Guiding the advancement of ecosystem considerations within the U.S. Gulf of Mexico: A proposed planning process for the development of a regional fishery ecosystem plan

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Executive summary

This document is intended to inform the Gulf of Mexico Fisheries Management Council (GMFMC) about the findings of a study[2] that provided a multi-level analysis, both at the federal and regional level, and narrative for the integration of ecosystem science and considerations into fisheries management frameworks within the Gulf of Mexico large marine ecosystem (GOM-LME). In our view, this information can support Council's ongoing efforts to plan, develop, and implement a Gulf of Mexico fishery ecosystem plan (FEP) that aligns with existing FEPs developed by other U.S. regional fisheries management Councils.

The objectives of this study[2] were to: 1) examine the ecosystem management (EM) literature with respect to the ecosystem approach to fisheries management (EAFM) and ecosystem-based fisheries management (EBFM) within the GOM-LME, and in relation to best practices for the development of FEPs; 2) synthesize this information into a proposed planning process to support current efforts for developing a FEP; and 3) describe two applications of EAFM and EBFM, respectively, as case studies exemplifying potential ways to navigate through the proposed FEP planning process.

The results of our investigation suggested that, although the GOM's fishery management and ecosystem community appears to be keeping pace with other U.S. regional efforts to advance EBFM, more tools like FEPs are needed to inform and guide EBFM work in the region. Our proposed structured planning process for the development of a FEP can help fill this need, and offers strategic guidance and insights to support efforts of GMFMC's managers to translate EM principles, approaches, and objectives into an "action oriented" management plan for fisheries resources in the GOM-LME.

Although recognizing the existence of many more EM applications for fisheries resources in the GOM-LME that could have been used as potential useful examples to describe how to achieve specific steps of the proposed FEP planning process, we consider the two cases highlighted in our study as sufficiently compelling to help navigate through the process within the sphere of EAFM and EBFM frameworks, respectively.

It is our hope that the information provided in this study can contribute to guiding and strengthening the efforts of, and partnerships between, federal and regional managers, fisheries scientists, and key stakeholders, which are critically needed to advance regional efforts for the development and implementation of an actionable FEP-type management vehicle for the GOM-LME's diverse fisheries resources.

[2] This summary describes and expands upon findings from the study "*Advancing ecosystem management strategies for the Gulf of Mexico's fisheries resources: Implications for the development of a fishery ecosystem plan*" by Dell'Apa, Kilborn, and Harford, which is currently under review in a scientific peer-reviewed journal.

Introduction and background

The U.S. fishery management system includes multiple layers of ecosystem management (EM) strategies that are applied and implemented across federal and regional jurisdictions. These strategies, and associated planning efforts, are parts of a larger scheme aimed at integrating more comprehensive approaches for the management of living marine resources within the U.S. network of large marine ecosystems (LMEs). Over the last two decades, these concerted efforts, along with more restrictive limits, have generally proved to be successful in rebuilding many of the U.S. regional fish stocks that were considered overfished or experiencing overfishing.[3] Furthermore, within the larger picture, the U.S. fishery management system reflects recent improvements to fishery sustainability and ecosystem resiliency that, globally, have been achieved also through the adoption of more holistic fishery management frameworks. This has led to a transition from the single-species (SS, or single-stock) focus toward the integration of more complex foci of multispecies (MS) community and ecosystem considerations, such as the ecosystem approach to fisheries management (EAFM) and ecosystem-based fisheries management (EBFM) (Murawski 2007, Link 2010, Fogarty 2014, Link & Browman 2014, Dolan et al. 2016).

Although they are often used interchangeably, EAFM and EBFM are two distinct views on how to integrate EM for fisheries sectors (Table 1). In detail, these two frameworks differ in their specific trajectories, with respect to their particular foci, along the gradient representing the integration of ecosystem aspects into fishery management. The EAFM trajectory proceeds from an initial SS focus toward one including the integration of the effects of other fishery sectors and environmental and ecological considerations in a more holistic way, aiming to, eventually, manage single stocks through the integration of more complex multi-species (MS) community dynamics, while considering the broader interactions within the ecosystem. Conversely, EBFM begins with a focus on the whole ecosystem's physical conditions, fisheries, and fish stocks, and proceeds toward considering these components in an integrated fashion to account for MS considerations. Ultimately, the EBFM focus proceeds to diagnose optimal productivity across MS fisheries sectors (Link 2010, Dolan et al. 2016).

There is wide recognition that more EM strategies are needed to manage fisheries resources in the U.S., both at the federal and regional level, as part of a larger strategy to integrate ecosystem considerations into the management of U.S. marine resources and habitats (POC 2003, USCOP 2004). Accordingly, the National Marine Fisheries Service (NMFS) has strived to advance an EM strategy for U.S. fishery resources. This strategy is specifically conceptualized and delivered in the form of an EBFM Policy based on six guiding principles (NMFS 2016a), which is further reinforced through the EBFM Road Map (NMFS 2016b) describing how to operationalize these principles to make actionable steps for federal EBFM implementation.

Moreover, the U.S. National Oceanic and Atmospheric Administration (NOAA) has opted for the integrated ecosystem assessment (IEA) framework as the primary scientific engine to support the advancement and implementation of both EBM for marine resources (Levin et al. 2009, Samhouri et al. 2014), and EBFM for fisheries resources (NMFS 2016b), at the federal level. The IEA framework is broadly based on a five-step iterative loop (Figure 1), which includes: 1) defining the most critical

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[3] The most current status of U.S. fishery stocks can be found in the NOAA Fishery Status Stock Update – at: https://www.fisheries.noaa.gov/national/population-assessments/fishery-stock-status-updates

management goals and targets for the implementation of EBM, or EBFM, in the ecosystem at hand; 2) selecting key indicators that can be used as proxies for evaluating the status of the ecosystem; 3) assessing and monitoring the status and trends of those indicators relative to ecosystem management goals and targets; 4) analyzing the risks of anthropogenic and natural stressors to the ecosystem; and 5) determining, through various quantitative and qualitative management strategy evaluations (MSEs, see Punt et al. 2016), the trade-offs between achievement of socio-economic and ecological management goals (Levin et al. 2009, Samhouri et al. 2014, Harvey et al. 2016).

Table 1: Summary of the different fisheries management frameworks, with a description of specific aspects for each framework (adapted from Link and Browman 2014, Dolan et al. 2016). FM = fisheries management, EAFM = ecosystem approach to fisheries management, EBFM = ecosystem based fisheries management, SA = stock assessment, ISA = integrated stock assessment, LMRs = living marine resources, BRPs = biological reference points, SRPs = systemic reference points, SAMs = stock assessment models, ESAMs = extended stock assessment models, MSMs = multispecies models, MSEs = management strategy evaluations, EMs = ecosystem models, RA = risk analysis, FMP = fishery management plan, FEP = fishery ecosystem plan, RFMC = Regional Fishery Management Council.

