IMPLEMENTATION VOLUME

BUILDING EFFECTIVE FISHERY ECOSYSTEM PLANS:
A REPORT FROM THE LENFEST FISHERY ECOSYSTEM TASK FORCE

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Science tools for Step 1: “Where are we now?”

The first component of our proposed blueprint for Fishery Ecosystem Plans (FEPs), the “FEP loop,” is to answer the question, “Where are we?” This component involves three steps: 1) defining the fishery system by identifying its key components and how they interact, 2) quantifying the status and trends of the fishery system using indicators, and 3) identifying threats to the system.

Fishery system inventories have already been completed for many regions of the U.S., and are underway in others. For example, the North Pacific, Pacific, Gulf of Mexico, and New England Councils received ecosystem status reports for their respective regions in the past few years. While some modification of these existing suites of indicators may be desired in the future, the bulk of the work of selecting, evaluating, and quantifying indicators has been completed in most regions as part of existing FEPs, NOAA Integrated Ecosystem Assessments (IEAs), and/or regular Council assessment cycles.

The Task Force acknowledges the UN Food and Agriculture Organization (FAO) Ecosystem Approach to Fisheries (EAF) toolbox (http://www.fao.org/fishery/eaf-net/toolbox/en), which provides similar guidance in an online format.

Step 1a, Develop a conceptual model

What are conceptual models and why are they useful?

Conceptual models are tools that identify key components of the fishery system and how they interact (Ecosystems Principles Advisory Panel, 1999). This is preferable to a simple list of components because it organizes diverse sets of stakeholder values and goals (Jones et al., 2011), improves communication among stakeholders from diverse backgrounds (Abel et al,. 1998), and increases understanding of complex system dynamics (Ozesmi and Ozesmi, 2004, Dray et al., 2006).

There are many types of conceptual ecosystem models, but often all that is necessary is a diagram of ecosystem components and how they interact (Figure 1). Qualitative information can be added to these models using, for example, colors, line styles and shapes (Harwell et al., 2010).

In any case, the central purpose of a conceptual model is to guide management strategies and tactics by identifying ecological, economic, and social endpoints of concern, key threats impacting the endpoints, and information on how decisions may affect those endpoints (Levin et al., 2016). Conceptual modeling is often carried out in a public forum aimed at exploring the costs and benefits of potential management actions. This process, and the resulting model itself, have proven useful in fostering communication among stakeholders, managers, and policymakers (Harwell et al., 1999).

A conceptual model can be considered complete when consensus is reached among those constructing the model. In cases where consensus cannot be reached, the FEP can proceed with alternative conceptualizations (Stier et al., 2016).

Best practices

Identify key fishery system components

Developing a conceptual model begins with identifying the key components of the fishery system. This may be quickly and easily accomplished through a brainstorming exercise with stakeholders and supplemented with expert elicitation. A more structured starting point is a generic component list, such as that provided by the FAO (Fletcher and Bianchi, 2014). A generic list can ensure that broad types of categories (e.g., social and ecological) are considered, but can be easily modified to add or subtract components as relevant to the region under consideration.

Building the model

Two tools are particularly useful for organizing key system components: component trees and cognitive maps.

The process of developing a component tree (Chesson et al., 1999; Fletcher et al., 2005) can begin with a generic structure, such as the component lists mentioned above, and proceed by modifying the generic tree in real-time as part of a stakeholder workshop (for example, see generic trees developed by FAO). A benefit of this approach to developing a conceptual model is that using a structured process and generic starting point reduces the chance that important components would be accidentally left out. However, imposing a structure, even a generic one, may prematurely narrow the focus of a brainstorming session. A component tree exercise is also constrained by its hierarchical nature, and does not include dynamic linkages among system components.

A cognitive map is a simple diagram that illustrates the key fishery system components and the directional linkages between them. Linkages describe how one component directly affects another (positively or negatively). Cognitive maps can also include qualitative information about the strength of linkages. Cognitive mapping is particular useful to evaluate and compare how different stakeholders view the fishery system (Prigent et al., 2008), revealing linkages among components that are clear to one group of stakeholders but that are not well known to others.

Important Considerations

An important consideration in developing a conceptual model for a fishery system is who contributes to the process of identifying key components and how they are connected, particularly if the process does not begin with a generic list. As mentioned above, this step is a key opportunity to integrate scientist, stakeholder, and manager input. It is critical for conceptual models to be developed as part of an open process (or available for public comment) because they structure many of the subsequent components of the FEP ("Where are we?" and "Where are we going?").

