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Southeast Fisheries Science Center Management Strategy Evaluation Strategic Plan

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Executive Summary

NOAA Fisheries and the Southeast Fisheries Science Center are embarking on a process of strategically using Management Strategy Evaluation (MSE) to advance fisheries monitoring, assessment, and management. The SEFSC will follow the National MSE Working Group's vision statement:

> *"We anticipate that MSEs will result in improved understanding of our ability to assess stocks, ecosystems, and fishing and coastal communities. This will lead to more efficient allocation of survey and assessment resources, greater potential for stakeholder ownership of the process and, ultimately, increased economic benefits and improved capacity for sustainable management for current and future generations."*

MSE is a framework in which the performance of candidate management procedures, or designated recipes of data collection and analysis protocols, decision rules, and management action implementation, is tested across a range of system uncertainties in a closed-loop simulation (Punt et al. 2016). Management procedure performance is reflected by how well each management procedure meets the fishery management objectives, which oftentimes require stakeholder input to identify (e.g., Goethel et al. 2019) and which are operationalized into quantitative performance measures.

Given that MSE processes can be highly technical and resource-heavy, many internal and external partners and collaborators will be necessary to truly make the most of this effort to advance MSE applications within the SEFSC. This includes collaborators with relevant expertise in stock assessment, ecosystem modeling, social science, economics, fishery management, survey design and data collection, species biology and ecology, and computer programming, among others.

This document identifies the goals of the MSE enterprise and presents the areas in which MSE would be most beneficial to advancing the Southeast Fisheries Science Center's mission of "providing the scientific advice and data needed to effectively manage the living marine resources of the Southeast region and Atlantic high seas" (see Box 1). We present three flagship MSEs that have been initiated within the Center, which each have the potential to be paradigm-shifting or have significant ramifications for the way in which fisheries are assessed and managed within the Southeast and more broadly. We outline activities that are ongoing to meet the MSE strategic objectives within the Center and provide future research directions.

Box 1: MSE Priorities in the SEFSC

1. Capacity Development
2. Explore Data-Limited Management Procedures
3. Explore Interim Approaches and Assessment Frequency
4. Explicitly Include Management Procedure Performance Across Climate Change and Nonstationarity
5. Consider Ecosystem Impacts of Fisheries Management
6. Focus on Recreationally Dominated Fisheries
7. "Right-Weight" Assessment Complexity
8. Prioritize Data Availability / Quality / Efficiency
9. Desk MSEs to Improve Understanding of Population Dynamics, Stock Assessment, and Management Processes

Each priority is discussed in more detail below.

Background

The management strategy evaluation (MSE) framework is a way to explore the performance of various management procedures (MPs) by simulating the feedback of an MP on the state of the fishery (e.g., De Oliveira et al. 2008; Holland 2010). MPs are pre-defined formulas that are designed to adaptively adjust management advice based on the status of the stock. An MP is comprised of an observation model or data-generating process, estimating model (EM; e.g., assessment model or suitable approximation of stock status), catch control rule (CCR; designed to reduce the MSY-based overfishing limit to account for stock status and sources of scientific and implementation uncertainty), and implementation model (including implementation uncertainty; Sainsbury et al. 2000). An operating model (OM) represents a unique hypothesis of the state of a stock and fishery on which the performance of various MPs are simulation tested (Figure 1).

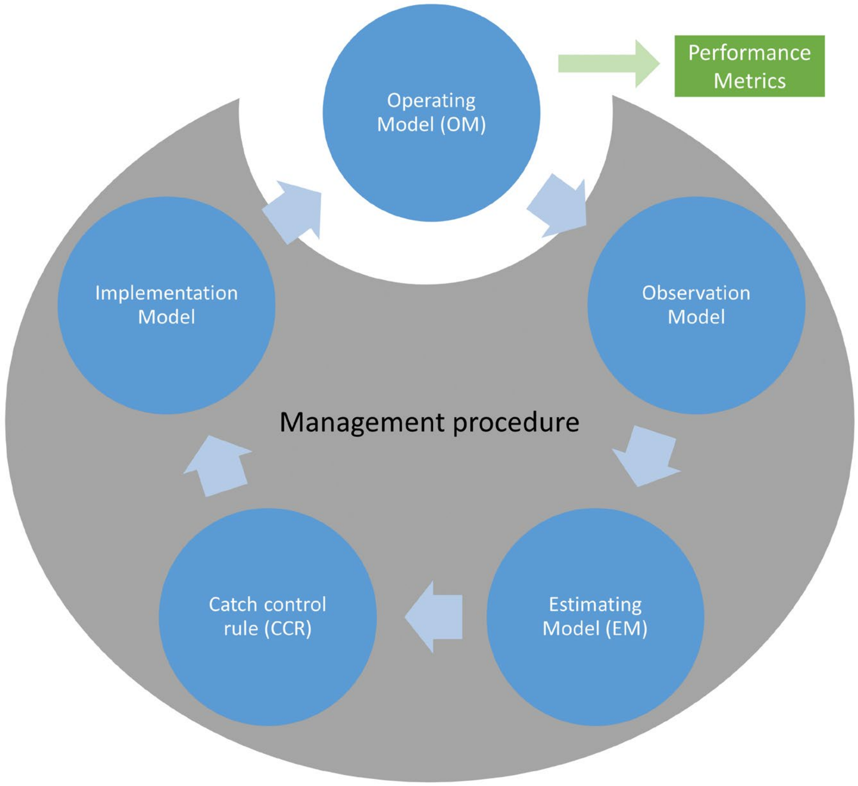

Figure 1. The MSE process, including the operating model (OM), observation model or data-generating process, estimating model (EM), catch control rule (CCR), and the implementation model.

In addition to the technical modeling exercise, MSEs require defining the management objectives of the fishery (Sainsbury et al. 2000; Holland 2010; Punt et al. 2016), articulation of uncertainties within the system (Francis & Shotton 1997, Butterworth and Punt 1999; Rademeyer et al. 2007; Punt et al. 2016), choosing candidate management procedures/harvest strategies (Deroba and Bence 2008; Punt 2010; Kvamsdal et al. 2016), and presentation of easily digestible results (Francis and Shotton 1997; Punt et al. 2016; Miller et al. 2019). Stakeholder input is recommended when the MSE is intended to directly inform decisions by natural resource managers (Goethel et al. 2019, Feeney et al. 2019; Miller et al. 2019) or where the management goals and uncertainties are not clearly articulated (e.g., Walter et al. 2023), whereas stakeholder input may not be strictly necessary (or worthy of additional expense) when asking straightforward analytical questions under clearly defined existing management objectives ("desk MSEs").

Given the thorough simulation framework, MSEs can be used to address any questions related to the various components of an MP or OM, including management performance with respect to nonstationarity, design of data collection protocols, assessment model complexity, catch control rule parameterization, and implementation overages (Figure 2). After conducting an MSE for a fishery, the tradeoffs of various management objectives should be fully characterized, candidate MPs that are not robust to uncertainties should be eliminated, the implications of fishery management decision making should be considered across a broader time-horizon, and potentially, stakeholder buy-in to the management process should be facilitated (Sainsbury et al. 2000; Holland 2010; Punt et al. 2016).