Specific aspects	**Traditional FM**	**EAFM**	**EBFM**
Focus of biological hierarchy for management	Single stock/population	Single stock/population	Community/whole ecosystem
Evaluation framework	Single SA	ISA	ISA with focus on fisheries sectors
Main objective of the analysis	Determine stock status	Determine stock status	Address trade-offs across fisheries and other sectors, and LMRs
	Determine stock productivity	Determine stock productivity	Determine ecosystem productivity
	Diagnose levels of optimal stock production	Diagnose levels of optimal stock production by integrating ecosystem factors and interactions	Diagnose optimal productivity across multispecies fisheries
	Assess within-stock effects of fishing and implications for management	Assess within-stock effects of multiple fisheries and environmental factors/drivers	Assess within-(fishing) sector cumulative effects across multispecies fisheries
Primary output for scientific advice	BRPs for fishery stock	BRPs for fishery stock	SRPs, including BRPs
Analytic tool for decision-makers	SAMs, MSEs	ESAMs, MSMs, and MSEs	EMs with focus on fisheries, MSMs, MSEs, and RA
Implementation framework	FMP	FMP	FEP
Implementation body (U.S.'s jurisdiction)	RFMC	RFMC	RFMC

Currently, the IEA framework has been implemented by NOAA in five regions: Alaska, the Northeast Shelf, the Gulf of Mexico, the California Current, and the Pacific Islands. For each of those regions, an ecosystem status report (ESR) was developed by each pertinent IEA's regional program, containing a full suite of indicators that provide critical information about the status and trends of key socio-economic, biological, climatological, and physical-chemical components of the ecosystem. This information provides ecosystem-wide context for managers regarding the ecosystem's structure and function through a better understanding of environmental, ecological, and socio-economic conditions

(NOAA 2009, Karnauskas et al. 2017, Harvey et al. 2018), and can help managers identify and select key ecosystem indicators (*i.e.*, Step 2 of the IEA loop).

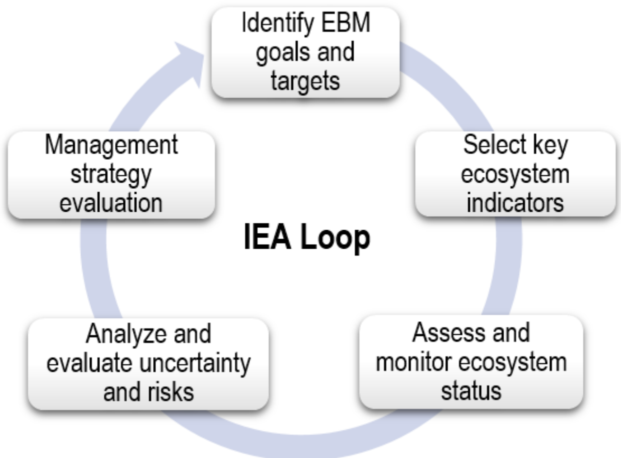

Figure 1: The five-step, iterative process of the integrated ecosystem assessment (IEA) loop (adapted from Levin et al. 2009, and Samhouri et al. 2014), as adopted by NOAA for conducting and implementing integrated, cross-sectoral science to support EBM goals and objectives for the conservation and management of U.S. marine resources.

For the Gulf of Mexico (GOM), the GOM-IEA program developed two ESRs (Karnauskas et al. 2013, 2017)[4] and, more recently, a GOM-EBFM Implementation Plan (NMFS 2019), with the aim of supporting the coordination of efforts across regional fishery scientists and managers. Additionally, the GOM-IEA team and the GMFMC have been working together to identify potential strategies to effectively integrate ecosystem science and research into fisheries management and to advance EBFM in the GOM.[5] Collectively, these efforts indicate the presence of a perceived need by regional fishery managers and researchers for more EBFM work in the GOM-LME. In this regard, among managers of the eight U.S. Regional Fishery Management Councils (hereafter referred to as the Councils), there is a wide recognition that more EM strategies would bolster current regional management efforts for U.S. fisheries resources (PFMC 2014, Marshall et al. 2018). This view is also a direct response to conclusions of the Ecosystem Principles Advisory Panel (EPAP)'s report to the U.S. Congress (EPAP 1999). The report concluded that, within the U.S. fishery management framework, conventional management strategies included provisions that could address some, but not all, aspects of EBFM, and that some of the principles and goals of EBFM were not applied comprehensively across Councils' jurisdictions (EPAP 1999, Dereynier 2014). Hence, the EPAP recommended the need for the introduction of fishery ecosystem plans (FEPs) as new comprehensive management tools to achieve a more systematic implementation of EBFM at the regional Council's level (EPAP 1999).

Over the last decade, nine FEPs have been completed by various Councils (the North Pacific, Pacific, Western Pacific, and South Atlantic Councils), with another two under development (the New

[4] The results of the GOM-ESRs (Karnauskas et al. 2013, 2017) indicated significant trend changes for multiple ecosystem indicators relevant to fisheries management, including, among others, accelerating rates in recent years for sea surface temperature and sea level rise, an increasing rate of ocean acidification, a recent rise in primary productivity (compared to the long-term average of the period analyzed), increasing average trophic levels of both U.S. and Mexican landings over time, and a decreasing trend in fishing effort over recent decades, although marked by a more recent increase in total fish and invertebrate commercial landings and revenues.

[5] See https://www.integratedecosystemassessment.noaa.gov/regions/gulf-of-mexico/ecosystem-support-fisheries

England and Caribbean Councils). More recently, the GMFMC has tasked its staff (GMFMC 2018) with initiating the process for the development of a GOM-FEP.

Summary of main findings

Fishery ecosystem plans for U.S. regional fisheries and jurisdictions: a closer look

Conceptually, a FEP is an informative guidance document that can be developed discretionarily by the Councils to support the integration of ecosystem principles, goals, and policies within their fishery management frameworks. As such, a FEP is meant to serve as the primary EBFM instrument to guide managers and decision-makers in achieving sustainable, ecosystem-wide fishery management, by means of a process that can address the incorporation of ecosystem goals and actions into regional EBFM strategies (EPAP 1999, Levin et al. 2018, Marshall et al. 2018). Specifically, FEPs are intended to: enhance Councils' understanding of the fundamental biological, physical, and socio-economic aspects of the ecosystem within which fisheries are managed, guide managers in deciding how this information should be used within the context of fishery management plans (FMPs), and support Councils' efforts to introduce policies that can support the development and implementation of alternative fishery management options.[6]

FMPs vs FEPs: compare and contrast

Although sharing some similarities, FMPs and FEPs are functionally different in purpose, legal mandate, and scope (Essington et al. 2016). FMPs are statutorily designed, under the requirements of the U.S. Magnuson-Stevens Fishery Conservation and Management Act (MSA), to achieve management goals that are set for SS or single sector fisheries (historically more so through EAFM approaches). Conversely, FEPs are conceptualized as non-prescriptive management tools that can support Councils' efforts to achieve EBFM objectives for the broader fishery ecosystem. Thus, the scale of FMPs is usually confined within the spatial focus of single stock's range, whereas for FEPs the scale is widened to the spatial extent of the whole fishery ecosystem, or to a specific portion of a LME (*e.g.*, the Aleutian Islands FEP[7] managed by the NPFMC). In other words, a FEP can be also viewed as a compass for directing planning efforts for the integration of ecosystem considerations within and across FMPs, which can help enhance fishery sustainability by addressing issues that would be more difficult to be accounted for within the framework of single FMPs.

