection. Despite NOAA's efforts to build modeling tools and capacity, many of the models currently available are still quite data limited.
- The Panama City Lab (SEFSC) has been working with the Pascagoula lab to collect stomachs from some of the regular fish surveys. They currently have approximately 1,000 samples which are largely teleosts (including many red snapper) and some elasmobranchs. They currently lack adequate funding to analyze these samples; however, they are being preserved with hopes that they may be analyzed in the

future. When collected using hook-and-line gear, there is some bias with bait being in the stomach and fish having empty stomachs to begin with.

The group noted that fundamental data are always needed and that agencies should be aware of these gaps and include them in funded projects. It was also observed that the NMFS cruises go out regularly and often have empty bunks, which can provide opportunities for students or academic partners to go out on an opportunistic basis; however, this does not address systemic data issues.

One potential task suggested for this workgroup was that it collate gut or stable isotope data that are available for each species and coordinate focus to some of the target species that are lacking data. An attendee also noted that there is a potential connection between the needs of this working group and students that are supported by NOAA's Office of Education Educational Partnership Program (EPP) with Minority Serving Institutions (MSIs) and scholarships. This program has undergraduate, Master's, and Ph.D. students who are often looking for applied research topics for their theses and who have a requirement to complete a NOAA Experiential Research Training Opportunity (NERTO) which entails a 3-month residency at a NOAA facility. Postdocs within the NOAA EPP Cooperative Science Centers (CSCs) also require a 6-month NOAA embedded assignment. These programs provide potential sources of manpower for filling information gaps. To participate, NOAA scientists just need to create a program description in the NOAA Student Scholarship Internship Opportunity Online (SSIO) System. Additional support is provided for the student, boat time, and field sampling but direct funding is not available for the hosting lab.

The group also discussed the GoMexSI database, which is a substantial effort led by Jim Simons that compiles trophic information from across the Gulf of Mexico. The data include entries from a historical literature search, as well as more recent data collections that were carried out as part of the effort. Succession planning for the management of database was unclear. There have been some conversations within NOAA regarding how the database should be maintained and potentially updated. Currently, the database does not include state data collection, so additional efforts would have to be put toward merging these data sources.

Comments initiated a discussion on model structure and consideration of whether bioenergetics should be considered. In particular, the group was asked to consider whether the right type of model for the data has been identified and the degree to which the models are projecting reality. One attendee noted that existing work with cetaceans and bioenergetics has led to an understanding of why predators may have certain prey preferences. They noted that there is scientific capacity (including within NOAA) to evaluate energetics, if that sort of analysis is desired. It was also noted that there is some interest in doing this work within NOAA Fisheries' Protected Resources Division. In terms of reproductive success, energetics and fatty acid content is a huge determinant, rather than biomass, and a participant posited that it could be worthwhile to shift away from the focus of biomass, given that biomass alone is a poor determinant of recruitment in stock assessments. There was some discussion regarding what would be required to jump from a model based on diet data to a model based on bioenergetics. A user of the Atlantis model pointed at that bioenergetics are not completely ignored within it because consumption affects reproductive success and changes body size and age, which are linked to feeding algorithms. Thus, the jump from a biomass model to a bioenergetics models is not necessarily significant.

Presentation: Trait-Based Tools to Inform Species Interactions in Data-Limited and Rapidly Changing Systems

Stephanie Green
Assistant Professor
Department of Biological Sciences
University of Alberta

To conclude the discussion on data gaps, the group heard details on a method developed to address situations where data are lacking. The presenter advocated accounting for changes in feeding relationships when predicting species abundance and distribution drawing lessons from the invasion of Indo-Pacific lionfish in the Atlantic. In systems that are rapidly changing, as would be the case for the spread of an invasive species, a study of impacts based on observational data may be limiting. This approach identified prey species that were most vulnerable, deviating from traditional diet analysis, and instead relied on the concept that there are particular traits that can be modeled to determine which species might be most susceptible to predation. These traits include prey morphology, physical or chemical defenses, aggregation behavior, body size, and diel behavior. Data showed that smaller prey species with narrow morphologies were at greater risk for predation than larger or deep-bodied species and that solitary, nocturnal species were more at risk than benthic cleaning species (Green et al., 2014). When examining interspecific variation between a mid-water roving predator, a demersal stalking predator, and a benthic ambush predator, there were discernible differences in the probability of encounter, strike, and capture in three different types of prey (Green et al., 2019). Finally, the presenter offered a short description of a regional-scale lionfish removal study being performed in St. Croix (USVI) and south Florida to determine if patterns and trends are consistent across different areas. Using albacore tuna as a second example, the presentation closed with the utility of using a traits-based approach in systems in which there are complex trophic interactions, diet composition is variable or unknown, and rapid range and abundance shifts are anticipated.