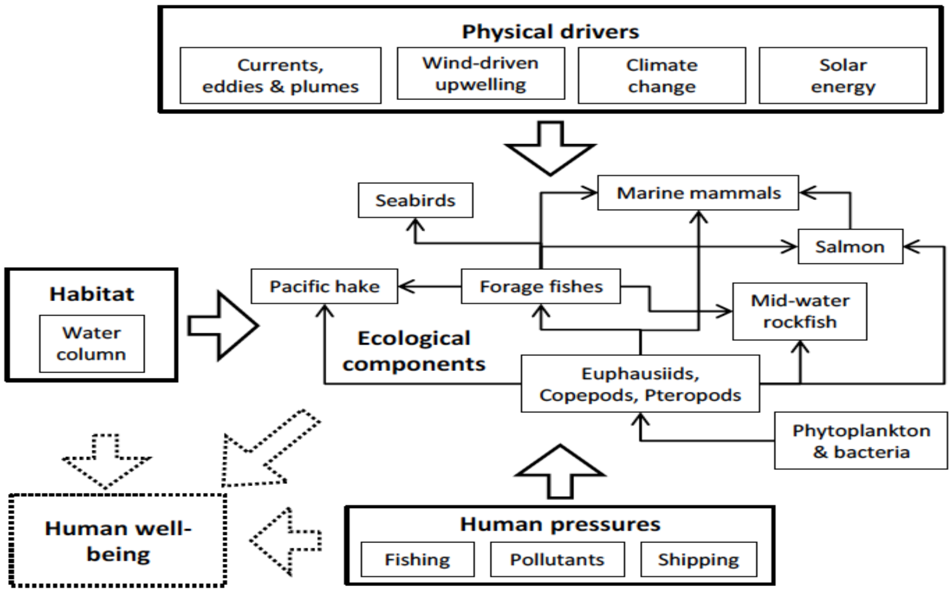

Figure 1. An example of a basic conceptual model of the coastal pelagic system in the Northern California Current. Model from Andrews et al., 2015

Examples

Two examples of conceptual models are provided in Chapter 3, one of which is from the California Current Integrated Ecosystem Assessment, reprinted as Figure 1.

Figure 2 is an example of a component tree developed for an Australian trawl fishery that illustrates the effects of fishing on the human and biophysical (called "environment" in this example) components (Chesson et al., 1999).

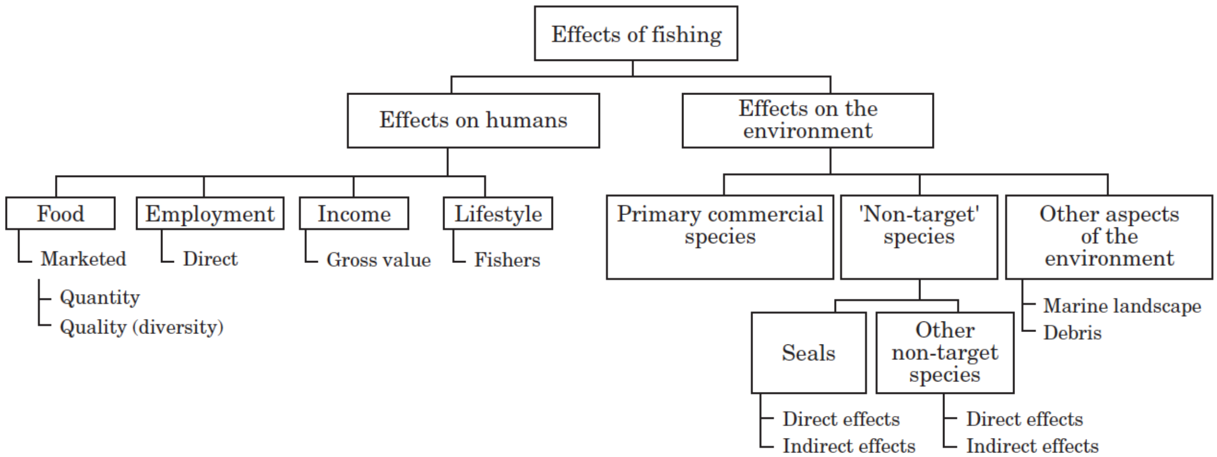

Figure 2. An example of a component tree for an Australian trawl fishery (Chesson et al., 1999).

Step 1b, Select and calculate indicators

What are indicators and why do we need them?

In order to understand "where we are," we need to have a measure of the status of the fishery system, how it responds to environmental and anthropogenic drivers, and how it has changed over time. These properties can be tracked using indicators, which are measurable attributes of fishery systems that reflect their structure, composition, and functioning. Indicators can focus attention on various system properties, from single drivers (e.g., fishing pressure), to impacts of drivers on system functioning and community well-being, to community or whole-system syntheses. They may be direct measures, such as fishing pressure, and can also be proxies for attributes that are not directly measureable, such as resilience or equity (Fay et al., 2013; Jennings, 2005; Kershner et al., 2011). It is this latter function that makes indicators an invaluable tool for ecosystem-based fisheries management (EBFM) (deYoung et al., 2008; Shin et al., 2012). The selection of indicators to assess "where we are" does not necessarily require the development of new indicators, since a plethora of indicators have been proposed for use in EBFM (Kershner et al., 2011; Shin et al., 2010).

Indicators can be categorized along many dimensions. Typically, they represent aspects of a system in one of two fundamental ways: the status at a given moment or a trend over a given period (e.g., increasing, decreasing, or no change). Indicators can be simple (e.g., biomass of demersal fish, average earnings in fishery "X") or composed of multiple data streams (e.g. proportion of non-declining exploited species (NDES, Kleisner et al., 2015), the Ocean Health Index (Halpern et al., 2012) or the Human Development Index (Jahan, 2015). Indicators are often further classed as follows, depending on what they are used for:

- Performance indicators (Fay et al., 2015), which are used in step 3a below
- DPSIR indicators, for driver, pressure, state, impact or response (Jennings, 2005; Martins et al., 2012)
- surveillance indicators (Shepherd et al., 2015)

Importantly, the same indicator (e.g., biomass of demersal fish) may be used in multiple settings and categorized differently depending on how it is used (e.g., surveillance indicator, performance indicator, state indicator, or response indicator).