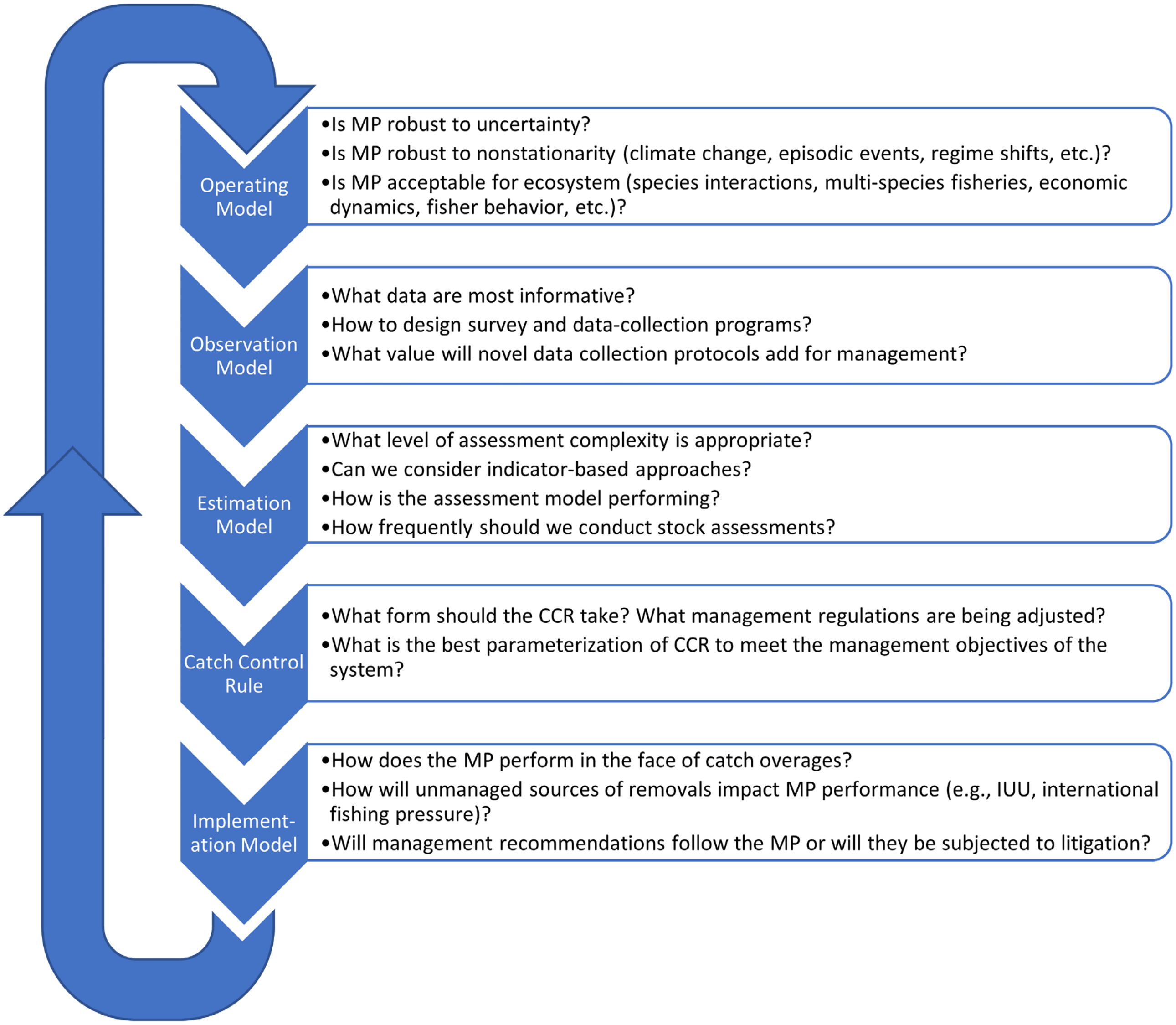

Figure 2. Example research questions that can be asked within each step of the MSE.

Mission Statements of SEFSC MSE Team

- To employ full stakeholder MSEs to develop robust management procedures for high-profile and high priority societal and management objectives, ideally ones that might change existing management paradigms
- To employ desk MSEs to improve our internal processes and scientific understanding
- To prioritize MSE projects that will have the greatest impact for the SEFSC and ensure activity alignment with strategic goals
- To coordinate MSE activities within the southeast management region, leveraging existing research activities, and maximize capacity to conduct MSEs

Purpose

This document highlights and prioritizes the areas in which MSE can be most beneficial to the SEFSC (see Walter et al. 2023 for further details on MSE prioritization). This prioritization has been the result of input and communication from scientists within the Science Center and following research priorities specified from interactions with the regional Fishery Management Councils. This document outlines broad goals towards which the Center should advance over the next decade; though capacity limitations will play a key role in the timeline over which these priorities are addressed.

We highlight three flagship MSEs on which we are initially embarking. These MSEs are deemed ‘flagships’ due to their novelty and potential to alter the *status quo*, in terms of providing management advice. These flagship MSEs also fulfill one or more of the MSE priorities. We then categorize the MSE priorities for the SEFSC. We note that these priorities are broad and their relative importance may shift over time.

Challenges

Management strategy evaluation requires significant resources to conduct. Stakeholder participation is expensive and time consuming, typically requiring several workshops wherein stakeholders are familiarized with the MSE process and goals prior to the iterative interaction required to inform the development of management objectives and relevant stock and fishery uncertainties. Even desk MSEs, which lack stakeholder participation, can require significant resources, including: highly skilled analysts and computer programmers to develop operating models and the MSE simulation loop; large amounts of time; substantial computing resources to carry out the simulation; and frequently collaborations with interdisciplinary researchers to inform the model structure, inputs, and outputs. Further, MSEs ideally require data and expert understanding of the biological/ecosystem, socioeconomic, and fishery dynamics that are being modeled.

The scientific expertise, time, computing power, and number of stakeholders and researchers required will vary based on the complexity and management objectives to be addressed. As such, MSE activities will be maximized by utilizing pre-built software (e.g., SSMSE, openMSE, etc., to avoid ‘reinventing the wheel’), internal technical teamwork, and collaboration with external partners. Due to the heavy lifting required by MSEs, it is imperative to ensure that the highest priority MSEs are provided sufficient resources, able to leverage existing research efforts as available, and not redundant of ongoing activities.

Highlighted Flagship MSEs for the SEFSC

Below we introduce flagship MSEs that are of priority in FY22-FY25. Flagship MSEs are led directly by the SEFSC, are potentially paradigm shifting, and that will substantially advance our ability to monitor, assess, and manage living marine resources in the Southeast region and Atlantic high seas. All flagship MSEs will incorporate some degree of stakeholder input, and they are currently in various stages of completion.

