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PERSPECTIVE

Case studies demonstrate capacity for a structured planning process for ecosystem-based fisheries management

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Abstract: Structured, systematic processes for decision-making can facilitate implementation of ecosystem-based fisheries management (EBFM). In US fisheries management, existing fishery ecosystem plans (FEPs) are primarily descriptive documents — not action-oriented planning processes. "Next-generation" FEPs extend existing FEPs by translating ecosystem principles into action through a structured process, including identifying and prioritizing objectives and evaluating trade-offs while assessing alternative management strategies for meeting objectives. We illustrate the potential for implementing a structured decision-making process for EBFM by reviewing fisheries management case studies through the lens of the next-generation FEP process, highlighting two perspectives. First, across case studies almost all steps occur, many occurring in multiple regions, indicating scientific and fisheries management capacity exists to conduct structured process components. Second, adjustments would be needed to transition to next-generation FEPs, as existing activity is rarely conducted within a fully structured, integrated process and examples of certain steps are scarce, but existing examples can guide future management. Implementing ongoing activity within next-generation FEPs would likely streamline fisheries management activity, saving time and resources while improving outcomes for stakeholders and ecosystems.

Résumé : Des processus décisionnels systématiques structurés peuvent faciliter la mise en œuvre de la gestion écosystémique des pêches (GEP). Dans la gestion des pêches aux États-Unis, les plans écosystémiques de gestion des pêches (PEGP) sont principalement des documents descriptifs, et non des processus de planification axés sur les actions. Les PEGP de « prochaine génération » élargissent les PEGP existants en traduisant des principes écosystémiques en actions concrètes par l'entremise d'un processus structuré qui comprend la détermination et la priorisation des objectifs et l'évaluation des compromis, parallèlement à l'évaluation de différentes stratégies de gestion visant l'atteinte des objectifs. Nous illustrons le potentiel d'application d'un processus décisionnel structuré pour la GEP en examinant des études de cas de gestion des pêches à travers la lorgnette du processus de PEGP de prochaine génération, faisant ressortir deux perspectives. D'abord, d'une étude de cas à l'autre, presque toutes les étapes ont lieu, dont bon nombre dans plusieurs régions, ce qui indique que les capacités scientifiques et de gestion des pêches nécessaires à la réalisation des éléments du processus structuré existent bel et bien. Deuxièmement, des ajustements seraient nécessaires pour passer aux PEGP de prochaine génération, les activités existantes étant rarement réalisées dans le cadre d'un processus intégré et entièrement structuré, et des exemples de certaines étapes étant rares; des exemples existants peuvent toutefois guider la gestion future. La mise en œuvre d'activités permanentes dans le cadre de PEGP de prochaine génération rationaliserait vraisemblablement les activités de gestion, épargnant temps et ressources tout en améliorant les résultats pour les parties prenantes et les écosystèmes. [Traduit par la Rédaction]

Introduction

Ecosystem-based fisheries management (EBFM) is a holistic approach to fisheries decision-making that is intended to improve fisheries management outcomes for people and the planet (Pikitch et al. 2004; Fogarty 2014). The management of fisheries through EBFM strives to maintain multiple services that ecosystems provide while accounting for relationships among fishery system components (Pikitch et al. 2004). Though benefits of a more holistic approach have been claimed by many (Pikitch et al. 2004;

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Tyrrell et al. 2011; Fogarty 2014), the majority of fisheries are managed with a focus on maximizing sustainable catches of individual species without considering the consequences on the larger system, including habitat, climate, species interactions, and human dimensions such as cultural, social, and economic considerations (Pitcher et al. 2009; Travis et al. 2014). In relation to this, the incorporation of EBFM principles into tactical fisheries management has been rare (Skern-Mauritzen et al. 2016; Marshall et al. 2019).

To improve fisheries decision-making in an ecosystem context, many tools and processes have been proposed for EBFM implementation (Essington et al. 2016). Tools such as ecosystem modeling (Collie et al. 2016), management strategy evaluation (MSE), ecological risk assessment (Smith et al. 2007), portfolio approaches (Sanchirico et al. 2008), and ecosystem indicators (Link and Watson 2019; Tam et al. 2019; Fu et al. 2019), to name a few, have all been suggested for implementation of EBFM. Similarly many stepwise frameworks or processes for fisheries management have been proposed that include synthesis of ecosystem information and subsequent quantitative analyses (FAO 2003, 2009; Levin et al. 2009; Fletcher et al. 2010; Möllmann et al. 2013). Fisheries managers have adopted some of these approaches into practice outside of the US, including in Europe (FAO 2003, 2009) and Australia (Fletcher et al. 2010; Hobday et al. 2011). Within the US, the National Marine Fisheries Service (NMFS) recently proposed a roadmap for EBFM (National Marine Fisheries Service 2016), and NOAA Integrated Ecosystem Assessments (IEAs) have been developed for most regions (https://www.integratedecosystemassessment.noaa.gov/). These tools and associated guidance are strategic in nature, and the underlying principles have largely not been translated into policy action to implement EBFM (i.e., no clear measurable objectives, strategies, and specified management responses and tactics).

Despite the plethora of tools and processes that have been proposed for implementing EBFM, there is still a sentiment among fisheries managers in the US and some scientists that tools for implementing EBFM are not yet ready for putting ecosystem principles into action. Scientists continue to point to potential shortcomings of current analytical tools, such as ecosystem models (Espinoza-Tenorio et al. 2012; Hilborn et al. 2017). Regional Fishery Management Council advisory bodies continue to comment on the inabilities and limited capabilities of ecosystem models and MSE for use in management, including for developing quantitative ecosystem objectives (Pacific Fishery Management Council 2019) and for tactical management (Pacific Fishery Management Council 2018). Others have noted existing data gaps that prevent advances in EBFM implementation (South Atlantic Fishery Management Council 2016). Councils have also implied that the information they need for complex analytical analyses for the NOAA EBFM roadmap initiative are "not well documented in the scientific literature", including for ecosystem risk assessment and ecosystem-level trade-off analysis via MSE (Pacific Fishery Management Council 2016). And without further information (such as an EBFM toolbox), it will be "difficult to implement any meaningful EBFM" (Gulf of Mexico Fishery Management Council 2016). However, based on our experience, examples of activities and analyses exist in current management, and the capacity does exist for councils to begin incorporating EBFM principles into actionable management now via a recently developed framework: "Next-Generation Fishery Ecosystem Plans" (Levin et al. 2018) and tools encompassed in this framework.

Existing fishery ecosystem plans (FEPs) are mainly descriptive and do not directly link to fisheries management actions (Wilkinson and Abrams 2015; Essington et al. 2016; Marshall et al. 2018; Dawson and Levin 2019), but next-generation FEPs explicitly translate EBFM principles into action (Levin et al. 2018; Marshall et al. 2018). Existing FEPs were originally devised to be guidance documents for US Regional Fisheries Councils (Ecosystem Principles Advisory Panel 1999) and mainly include information on interactions within an ecosystem across multiple individually managed fisheries stocks (via fisheries management plans, FMPs), without providing advice to link that information to fisheries management actions (Marshall et al. 2018). The Lenfest Ecosystem Task Force (hereinafter referred to as "Task Force") reviewed the current state of policy, science, and decision-making processes related to EBFM, including existing FEPs, and suggested that a more structured, systematic, and transparent process is needed to overcome impediments and foster implementation of EBFM (Essington et al. 2016). They specifically proposed "next-generation" fishery ecosystem plans that expand on existing FEPs (hence "next-generation"). The process for next-generation plans is founded in adaptive management, is both structured and transparent, and includes periodic reassessment and modification of strategies based on learning that ensues from implementation (Essington et al. 2016; Levin et al. 2018). Specific steps and tools applied within the next-generation process address perceived challenges to EBFM implementation, particularly related to uncertainty, complexity, and lack of clear objectives (Essington et al. 2016).

The next-generation fishery ecosystem planning process is an avenue for operationalizing EBFM or "putting EBFM into practice" (Marshall et al. 2018). Levin et al. (2018) describe in detail how next-generation FEPs lead to actionable EBFM. In short, this process shares many features with other structured decision-making processes (e.g., the IEA processes developed within NOAA), but FEPs are Fishery Management Council products, which create more opportunity for actionable management responses. Like the first generation of FEPs, next-generation FEPs still contain aspirational goals for managing fisheries in an ecosystem context and descriptions of systems, but they also have explicit steps for identifying measurable objectives and prioritizing objectives. Next-generation FEPs contain steps to formally evaluate trade-offs and analyze how different actions can achieve measurable objectives. Ideally, next-generation FEPs would analyze outcomes and objectives from a triple-bottom line perspective — ecological, economic, and social (Marshall et al. 2018). This process places management activity in a structured framework so that decisions are transparent and not ad hoc (Marshall et al. 2018).

Levin et al. (2018) note that steps in the proposed next-generation FEP process are already being carried out by fisheries managers (e.g., Dawson and Levin 2019). Here, we review case studies of fisheries management systems globally to show how individual steps in the process have been completed in many regions, demonstrate examples of these actions, and provide recommendations for moving fisheries decision-makers towards the use of next-generation FEPs for implementing EBFM. By reviewing how activity within current fisheries management matches steps in the next-generation FEP process, we can show the potential for managers, including Fishery Management Councils, to implement EBFM via the next-generation FEP process. Though FEPs are generally a US fisheries management tool, next-generation FEPs are a structured decision-making process that could be applied to other regions as well. We specifically show and address the following: (*i*) In the US, Canada, Australia, and Europe, a diverse array of ongoing fisheries management activities exist that match the steps of the proposed next-generation Fishery Ecosystem Plan process, indicating that potential exists for management to conduct this process. Throughout this paper, we provide examples of steps as illustrations for fisheries managers for tackling these tasks in the future. (*ii*) At the same time, a few key steps are not commonly conducted, and ongoing activity is rarely conducted as a fully structured, integrated process. Also, for certain activities, modifications would be needed to further align ongoing management activity with specific details described in the process. (*iii*) However, examples of almost all steps exist and fisheries man-

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Box 1. Next-Generation Fishery Ecosystem Plan Process.

The planning process begins with 1. *Where are we now?* which includes understanding the current fishery system, through taking an inventory of the system or developing a conceptual model of the ecosystem, selecting and calculating indicators that represent the current status of components of the system (fish species, fisheries, predators, etc.), and taking an inventory of potential threats to the ecosystem. The next component (2. *Where are we going?*) and steps therein involve creating broad vision statements that are then broken down into several strategic objectives for multiple domains (ecological, economic, etc.). Risks to meeting the objectives are identified, prioritized and reduced to a few key objectives, and then these selected few are reconfigured and specified as measurable, achievable operational objectives.

