Management Challenges are Opportunities for Fisheries Ecosystem Models in the Gulf of Mexico

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Abstract

Fisheries resources in the U.S. Gulf of Mexico (GoM) are under increasing pressure from both natural and anthropogenic stressors that have potentially broad effects on the ecosystem and introduce considerable uncertainty into management outcomes. To address these issues, more holistic, ecosystem-based tools are needed to inform decision-making. A Scoping Workshop with scientists, managers, and other stakeholders was held to identify and prioritize challenges in the GoM that could be addressed using ecosystem models, and how best to incorporate those models into the existing fisheries assessment and management framework. Challenges identified were associated with uncertainty in stock assessments, environmental stressors, multi-species reference points, invasive species, habitat effects, spatial management, and forage fisheries. Short-term priorities included those that address critical assumptions in stock assessments and inform imminent decision making, whereas long-term priorities were those associated with environmental stressors and novel management approaches. This information is intended to guide future ecosystem modeling efforts and help advance ecosystem based fisheries management in the region.

1. Introduction

The U.S. Gulf of Mexico (GoM) supports some of the most valuable and productive fisheries in the world. In 2016, the annual dockside value of commercial seafood landings from the GoM exceeded $900 billion USD and more than 20 million recreational fishing trips were taken [1]. Fisheries resources in the GoM are under increasing pressure from both natural and anthropogenic stressors that have potentially broad effects on the ecosystem. The diversity and multi-species nature of the fisheries along with environmental variability and complex food web and habitat interactions introduce considerable uncertainty into management outcomes. In order to address these issues, more holistic, ecosystem-based fisheries management (EBFM) tools are needed to aid in decision-making. Ecosystem models were first developed in the GoM at least as early as 1983 [2], and there have been numerous applications of Ecopath with Ecosim (EwE) as well as Atlantis ecosystem models [3]. Despite this long history of ecosystem modeling and growing support for ecosystem-based approaches, the models have not been part of the decision-making process. One reason is that most modeling studies have been informative and strategic, rather than tied to a management action [4]. Ecosystem modeling activities have also not been well coordinated with the management timeline and information has not been available when needed. Current modeling efforts in the GoM [5, 6] are seeking to resolve these shortcomings through better planning and collaboration with managers.

A Scoping Workshop was held to identify, from the perspective of fisheries managers, the important questions that we should be asking of GoM ecosystem models and how to better integrate them into the management process. Participants included representatives from five fisheries management bodies in the GoM, each with different but overlapping jurisdictions and responsibilities (Table 1). The workshop consisted of presentations by managers and stakeholders that highlighted their current and future challenges, round-table discussions, and a prioritization activity. This paper summarizes the important management questions identified in the Scoping Workshop and is intended to guide future ecosystem modeling efforts and advance EBFM in the Gulf of Mexico as well as in other regions with similar challenges.

Table 1. Fisheries management agencies represented at the Scoping Workshop along with broad jurisdictions and responsibilities.

Title	Jurisdiction and Responsibility
Gulf of Mexico Fisheries Management Council (GMFMC)	• Fishery resources in the federal waters of the Gulf of Mexico • Consists of scientific and stakeholder advisory committees • Prepares Fishery Management Plans and makes recommendations based on scientific and public input • Complies with National Standards laid out by the Magnuson Stevens Act
GMFMC Scientific and Statistical Committees (SSC)	• Composed of quantitative fish biologists/ecologists, stock assessment/ecosystem modelers, economists, and anthropologists • Provides expert scientific and technical advice to the Council • Reviews statistical, biological, economic, social, and other relevant information • Makes catch limit recommendations, sets the acceptable biological catch
NOAA Southeast Fisheries Science Center (SEFSC)	• Responsible for multi-disciplinary research to support management of living marine resources in the GoM, South Atlantic, U.S. Caribbean, and Atlantic (Highly Migratory Species) • Responds to needs of regional councils and interjurisdictional commissions • Fisheries statistics and data collection, stock assessments, protected species biology, fish ecology, fishery economics, engineering and gear development
NOAA Southeast Regional Office (SERO)	• Rebuild and sustain fisheries, recover protected species, and restore and enhance important marine, estuarine, and riverine habitats in the Gulf of Mexico, South Atlantic, and U.S. Caribbean • Works with regional fishery management councils to implement requirements of the Magnuson-Stevens Fishery Conservation and Management Act • Oversees National Environmental Policy Act compliance, regional aquaculture programs, and Gulf of Mexico Environmental Compliance Programs for restoration projects • Protected resources division manages marine mammals and endangered and threaten species
Gulf States Marine Fisheries Commission (GSMFC)	• Coordinates fisheries management in Gulf of Mexico state waters • Data collection and dissemination, stock assessments for state-managed species, fisheries disaster recovery, interjurisdictional management, sportfish restoration • Develops fishery management plan for Gulf Menhaden
Florida Fish and Wildlife Conservation Commission (FWC)	• Conducts research, data collection, stock assessments, and restoration of ecosystems, fisheries, wildlife, imperiled species, and red tides in Florida • Develops regulatory and management recommendations designed to ensure the long-term conservation of Florida's marine fisheries resources. • Liaison to federal agencies and represented on regional fishery management councils.