In summary, due to their non-prescriptive nature, FEPs do not necessarily have similar "management teeth" that FMPs are required to have by federal law under the MSA. FEPs are more commonly developed by Councils with the intent of providing policy options and highlighting trade-offs to better coordinate SS management within and across FMPs, and as attempts to integrate EM considerations and implement EBFM strategies. Consequently, FEPs can take different forms and contain various approaches, based on the specific needs and fishery management issues considered most relevant by fishery managers and other regional stakeholders for the ecosystem at hand. Accordingly, Councils have been opting for different approaches when developing and implementing their own FEPs.

For example, the Mid-Atlantic Fishery Management Council (MAFMC) has opted for the use of an EAFM framework when strategizing the introduction and integration of ecosystem considerations

[6] See https://www.st.nmfs.noaa.gov/ecosystems/ebfm/fishery-ecosystem-plan
[7] See https://www.npfmc.org/wp-content/PDFdocuments/conservation_issues/AIFEP/AIFEP12_07.pdf

into its fisheries management processes. As a result, in 2016, the MAFMC released a guidance document describing the Council's planning strategy for transitioning to EAFM, although further specifying that future expansions of the document, and its underlying planning process, could potentially be converted into a stand-alone, broader-focused FEP (MAFMC 2016).[8] At the other end of the spectrum, a more comprehensive EBFM approach has been considered by the Pacific Fishery Management Council (PFMC), which, in 2013, led to the development of a FEP for the U.S. portion of the California Current-LME. In the words of the PFMC, the main purpose of this FEP was *"...to enhance the Council's species-specific management programs with more ecosystem science, broader ecosystem considerations and management policies that coordinate Council management across its FMPs and the California Current Ecosystem."*[9]

Recommendations

Based on the results of our multi-level analysis[2], we view it as strategically important for the GMFMC to develop a GOM-FEP that can be capable of both complementing the focus on SS paradigms, while also expanding planning objectives to be more in line with the long-term vision and concepts of "next generation" FEPs, which reside under the umbrella of EBFM.[10] Moreover, a preliminary list of initial priorities to achieve this long-term vision has been developed (Chagaris et al. 2019), and which could be further refined through open and transparent communication between fishery managers, scientists, and other regional stakeholders. These communications are key to correctly aligning any strategies for the advancement of EBFM with the agreed-upon objectives for a FEP in the GOM-LME. Finally, although we recognize the GMFMC has the leading role to spearhead and complete the process of developing and implementing a GOM-FEP, we also consider it important to acknowledge that the effort's framework, goals, and initiatives should not be disjointed in their broader vision or practical terms, and, to the extent possible, from the GOM-IEA program's current strategy specifically conceptualized under the EBFM framework.

A proposed "loop" for the development of a GOM-FEP

To support ongoing efforts of the GMFMC, we propose a planning process (*i.e.*, "the loop") as a structured approach for guiding the development of a GOM-FEP (Figure 2). This loop, which was conceptualized from the IEA framework (Figure 1), is meant to be specific to the reality of the GOM fishery ecosystem, and draws upon the recommendations of the Lenfest Fishery Ecosystem Task Force describing the requirements for "next generation" FEPs in the U.S.[10], the benchmarking analysis of the PFMC-FEP regarding those recommendations[11], and the conclusions of a recent review on existing FEPs with respect to the original EPAP's recommendations (EPAP 1999) for developing FEPs.[12]

[8] See a revised version to February 2019 http://www.mafmc.org/eafm
[9] See https://www.pcouncil.org/ecosystem-based-management/fep/
[10] See Essington et al. 2016, Levin et al. 2018, and Marshall et al. 2018
[11] i.e., Dawson and Levin 2019
[12] i.e., Wilkinson and Abrams 2015

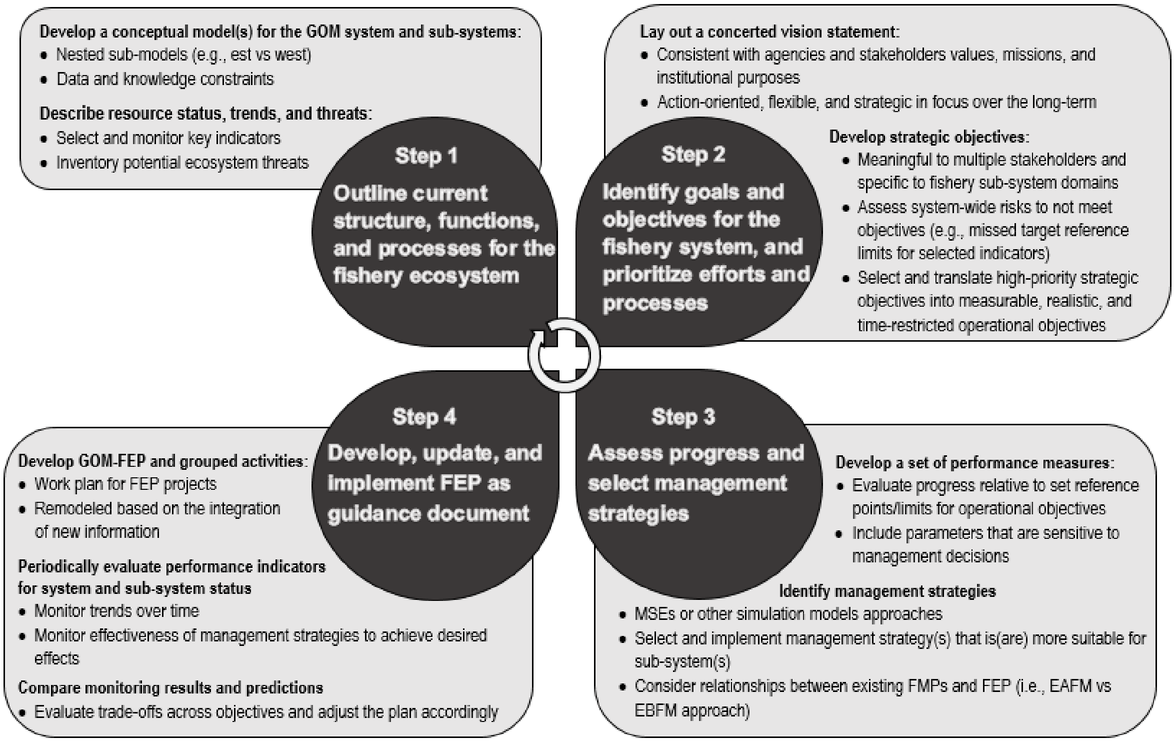

Figure 2: The proposed "loop" as a planning process for guiding the development of a GOM-FEP. The loop is based on four iterative steps (dark grey polygons) with associated actions (bold text within light grey boxes) and considerations (bullet points) (adapted from Essington et al. 2016, Levin et al. 2018). MSEs = management strategy evaluations, FMPs = fishery management plans, EAFM = ecosystem approach to fishery management, EBFM = ecosystem-based fishery management.