1. Dolphinfish

Development of empirical MPs for dolphinfish

Dolphinfish (e.g., dolphin, mahi mahi) are an iconic species of significant demand in the southeast US. Recent indicators of reduced abundance in south Florida have resulted in stakeholder concern regarding the status and current management approach for dolphinfish. However, data limitation combined with the international transboundary distribution and exploitation of dolphinfish has largely precluded development of a stock assessment. Dolphinfish are a short-lived productive species, whose productivity is largely environmentally-driven. As such, empirical (or indicator-based) MPs may be a more appropriate mechanism to generate catch advice compared to more traditional model-based MPs or to the broadly utilized best-stock assessment plus projection process. The goal of this MSE is to develop an empirical MP that best achieves the suite of operational management objectives for the US Atlantic (mainly South Atlantic) fishery. Operating models will account for space, seasonality, movement, environmental stochasticity, uncertainty in international fisheries, and differences in regional fishery practices and objectives. The empirical or index-based MP will dynamically adjust the allowable biological catch and/or the overfishing limit based on indicators of abundance.

A key element of the project is stakeholder participatory workshops to quantify operational management objectives with probabilities and timelines, elucidating key uncertainties and features of the underlying simulation or operating models and developing potential indicators for empirical MPs. These stakeholder workshops were initiated in 2022, with the initial stakeholder workshops, and is anticipated to be ongoing through 2024. The operating model framework will be spatiotemporal and length-based. The project will be led by the SEFSC (Matt Damiano, Cassidy Peterson, Kyle Shertzer, Mandy Karnauskas, Matt McPherson, Suzana Blake), and include partners at NCSU (Jie Cao), SAFMC (Julia Byrd, John Hadley), external experts in the field (Wess Merten; Beyond Our Shores), and potentially others.

2. Gulf of Mexico Shrimp

Empirical dynamic modeling (EDM) to manage shrimp in the Gulf of Mexico

Similar to dolphinfish, shrimp in the Gulf of Mexico are very short-lived with variable stock dynamics and productivity. Gulf of Mexico shrimp were previously assessed with a full integrated statistical-catch-at-age model. The current delay between data collection, assessment, and management implementation is longer than the lifespan for Gulf of Mexico shrimp. This management delay, combined with the comparatively rigid structure of an assessment model compared to the highly variable dynamics of the stock, begs the question of whether a fully parameterized Stock Synthesis assessment model is the most appropriate way to manage them.

Indeed, empirical MPs have proven useful for short-lived and highly variable fisheries (de Moor et al. 2011; Sánchez-Maroño et al. 2021; Blamey et al. 2022).

While the TAC is currently set very high for shrimp, the fishery is functionally driven by economic considerations and bycatch-related effort restrictions. Given that the drivers of fishing activity are unconventional, stakeholder input may be useful to identify the fishery management objectives of the shrimp stocks. Once identified, a full, stakeholder-inclusive management strategy evaluation (MSE) could serve to explicitly identify potentially competing operational management objectives, and provide a framework in which to maximize the ability of management to achieve these objectives.

Empirical dynamic modelling (EDM) has proved useful for describing and forecasting time-series within non-linear, dynamical systems (Munch et al. 2018; 2020). EDM has been applied to Gulf of Mexico shrimp (Tsai et al. 2022) and we ask whether EDM's exceptional forecasting ability could be co-opted for use in providing management recommendations for short-lived species (e.g., consider the EDM forecast as an index within an empirical MP).

The goal of this MSE is to develop an empirical MP that best achieves the suite of operational management objectives for the Gulf of Mexico shrimp fishery. We anticipate that this project will be conducted through the SouthEast Data, Assessment and Research (SEDAR) research-track assessment, scheduled for completion in 2025, in collaboration with lead shrimp assessment analyst, Molly Stevens (SEFSC), Steve Munch and post doc Cheng-Han Tsai (SWFSC & USC), and Michelle Masi (SERO).

3. Kemp's Ridley Sea Turtle

Explore protected resource conservation strategies: Kemp's ridley case study

The MSE process was pioneered by the International Whaling Commission (IWC) in the 1980s (Butterworth 2007; Punt and Donovan, 2007). Subsequent applications of MSE on protected resources have been conducted by the IWC (see Punt and Donovan, 2007 and references therein) and centered around testing the robustness of the Potential Biological Removal approach to determine maximum levels of human-induced mortality that do not inhibit marine mammal recovery (Wade 1998; Punt et al. 2020). We seek to apply MSEs to protected species in the Southeast region, following these previous MSE examples, to conceptually explore conservation procedures. Example questions that can be posed include: how will current conservation measures be impacted by future nonstationarity, including climate change and anthropogenic activities?; are there other alternate conservation procedures that may be able to more quickly or successfully reach the conservation goals for the target species?; how can we design research surveys to maximize their impact on recovery efforts?; what value can novel data collection schemes (like close-kin mark-recapture) add in the assessment and recovery of protected species?; what uncertainties have the greatest impact on conservation procedure performance, and therefore should be prioritized for future research?; etc. While we note that much of the verbiage throughout this Strategic Plan is fisheries-centric, these concepts can and should be readily translated and applied to protected resources.

Our initial MSE application for protected species will use Kemp's ridley sea turtles as a case study. We will explore how the current and alternate conservation procedures perform for Kemp's ridley sea turtles across a suite of current and future uncertainties. Here, we describe conservation procedures as the process by which data are collected, the way in which that data is used to monitor the population, and the calculation, designation, and implementation of any conservation measures (e.g., take limits) applied on behalf of the species.

The primary research objective of this study is to develop and test conservation procedures that result in the largest increase in population growth rate, given a suite of potential underlying biological hypotheses for the population dynamics of this species, such as mechanisms for density-dependence (nesting sites vs. foraging areas), fishing gear "catchability" (probability of take given turtle-vessel proximity), age-class specific movement patterns, and fishing vessel spatial movement patterns. The impact of these various conservation procedures are measured by their ability to maximize the conservation goals for the species, as defined by stakeholders (which includes the protected species population, any relevant ecosystem or environmental linkages, human or other socioeconomic considerations, or any other dimension identified by stakeholders that should be explicitly considered in modeling the conservation of the target population). Conservation objectives which are ideally defined by stakeholders and must abide by the legal mandates of the ESA and MMPA. Importantly, we stress that we are not aiming to change any ESA conservation or recovery objectives, but explore multiple paths that managers could use to best achieve existing recovery objectives.

Additional research questions that can be explored within this MSE framework include testing research and monitoring strategies (e.g., what is the benefit to additional data-generation schemes?), and/or conservation strategy-related questions (e.g., consider bycatch limits by gear, time/area closures, or other adaptive regulations) through projection simulation analyses with a closed feedback loop (see Figure 2). The results of this study will provide clarity on future research prioritization efforts (e.g., which uncertainties have the greatest impact on conservation success?) and will help to refine future monitoring efforts for Kemp's ridley sea turtles in the most cost-effective manner (e.g., should we prioritize in-water population surveys, dedicated tagging, low altitude high def aerial/uncrewed systems surveys, close-kin mark-recapture analyses).