DPSIR indicators are often used to describe "where we are", and can be linked directly to conceptual models. They will also be useful for the 2nd component of the FEP loop, "where are we going?" Martins et al. (2012) provide a review of DPSIR indicators, with examples. We provide the following hypothetical examples relevant to fisheries:

- Driver indicators: market demand, number of fish harvesters
- Pressure indicators: fishing effort, eutrophication (e.g., average dissolved inorganic nitrogen), fuel price
- State indicators: species richness, average size or biomass of key species groups such as forage fish, profits to the commercial sector, average age of participants in the fishery
- Impact indicators: overfishing, quality of fish for human consumption
- Response indicators: legislation, marine protected areas (MPAs), quotas

This stage of the FEP loop requires the selection of pressure and state indicators that capture the status and trends of the key components of the fishery system.

However, at this early stage of a FEP, most indicators would be considered surveillance indicators, because they are used for monitoring and information purposes and do not need to be related directly to an objective (e.g., primary production, sea surface temperature). At late steps in the FEP process, performance indicators are chosen specifically to judge the effectiveness of management actions or to judge whether operational objectives are being met (see below). In many cases, these performance indicators may be selected from the initial suite of indicators chosen for initial monitoring.

The type of information required for indicators is related to the type of indicator and what it is intended to measure. Commonly, indicators rely on data routinely collected by fisheries agencies, such as biophysical data, catch and effort data, and fisheries-independent survey data. However, as thinking about fisheries has expanded to conceive of fisheries as systems, some types of information, such as social, cultural, and economic data, may not be as readily available. A proxy may be a necessary stop-gap indicator to represent a desired attribute for which data currently do not exist (e.g., using fishery revenues in lieu of profits to represent economic conditions).

Indicators are rarely used alone. Instead, a suite, or portfolio, of complementary indicators is recommended (Kershner et al., 2011; Methratta and Link, 2006; Rice and Rochet, 2005; Shin et al., 2010). There are two types of suites of indicator (Longo et al., 2015): (i) a suite designed to measure different aspects of the same attribute and (ii) a suite designed to capture all the dimensions of a fishery system (e.g., physical, ecological, economic, social, and cultural). At this early stage of a FEP, the latter option is generally preferred to give broad coverage.

Best practices

Selection of Indicators

In the "Where are we?" step, indicators should be chosen to represent each of the key ecosystem components in the conceptual model. Several frameworks have been defined for selecting indicators (e.g., Jennings, 2005; Kershner et al., 2011; O'Boyle and Jamieson, 2006; Rice and Rochet, 2005). A hierarchical approach is common to these frameworks, where the overall goal or vision for the fishery system, which is analogous to the FEP strategic objective (Chapter 3), is decomposed into narrower, more concrete objectives for specific components of the fishery system, which are in turn "unpacked" (O'Boyle and Jamieson, 2006) to the point where they are operational objectives that can be measured by an indicator. We focus on selecting indicators that match key ecosystem components rather than operational objectives in this section because operational objectives are specified in the next component of the FEP ("Where are we going?"). However, the same methodology and best practices would apply for selecting indicators at that later step.

Following the literature, and the terminology used in Kershner et al. (2011) we outline four steps in the selection of indicators.

The first is to translate key components into "attributes," which are characteristics that describe the state of a component. In the Kershner et al. (2011) example for Puget Sound, one focal component was "Marine Species" and its attributes were population size and population condition. The authors describe a hierarchical framework for mapping attributes onto key ecosystem components and developing indicators for each. They also provide a detailed example of selecting indicators for the Puget Sound Ecosystem in Washington State. We note that different frameworks use alternative terminology (e.g. operational objectives may be used in place of key attributes).

The second step is to develop a candidate list of indicators to measure the key attributes. There are many descriptions of indicators in the literature, including physical, ecological, economic, social, and cultural indicators. For example, in the California Current IEA, one key component is groundfish. Two attributes for groundfish were biomass and population structure. Two candidate indicators for biomass were depletion and biomass in the most recent year of the survey, and a candidate indicator for population structure was the proportion of the population that is mature. For further detail on these indicators, see Levin et al., (2011).

The third step is to score the candidate indicators against a set of criteria. Multiple lists of criteria exist and can be adapted to a Council's needs. Rice and Rochet (2005) provide a useful starting point, a set of criteria that offer a consistent method to evaluate individual indicator suitability and effectiveness. These criteria have been widely adopted (e.g., Shin et al., 2010, 2012) and expanded (e.g., Kershner et al., 2011). At their core, the criteria recommend the following nine properties:

- Concreteness (indicators should have tangible qualities, as opposed to abstract qualities)
- Theoretical basis (indicators should have a sound theoretical basis that is not in dispute)
- Public awareness (the indicator is understandable to the general public)
- Cost
- Measurement
- Availability of historic data
- Sensitivity (the indicator is sensitive to the pressure it is intended to measure)
- Responsiveness (the indicator responds in a timely fashion to the pressure it is intended to measure)
- Specificity (the indicator's response is specific to the pressure it is intended to measure, and/or influence of other pressures understood)

Weighting criteria may be desirable so that some criteria are given more consideration than others. Rice and Rochet (2005) recommend that user groups should weight the criteria. In the Kershner et al. (2011) example, they weighted scientific criteria more highly (e.g., concreteness, theoretical basis, sensitivity, and responsiveness) than other criteria, such as those that captured public awareness. Ultimately, the decision if and how to weight criteria is up to users who are selecting the indicators. However, if weighting is used, the sensitivity of results to the weighting scheme should be explored.