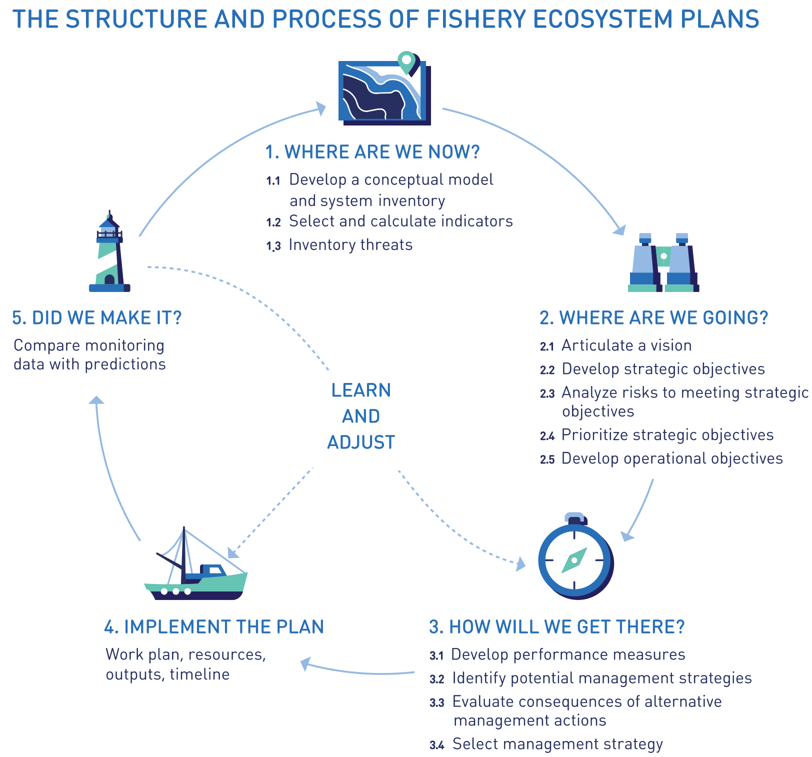

Figure 1 modified from Levin et al. (2018). Process proposed for developing next-generation Fishery Ecosystem Plans.

Component 3, *How will we get there?*, involves developing indicators and reference points based on objectives (targets, limits, or system states to avoid) and evaluating multiple management actions to determine which meet the objectives from component 2 based on the indicators and reference points. Then, based on this analysis, selecting one of the management strategies for implementation. Next, 4. *Implement the plan*, includes the final planning logistics of how the management action will be implemented, including potentially, work plans, timelines, etc. Management actions are then monitored overtime to see if objectives are met (5. *Did we make it?*). This can lead to changes in the development and implementation of indicators, reference points, and management strategies, as in Adaptive Management ("Adjust and Learn" arrows, inner loop). On a large, slower scale, the process repeats based on changes to the ecosystem (large loop).

agers can learn from these when beginning to implement the next-generation FEP process.

The next-generation ecosystem plan process

Using the planning process described for next-generation FEPs (Box 1; Essington et al. 2016), we illustrate how current fisheries management activity, both inside and outside the US, matches this planning process and show this tool to be a feasible next step for EBFM implementation. For brevity, we refer to the next-generation FEP process as either "Next-generation or ecosystem planning process" or more simply "planning process". A full description of the process can be found in Levin et al. (2018) and Essington et al. (2016). We refer to the high-level categories in the planning process, such as *Where are we now?*, *Where are we going?*, etc. as "components" of the plan and indicate them with italic font, and actions within each component (bullet points in Box 1; e.g., "Develop a conceptual model and system inventory", "Select and calculate indicators," etc.) are referred to as "steps" and are indicated with quotation marks. For component 4 (*Implement the plan*), we used a simpler review, looking only for any evidence of putting the plan into action. Similarly, for component 5 (*Did we make it?*), there is only one action, which defines the component, so there are no individual steps to analyze for this component. This gives a total of 14 steps that we illustrate fisheries management activity for (three steps in component 1, five steps in component 2, four steps in component 3, and then components 4 and 5 each having a single step).

Case study selection and review

Based on our collective experience, we reviewed 10 case studies to illustrate where current fisheries management actions match steps in the next-generation process. We chose each case study based on a current use of EBFM or an ecosystem approach (known management activity), a need for EBFM, or a known connection between parts of the ecosystem (species to species, species to environment, etc.) and known activity related to the planning process. We also selected case studies covering a wide range of regions in the US, with three additional case studies from outside of the US providing international perspectives and examples. We note that other management examples from these regions may

Table 1. The 10 case study regions and management issues examined to evaluate management activity related to the steps in the proposed next-generation fishery ecosystem plan process.

Case study region	Fisheries management issue
New England	Habitat area closures for improved groundfish protection
Mid-Atlantic	Butterfish and habitat-based survey availability
Mid-Atlantic – Chesapeake Bay	Needs of menhaden predators
Gulf of Mexico	Environmentally linked mortality of gag grouper
Northeast Pacific	Pacific sardine and environmentally linked harvest control rules
Northeast Pacific – US west coast	Interacting protected species
Bering Sea	Groundfish and avoiding ecosystem overfishing
Western Scotian Shelf	Declining traditional fisheries
Eastern Baltic Sea	Cod–herring–sprat interactions
Eastern and southern Australia	Small pelagic fishery impacts on the ecosystem

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also represent an ecosystem perspective or need for EBFM, but we chose to focus on case studies that illustrate a range of EBFM topics and range of examples of process steps. Finally, each author of this paper has expert knowledge in at least one of the case study regions; consequently, the case study topics also reflect the expertise of the regional author. The regional experts include academics as well as members of government agencies, Regional Fishery Management Councils, and US Regional Council Scientific and Statistical Committees.

Six of the eight US Fishery Management Councils are represented by the US case studies, with no case studies for the Western Pacific Fishery Management Council or the Caribbean Fishery Management Council (a consequence of there being no Task Force members from these regions). Though the Western Pacific Fishery Management Council has developed FEPs, these do not differ substantially from FEPs in other regions or from FMPs (see Essington et al. 2016), so likely another case study would add more examples but not alter our conclusions about capacity for the ecosystem planning process as a whole. The final case study regions and main management issue or topic for each region are listed in Table 1. From here forward, we generally refer to each case study in shorthand by either its location or key species.

Each regional expert author provided information on an individual case study (Appendix A). We collated information for each case study that highlights a specific major management question(s) or challenge(s) and how management action around that challenge exemplifies the steps in the planning process. Each author first provided information on two main questions for an individual case study: "What is the major fishery system issue relevant to management?" and "What management actions have occurred to address that issue?" Authors then considered each step in the process and identified whether action related to the definition of those steps had occurred pertaining to the main management issue for that case study.

Additionally, we conducted searches of US Fisheries Council and fisheries management documents and websites to find additional examples of activities occurring related to the individual steps in the ecosystem planning process for specific US case studies. We searched Council websites, NMFS science center websites, and NOAA regional IEA websites for activity related to specific steps — particularly steps within the first two components ("Develop a conceptual model and system inventory", "Select and calculate indicators", "Articulate a vision", and "Develop strategic objectives", and "Develop operational objectives", etc.) that are more broadly applicable at a regional scale than other steps. We searched documents of Council minutes and previous stock assessments only when it was known (through author expert knowledge) that a specific management action or plan (related to a step in the planning process) was considered at a specific meeting or in a specific assessment. Finally, we contacted regional scientists or managers (US Fisheries Council members) when we knew there was action related to a specific step, but we needed additional information to clarify what had occurred.

We identified and enumerated case study activity for each of the planning process steps (14 steps) only when that activity was applied to a management decision in an ecosystem context (hereinafter called management activity). Management activity refers to actions taken by the Councils in the US or other governing body for international case studies (Department of Fisheries and Oceans Canada (DFO), International Council for the Exploration of the Seas (ICES) or European Union (EU) council, or the Australian Fisheries Management Authority). It also refers to US management authorities outside of Councils (such as the Atlantic States Marine Fisheries Commission, ASMFC) and plans or recommended actions presented to or intended for Council use (i.e., IEA, Chesapeake Bay Fishery Ecosystem Plan). Reference to "fisheries managers" pertains to managers within these entities.

By "ecosystem perspective", the action taken must be related to multiple components in the system and not focused on a single species in isolation from its environment. Such actions included those related to habitat, environment and (or) climate, trophic interactions, protected species, and indigenous and traditional fisheries. This criteria for ecosystem perspective adheres to definitions of both ecosystem approaches to fisheries management and EBFM as defined by NMFS in the EBFM roadmap (National Marine Fisheries Service 2016), therefore focusing on the ecological side of triple-bottom line management (ecological, social, and economic). Activities within management must be from an ecosystem perspective to show that the next-generation process can be accomplished for EBFM specifically (rather than just single-species management).

We also made note of any documented presence and extent of stakeholder involvement that occurred within the management activity. By stakeholder involvement, we mean stakeholder involvement in multiple steps throughout the process and where stakeholders participate throughout the process beyond solely consultation, in a manner specifically defined by the next-generation FEP planning process (Essington et al. 2016).

We illustrate where examples of each step have occurred in a binary fashion (did or did not occur) using criteria described in Table 2. This determination was made for each case study by the primary author and the author who provided the information for the case study and was reviewed by a core set of the authors. We note that in general, our benchmark for "occurrence" was based on a modest level of activity related to each step. Also, activity for individual steps did not need to occur in coordination with other steps in a structured process (although that is the eventual goal). Criteria used to determine whether a step was completed were directly related to the definition of each step from Levin et al. (2018). We also note that fisheries managers may have completed steps for other fisheries in the system, but we focus on activities related to the specific case studies. This may result in some varia-

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Table 2. Minimum criteria used to determine whether activity within each case study adhered to steps from the next-generation fishery ecosystem plan process.

Component	Step	Minimum criteria for completion
1, *Where are we now?*	1.1, "Develop a conceptual model and system inventory"	A summary of multiple (at least two) components of the fishery system and connections between those multiple components.
	1.2, "Select and calculate indicators"	Selected and documented indicators related to at least two system components and status and (or) trend of each indicator. Indicators are selected using best practices (not ad hoc indicators; see Essington et al. 2016).
	1.3, "Inventory threats"	Within documentation, mention of at least two threats to the entire system or a component of the system; does not need to be a literal list.
2, *Where are we going?*	2.1, "Articulate a vision"	A broad statement about management goals or core values for a fishery system — must refer to multiple components in the system or the system as a whole (no single species).
	2.2, "Develop strategic objectives"	Similar to vision statement but more specific; must relate to multiple components in a system or one component's connection to other parts of the system — should relate directly to main case study topic.
	2.3, "Analyze risks to meeting strategic objectives"	Any qualitative or quantitative evaluation of risk related to the main species or topic of the case study with reference to some other components in the system (at least one other component).
	2.4, "Prioritize strategic objectives"	Some explicit prioritization of the strategic objectives; must mention objective related to main case study topic.
	2.5, "Develop operational objectives"	More specific objectives that do or do not stem directly from the strategic objectives; must contain main topic of the case study in reference to its connection to the larger system or another component in the system (not solely a single species objective); must contain either a desired value or value to avoid or directional goal for the future; may be implied by later steps (performance measures or strategies chosen) but must be explicitly stated.
3, *How will we get there?*	3.1, "Develop performance measures"	Selection of any performance measures used to evaluate potential management strategies for meeting objectives; ideally are connected to operational objectives from component 2, but not essential.
	3.2, "Identify potential management strategies"	Consideration of more than one potential management strategy.
	3.3, "Evaluate consequences of alternative management actions"	Similar to above, must have qualitative or quantitative evaluation of more than one management strategy; evaluate based on performance measures.
	3.4, "Select management strategy"	A single strategy must be chosen. Reference points are used in management strategies, so modifications of conventional reference points, using environmental data, count as selecting a strategy (since this will lead to a management strategy).
4, *Implement the plan*	Work plan, resources, outputs, timeline	Strategy selected from component 3, *How will we get there?*, is currently used (or was used at one point) in management (harvest control rules, used to set quota, put in management plans or amendments, etc.). No specific evidence of planning documents or logistics is needed as long as the strategy was implemented.
5, *Did we make it?*	Compare monitoring data with predictions	Collection and evaluation of data to determine whether objectives were met; must be connected back to operational objectives from component 2 (therefore, without operational objectives, cannot be completed). Continued monitoring of status and trends of indicators without connection to objectives does not count.

