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Building effective fishery ecosystem plans

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ABSTRACT

U.S. fisheries management has made tremendous strides under the current management framework, which centers on single stocks rather than ecosystems. However, conventional management focuses on one fishing sector at a time, considers a narrow range of issues, and is separated into individual fishery management plans often leaving little opportunity to consider overarching management goals across fisheries. Ecosystem-based Fisheries Management (EBFM) provides mechanisms to address these but has not been widely adopted. Here, we review and analyze the development of Fisheries Ecosystem Plans (FEPs) as a means to implement EBFM. In doing so, we provide a blueprint for next-generation FEPS that have the potential to translate EBFM to action. We highlight FEPs as a structured planning process that uses adaptive management to operationalize EBFM. This "FEP Loop" process starts by identifying the key factors that shape a fishery system and considering them simultaneously, as a coherent whole. It then helps managers and stakeholders delineate their overarching goals for the system and refine them into specific, realistic projects. And it charts a course forward with a set of management actions that work in concert to achieve the highest-priority objectives. We conclude that EBFM is feasible today using existing science tools, policy instruments, and management structures. Not only that, nearly all of the steps in the proposed "FEP Loop" process are presently being carried out by U.S. fishery managers. The process of reviewing regional experiences in developing and applying the FEP loop will lead to adaptations and improvements of the process we propose.

1. Introduction

U.S. fisheries management has made tremendous strides under the mandates for sustainability prescribed by the Magnuson Stevens Act (MSA) [1]. Since reforms to MSA in 1996 [2], the number of stocks with biomass below overfished thresholds has declined dramatically, from

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86 to 38, and the number of stocks subjected to unsustainable rates of harvest has plunged from 72 to 28 [3]. In addition, fishers and other stakeholders, managers, and scientists have cooperated to reduce bycatch (e.g, [4]), conserve habitats (e.g., [5]), and improve the equity and safety of fisheries (e.g. [6]).

Despite these successes, conventional fisheries management has limitations. It generally focuses on one fishing sector (e.g., groundfish, coastal pelagic species, anadromous species) at a time, which may lead to perverse outcomes for other sectors [7]. It often considers a narrow range of issues, potentially overlooking factors that shape fishery systems at larger scales, such as loss of habitat and the behavior of people and markets [8]. And fundamentally, the current management system is segmented into individual fishery management plans (FMPs), restricting opportunities to consider overarching management goals for the fishery system or the trade-offs across fisheries that attend almost every decision [9].

Ecosystem-based Fisheries Management (EBFM) provides mechanisms to address these issues and many others. Here we define EBFM as a holistic, place-based framework that seeks to sustain fisheries and other services that humans want and need by maintaining healthy, productive and resilient fishery systems [9–13]. This contrasts with the focus of conventional fisheries management that emphasizes the *direct* consequences of management actions on targeted stocks and protected nontarget species.

Fundamental to EBFM is conceptualizing fisheries as systems. Fishery systems consist of linked biophysical and human subsystems with interacting ecological, economic, social, and cultural components [14,15]. A system is made up of its components (e.g., targeted fish stock, interacting species, habitats, people employed by fishing), and the links among them (e.g., predator-prey interactions, fishermen who shift from one fishery to another). These links can span regulatory units and jurisdictions. Management actions that do not account for these links can produce unintended indirect effects [16].

The goal of EBFM is to improve decision-making by providing a means for managers to explicitly consider all components of a fishery system, ecological, social, and economic, across all fisheries prosecuted in the system, that is, the "triple bottom line" (*cf*, [17]). Conventional management can take the triple bottom line into account within a single fishery, but EBFM does this comprehensively by looking across species, fisheries, and jurisdictions [18]. That is, it considers the system as a whole. A holistic view of systems can help managers better identify the full suite of threats to fisheries and provide a more coherent framework to account for the dynamics of systems. EBFM can identify elements that confer resilience, helping managers avoid exceeding limits that may lead to rapid and irreversible system change. Finally, EBFM can improve the rigor of setting catch levels by explicitly incorporating environmental and ecological information in science advice, where appropriate.

In the United States, revisions to the MSA have incentivized Regional Fishery Management Councils – the bodies that manage U.S. federal fisheries along with the National Oceanic and Atmospheric Administration (NOAA) – to expand the scope of conventional management over the past several decades. In addition to habitat protection and reduction of bycatch, fisheries managers have enacted precautionary measures such as biomass buffers to protect forage fish, which can serve as important prey to other species [19]. Stock assessment models have also advanced. Some stock assessments now link recruitment to environmental conditions, track changes in mortality due to predators, or use information on habitats to support abundance indices and assessment recommendations. In a recent review of 207 quantitative stock assessments, Essington and colleagues [20] found that roughly 22% included habitat or oceanographic conditions and 1% included predation (an additional 11% of assessments included data on predation in the report for context). This progress demonstrates the capacity to include ecosystem information in stock assessments and the opportunity to expand the application of EBFM in conventional management.

Concurrent with Councils' expanding scope of conventional management, an effort to establish ecosystem planning in the U.S. began two decades ago. In 1999, the Ecosystem Principles Advisory Panel (EPAP) concluded that while conventional fishery planning approaches included provisions to address ecosystem principles, they were not sufficient to implement EBFM [21]. Instead, a new tool was needed: Fishery Ecosystem Plans (FEPs). The purpose of an FEP is to improve decision-making through the incorporation of the principles of EBFM. By applying a broad suite of ecosystem-based considerations and scientific tools, managers can achieve sustainability goals for fishery systems. The EPAP report included recommendations for the development of FEPs with three objectives in mind: 1) provide a clear description and understanding of the biophysical, and human/institutional context of ecosystems within which fisheries are managed; 2) direct how that information should be used in the context of Fishery Management Plans; and 3) set policies by which management options would be developed and implemented [21].

Over subsequent years, eight FEPs have been developed (others are currently in development), covering four Council regions. The scope of these FEPs varies widely (Table 1), but one notable and consistent pattern is that FEPs generally do not include direct links to management actions. This point is also noted in a recent review of FEPs in relation to the recommendations in the EPAP Report [22], which found that several of the EPAP recommendations had not been implemented.

2. Next generation fishery ecosystem plans

Recognizing the challenges in implementing EBFM, The Lenfest Fishery Ecosystem Task Force[1] was convened in 2014 to review existing FEPs (and similar EBFM projects around the globe), and to provide a blueprint for the next generation of FEPs [20]. Over 2.5 years, the Task Force members and staff, engaged with scientists, stakeholders, managers, and other decision-makers through workshops around the U.S. At each workshop, the Task Force invited individuals to share their experiences with EBFM in their region and had candid discussions about EBFM progress, hurdles, and potential next steps.

These conversations were valuable in shaping the Task Force perspective of what is possible and in developing recommendations of what is necessary to move EBFM forward in U.S. fisheries management. The Task Force concluded that existing FEPs often focus on system description rather than management action [20]. To support progress, The Task Force recommended that FEPs be used to create a structured process for translating EBFM principles into action. This means developing actionable components for FEPs – ways in which ecosystem considerations lead to management responses.

Decision-making in an EBFM context needs to be structured and deliberate to account for uncertainty and trade-offs among competing objectives [23,24]. By structured, The Task Force means that there is a logical, sequenced process, and by deliberate, The Task Force means that the process is conducted with clearly articulated intentions to achieve specific goals.

Below, a Fishery Ecosystem Plan (FEP) process is described that is intended to support decision-making, thereby translating the concepts and principles of EBFM into action. This process relies on the active participation of stakeholders throughout FEP development. It allows for both the long-term aspirational nature of EBFM and the need for actionable, practical steps in the short term.

The Task Force approach, summarized in Fig. 1, is grounded in the concept of adaptive management [23,25], a structured approach for improving resource management by systematically learning from

[1] The Lenfest Task Force was chaired by T.E. Essington, co-chaired by P.S. Levin and staffed by K. N. Marshall and L. Koehn. Members included L.G. Anderson, A. Bundy, C. Carothers, F. Coleman, L.R. Gerber, J.H. Grabowski, E. Houde, O.P Jensen, C. Möllmann, K. Rose, J.N. Sanchirico and A.D.M. Smith.

Table 1
Sample vision statements, strategic objectives and operational objectives.