The proposed loop is based on four iterative steps. Each step contains a series of actions and considerations that align with the adaptive management framework, and which are described below in bullet forms:

Step-1: Outline current structure, functions, and processes for the GOM fishery ecosystem

- Action #1: Develop a conceptual model for the GOM-LME fishery ecosystem and its various integrated sub-systems
  In ecological and fishery systems, conceptual models[13] are useful tools for synthesizing, integrating, and communicating multiple lines of information, thereby fostering our understanding of the complexity of these systems by revealing links within and across their components.[14] The development of a conceptual model for the GOM-LME could result from collaborative partnerships between the GMFMC, the GOM-IEA program, and other regional stakeholders. Additionally, due to the relative paucity of comprehensive data for many of the GOM's sub-systems, qualitative[15], rather than quantitative, conceptual models may be required to explore socio-ecological relationships, compare management strategies, and identify trade-offs. Lastly, due to the nature of the GOM fishery system, any LME-wide conceptual model would need to be a nested general model for the whole fishery ecosystem, with various sub-models

[13] See an example for the California Current ecosystem by Levin et al. (2016).
[14] See Ogden et al. 2005, Hunt et al. 2013, Harvey et al. 2016, and Levin et al. 2016.
[15] See an example of the application of qualitative network models for the California Current ecosystem by Harvey et al. (2016).

accounting for species interactions and relationships among fishery and non-fishery components (*e.g.*, differences between western and eastern basin, climatology changes).

- Action #2: Describe the status and trends of key ecosystem resources, and potential threats to the GOM fishery ecosystem
  Based on the system-wide conceptual model, managers would need to capture the status and trends of key ecological and social components of the fishery ecosystem through the selection and monitoring of relevant biophysical and socio-economic indicators. The GOM-ESR[16] is a starting point for identifying those indicators, and would also maintain continuity with the ongoing efforts of the GOM-IEA program. However, other reliable data sources should be used if available.

  Next, managers should create a list of potential threats that may impact the GOM fishery ecosystem, including terrestrial (*e.g.*, freshwater runoff), climatological (*e.g.*, local and regional weather conditions), coastal (*e.g.*, coastal development, persistent habitat change), and marine (*e.g.*, shipping activity, underwater noise, and physical-chemical conditions) components of the system, along with other human sub-systems (*e.g.*, market conditions and exploitation rates). This list should clearly account for the most relevant threats and their appropriate temporal scales. Arguably, those threats should be subdivided spatially to reflect inherent differences across socio-ecological sub-systems within the wider scale of the GOM-LME, and their selection should allow for investigating variability among spatial extents, relative magnitudes, and frequencies of their occurrences.

Step-2: Identify agreed-upon goals and objectives for the fishery system, and prioritize key efforts, focus areas, and processes

- Action #1: Develop a concerted vision statement for the GOM-LME
  A vision statement needs to be action-oriented, flexible, strategic over the long-term, and agreed-upon by a diverse set of managers, scientists, and stakeholders. This vision should offer a clear, ambitious identity for common goals, beliefs, and priorities across the fishery ecosystem, and provide flexible options for strategies to achieve them. Also, this vision would need to be broad in scope to limit the possibility for potential fundamental modifications reflecting political changes and institutional turnover within a relatively short time-frame (*e.g.*, 10 years). Importantly, while being inclusive of other agencies' and stakeholders' missions, this common-vision should be largely based upon the GMFMC's guiding ecosystem values and stated institutional purpose.

- Action #2: Develop strategic objectives
  To help prioritize the most realistic and effective management options, the structure and content of the common-vision (*i.e.*, *Step 2* - *Action #1*) would need to be translated into a set of strategic objectives meaningful to different stakeholders, and centered on specific fisheries sub-systems within the GOM-LME.

  Also, for each strategic objective, managers would need to analyze the risks of failing to meet the stated targets. For some objectives, reference limits for key indicators could be set and used as proxies for the desired status of the fishery ecosystem. In turn, this would allow for simulation

[16] i.e., Karnauskas et al. 2013, 2017 in the references.

studies that not only quantify the risks associated with surpassing those limits, but also quantify those limits' boundaries. Preferably, these risk assessments should be conducted in a MS context.

Next, managers should condense the list of strategic objectives into a more practical set of high-priority, actionable objectives through a transparent selection process that is inclusive of various stakeholders' perspectives.[17] Lastly, based on this set of more practical objectives, managers would need to develop specific operational objectives that are measurable, realistic, and time-restricted (Levin et al. 2013), and that should include target goals that are capable of capturing (preferably quantitatively) the desired status of the GOM fishery ecosystem and its components (*i.e.*, ecological, socio-economic, institutional).

Step 3: Assess progress and select management strategies

- Action #1: Develop a set of performance measures
  Based on the list of operational objectives (*i.e.*, *Step 2- Action #2*), managers should select a set of performance indicators (*e.g.*, fishery revenue, stock abundance, social well-being) that are sensitive to management actions (Levin et al. 2018), and which will help assess whether operational objectives have been met.[18]

  Next, managers should set appropriate reference points as target levels for evaluating indicators' performance and overall progress towards the stated operational objectives. These reference points should be based on scientific information and set to meet specific policy outcomes (*i.e.*, *Step 2 – Action #2*), while bearing in mind that historical indicators, and particularly so for ecological indicators, should not be used as reference points to represent baseline conditions of the fishery system (Levin et al. 2018).[19]

- Action #2: Identify management strategies
  Managers would need to evaluate alternative management strategies, ideally through a formal MSE or other simulation-based modeling approach (Grüss et al. 2016; Harford et al. 2018). Doing so will help assess strengths and weaknesses of different options in a way that is robust and transparent, and which supports the trade-off evaluation of different fishery management strategies within the context of the FEP planning effort. Finally, these results will help managers select a strategy for implementation, which, depending on the case and sub-system at hand, could be a modification of an existing FMP (an EAFM-type approach) or part of the development for a larger EBFM (*i.e.*, FEP-type) adaptive planning strategy.