Note: Minimum criteria stem from the definition of each step from Levin et al. (2018).

tion in the number of examples for each step, but likely not the representation of capacity for the overall process across all case studies based on how we selected case studies. Finally, we only determined that a step had occurred when clear evidence existed, either through documentation or expert opinion. In some cases, the absence of evidence for a step may not confirm that activity related to that step did not occur, but could reveal a portion of the decision-making process that was not documented or accessible.

Our synthesis and examples stem directly from information found within summaries of the case studies (Appendix A). Within the main text, we summarize major findings across all case studies for each step, provide recommendations for modifying activity in the future, and show the capacity for components of next-generation FEPs. The summaries in the appendix provide more detail of the specific management activity that match process steps for each case study and also provide more detailed information about specific examples for certain steps. However, we have also highlighted in boxes below specific examples for steps that were rare to provide useful examples for fisheries managers. In both the main text and appendix, component names are italicized (e.g., *Where are we going?*) and individual steps within components are in quotes (e.g., "Select a management strategy") with step number provided. All information is reflective of management activity up to the beginning of the calendar year 2018.

Case study review and examples

Overview

Across all case studies, nearly all next-generation FEP process components and steps were conducted in some manner in at least one region and usually in multiple regions (Table 3). In most case studies, fisheries managers have conducted activity related to at least one step within each component of the process. Almost all case studies have examples of at least half the 14 steps, and many

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Table 3. For each case study, a check mark indicates there is management activity related to an individual step in the next-generation fishery ecosystem plan process.

Step	New England groundfish	Mid-Atlantic butterfish and habitat	Atlantic menhaden	Gulf of Mexico gag grouper	Pacific sardine	Pacific interacting protected species	Bering Sea groundfish	Western Scotian Shelf	Eastern Baltic Sea	Australian small pelagics
1, *Where are we?*										
1.1, "Develop a conceptual model and system inventory"	✓	✓	✓	✓	✓	✓	✓	✓	✓	
1.2, "Select and calculate indicators"	✓	✓	✓	✓	✓	✓	✓	✓	✓	
1.3, "Inventory threats"	✓	✓	✓	✓	✓	✓	✓	✓	✓	
2, *Where are we going?*										
2.1, "Articulate a vision"		✓	✓				✓	✓	✓	
2.2, "Develop strategic objectives"	✓	✓	✓		✓	✓	✓	✓	✓	✓
2.3, "Analyze risks to meeting strategic objectives"						✓	✓			✓
2.4, "Prioritize strategic objectives"										
2.5, "Develop operational objectives"	✓						✓			✓
3, *How will we get there?*										
3.1, "Develop performance measures"	✓				✓		✓			✓
3.2, "Identify potential management strategies"	✓				✓	✓	✓			✓
3.3, "Evaluate consequences of alternative management actions"	✓				✓	✓	✓			✓
3.4, "Select management strategy"	✓	✓	✓	✓	✓	✓	✓		✓	✓
4, *Implement the plan*	✓	✓	✓	✓	✓		✓		✓	✓
5, *Did we make it?*										

have examples for over two-thirds of the steps (Table 3). Most case studies show management activity pertaining to components 1–4 (*Where are we now? Where are we going? How will we get there? Implement the plan*), whereas activities for component 5 (*Did we make it?*) were absent. Fisheries managers may have conducted additional relevant activities but did not document that activity in an accessible manner.

The number of steps with management activity (for components with multiple steps) varied among components, with more examples of steps in the first component. For component 1 (*Where are we now?*), almost all case studies had activity pertaining to every step. In comparison, for components 2 and 3 (*Where are we going? How will we get there?*), multiple case studies had activity pertaining to fewer than half of the steps. This illustrates areas in the process that fisheries managers across the board have already conducted versus areas where more effort would be needed (but is possible) to apply the next-generation process as a whole. Below we review, in turn, activities conducted related to each component.

Component 1, *Where are we now?*

For component 1, almost all case studies have examples for each step, and the first step, "Develop a conceptual model and system inventory", was accomplished through a variety of avenues. Therefore, across regions, component 1 is already being conducted.

Management activity related to developing a conceptual model and inventory (step 1.1 in the process) was among the most commonly conducted of all steps. Some examples of inventories appear as part of an existing FEPs, such as the Pacific Coast ecosystem plan (Pacific Fishery Management Council 2013) and the Chesapeake Bay ecosystem plan (Chesapeake Bay Fisheries Ecosystem Advisory Panel 2006). Other examples exist outside of ecosystem plans and include overviews of the system and its status and trends, including the Ecosystem Status Report for the Gulf of Mexico (Karnauskas et al. 2013), Ecosystem Status Report for the Northeast Shelf Large Marine Ecosystem (Ecosystem Assessment Program 2012), Alaska Marine Ecosystem Considerations Report (North Pacific Fishery Management Council 2015), the DFO State of the Ocean Report (Fisheries and Oceans Canada 2012), and the Integrated Assessments of the Baltic Sea (ICES 2015). Additionally, most case studies with inventories also had conceptual models or used the DPSIR–DPSER (Driver, Pressure, State, Impact (or Ecosystem service), and Response) conceptual model framework (Kelble et al. 2013), either in the same document or through related activities such as IEAs (see the Gulf of Mexico, Northeast Pacific sardine, and Northeast Pacific interacting protected species case studies in Appendix A). As with conceptual models, activity related to "Select and calculate indicators" (step 1.2), and associated status and trends of indicators, were included in the system inventories or IEAs for most case study regions. Finally, most of the discussions of threats to the ecosystem (step 1.3 in the process, "Inventory threats") were also included in the system inventories (step 1.1).

However, the breadth of threats recognized was limited. Accordingly, when conducting future inventories of threats within the next-generation process, inventories could be expanded based on specifications in the next-generation planning process. Levin et al. (2018) suggest that inventories should include more threats than those occurring in the sea (shipping, fishing, etc.), for example, pressures from the human system (changing markets) and terrestrial pressures (e.g., development and agriculture). Additionally, the planning process proposed that threats not only be identified, but that their magnitude, frequency, and spatial scale be characterized.

Component 2, *Where are we going?*

Although across case studies there is activity related to the initial steps in component 2 ("Articulate a vision" and "Develop

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Box 2. *Where are we going?* Highlighted example: Bering Sea.

For component 2, *Where are we going*, there is activity for almost all steps for the Bering Sea. For Alaska fisheries, there is a broad ecosystem vision statement (step 2.1 "Articulate a vision statement") from the North Pacific Fisheries Management Council that states:

> "*Vision Statement – The Council envisions sustainable fisheries that provide benefits for harvesters, processors, recreational and subsistence users, and fishing communities, which (1) are maintained by healthy, productive, biodiverse, resilient marine ecosystems that support a range of services; (2) support robust populations of marine species at all trophic levels, including marine mammals and seabirds; and (3) are managed using a precautionary, transparent, and inclusive process that allows for analyses of tradeoffs, accounts for changing conditions, and mitigates threats*," (North Pacific Fishery Management Council 2014).

This statement was developed by the Ecosystem Committee for the North Pacific Fishery Management Council, brought on partly by input from stakeholders that the Council did not previously have a vision statement or ecosystem objectives (Bill Tweit, personal communication). Additionally, for more specific strategies/goals (step 2.2 "Develop strategic objectives"), the Groundfish FMP has multiple high level ecosystem related objectives that stem from the 45 objectives from the Alaska Groundfish Programmatic Supplemental Environmental Impact Statement (PSEIS), including: "*Preserve food web*" and "*Incorporate ecosystem-based considerations into fishery management decisions, as appropriate*." In line with the Lenfest process step of "Assess risk to meeting objectives" (step 2.3), the ecological impact study also (National Marine Fisheries Service 2004) included assessments of risk to meeting all of these objectives for various potential management strategies. However, there was no evidence of "Prioritize operational objectives" (step 2.4). Within the PSEIS and Groundfish FMP, there are more specific operational objectives, including "*Maintain or adjust current protection measures as appropriate to avoid jeopardy of extinction or adverse modification of critical habitat for ESA-listed Steller sea lions*", examples of activity pertaining to step 2.5 ("Develop operational objectives"). There are also both strategic and operational objectives described in each iteration of the Bering Sea/Aleutians Island groundfish FMP (see North Pacific Fishery Management Council 2017) (many of which stem from the PSEIS objectives).

strategic objectives"), there is limited activity for later steps ("Prioritize strategic objectives", "Analyze risks to meeting strategic objectives", and "Develop operational objectives"). Therefore, more effort may be needed to begin to conduct these steps as part of the process, but examples exist. In particular, across all case studies, there are examples for almost all steps in component 2.

"Articulate a vision" and "Develop strategic objectives" (steps 2.1 and 2.2) were derived from regional (US Council processes) and (or) federal agencies. For example, vision statements and objectives for the Bering Sea and the Mid-Atlantic case studies were developed via regional Fishery Management Council efforts (the Ecosystem Committee for the North Pacific Fishery Management Council (NPFMC) and a strategic planning process by the Mid-Atlantic Fishery Management Council (MAFMC)). In the New England case study, the identified strategic objective came from a legislative mandate. Specifically, the objective stemmed from the Magnuson Stevens Act requirements that Fisheries Management Councils must "minimize to the extent practicable the adverse effects of fishing on essential fish habitats (EFHs)" (Grabowski et al. 2014; New England Fishery Management Council 2016). For the Northeast Pacific interacting protected species case study, strategic objectives were listed in the killer whale (*Orcinus orca*) and Pacific salmon (*Oncorhynchus* spp.) recovery plan documents developed by NOAA and triggered by the Endangered Species Act, again relying on objectives stemming from a federal agency.

Stakeholder involvement varied widely across case studies for activity in this component, and the planning process specifically highlights the need for collaboration with stakeholders in these steps (Essington et al. 2016). For the Bering Sea and Chesapeake menhaden case studies, the NPFMC and the ASMFC adopted or modified vision statements (step 2.1, "Articulate a vision") in response to stakeholder requests (Atlantic States Marine Fisheries Commission 2012; North Pacific Fishery Management Council 2014). In contrast, the vision statement and strategic objectives (steps 2.1 and 2.2) for the Mid-Atlantic case study were developed by the MAFMC with more in-depth stakeholder involvement. The development of the Mid-Atlantic Council's strategic plan included a large-scale outreach effort with more than 1500 participants (Mid-Atlantic Fishery Management Council 2012). This effort included stakeholders from commercial and recreational fisheries, environmental organizations, seafood users, scientists, and more. Other examples of vision statements and strategic objectives for specific case studies were developed mainly by managers and (or) scientists (as far as was documented; see Pacific case studies, New England case study, and others). We note here that some Councils (e.g., the North Pacific Fishery Management Council) may have assigned representatives to represent larger groups rather than involving large numbers of individuals.

Step 2.3, "Analyze risks to meeting strategic objectives" was not commonly conducted, though we found a few examples, but in many, these were disconnected from other steps. For instance, the Alaska Groundfish Programmatic Supplemental Environmental Impact Statement (National Marine Fisheries Service 2004) analyzed risk to fishery management alternatives for various previously identified objectives (see Box 2). For the objective to "Avoid impacts to Seabirds and Marine Mammals," fisheries manage-

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Box 3. Operational objective and ecosystem MSE highlighted example: Australia.