Emerging Topics for Further Discussion

During the lunch break, workshop participants were encouraged to add suggested discussion topics to the 'Idea Marina' (Appendix D). A number of topics were proposed, including understanding the ecosystem effects of invasive species, use of molecular techniques, a need to catalog non-traditional data to supplement cataloging of models, a merger of academic and scientific development timelines with regulatory timelines, and tactical use of ecosystem models in Monitoring and Adaptive Management. While time constraints prevented discussion of all these topics, it is worth acknowledging their mention as issues that workshop participants considered relevant to the meeting.

Concerns about invasive species and their impacts on Southeast US and Gulf of Mexico ecosystem productivity have been investigated to some degree. For example, Chagaris et al. (2017) investigated the impacts of the lionfish (*Pterois* spp.) invasion on harvest of native reef fish on the West Florida Shelf using an Ecopath with Ecosim framework. Similar work should be expanded to other areas of concern (Johnston et al. 2016) or other species, such as tiger shrimp *Penaeus monodon* (Fuller et al. 2014, Zink et al. 2019). As one of four topics comprising NOAA's current strategy for applying emerging science and technology (NOAA 2020), workshop participants noted the important role that 'Omics research and application will play in expanding ecology and ecological modeling in the southeast. For example, eDNA techniques should be developed and applied to monitor species presence and abundance, which could lead to less invasive sampling techniques and reduce ecological monitoring costs. More recent discussions between SEFSC and SERO regarding science needs have included discussion of employing sub-population level population genetics and other technologies, such as otolith microchemistry or stable isotopes, to identify and possibly quantify contributions to adult populations from specific estuaries. Workshop participants noted that, in order to support ecosystem modeling efforts, non-traditional data, such as unpublished datasets, white papers, grey literature, and local ecological knowledge, should be catalogued. This catalogue would ensure these sources of information could be readily searched for content which may be useful for specific modeling or management decision inquiries and reduces the duplication of literature review and data identification efforts.

Other concerns that were raised focused on the application of ecological modeling. Participants noted that there was a need to align or rectify timelines of academic and scientific ecosystem model development with shorter regulatory timelines which require model outputs to support the decision making process. Related to this concern is a desire to properly vet or review an ecosystem model and its assumptions, whether via a more internalized process akin to stock assessment reviews or externally via a peer-reviewed publication process, before its use in decision making. Others noted that an opportunity exists to increase the use of ecosystem modeling in Monitoring and Adaptive Management (MAM) applications.

Workshop Outcomes/Observations/Challenges

A two-hour section of the afternoon was dedicated to group discussion on various topics that had come up throughout the day, as well as items that had been put in the Idea Marina (Appendix D). Many of the points that were brought up identified challenges in advancing the use of ecosystem modeling in different management contexts, given the constraints that exist with staff and financial resources, management timelines, management buy-in, and review. Therefore, the discussion largely organized around a series of questions that addressed some of these limitations. These were:

Challenge Question 1: How can we can get more uptake of ecosystem models in management?

Challenge Question 2: What would a model review process look like for ecosystem models in the region?
Challenge Question 3: How do we communicate better and begin socializing these ideas with management processes?
Challenge Question 4: How do we address funding limitations?
Challenge Question 5: Where are examples of success that we can learn from?

Challenge Question 1: How we can get more uptake of ecosystem models in management?

A major undercurrent of this theme was the differing timelines for management and model development and whether and how to merge these timelines. In a perfect world, management would assess the potential impacts of a given project or action and a purpose-built model would be developed. The group acknowledged the limitations of such a scenario, given that many complex models take years to develop, but management is often under strict decision-making timelines. Model uptake would need to be more of an iterative process with management including frequent communication between managers and modelers. Managers need to have a better understanding of what models are available and which could potentially be used, whereas modelers need to have an understanding of the issues managers are struggling with and how models can help address these issues. There are many examples of models that have been useful for a management question (e.g., stock assessment) and thought that what was potentially missing was a peer review process to know when a model is useful for a certain type of management question. Case-by-case assessments could be considered, but there could also be standardized processes such as those that exist for stock assessment (e.g., the SEDAR process).

There was discussion of an iterative process, specifically regarding some of the large-scale restoration projects being proposed, and also for the MAM process going forward under the Trustee Implementation Groups. There is a need to integrate modeling activities not only into the projects that are proposed, but in the pre-planning stages. Models are being used in the pre-planning stages of the Barataria Bay proposed diversions project, and several modelers in the room had been involved in this process and could offer insights. Those models were developed on top of some existing similar work, and therefore could be adapted for the particular management question; however, funding was not sufficient to implement all of the recommendations that were made. Several group members expressed that there was something to be learned from the Barataria Bay diversions case study, in which the modeling came together with the management effectively, and there were some questions as to whether any best practices resulted from that process.