Step 4: Develop, update, and implement the FEP as a management guidance document

- Action #1: Develop a GOM-FEP and grouped activities
  The overall work from the previous steps would need to be translated into a structured GOM-FEP with specific groups of activities (*i.e.*, FEP "projects" as defined by Levin et al. 2018) that can be used to achieve the operational objectives related to the most highly-prioritized efforts and

[17] An initial list of objectives can be drawn from the results of Chagaris et al. 2019, though further engagement with additional stakeholders is required for these regional results to be more reflective of a wide-scale consensus of current high-priority objectives for the GOM-LME.
[18] These performance indicators are different from the ecosystem indicators described in *Step 1 – Action #2*, which are meant to provide general information on the status and trends of key ecological and socio-economic components of the fishery ecosystem, and are not directly linked to specific operational objectives within the planning process.
[19] This is due to the fact that, within an EBFM context, humans are considered an integral component of the system and, thus, the status of performance indicators should be considered relative to a fishery system that is impacted by anthropogenic activities and pressures.

processes (*i.e.*, *Step 2 – Action #2*). In turn, these objectives should be reshaped into a work plan for the FEP projects.[20]

- <u>Action #2: Periodically evaluate performance indicators</u>
  FEP projects should be regularly refined by the integration of new information from recursive iterations of the whole process. Thus, managers would need to consider the continuous monitoring and evaluation of performance indicators (*i.e.*, *Step 3 – Action #1*) and management strategies (*i.e.*, *Step 3 – Action #2*) to determine the status of the GOM fishery system and its sub-systems, and the efficacy of the GOM-FEP.

- <u>Action #3: Compare monitoring results and predictions</u>
  As part of an adaptive management framework, a key component throughout the entire loop is the systematic comparison of monitoring results and predictions, which will help consider trade-offs and adjust the FEP and its goals, along with their specific operational objectives.

Implications for the development of a GOM-FEP

<u>Integrating regional EM strategies for fisheries resources within the authority of the GMFMC</u>
The main scope of the IEA framework and programs is to support the scientific process of creating informed EBFM at the regional level (Harvey et al. 2017). Thus, appropriate IEA objectives are best defined relative to the needs and concerns of a given ecosystem and its stakeholders, along with its management focus. This implies that, on a case-by-case basis, IEA efforts could also supplement more traditional SS approaches (Levin et al. 2009), and that to be more effective, any EM strategy should account for the multi-scale realities of fishery resources within the management unit. To develop a pragmatic FEP that is reflective of the specific fisheries issues for the GOM-LME, managers should consider the realities of those issues at the appropriate spatiotemporal scale. Hence, for some issues, EAFM approaches might be considered more practical for supporting single FMP objectives, whereas EBFM approaches would be more effective at the larger, ecosystem-wide scale. Because we view this distinction as critically important across current fishery management strategies for the GOM-LME, we presented in this study[2] two specific cases elucidating approaches of how to effectively consider EAFM and EBFM aspects, respectively, throughout the steps of the GOM-FEP development loop proposed here. These two cases represent applications of EM in the GOM that can support the modification of existing FMPs, or inform the development of a FEP in the GOM-LME.

<u>Case #1: Integrating "red tide"-induced mortality into fishery management strategies</u>
This case study[21] illustrated an EAFM approach, and linked considerations, in which the authors conducted a MSE pertaining to the ongoing fishery and ecosystem management issues regarding harmful algal blooms of the dinoflagellate *Karenia brevis*, or "red tide" events (RTEs), that contribute to mass fish mortality events (*i.e.*, "fish kills"). Over recent decades, these RTE-induced fish kills have been particularly severe for red grouper (*Epinephelus morio*) and gag grouper (*Mycteroperca microlepis*), among other species, along the West Florida Shelf (WFS) and in nearby coastal waters. Accordingly, increased awareness of this issue, both among managers and fishing communities, has led to recent advancements in the estimation of red tide severity, applications to fish stock assessments, and in modeling of trophic interactions.[22] Consequently, and over time, the GMFMC has taken meaningful management actions to address this issue, the last of which, in response to a severe

[20] For example, see the ecosystem initiatives for the U.S. portion of the California Current-LME FEP by the PFMC.
[21] i.e., Harford et al. 2018 in the references.
[22] See Walter et al. 2013, SEDAR 2015, and Grüss et al. 2016.

RTE in the fall of 2017 and growing concerns among fishers, was the setting of catch limits for red grouper that were lower than the catch advice from the most recent stock assessment conducted in 2015.[23]

Using the GOM red grouper stock, the authors performed MSE simulation testing to weigh candidate decision-making approaches for modifying commercial catch limits that considered: 1) measurements of red tide severity; 2) the analytical assessment of the stock; and 3) subsequent use of stock assessment results in a harvest control rule to adjust catch limits according to prevailing conditions (Harford et al. 2018). This MSE approach evaluated the likely effects of different management strategies on a fishery and associated fish stock in achieving pre-agreed upon management objectives. Thus, this approach aligns with an EAFM strategy in the sense that SS management (*i.e.*, setting catch limits for a single stock) was extended to explicitly consider a key environmental effect (*i.e.*, fish mortality induced by RTEs) on the red grouper stock and its assessment, as well as any effect on subsequent management decisions.

<u>Case #2: Identifying relevant ecosystem-level, fishery-management indicators in the GOM</u>

This case study[24], considered within the EBFM framework, introduced the "ecosystem-level, management-indicator selection tool" (EL-MIST) and explored the complex dynamics of the GOM-LME and its fishery resources. This new multivariate-statistical protocol, among other things, is capable of highlighting relevant fishery ecosystem dynamics and trade-offs among management indicators. The authors examined the period between 1980 and 2011 using a total of 79 time-series management indicators drawn from the 2013 GOM-ESR (Karnauskas et al. 2013). Of those indicators, 49 were classified as responses (**Y** matrix; Table 1 in Kilborn et al. 2018)[25] while the remaining 30 indicators were considered predictors (**X** matrix; Table 2 in Kilborn et al. 2018).[26] This data structure (*i.e.*, **X** and **Y** matrices) allows for testing hypotheses regarding the effects of predictors (**X**) on a set of ecosystem-wide responses (**Y**), and to describe how **X** influenced the multivariate organization (*i.e.*, regime state) of **Y** over time. In other words, the EL-MIST approach was conceptualized to support the inquiry of whether the GOM-LME's natural physical-chemical environment, changing climatology, and variable anthropogenic exploitation patterns in the fishery ecosystem had any effect on the multispecies organization, health, structure, and function of the living marine resources and their related commercial revenue values over time (Kilborn et al. 2018).