The small pelagic fishery (SPF) in Eastern and Southern Australia is managed by the Australian Fishery Management Authority (AFMA) and is comprised of commercial mid-water and bottom trawl fisheries targeting four low- to mid-trophic level species (Australian sardine *Sardinop sagax*, blue mackerel *Scomber australasicus*, jack mackerel *Trachurus declivis*, and redbait *Emmelichthys nitidus*). A constellation of factors led AFMA to review the SPF harvest strategy in 2013, in order to determine target and limit reference points for the SPF that consider impacts on predators and the food web. The AFMA review of the harvest policy met our criteria for 2.5, "Develop operational objective", and all steps in component 3 (*How will we get there?*). A scientific group suggested using Marine Stewardship Council criteria as objectives/performance indicators for the review and this was endorsed by the Resource Assessment Group for the fishery and by AFMA management. The criteria for determining acceptable impact are that: *(1) No other species abundance is impacted by more than 70% and (2) The abundance of no more than 15% of other species or groups is impacted by more than 40%.* These criteria are specific "Develop operational objectives" (step 2.5), and also contain the step "Develop performance measures" (step 3.1, specific limits). The scientific group then used an existing Atlantis ecosystem model (Smith et al. 2015) to evaluate multiple management strategies that would meet these operational objectives and performance indicators; (steps 3.2 "Identify management strategies" and 3.3 "Evaluate consequences of alternative management actions"). The analysis concluded that harvest rates that achieved a target stock size of B_{50} (50% of unexploited biomass) met the performance criterion (Smith et al. 2015) and no changes were made to the harvest strategy because the B_{50} strategy was the status quo strategy (step 3.4, "Select management strategy" and component 4, *Implement the plan*).

ment alternatives were analyzed for direct or indirect impacts on seabirds and marine mammals (see Box 2). In this case, the existing optimal yield range for the groundfish fishery resulted in no major or negative impacts to seabirds and marine mammals, according to the analysis.

We did not identify any case study where "Prioritize strategic objectives" (step 2.4) was explicit and documented. It is possible that prioritization was conducted, but not formally expressed. Yet, it is clear that some prioritization occurred, as many case studies had other activities that require prioritization (such as step 2.5, "Develop operational objectives"). At best, prioritization was poorly documented or possibly not conducted in a systematic way.

Based on the results from this review, occasionally operational objectives have been developed (step 2.5) related to a specific management issue. The operational objectives that were clearly defined were either directional (e.g., improve the status of system component) or included limit or target levels for ecosystem components, as used in conventional fishery management. In both the New England groundfish habitat case study and Bering Sea groundfish case study, there were operational objectives with directional goals but without specific targets, such as "…reduce impacts on spawning groundfish and on the spawning activity of key groundfish species…" (New England Fishery Management Council 2016). For the Australian small pelagic fishery case study, there were operational objectives with specific targets set for impacts on predators, including insurance that biomass of other species not be impacted by more than 70% (see Box 3). However, these three case studies were the only ones where we could identify ecosystem-related operational objectives. Accordingly, the capacity exists to develop either directional operational objectives or objectives with specific target values, but this activity is not commonly occurring (or documented). More effort is needed in this area to conduct the next-generation process.

Component 3, *How will we get there?*

Across all case studies, we found examples for every step in component 3 in at least one region. However, there are some particular discrepancies between case study activity and specifications outlined in the next-generation planning process that we highlight for certain steps.

While alternative management strategies were sometimes evaluated against performance indicators, in no case was there a formal and deliberate process of identifying, evaluating, and selecting portfolios of measures for the step "Develop performance measures" (step 3.1) based on objectives that could be used to track success of policies. Specific performance indicators were used in MSE, but these indicators usually did not represent the full suite of ecosystem components likely impacted by strategies. Although we counted indicators used in MSE as completion of this step, ideally, performance measures would be used to evaluate progress towards the operational objectives and therefore include indicators that reflect the multiple ecosystem components contained in the operational objective(s). We suspect that this finding is related to the general lack of operational objectives (step 2.5) noted above because performance measures stem directly from desired levels identified in the operational objectives.

Most commonly, ecosystem management strategies chosen (step 3.4, "Select management strategy") were modifications of conventional management strategies. This supports findings in Essington et al. (2016), Levin et al. (2018), and Patrick and Link (2015) that indicate that many ecosystem goals can be achieved by modifying conventional strategies. All strategies chosen adjusted status quo fisheries management through either modification of estimated stock status relative to reference points by including environmental data in stock assessments or modification of catch limits via caps or cut-offs. For instance, in the Australian small pelagic case study, fisheries managers chose a stock biomass target to diminish effects on predators (Box 3). This example specifically linked the chosen management strategy to previously identified objectives, but some case studies with modifications of harvest control rules did not appear to have ecosystem operational objectives. These objectives likely existed implicitly, but were not explicitly documented. Finally, the ecosystem planning process calls for examination of a broader suite of management

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strategies and more novel configurations of existing management strategies or policy instruments (Essington et al. 2016) than presented by many of these case studies.

Other than the modifications to conventional management mentioned above, other strategies chosen (step 3.4, "Select management strategy") were conventional strategies already in use. In both the interacting protected species case study and Australian small pelagic case study, the selected strategy did not change status quo management. This highlights that conducting activity related to this step within the next-generation planning process may not always result in a change to management. However, the process of evaluating multiple strategies may provide more confidence in the strategy selected and provide documentation that issues were considered.

Although "Select management strategy" (step 3.4) was one of the most commonly completed steps, the preceding steps in component 3 were not (3.2, "Identify potential management strategies" and 3.3, "Evaluate consequences of alternative management actions"). Thus, in some cases, activity related to step 3.4 apparently was conducted, but steps seemingly necessary for its completion may not have been done. For example, red tide is included as an additional source of mortality (modeled as extra "fishing" mortality) decoupled from natural mortality in the gag grouper (*Mycteroperca microlepis*) stock assessment in the Gulf of Mexico (SEDAR 2014, 2016). Its inclusion leads to modification of estimated stock status relative to the reference point. Thus, consideration of red tide conditions influences the estimation of stock status, and this stock status relative to the reference point impacts the management strategy chosen (e.g., allowable catch; exemplifying step 3.4, "Select management strategy"). However, there was no formal management evaluation in which multiple strategies were selected and assessed (steps 3.2 and 3.3). Activities for all of these steps would need to be completed, and in order, to conduct the next-generation process.

Component 4, *Implement the plan*

It is difficult to find evidence of specific work plans, timelines, and resources (funding, staff, etc.) required for this component (as defined in the planning process). Nonetheless, implementation has occurred. For most case studies, strategies were implemented as evidenced in subsequent FMPs and amendments that enacted the selected strategies (from component 3) into management. Therefore, all case studies that have activity for step 3.4, "Select management strategy" also have activity for component 4, *Implement the plan* (Table 3).

Component 5, *Did we make it?*

We found no explicit activity for component 5, *Did we make it?*, that fits the specifications of the recommended ecosystem planning process, indicating that this is an area where fisheries managers can focus attention to move toward the next-generation planning process and EBFM implementation. This component specifically refers to determining whether selected management strategies (from step 3.4) improved the fishery system and sustainability and whether objectives (from component 2) are met. Addressing and answering this question requires more than monitoring the system. A specific hurdle to conducting activity addressing component 5 is the paucity of developing operational objectives (step 2.5) in component 2 (*Where are we going?*). It is, of course, difficult to identify activities directed at evaluating strategies relative to objectives without knowing the original objectives. Additionally, many strategies were evaluated or implemented recently (e.g., Australian small pelagics case study management evaluation) or are currently being implemented (e.g., the area closures in the New England groundfish case study, ASMFC menhaden (*Brevoortia tyrannus*) ecosystem reference points). Perhaps insufficient time has passed to evaluate whether these strategies are applying the protocol proposed in the next-generation ecosystem planning process. We did find examples of monitoring individual indicators from *How will we get there?* (component 3) that could allow preliminary answers to *Did we make it?*, but these examples would need further evaluation and linkage to objectives to benefit future management decisions.

Discussion

We provided examples of the existing capacity for implementing steps of a structured decision-making process for EBFM via next-generation FEPs. On one hand, we found that across case studies, management activity exists that follows steps in this proposed fisheries ecosystem planning process. On the other hand, we also identified areas where fisheries managers would need to make adjustments or initiate new actions to connect individual activities within the next-generation FEP process. Still, several regions have examples for almost all steps, and though modifications are needed, time and resources are already being used for activity similar to steps in the process. Therefore, fisheries managers can begin to move towards implementing EBFM via the next-generation FEP process by placing ongoing activity within this structured framework.

Capacity exists

Looking across all case studies, the potential to follow the next-generation FEP structured decision-making process exists — nearly all steps have been conducted in some manner, usually in multiple regions. We also revealed that activities are being accomplished in numerous ways, indicating that capacity to complete each step is flexible. It is apparent that fisheries managers, including US Councils, may tailor the process to use tools already at hand and use available technical experts and capacity to meet ecosystem objectives. Though we found little evidence for activity directed to a few key steps — namely "Prioritize strategic objectives", "Develop operational objectives", and assessing whether objectives were met (component 5, *Did we make it?*) — activity for these steps could be occurring (based on evidence of proceeding steps), but not in an explicit manner. As such, the potential for fisheries managers to follow the proposed process and develop next-generation ecosystem plans may be even greater than indicated by the documentation we could find.

Although we found evidence of activity corresponding to most of the next-generation planning steps, a few steps lacked examples, suggesting that barriers may still exist for transitioning to the planning process as a means to implement EBFM. First, there could be local institutional, political, or technical barriers that prevent the initiation or completion of steps. Similar barriers have been described in detail previously (Christie et al. 2007; Hilborn 2011; Cowan et al. 2012), including the mismatch of ecological and jurisdictional scales and costs of monitoring and resources needed for EBFM. Alternatively, or in addition, there could be a lack of incentives to engage in activity related to fisheries ecosystem planning and EBFM in general. Finally, many of the examples of steps in the case studies were narrowly focused (species- or fisheries-specific), and, moving forward, there could remain a lack of a coordinated effort to participate in fishery planning at an ecosystem scale. Still, across all case studies, there are examples for almost every step, and fisheries management entities can learn and borrow from others for conducting individual steps in the future.

Areas for improvement

Based on our review, we identify three priority actions to enhance the implementation of EBFM through use of next-generation fisheries ecosystem plans: (*i*) place activities within a structured decision-making process like next-generation FEPs rather than stand-alone activities; (*ii*) explicitly document activity related to decision-making; and (*iii*) include stakeholder involvement throughout the process. These are areas where more effort may be needed to make the transition to next-generation FEPs. We believe that progress is possible, since efforts can be guided by examples summarized in this paper.

First, efforts to implement EBFM may have greater influence on decision-making if they are integrated within an ordered, structured, stepwise process like that proposed for next-generation FEPs (Essington et al. 2016). Couching activities within a larger planning process may streamline management planning by satisfying multiple government mandates at once and prioritizing management issues (Marshall et al. 2018). Within the case studies, activities for many steps and components were developed in isolation, via various management mandates, workshops, etc., which can lead to repeated efforts across management activities and, consequently, resource costs. For example, the Northeast Pacific protected resources case study included examples of broad visions from the salmon FMP and objectives from the killer whale recovery plan. Objectives likely also exist in salmon recovery plans or documents for other protected resources under Endangered Species Act or the Marine Mammal Protection Act. Although there often are objectives that address species individually, there also are objectives that overlap due to the interactions among species. Integrating activities within the proposed structured planning process would facilitate addressing mandates simultaneously and reduce repetitiveness across mandates (Fogarty 2014).