2. Management Questions for Gulf of Mexico Ecosystem Models

2.1 What are the effects of environmental stressors on exploited fish stocks and marine ecosystems?

A critical need exists to quantify the effects of environmental disturbances on fish stocks, whether they be geographically large and persistent, or acute localize events. For instance, red tides and other harmful algal blooms occur throughout the GoM but are particularly severe on the west coast of Florida where they often result in massive fish kills, including valuable grouper species [7, 8]. When blooms are present, contemporaneous estimates of their effects on fish stocks are not available to managers who must decide whether and how much to reduce harvest in order to compensate for lost biomass. Another reoccurring disturbance is the hypoxic zone that forms each off the Mississippi River, with 2017 being the largest on record at 22,720 km^2 [9]. This “dead zone” is driven by nutrient inputs and may kill some fish while reducing the amount of suitable habitat for others, forcing them to move [10] into areas where they are more vulnerable to predation or harvest. Evaluations with an ecosystem model suggested that impacts of the hypoxic zone are mixed across species, but in general do not outweigh the positive effects of increased productivity through nutrient loading [11]. An example of an acute disturbance is the the Deepwater Horizon (DWH) disaster, which resulted in the largest marine oil spill in history that affected marine life at the individual, population, and community level [12], however these effects have not been quantified in a way that is useful to fisheries managers. Lastly, climate change has the potential to shift species distribution patterns and food web interactions, alter rates of reproduction and growth, affect recruitment success, and degrade habitat, thereby affecting stock status, species composition of the catch and economic value [13, 14, 15]. When assessing the impacts of environmental stressors on marine fisheries and ecosystems, it is important to provide both localized and regional estimates while also accounting for fish movement, food web impacts, and habitat mediations. Furthermore, the cumulative effects of fishing along with those caused by chronic and episodic events need to be considered [16]. Ecosystem models provide a platform to quantify impacts of environmental stressors, in terms of mortality rates and biomass responses, but more importantly can be structured as management strategy evaluations (MSE) to test performance of different management responses under these uncertainties.

2.2 Do multi-species reference points lead to better management outcomes?

Interspecific competition or top-down predation effects may result in tradeoffs, where rebuilding or harvest of one species has negative effects on others. Due to these interactions, questions have been raised about whether single-species MSY-based reference points and annual catch limits (ACLs) are appropriate in multi-species fisheries [17] and if these reference points result in the optimal system-wide harvest strategy [18]. For unassessed or data-limited stocks, as well as those that cannot be caught independently of others, one option is to group species together and manage the complex with an aggregate ACL [19]. Going further, optimum yield (OY) could be defined at the level of stock complex or the entire ecosystem, which would set a cap on total removals in order to increase resiliency to overfishing and balance ecological and socio-economic tradeoffs [20]. Moving towards OY-based reference points in the GoM, and especially those that are estimated inclusive of ecosystem interactions, would represent a shift towards setting target rather than threshold reference points for fisheries management. The concept of system-wide OY has been in practice for North Pacific groundfish fisheries for several decades where OY is usually ~75% of the sum of each species' MSY and the allowable catch of each stock is then optimized [21]. Ecosystem models can play a key role in first defining system-wide OY and then conducting trade-off analysis to optimize catch of individual stocks [20]. A fishery-wide OY would be especially useful in the GoM reef fish fishery where many stocks are data limited, species are closely related through food web and habitat preferences, and many species are difficult to avoid catching while fishing for others.