Vision statements	The vision for the Eastern Scotian Shelf is of healthy and sustainable ecosystems, economies, and communities supported by collaborative, integrated, and harmonized governance and management. Eastern Scotian Shelf Integrated management Plan [75]
	Healthy and productive marine ecosystems supporting thriving, sustainable marine fisheries that provide the greatest overall benefit to stakeholders [76]
	Maintain biologically diverse and productive marine ecosystems and foster the long-term sustainable use of marine resources in an ecologically and culturally sensitive manner through the use of a science-based ecosystem approach to resource management (Western Pacific Council FEP, www.wpcouncil.org)
Strategic objectives	Maintain the biomass of keystone species at levels that will ensure maintenance of their specific role in ecosystem function [77]
	Diversity of benthic, demersal, and pelagic community types is conserved. [75]
	"[M]inimize 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," (Magnuson Stevens Act, 2007)
Operational objectives	Maintain or increase regional/local employment in the fishery and related industries [77]
	Increase the overall abundance of spawning herring to 19,380 t by 2020 (Puget Sound Partnership website: http://www.psp.wa.gov/)

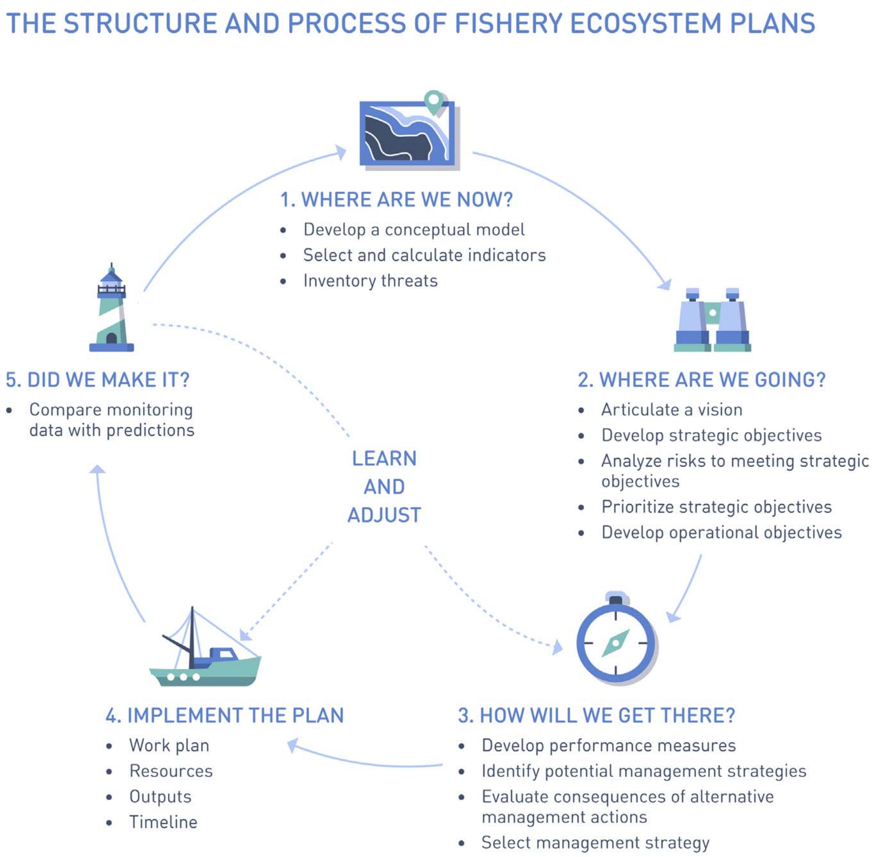

Fig. 1. The FEP loop is an interpretation of adaptive management as applied to Fishery Ecosystem Planning.

management outcomes [26]. This approach shares many features of the Integrated Ecosystem Assessment process already employed by NOAA and others [27,28], but builds upon that process by focusing on management actions. While this approach shares the features of any adaptive planning process, our framework explicitly considers how principles of EBFM can be translated into better decision making.

The framework outlined below describes the FEP process in five well-defined stages, with the whole cycle being repeated over time. Learning and adaptation occur at two distinct time scales. Over short time scales (perhaps one to three years), management actions will be implemented and their results monitored and analyzed. Based on this information, management tactics can be adjusted relatively quickly in an attempt to achieve the desired outcomes. At longer time scales (perhaps five to 10 years), monitoring and evaluation will yield insights on the wisdom and efficacy of the strategic approach being employed, allowing for adaptation in choice of objectives and the overall approach.

This "FEP Loop" does not offer a ready-made cookbook for EBFM (c.f. [28,29]). The Task Force decided that a cookbook approach was not useful to decision-makers because of the diversity of regional conditions, needs, and constraints, and because Councils will need and want to customize their approach to FEP development and implementation. As an adaptive framework, it is expected that it will change and that Councils will improve and modify our guidelines. Accordingly, this paper provides a blueprint that outlines key activities, their intended outcomes and purposes, and the sequence with which they should occur to guide the development of next-generation FEPs.

Below the five steps in the development of an FEP are described. Additional detailed guidance on the FEP Loop can be found here (http://www.lenfestocean.org/en/research-projects/lenfest-fishery-ecosystem-task-force).

3. The "FEP Loop"

3.1. Step 1: Where are we now? Model and inventory the Fishery System

The first step in generating an FEP is to answer the question, "where are we?" This process starts with a conceptual model, which describes the components of the system—ecological, economic, social, and institutional—and their causal connections to one another [9]. Next is an inventory of the status and trends of key components followed by an inventory of the threats that the system faces.

3.1.1. Conceptual models as tools for Fishery System inventories

Conceptual models identify important components of the fishery system and how they interact [21]. Their purpose is to guide planning by identifying ecological, economic, and social endpoints of concern, key threats impacting the endpoints, and information on how management decisions may affect those endpoints [14]. Conceptual modeling is often carried out with stakeholders in a public forum. This process, and the resulting model, are useful to organize stakeholder values and goals [29], foster communication among stakeholders, managers, and policymakers with diverse backgrounds [30,31] and increase understanding of complex system dynamics [32,33].

3.1.2. Select and calculate indicators for key Fishery System components

The next step in inventorying is to select indicators that capture the status and trends of important ecological, economic, and social/cultural components of the fishery system: its "vital signs" (ideally the same components as in the conceptual model). Indicators can be measured directly and serve as metrics for attributes of biophysical and human systems [34]. Reliable, usable indicators are invaluable, since many attributes that stakeholders value are challenging to measure directly, such as biodiversity, ecological resilience, sense of place, trust, and equity [35,36].

Many indicators and indicator-selection frameworks have been proposed for use in EBFM (e.g. [37–39]). A common theme is a focus on indicators that are directly observable, based on well-defined theory, understandable to the general public, cost effective to measure, supported by historical time series, and sensitive and responsive to the properties they are intended to measure.

Indicators should be quantified wherever possible. This is straightforward for existing single-species indicators and for indicators based on fishery-independent survey data, landings data, or other regularly collected data. For indicators that cannot be quantified directly, we recommend using a proxy. For example, while fishing profit is a measure of the economic health of the fishery, fishing cost data are often difficult to collect. Instead, ex-vessel prices and catches can be used to measure fishing revenues. Trends in fishing revenues along with trends in participation (e.g., active vessels) could provide a proxy for the economic conditions of the fishery. If both indicators are increasing (or decreasing), then the economic conditions would appear to be improving (or worsening).

3.1.3. Inventory the threats facing the Fishery System

Creating a list of threats that may impact the fishery system is the last component of Step 1. Published lists of potential threats to marine systems (e.g., [22–25]) are a good starting point, and include pressures that occur in human systems (e.g., changing market conditions and consumer preferences, compliance with regulations), on land (e.g., coastal development, agriculture, changing river flows), in the air (e.g., weather, climate), and in the ocean (e.g., shipping, naval exercises, fishing, energy extraction, aquaculture, and physical and chemical conditions) [40]. For each threat identified as relevant to the fishery system, documenting its spatial scale, magnitude, and frequency allows for a full cataloging of risks to the fishery system [22]. When identifying threats, time scale is important. Some threats may act immediately (e.g. noise from naval exercises), while others (e.g. climate change) will come into full force in the future.