Challenge Question 2: What would a model review process look like for ecosystem models in the region?

In other regions, ecosystem models such as Atlantis have undergone formal reviews, and this was suggested as a good next step for the Southeast. Other regions have formed technical committees that are able to suggest appropriate approaches and can review models if they are applied to specific projects. The group was encouraged to think broadly about such processes so that they could be applied beyond the fishery management councils and to other management bodies. The Highly Migratory Species (HMS) Division is interested in participating in such endeavors, and the GMFMC Scientific and Statistical Committees is another source of expertise that could provide review, as is utilized in other regions. It was noted that the level of confidence one must have in a model is dependent on the application, and particularly litigation sensitivity; if the risk is high, peer-review or other independent reviews could be a good standard. Ecosystem modelers in the group noted that the level of review will be highly dependent on the familiarity of the reviewer with the modeling platform, and that there are many "cultural" differences that one would encounter. In some cases, the review process could become a roadblock to otherwise useful applications.

Models are not expected to be perfect, but rather that uncertainties need to be defined and described in a way that is useful in management. The group provided examples of sensitivity measures or validation measures, or best practices guidelines that have been set out by others (e.g., Kaplan and Marshall 2016). This working group would be in a good position to suggest potential participants in a review process, including individuals with diverse backgrounds such as physical scientists and industry members. It is important to have goals and objectives spelled out up front, but the group noted that in many cases (e.g., MAM planning) these goals are still in development.

Challenge Question 3: How do we communicate better and begin socializing these ideas with management processes?

In reference to the Gulf Council, the Ecosystem Technical Committee was mentioned as the most appropriate body with which to initiate discussions, before elaborating from there. Years ago, the Ecosystem SSC typically met more frequently, and that the timing was good to get that group meeting again. Chad Hanson noted that in the past, such an SSC would not be gathered to meet without specific discussion items. A presentation on how ecosystem models could be used was given to the SSC in March 2019 and was well received. At that time, the sentiment was that models could be used for some specific and discrete questions, and that this would open the door for more broader applications through time.

Some momentum is needed to be generated to keep such interest in model applications moving forward, but that it was very difficult to do so individually. Often during Council meetings, members will bring up specific issues or questions that could likely be informed by available tools. However, lacking some sort of communication network, it is difficult to gauge what tools are immediately available to inform such issues. Discussion then focused on how this informal working group could improve communication so that the rate of progress could increase. Council staff noted that there are meeting minutes for all Council meetings that are posted; however, these are lengthy and are not the most efficient mechanism for communication. Increased networking within the work group would likely lead to advances in applications. Examples were provided of recent issues that have come up that were informed with ecosystem models once communicated; these include shark depredation (which is thought to be increasing) and the impacts of red tide on grouper species. Issues that come up at Council meetings could be more formalized into actions, and that they might be more motivated to propose such actions if they were informed of information and tools that are available to them.

Challenge Question 3: How do we address funding limitations?

Members of the group noted that many good ideas had been brought up but that most of them would require additional resources to carry out effectively. A suggestion was offered to integrate priority management issues into federal funding opportunities such as MARFIN; the downside of such an approach would be that there is a long time lag between the time that the priority gets integrated into the funding opportunity and the funds are actually allocated to investigate it. Some members felt it was important to set appropriate expectations. Just as a stock assessment model could not be built overnight, it should not be assumed that ecosystem models are on the shelf and ready to use. The group recognized that it takes dedicated time and staff to work on these issues, and felt that additional resources should be put toward ecosystem modeling to inform management. At the same time, the group recognized that many management processes (in particular stock assessment processes) are overstretched and that carving out additional resources would continue to be a challenge. The new "research track" for stock assessment may afford some additional opportunities, though it was clarified that these assessments are being carried out with no additional resources (and a greater workload).

Challenge Question 5: Where are the examples of success that we can learn from?

The Barataria Bay Diversions project was considered a good example of a success story. Because of the significance of the project in terms of size and potential impact, there was a consistent focus on this area over an extended time. SERO came up with modeling needs and evaluated the models that were available to answer specific questions, using an expert review panel. That panel evaluated the various models with respect to the questions at hand, and concluded that they were not necessarily the most ideal, but that they were still useful. Following that finding was an iterative process of improving the models and checking back with the review panel with progress.