2.3 What are the impacts of invasive Lionfish and how do we mitigate them?

Indo-Pacific Lionfish (*Pterois volitans*) invaded the GoM in 2010, and densities on artificial reefs there have grown to some of the highest in their invaded range [22]. While the effects of Lionfish on small demersal reef fish have been well documented [23], considerable uncertainty remains regarding the long term effects on exploited species and their food webs. Juveniles of Vermilion and Red Snapper (*Rhombopolites aurorubens* and *Lutjanus campechanus*) have been observed in Lionfish stomachs [24] and recent ecosystem modeling suggests that Lionfish may also have modest negative impacts on large groupers [25], due to indirect food web effects. Management agencies in Florida and the GoM have promoted Lionfish spearfishing and de-regulated lionfish harvest as a way to control population size. Lionfish traps are being tested as a way to harvest them from mesophotic reefs that are beyond the depths of recreational diving [26]. There is a need to quantify the potential impacts of Lionfish on both exploited and non-exploited reef fishes across depths, habitats, and regions and ecosystem models can serve to scale-up the results from localized studies [27]. Additionally, ecosystem models should be configured to simulate Lionfish harvest scenarios and set achievable targets for proposed mitigation activities.

2.4 To what degree does habitat contribute to fisheries productivity?

Gulf of Mexico habitats such as corals, seagrass, reef banks, and intertidal areas are designated as Essential Fish Habitat, Habitat Areas of Particular Concern, or Critical Habitat under the Endangered Species Act. However, little is known about how these ecosystems quantitatively contribute to the productivity of GoM fisheries. Following the DWH disaster and subsequent legal settlements, large-scale habitat restoration has begun in the GoM, and there is a need to incorporate ecosystem models into the design and assessment of restoration projects [28, 29, 30]. Artificial reefs continue to be promoted as a way to restore fishing opportunities but the debate continues about whether they are effective at enhancing stock productivity or only increase catchability [31, 32]. Spatially-explicit simulation tools have been developed to address specific questions about the effects of habitat alteration on fish populations [33, 34]. Management agencies such as NOAA and the GMFMC have dedicated resources towards habitat-related issues, however that work largely occurs outside of the fisheries assessment and management process. Ecosystem models provide a framework to integrate habitat management with fisheries, for example, by linking growth, survival, and ecosystem productivity to habitat quality and simulating policy options under habitat alteration scenarios.

2.5 Can spatial management enhance sustainability and recovery of exploited species?

Marine Protected Areas (MPAs) in the GoM include several small marine sanctuaries and larger areas that are closed seasonally to certain fishing gears. These were established to protect spawning aggregations, reduce interactions with protected species, or preserve critical habitats. In the GoM, a formal evaluation of sizes and placements of MPAs has not been conducted. Where MPAs were implemented with a goal of enhancing exploited fish stocks, local benefits (e.g. larger fish, higher densities, and improved sex ratios) [35] have been observed but the effects on overall stock size are still undetermined. Managing fisheries in the GoM is further complicated by different regulations (size/bag limits, harvest seasons) in state versus federal waters. Little is known regarding whether more conservative measures in one area translate to stock improvements in that region or overall. This is because important spatial processes such as how fish recruit to, and move between, jurisdictional boundaries, and the spatial distribution of fishing effort have not been incorporated into fishery policy evaluations [36]. While these options could be explored using spatially explicit single-species models, ecosystem models are better suited to elucidate indirect multi-species responses, such as increased bycatch due to spatial effort shifting and food web effects associated with changes in fish biomass within management areas.

2.6 How to account for ecosystem services when managing forage fisheries?

A common tradeoff facing fisheries managers involves allocating forage fish production to harvest versus allowing it to support predator populations [37]. In 2017, 460,707 mt of Gulf Menhaden (*Brevoortia patronus*) were harvested from the GoM, making it the largest fishery by weight in the GoM and ranking second in the U.S. [38]. There are numerous predators on Gulf Menhaden [39] and a stated goal of the Gulf Menhaden fishery management plan is to maintain menhaden populations at levels that support their role as prey, while also ensuring economically viable fisheries [40]. However, many menhaden predators are also generalists, feeding on a suite of available prey items so the relationships between menhaden harvest and predator populations is less clear. More research is needed to determine the trophic role of Gulf Menhaden, identify dependent predators, quantify abundance of alternative prey, estimate transfer efficiencies, and account for important bottom-up processes. Ecosystem models are particularly useful in their ability to integrate datasets on predator diet compositions, population dynamics, and environmental drivers to provide management advice in these predator-prey systems [41].