3.2. Step 2: Where are we going? The Strategic vision, objectives, and priorities of the Fisheries Ecosystem Plan

3.2.1. Crafting an effective vision statement

The second step in developing an FEP begins with the articulation of a vision statement that encompasses the stakeholders' and management body's core values and purpose and provides the foundation for clear goals for the fishery system [26–28] (Table 1). A vision statement is durable and meant to persist through changes in staff and organizational structure, so it must be sufficiently broad in scope that it does not change over reasonable time frames (e.g., 10 years) [29]. The role of the vision statement is to create a fundamental, ambitious sense of purpose that is pursued over many years [30]. Empirical studies reveal that a well-crafted and effectively communicated vision has positive effects on organizational performance [31] because it forces prioritization by linking all levels of planning and goal setting [32].

The most effective FEP visions will be action-oriented, aimed at desired future states, flexible, long-term, and strategic yet still focused [33]. A well-constructed vision establishes what management will emphasize and prioritize, but still offers flexibility regarding what strategies might be used.

Vision statements for FEPs ideally consist of three general elements [34]:

1. The guiding ecosystem values and principles of the Regional Fisheries Management Council (or other management entity) and stakeholders
2. The enduring institutional purpose that grows out of these beliefs; and
3. A catalyzing mission that is consistent with the FEP's purpose

3.2.2. Developing strategic objectives for FEPs

Objectives translate vision statements into action. Strategic objectives unpack vision statements into high-level statements of what is to be attained [35,36] (Table 1). While vision statements typically refer to the fishery system as a whole, strategic objectives will be more focused on particular social, ecological, institutional, or economic domains. Thus, there will be several strategic objectives underlying the FEP vision. A number of them may derive from legislative or policy requirements. There will also be "missing" objectives that matter to stakeholders but are not necessarily codified in law. For example, consistent profits may be an objective of fishers, but may not be articulated in legal or regulatory documents.

3.2.3. Analyze risks to meeting strategic objectives

Risks to meeting the chosen strategic objectives should be analyzed to determine the likelihood that one or more components of the fishery system, as measured by the indicators, will reach or remain in an undesirable state (i.e., breach a reference limit) [41]. A risk analysis for a fishery system requires an understanding of the distribution and intensity of socioeconomic and land-, air-, and sea-based threats, as well as their impacts on fishery system components (identified in previous steps). Risk analysis must consider the inevitable uncertainties in the dynamics within biophysical and human systems and how they are coupled [42], and the possibility of cumulative impacts [43–45]. Holsman and colleagues [46] offer a useful framework for ecosystem-based risk assessment, highlighting how they could be useful as support tools for planning efforts like FEPs.

3.2.4. Prioritize strategic objectives

Regional Fishery Management Councils and other fishery management institutions have limited financial and human resources, and thus must move from the aspirational "we will do it all" to a more practical, actionable set of objectives. Managers and policymakers should rank strategic objectives to target investments in support of the FEP. Knowledge of status, trends, and risks provides an assessment of urgency. Prioritization may also consider criteria such as feasibility and logistics, governance and institutional issues, stakeholder support, reversibility of threats, and the costs of implementation, management, and lack of recovery [47]. Input on priorities should be gathered from stakeholders and prioritization decisions made transparently, documenting criteria and how they influenced the final decision.

3.2.5. Develop operational objectives

Strategic objectives are high level statements that provide direction. However, once prioritized, the next step is to use them to develop operational objectives that are specific, measurable, achievable, realistic, and time-bound [28,48] (Table 1). Developing operational objectives requires that practitioners and managers articulate what the FEP will do and what it will not address. Operational objectives are crucial because they (a) enable progress to the end goal to be measured and (b) lessen the risk of deploying limited capacity too thinly, thus failing to accomplish tasks with enough rigor to make progress towards the FEP vision [49]. Effective operational objectives will focus on changes in the state of the fishery system (e.g., fishery revenues, equity, fish biomass, ecosystem productivity, area of habitat protected) that generate benefits (e.g., greater well-being and profits, enhanced biodiversity, increased nursery habitat). It is essential to consider operational objectives for each major endpoint of the fishery system—ecological, economic, social /cultural, and institutional.

Operational objectives must include targets, i.e., goals that quantify the desired status of a component of the fishery system [19,50]. Although targets and associated reference points are crucial to EBFM [51,52], they can be challenging to define. To avoid hindering the progress of the FEP, they do not necessarily need to be included as part of the operational objective at its outset [53], but if they are not included at this stage, it will be critical to develop indicators and reference points to assess the effectiveness of the FEP (see below).

3.3. Step 3: How will we get there?

3.3.1. Develop indicators and reference points

As we describe above, indicators are measures for characterizing key attributes of biophysical and human systems. Indicators for a general evaluation of fishery system status and trends (in Step 1) are coarse-grained and useful for an evaluation of the "vital signs" of a system [34]. The implementation phase of an FEP requires "performance indicators" that track elements of the fishery system that are relevant for judging whether the operational objectives have been met. Performance indicators focus on fisheries system state variables of interest (e.g., habitat area, measures of abundance, fishery revenues, measures of well-being) that are responsive to management action. They provide technically robust and rigorous understanding of fishery system structure and dynamics. They also provide the detailed information necessary to diagnose specific problems, develop strategies to mitigate them, and monitor responses of the fishery system to management actions on multiple time scales.

Reference points set target levels for the performance indicators and provide context for evaluating performance and progress towards FEP operational objectives. Establishing targets for performance indicators that reflect progress towards specific operational objectives is critical for a successful FEP [54]. Reference points can be drawn from the underlying dynamics of the natural and human systems (e.g. [55]), or they can be designated as part of the process of developing the ecosystem vision and objectives. Reference points are informed by science but set to achieve a desired policy outcome [52,56].

Using historical values of indicators as reference points to reflect a "baseline condition" of the fishery system is not recommended, except with great care. Often, this approach attempts to express the status of an ecological indicator relative to that which might exist in a system free from human pressures [57]. Because a central tenet of FEPs, as presented here, is that humans are an integral part of fishery systems, we believe baseline reference points can provide context for FEPs, but are rarely appropriate targets to track progress towards operational objectives.

As in single-species management, reference points can be selected as targets for performance indicators [50,58] or as limits to be avoided [51]. For example, in single-species management "optimum yield" is a reference target and "overfished" is a reference limit. Limit reference points allow policy makers to implement pre-negotiated management responses in the event that a fishery system moves towards undesirable states, much in the way that reference points are used to set annual catch limits according to a harvest control rule. It may be easier to reach consensus on fishery system states to be avoided rather than desirable target states to be achieved [59], and in such cases, this may be a reasonable starting place for target setting.

3.3.2. Identify potential management actions

A strength of single-species management in the U.S. is that when reference points are breached, pre-determined management actions are triggered [35]. Extending this strength to EBFM requires that FEPs identify and evaluate potential management strategies before crossing the threshold of a FEP reference point. As with all fisheries management, stakeholder involvement is critical for generating a suite of potential management responses [60].

The range of responses by management in an EBFM context may include actions beyond altering catch limits or closing areas. As examples, when reference point thresholds are crossed, this could prompt 1) a scientific workshop to review information and provide guidance to managers, and 2) stakeholder meetings to develop potential solutions to a problem. Another possible response might be altering surveys to increase the accuracy and precision of monitoring relevant indicators.

3.3.3. Evaluate management strategies and alternative management actions

With management alternatives in hand, a formal analysis of policy options can occur. Management Strategy Evaluation (MSE) [61] is a commonly used policy analysis approach that assesses the strengths and weaknesses of different management options [62]. By evaluating a range of potential management actions using indicators to assess their performance, MSE can be used to test the robustness of management strategies and decision rules. The objective of MSE is not to select the "best" management alternative. Rather, it screens out poorly performing management strategies and identifies approaches that are robust to uncertainty. There may be no clear winning strategy, but MSE provides a thorough, transparent analysis of the trade-offs involved in choosing one strategy over another.