This MSE will need to explicitly consider interacting fisheries and ecosystem dynamics. For example, if we only consider Kemp's ridley sea turtles without any other species or fishery impacts, the most effective conservation strategy would be to prohibit all takes. However, in practice, this would be an unreasonable approach given the interactions that Kemp's ridley sea turtles have with directed fisheries. Following the National Bycatch Reduction Strategy, the U.S. should prioritize research on bycatch rates and bycatch reduction to sustainably manage fisheries with the goal of recovering and conserving protected species (NMFS, 2016).

Stakeholder input is likely to be necessary, as there are competing and disenfranchised stakeholders and clear operational conservation objectives have not already been defined (Walter et al. 2023). Operational conservation objectives differ from conceptual objectives in that they are explicitly defined, quantitative, measurable metrics that reflect the stated objectives. For instance, whereas a conceptual conservation objective could be to recover the population, an example of an operationalized objective could be to ensure that the population is recovered, as measured by at least x number of nesting females, by the year y with at least a $p\%$ probability across all of the reference operating models considered. As such, this MSE will involve dedicated stakeholder workshops, wherein all interested stakeholders, as defined as any individual with a vested interest in the resource, are asked to identify conservation goals and system uncertainties to which the resulting procedure should be robust (e.g., offshore wind, climate change considerations, etc.). Operational objectives are used to design performance metrics, or metrics from the operating model simulations that quantitatively reflect conservation objectives that will be measured through the MSE analysis to measure conservation procedure performance. Stated recovery goals and down- or delisting criteria can be explicitly measured as performance metrics.

Notably, as scientists, MSE analysts and Center staff should remain impartial and not make any management decisions. Managers should accordingly play a key role throughout the MSE process in identifying how management or conservation procedures will be implemented operationally. The Center aims to work with the

Office of Protected Resources and Southeast Regional Office to identify the path to translating this research into effective management actions, if desired.

SEFSC partners include Paul Richards, Melissa Cook, Chris Sasso, and Joe Pfaller, and Jennifer Lee is a collaborator representing SERO. Susan Piacenza (Oregon State University) has been identified as the external partner who will lead this study, which will involve building a spatially-explicit, individual-based MSE for Kemp's ridley sea turtles using Netlogo. Spatial shrimping dynamics and potential ecosystem changes resulting from climate change will be incorporated into the operating model reference grid. To date, an initial proof-of-concept individual-based operating model has been developed. The collaborators have actively socialized the project within the SEFSC, SERO, and the Office of Protected Resources, and are exploring funding avenues.

MSE Priorities in the SEFSC

Below we elaborate on the areas in which MSE may have the greatest impact for the SEFSC. These priorities are designed to reflect the unique challenges of the southeast region, and advertise the associated research needs. We note that the relative importance of each priority may shift over time, and accordingly the order does not necessarily indicate importance. Under each overarching goal, we include a subset of specific goals and a list of recent or ongoing activities that the SEFSC is leading or collaborating on that address the objective.

1. Capacity development

Specific goals:

1.1 Develop technical pool of MSE collaborators

1.2 Collaborate across Science Centers and Councils to develop best practices for MSE applications within the US

1.3 Contribute to externally-sponsored MSEs and pursue external collaborations with Councils, academic partners, RFMOs, NGOs, or other scientific agencies

1.4 Build and automate MSE tools and packages

A main limitation to MSE activities within the center is a lack of available scientists with the necessary availability and training to conduct MSEs; this lack of personnel is exacerbated by the extraordinarily long time required for a single desk MSE. Full stakeholder MSEs are even more expensive and even more time-consuming, requiring multiple rounds of stakeholder meetings, collectively consisting of training, clarifying management objectives, developing alternative MPs, refining management objectives and MPs, and dissemination of results (e.g., Goethel et al. 2019).

Within the Center, the optimal way forward may be to develop a technical team (TT) approach to MSEs. This approach would 'borrow' analysts with appropriate expertise from various branches/departments to participate in each MSE (with supervisory permission). These team members may be internal or external to the Center, and will be able to leverage their existing research expertise to assist in the MSE application at hand. Individuals who participate or are interested in participating on MSE activities may form a potential pool of collaborators (1.1). Developing a pool of interested and technically sound collaborators from which to pull, including external research partners, is an ideal way forward. Allowing a broad pool of collaborators the opportunity to focus on selected MSE activities that are of greatest interest and fit into their schedules, but not mandating their participation, would serve to not overwhelm technical team members, while still providing the interdisciplinary support required by the MSE. A dedicated working group, which may or may not only include analysts tasked with carrying out the strategic plan, will serve to maximize, prioritize, coordinate, and track MSE activities, ensure activity alignment with NMFS/SEFSC strategic goals.

Collaborations between regional center scientists and outside collaborators, including those from the Councils, regional fishery management organizations (RFMOs), and from academic institutions, are encouraged to maximize MSE activities (1.2-1.3). The National MSE Working Group brings together MSE experts across the regional Science Centers to collaborate and develop best practices for MSE within the US. Discussion and creation of these best practices will enhance subsequent MSE activities and ensure that MSEs are appropriately prioritized and used to provide management advice (e.g., Walter et al. 2023; currently developing guidance for MSEs within the US Federal Management framework). There are a number of in progress MSEs by our research partners, like the South Atlantic snapper / grouper MSE, which is sponsored by the SAFMC and is being executed by Blue Matter Science. The SEFSC further contributes to ongoing MSEs at the International Commission for the Conservation of Atlantic Tunas (ICCAT) for North Atlantic Swordfish, Atlantic Bluefin tuna, tropical tunas and a completed MSE for North Atlantic Albacore. Where appropriate, the SEFSC should identify, participate in, and contribute to regional MSE activities organized through RFMOs, regional fishery management councils, academic partners, or by other external partners.

The initial investment required to develop an MSE framework is great. However, once built, an existing MSE framework can be readily modified to answer many additional research questions. Similarly, pre-built tools and packages have been developed to aid in MSE development. Existing packages include SSMSE, developed jointly by the Northwest and Southeast Fisheries Science Centers (Doering and Vaughan 2023), which serves to convert an existing Stock Synthesis-based assessment model into an MSE operating model, and openMSE, an R package suite to conduct MSEs developed by Blue Matter Science (Hordyk et al. 2022). Though pre-built tools may be limited for many real-world scenarios, the value of user-friendly packages make MSE research more accessible to a wider pool of researchers. Leveraging existing MSE frameworks and platforms may serve to increase MSE throughput without needing to 're-invent the wheel.' Using standardized, peer-reviewed, and publicly available code can increase transparency and reproducibility, while reducing the likelihood of coding errors that are unchecked by several practitioners. Investment in building additional tools should carefully consider the benefits versus the costs. For example, will building a BAM MSE framework be worth the requisite resources when the Fisheries Integrated Modeling System (FIMS) is scheduled to be operational in the near future with the goal of replacing all regional assessment modeling frameworks? Some level of familiarization with these tools by the SEFSC pool of MSE analysts would help to understand which tool is most appropriate to answer each research question and the corresponding benefits and limitations of each approach.