The results of this analysis were able to pinpoint five distinct dynamic fisheries regimes in the GOM-LME between 1980 and 2011 with respect to the organization of underlying responses. Furthermore, in order to identify the subset of predictors that were best suited to describe the variability among those dynamic regime states, the initial list of 30 predictors was reduced to the 14 most influential to the GOM fishery resources' organization (Table 4 in Kilborn et al. 2018). Based on the EL-MIST model's outputs, a historical narrative for the GOM-LME's dynamic regime trajectory was created suggesting a major shift in the system's resource organization between the two stable periods of 1987-1994 and 1995-2001. That shift was punctuated by two intermediate shifts surrounding the 1994/1995 major-bifurcation point, with one around 1986/1987 and the other between 2002/2003. By examining the optimal subset of indicators retained by EL-MIST from **X** and their relative

[23] See Gulf of Mexico Fishery Management Council, 271st meeting, full council session. October 24-25, 2018, Mobile, AL.
[24] i.e., Kilborn et al. 2018 in the references.
[25] These indicators represented: 1) population status for important upper and lower trophic level species; 2) commercial fishery revenue values; and 3) indices of stock structure and function for a) fisheries independent monitoring catches, b) fisheries dependent catches (commercial and recreational), and c) individual species from various taxa.
[26] These indicators were selected for their capacity to describe: 1) the local, regional, and basin-scale climatology; 2) total commercial and recreational fisheries extractions; 3) fishing effort for all sectors; 4) the physical-chemical marine environment; and 5) oil industry activity.

influences to the model for **Y** (Table 4 in Kilborn et al. 2018), the authors determined that the primary drivers of fisheries resource reorganization in the GOM-LME were very strongly related to total fisheries extractions and effort across all sectors, along with changes in basin- and regional-scale climatological conditions and their associated teleconnected environmental processes (Kilborn et al. 2018).

Contributions to the GOM-FEP planning process from the two case studies presented

The two case studies described here contain many of the "ingredients," or actions, characterized in our proposed GOM-FEP planning process (Table 2). Specifically, these cases illustrate methods and associated potential considerations that can be used to achieve specific portions of the loop within the EAFM and EBFM frameworks, respectively (Table 3).

The EAFM approach of Harford et al. (2018) explored management strategies for the red grouper stock (currently managed under the Reef Fish FMP by the GMFMC), and provided several insights related to appropriately integrating ecosystem considerations for a fishery management issue that, although potentially perceived as localized within the GOM-LME (*i.e.*, RTE-driven mortality along the WFS and coastal Florida), was prioritized as an urgent EBFM research area.[17] Due to the likely influence of severe RTEs in reducing the abundance statuses for many economically important species, such as the GOM grouper complex[27], these events should be considered potential candidates for inclusion in the list of critical spatial threats to the GOM ecosystem (*Step 1*).

Additionally, as an indicator carrying information with both biophysical (*e.g.*, by favoring the spreading of hypoxic water conditions and higher mortalities among marine natural resources) and socio-economic (*e.g.*, by impacting human health, and fishery and tourism revenues) relevance, the occurrence of RTEs appears to be a strong candidate for further attention from regional managers, scientists, and other stakeholders developing the mutual vision statement for the GOM-LME (*Step 2*). Moreover, including RTE considerations could translate management goals into "real" actions by explicitly incorporating them into tactical decision-making for a specific GOM fishery sub-system (*e.g.*, the WFS) and/or management domains (*e.g.*, the Reef Fish FMP).

The MSE approach by Harford et al. (2018) also revealed a key management trade-off by comparing a management strategy for red grouper where decision-making dynamically reacts, following severe RTEs, against alternatives based on static decision-making reference points (independent of event occurrences) and the reliance on precautionary catch buffers. This trade-off involved balancing modest gains in catches that could be achieved through reactive catch limit adjustments against the practical impediments of implementing such demanding strategies (*e.g.*, timeliness of red tide detection, accurate observation of severity as a trigger for management intervention, and availability of fiscal resources necessary to conduct stock assessments or other comprehensive analyses). Also, several reef fishes appear susceptible to RTEs, posing an additional management challenge regarding whether other affected stocks should be episodically prioritized for assessment at the expense of non-affected stocks (Sagarese et al. 2017).

[27] See Karnauskas et al. 2017 in the references.

Table 2: Summary of potential contributions, in the form of "food for thought" describing applications of EAFM and EBFM approaches that can help navigate stakeholders through the proposed GOM-FEP planning process (*i.e.*, "the loop"), and details of how to achieve specific steps of the loop, as informed by the two case studies presented.

Steps and actions	Case #1 – EAFM approach	Case #2 – EBFM approach
1. Outline current structure, functions, and processes for the fishery ecosystem		
• Develop a conceptual model(s) for the GOM system and sub-systems		
• Describe resource status, trends, and threats	Supports inclusion of RTEs in the list of spatial threats to the GOM fishery ecosystem that are relevant for management considerations (*i.e.*, modifications of Reef Fish FMP)	Supports identification of key ecosystem indicators and spatial threats at the system and sub-system level, and helps detect significant state reorganizations of specific biophysical and socio-economic components
2. Identify goals and objectives for the fishery system, and prioritize efforts and processes		
• Lay out a concerted, agreed-upon vision statement	Supports considering RTEs as a key discussion point for a specific GOM fishery sub-system (*i.e.*, the WFS) and management domains (*i.e.*, Reef Fish FMP) when laying out vision statement for the GOM-LME	Customized configurations of EL-MIST can help account for key consideration when laying out vision statement for the GOM-LME
• Develop strategic objectives		Supports identification of strategic objectives at the system and sub-system level across GOM-LME
3. Assess progress and select management strategies		
• Develop a set of performance measures		Customized EL-MIST's hypothesis testing of specific performance measures/indicators can help evaluate progress of operational objectives
• Identify management strategies	MSE for a SS stock management domain (*i.e.*, Reef Fish FMP)	Distill complex ecosystem-level information to help strategy selection and decision-making process
4. Develop, update, and implement the FEP as a management guidance document		
• Develop GOM-FEP and group activities		
• Periodically evaluate performance indicators for system and sub-system status		Customized configurations of EL-MIST can support the periodic monitoring of performance indicators and system trends over time
• Compare monitoring results and predictions	MSE to support evaluation of management approaches	

Table 3: Walk-through examples to illustrate how the two case studies for EAFM[21] (left panel) and EBFM[24] (right panel) applications can help achieve specific steps of the proposed GOM-FEP planning process. RTEs = "Red tide" events; FEP = fishery ecosystem plan; WFS = West Florida Shelf; GOM = Gulf of Mexico; objs. = objectives; FMP = fishery management plan; MSY = maximum sustainable yield; ABC = acceptable biological catch; mgmt. = management; ACL = annual catch limit; MSE = management strategy evaluation; MS = multispecies; MTL = mean trophic level; recreat. = recreational; commerc. = commercial; AMO = Atlantic Multidecadal Oscillation.