Often, MSE uses simulation models to compare alternative strategies in a virtual world. MSE is an ideal approach to support FEP processes because [28,50]:

1) Performance metrics can be evaluated in a simulation framework utilizing the indicators developed earlier in the FEP process.
2) A variety of models or sub-models may be used for evaluation. This allows managers and stakeholders to explore alternative hypotheses about fishery-system functioning to illuminate key issues and uncertainties.
3) MSE focuses on key areas of system uncertainty and evaluates the performance of alternative management strategies under a wide range of scenarios.
4) The whole management decision system is evaluated. The process may include a full suite of input/output harvest control rules, pre-set management responses, or other decision support mechanisms.
5) The process often identifies data and knowledge gaps, which in turn can be used to inform future research.

Table 2
Key questions to address when planning implementation of FEP strategies.

What specific work will be done?
Why is it necessary to do this work? (The project should relate to vision and objectives via conceptual models.)
How will the work be done (i.e., the technical steps, what models or tools will be employed)?
What are the project outputs?
What human resources are needed and who will provide them?
What will the project cost in money and in-kind resources?
What is the project timeline?
How is the project related to other projects? Can there be efficiencies in resource/ time use?

3.3.4. Select management strategies

Based on these analyses, managers can select a management strategy for implementation. In the context of the FEP, a management strategy identifies the management actions to be implemented (e.g., an ecosystem quota or area to be managed in some way) as well as management responses in the event the fishery system is in an undesirable state. These examples are extensions of single-species approaches. However, in an FEP strategy, crossing a biomass limit would serve to trigger an action to avoid risk to the long-term sustainability of stocks.

3.4. Step 4: How to implement FEP strategies

The implementation of the FEP transforms all the work described above into tangible projects. Here, FEP projects are considered as an interrelated group of activities needed to achieve an operational objective [29]. Implementation of FEP projects follows the same principles of conventional fisheries (or other natural resource) management. Projects in an FEP ideally answer the questions posed in Table 2.

It is during this step that individual projects are designed, with allocations of time, funding, and human resources. Indeed, for each project, and for the FEP as a whole, a formal work plan that describes the project, the resources needed, the outputs and the timeline is recommended. Though seemingly obvious and simple, it is only through a thoughtful planning process that a team's strategic intent can be translated to specific tactics and implemented. Importantly, careful attention to the implementation costs and benefits of various strategies allows managers to prioritize based on the value of each activity to strategic objectives and cost.

3.5. Step 5: Did we make it?

Monitoring and evaluating performance indicators and management strategies is an integral part of the FEP process. Monitoring and evaluation is necessary to determine whether management strategies that were implemented in the previous step improve the delivery of ecosystem services and sustainability, and may reveal trade-offs and unintended consequences of management actions.

At its core, monitoring is straightforward; it is the systematic collection of data on the biotic, abiotic, and human attributes of the fishery system to answer management questions [53]. Monitoring of performance indicators for FEPs must be sufficient to say whether the operational objectives of the FEP process have been achieved. While conceptually simple, monitoring is costly and subject to the changing priorities of funding agencies. Thus, successful monitoring depends on developing efficient sampling programs that foster cost-effective determination of the state of the ecosystem and the effectiveness of management actions. Moreover, effective monitoring is rooted in a prioritization of what to monitor, and how to allocate limited human and financial resources.

Two types of monitoring are relevant to FEPs:

Trend monitoring is a systematic series of observations over time for the purpose of detecting change in the state of the fishery system [54]. It relates to the "taking inventory" activities of the FEP, and to the subsequent adaptive management process, risk analyses, and management strategy evaluations. These subsequent activities will reveal if additional indicators need to be included as part of the monitoring process. (This is depicted in Fig. 1 as a return from step 5 to step 3.) Typically, trend monitoring is not used to evaluate the consequences of management actions, although some indicators may prove useful for this.

Effectiveness monitoring is used to evaluate whether specific management actions had the desired effect. It focuses in part on changes in risks identified in the "taking inventory" phase of the FEP and links threat reduction to changes in the status of key fishery system components. Thus, effectiveness monitoring requires observations of threats as well as the fishery system components targeted by the management action. For example, in trend monitoring, one might monitor the biomass or recruitment of a fish species or fishing revenues. In order to reduce the threat of low recruitment, managers might attempt to restore nursery habitat via spatial restriction of trawling or of some other human activity. Effectiveness monitoring would then focus on the changes in habitat targeted by the management action.

Monitoring should include measurements of the biophysical environment, but also includes social and economic systems. McLeod and Leslie [55] provide guidance on socioeconomic monitoring, and suggest that it can enhance the ability of managers to:

a. estimate how coastal management is contributing to community development
b. value marine resources from ecosystem services and cultural and economic significance
c. measure people's support for various management actions, including conservation
d. facilitate stakeholder involvement by gaining greater understanding of perceptions
e. tailor management to local conditions by developing education programs based on community understanding of resource conditions and threats.

4. Key considerations for the next generation FEPs

Above, we propose an adaptive planning cycle for ecosystem-based fisheries management (EBFM). This "FEP Loop" is not prescriptive because implementation will need to be customized to regional needs and constraints by each Regional Fishery Management Council.

We believe three key considerations should underlie the creation and implementation of Fishery Ecosystem Plans (FEPs):

- Existing tools and processes are sufficient to develop FEPs and implement EBFM;
- Stakeholder input is critical and should be central to fishery system planning;
- Managers must rely on both science and societal value judgments in setting explicit, measurable goals, identifying alternative strategies, and choosing among them. We elaborate on each below.

4.1. Existing tools and processes are sufficient to develop next-generation FEPs and implement EBFM

4.1.1. Science tools

In depth review of selected case studies and review of tools used for FEP steps described above revealed that existing scientific tools are already being used and applied for all parts of the FEP process [18,62]. These tools cover a broad range of qualitative, semi-quantitative, and quantitative methods, and span socio-cultural, economic, and ecological dimensions of fisheries. We therefore conclude, as have others, that scientific tools exist to support the FEP process at many levels of information availability and technical capacity [64–66]. This finding

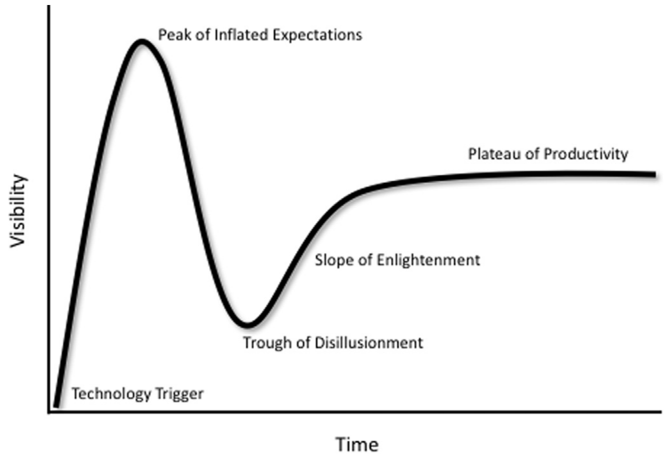

Fig. 2. The Hype Cycle is a branded graphical presentation developed and used by American Information Technology (IT) research and advisory firm Gartner for representing the maturity, adoption and social application of specific technologies [66]. The Hype Cycle provides a graphical and conceptual presentation of the maturity of emerging technologies through five phases.

contrasts with the common objection that we lack the ability to provide a technical basis for EBFM. Available science tools span a range of information needs and scientific capacity, meaning that Councils can choose the tools that are the most appropriate given their access to technical experts and data availability. FEPs do not necessarily require the support of large, complex systems models.

This view that science is limiting arises partly from a tendency to hold EBFM science tools to the same technical standards as those used today in conventional fisheries management. The Lenfest Ecosystem Task Force concluded that these technical standards are unrealistic and inappropriate, in part because EBFM tools are new in comparison to conventional fisheries tools such as stock assessments. In the case of single-species tools, decades of experience and development of stock assessment methods have led to a standardized process of application, evaluation, and interpretation. Prior to arriving at this point, single-species tools followed the "hype cycle" (Fig. 2, [67]). With many EBFM tools, we may be near the peak in the first cycle of technology adoption. Thus, as these tools are used, disappointment and tension should not be viewed as failure of EBFM, but as normal, healthy development and adoption, just as single-species tools developed and were adopted. Moreover, single-species tools were used for many years before the performance of the models was fully understood, yet managers did not wait to use them until they reached present-day capabilities.