2.7 In what ways can ecosystem models help improve stock assessments?

The next generation of stock assessments will need to consider multispecies interactions, environmental drivers, seasonality, and spatial processes [42]. In Stock Synthesis (SS) assessment models, the modeling platform used for most GoM stock assessments, parameters for growth, catchability, mortality, and recruitment can be linked to environmental factors [43]. However, justification for such linkages has often been correlative and lacking strong empirical evidence. Stock-recruitment parameters (i.e. steepness) for many stocks are poorly estimated and primary drivers behind year class strength are largely unknown. Furthermore, mean recruitment estimates used for stock projections are lagged by several years and may not reflect current recruitment observations, emphasizing the need for contemporary estimates of recruitment [44] for policy evaluation. Natural mortality rates directly affect stock productivity estimates, yet they are based on simple assumptions about life history and assumed to be constant over time in stock assessments, even though it is believed that environmental conditions and predator populations are likely to influence survival. In summary, there is considerable uncertainty around stock recruit relationships, environmental drivers, and natural mortality in fisheries stock assessments. Many ecosystem models explicitly account for these processes and through model fitting and hypothesis testing they can provide insight into the important drivers that should be considered in the single species assessment models. Ultimately, ecosystem models can be used to generate inputs for stock assessment, such as time and age varying estimates of natural mortality [45, 46, 47] and priors for stock-recruit parameters, or used as operating models to conduct single-species MSE [48].

3. Prioritizing Management Needs

During the Scoping Workshop, participants were asked to complete a priority matrix (Figure 1) by assigning the research topics described above and in Table 2 to a quadrat classified as more or less important and more or less urgent. In this approach, topics classified as important and urgent (Box 1) are of highest priority and should be addressed immediately. Topics classified as important but not urgent (Box 2) emphasize long-term challenges. Those classified as less important and urgent (Box 3) are potential time-pressured distractions and those grouped into Box 4 are of minimal interest to stakeholders. The priority matrix was completed by 15 participants from the workshop, including eight end users (representing state or federal fisheries management agencies in Table 1) and seven agency or academic scientists. The results were combined and the number of votes for each topic in each quadrat were counted.

Table 2. A summary of the management topics identified at the Scoping Workshop and included in the prioritization exercise.

Topic	Context for Management
Artificial reefs	How do artificial reefs function to support spawning biomass, provide essential fish habitat, increase stock productivity, and enhance fishery catchability.
Catch targets	Use ecosystem models to develop catch targets (OY) rather thresholds (ACLs), inform buffers between the acceptable biological catch and the annual catch limit, evaluate reference points for data limited species, and quantify uncertainty in ACL projections.
Climate change	Quantify the expected impacts of climate change on fish stocks and fisheries, including shifts in spatial distribution patterns and resulting changes to the food web and species catch composition, as well as effects on population survival and stock productivity.
Communication	Develop non-technical communication products and visualization tools for managers and general public to improve understanding of ecosystem models and EBFM concepts.
Cumulative effects	Quantify the combined effects of fishing and environmental effects on managed species and the ecosystem as whole.
Data gap analysis	Describe availability of baseline data for ecosystem models, how that availability limits model utility, and make research recommendations.
Ecological Restoration	Incorporate large-scale habitat restoration into fisheries models where appropriate.
Ecosystem metrics	Evaluate changes in ecological indicators such as species diversity, system ascendancy, energy flows, cycles, and pathways associated with policy options.
Episodic events	Quantify the acute and chronic effects of episodic events (e.g. oil spills, red tides, cold kills) on fish mortality and stock productivity at both localized and regional scales.
Habitat	How do different habitat types (e.g. corals, seagrass, oysters, reef banks), especially those defined as essential fish habitat (EFH) and habitat areas of particular concern (HAPC) contribute to fisheries productivity.
Hypoxia	How does large-scale hypoxic conditions, and in particular the 'dead zone' near the Mississippi River, affect fish stocks and fisheries.
Lionfish	Quantify the long term effects of invasive lionfish on reef food webs and managed reef fish species and develop removal targets to mitigate impacts.
Management tradeoffs	Identify tradeoffs in broad-scale and strategic management objectives (e.g. conservation vs. fishery profits) and search for policies that optimize those objectives.
Marine Protected Areas (MPA)	Quantify the localized and stock-wide benefits of current MPAs and develop tools to evaluate the size and placement of proposed MPAs
Model review	Conduct a formal and technical review of ecosystem models.
Model skill assessment	Demonstrate predictability of ecosystem models by comparing predictions in retrospect of past management actions and over a range of time durations.
Multispecies management	Define the tradeoffs associated with harvest strategies and the ecological interactions between species, especially in predator-prey systems (forage fisheries), and develop reference points for aggregate species complexes such as reef fish.
Natural mortality	Estimate changes in natural mortality over time, age, and habitats and partition it into components of predation, episodic, and other mortality.
Red tides	Quantify the effects of red tide on fish stocks and the ecosystem as a whole both locally and regionally.
Role of menhaden	Define the ecological role of Gulf Menhaden by identifying dependent predators, and estimating energy transfer efficiencies with respect to availability and consumption of other prey.
SEDAR integration	Align ecosystem modeling efforts with 5-year stock assessment calendar, add ecosystem considerations component to stock assessment workshops, and provide ecosystem dynamics alongside single-species model projections.