List of tools and packages for performing MSEs:

- openMSE (containing DLMtool, MSEtool, and SAMtool), https://openmse.com/;
- SSMSE, https://github.com/nmfs-fish-tools/SSMSE;
- rPath for use with Ecopath with Ecosim, Lucey et al. manuscript submitted to Fisheries Research; https://github.com/NOAA-EDAB;
- Closed-loop, MSE routine in Atlantis ecosystem modeling software, a pre-built, internal model routine (https://www.cmar.csiro.au/research/mse/atlantis.htm);
    - Note a Gulf of Mexico Atlantis model has been developed and was used to assess multispecies CCR (Masi et al. 2018);

- WHAM, a recoding of ASAP in R & TMB w/ random effects, is available as an R package (https://timjmiller.github.io/wham/) and associated MSE capabilities are in development;
- FLR – Kell et al. 2007, https://flr-project.org/;
- mseR – Cox et al., https://github.com/mseR-code/mseR-base;
- GMSE – Duthie et al., https://github.com/bradduthie/gmse;
- POPSIM - NMFS toolbox (e.g., Schirripa 2016)

Actions:

- Pursue external collaborations (university partners, SAFMC, ICCAT)
- Introduce and socialize MSE and MSE technical team to SEFSC Leadership and Staff and external partners
- National MSE working group: Walter et al. 2023; developing guidelines for conducting MSEs within the US Federal Management framework
- South Atlantic Council snapper/grouper MSE (https://safmc.net/science-sedar/snapper-grouper-management-strategy-evaluation/)
- ICCAT MSEs
    - Atlantic bluefin tuna
    - Northern swordfish
    - Tropical tunas
- SSMSE (Doering and Vaughan 2023)
- Forecasting best practices working group (Lead: Vaughan & Siegfried)
- OpenMSE operating models built for South Atlantic managed fishes (Klibansky et al. *in revision*)

2. Explore Data-Limited MPs and Empirical MPs

Specific goals:

2.1 Caribbean stocks

2.2 Recreationally-dominated species

2.3 Transient /shared stocks

2.4 Empirical MPs

2.4.1 Tune to specific stocks

2.4.2 Consider alternative indicators (beyond indices, mean length, etc.) and multiple indicators

2.4.3 Deal with lack of stock status determination -- modify empirical MPs to produce stock status determination or incorporate DLM approaches to get stock status within empirical MP approach

Within the Southeast region, including the Caribbean, the majority of stocks may be described as data-poor. Many of these stocks cannot be assessed using a conventional, integrated, statistical catch-at-age stock assessment due to limited or completely un-available data. Incomplete data may also affect species for which total removals are uncertain, like recreationally-dominated species or transient, highly-migratory stocks. Data poor species need to be assessed and managed differently, using different assessment approaches and different management procedures (2.1-2.3). In some management organizations, fisheries managers utilize a 'tier' approach, wherein species are assessed and managed differently according to the data available for each stock (Gulf of Mexico, Caribbean). Some stocks may be best managed as part of a species complex.

There is a whole library of data-limited models (DLMs) to aid in determining stock status and providing management advice for stocks (MacCall 2009; Carruthers et al. 2014; DLMtool, Carruthers and Hordyk 2018). Accordingly, there is a corresponding body of research dedicated to data-limited MPs (Dowling et al. 2008; Carruthers et al. 2014, 2016; Berkson and Thorson 2015; Sagarese et al. 2018, 2019). Contrary to conventional model-based MPs, empirical MPs are a data-limited approach to manage fisheries, requiring only an indicator of abundance (2.4).

Empirical MPs regularly adjust TAC based on the behavior of the chosen indicator. While the indicator is typically an index of abundance, other indicators should be explored to apply to species for which a representative index of abundance is unavailable or unsuitable (e.g., data limitations or indices that are representative of local availability rather than stock-wide dynamics, are particularly variable or unrepresentative, or for which there are clear trends in residuals from a fitted assessment model), like mean length in commercial catches or environmental indicators (2.4.2). Further, guidance detailing choice in indicator should be developed for species for which traditional assessment models are unavailable.

Empirical MPs have value beyond data-limited scenarios, and may also be considered for data-rich or data-moderate species when traditional management approaches are failing or may be inappropriate (e.g., Atlantic bluefin tuna, Carruthers and Butterworth 2018; Sánchez-Maroño et al. 2021), and as interim assessment approaches (Huyhn et al. 2020). For short- or long-lived species whose productivity is largely environmentally-driven (with “boom and bust” dynamics), empirical MPs may be a more appropriate mechanism to generate catch advice compared to more traditional model-based MPs (de Moor et al. 2011; Licandeo et al. 2020). Empirical MPs have the flexibility to incorporate climatic or environmental drivers of regional abundance and/or local availability. Further, empirical MPs are easily understandable by stakeholders and can readily be modified to incorporate a variety of stakeholder-desired properties (Butterworth 2007).

Empirical MPs require species-specific tuning and refinement testing before they should be implemented in practice (e.g., Butterworth 2007; Carruthers et al. 2016), as their implementation relies on selecting an appropriate indicator, tuning the magnitude of change of the TAC relative to the change in the indicator, testing other relevant controls (e.g., TAC caps, restrictions on the allowable annual percent change in TAC, additional buffers on TAC), and tuning to achieve appropriate management objectives. Guidance on the most appropriate way to tune empirical MPs is lacking (2.4.1), and retrospective analyses could be a useful mechanism to explore this topic (Geromont and Butterworth 2015).

Research that demonstrates the situational value that empirical MPs may serve (e.g., for short-lived species, to reduce the data-assessment-management lag, in the face of future nonstationarity, etc.) is also warranted (2.4), as it may facilitate added buy-in to the empirical MP process. Another consideration is the lack of stock-status determination provided by empirical MPs, which is currently required by the Magnuson Stevens Fishery Conservation and Management Act (2.4.3). In South Africa, it is recognized that traditional stock assessments are the best tool to determine stock status, but may not be the best tools to determine management targets or the path to reach those targets (Geromont and Butterworth 2015). Conceptual research that justifies less frequent stock status determination required for providing management advice, incorporates stock status estimation procedures from DLM approaches into an empirical MP framework, or explores the possibility of obtaining relative stock status information from the empirical indicator is prioritized.

Actions:

- ICCAT Atlantic Bluefin Tuna MSE (ABTMSE) implemented an empirical MP shown to be robust to plausible future regime shifts
- Test dolphinfish empirical MP (Damiano, Cao, Shertzer, et al.)
- Test empirical dynamic modeling (EDM)-based MP for GOM shrimp
- Empirical vs. model-based MP performance in the face of climate-induced nonstationarity (ongoing; Peterson et al.)
- Previous activities: SEDAR 46 2016, SEDAR 49 2016, Sagarese et al. 2018, 2019

3. Explore Interim Approaches and Assessment Frequency

Specific goals:

3.1 Explore / test interim assessment approaches

3.1.2 Tune interim assessment approaches to specific fisheries

3.2 Identify impacts of altered / reduced assessment frequency

3.3 Measure the impact of time-lags within the assessment process

3.4 Provide guidance on exceptional circumstances to monitoring MPs after implementation to ensure that future conditions are not outside the range of simulated OMs

The demand for full stock assessments outstrips the SEFSC capacity to conduct assessments (Methot 2015; Lynch et al. 2018), emphasizing the need to explore the effects of assessment frequency and mechanisms to provide management advice between stock assessment years (3.1-3.2; e.g., empirical interim approaches; Huynh et al. 2019). In addition to freeing time for additional assessments, these approaches may also allow additional time for assessment analysts to conduct related research with the goal of advancing assessment methods.