Without integrating activities within a larger planning process, steps may also be missed or addressed out of order. Several case studies illustrate the identification and evaluation of management strategies (steps 3.2, 3.3), but few provide evidence of the steps that should precede this step — development of operational objectives and targets and limits therein (performance measures). Specifically, within the Atlantic menhaden case study, the Atlantic Menhaden Technical Team identified potential performance indicators (such as environmental indicators, indices of forage abundance, and prey–predator biomass ratios) and ecosystem reference points. However, the Technical Team noted that without clear statements of system goals by the Atlantic States Marine Fisheries Commission, it could not make appropriate selections from those indicator lists (SEDAR 2015), except for setting a catch cap for menhaden within Chesapeake Bay. In the past few years the Commission has clarified its strategic (but not operational) objectives, and its Biological–Ecological Reference Point Working Group has reviewed models to develop reference points based on the strategic objectives (Atlantic States Marine Fisheries Commission 2017). With hindsight, the ongoing process might have been streamlined by adopting a more structured process at the outset to articulate goals and prioritize objectives.

In contrast, the Australian small pelagic fishery (SPF) was the only case study we could identify with an example of a measurable operational objective (step 2.5) and corresponding performance measures (step 3.1) to evaluate alternative management strategies. Specifically, that abundance of no more than 15% of other species or groups is impacted by more than 40%, and no species abundance is impacted by more than 70% (adopted from Marine Stewardship Council 2014). Researchers then tested management strategies to determine which met these EBFM criteria. Accordingly, operational objectives and targets therein were identified before the evaluation of management strategies, as outlined in the ecosystem planning process.

Second, in our search for examples of each step, it was difficult to find documentation of some steps, specifically "Prioritize strategic objectives" and "Develop operational objectives". Therefore, additional activity related to these steps is needed to advance towards the use of next-generation FEPs for EBFM. Leslie et al. (2015) determined that successful ecosystem-based management projects included a defined set of specific objectives and prioritization, and ecosystem-based management projects in Australia that were successful had clear operational objectives (Smith et al. 2017). Lacking prioritization, managers may fail to foresee certain risks or trade-offs and (or) inefficiently allocate resources within management (Fletcher 2005; Levin et al. 2014). We provided a few examples here of objectives, but also lessons can be borrowed from analogous situations. For example, the NMFS has developed a framework for prioritizing fisheries species for stock assessments that includes, among other objectives, how important a target species is as a predator or prey item in its ecosystem (Methot 2015). As fisheries managers move towards implementing next-generation FEPs, lessons can be learned from examples outside of EBFM, and additional tools for prioritizing objectives also exist (see Essington et al. 2016).

Stakeholder involvement in FEP planning is key to success in the planning process so that they help develop and support the management measures used to enforce their fishery (Donkersloot and Carothers 2017). While stakeholder involvement is often considered expensive (FAO 2003; Tallis et al. 2010), involving stakeholders either directly or indirectly is likely far cheaper than conducting fisheries stock monitoring (Scyphers et al. 2019). The next-generation FEP process outlined by the Task Force calls for stakeholder participation in all steps and in more than a consultation capacity, in particular, incorporating stakeholder knowledge to describe the system and develop management strategies, including stakeholder values and needs (Essington et al. 2016). However, evidence of stakeholder inclusion, across a range of stakeholders and in multiple steps, was limited in our examples. There are multiple potential explanations for this. First, the case study topics may not reflect stakeholder involvement occurring in regions (i.e., fisheries managers may be using greater stakeholder involvement for other management issues within regions). Second, as with other steps and specifications for this process, there may be little documentation on stakeholder involvement, which may not be explicitly documented if stakeholders have long standing representation on a US Fisheries Council or Council committee. Nonetheless, enhanced stakeholder involvement within case study regions is beginning to emerge. For example, the recently released Bering Sea Fishery Ecosystem Plan outlines steps and protocols (action modules) for the North Pacific Fishery Management Council to consider and incorporate local and traditional knowledge into the management process, not just through integrating it into Western science, but through extensive collaboration with local and indigenous peoples at the outset (North Pacific Fishery Management Council 2019).

Summary

Our analysis demonstrates that, on one hand, there is capacity for all of the steps of a structured decision-making process and next-generation FEPs, and this process is a plausible avenue for EBFM implementation. Fisheries managers have conducted the majority of steps in the process, and multiple tools exist to complete the steps (based on case study examples and tools listed in Essington et al. (2016)). On the other hand, activity pertaining to some steps is not common (prioritize objectives, develop operational objectives). Still, as fisheries management bodies move towards adopting the planning process, there is opportunity to learn, adapt, and share experiences across management regions. Also, ongoing activity may be streamlined, reducing costs, and made more effective by placing activity within an integrated decision-making process that includes prioritization and identification of specific operational objectives and appropriate performance measures. The implementation of EBFM is not constrained by the need for new science tools; progress can be made with existing tools and activity within the next-generation FEP framework. Based on existing activity, fisheries managers have the potential to move towards the use of next-generation FEPs to save resources by streamlining management and potentially leading to better outcomes for ecosystem services by explicitly addressing trade-offs through this action-oriented EBFM process.

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Appendix A. Case study summaries

Australia and small pelagic fishery (SPF) impacts on the ecosystem

The SPF in eastern and southern Australia is managed by the Australian Fishery Management Authority (AFMA) and is composed of commercial midwater and bottom trawl fisheries targeting four low- to mid-trophic level species (Australian sardine (*Sardinops sagax*), blue mackerel (*Scomber australasicus*), jack mackerel (*Trachurus declivis*), and redbait (*Emmelichthys nitidus*)). A constellation of factors led AFMA to review the SPF harvest strategy in 2013 to determine target and limit reference points for the SPF that consider impacts on predators and the food web. These factors included public concern about a factory trawler brought in by a license holder (quota owner) to fish SPF and its impact on predators, protected species, the ecosystem, and other fisheries (Tracey et al. 2013). This coincided with a heightened public awareness about the trophic impacts of fishing "forage fish" due to publications such as the Lenfest Report (Pikitch et al. 2012) and the Marine Stewardship Council (MSC) criteria for assessing the sustainability of low trophic fisheries to account for trophic impacts (MSC 2014).

For this case study, activity pertaining to steps in the Lenfest process began in the second component, *Where are we going?*. In Australia, ecological risk assessment is used to inform management of all federally managed (and many state-managed) fisheries and a comprehensive risk assessment was completed for the SPF fishery in 2007 (Daley et al. 2007). Note that the ecological risk assessment focuses on the effects of fishing and not on other potential stressors (e.g., climate change). This risk assessment is similar to step 2.3, "Analyze risks to meeting strategic objectives" in the Lenfest process. One step in the risk assessment process is the selection of objectives; therefore, step 2.2, "Develop strategic objectives" was also conducted through the risk assessment process. However, the risk assessment was not conducted in connection to the AFMA review, and objectives were distinct from the operational objective determined later on.

The AFMA review of the harvest policy met our criteria for step 2.5, "Develop operational objectives", and all steps in component 3 (*How will we get there?*). The review of the SPF harvest strategy was undertaken by a group of fishery scientists and involved considerable interaction with AFMA and with stakeholders in the fishery, in the initial design phase and during the course of the review. The scientific group suggested using MSC criteria as objectives or performance indicators for the review, and this was endorsed by the Resource Assessment Group for the fishery and by AFMA management. Adopting MSC criteria was seen as adopting a credible international standard. The criteria for determining acceptable impact are that (*i*) no other species abundance is impacted by more than 70%, and (*ii*) the abundance of no more than 15% of other species or groups is impacted by more than 40%. These criteria are specific examples of "Develop operational objectives" (step 2.5) and also contain "Develop performance measures" (step 3.1).

The scientific group then used an existing Atlantis ecosystem model (Smith et al. 2015) to evaluate management strategies that would meet these operational objectives and performance indicators (steps 3.2, "Identify potential management strategies" and 3.3, "Evaluate consequences of alternative management actions"). The analysis concluded that harvest rates that achieved a target stock size of B_{50} (50% of unexploited biomass) met the performance criterion (Smith et al. 2015), and no changes were made to the harvest strategy because the B_{50} strategy was the status quo strategy (step 3.4, "Select management strategy" and component 4, *Implement the plan*).

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Eastern Baltic Sea and cod–herring–sprat interactions

Eastern Baltic Sea fisheries are mainly focused on demersal cod (*Gadus morhua*) (bottom–pelagic trawling, gill nets) and pelagic forage fish, herring (*Clupea harengus*) and sprat (*Sprattus sprattus*). A main EBFM topic is centered around the strong ecological interactions between cod and forage fishes (Casini et al. 2008). Specifically, (*i*) cod top-down predation on sprat and herring (Köster et al. 2001) and (*ii*) sprat and herring predation on cod eggs (Köster et al. 2001; Neumann et al. 2017). Furthermore, there is competition for zooplankton food between sprat and herring (Möllmann et al. 2005). All species, but especially cod, are strongly dependent (mainly recruitment) on the physical oceanographic environment (Köster et al. 2017). Recent environmental conditions have resulted in distribution changes leading to a spatial mismatch of species interactions (Casini et al. 2016; Orio et al. 2017). Analytical assessments of eastern Baltic cod are presently not conducted due to deficient input data and rapidly changing environmental conditions (Eero et al. 2015).

Activity for component 1, *Where are we now?*, is well represented for the Baltic Sea case study. System inventories for the Baltic Sea have been conducted within different International Council for the Exploration of the Sea (ICES) initiatives, matching step 1.1 in the process of "Develop a conceptual model and system inventory". The ICES–HELCOM (Baltic Marine Environment Protection Commission – Helsinki Commission) Working Group on Integrated Assessments of the Baltic Sea (WGIAB) conducted Integrated Trends Assessments of the various subsystems of the Baltic Sea. These assessments include multivariate analyses of time series encompassing abiotic (nutrients, hydrography, fishing pressure) as well as plankton (phytoplankton and zooplankton) and fish (pelagic and demersal) time series (step 1.2, "Select and calculate indicators"). Results for assessments for the central Baltic are published in Möllmann et al. (2009), and analyses for multiple subsystems are contained in Diekmann and Möllmann (2010), which are irregularly updated within WGIAB. Threats to the system (related to step 1.3, "Inventory threats") are included in the discussion of trends in indicators in Diekmann and Möllmann (2010), but not as an explicit list of threats as the step suggests.

Evidence and examples of "Articulate a vision" and "Develop strategic objectives" (steps 2.1 and 2.2, respectively) can be found in the Common Fisheries Policy and the Marine Strategy Framework Directive. The Common Fishery Policy of the European Union (EU) (reformed in 2014) has the broad goal that "Fish stocks should be brought up to healthy levels and be maintained in healthy conditions" (European Commission 2013), a statement similar to that developed in step 2.1, articulating a strategic vision. More specifically (similar to step 2.2, "Develop strategic objectives"), the Common Fisheries Policy strives to develop ecosystem-based fisheries management by applying an MSY approach: "Fish stocks should be exploited at maximum sustainable yield levels. These levels can be defined as the highest catch that can be safely taken year after year and which maintains the fish population size at maximum productivity." A common multiannual plan has been established by the EU for the stocks of cod, herring, and sprat in the Baltic Sea and the fisheries exploiting those stocks. The plan implicitly accounts for multispecies management goals by defining F_{MSY} ranges (European Commission 2016); however, this is presently not defined for eastern Baltic cod. In addition, minimum levels of spawning stock biomass are set for conservation purposes. Overall though, management of Baltic fish stocks can still be considered single-species.

One potential effort that would exemplify an ecosystem example of step 3.4 ("Select management strategy") was previous efforts within ICES to evaluate and use multispecies F_{MSY} values for cod, sprat, and herring. However, the multispecies F_{MSY} values are presently not used as a management strategy due to uncertainties inherent in multispecies model and cod input data (ICES 2013). On the other hand, there are management strategies chosen (step 3.4, "Select a management strategy" and component 4, *Implement the plan*) to estimate biological reference points by considering shifting predation and growth for herring and sprat. This is done by incorporating predation mortality parameters from a stochastic multispecies model into stock assessments (ICES 2015). Therefore, this is a management strategy with an ecosystem consideration, though still from a single-species perspective, and without a full management-strategy evaluation approach (other steps in component 3).