Topic	Context for Management
Spatial management	Develop spatially explicit ecosystem models to evaluate how regional management options affect overall stock sizes. Models should account for spatial effort dynamics, fish movement, species distribution patterns.
Stock-recruit relationships	Examine stock-recruit relationships and environmental drivers of recruitment to provide better informed parameter estimates for stock assessment models.
Unintended consequences	Conduct ecological risk assessment to identify winners and losers associated with proposed policy options.

Managers and scientists did not always agree on the priority status of each topic, and in general there was better consensus within the manager group than within scientists (Figure 1). A notable exception among managers is the lack of consensus with regards to the importance and urgency of incorporating climate change effects into management. This result may be reflective of the varying purviews of each agency and may also highlight an area of disconnect among management bodies on an issue with potentially broad impacts. Topics most frequently assigned to Box 1 by the fishery managers were those that directly inform decision making (e.g. setting catch targets, evaluating management tradeoffs) and improve stock assessments (e.g. natural mortality, stock-recruitment relationships, and SEDAR integration). In most cases, these topics were deemed to be either less urgent and/or less important for scientists. The topics most frequently assigned in Box 2 by end users largely represented environmental processes such as episodic events, habitat effects, broader multi-species management approaches, and spatially explicit management with considerable overlap with scientists in this quadrant. Additionally, improving communication ranked high as a long-term need by managers. Ecosystem metrics were most often assigned to box 3 by managers, suggesting that this type of information might be esoteric and of little immediate use for setting policy whereas this topic was tied among scientists in boxes 1-3. Lastly, Box 4 ranked highest by managers for quantifying the role of menhaden in the ecosystem and data gap analysis. This reflects a preference for more actionable model outputs and the notion that data limitations are largely known by managers.

		More Urgent	Less Urgent
More Important	Managers	**1** catch targets, management tradeoffs, natural mortality, SEDAR integration, stock-recruit relationships *climate change, cumulative effects, lionfish*	**2** artificial reefs, communication, episodic events, habitat, hypoxia, MPAs, multi-species management, spatial management, unintended consequences *climate change, cumulative effects, model review, red tides, restoration*
	Scientists	communication, gap analysis, lionfish, management tradeoffs, red tides, spatial management, unintended consequences *catch targets, ecosystem metrics, episodic events, multi-species management*	climate change, cumulative effects, hypoxia, stock-recruit relationships *artificial reefs, ecosystem metrics, episodic events, habitat, MPAs, natural mortality, role of menhaden*
Less Important	Managers	**3** ecosystem metrics *climate change, lionfish, model skill assessment, red tides*	**4** gap analysis, role of menhaden *climate change*
	Scientists	SEDAR integration *ecosystem metrics, model review & skill assessment, natural mortality, restoration*	MPAs *natural mortality*

Figure 1. Prioritized research areas for ecosystem approaches that support fisheries management. A topic was classified into a box if it received votes from at least half of each group's participants (8 managers and 7 scientists). Topics are italicized when the maximum number of votes was fewer than half and ties appear in multiple boxes. See Table 2 for a brief definition of each research topic.