The final step is to select a sufficient number of indicators to provide the "vital signs" of the fishery system, without swamping the analysis with hundreds of indicators. Minimally, these should include indicators to assess the status of the key components of the fishery system identified in the conceptual model. The ultimate number of indicators selected is often a compromise between policy makers (who typically prefer few indicators) and scientists (who often recommend many indicators) (Levin et al., 2010), though parsimony is recommended because of practicalities such as data availability (Shin et al., 2010). Further, when developing the final suite of indicators the combination of indictors should be carefully considered in order to form a well-rounded toolbox (Kershner et al., 2011). Jennings (2005, p. 229) cautions that "indicators need to track the state of components and attributes that are adversely impacted by fishing, with priority given to the impacts that are most likely to be unsustainable".

This stepwise procedure for indicator selection may seem challenging, but the extent of the process may be reduced to accommodate the availability of resources and data. The key is to have a formalized process and not select indicators haphazardly.

Quantification of Indicators

Once indicators have been selected, they should be quantified wherever possible. This should be straightforward for existing single-species indicators, and for ecosystem indicators based on fisheries-independent survey data, landings data, or other regularly collected survey data, such as physical oceanographic and environmental data.

However, quantity, scale, and types of information available to quantify indicators vary considerably among the different dimensions of EBFM. For some indicators, there simply may be insufficient data to calculate the indicator, for example, due to lack of spatial and/or temporal coverage, lack of consistent or standardized data collection, or simply lack of data. For social indicators, data may be qualitative and not easily expressed quantitatively. Social science data may be at a different spatial scale than other types; for example, it may be at the fishing community scale while coastal benthic data are at the single bay or estuary scale. In these cases, it is necessary to develop indicators that summarize local information into broader system-level quantities. There is a growing body of information available on social and cultural indicators on the NOAA website: http://www.st.nmfs.noaa.gov/humandimensions/index

For data-poor situations there are three general options:

1. Expert opinion using a Likert scale can be used to evaluate perceptions of system and pressures status in the absence of detailed monitoring programs aimed at important components of fishery systems.
2. A proxy can be used until sufficient data are available
3. The indicator is not used until there are sufficient data with which to quantify it; in the meantime, this gap should be considered an uncertainty.

For indicators where there are less/no data available, it is critical that appropriate experts are involved in addressing this deficit.

Summarizing Indicator Results

For a suite of EBFM indicators, it is usually necessary to reduce the large number of indicators into a small number of dimensions. The complexity of this task varies with the number of fishery components, key attributes, and indicators under consideration.

There are several methods to combine the results from a suite of indicators. These include multivariate analyses such as MDS, PCS, cluster analysis, aggregation into composite indicators, fuzzy logic, and decision trees. Also useful are graphical depictions, such as heat maps, stoplight report cards (e.g., Doren et al., 2009), radar plots, or petal plots. Rice and Rochet (2005, Table 3) provide a good summary of data reduction methods and the pros and cons of each. There are concerns about condensing a large amount of information into one indicator, and Rice and Rochet (2005) advise that there is a "trade-off between the complexity of trying to interpret large quantities of information and the risks inherent in collapsing information in apparently simple ways." They further note that "aggregated trends should always be used with caution" (Rice and Rochet, 2005).

Important considerations

The nine selection criteria outlined by Rice and Rochet (2005) have been widely cited, but three of the criteria, sensitivity, responsiveness, and specificity, have received relatively little attention. These criteria measure the behavior and robustness of ecological indicators. For example, indicators should respond specifically to changes in the pressures they are designed to detect (e.g. fishing) rather than changes other drivers (e.g. environment). They should be sensitive to changes in that pressure and respond within a time frame that is useful to for management. There is a growing body of work examining these criteria, and ideally these should be examined for all indicators selected for EBFM.

A suite of ecological indicators has also been shown to be valuable for resolving inconsistencies between various indicators that measure different ecosystem attributes (Shin et al., 2010).

Examples

- The Alaska Ecosystem Considerations Report, prepared for the North Pacific Fishery Management Council (NPFMC), includes indicators such as: fish guild biomass, marine mammal counts and predator biomass, seabird diet trends, and indices from the physical environment among others. A short list of indicators for status and trends was originally identified using a stepwise framework DPSIR approach (Elliott, 2002). This was done to align this work with other Integrated Ecosystem Assessment research (see below). Drivers and pressures were identified based on four objectives following the NPFMC ecosystem-based goals: "maintain predator-prey relationships, maintain diversity, maintain habitat, and incorporate/monitor effects of climate change." Indicators were then chosen related to the "availability, sensitivity, reliability, ease of interpretation, and pertinence" of an indicator to address one of the objectives (NPFMC, 2015). Assessments were done for multiple regions in Alaska, and the Bering Sea/Aleutian Islands assessments include the general DPSIR approach and additional contributions by the Ecosystem Synthesis Team of community-level indicators and indicators related to non-fishery apex predators.
- Good Environmental Status: Reaching "good environmental status" by 2020 is a main focus of the Marine Directive of the European Commission (EC). Reaching good environmental status entails achieving 11 "descriptors" which include: "Biodiversity is maintained," "Eutrophication is minimized," and "Marine litter does not cause harm." With these broad descriptors, the EC also developed in 2010 more specific

indicators to track. For example, for the descriptor "Biological diversity is maintained," indicators include: distributional range of species, population abundances of species, and population genetic structure for different species.