Example applications include testing various configurations of empirical, interim control rules for updating catch advice and tuning these control rules to specific fisheries (3.1). There is a lack of guidance governing the 'best' way to tune empirical MPs, so simulation studies that provide guidance on tuning empirical MPs is warranted. Considering the specificity of interim approaches, more time may be required for developing fishery-specific interim MPs. In addition to understanding how to develop these empirical MPs, it is also important to define scenarios in which these approaches may not be appropriate. Consider a survey with 'red noise' inflicted by some temporal pattern in availability or catchability; using this survey as the basis for interim assessment advice would intuitively be ill-fated, though full impacts on the fishery remain unexplored through conceptual simulation studies.

Understanding the effects of altered assessment frequency on management objectives (e.g., impacts on total catch, probability of overfishing, economic impact, etc.) would support more appropriate decision-making regarding optimal use of available stock assessment resources (3.2). Species that are long-lived and slow growing, with a relatively direct stock recruitment relationship, and for which economic value of their fisheries is relatively low, like coastal sharks (Peterson et al. 2022a), may pose suitable for reduced assessment frequency. What is considered acceptable stock assessment frequency is broad and species-specific, but may vary from annual assessment updates to interim periods of 10 or more years (Methot 2015).

Associated with assessment frequency, lags between data collection and availability for stock assessment, as well as lags between the completion of a stock assessment and the implementation of management have been shown to be problematic (Shertzer and Prager 2007). More fully understanding the management impacts of these time lags and how these lags affect MP behavior may serve to weed out non-robust MPs and even further motivate reduction in these time lags in the future (3.3).

Following implementation of a new MP, it is important to continue to monitor the fishery and the performance of the MP to ensure that fishery behavior is consistent with what was expected (Holland 2010). When fishery behavior falls outside of the simulation-tested scenarios or expected behavior, it is termed exceptional circumstances. Developing rules to determine when exceptional circumstances have occurred, how management will respond, and what severity of exceptional circumstances should trigger an updated MSE analysis and MP redevelopment is still relatively new (Carruthers and Hordyk 2019). Additional guidance on monitoring MPs post-implementation should be developed (3.4).

Actions:

- South Atlantic interim assessment working group to explore utilization of interim approaches for South Atlantic species (Klibansky et al. *in revision*)
- Effect of stock assessment frequency on sandbar shark (Peterson et al. 2022a)

4. Explore Management Procedure Performance Across Climate Change and Nonstationarity

Specific goals:

4.1 Consider climate change and future nonstationarity

4.1.1 Ecosystem drivers (episodic events, complex space use, storm events, regime shifts, ecosystem-level productivity or carrying capacity, changing anthropogenic impacts)

4.1.2 MP performance across nonstationary projections

4.1.3 Merge species-specific climate projections into MP projections (e.g., shifting distributions, shifting allocations, changing productivity)

4.2. Combine with Climate Fisheries Initiative (https://www.fisheries.noaa.gov/topic/climate-change)

It is readily apparent that climate change and nonstationarity are currently impacting fish stocks (Morley et al. 2018), and management will need to adapt accordingly. Where mechanistic drivers of climate change can be linked to fish stocks and protected resources (e.g., species distribution modeling, environmental drivers of stock productivity, increased storm or episodic events, climatic decadal forcings, ecological tipping points / hysteresis) or fishing behavior (e.g., shifts in species targeting, increased distance traveled to fish/increased fishing expenditures, locally emerging fisheries and allocation changes), these considerations can be explicitly implemented in an operating model. However, knowledge of these linkages and the ability to scale the effects of climate from an organismal response to a stock-wide impact is rare. In these cases, we can implement the empirical approach to explore management performance when faced with broad, plausible impacts of climate change, wherein a shift in future stock dynamics is shifted without identifying the underlying causal mechanism (Punt et al. 2014). Accordingly, MPs can be tested across these dynamic future projections (4.1).

For example, climate change has the potential to increase storm events which could lead to episodic mortality in affected stocks (e.g., consider red tide-induced mortality events in red grouper; Harford et al. 2018). MP performance could be tested across OM projections that include sporadic episodic mortality events (4.1.1). Species distribution modeling has been used to project future habitat availability. By scaling projected fishing and survey availability (e.g., catchability) according to projected habitat availability, the impacts of shifting distributions can be accounted for within spatially explicit OM projections (4.1.3). Similarly, if climate change is suspected to affect stock productivity through altered recruitment success or habitat degradation, this too could be explicitly modeled in an OM (Punt et al. 2014). These nonstationary OMs could be used to test the effectiveness of current or proposed management paradigms (4.1.2). MP performance across a climate-sensitive OM should be compared to a stationary OM to consider the potential scope of error of assuming stationary future projections within an MSE (e.g., Haltuch et al. 2019; Blamey et al. 2022; Mazur et al. 2023).

The emerging capacity provided by the Climate Fisheries Initiative will allow for more informative quantitative information on climate impact on fishery resources to be considered in assessment and management applications. We envision MSE providing the critical testing ground to develop robust management procedures in the face of rapid climate change (4.2; Karp et al. 2019).

Actions:

- Exploring the impact of red tide on red grouper management performance using SSMSE (Vaughan and Sagarese et al., *ongoing*)
- Testing management procedures for climate-ready fisheries management in the southeast U.S. Atlantic (Peterson, Klibansky, et al. *in preparation*)

5. Consider Ecosystem Impacts of Fisheries Management

Specific goals:

5.1 Better understand and characterize optimal yield (OY)

5.2 Explicitly consider and model human behavior (technical interactions, fisher behavior, shifting species targeting, etc.)

5.3 Build-in economics (social performance metrics to address human/social management objectives)

5.4 Incorporating local ecological knowledge (LEK) / traditional ecological knowledge (TEK) into management procedures and stock assessments

5.5 Single species MP performance in multispecies / ecosystem context

5.6 Multi-species / ecosystem-based CCRs

5.7 Multi-species / ecosystem-based BRPs

Single-species stock assessment and management inherently assume that other factors that could influence biological reference points and management targets are static. However, it is readily apparent that the ecosystem around a stock is never constant and that ecosystem dynamics may influence realized maximum yield (e.g., forage species), which calls single-species assessment and management practices into question (e.g., Pauly and Froese 2021). Accordingly, a focus on ecosystem-based fisheries management (EBFM) has been highlighted in the next generation stock assessment enterprise to more formally consider climate change and nonstationarity, multispecies fisheries and interactions, environmental and ecosystem drivers, and socioeconomics (including human behavior; Lynch et al. 2018).