4. Considerations for Integrating Ecosystem Models into Management

4.1 A process for technical review

Ecosystem models in the GoM have not undergone rigorous technical review like those developed for the west coast USA [49] and northeast USA [50], which greatly limits the degree to which they can be used for actual management application. Thus, GoM ecosystem models must undergo formal review and vetting, as done for stock assessments, possibly through the Center for Independent Experts peer review program (www.st.nmfs.noaa.gov/science-quality-assurance/cie-peer-reviews/index). A critical review should include gap analysis to identify where data limitations may hinder ecosystem analyses, description of critical assumptions, evaluation of model stability, demonstration of fits to observed data, comparison of model outputs with other approaches, and sensitivity analysis [49]. The review panel should be composed of technical and scientific advisors with knowledge of GoM fisheries and datasets as well as external independent reviewers with expertise in ecosystem modeling. To facilitate review and increase transparency, model developers should provide the panel a technical report clearly documenting all data inputs and scenario configurations.

4.2 Working within the existing management framework

Several appropriate venues are available where ecosystem models can contribute to decision making. In the current framework, the National Marine Fisheries Service (NMFS) completes a stock assessment, through the Southeast Data Assessment and Review (SEDAR) process, the GMFMC Scientific and Statistical Committee (SSC) then evaluates stock projections and recommends the allowable biological catch (ABC). In parallel with the SEDAR and SSC process, projections from ecosystem models can be compared with the single species model, while also predicting the concomitant responses of multiple species. The ecosystem model projections may further serve as ecological risk assessments [51] to identify species likely to be adversely affected by a proposed management action, or to evaluate the performance of different policy options under variable environmental conditions. For federally managed fisheries in the Gulf of Mexico, when a management action is anticipated, an interdisciplinary planning team (IPT) is formed that consists of resource managers and scientists from the NMFS Southeast Regional Office and the GMFMC. The IPT defines the analyses associated with upcoming actions and develops documents that describe a range of reasonable policy options. In this setting, the IPT could utilize operational ecosystem models to understand ecosystem impacts and evaluate tradeoffs of proposed policy options, ultimately leading to better informed fisheries management plans. By utilizing the SEDAR, SSC, and IPT process and working closing with management agencies, GoM ecosystem models can be brought out of the realm of academia and integrated into the management framework as it currently exists. This would be a major first step towards using ecosystem models in a broader EBFM approach.

4.3 Increasing awareness about ecosystem models through better communication

Fisheries stakeholders in the GoM include recreational anglers, commercial fishermen, environmental organizations, seafood dealers, coastal tourism operators, politicians, scientists, resource managers, and engaged citizens. Modelers typically do a good job communicating with other modelers, scientists, and some resource managers that are accustomed to technical descriptions, but there has been far less emphasis on communicating ecosystem models to a larger audience. Important considerations when communicating complex ecological models are the political context, stakeholder experience, model characteristics, and conveying of uncertainty [52]. Communication formats that are less technical such as FAQs, conceptual diagrams, and short videos would serve to increase awareness and thereby reduce skepticism about ecosystem models. Visualization tools that use computer graphics to illustrate underlying model dynamics may help many audiences understand model predictions and the role ecosystem models can play in marine resource management [53].

5. Discussion and Conclusions

Based on the information exchanged at the Scoping Workshop, the most pressing needs for fisheries managers in the Gulf of Mexico are to address critical assumptions and uncertainties in stock assessment models and inform routine management actions, specifically the setting of single species catch limits in multi-species and forage fisheries. This presents a challenge because ecosystem models are generally better at providing strategic advice, and there is little precedent for this type of tactical management output from complex food web models. Careful parameterization and simulation design will be necessary to generate outputs that address these needs. At a minimum, the relative differences between alternative actions can be compared to provide a robust measure of ecosystem responses, especially in the presence of model data gaps and uninformed parameters. Habitat effects, environmental drivers, and innovative spatial and multi-species management approaches were identified as longer-term needs that are not typically considered in the current fisheries assessment and management framework. These topics represent an opportunity for ecosystem model application given the ability to incorporate empirical drivers of productivity, essential habitats, and environmental change in an integrated framework that also allows for fitting to single-species time series consistent with current stock assessment approaches. Lastly, the Scoping Workshop described here was successful in outlining the questions on which ecosystem modelers should focus and the apparent disconnect between scientists and managers in prioritizing those topics highlights the need for such workshops as a way to align the scientific and modeling community with actual management needs. We see this as a valuable first step for any ecosystem modeling endeavor.

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