- Integrated Ecosystem Assessments for California Current (CCIEA, Levin et al., 2013) and Gulf of Mexico (Ecosystem Status Report; Karnauskas et al., 2013) have been conducted by NOAA IEA programs. Both broadly use DPSIR conceptual models to identify indicators. Specifically, the CCIEA lists ecosystem-based management components, drivers, and pressures. The components that are focused on are habitat, wild fisheries, ecosystem integrity, vibrant coastal communities, and protected resources. The drivers focused on are components that lead to pressures that then lead to ecosystem changes. The Ecosystem Status Report for the Gulf of Mexico uses a related DPSER (Drivers, Pressures, States, Ecosystem services, Responses) conceptual model (Kelble et al., 2013) to select indicators. The final selected indicators span a wide range of topics from physical components to benthic habitat and low trophic level communities to upper trophic level communities and socioeconomic indicators.

Step 1c, Inventory threats

What are threats and why do we need to describe them?

The final step in "Where are we?" is to identify potential threats to the fishery system. Threats are factors or activities that may adversely affect a fishery system, such as pollution, shipping, or fishery removals. Identifying potential threats in this early stage provides a base on which to build later risk assessment and prioritization steps.

The approaches for identifying threats are very similar, if not identical, to identifying key fishery system components. Indeed, it may be desirable to simultaneously elicit key components and threats from stakeholder and expert workshops.

Best Practices

Many published lists of potential threats are available, and summarized in Chapter 3, Table 3.1 (Andrews et al., 2015; Halpern et al., 2012). A discussion with stakeholders can begin with an extensive list and prune it to only those threats relevant to a particular system. Brainstorming can also supplement these lists.

Important Considerations

As with the conceptual modeling step, the involvement of scientists, stakeholders, and managers in the identification of threats is important. Developing an inventory of threats in this step bounds the risk assessment and prioritization step in "Where are we going?" Therefore, it is desirable to consider a broad range of potential threats at this stage.

Examples

Many examples of lists of potential threats exist in the primary literature and have been compiled by existing FEP or IEA efforts. We provide three examples here as a starting point, but not that these are not exhaustive of all potential threats.

Andrews et al. (2015) provided a list of anthropogenic pressures for the California Current ecosystem, for which they developed and quantified indicators. The pressures they identified included: finfish and shellfish aquaculture, atmospheric pollution, benthic structures, coastal engineering, commercial shipping activity, dredging, fishery removals, freshwater retention, habitat modification, inorganic pollution, invasive species, light pollution, marine debris, nutrient input, ocean-based pollution, offshore oil activities, organic pollution, power plants, recreational beach use, seafood demand, and sediment retention. For additional explanation of these threats, see Andrews et al. (2015).

As a second example, the South Atlantic Council's FEP extensively documents potential threats to habitat (SAFMC, 2009). They characterized threats as non-fishing and fishing. Non-fishing threats were further broken down into threats to estuarine processes and threats to offshore processes. Threats to estuarine processes included agriculture; aquaculture; silviculture; urban/suburban development; commercial and industrial activities; navigation; recreational boating; mining; hydrologic modifications; transportation projects; and natural events and global change. Threats to offshore processes included navigation; dumping; offshore sand and mineral mining; oil and gas exploration, development, and transportation; commercial and industrial activities; and natural events and global change. Fishing threats consisted of all bottom-contact gear types.

As a third example, the Aleutian Islands Fishery Ecosystem Plan (NPFMC, 2007) documented potential threats (which they refer to as stressors) to the Aleutian Islands ecosystem. The categorized 21 potential threats into five types of interactions: climate/physical interactions, predator-prey interactions, endangered species interactions, fishery interactions, and socioeconomic activities. They then conducted a qualitative risk assessment of these threats (described under Step 2 of this volume).

The three examples detailed above provide a starting place to evaluate threats and demonstrate how threat lists may vary depending on the scope and purposes of the activity and on what threats are relevant in a particular region. Andrews et al. (2015) focused on anthropogenic stressors to the ecosystem, the South Atlantic Council described human and non-human threats to one component of the ecosystem (habitat), and the Aleutian Islands FEP considered human and non-human threats to the ecosystem.

Implementation Volume. Step 1: "Where are we now?"

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Science tools for Step 2: “Where are we going?”

Steps 2a & 2b, Articulate a strategic vision and develop strategic objectives

What are vision statements?

An FEP vision statement should clearly articulate the management body’s core values and purpose and provide the foundation for clear goals for the fishery system (Jennings, 2005; Rice et al., 2005; Rogers and Biggs, 1999). A vision statement is durable and is 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) (Meffe et al., 2012). Vision statements create a fundamental, ambitious sense of purpose that is pursued over many years (Kantabutra and Avery, 2010). Empirical studies reveal that a well-crafted and effectively communicated vision has positive effects on organizational performance (Baum et al., 1998) because it forces prioritization by linking all levels of planning and goal setting (Kantabutra, 2009).

The most effective FEP visions will be action-oriented, aimed at desired future states, flexible, long-term, and strategic yet still focused (Larwood et al., 1995). 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 should ideally consist of three general elements (Collins and Porras, 1996):

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
3. A catalyzing mission that is consistent with the FEP’s purpose

What are strategic objectives?

Strategic objectives are high-level statements of what is to be attained (O’Boyle and Jamieson, 2006; Sainsbury and Sumaila, 2003) and move from vision to action. Vision statements are too general to directly guide management actions, but strategic objectives serve to unpack and focus vision statements. 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 (Figure 3).