One of the gaps for managers was simply knowing what models are available and what sorts of questions they can address. A simple overview that targets a management audience could be a useful product. Group members expressed that it would also be useful for the community to understand what types of issues or management questions might be coming down the line. There were some relevant activities on the horizon for Monitoring and Adaptive Management, and that the Open Ocean Trustee Implementation Group (TIG) would be releasing its strategic plan in the 2020. Sometimes there are periods of outreach from the TIG to the scientific community, but that this was not consistent and that they were not necessarily reaching out to the correct people. In terms of model development, it is useful to think of simple questions and scenarios initially, and build complexity from that point. This is also helpful during the conceptual planning process. Managers need to also build an awareness of what models can and cannot accomplish.

Recommendations/Concluding Remarks

The group concluded the afternoon discussion by acknowledging the next steps that had been agreed upon. A workshop report would be put together and proposed several options for continuing communication. One option would be to ask for monthly updates on advancement or needs that could be shared with the group. Another option was to start a list-serve where such updates could be shared as they became available. The group concurred that an email list-serv would be useful. Group members questioned whether it was likely that meetings such as this could be continued in the future, and it was clarified that the present meeting was funded through the SEFSC through a source that could potentially be tapped into in future years. Group members expressed interest in maintaining communication through any mechanism that might be available, in order to keep the momentum in applying models in support of improved management.

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Appendix A. Workshop Participants and Affiliations

Name	Affiliation	Email Address
Cameron Ainsworth	University of South Florida	ainsworth@usf.edu
Jerald Ault	University of Miami Rosentiel School of Marine and Atmospheric Science	jault@rsmas.miami.edu
Elizabeth Babcock	University of Miami Rosentiel School of Marine and Atmospheric Science, Department of Marine Biology and Ecology	bbabcock@rsmas.miami.edu
Melissa Carle	DWH Monitoring and Adaptive Management	melissa.carle@noaa.gov
Joan Browder	SEFSC Protected Resources and Biodiversity	joan.browder@noaa.gov
David Chagaris	University of Florida IFAS Nature Coast Biological Station	dchagaris@ufl.edu
Kevin Craig	Beaufort Lab- Stock Assessment / Ecosystems	kevin.craig@noaa.gov
Jennifer Cudney	Atlantic HMS Management Division	jennifer.cudney@noaa.gov
Michael Drexler	Ocean Conservancy	ecosystem technical committee for Gulf
Kim de Mutsert	George Mason University	kdemutse@gmu.edu
Tom Dolan	DWH Monitoring and Adaptive Management	thomas.dolan@noaa.gov
Michael Drexler	Ocean Conservancy	mdrexler@oceanconservancy.org
Nick Farmer	SERO Species Conservation Branch	nick.farmer@noaa.gov
Ginny Fay	SERO Habitat Conservation Division	virginia.fay@noaa.gov
John Froeschke	Gulf of Mexico Fishery Management Council	john.froeschke@gulfcouncil.org
Sue Gerry	UF/FWRI	
Steve Giordano	SERO Directorate Office	steve.giordano@noaa.gov
Malloree Hagerty-Runoz	Florida Fish and Wildlife Commission	malloree.hagerty@myfwc.com
Chad Hanson	The Pew Charitable Trusts	chanson@pewtrusts.org
Chris Harvey	NWFSC Conservation Biology Division	chris.harvey@noaa.gov
Eric Hoffmayer	SEFSC Pascagoula Lab	eric.hoffmayer@noaa.gov
Dionne Hoskins-Brown	SEFSC Habitat Ecology Branch/Savannah State University	dionne.hoskins-brown@noaa.gov
Michael Jepson	SERO Social Sciences Division	mike.jepson@noaa.gov

Isaac Kaplan	NWFSC Conservation Biology Division	isaac.kaplan@noaa.gov
Mandy Karnauskas	SEFSC Directorate Office	mandy.karnauskas@noaa.gov
Josh Kilborn	University of South Florida	jpk@**mail.usf**.edu
Julianne Knight	Florida Fish and Wildlife Commission	julianne.knight@myfwc.com
Andrea Kroetz	SEFSC Panama City Lab	andrea.kroetz@noaa.gov
Susan Lowerre-Barbieri	University of Florida and Fish and Wildlife Research Institute	susan.lowerre-barbieri@myfwc.com
Sean Lucey	NEFSC Resource Evaluation & Assessment/Ecosystem Dynamics & Assessment Division	sean.lucey@noaa.gov
Michelle Masi	SEFSC Galveston Lab	michelle.masi@noaa.gov
John McGovern	SERO Sustainable Fisheries Division	john.mcgovern@noaa.gov
Natasha Mendez-Ferrer	Gulf of Mexico Fishery Management Council	natasha.mendez@gulfcouncil.org
Mark Miller	SERO Sustainable Fisheries	mark.wayne.miller@noaa.gov
Kelli O'Donnell	SERO Sustainable Fisheries Division	kelli.oDonnell@noaa.gov
Gabriel Ramos	Florida Fish and Wildlife Commission	gabriel.ramos@myfwc.com
Skyler Sagarese	SEFSC Sustainable Fisheries Division	skyler.sagarese@noaa.gov
Joe Serafy	SEFSC Protected Resources and Biodiversity Division	joe.serafy@noaa.gov
Carrie Simmons	Gulf of Mexico Fishery Management Council	carrie.simmons@gulfcouncil.org
Sarah Stephenson	SERO Sustainable Fisheries	sarah.stephenson@noaa.gov
Rachel Sweeney	NOAA Office of Habitat Conservation	rachel.sweeney@noaa.gov
Kevin Thompson	Florida Fish and Wildlife Commission	kevin.thompson@myfwc.com
Howard Townsend	NOAA Chesapeake Bay Office - Oxford Lab	howard.townsend@noaa.gov
Brittany Troast	University of Central Florida/ SERO	brittany.troast@rsmas.miami.edu
Lauren Waters	SERO Fisheries Management Division	lauren.waters@noaa.gov
Ian Zink	SEFSC Protected Resources and Biodiversity Division	ian.zink@noaa.gov