EBFM tools and models should be applied early in any process of assessment or analysis and not delayed until all of the data and information deemed necessary are available. There is a misconception about EBFM tools, and modeling tools in general, that they should be the last step in analyses and should not be attempted with incomplete or imperfect information [68]. EBFM tool development, like most analyses, is best conducted iteratively, with the initial attempts serving to identify critical unknowns, allowing subsequent applications to become increasingly robust and relevant to management. Often the model will identify a different set of critical information needs than conventional wisdom or intuition would suggest [23].

4.1.2. Policy instruments

FEPs will use novel mixtures of existing policy instruments to achieve FEP goals. These instruments have mostly been designed under conventional fisheries management objectives and include harvest control rules, community development quotas, catch shares, time and space management, bycatch quotas, risk pools, and quota baskets.

To illustrate how existing policy instruments can be modified for EBFM, two real-world examples are described below:

- Ecosystem-based management strategies often consist of conventional fisheries policy instruments, modified to achieve management objectives for the fishery system.
- Modifications to policy instruments can be based on simple calculations rather than complex models.

In the first example, from the Barents Sea, a harvest control rule for capelin was modified to reduce the risk of recruitment failure. Capelin is a commercially fished species, as well as a key prey species for cod, seabirds, and pinnipeds. Capelin undergo wide fluctuations in population productivity based on environmental conditions and predator abundances [69]. The Joint Norwegian-Russian Fishery Commission, which overseas fisheries management in this region, has dual objectives of sustaining capelin fisheries while conserving adequate prey for predators. To meet the objectives, a strategy was chosen using the conventional idea of a harvest control rule, but modified based on the idea that management should minimize the risk of capelin recruitment failure. To this end, a harvest control rule was modified, wherein annual catches are set such that there is a 95-percent probability of maintaining the capelin spawning stock biomass above a limit reference point of 200,000 metric tons (mt), after accounting for estimated predation removals by the cod population. The limit reference point was selected by identifying the smallest spawning biomass in the capelin dataset that had produced a strong recruitment event (100,000 mt), which was then doubled to account for assessment uncertainty [70].

In the second example, from the Bering Sea-Aleutian Islands ecosystem of Alaska, a catch cap was implemented across all groundfish species. Alaskan groundfish fisheries catch numerous species, including walleye pollock, Pacific cod, sablefish, and several flatfish species. The North Pacific Fisheries Management Council (NPFMC) set an ecosystem strategic objective to "assure the continued health of the target species themselves and to mitigate the impact of commercial groundfish operations on other elements of the natural environment." An operational objective was to avoid significant and adverse changes to the productivity of the Bering Sea and Aleutian Islands fisheries [71]. To achieve this objective, the NPFMC modified a conventional single-species catch cap to instead limit combined landings of all groundfish at 2 million metric tons annually. This reference point was based on the notion that productivity levels of the groundfish species are interdependent. However, quantifying those dependencies is challenging, and existing science tools were not capable of estimating multi-species maximum sustainable yield (MSY). The council therefore took a simple, but well rationalized, approach of setting a cap on yields that was within the range of MSY levels summed over all stocks, reduced to account for uncertainty and to make MSY levels closer to optimal yield. The 2 million metric ton cap has been triggered multiple times since the policy was implemented. Consequently, exploitation rates in this ecosystem are commonly less than maximum sustainable yield.

4.1.3. Stakeholder input is central to fishery system planning

Stakeholders will make substantial contributions to next-generation FEPs [72]. They provide knowledge of biophysical systems, socio-cultural systems, and technical (gear) interactions in fisheries. This information is critical for describing a system and identifying alternative management strategies, including setting objectives, performance indicators, and reference levels. Further, stakeholder participation is necessary to understand and account for their values, needs, and desires for the fishery system. Finally, stakeholder participation will help build a sense of ownership and trust in the FEP process.

Effective stakeholder participation can be challenging to achieve. One main challenge is ensuring appropriate representation. Generally, if the cost of participation is high, stakeholder groups with greater financial resources will be disproportionately represented [73,74]. Participation costs can be substantial – travel costs and time commitment can dissuade many stakeholders. While such costs cannot be eliminated, they can be reduced by careful planning, selection of appropriate participation tools, and efficient conduct of meetings. The rotation of meeting locations by Councils already is an important step. An additional challenge is that effective participation requires a degree of trust among stakeholders. Well-trained facilitators are often needed for the more contentious issues [75]. Shared construction of qualitative fishery system models can be an effective way of building trust and shared understanding among diverse stakeholders.

4.1.4. Managers must rely on both science and societal value judgments in setting explicit, measurable goals, identifying alternative strategies, and choosing among them

Both scientific analysis and societal values contribute to the FEP process. Science can inform decisions, but answering questions such as "what is important to us", "what are desired states of fishery systems", and "what is the best choice given trade-offs" requires value judgments. We emphasize this point because unrealistic expectations for science can lead to delays in taking action with the hope that additional scientific study will simplify decision-making.

This concept is not unique to EBFM. In fact, conventional fisheries management already embeds values in the choice of stock population targets and limits. Biomass target levels (e.g., B_{MSY}, B_{MEY}) for fisheries are informed by scientific principles, but the levels that fisheries management *should* use are based upon societal values and goals. Similarly, the choice of biomass limits defining overfished (in the U.S. ½ of Bmsy levels) is informed by science (the risk of recruitment impairment), yet science usually does not determine the level of acceptable risk. We expect progress on EBFM despite limits of scientific guidance, in much the same way that conventional management has progressed.

The interplay between science and values to inform EBFM decisions is illustrated using a recent example from southeast Australia [61]. Like most fishery systems, the southern and eastern scalefish and shark fishery in Australia is complex, with many distinct stakeholders, legal mandates, and objectives. Beginning in the early 2000s, poor economic performance and deteriorating ecological status prompted managers to engage stakeholders and scientists to identify management objectives, select performance measures, and identify alternative management strategies. Technical science staff used this information to establish modeling experiments to predict how performance measures would likely respond to each strategy and then summarized the findings to reveal the trade-offs among strategies tested (Fig. 3). A key finding was that no single strategy outperformed all others on each performance measure. Rather, there were trade-offs that could not be eliminated via additional scientific study or strategy evaluation. Thus, decision-making required the judgment of policy makers, who selected the "integrated" strategy because it demonstrated the best balance across management objectives.

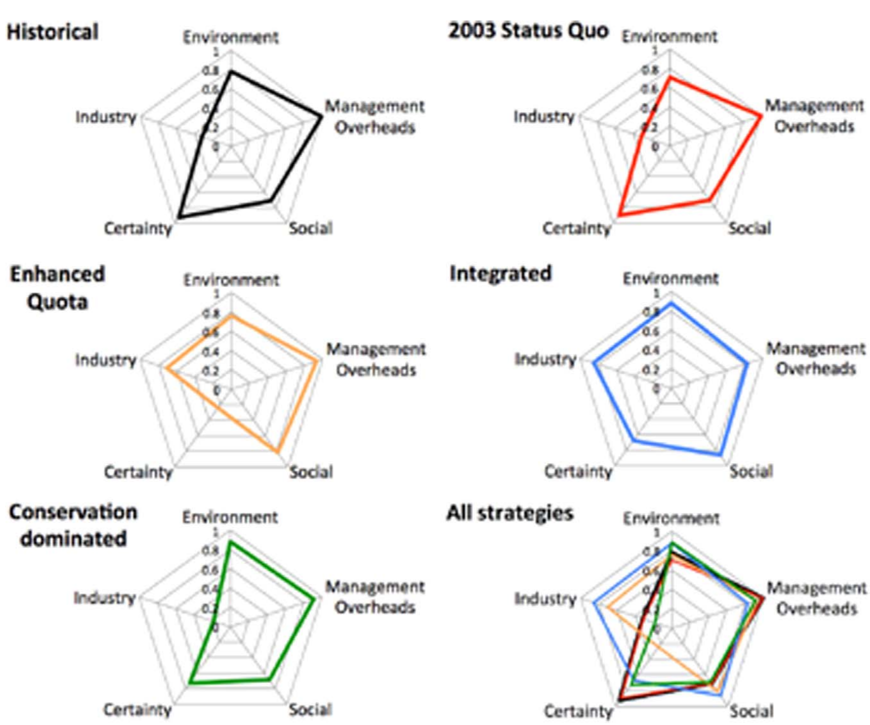

Fig. 3. Predicted outcomes of performance measures among five key dimensions, for five alternative strategy scenarios examined for the Australian the southern and eastern scalefish and shark fishery. 1 indicates good performance, 0 indicates poor performance. No strategy outperformed others across every management dimension. From [61].