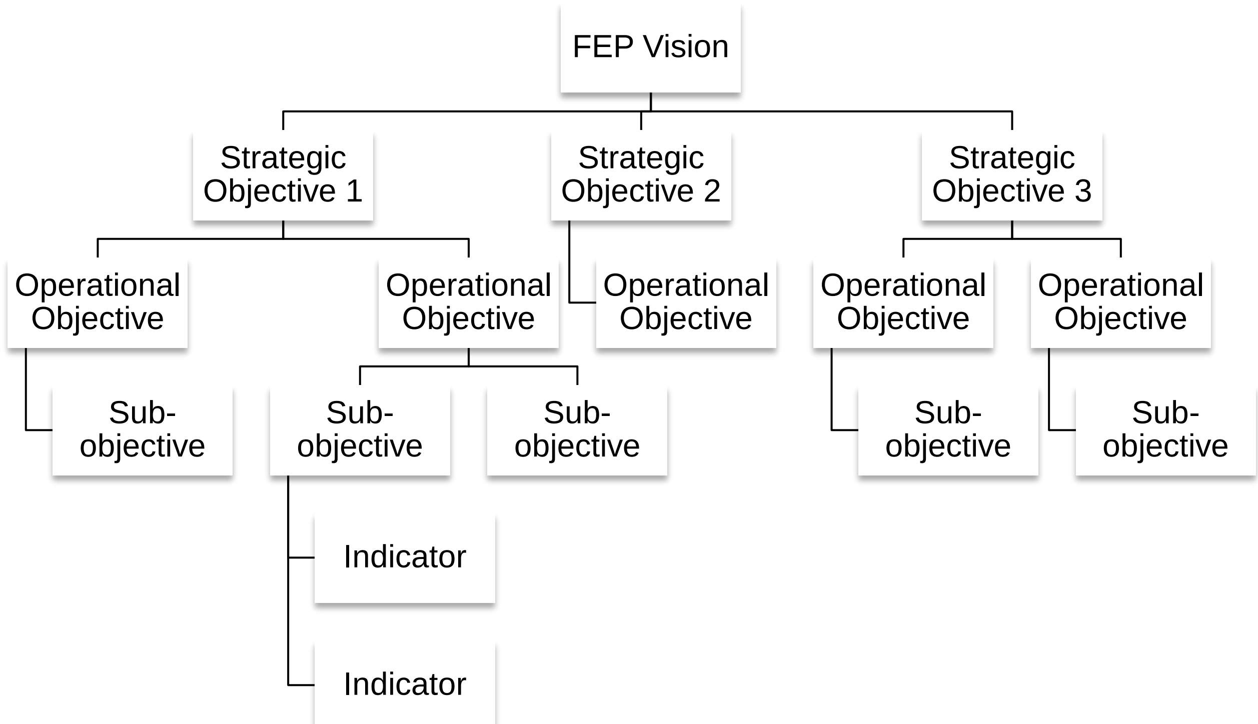

Figure 3. The hierarchical structure of FEP Visions, Strategic Objectives, and Operational Objectives

Successful vision statements and strategic objectives share the following key attributes:

- Concise
- Clear
- Aspirational
- Achievable but challenging
- Empower individuals to act
- Motivate science, management, and communities

Tools for developing vision statements and strategic objectives

Because the tools to develop FEP visions and strategic objectives are typically identical, we discuss them jointly here. The inclusion and participation of stakeholders is critical to success, and thus all of these tools require broad input. In general, there are two classes of tools for generating vision statements and strategic objectives: those related to gathering information, and those seeking to organize the information. We discuss these in turn below.

Tools for gathering information to inform vision statements and strategic objectives

Gathering input and information from stakeholders can be time-consuming and challenging to do effectively. This section highlights some common approaches among the numerous tools available for working collaboratively to generate inclusive effective vision statements and strategic objectives. This process can be undertaken at the same time as the process for creating an inventory and conceptual model (step 1a), if managers are satisfied that enough time is available and stakeholders are willing to participate in both exercises.

Brainstorming. Brainstorming is a familiar process for identifying issues and can also be used to creatively generate many alternative ideas for vision statements and strategic objectives. Once ideas are generated they can be analyzed and discussed. Brainstorming is especially useful for allowing stakeholders to participate in the visioning and objective setting process since it creates a non-judgmental environment where ideas can be openly discussed. The following guidelines are useful for this process:

- Outputs of the brainstorming process should be clearly articulated.
- Ground rules that encourage a criticism-free environment and that enhance opportunities for all to participate should be established.
- Smaller groups (about 10 people) provide an opportunity for more people to participate and express their ideas.
- When smaller groups are created, individuals should be assigned to groups (rather than self-select).
- Individual brainstorming sessions should be about 30 minutes
- Where possible, a good facilitator should be engaged in this process since they are neutral, trained to keep the group on task, and can synthesize information generated by the brainstorming exercise, producing the best products.

Rapid community assessment (RCA). In RCA, the FEP team would use semi-structured interviews to reach out to key stakeholders and participants in the fishery system. When large in-person meetings are not desired or feasible, this technique can provide information from stakeholders that will be critical for the development of inclusive vision statements and objectives. RCA can also be used as an initial scoping tool ahead of workshops with key stakeholders to streamline the visioning and objective setting process. The following guidelines and limitations should be considered:

- Standard protocols for semi-structured interviews should be employed.
- Because this tool focuses on only on a limited number of key participants in the fishery, it is important not to overgeneralize results.
- Care must be taken to identify key stakeholders for the RCA to ensure that all perspectives are represented.