With progress in ecosystem modeling and advances in EBFM, it is correspondingly important to develop management procedures that explicitly incorporate ecosystem considerations. This includes both testing single-species MPs in a multispecies or broader ecosystem context and generating multi-species or ecosystem-based CCRs and biological reference points (BRPs; 5.5-5.7). Ecosystem MPs may consider environmental drivers on productivity, multispecies interactions (e.g., predation -- leave a fraction of forage fishes 'for the birds'; menhaden, Chagaris et al. 2020; competition; etc.), technical fishery interactions (including discard mortality and depredation; Punt et al. 2005; Dichmont et al. 2008; Ono et al. 2018), and fisher behavior (e.g., shifting species targeting, high-grading, learning, gear modifications, etc.; Hilborn and Walters 1992; Wilberg et al. 2010; Ono et al. 2018).

Further, consideration of ecosystem and socioeconomic performance metrics have rarely been explicitly incorporated into an MSE within the US (5.2-5.4; Hutniczak et al. 2019). Social studies analyzing drivers of angler satisfaction and utility are particularly relevant within the recreational sector (e.g., MAFMC summer flounder MSE, https://www.mafmc.org/actions/summer-flounder-mse; Goldsmith et al. 2018).

Local or traditional ecological knowledge (LEK/TEK) represents the generational knowledge accumulated by local fishers or traditional ecosystem inhabitants. LEK has often been reinforced by scientific investigations and is increasingly being recognized as a valuable source of information (dolphinfish/wahoo stakeholder workshops; McPherson et al. 2022; Blake et al. 2022). Incorporation of LEK in the management process poses an area of further study that could lead to an overall improved management process and foster improved fisher buy-in to the management process (5.4; SocioEconomic Aspects in Stock Assessments Workshop, SEASAW; Chan et al. 2022).

Stakeholder and ecosystem input are key aspects to fully understanding, defining, and operationalizing fishery management objectives. Selecting the ideal compromise between competing objectives ('maximizing net happiness') requires full characterization of the management trade-offs associated with alternate management actions and iterative engagement with stakeholders and managers. This full incorporation of ecosystem dynamics is critical to defining and managing for optimum yield (OY), as specified by the Magnuson-Stevens Fishery Conservation and Management Act. OY is defined as the yield which provides the greatest benefit to the nation, with explicit consideration of economic, ecological, and social factors (NS1 Guidelines). Rather than being a quantity that can be explicitly solved for within a model, OY will emerge as a function and relative weighting of stock-specific operational management objectives. Fishery management objectives reflect the stakeholder-defined goals and priorities of the fishery, potentially including environmental, ecological, and socioeconomic considerations and perspectives from disenfranchised interest groups (5.1).

Actions:

- Bycatch and technical interactions (from the shrimping fleet) will be explored in Kemp's Ridley sea turtle MSE
- Local ecological knowledge collected from stakeholder participatory workshops (McPherson et al. 2022); findings obtained from the dolphinfish/wahoo workshops will be leveraged to inform the dolphinfish MSE
- ICCAT-led bluefin tuna MSE was a multi-stock, multi-area simulation
- SAFMC-led MSE on South Atlantic snapper/grouper complex; a multi-species MSE to address high discard mortality within the South Atlantic
- Chasing OY defined as a Gulf of Mexico Fishery Ecosystem Issue (FEI; as defined in the Gulf of Mexico Fishery Ecosystem Plan)

6. Focus on Recreationally Dominated Fisheries and Non-constant Allocation

Specific goals:

6.1 Magnitude of total F/removals given uncertain data

6.2 Candidate MPs and MP performance for recreationally-dominated fisheries

6.3 Define recreational fishery management objectives

6.4 Allocation impacts

6.4.1 Can we define an optimal allocation scheme between recreational, commercial, other fisheries?

6.4.2 How effective is allocation advice -- can we utilize it?

Recreationally dominated fisheries are particularly challenging to manage, because recreational fishing activities are notoriously difficult to regulate and monitor. The Southeast is uniquely challenged by a collection of fisheries for which the recreational sector dominates (Shertzer et al. 2019). Recreational removals are particularly uncertain and challenging to estimate, and management measures designed for commercial fisheries may not be applicable to recreational fisheries or suit their unique management objectives (e.g., Goldsmith et al. 2018). Not only are recreational removals difficult to tabulate, but fishery objectives vary significantly across sectors or regions.

Management procedures have rarely been generated for recreationally-focused fisheries (Ahrens et al. 2020; Cao et al. MARFIN project), and additional research should be conducted to address this information gap, focusing on less traditional management measures (e.g., slot/size restrictions, bag/trip limits, closed areas, fixed seasons, etc.) that may be more effective for regulating recreational effort (6.2). Uncertainties in recreationally-focused fishery MSEs should reflect the uncertainties inherent in estimated recreational removals (and consider the impact of changing MRIP protocols), altered management goals, economic structure, and fisher behaviors (6.1, 6.3).

Along with uncertainty in total fishing pressure attributed to the recreational sector comes uncertainty in sector allocation. MPs that address alternate or changing allocations could be a fruitful area of research (6.4). This further begs the question of whether fisheries managers can manage for an ‘optimal’ allocation scheme (6.4.1; related to identifying “Optimum yield” as discussed in the previous sections). Is allocation advice able to be controlled or utilized within a management context (6.4.2)? This question may be particularly relevant as the recreational sector has grown substantially in recent years and catchability is continuing to improve with advancements in technology and social media communication.

Actions:

- MARFIN (NA19NMF4330236) Development and application of a management strategy evaluation tool: tradeoffs between the management objectives of recreational and commercial fisheries. Jie Cao, Matt Damiano, Kyle Shertzer
- SAFMC-funded South Atlantic snapper/grouper MSE
- Chasing OY defined as a Gulf of Mexico Fishery Ecosystem Issue (FEI; as defined in the Gulf of Mexico Fishery Ecosystem Plan)

7. "Right-weight" Assessment and MP Complexity

Specific goals:

7.1 Optimize MP / EM complexity with respect to OM complexity

7.1.1 Consider trade-offs between performance [management performance, assessment accuracy and precision] and costs [assessment cost, data requirements, time requirements]

7.1.2 Consider EM/MP complexity, including consideration of the CCR, EM/assessment model [explicitly modeling space-use, time-varying parameter estimates, state-space modeling, regime shifts, treatment and incorporation of additional data sources, etc.], data quality/quantity, implementation model

7.1.3 Consider the impact of OM complexity: how complex should OMs be to adequately measure and predict MP performance?

7.2 Explore empirical MPs

Significant energy is invested in advancing the methodology and computational complexity of stock assessments. However, increasing model complexity comes with added cost in terms of analyst time and data requirements, such that the tradeoffs (bias and precision) of assessment model complexity should be fully explored (7.1). Simpler models leave out important dynamics of the system, necessitating simplifying assumptions, yet requiring less data. Thus, simpler models are prone to error due to approximation. More complex models theoretically are better able to capture the true dynamics of the system, yet require estimation of many more parameters, which cannot be precisely estimated given limited data (Hilborn & Walters 1992), are vulnerable to model misspecification (Sainsbury et al. 2000), and model overfitting, in which parameter estimation follows noise as opposed to the underlying signal of the dynamics (Butterworth & Punt 1999). Therefore, estimation error plagues complex models, and can accumulate throughout the model. Adding model complexity is also accompanied by additional model assumptions (Hilborn & Walters 1992).