5. Closing comments

In this paper, a blueprint for developing and implementing next-generation FEPs is developed. We recognize that our proposal follows standard principles of decision theory; however, the comprehensive framework proposed here is distinct from current FEPs. Specifically, the Task Force vision calls for scoping, prioritization, objective setting, evaluation of alternative policies to achieve objectives, and monitoring of performance to permit adaptive management. In this way, and critically, FEPs remain aspirational (through scoping) but actionable through specific measurable objectives. Additionally, they facilitate explicit consideration of trade-offs of alternative ways to achieve objectives. Moreover, based on our deliberations and consultations with stakeholders, scientists and managers, it is clear that FEPs can be developed using existing science and policy tools, engaging stakeholders, and integrating science and societal value judgements.

The proposed framework for next- generation FEPs stands on the shoulders of accepted standards of decision theory and adaptive management, yet application of this framework to EBFM is currently untested. We encourage adaptation and improvement of the decision-making framework to serve regional needs within and outside of the USA. Such experimentation presents an opportunity for learning and for sharing successes and challenges. The process of reviewing regional experiences in developing and applying the FEP loop will lead to adaptations and improvements of the process proposed here.

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References

[1] K.M. Wyman, The recovery of U.S. fisheries, J. L. Use Environ. Law 31 (2016) 149–196 ⟨http://www.law.fsu.edu/docs/default-source/journals/jluel/current-issue/jluelv31n2_(1)wymanarticle.pdf?sfvrsn=2⟩ (Accessed 22 March 2017).
[2] Sustainable Fisheries Act of 1996, 1996.
[3] NMFS, Status of Stocks 2015. Annual Report to Congress on the Status of U.S. Fisheries, 2016. ⟨http://www.nmfs.noaa.gov/sfa/fisheries_eco/status_of_fisheries/archive/2015/2015_status_of_stocks_updated.pdf⟩ (Accessed 22 March 2017).
[4] C.K.A. Geijer, A.J. Read, Mitigation of marine mammal bycatch in U.S. fisheries since 1994, Biol. Conserv. 159 (2013) 54–60, http://dx.doi.org/10.1016/j.biocon.2012.11.009.
[5] M.A. Bellman, S.A. Heppell, C. Goldfinger, Evaluation of a US west coast groundfish habitat conservation regulation via analysis of spatial and temporal patterns of trawl fishing effort, Can. J. Fish. Aquat. Sci. 62 (2005) 2886–2900, http://dx.doi.org/10.1139/F05-180.
[6] J.M. Lincoln, D.L. Lucas, Occupational fatalities in the United States commercial fishing industry, 2000–2009, J. Agromed. 15 (2010) 343–350.
[7] A.D. Smith, C.J. Brown, C.M. Bulman, E.A. Fulton, P. Johnson, I.C. Kaplan, H. Lozano-Montes, S. Mackinson, M. Marzloff, L.J. Shannon, Y.-J. Shin, J. Tam, Impacts of fishing low-trophic level species on marine ecosystems, Science 333 (2011) 1147–1150, http://dx.doi.org/10.1126/science.1208467 (80-.).
[8] K. Kroetz, J.N. Sanchirico, The bioeconomics of spatial-dynamic systems in natural resource management, Annu. Rev. Resour. Econ. 7 (2015) 189–207, http://dx.doi.org/10.1146/annurev-resource-083110-120047.
[9] J. Link, Ecosystem-Based Fisheries Management Confronting Tradeoffs, Cambridge University Press, Cambridge, U.K, 2010⟨www.cambridge.org⟩ (Accessed 23 March 2017).
[10] M.J. Fogarty, The art of ecosystem-based fishery management, Can. J. Fish. Aquat. Sci. 71 (2014) 479–490, http://dx.doi.org/10.1139/cjfas-2013-0203.
[11] S.M. Garcia, A. Zerbi, C. Aliaume, T. Do Chi, G. Lasserre, The ecosystem approach to fisheries. Issues, terminology, principles, institutional foundations, implementation and outlook., FAO Fish. Tech. Pap. Food Agric. Organ. Rome.
[12] P.A. Larkin, Concepts and issues in marine ecosystem management, Rev. Fish. Biol. Fish. 6 (1996) 139–164.
[13] E.K. Pikitch, C. Santora, E.A. Babcock, A. Bakun, R. Bonfil, D.O. Conover, P. Dayton, P. Doukakis, D. Fluharty, B. Heneman, E.D. Houde, J. Link, Ecosystem-based fishery management, Science 305 (2004) 346–347 (80-.).
[14] P.S. Levin, S. Breslow, C. Harvey, K.C. Norman, M.R. Poe, G.D. WIlliams, Conceptualization of social-ecological systems of the California current: an examination of interdisciplinary science supporting ecosystem-based management, Coast. Manag. 44 (2016) 397–408, http://dx.doi.org/10.1080/08920753.2016.1208036.
[15] A. Charles, Human dimensions in marine ecosystem-based management, in: M. Fogarty, J.J. McCarthy (Eds.), Sea, Harvard University Press, 2014, pp. 57–75.
[16] E. Plagany, E.A. Fulton, The future of modelling to support conservation decisions in the Anthropocene ocean, in: P.S. Levin, M.R. Poe (Eds.), Conserv. Anthr. Ocean Interdiscplinary Sci. Nat. People, Academic Press, San Diego, CA, 2017, pp. 423–446.
[17] B.S. Halpern, C.J. Klein, C.J. Brown, M. Beger, H.S. Grantham, S. Mangubhai, M. Ruckelshaus, V.J. Tulloch, M. Watts, C. White, H.P. Possingham, Achieving the triple bottom line in the face of inherent trade-offs among social equity, economic return, and conservation, Proc. Natl. Acad. Sci. USA 110 (2013) 6229–6234, http://dx.doi.org/10.1073/pnas.1217689110.
[18] K.N. Marshall, P.S. Levin, T.E. Essington, L.E. Koehn, L.G. Anderson, A. Bundy, C. Carothers, F. Coleman, L.R. Gerber, J.H. Grabowski, E. Houde, O.P. Jensen, C. Möllmann, K. Rose, J.N. Sanchirico, A.D.M. Smith, Ecosystem-based fisheries management for social-ecological systems: renewing the focus in the United States with next generation fishery ecosystem plans, Conserv. Lett. (2017), http://dx.doi.org/10.1111/conl.12367.
[19] E.K. Pikitch, P.D. Boersma, I.L. Boyd, D.O. Conover, P. Cury, T.E. Essington, S.S. Heppell, E.D. Houde, M. Mangel, D. Pauly, E.E. Plaganyi, K. Sainsbury, R. Steneck, Little fish, big impact: Managing a crucial link in ocean food webs, Lenfest Ocean Program, Washington, D.C, 2012.
[20] T.E. Essington, P.S. Levin, K.N. Marshall, L. Koehn, L.G. Anderson, A. Bundy, C. Carothers, F.C. Coleman, J.H. Grabowski, L.R. Gerber, E.D. Houde, O.P. Jensen, C. Mollmann, K. Rose, J.N. Sanchirico, A.D.M. Smith, Building Effective Fishery Ecosystem Plans: A Report from the Lenfest Fishery Ecosystem Task Force, Lenfest Ocean Program, Washington, D.C, 2016.