Scoping Check Lists. A key step in developing a vision statement is to determine the scope of what is to be managed. While this may seem trivial, it is important that the perspectives of diverse stakeholders be considered. For an FEP, a scoping check list would consist of a set of questions that are developed to ensure that there is a clear understanding of the FEP scope. Typically, a scoping check list would ask questions about what we are managing (i.e. the human components of the system) as well as what we are managing for (the desired outcomes from the system). The FAO Ecosystem Approach to Fisheries (EAF) Toolbox provides an example checklist that could be adapted by managers in the U.S. It focuses on a single fishery and includes the following categories/questions for discussion with stakeholders:

- Name of the fishery
- What fishers are included
- Fishers not included (but may impact target resources)
- Methods (gears) included
- Methods (gears) not included but impact target resources
- Main species (targets)
- Areas included
- Areas not included but impact target resources
- Values--Objectives to achieve and priority
- Primary agenc(ies)/groups--Those who have to take direct responsibility
- Other agenc(ies)/groups--Manage related aspects, but no direct responsibility
- Time frame(s)

Tools for summarizing diverse information to inform vision statements and strategic objectives

SWOT (Strength, Weakness, Opportunity, Threat) analysis is a general strategic planning tool that is often used to inform visioning and strategic objective setting. In an FEP context, it will identify strengths and weaknesses of existing management, explore realistic opportunities to improve, and threats posed by changing the management approach.

SWOT analysis is typically completed using focus groups. The aim in this context is to combine diverse information in a manner that focuses the visioning and objective setting. Naturally, SWOT analysis will build upon the conceptual model developed in the first step of the FEP and also include additional information from brainstorming and other participatory activities. SWOT can be a useful tool to highlight key attributes of the system that are within control of fishery managers, as well as opportunities and threats, which are outside their control. The highest-level concerns can then be incorporated into vision statements and strategic objectives.

Appreciative inquiry (**AI**) is an alternative to SWOT and is based on the notion that "problem solving" approaches limit discussions of novel organizational models or goals (Cooperrider et al., 2008). Rather than focusing on problems, the AI approach focuses on organizational strengths by looking at experience and its potential, with the aim of elucidating the assets and motivations that are the organization's strengths. When used for developing strategic visions or objectives in FEPs, AI would employ a three step process: 1) Identify the EBFM and management processes that work well; 2) envision a sustainable fishery system state that would work well in the future; 3) co-construct a vision of a fishery system whereby the institutional processes would support a common vision of the future.

In its implementation, the AI approach is similar to SWOT in that AI is conducted through a series of workshops with stakeholders, scientists, and managers. It differs philosophically from SWOT in that the aim is to build upon positive attributes of the system rather than to solve specific problems. As such, AI and SWOT will often lead to different visions and objectives. AI tends to lead to more evolutionary change in well-functioning institutions, while SWOT can trigger more dramatic change.

Steps 2c & 2d, Analyze risks to meeting strategic objectives and prioritize strategic objectives

What is risk analysis and how can it inform a prioritization process?

Analyzing the risks to meeting the chosen strategic objectives can inform the likelihood that one or more components of the fishery system, as measured by ecosystem and socioeconomic indicators, will reach or remain in an undesirable state (i.e., breach a reference limit). Risk analysis must explicitly consider the inevitable uncertainties involved in understanding and quantifying dynamics within and between biophysical and social systems, and the positive and negative impacts of these dynamics on social systems.

Risk analysis ideally includes pressures that occur in the social and economic realm (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 itself (e.g., shipping, naval exercises, fishing, energy extraction, aquaculture, and physical and chemical conditions) (Halpern et al., 2009). Thus, an ecosystem risk analysis requires an understanding of the distribution and intensity of socioeconomic and land-, air-, and sea-based pressures, as well as their impacts on ecosystem components. Additionally, because cumulative effects of multiple stressors may not simply equal the sum of the individual stressors' effects, risk analysis should consider cumulative impacts (Ban et al., 2010; Crain et al., 2008; Kaplan et al., 2012).

Prioritization (Step 2d) is essential because Regional Fishery Management Councils and similar 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 can prioritize their potential activities in the support of the FEP by selecting the most pertinent set of potential threats to the fishery system on which to focus, and by ranking strategic objectives to most effectively target resources in support of the FEP.

Potential criteria for ranking include status, trends, and risks. Prioritization may also consider feasibility and logistics, governance and institutional issues, stakeholder support, reversibility of threats, and the costs of implementation, management, and lack of recovery (Mace et al., 2007). Input on priorities should be gathered from stakeholders, especially during the development of the strategic objectives (Step 2b).

Best practices for risk assessment

A common way to prioritize is based on risk. A risk assessment framework can be applied to each strategic objective to identify a subset of issues for which management action is most needed and most likely to be effective. Many frameworks for assessing risk exist, and here we apply the well-accepted "ecological risk assessment for the effects of fishing" (ERAEF) framework to fisheries (Hobday et al., 2011; Smith et al., 2007). The Australian government has applied this framework to all of its fisheries and used it, for example, to prioritize the bycatch species for which mitigation measures are developed in the management plans. The framework has been described in the literature for ecological endpoints only, but it can easily be expanded to include economic and social endpoints.

ERAEF is a three-step hierarchical process that sequentially eliminates likely low-risk threats through a series of increasingly intensive risk analyses. At each level, threats that are scored as medium risk or higher are referred to either the next level of risk assessment or targeted for a risk management response (Figure 4). This risk-screening process allows rapid assessment of many potential threats and can quickly eliminate low-risk threats from further consideration. We describe the three levels of the risk assessment below.