Appendix B. Workshop Agenda

Southeast Trophic Ecology and Ecosystem Modeling Working Group
Strategic Planning Meeting Agenda
St. Petersburg, FL, December 11th - 12th, 2019
University of South Florida - MSL Conference Room 134

Meeting Motivation

In recent years, the SEFSC has made major progress in its capacity to conduct ecosystem modeling in collaboration with its federal, state, academic and NGO partners. Thanks to scientific advances, as well as investments in the research community spurred by new funding such as the RESTORE Act, there are now a number of robust tools available for providing marine resource managers with strategic guidance. This strategic planning meeting builds on the extensive foundation of data collection and model development activities that have been conducted to date, and advances the outcomes from recent workshops relating to refining ecosystem model data inputs and management priorities. The objective of this meeting will be to create a specific action plan for the SEFSC and its collaborative partners to conduct ecosystem modeling in support of defined, high-priority resource management questions.

Meeting Objectives

- Familiarize the science and management community with how ecosystem models are being used to support decision-making in different regions around the country
- Understand the wider context of priority management issues in the Southeast region
- Review the suite of modeling tools in the Southeast region available to address ecosystem-level questions
- Identify data gaps and limitations in funding, time, or expertise
- Discuss actionable ecosystem model outputs and chart a path forward to address priority issues

Meeting Agenda

Wednesday, December 11th – Insights from other regions

3:00 Ecosystem modeling to management: examples from around the U.S.

Isaac Kaplan (NWFSC)
"Applications of ecosystem models for US West Coast fisheries management"
Sean Lucey (NEFSC)
Howard Townsend (OST)

5:30 Joint happy hour with concurrent NFWF-sponsored workshop attendees

"Gulf of Mexico Fishery Independent Monitoring Workshop" -- Dec. 12-13
The Ale and the Witch (111 2nd Ave NE, St. Pete, FL 33701)

Thursday, December 12th – Strategic Planning for the SE region

8:30 Arrival and welcome; workshop expectations and objectives

8:45 Introductions

9:00 Panel 1: Current management landscape in the Southeast U.S.
Natasha Mendez-Ferrer, Gulf of Mexico Fishery Management Council
Nick Farmer, SERO, *"SERO Ecosystem Modeling Needs"*
Steve Giordano, SERO
Jack McGovern (or designee), SERO

10:20 Coffee Break

10:30 Panel 2: Ecosystem modeling in the Southeast Region -- tools and applications
Elizabeth A. Babcock, University of Miami, *"Reviewing ecosystem models and monitoring programs to inform management in the GoM (E. Babcock & A. Gruss)"*
Cam Ainsworth, University of South Florida
Dave Chagaris, University of Florida
Kim DeMutsert, George Mason University, "*Using coupled ecosystem modeling to evaluate effects of nutrient and hypoxia reductions on living marine resources (K. de Mutsert, A. Laurent & J. Buszowski)"*

11:50 Discussion
Visit the idea marina, structure afternoon discussion

12:15 Lunch (working lunch in meeting room)

1:15 Panel 3: Data availability and data gaps
Skyler Sagarese, SEFSC, *"Informing data gaps with regard to menhaden predation"*
Stephanie Green, University of Alberta (remote)
Other data providers available to give overviews

1:45 Discussion of priority research themes

2:00 Breakout group or plenary discussions
Determine priority gaps in data, funding and expertise and chart course for future work

3:15 Coffee break

3:30 Plenary discussion
Document short-term and long-term action items
Concluding thoughts and remarks

4:30 Adjourn

Appendix C. Idea Marina

This section documents ideas and topics for further discussion that arose over the course of the meeting.