Western Scotian Shelf and declining traditional fisheries

There are several ecosystem considerations for the western Scotian Shelf fisheries, which include fisheries for groundfish, pelagic fish, and invertebrates. Groundfish are harvested as part of a multispecies groundfish fishery, mostly targeting pollock (*Pollachius virens*), haddock (*Melanogrammus aeglefinus*), and cod (*Gadus morhua*). Cod is primarily caught as bycatch now, due to its low abundance. Herring (*Clupea harengus*) are prey for many groundfish, seabirds, and mammals, are the main forage fish species in the area, and are over-fished. The main invertebrate fisheries are for scallop (*Placopecten magellanicus*) and American lobster (*Homarus americanus*), with some by-catch of groundfish, especially flatfish, in the former. Currently, there is a decline in traditional groundfish fisheries and herring stocks are depressed, but invertebrate stocks (scallop and lobster) are doing well.

Fisheries and Oceans Canada (DFO) uses Integrated Fisheries Management Plans (IFMPs) to guide the conservation and sustainable use of marine resources. An IFMP is developed to manage the fishery of a particular species in a given region. It combines the best available science on a species with industry data on capacity and methods for harvesting that species and includes social, cultural, and economic objectives. The latter can reflect the aboriginal right to fish for food and social and ceremonial purposes and can recognize the economic contribution that the fishing industry makes to Canadian businesses and many coastal communities. Ultimately, the economic viability of fisheries depends on the industry itself. However, the department is committed to managing the fisheries in a manner that helps them be economically successful while using the ocean's resources in an environmentally sustainable manner.

Activity pertaining to steps in component 1, *Where are we now?*, are all encompassed in DFO State of the Ocean Reports for Canadian marine regions. The State of the Ocean Report for the Scotian Shelf, including the western Scotian Shelf, covers a range of topics, including ocean acidification, climate change and its effects on ecosystems, habitats and biota, at-risk species, marine habitats and communities, and more. This report also uses the Driver, Pressure, State, Impact, and Response (DPSIR) conceptual model framework (Kelble et al. 2013) to identify indicators (http://www.dfo-mpo.gc.ca/oceans/publications/soto-rceo/2012/scotian-ecossais-eng.html), thus "Develop a conceptual model and system inventory" (step 1.1). Activity related to "Select and calculate indicators" (step 1.2) is included both in the State of the Ocean reports as well as the Ecosystem Status and Trends Report for the Gulf of Maine and Scotian Shelf (Worcester and Parker 2010) as time series data. Additionally, though not an explicit list of threats as step 1.3, "Inventory threats" in the process suggests, many of the major topics covered throughout the State of the Ocean Report are threats to the system (ocean acidification, ocean noise, etc.).

Examples of "Articulate a vision" as well as "Develop strategic objectives" (steps 2.1 and 2.2 in component 2, *Where are we going?*) exist for the Scotian Shelf region. Specifically, within the DFO Regional Oceans Plan for the Maritimes Region (that includes the Scotian Shelf), there is the following broad vision statement (step 2.1, "Articulate a vision") for the region: "Healthy marine and coastal ecosystems, sustainable communities and responsible use supported by effective management processes" (DFO 2014). Each individual species or fishery in this case study (herring, ground-

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fish, lobster, and scallop) has an IFMP with specific goals or objectives (step 2.2, "Develop strategic objectives"). Within the lobster management plan, for example, there are goals related to broader ecosystem impacts, including "Control unintended incidental mortality of North Atlantic right whales" and "Manage area disturbed of bottom habitat" (DFO 2011). Overarching all fisheries in the region is a list of conservation and social objectives (see list in DFO 2013), which includes "Respect Aboriginal and treaty rights to fish".

Bering Sea groundfish and avoiding ecosystem overfishing

One EBFM consideration for the Bering Sea region revolves around the groundfish fishery and the 2 million metric ton removal cap on the fishery. Main Bering Sea fisheries consist of high-volume walleye pollock (*Gadus chalcogrammus*) fisheries and other groundfish fisheries, including Pacific halibut (*Hippoglossus stenolepis*), sablefish (*Anoplopoma fimbria*), and Pacific cod (*Gadus macrocephalus*). Many of these fisheries are rationalized as individual transferable quotas or cooperatives and the fleet is socially heterogeneous, consisting of non-Alaska residents, nonindigenous Alaska residents, and indigenous Alaska residents. Most groundfish fisheries also are conducted by multiple commercial sectors defined by gears or vessel characteristics. Species use across sectors has generated recent controversy. For instance, the bycatch of Chinook salmon (*Oncorhynchus tshawytscha*) and halibut in the trawl sector might reduce returns and opportunities for subsistence, recreational, and directed commercial fisheries for these species. Because of the total cap on groundfish removals at 2 million metric tons per year, high quotas for walleye pollock will reduce opportunities for fisheries in other groundfish sectors.

Activity related to all steps in component 1, *Where are we now?*, is present in the Ecosystem Considerations Report for the Alaska Regions (Bering Sea – Aleutian Islands, Gulf of Alaska, and Arctic). The goal of this annual report is to provide an ecosystem context for fishery management decisions. This report stems from the groundfish FMPs (Arctic, Bering Sea – Aleutian Islands, and Gulf; North Pacific Fishery Management Council 2015*a*) and contains ecosystem assessments, similar to "Develop a conceptual model and system inventory" (step 1.1). The report also includes ecosystem status and trends and indicators (using the DPSIR conceptual model framework) for each region in Alaska, leading to indicators similar to what would be selected and calculated in step 1.2, "Select and calculate indicators". Finally, the Ecosystem Considerations reports mention individual threats throughout, specifically anomalies in indicators, such as warm ocean conditions, or some new or emerging potential problems in the "Hot Topics" section, which relate to step 1.3 "Inventory threats", but without a full, comprehensive, explicit list.

Additionally, an FEP for the Bering Sea is currently in development, which also is an example of step 1.1, "Develop conceptual model and system inventory", and the FEP includes selected indicators and specific ecosystem threats (steps 1.2 and 1.3) as well. The Bering Sea FEP also calls for increased stakeholder involvement by outlining steps to consider and incorporate local and traditional knowledge into the management process, not just through integrating it into Western science but through collaboration with local and indigenous peoples from the beginning (North Pacific Fishery Management Council 2019).

For component 2, *Where are we going?*, there is activity for almost all steps for the Bering Sea. For Alaska fisheries, there is a broad ecosystem vision statement (step 2.1, "Articulate a vision") that states the following:

> "Vision Statement — The Council envisions sustainable fisheries that provide benefits for harvesters, processors, recreational and subsistence users, and fishing communities, which (1) are maintained by healthy, productive, biodiverse, resilient marine ecosystems that support a range of services; (2) support robust populations of marine species at all trophic levels, including marine mammals and seabirds; and (3) are managed using a precautionary, transparent, and inclusive process that allows for analyses of tradeoffs, accounts for changing conditions, and mitigates threats," (North Pacific Fishery Management Council 2014).

This statement was developed by the Ecosystem Committee for the North Pacific Fishery Management Council, brought on partly by input from stakeholders that the council did not previously have a vision statement or ecosystem objectives (Bill Tweit, personal communication). Additionally, for more specific strategies or goals (step 2.2, "Develop strategic objectives"), the groundfish FMP has multiple high-level ecosystem-related objectives that stem from the 45 objectives from the Alaska Groundfish Programmatic Supplemental Environmental Impact Statement (PSEIS), including "Preserve food web" and "Incorporate ecosystem-based considerations into fishery management decisions, as appropriate". In line with the Lenfest process step of "Analyze risks to meeting strategic objectives" (step 2.3), the PSEIS also includes assessments of risk for all objectives (National Marine Fisheries Service 2004). However, there was no evidence of "Prioritize strategic objectives" (step 2.4). Within the PSEIS and groundfish FMP, there are more specific operational objectives, including "Maintain or adjust current protection measures as appropriate to avoid jeopardy of extinction or adverse modification of critical habitat for ESA-listed Steller sea lions", examples of activity pertaining to step 2.5, "Develop operational objectives". There are also both strategic and operational objectives described in each iteration of the Bering Sea – Aleutians Island groundfish FMP (many of which stem from the PSEIS objectives; see North Pacific Fishery Management Council 2017).

There is activity related to all steps in component 3, *How will we get there?*, due to various reviews of, and continued use of, the 2 million metric ton cap on the groundfish fishery. An optimum yield of 2 million metric tons was originally selected from three primary alternative strategies for the groundfish fishery in January of 1984, as part of amendment 1 to the Bering Sea – Aleutian Islands (BSAI) groundfish FMP (49 FR 397; North Pacific Fishery Management Council 2016). In this and multiple subsequent reviews of the cap, multiple strategies and variations on the cap were suggested and evaluated (steps 3.2 and 3.3, "Identify potential management strategies" and "Evaluate consequences of alternative management actions"). These subsequent reviews included the General Accounting Office report (General Accounting Office 1991), the review of the F40% reference point (Goodman et al. 2002), and the 2004 PSEIS (National Marine Fisheries Service 2004).

As a more in-depth example, the PSEIS includes multiple performance measures for various ecosystem metrics (and implied desired directions for those metrics; step 3.1, "Develop performance measures"). Based on these measures, four alternative harvest management policies for groundfish were considered, similar to the selection of multiple strategies as outlined by step 3.2, "Identify management strategies" and the strategies were evaluated based on the performance metrics (step 3.3, "Evaluate consequences of alternative actions"). The Council selected the strategy and continued use of a system-wide cap of 2 million metric tons on groundfish catch (North Pacific Fishery Management Council 2015*b*; step 3.4, "Select a management strategy" and component 4, *Implement the plan*). Acceptable biological catch are set for each stock separately, and then annual catch limits are set so that the total annual catch limits for all species combined do not sum to above 2 million metric tons (only partially based on the ecosystem state). This cap was put into place to limit fleet capacity and avoid ecosystem overfishing (North Pacific Fishery Management Council 2015*b*). The optimum yield of 2 million metric tons was chosen based on 85% of historical annual summed MSY estimates (1.4 to 2 million metric tons; North Pacific Fishery Management

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Council 2015*b*). This cap has been triggered in multiple years, leading to reductions in catch limits, and exploitation rates are thereby commonly less than single-species MSY for most species.

Northeast Pacific and interacting protected species

Pacific salmon fisheries on the US west coast primarily target Chinook (*Oncorhynchus tshawytscha*), coho (*Oncorhynchus kisutch*), and pink salmon (*Oncorhynchus gorbuscha*), and 17 populations are ESA-listed. Potential EBFM-related conflicts between fisheries and marine mammals center on Chinook salmon, southern resident killer whales (*Orcinus orca*), and pinnipeds (primarily harbor seals (*Phoca vitulina*) and California sea lions (*Zalophus californianus*)). Southern resident killer whales are listed as Endangered under the US Endangered Species Act, and pinnipeds are protected by the Marine Mammal Protection Act. Since its inception in 1972, many protected pinnipeds on the west coast have been increasing rapidly. The effects of pinniped and killer whale predation on Pacific salmon are not currently addressed by management. Salmon and killer whales are iconic in the Pacific Northwest and both have high nonmonetary value.