While many applications may require complex assessment configurations, there are likely species for which a simple stock assessment approach would produce equivalent management performance at a much faster and cheaper rate. In several instances, simpler models have been shown to perform better or as well as simpler models (e.g., Hilborn & Walters 1992; Butterworth & Punt 1999). Because simulation analyses, including MSE, explicitly model the dynamics of the OM and EM (stock assessment process), they can be used to explore the relative impact of EM complexity, given the complexity of the system as modeled in the OM and the data quality and availability, to determine if simpler assessment models could be used to provide the same management success (7.1). Using an MSE framework to simulation test the value of added EM complexity, including spatial dynamics, time-varying parameters, state-space modeling approaches, inclusion and treatment of additional or nontraditional sources of data, modeling environmental linkages, and more, would address this hypothesis (7.1.1-7.1.2). Notably, the level of EM complexity required to successfully manage stocks may depend on the underlying dynamics of the stock (e.g., the OM complexity). Understanding the relationship between EM and OM complexity may serve to streamline the stock assessment process and allow for additional species to be assessed.

Consideration of MP complexity also includes full consideration of empirical MPs (7.2). Empirical (or indicator-based) MPs rely on an indicator of stock status (typically index of abundance) to adjust total allowable catch (TAC) advice from year-to-year. Because empirical MPs do not require a full stock assessment, which is a particularly time-consuming process, they can be used to quickly provide management advice, potentially even within the same year. As such, empirical MPs are not necessarily subjected to the same data - assessment -

management delay as conventional stock assessments, which could serve to improve potential negative outcomes associated with such delays (Shertzer and Prager 2007; see Section 8 for more on empirical MPs).

Actions:

- MP complexity for short-lived species is being explored via empirical MPs and/or EDM for Gulf of Mexico shrimp, dolphinfish, and bluefin tuna

8. Prioritize data availability / quality / efficiency

Specific goals:

8.1 Prioritize data collection systems

8.1.1 Identify essential surveys

8.1.2 Identify uncertainties that are most impactful for management success

8.1.3 Measure the impact of potential future data collection regimes on management success

8.2 Optimize sampling and design

8.2.1 Identify requisite / optimal sample sizes

A benefit of the MSE process is that it highlights future research priorities (Butterworth and Punt 1999; De Oliveira et al. 2008), including identification of the uncertainties which most greatly impact the ability to successfully manage the fishery or ecosystem and identifying the most important / useful sources of data and which data streams contribute less to the successful management of the resource (8.1-8.1.2). Considering the high expense of data collection programs, understanding the relative benefit of increasing / decreasing survey frequency, survey spatial coverage, and effective sample sizes of age and length compositions will help to optimize data generating protocols (8.2-8.2.1). This explicitly includes measuring the potential added value of new or novel data collection schemes (e.g., in-water surveys or close-kin mark-recapture for Kemp's ridley sea turtles; 8.1.3).

Additional considerations include identifying the minimum length of an index of relative abundance required for the index to be included in a stock assessment, the impact of improved data quality over time, and the added value that novel data collection programs (e.g., acoustic surveys, genetics research) would add to the management of a stock. While these questions could be addressed in a full or desk MSE, a risk analysis or non-feedback simulation approach may also be a less resource-intensive method of answering some of these questions (e.g., Siegfried et al. 2016).

Actions:

- Once the MSE framework is created for Kemp's ridley sea turtle, it may be used to explore the impact of additional data-collection protocols on conservation success

9. Desk MSEs to Improve Understanding of Population Dynamics, Stock Assessment, and Management Processes

Specific goals:

9.1 Desk MSEs to advance understanding / acceptance of MPs and the assessment process as relevant for the SEFSC

9.2 Species-specific or species complex-specific MSEs for implementation (primarily for controversial species)

9.3 To address other relevant conceptual questions; examples include:

9.3.1 Assess likelihood of MP utilization -- are there some MPs that are unlikely to be implemented in practice

9.3.2 Explore mechanisms to provide status determination along with TAC advice from empirical MPs

9.3.3 Improve and explore generic MP performance

9.3.4 Improve stock assessment processes

Additional goals include performing desk MSEs to advance our understanding and buy-in of MP performance (9.3), stock assessment (9.3.4), and fishery population dynamics (9.3). Desk MSEs can be exploratory in nature or be performed when the goal of the simulation is to adapt an MP where management objectives and stock and fishery uncertainties are already fully identified (9.2; Walter et al. 2023). These desk MSEs may also serve to ask practical questions, including improving the assessment process (e.g., Irwin et al. 2008; Carruthers et al. 2018; Harford et al. 2019), evaluating inclusion of environmental factors in assessments (Harford et al. 2018; Haltuch et al. 2019), and developing modeling capacity and tools for MSEs with a scope beyond single species management (9.1-9.3; Kaplan et al. 2021). For example, an application of MSE to the sandbar shark highlighted the significant impact that unmanaged, international exploitation may have on the management of US species (Peterson et al. 2022b). Future extensions of desk MSEs within the SEFSC may focus on developing and tuning empirical MPs, how to identify regime shifts or other indicators of nonstationarity, which management approaches would be more likely to be implemented in practice, providing additional guidance on identifying exceptional circumstances, or improving the stock assessment process (9.1-9.3).

Actions:

- Small-scale desk MSE to beta test SSMSE (planned)
- Development of best practices for MSE within the US by the National MSE WG (e.g., Walter et al. 2023)
- Sandbar shark MSE (Peterson et al. 2022b)

Summary

We further note that many of the priorities are interrelated. Inclusion of ecosystem dynamics may impact 'right weighting' assessment complexity dynamics, and limited data availability will limit our ability to realistically explore many complex questions related to human behavior, climate change, ecosystem dynamics, or multi-sector exploitation. We further emphasize the technical challenges inherent in many of these areas of exploration. For example, investigation into ecosystem-based fisheries management requires development of full ecosystem OMs.

The ability to leverage already existing resources will be imperative to advance MSE within the Southeast. This includes building on pre-existing research, like Masi et al.'s (2018) Atlantis model of the Gulf of Mexico and pre-packaged MSE software (e.g., SSMSE; Doering and Vaughan 2023; openMSE; Hordyk et al. 2022), and ensuring new project initiatives are not duplicative of existing efforts. Lastly, we highlight that this research necessitates the collaboration of many interdisciplinary partners. The SEFSC, which includes the MSE technical team and Center leadership, will work with academic agencies, Fishery Management Councils, RFMOs, federal agency partners, and others to procure competitive funding and provide research recommendations that will be of greatest benefit to the southeast region.

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