1. Top Research Priorities

Thematic areas emerging from recent ecosystem workshops and management input:

- Implications of future climate conditions on habitat, effectiveness of restoration, fish populations, shifting fish distributions, fishing communities
- Linkages between habitat restoration and fisheries productivity
- Management of forage fish species
- Impacts of lionfish invasion
- Combined impacts of Gulf restoration on Deepwater Horizon injured species

Other issues: Hypoxia, red tide, impact of increased shark abundances on reef fish, bycatch and discards, sediment diversions, shelf impacts and connectivity to offshore fisheries

Chagaris et al. (2019) Marine Policy findings

More Urgent/More Important

- Managers: catch targets, management tradeoffs, natural mortality, SEDAR integration, stock-recruit relationships
- Scientists: communication, gap analysis, lionfish, management tradeoffs, red tides, spatial management, unintended consequences

2. Strategic vs Tactical advice

- How to bridge the gap between ecosystem models and management actions
  - Dave's red tide work during stock assessment process for gag and red grouper
- Research Track Assessments include Terms of Reference (ToRs) covering ecosystem model data inputs (see for example http://sedarweb.org/docs/supp/S68_Scamp_ToRs_FINAL.pdf, TOR #7)
  - Success of these TORs will likely depend on external resources. There is an excellent opportunity for academics/students/others to contribute to SEDAR process
- How to move beyond simply tweaking stock assessments and getting lost in the modeling. Focusing too narrowly on intricacies of model doesn't help management much in real time decision-making and can be a missed opportunity for the SEFSC. What would be very helpful is for management to have "access" to a group of people who can provide insight to parameters/species on which the management side needs to recommend to another agency

3. Model Review

- There is a need for a peer-review just like stock assessment process
- How to conduct review (SEDAR? Outside SEDAR? CIE)
- Who will lead efforts? (Michelle Masi/Cameron Ainsworth - Atlantis)

- Resource: Kaplan, I. C., and Marshall, K. N. 2016. *A Guinea Pig's Tale: Learning to Review End-to-End Marine Ecosystem Models for Management Applications* ICES Journal of Marine Science, 73(7):1715-1724. https://doi.org/10.1093/icesjms/fsw047

4. Gaps in Diet Composition

- With limited resources, should we prioritize investing in GOMEXSI or fund new diet studies? What is the future for GoMEXSI? Funding? Staff? Maintenance? Utility?
- Augment diet composition with input from fishermen/LEK workshops?
  Resource: Bentley, J. W., Hines, D. E., Borrett, S. R., Serpetti, N., Hernandez-Milian, G., Fox, C., Heymans, J. J., and Reid, D. G. 2019. *Combining scientific and fishers' knowledge to co-create indicators of food web structure and function* ICES Journal of Marine Science, 76(7):2218–2234, https://doi.org/10.1093/icesjms/fsz121
- Note: Cameron Ainsworth has a large diet data set already, with error (Masi et al. 2014 + Tarnecki et al. 2016 + Morzaria-Luna et al. 2019 = 52,925 stomachs), and this could be utilized across models
- South Atlantic data?

5. Gut Content Analysis vs Stable Isotopes

- Stable isotopes – could be used to determine outcome of restoration efforts
- Can we incorporate stable isotopes into ecosystem models? Use as a check for TL estimates?

6. Potential funding sources for future work:

- SEFSC Request For Ideas, Others?
- QUEST program (training students)
- NMFS/Sea Grant Fellowship

Opportunities:

- Restoration, NEPA, EIS, other processes have more predictable schedules
- Multiple clients
- Strategic planning currently going on
- Not just federal but states and their restoration plans
- Bycatch practicability analysis - consequences of proposed actions - currently no dynamic feedback
- Ocean Modeling Forum (UW)
- Funding projects that already propose multi-model approaches
- Fisheries Model Intercomparison Group

Bottlenecks:

- Flexible models have long development time, strategic planning needs
- Vetting models with the agencies, getting the confidence such that they can be used as best available science
- Need to incorporate multi-model inference in projects from the start (project planning timescales)