[21] Ecosystem Principles Advisory Panel, Ecosystem-based fishery management, National Marine Fisheries Service, Silver Spring, MD, 1999.
[22] E.B. Wilkinson, K. Abrams, Benchmarking the 1999 EPAP recommendations with existing fishery ecosystem plans, NOAA Tech. Memo. NMFS-OSF-5, 2015.
[23] C.J. Walters, Adaptive Management of Renewable Resources, MacMillan Publishing Co, New York, 1986.
[24] S. Polasky, S.R. Carpenter, C. Folke, B. Keeler, Decision-making under great uncertainty: environmental management in an era of global change, Trends Ecol. Evol. 26 (2011) 398–404.
[25] C.S. Holling, Adaptive Environmental Assessment and Management, Wiley-Interscience, Chichester, UK, 1978.
[26] M.J. Westgate, G.E. Likens, L. D.B, Adaptive management of biological systems: a review, Biol. Conserv. 158 (2013) 128–139.
[27] P.S. Levin, M.J. Fogarty, S.A. Murawski, D. Fluharty, Integrated ecosystem assessments: developing the scientific basis for ecosystem-based management of the ocean, PLoS Biol. 7 (2009), http://dx.doi.org/10.1371/journal.pbio.1000014.
[28] P.S. Levin, C.R. Kelble, R.L. Shuford, C. Ainsworth, Y. DeReynier, R. Dunsmore, M.J. Fogarty, K. Holsman, E.A. Howell, M.E. Monaco, S.A. Oakes, F. Werner, Guidance for implementation of integrated ecosystem assessments: a US perspective, ICES J. Mar. Sci. 71 (2013) 1198–1204.
[29] J. Haller, The Blue Strawberry Cookbook: Cooking (Brilliantly) Without Recipes, Harvard Commons Press, Cambridge, MA, 1976.
[30] P.S. Levin, T.B. Francis, N.G. Taylor, Thirty-two essential questions for understanding the social–ecological system of forage fish: the case of Pacific Herring, Ecosyst. Heal. Sustain. 2 (2016), http://dx.doi.org/10.1002/ehs2.1213.
[31] J. Gentile, M. Harwell, W. Cropper Jr, C. Harwell, D. DeAngelis, S. Davis, J. Ogden, D. Lirman, Ecological conceptual models: a framework and case study on ecosystem management for South Florida sustainability, Sci. Total Environ. 274 (2001) 231–253, http://dx.doi.org/10.1016/S0048-9697(01)00746-X.
[32] U. Ozesmi, S.L. Ozesmi, Ecological models based on people's knowledge: a multi-step fuzzy cognitive mapping approach, Ecol. Model. 176 (2004) 43–64.
[33] A. Dray, P. Perez, N. jones, C. La Page, P. D´Aquino, T. Auatabu, The AtollGame experience: from knowledge engineering to a computer-assisted role playing game, J. Artif. Soc. Soc. Simul. 9 (2006) 1–10.
[34] J. Kershner, J.F. Samhouri, C.A. James, P.S. Levin, Selecting indicator portfolios for marine species and food webs: a Puget Sound case study, PLoS One 6 (2011), http://dx.doi.org/10.1371/journal.pone.0025248.
[35] Y.-J. Shin, L.J. Shannon, A. Bundy, M. Coll, K. Aydin, N. Bez, J.L. Blanchard, M. de, F. Borges, I. Diallo, E. Diaz, J.J. Heymans, L. Hill, E. Johannesen, D. Jouffre, S. Kifani, P. Labrosse, J.S. Link, S. Mackinson, H. Masski, C. MÃ¶llmann, S. Neira, H. Ojaveer, K. ould Mohammed Abdallahi, I. Perry, D. Thiao, D. Yemane, P.M. Cury, Using indicators for evaluating, comparing, and communicating the ecological status of exploited marine ecosystems. 2. Setting the scene, ICES J. Mar. Sci. J. Du Cons. 67 (2011) 692–716, http://dx.doi.org/10.1093/icesjms/fsp294.
[36] S.J. Breslow, B. Sojka, R. Barnea, X. Basurto, C. Carothers, S. Charnley, S. Coulthard, N. Dolsak, J. Donatuto, C. Garcia-Quijano, C.C. Hicks, A. Levine, M.B. Mascia, K. Norman, M. Poe, T. Satterfield, K.S. Martin, P.S. Levin, Conceptualizing and operationalizing human wellbeing for ecosystem assessment and management, Environ. Sci. Policy 66 (2016) 250–259, http://dx.doi.org/10.1016/j.envsci.2016.06.023.
[37] C.A. James, J. Kershner, J. Samhouri, S. O'Neill, P.S. Levin, A methodology for evaluating and ranking water quantity indicators in support of ecosystem-based management, Environ. Manag. 49 (2012) 703–719, http://dx.doi.org/10.1007/s00267-012-9808-7.
[38] J. Rice, M. Rochet, A framework for selecting a suite of indicators for fisheries management, ICES J. Mar. Sci. 62 (2005) 516–527, http://dx.doi.org/10.1016/j.icesjms.2005.01.003.
[39] P. Levin, M. Damon, J. Samhouri, Developing meaningful marine ecosystem indicators in the face of a changing climate, J. Law Sci. Policy (2010) 36–48 (http://www.stanford.edu/group/sjlsp/cgi-bin/orange_web/users_images/pdfs/61_Levin Final.pdf).
[40] B.S. Halpern, S. Walbridge, K.A. Selkoe, C.V. Kappel, F. Micheli, C. D'Agrosa, J.F. Bruno, K.S. Casey, C. Ebert, H.E. Fox, R. Fujita, D. Heinemann, H.S. Lenihan, E.M.P. Madin, M.T. Perry, E.R. Selig, M. Spalding, R. Steneck, R. Watson, A global map of human impact on marine ecosystems, Science 319 (2008) 948–952 (80-.).
[41] A.J. Hobday, A.D.M. Smith, I.C. Stobutzki, C. Bulman, R. Daley, J.M. Dambacher, R.A. Deng, J. Dowdney, M. Fuller, D. Furlani, S.P. Griffiths, D. Johnson, R. Kenyon, I.A. Knuckey, S.D. Ling, R. Pitcher, K.J. Sainsbury, M. Sporcic, T. Smith, C. Turnbull, T.I. Walker, S.E. Wayte, H. Webb, A. Williams, B.S. Wise, S. Zhou, Ecological risk assessment for the effects of fishing, Fish. Res. 108 (2011) 372–384, http://dx.doi.org/10.1016/j.fishres.2011.01.013.
[42] C.C. Hicks, A. Levine, A. Agrawal, X. Basurto, S.J. Breslow, C. Carothers, S. Charnley, S. Coulthard, N. Dolsak, J. Donatuto, C. Garcia-Quijano, M.B. Mascia, K. Norman, M.R. Poe, T. Satterfield, K. St. Martin, P.S. Levin, Engage key social concepts for sustainability, Science 352 (2016) 38–40, http://dx.doi.org/10.1126/science.aad4977 (80-.).
[43] N.C. Ban, H.M. Alidina, J.A. Ardron, Cumulative impact mapping: advances, relevance and limitations to marine management and conservation, using Canada's Pacific waters as a case study, Mar. Policy 34 (2010) 876–886, http://dx.doi.org/10.1016/j.marpol.2010.01.010.
[44] I.C. Kaplan, I.A. Gray, P.S. Levin, Cumulative impacts of fisheries in the California Current, Fish Fish. 14 (2013) 515–527, http://dx.doi.org/10.1111/j.1467-2979.2012.00484.x.
[45] C.M. Crain, K. Kroeker, B.S. Halpern, Interactive and cumulative effects of multiple human stressors in marine systems, Ecol. Lett. 11 (2008) 1304–1315, http://dx.doi.org/10.1111/j.1461-0248.2008.01253.x.
[46] K. Holsman, J. Samhouri, G. Cook, E. Hazen, E. Olsen, M. Dillard, S. Kasperski, S. Gaichas, C.R. Kelble, M. Fogarty, K. Andrews, An ecosystem-based approach to