Activity related to all steps in component 1, *Where are we now?*, of the process can be found in documents highlighting either council or NOAA efforts for this region and mammal–salmon interactions. The Pacific Council's FEP serves to "Develop a conceptual model and system inventory" (step 1.1) and provides general information on direct and indirect interactions between fisheries and marine mammals on the west coast. The FEP also mentions the importance of salmon in the diets of endangered killer whales (Pacific Fishery Management Council 2013*a*). NOAA's IEA for the California Current includes salmon and marine mammals as key ecosystem components, with multiple indicators for each, thus showing activity related to step 1.2, "Select and calculate indicators". The IEA also includes a conceptual model for the system. Finally, certain threats are mentioned throughout the IEA report (similar to threats that would be listed in step 1.3, "Inventory threats") related to specific indicators, such as threats of ship strikes and fisheries gear entanglements for cetaceans (Levin et al. 2013). The risk analyses portions of the IEA reports also mention threats, but there is never an explicit list of threats in the report.

There is less activity related to component 2, *Where are we going?*. The Pacific Council's Salmon FMP does not have specific objectives for managing salmon fisheries relating to their importance as prey to marine mammals. However, protected species in marine waters are managed by NOAA Fisheries, and there are broad-level objectives–goals (step 2.2, "Develop strategic objectives") stemming from the killer whale recovery plan (mandated by the Endangered Species Act). These objectives include "Ensure adequate habitat to support a recovered population of Southern Resident killer whales. Habitat needs include sufficient quantity, quality, and accessibility of prey species" (National Marine Fisheries Service 2008). Related to step 2.3, "Analyze risks to meeting strategic objectives", there is a recent environmental impact statement for salmon populations that qualitatively considers the impacts of fishing on killer whales and pinnipeds (National Marine Fisheries Service 2017) and likely previous environmental impact statements as well.

Activities related to component 3, *How do we get there?*, stem from work by NOAA Fisheries and DFO, which convened an independent scientific review panel to evaluate the effects of salmon fisheries on southern resident killer whales (Hilborn et al. 2012). The panel reviewed science that suggested southern resident killer whale survival and fecundity rates were correlated with indices of Chinook salmon abundance (Hilborn et al. 2012; Ward et al. 2009). From this, a possible strategy of closing all ocean fishing on Chinook was simulated (steps 3.2 and 3.3, "Identify potential management strategies" and "Evaluate consequences of alternative management actions"). A salmon population model was used to assess the strategy of closing all ocean fishing and concluded that even complete cessation of fishing would increase Chinook abundance by a maximum of 25%. The panel concluded that the effects of this small change in Chinook abundance would be difficult to predict and would likely not translate to increased prey (or survival or fecundity) for killer whales. Instead, Chinook abundance is more strongly influenced by freshwater habitat and ocean conditions than by fishing mortality. Therefore, the no fishing strategy was not pursued (step 3.4, "Select management strategy").

Northeast Pacific sardine and environmentally linked harvest control rules

The Pacific sardine (*Sardinops sagax*) fishery was the largest in terms of catch for any of the species included in the PFMC CPS (coastal pelagic species) FMP in the California Current system, till the closure of the fishery in 2015. Potential EBFM topics related to sardine stem from the importance of sardine as prey for predators and the relationship between sardine abundance and oceanic conditions. Sardine are prey for predatory fish in the west coast groundfish, salmon, halibut, and migratory species (including albacore, *Thunnus alalunga*) fisheries, leading to potential trade-offs among fisheries. Sardine are also prey for other marine species, including protected marine mammals and seabirds. Additionally, sardine recruitment is related to ocean conditions, with specifically higher recruitment in warm ocean conditions (related to the Pacific decadal oscillation; Jacobson and MacCall 1995).

Again, activity related to all steps in component 1, *Where are we now?*, can be found in documents from council or NOAA efforts. The Pacific Coast Fishery Ecosystem Plan summarizes information on the entire California Current ecosystem and includes information on Pacific sardine (Pacific Fishery Management Council 2013*a*), thus acting to "Develop a conceptual model and system inventory" (step 1.1). Additionally, the IEA for the California Current includes status and trends of indicators related to environment (temperature) and CPS (similar to indicators that would be produced by step 1.2, "Select and calculate indicators") and includes a conceptual model for the system (Levin et al. 2013). As mentioned in the previous case study, threats to the system are listed throughout portions of the IEA report (step 1.3, "Inventory threats"), but not as an explicit list.

Related to component 2, *Where are we going?*, there is activity for only step 2.2, "Develop strategic objectives". Within the FEP, there is a summary of ecosystem goals across FMPs, and one broad goal or objective for CPS (including sardine) is to "Provide adequate forage for dependent predators" (Pacific Fishery Management Council 2013*a*).

All of component 3, *How will we get there?*, is exemplified by work surrounding the Pacific sardine harvest control rule. Because sardine recruitment is related to oceanic conditions, the harvest control rule for Pacific sardine includes a temperature predictor to set catch based on the relationship between sardine recruitment and sea surface temperature. In the early 2010s, stock assessment scientists in the Scientific and Statistical Committee determined that the previously used temperature predictor (temperature off Scripps Pier) was deficient (McClatchie et al. 2010; Lindegren and Checkley 2012). Work by McClatchie et al. 2010 showed an alternative relationship between California Cooperative Oceanic Fisheries Investigations (CalCOFI) sea surface temperature and sardine productivity. Therefore, the Pacific Fishery Management Council convened a workshop to determine new potential management strategies (Pacific Fishery Management Council 2013*b*). This workshop included members of the Scientific and Statistical Committee, the PFMC CPS Advisory subpanel and management team, and other scientists. Similar to step 3.2, "Identify potential management strategies", the members identified multiple strategies for a sardine harvest control rule, including using the previous temperature indicator (from off the Scripps Pier), the new temperature indicator (CalCOFI temperature), and various levels

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of a "cutoff" value to protect the stock at low levels (close fishery if stock drops below this level). Then, Hurtado-Ferro and Punt (2014) performed a management strategy evaluation (MSE) using the strategies identified in the 2013 workshop (step 3.3, "Evaluate consequences of alternative management actions"). They used an age-structured population model of Pacific sardine as the operating model and evaluated strategies based on performance criteria (indicators), such as variance of catch, mean catch, spawning stock biomass, and more. These performance criteria or indicators are similar to what would be produced in step 3.1, "Develop performance measures" (see Hurtado-Ferro and Punt 2014 for all criteria and strategies). After the MSE was reviewed, the Council chose the control rule that included the use of CalCOFI temperature (see Pacific Fishery Management Council 2014*a*, 2014*b*) and a 150 000 metric ton cutoff (exemplifying step 3.4, "Select management strategy" and component 4, *Implement the plan*).

Moving forward, there is no formal re-evaluation of the temperature–recruitment relationship from year to year, but there is monitoring of these indicators within the stock assessments, and this can show when or if there is any deviation from the pattern. This acts to continuously monitor the strategy, similar to component 5 of the process (*Did we make it?*). However, component 5 particularly focuses on monitoring strategies in terms of meeting the objectives identified in component 2, and there were no explicit operational objectives that could be identified for this case study.

Gulf of Mexico and environmentally linked mortality of gag grouper

This case study focuses on the EBFM topics surrounding gag grouper in the Gulf of Mexico and increased mortality of gag during red tide events. Gag grouper is a second-level priority species (designated as overfished or undergoing overfishing or in need of an assessment) in the Gulf of Mexico and one of the more important reef fish species exploited in the eastern Gulf (second only to red grouper, *Epinephelus morio*). Harmful algal blooms or red tide events in the West Florida Shelf likely cause increased mortality for gag grouper. Specifically, a severe event in 2005 coincided with a sharp decline in gag grouper abundance indices. However, the mechanism behind how red tide causes mortality in gag is not known (direct toxicity or indirect impact; Southeast Data, Assessment, and Review 2014).

Activity related to all steps in component 1, *Where are we now?*, can be found in the Ecosystem Status Report for the Gulf of Mexico (Karnauskas et al. 2013, 2017). The status report summarizes components of the fishery system (step 1.1, "Develop a conceptual model and system inventory"). This report also has activity related to step 1.2, "Select and calculate indicators", by including status and trends for individual species, fisheries and environmental components, and indicators such as data on trends of red tide events. The status report was part of the IEA work for the Gulf of Mexico, and a Driver, Pressure, State, Ecosystem service, and Response (DPSER) conceptual model was used to select indicators that "reflect the status of key drivers, pressures, states, ecosystem services, and responses in the ecosystem" (Kelble et al. 2013). Finally, the status report also lists a number of stressors, including oil spills, hurricanes, and more, similar to step 1.3, "Inventory threats", though not as an exhaustive, explicit list as the step specifies.

Because of the mortality caused by red tide in 2005, an additional source of mortality was added to the gag grouper stock assessment in the Gulf of Mexico (Southeast Data, Assessment, and Review 2014), thus exemplifying step 3.4, "Select management strategy", with an ecosystem consideration. Red tide was modeled as a fishing fleet "discard" removal of gag (versus a "directed fishing mortality"), doubling mortality predicted in the previous assessment. Therefore, this strategy modified the estimated stock status relative to the reference point using ecosystem information, modifying the management strategy (step 3.4, "Select management strategy") based on ecosystem information, and was then put into practice for gag grouper (component 4, *Implement the plan*). There is also ongoing work by the IEA working group on red tide severity indices that could be used as covariates in the stock assessment model (Southeast Data, Assessment, and Review 2014), but are not currently used. Finally, there is continued monitoring of red tide events, but not in connection to gag mortality, which would be needed to exemplify component 5 of the process, *Did we make it?*.

Mid-Atlantic butterfish and habitat-based availability

One approach to establishing EBFM in the Mid-Atlantic centers on butterfish (*Peprilus triacanthus*), primarily a bycatch species, and how butterfish bycatch caps have historically constrained the longfin inshore squid (*Doryteuthis pealeii*) fishery (prior to the 2014 butterfish assessment). There is a high degree of habitat overlap between butterfish and squid, and technical measures (e.g., minimum mesh size) have only been partly successful in reducing bycatch. The butterfish stock was determined to be overfished in the 2003 stock assessment, but the trends in the 2003 assessment conflicted with trends observed in the follow-up assessment in 2009. One problem with the stock assessment of butterfish is that the degree of overlap between the stock and the trawl survey frame (i.e., the region from which random trawl locations are drawn) is variable depending on environmental conditions. The 2009 stock assessment resulted in a determination that fishing mortality rates had been extremely low in recent years and could not account for the apparent decline in butterfish biomass. Nevertheless, the biological reference points estimated from the 2009 assessment were rejected by the assessment review panel (Northeast Fisheries Science Center 2010). As a result, the industry was faced with a situation in which it was widely acknowledged that fishing mortality rates on butterfish were extremely low, yet the rebuilding plan continued to call for tight caps on butterfish bycatch in the squid fishery. This example of a technical interaction is common in conventional management but is highlighted here because it led to incorporation of environmental habitat models and data in the stock assessment and management of butterfish.

Activity for component 1, *Where are we now?*, can be found in the Mid-Atlantic Fisheries Management Council's (MAFMC) Ecosystem Approach to Fishery Management Guidance Document (Mid-Atlantic Fisheries Management Council 2016). This document includes specific information on butterfish and climate and has summaries of system components, creating an inventory similar to step 1.1, "Develop a conceptual model and system inventory". The guidance document includes trends in indicators such as temperature and landings, which is the same as step 1.2, "Select and calculate indicators". It also contains multiple conceptual models linking climate, habitat, species, and more in the mid-Atlantic (http://www.mafmc.org/s/EAFM_Guidance-Doc_2017–02–07.pdf; Mid-Atlantic Fisheries Management Council 2016). Additionally, a list of threats to the system (step 1.3, "Inventory threats") can be found within the Northeast region US Ecosystem status report (https://www.nefsc.noaa.gov/ecosys/) under "stressors and impact", including water contaminants, climate change, and fishing gear impacts.