Appendix D. Description of SEFSC ecosystem modeling capacity

Ecopath

To support EBFM within the Gulf of Mexico Large Marine Ecosystem, research pertaining to ecosystem dynamics as they relate to forage species dynamics (e.g., menhaden) is needed including: (1) consideration of ecological interactions (e.g., predator-prey) in modeling ecosystem dynamics to assess structure and function of marine ecosystems; and (2) development of ecological indices (e.g., natural mortality due to predation) for consideration and ultimately incorporation into stock assessments. An Ecopath model of the northern U.S. GoM was initially developed to fill in key data gaps in previous ecosystem models, with a particular emphasis on the trophic importance of Gulf menhaden (i.e., the importance of menhaden to higher trophic level species; Sagarese et al. 2016) and comprehensive consideration of discards for fisheries in the Gulf of Mexico, including the menhaden purse seine reduction fishery. The model was designed to focus on federally (i.e., NMFS) and internationally (ICCAT) managed species as well as protected species such as dolphins and seabirds. The spatial domain covered an area of approximately 310,000 km2 within the northern GoM and 2,934 km of U.S. coastline from Brownsville, Texas to the Florida Keys and extended roughly to 400 m depth in the pelagic environment (Figure 1; Sagarese et al. 2017). This model focused on the time-frame 2005-2009 and included a total of 75 functional groups including one marine mammal group, one seabird group, one sea turtle group, eight shark groups, 53 fish groups, seven invertebrate groups, three primary producer (PP) groups, and one detritus group.

Recent efforts have included updating the U.S. Gulf-wide Ecopath model to reflect 1980 conditions and calibrating predicted dynamics to time series of observed biomass and catches for the period 1980 to 2016. This work has been funded via the Restore Science Program (https://restoreactscienceprogram.noaa.gov/projects/fisheries-ecosystem-models) as a component of a larger project aimed at refining Gulf of Mexico ecosystem models and working in concert with fisheries managers to make sure the model outputs are relevant to the decisions managers face (Chagaris et al. 2018). Once calibrated, the U.S. Gulf-wide EwE model will be available for use to simulate potential restoration measures for the GoM, including changes in species biomass related to reduced fishing effort, mortality, and bycatch. A better understanding of predator-prey interrelationships and the impact of massive prey removals may be gained by identifying key policies that target one component of the food web, evaluating the predicted responses of associated predators and prey using the ecosystem model, and monitoring the observed changes in populations.

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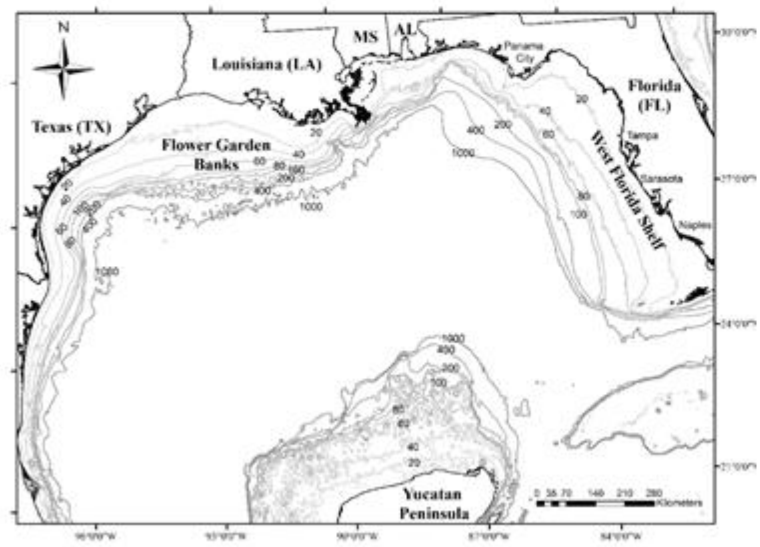

Figure 1. Map of the northern Gulf of Mexico with depth contours (m) identifiable by solid lines. The modeled area spans approximately 310,000 km2 in U.S. waters between the land mass and the 400-m dashed contour line.

Atlantis

The developed Gulf of Mexico (GoM) Atlantis model includes 91 species and biological groups, 23 commercial and recreational fishing fleets, as well as dynamic oceanography and habitat effects (Ainsworth et al. 2015). Of the 91 functional groups accounted for in the GoM Atlantis model, 72 functional groups are harvested single-species groups – allowing for analytical outputs at both a species and ecosystem level. Harvested single-species groups include both state and federally managed species, and combined with the aggregate functional groups in the model, holistically represents all trophic levels of the GoM marine ecosystem (Table 1). The utility of using Atlantis, a spatially-explicit biogeochemical model (Fulton et al. 2004c), is to inclusively represent an extensive suite of ecosystem processes that can influence fisheries productivity and safe harvest rates across both space (including in 3 dimensions; see Figure 1 a. and b.) and time (e.g. both historic and forward-looking simulations). Representing these integrated ecosystem processes is essential to achieving EBFM, a NMFS priority.