Incorporating RTEs into FEP
Steps & actions within proposed planning process
Identify key spatiotemporal threats (Step #1, Act. #2) • RTEs for the WFS's fishery sub-system
Over-arching ecosystem-based vision statement (Step #2, Act. #1) • *E.g.*, to maintain/manage GOM's fisheries in balance with ecosystem needs, and natural & human factors
Develop strategic & operational objs. (Step #2, Act. #2) • Impacts from RTEs addressed to maintain affected fish populations (red grouper and/or reef fish species) at sustainable biomass levels
Assess progress of operational objs (Step #3, Act. #1) • Adapt fishery regulations (*i.e.*, Reef Fish FMP) to maintain red grouper population levels at, or above, its estimated biomass at MSY
Assess management strategies (Step #3, Act. #2) • Adjust regulations (*i.e.*, Reef Fish FMP) when assessment or other analysis post-RTE quantifies impacts • Incorporate buffer in ABC control rule to account for magnitude, spatial extent, intensity, and duration of most severe RTEs, and their frequency • Near 'real-time' regulation adjustments during or shortly after RTEs before true impacts on fish stocks can be quantified but to minimize negative impacts on the stock(s)
Develop performance measures (Step #3, Act. #1) • Use known impacts from previous severe RTEs to develop and incorporate mgmt. strategies Example: ○ If < 25% of 2004 RTE = take no specific mgmt. actions ○ If = 25-50% of 2004 RTE, then for a defined period: - Reduce ACLs by appropriate x% (*e.g.*, 20%) as informed by Harford et al. (2018) or other analysis - Close affected area and/or reduce bag limits/quotas ○ If = 50-75% of 2004 RTE, then for a defined period: - Reduce ACLs by appropriate x% (*e.g.*, 30%) as informed by Harford et al. (2018) or other analysis - Close affected area and/or reduce bag limits/quotas ○ If > 75% of 2004 RTE, then for a defined period: - Reduce ACLs by appropriate x% (*e.g.*, 40%) as informed by Harford et al. (2018) or other analysis - Close affected area and/or reduce bag limits/quotas
RTEs related project activities (Step #4, Acts. #1-#3) • Conduct MSE or other type of analysis to evaluate tradeoffs between mgmt. strategies and performance measures for noted species (*e.g.*, red grouper, gag) • Conduct analysis evaluating/comparing extent of previous RTEs and impacts on noted fish populations and associated fisheries • Conduct retrospective analysis on RTE impacts and mgmt. responses to inform future mgmt. strategies

Tools to integrate MS/multilevel ecosystem considerations into FEP
Steps & actions within proposed planning process
Identify key ecosystem indicators & threats (Step #1, Act. #2) • Tools used to identify key ecosystem- and sub-system level indicators and spatiotemporal threats to the GOM's fishery ecosystem over time *EL-MIST example: Results suggested that the MS structure of the GOM's fisheries resources is trending positively, such that MTLs and stocks' size structures have increased since the 1980s (e.g., recreat. & commerc. catches MTLs). However, some species have not experience such a recovery (e.g., declining southern kingfish individual sizes), and in other cases the positive trends are slowing (e.g., recreat. & commerc. MTLs). These trends appear to be driven primarily by basin- and regional-scale climatology as well as fisheries effort and extractions.*
Over-arching ecosystem-based vision statement (Step #2, Act. #1) • Tools can help consider ecosystem needs and stakeholders' concerns when managing GOM's fisheries, while accounting for significant state reorganizations of multiple ecosystem components over time *EL-MIST example: This multilevel-statistical protocol can support the identification of mgmt. trade-offs between stakeholders' interests and the GOM's fishery ecosystem's productivity, structure, and function, while accounting for significant ecosystem-wide reorganizations of its biophysical and socioeconomic ecosystem components.*
Develop strategic & operational objs. (Step #2, Act. #2) • Tools can be used within a MS context to support identification of strategic and operational objs. suitable to maintain all affected populations (*e.g.*, all reef fish species) at sustainable biomass levels *Example of informed strategic objs. from EL-MIST: Size structure variability for red snapper, southern flounder, spotted seatrout, and red drum appears to be positively related to declining commerc. and recreat. fishing pressure (and associated extractions) as well as to the shift in the AMO from the cold to the warm phase. The opposite effect was noted for the size structure of southern kingfish. Therefore, an advisable ecosystem-level strategic obj. would be to incorporate AMO variability into modeling efforts for these fishes, due to the importance of size structure on stock size estimates. More targeted actionable goals may be related to exploring the mechanisms behind each stocks' relationship with basin and regional-scale climatology and regional fishing activities to better inform the tuning of these models.*
Develop performance measures (Step #3, Act. #1) • Tools can help develop appropriate performance measures *EL-MIST example: Selected mgmt. indicators (e.g., Ryther index of ecosystem overfishing, spawning potential ratio) can be added to customized EL-MIST models to expose which may be more suitable for predicting fishery resource reorganizations specific to the GOM over time, which help evaluate progress of operational objs.*
Identify management strategies (Step #3, Act. #2) • Tools used at different spatiotemporal resolutions can help adjust regulations within a MS context (*e.g.*, Reef Fish FMP), and inform strategy selection and decision-making process *EL-MIST example: Detailed temporal models can be built and analyzed to explicitly account for the timing/duration of pertinent mgmt. actions to assess their historical effects for future decision making processes. This effort could also help refine/compliment other quantitative MSEs.*
Periodically evaluate performance indicators and compare monitoring results and predictions (Step #4, Acts. #2-#3) • Tools can help evaluate trade-offs between mgmt. strategies and performance measures within a MS context (*e.g.*, all reef fish species) *EL-MIST example: Regularly updated iterations of appropriate EL-MIST models can be used to assess effects of mgmt. changes over time on the structure, function, and health of the GOM's fisheries resources, and to monitor the progress of various strategic objs. The results of these analyses will inform managers about the sustainability of maintaining particular strategic objs. or monitoring programs, and which could benefit from additional refinement.*

While Harford et al. (2018) provided a strategic view for moving towards EAFM, their analysis stopped short of delivering tactical advice (*Step 3*). For instance, if a static precautionary catch buffer were identified as a preferable management option as, say, a strategy for the implementation of existing management measures for red grouper within the Reef Fish FMP, it would be necessary to further explore the acceptable range for such a buffer. This would also require examining trade-offs between maintaining low probabilities of falling below biomass thresholds while achieving the highest possible catches. Alternatively, if the preferred strategy is to be responsive in updating red grouper stock assessments, as a means to measure and account for red tide effects on stock status, then strategies could be further defined accordingly, such as implementing a catch buffer that is relative to RTE severity (*e.g.*, magnitude, spatial extent, intensity, and duration), which could be seen as responsive to future RTEs. Or, as a different option, monitoring observed trends in red tide severity and adjusting catch limits during interim periods between stock assessments could serve as a responsive management strategy that seeks to limit conducting assessments too frequently (*e.g.*, red grouper and gag grouper stock assessments have taken place every 3 to 6 years). Benchmarks for RTE severity could be based on previous events (*e.g.*, 2005's RTE) that provide some approximation of mortality risk, or, where steadier but less responsive solutions are sought, static buffering of catch limits could work to maintain higher average stock biomasses, and thus, better weather fluctuations in stock size. Regardless, there remain other tactical options to consider when responding to the aforementioned issue of RTEs (*e.g.*, adjustments to annual catch limits, temporary spatial closures of areas where red tide observations occurred, reductions in bag limits). Lastly, the effectiveness of any of these approaches in achieving the desired outcomes should be monitored (*Step 4*) and could be further evaluated using a similar MSE approach to that of Harford et al. (2018).