marine risk assessment, Ecosyst. Health Sustain. 3 (2017) e01256, http://dx.doi.org/10.1002/ehs2.1256.
[47] K.A. Wilson, M.F. McBride, M. Bode, H.P. Possingham, Prioritizing global conservation efforts, Nature 440 (2006) 337–340, http://dx.doi.org/10.1038/nature04366.
[48] G.M. Mace, H.P. Possingham, N. Leader-Williams, Prioritizing choices in conservation, in: D. MacDonald, K. Service (Eds.), Key Top. Conserv. Biol. John Wiley & Sons, Inc, 2009, pp. 17–34.
[49] W.F. Morris, D.F. Doak, Quantitative conservation biology: theory and practice of population viability analysis, in: Quant. Conserv. Biol. Theory Pract. Popul. Viability Anal:, 2002, pp. 325–372. 〈http://books.google.com/books?Id=8Z6GQgAACAAJ&printsec=frontcover%5Cnpapers://aff9d36b-a394-43cd-9752-0304ca342eae/Paper/p731〉.
[50] K.J. Sainsbury, A.E. Punt, A.D.M. Smith Sainsbury, K.J. Sainsbury, A.E. Punt, A.D.M. Smith, Design of operational management strategies for achieving fishery ecosystem objectives, ICES J. Mar. Sci. 57 (2000) 731–741 (doi:10.1006).
[51] J. Carwardine, C.J. Klein, K.A. Wilson, R.L. Pressey, H.P. Possingham, Hitting the target and missing the point: target-based conservation planning in context, Conserv. Lett. 2 (2009) 4–11, http://dx.doi.org/10.1111/j.1755-263X.2008.00042.x.
[52] J.F. Samhouri, S.E. Lester, E.R. Selig, B.S. Halpern, M.J. Fogarty, C. Longo, K.L. McLeod, Sea sick? Setting targets to assess ocean health and ecosystem services, Ecosphere 3 (2012) art41, http://dx.doi.org/10.1890/ES11-00366.1.
[53] V. Hatje, M.M. de Souza, L.F. Ribeiro, G.F. Eça, F. Barros, Detection of environmental impacts of shrimp farming through multiple lines of evidence, Environ. Pollut. 219 (2016) 672–684, http://dx.doi.org/10.1016/j.envpol.2016.06.056.
[54] J.F. Samhouri, P.S. Levin, C. Andrew James, J. Kershner, G. Williams, Using existing scientific capacity to set targets for ecosystem-based management: a Puget Sound case study, Mar. Policy 35 (2011) 508–518, http://dx.doi.org/10.1016/j.marpol.2010.12.002.
[55] J.F. Samhouri, K.S. Andrews, G. Fay, C.J. Harvey, E.L. Hazen, S.M. Hennessey, K. Holsman, M.E. Hunsicker, S.I. Large, K.N. Marshall, A.C. Stier, J.C. Tam, S.G. Zador, Defining ecosystem thresholds for human activities and environmental pressures in the California Current, Ecosphere 8 (2017) e01860, http://dx.doi.org/10.1002/ecs2.1860.
[56] P.S. Levin, G.D. Williams, A. Rehr, K.C. Norman, C.J. Harvey, Developing conservation targets in social-ecological systems, Ecol. Soc. 20 (2015), http://dx.doi.org/10.5751/ES-07866-200406.
[57] R.H. Thurstan, L. McClenachan, L.B. Crowder, J.A. Drew, J.N. Kittinger, P.S. Levin, C.M. Roberts, J.M. Pandolfi, Filling historical data gaps to foster solutions in marine conservation, Ocean Coast. Manag. 115 (2015) 31–40, http://dx.doi.org/10.1016/j.ocecoaman.2015.04.019.
[58] J.S. Link, J.K.T. Brodziak, S.F. Edwards, W.J. Overholtz, D. Mountain, J.W. Jossi, T.D. Smith, M.J. Fogarty, Marine ecosystem assessment in a fisheries management context, Can. J. Fish. Aquat. Sci. 59 (2002) 1429–1440, http://dx.doi.org/10.1139/f02-115.
[59] M.C. Bottrill, L.N. Joseph, J. Carwardine, M. Bode, C. Cook, E.T. Game, H. Grantham, S. Kark, S. Linke, E. McDonald-Madden, R.L. Pressey, S. Walker, K.A. Wilson, H.P. Possingham, Is conservation triage just smart decision making? Trends Ecol. Evol. 23 (2008) 649–654, http://dx.doi.org/10.1016/j.tree.2008.07.007.
[60] National Research Council, Evaluating the Effectiveness of Fish Stock Rebuilding Plans in the United States. doi:10.1371/journal.pone.0023601.Adkison, 2013.
[61] E.A. Fulton, F. Boschetti, M. Sporcic, T. Jones, L.R. Little, J.M. Dambacher, R. Gray, R. Scott, R. Gorton, A multi-model approach to engaging stakeholder and modellers in complex environmental problems, Environ. Sci. Policy 48 (2015) 44–56, http://dx.doi.org/10.1016/j.envsci.2014.12.006.
[62] A.D.M. Smith, G.P.O. Box, H. Tas, Management strategy evaluation - The light of the hill, Popul. Dyn. Fish. Manag. 538 (1994) 249–253.
[63] S.E. Lester, K.L. McLeod, H. Tallis, M. Ruckelshaus, B.S. Halpern, P.S. Levin, F.P. Chavez, C. Pomeroy, B.J. McCay, C. Costello, S.D. Gaines, A.J. Mace, J.A. Barth, D.L. Fluharty, J.K. Parrish, Science in support of ecosystem-based management for the US West Coast and beyond, Biol. Conserv. 143 (2010) 576–587, http://dx.doi.org/10.1016/j.biocon.2009.11.021.
[64] A.D.M. Smith, E.J. Fulton, A.J. Hobday, D.C. Smith, P. Shoulder, Scientific tools to support the practical implementation of ecosystem-based fisheries management, ICES J. Mar. Sci. 64 (2007) 633–639, http://dx.doi.org/10.1093/icesjms/fsm041.
[65] W.S. Patrick, J.S. Link, Myths that continue to impede progress in ecosystem-based fisheries management, Fisheries 40 (2015) 155–160, http://dx.doi.org/10.1080/03632415.2015.1024308.
[66] J.S. Link, System-level optimal yield: increased value, less risk, improved stability, and better fisheries, Can. J. Fish. Aquat. Sci. (2017) 1–16, http://dx.doi.org/10.1139/cjfas-2017-0250.
[67] J. Fenn, Understanding Gartner's Hype Cycles, Gartner Inc., Stamford, CT USA, 2007.
[68] A.M. Starfield, A pragmatic approach to modeling for wildlife management, J. Wildl. Manag. 61 (1997) 261–270 〈http://www.jstor.org/stable/3802581〉 (Accessed 13 September 2017).
[69] M.-J. Rochet, D.Ø. Hjermann, B. Bogstad, G.E. Dingsør, H. Gjøsæter, G. Ottersen, A.M. Eikeset, N.C. Stenseth, Trophic interactions affecting a key ecosystem component: a multistage analysis of the recruitment of the Barents Sea capelin (Mallotus villosus), Can. J. Fish. Aquat. Sci. 67 (2010) 1363–1375, http://dx.doi.org/10.1139/F10-064.
[70] ICES, Capelin in Subareas I and II, excluding Dvision IIa west of 5°W (Barents Sea Capelin), ICES, Copenhagen, 2014.
[71] NPFMC, Ecosystem Considerations 2015: Status of Alaska’s Marine Ecosystems., North Pacific Fisheries Management Council, Anchorage, AK. 〈https://www.afsc.noaa.gov/REFM/Docs/2015/ecosystem.pdf〉, 2015.
[72] C. Röckmann, M. Kraan, D. Goldsborough, L. van Hoof, Stakeholder participation in marine management: the importance of transparency and rules for participation, in: P.S. Levin, M.R. Poe (Eds.), Conserv. Anthr. Ocean, Academic Press, San Diego, CA, 2017, pp. 289–306.
[73] A.J. Berinsky, Silent Voices: Public Opinion and Political Participation in America, Princeton University Pres, Princeton, NJ., 2004.
[74] M.J. Osborne, J.S. Rosenthal, M.A. Turner, Meetings with costly participation, Am. Econ. Rev. 90 (2000) 927–943, http://dx.doi.org/10.1257/0002828054825628.
[75] R.S. Gregory, L. Failing, M. Harstone, G. Long, T. McDaniels, D. Ohlson, Structured Decision Making, John Wiley & Sons, Inc, Oxford, UK, 2012.
[76] Fisheries and Oceans Canada, Integrated Ocean Management Plan, Fisheries and Oceans Canada, Dartmouth, Nova Scotia, 2017. 〈http://www.dfo-mpo.gc.ca/Library/333115.pdf〉 (Accessed 6 December 2017).
[77] Mid-Atlantic Fisheries Management Council, 2014–2018 strategic plan. Mid-Atlantic Fishery Management Council, Mid-Atlantic Fisheries Management Council, Dover, Delaware, 2013.