Recent applications have used the GoM Atlantis model to analyze the impacts of oil spills (Ainsworth et al. 2018; Morzaria-Luna et al. 2018), to define ecological indicators sensitive to variable fishing mortality (Masi et al. 2016), and to test harvest control rules for GoM fisheries (Masi et al. 2018). Both the NWFSC and NEFSC have developed and are applying Atlantis ecosystem models in management applications (Kaplan et al. 2013; Kaplan and Marshall, 2016; Olsen et al. 2018). Although research-based applications using the GoM Atlantis model are ongoing, to date the SEFSC and the GMFMC have not applied the GoM Atlantis model to provide strategic advice. Recently, Dr. Michelle Masi - who has expertise using Atlantis to address ecological hypotheses, and is proficient in the EwE modeling platform, joined the SEFSC. Currently, she works full-time as a stock assessment analyst and her ecosystem modeling expertise has been untapped.

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Tables and Figures

Table 1. Atlantis Model Functional Groups

Guild	Functional Groups
Reef Fish	Gag Grouper, Red Grouper, Scamp, Shallow Serranidae, Deep Serranidae, Red Snapper, Vermilion Snapper, Lutjanidae, Bioeroding Fish, Large Reef Fish, Small Reef Fish
Demersal Fish	Black Drum, Red Drum, Seatrout, Small Sciaenidae, Ladyfish, Mullets, Pompano, Sheepshead, Snook, Flatfish, Cryptic Fish, Other Demersals
Pelagic Fish	Bluefin Tuna, Little Tunny, Other Tuna, Swordfish, White Marlin, Blue Marlin, Other Billfish, King Mackerel, Spanish Mackerel, Spanish Sardine, Large Pelagic Fish, Mesopelagic Fish
Forage	Menhaden, Pinfish, Medium Pelagic Fish, Small Pelagic Fish
Elasmobranchs	Blacktip Shark, Benthic Feeding Sharks, Large Sharks, Filter Feeding Sharks, Skates and Rays
Shrimp	Brown Shrimp, White Shrimp, Pink Shrimp, Other Shrimp
Seabirds	Diving Birds, Surface Feeding Birds
Mammals	Manatee, Mysticeti, Dolphins and Porpoises, Deep Diving Odontocetae
Turtles	Loggerhead, Kemps Ridley, Other Turtles
Structural Species	Stony Corals, Crustose Coralline Algae, Octocorals, Sponges
Macrobenthos	Blue Crab, Stone Crab, Crabs and Lobsters, Large Crabs/Lobsters, Carnivorous Macrobenthos, Infaunal Meiobenthos, Benthic Grazers
Filter Feeders	Oysters, Bivalves, Sessile Filter Feeders
Primary Producers	Epiphytes, Sea Grass, Macroalgae, Microphytobenthos, Large Phytoplankton, Small Phytoplankton, Toxic Dinoflagellates, Protists

Pelagic Invertebrates	Jellyfish, Squid, Large Zooplankton, Small Zooplankton
Nutrient Cycle	Carrion Detritus, Labile Detritus, Refractory Detritus

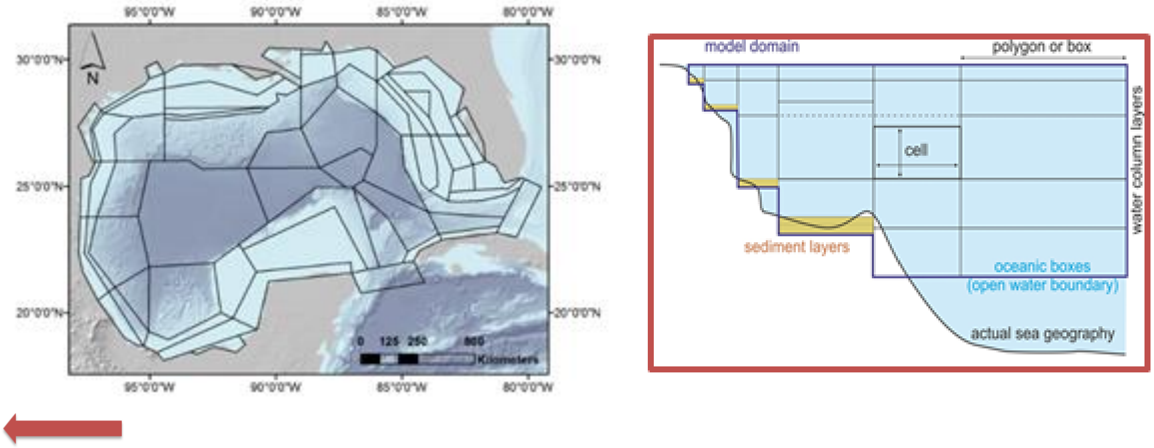

Figure 1. Description of the Atlantis Model. (a) Atlantis is a spatial, (b) 3D model (with up to 6 depth layers, including sediment layers). Each of the 66 Atlantis polygons have a varying number of depth layers (from 10 m to 4000 m), depending on the maximum depth of the represented subarea. These depth layers allow for explicit representation of biological and oceanic process across space and time.