Activity related to a few steps in component 2, *Where are we going?*, can be found within the MAFMC Strategic Plan (Mid-Atlantic Fisheries Management Council 2013). Work to "Articulate a vision" (step 2.1) and "Develop strategic objectives" (step 2.2) that broadly relate to the case study topic was completed in 2013 and presented in the MAFMC Strategic Plan. The final vision statement says, "Healthy and productive marine ecosystems supporting thriving, sustainable marine fisheries that provide the greatest overall benefit to stakeholders" (Mid-Atlantic Fisheries Management Council 2013). This vision, other goals, and a comprehensive strategic plan were developed through the Council's "Visioning and Strategic Planning Project". This project was initiated at a time when all MAFMC managed fisheries were

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rebuilt and no longer overfished, which promoted flexibility to cultivate the Council's management strategies (Mid-Atlantic Fisheries Management Council 2012). This planning strategy included a "large-scale stakeholder outreach effort" (Mid-Atlantic Fisheries Management Council 2012) with input from more than 1500 stakeholders through surveys, port meetings (roundtable sessions), and position letters (Mid-Atlantic Fisheries Management Council 2012). Stakeholders included commercial and recreational fisheries, environmental organizations, seafood users, scientists and researchers, and the public at large.

Finally, the inclusion of environmental data in the most recent butterfish stock assessment (Adams et al. 2015) led to selection of a single-species harvest control rule with an ecosystem consideration (step 3.4, "Select management strategy"). Owing to the potential mismatch in spatial occurrence of the butterfish stock and trawl surveys to estimate abundance, attributable to environmental conditions (leading to low stock estimates), there was a specific "Term of Reference" for the stock assessment in 2014 that required the assessment scientists to consider oceanographic factors and include them in the assessment model if possible. Through an academic–industry–NOAA collaborative process, key environmental drivers of butterfish spatial distribution were identified and used to estimate the annual overlap between the stock and the trawl survey. Specifically, bottom temperature was used to define the availability of butterfish to the NEFSC trawl survey by measuring overlap between their thermal habitat and the trawl survey frame. This thermal niche model estimated annual availability of butterfish to the trawl survey, but in the end, a constant availability (from the model) was incorporated into the assessment because there was relatively little interannual variability in availability (range: 62%–75% of butterfish habitat overlap with the survey frame). The 2014 assessment concluded that the stock is not overfished and that overfishing is not occurring and led to the implementation of the current harvest control rule (component 4, *Implement the plan*).

Mid-Atlantic – Chesapeake Bay: supporting needs of menhaden predators

Atlantic menhaden (*Brevoortia tyrannus*) constitutes the biggest fishery in the mid-Atlantic and has been referred to as "the most important fish in the sea", highlighting its role in supporting predators in the coastal ecosystem. A filter-feeder, menhaden also is believed to contribute to combatting eutrophication (Gottlieb 1998; Dalyander and Crecco 2010). As an important fishery and key forage species, management of Atlantic menhaden is at the core of developing EBFM in the Chesapeake Bay and coastal mid-Atlantic region.

Activity more than a decade ago related to component 1, *Where are we now?*, is documented in a Chesapeake Bay FEP. The FEP includes information on Atlantic menhaden and conceptual models of major elements of the ecosystem (Chesapeake Bay Fisheries Ecosystem Advisory Panel 2006). As such, it serves to "Develop a conceptual model and system inventory" (step 1.1). This FEP and publications that followed (Houde 2011; Maryland Sea Grant 2011) also recognize many threats to the system, including accelerated eutrophication and related hypoxia, invasive species, and fishing pressure. The FEP includes sections on major ecosystem issues and concerns in Chesapeake Bay, addressing step 1.3, "Inventory threats". Additionally, the Ecosystem Status Report for the Northeast Shelf Large Marine Ecosystem (Ecosystem Assessment Program 2012) provides a relevant system inventory on a broader regional scale that includes indicators (informing step 1.2, "Select and calculate indicators") and documentation of additional threats to the ecosystem.

In the past decade, there has been interest and activity directed toward developing an explicit menhaden management plan with ecosystem reference points that account for menhaden's important role in the mid-Atlantic coastal ecosystem. In this regard, there is activity related to initial steps in component 2, *Where are we going?*. Step 2.1 is to "Articulate a vision" for the system and the strategic vision for the menhaden fishery. The vision emphasizes maintaining a valuable and sustainable menhaden fishery while avoiding damage to the ecosystem and its menhaden-dependent predators. Broad objectives for the fishery were expressed in the most recent stock assessment (Southeast Data, Assessment, and Review 2015). It addressed strategic objectives for step 2.2, "Develop strategic objectives". The updated goal, provided in Amendment 3 to the FMP (Atlantic States Marine Fisheries Commission 2017), is to

> "…manage the Atlantic menhaden fishery in a manner which equitably allocates the resource's ecological and economic benefits between all user groups. The primary user groups include those who extract and utilize menhaden for human use, those who extract and utilize predators which rely on menhaden as a source of prey, and those whose livelihood depends on the health of the marine ecosystem. Pursuit of this goal will require a holistic management approach which allocates the resource in a method that is biologically, economically, and socially sound to protect the resource and those who benefit from it."

For component 3, *How will we get there?*, there is ongoing activity for two steps: step 3.2, "Identify potential management strategies" and step 3.4, "Select management strategy". Recent management of Atlantic menhaden has relied on modeling its age-specific predation mortality based on a multispecies virtual population analysis (Southeast Data, Assessment, and Review 2015). This single-species harvest control rule–strategy, with an ecosystem consideration, is a component of the management strategy for the coast-wide menhaden fishery. For Chesapeake Bay, the management strategy is to cap menhaden landings (Southeast Data, Assessment, and Review 2015), a measure aimed at reducing the likelihood of localized depletion of menhaden (Atlantic States Marine Fisheries Commission 2005), and exemplifies the Task Force's step 3.4, "Select management strategy". The initial menhaden cap for Chesapeake Bay was 87 120 metric tons, which was lowered to 51 000 metric tons in ASMFC's most recent action (Atlantic States Marine Fisheries Commission 2017), a strategy intended to benefit menhaden's predators and the recreational fishery that targets important predators (e.g., striped bass, *Morone saxatilis*).

The ASMFC Atlantic Menhaden Technical Team and its Biological–Ecological Reference Points (BERP) working group identified performance indicators for menhaden, including environmental indicators, indices of forage abundance, and prey:predator ratios (Appendix E in Southeast Data, Assessment, and Review 2015). The BERP's work led the ASMFC to develop ecosystem objectives (Atlantic States Marine Fisheries Commission Memorandum 2015). Fundamental objectives, such as "sustain menhaden to provide for predators", were identified (exemplifying step 2.2, "Develop strategic objectives"). The BERP also adopted explicit objectives provided by the ASMFC's Menhaden Board and an inclusive set of performance indicators. The BERP is developing ecosystem reference points (ERPs) for menhaden, activity specified in the Task Force's step 3.1, "Develop performance measures". The BERP is charged to formally recommend an ERP by 2019 (Atlantic States Marine Fisheries Commission 2017).

The Atlantic menhaden case study, while centered on a single species, exemplifies how concerns about its management address FEP goals in the Chesapeake Bay and the broader coastal zone. In this regard, a recently developed, coast-wide ecosystem model demonstrates how management decisions related to selection of ERPs for menhaden could resonate throughout the predator community in the mid-Atlantic region (Buchheister et al. 2017). Ongoing work by ASMFC and its BERP working group illustrates how the process now underway includes many activities embodied

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in the components and steps of the FEP process recommended by the Task Force.

New England and habitat area closures for improved groundfish protection

The multispecies groundfish fishery is one of the most ecologically and economically important finfish fishery in the Gulf of Maine. This fishery incudes as targets iconic species like Atlantic cod and haddock. The Gulf of Maine cod stock has been assessed as both overfished and that overfishing is still occurring, though fishers continue to find large amounts of cod. Therefore, there is tension between management and fishers, and fishers want greater access to catch and certainty in catch levels in the future (3–5 years out). Emergency actions shutting down the groundfish fishery and the annual assessments are causing the industry both severe economic hardship and inducing high levels of stress. There is specific ongoing EBFM activity surrounding the groundfish fishery (including cod) and habitat.

There is activity related to all steps in component 1, *Where are we now?*. The Ecosystem Status Report of the Northeast Shelf Large Marine Ecosystem (Ecosystem Assessment Program 2012) was completed in 2012 and contains descriptions of components of the fishery system, thus serving to "Develop a conceptual model and system inventory", as is specified in step 1.1. Additionally, the status report contains time-series data on components and indicators (integrative ecosystem measures), similar to step 1.2, "Select and calculate indicators". Finally, the updated Northeast status report (see Mid-Atlantic case study) includes a section on stressors, again acting as an example of an "Inventory threats" to the system (step 1.3), though not as an explicit list.

"Develop strategic objectives" (step 2.2), as well as more specific "Develop operational objectives" (step 2.5), from component 2, *Where are we going?*, exist for this case study. Step 2.2 is to "Develop strategic objectives", and the New England Fishery Management Council (NEFMC) adopted a specific strategic objective from the Essential Fish Habitat (EFH) mandate — "describe and identify essential fish habitat for the fishery based on the guidelines established by the Secretary under section 305(b)(1)(A), minimize to the extent practicable adverse effects on such habitat caused by fishing, and identify other actions to encourage the conservation and enhancement of such habitat" (New England Fishery Management Council 2016; Grabowski et al. 2014). Based on this objective, more specific objectives (step 2.5, "Develop operational objectives") were identified related to EFH and ongoing work on groundfish habitat in the NEFMC's Omnibus Habitat Amendment 2. Specifically:

> "The first groundfish-specific purpose of this amendment is to improve protection for juvenile groundfish and their habitats (Purpose D). Success at younger ages can have positive productivity benefits for managed resources, and therefore action is needed to protect the habitats important for juvenile groundfish, particularly for commercially valuable species. A second groundfish-specific purpose of this amendment is to identify seasonal closed areas in the Northeast Multi-species FMP that would reduce impacts on spawning groundfish and on the spawning activity of key groundfish species, because the protection of spawning fish is needed to sustainably manage stocks (Purpose E)" (New England Fishery Management Council 2016).

Additionally, activity related to all the steps in component 3, *How will we get there?*, can be found in the recent Omnibus habitat amendment 2 for New England, centered around groundfish habitat. An MSE process was used to evaluate various fisheries closures that may impact groundfish habitat based on the objectives above. Specifically, a swept area seabed impacts model (SASI) was developed to evaluate different gear types in terms of adverse effects on fish habitat (appendix D in Omnibus Habitat Amendment 2; Grabowski et al. 2014). The SASI model highlighted areas vulnerable to fishing gear, and this information was paired with analyses on juvenile habitat and adult spawning habitat of cod and other groundfish. A Closed Area Technical team used this information to "Identify potential management strategies" (step 3.2) in the form of possible alternative closed areas (see Habitat Omnibus Amendment II Volume 3). The alternative spatial management strategies were then evaluated (step 3.3, "Evaluate consequences of alternative management actions") based on performance indicators such as overlap with EFH, unique habitat features, and species diversity indices. These indicators are examples of the type of performance indicator that would be chosen in step 3.1, "Develop performance measures". The alternative spatial management strategies were then voted on by the Council (J. Grabowski, personal communication). As of September 2016, the amendment documents were submitted to NMFS Greater Atlantic Regional Fisheries Office for review; thus, a management strategy has been chosen (step 3.4, "Select management strategy") by the Council. In January of 2018, most of the amendment was approved by NMFS and was published in the federal register in April 2018 (83 FR 15240).

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