Over the extent of the whole GOM-LME, the EL-MIST statistical protocol advanced by Kilborn et al. (2018) represents a powerful application of the EBFM framework that can inform multiple steps and actions within the planning process proposed for developing a GOM-FEP (Table 2 and Table 3).[28] Specifically, the EL-MIST approach provided detailed information about the specific response indicators that best described significant state changes in the organization of the GOM-LME's fishery resources. The results of these analyses also corroborated findings from the GOM-ESR (Karnauskas et al. 2013) and other GOM-wide studies (Karnauskas et al. 2015), when selecting key ecosystem indicators accounting for the GOM-LME's organizational state changes (*Step 1*).[29]

Both conceptually and practically, the EL-MIST approach has other potential benefits that could help achieve specific steps and actions throughout the loop. For example, results from the GOM-EL-MIST indicated that the dynamic, fisheries regime-state trajectory followed a generally orderly path through time, and therefore, quantitative estimates of the magnitude and direction of incremental qualitative changes to the GOM-LME's fishery resources could be made by examining the response differences between temporally adjacent pairs of regime states over the study period. In turn, this information can help identify critical long- and short-term trends or threats to the GOM, and, if based

[28] The EL-MIST approach also provides key operational support to the IEA framework (Levin 2009) and the EBFM Policy (NMFS 2016a) and Road Map (NMFS 2016b) promoted by NOAA-NMFS.

[29] As pointed out by Kilborn et al. (2018), it is worth noting that within the GOM-ESRs, indicators are classified into independent subsets based on the drivers, pressures, states, ecosystem services/impacts, and responses (DPSER) conceptual model. This artificial segmentation raises a potential issue where the assumptions of the DPSER framework overlay an inherent hierarchical structure among categories that may not actually exist in the GOM-LME. This hierarchy creates a scenario-analysis based on a simplistic unidirectional chain that is not necessarily conducive to sufficiently describing all complex interrelationships across a LME's components, and among their underlying ecological processes (Niemeijer and De Groot 2008, Tscherning et al. 2012, Gari et al. 2015). The GOM-EL-MIST approach moves beyond these potential shortcomings of the DPSER model by relying on constrained analyses between paired sets of response and predictor indicators. This provides greater flexibility for exploring the broad scope of management priorities, while also allowing for the additional benefit of direct hypothesis testing for relationships between these two sets of relevant ecosystem components (Kilborn et al. 2018).

on customized parameterizations of the model, EL-MIST has the capacity to identify other threats (*e.g.*, spatial, socio-economic) specific to particular fishery sub-systems, thereby supporting the development of strategic objectives for these sub-systems as well as for the entire GOM-LME (*Step 2*).

Additionally, by virtue of the flexibility of the underlying statistical algorithms, it would be conceivable to use the EL-MIST protocol for evaluating progress made by specific operational objectives (*Step 3*) through direct hypothesis testing of a set of performance indicators (*i.e.*, responses) against a set of indicators characterizing changes in management decisions (*i.e.*, predictors). In turn, these alternative configurations of EL-MIST models could support the development of more strategic objectives capable of capturing underlying views of multiple stakeholders and the overall vision of the GOM-FEP (*Step 2*). This flexibility makes the EL-MIST approach an ideal instrument for efficiently distilling large amounts of ecosystem-level information into a more digestible format that managers and stakeholders can consider during strategy selection (*Step 3*) and decision-making (Kilborn et al. 2018). Lastly, the EL-MIST approach can be used to support the iterative aspects of implementing and monitoring a FEP in the GOM-LME by describing performance-indicator trends over time (*Step 4*), and detecting significant reorganizations in the states of specific biophysical and socio-economic components of GOM sub-systems (*Step 1*).

The GOM-EL-MIST developed by Kilborn et al. (2018) is consistent with the recommendation to translate EBFM principles into actions, rather than into a mere system-wide description, and can be used as a guide highlighting direct links to management actions and FEP effectiveness.[10,12] Specifically, managers and stakeholders hoping to assimilate the information learned from an EL-MIST model for the GOM fishery management system can begin by choosing the resolution of detail that they wish to consider from the software outputs.[30]

Finally, the flexibility of EL-MIST is not restricted to EBFM related research. Ecosystem-level results could be used to inform single species EAFM efforts by identifying the key covariates that should be considered for model parameterizations, both biotic and abiotic, as well as the relative dynamics between them. In turn, this information can be used to support the implementation of existing FMPs or future FEPs in the GOM-LME.

In conclusion, the aim of this document, as well as its accompanying paper[2], is to provide technical guidance to GMFMC's managers in implementing ecosystem-based strategies for the management of fisheries resources through a proposed, structured FEP planning process. Additionally, highlighting the two case studies, along with using them as examples to describe in more detail the steps and actions composing the planning process, would support current efforts to design and implement a FEP best suited to account for regional needs and to maximize the benefits of incorporating ecosystem-wide considerations into fishery resources management. Managers could follow the loop approach described here to develop and integrate action plans for prioritized ecosystem goals and objectives identified in conjunction with scientific experts and stakeholders.

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[30] The primary organization of any EL-MIST model is as response and predictor data tables representing the aspects that managers and stakeholders are "interested in" (i.e., responses), and those factors that are hypothesized to affect those "interesting" aspects (i.e., predictors). Thus, EL-MIST investigates an ecosystem by assessing the following questions, in order of increasing detail: 1) is there any statistical effect of the predictors on the responses; 2) are there any dynamic regime states with respect to the underlying responses over the study timeframe; 3) how is the LME's state trajectory affected by the set of predictors over time; 4) which response indicators characterize the most notable differences between any two dynamic regime states (and how do the predictors affect that); and 5) for any notable response indicators, how does the direction and magnitude of incremental change differ between relative regime shifts (and compared to any overall study period trends)? Based on the priorities of the management inquiry, which could be set during a focused management scoping process, any of the levels described here may be appropriate, but in an EBFM context it would be best to consider no less than the first three.

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