The key idea with ERAEF is to move from a quick and qualitative initial assessment to increasingly quantitative assessments of risk. For this step in the FEP process, Councils may decide that a Level 1 assessment is sufficient to inform decisions about prioritizing issues and strategic objectives in this iteration of the FEP. Alternatively, both Levels 1 and 2 may be employed. It is unlikely at this point in the process that a Level 3, fully quantitative assessment would be used because this requires more specific objectives, such as those that would follow from the operational objectives step (step 2e). However, we describe all three levels here for completeness, and because quantitative risk assessment may be used in later steps, such as operational objective setting and management strategy evaluation (MSE) (step 3c).

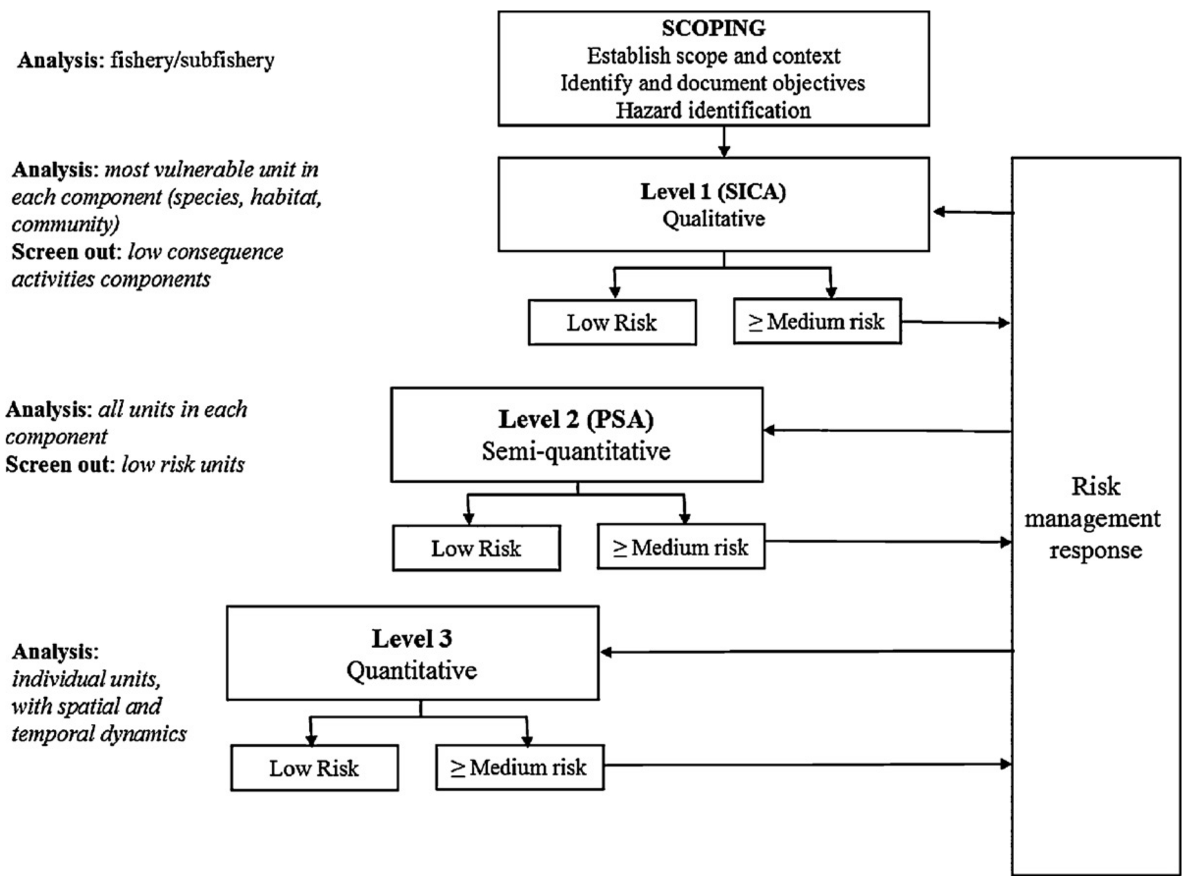

Figure 4. Ecological Risk Assessment Framework for an Australian fishery, from Hobday et al. (2011).

Level 1: Qualitative risk assessment using scale intensity consequence analysis (SICA)

A Level 1 risk assessment is generally informed by expert judgment, and should also involve stakeholders. For FEPs, this involves evaluating each threat against each strategic objective. Using expert opinion or existing literature, qualitative scores are assigned for the spatial and temporal *scale* and *intensity* of the threat, and then a *consequence* score is selected from a set of pre-determined scoring guidelines. Example consequence scoring guidelines are provided by Fletcher (2005), but these may need to be adapted for any specific application. The consequence score ranges from negligible to extreme (1 to 6). Scores that are assigned as 3 ("moderate") or higher would result in that threat-strategic objective combination being referred to a Level 2 assessment.

Level 2: Semi-quantitative risk assessment using productivity susceptibility analysis (PSA)

Productivity susceptibility analysis (PSA) is a well-accepted approach to defining vulnerability. In addition to its use for Australian fisheries, PSA is also a key step in the certification process of the Marine Stewardship Council (MSC, https://www.msc.org/), and has also been applied to evaluate the vulnerabilities of target stocks in six U.S. fisheries targeting 162 stocks (Patrick et al., 2010).

In its simplest form, PSA involves scoring each component being evaluated (e.g., a species or habitat) based on its inherent productivity and susceptibility to each threat. For individual species, productivity can be related to an intrinsic rate of population growth. For ecosystem and human dimensions, the notion of productivity can be extended to include the speed of recovery after a disturbance (Samhouri and Levin, 2012). The overall risk score is simply the combination of productivity and susceptibility, and this can be visualized as shown in Figure 5.

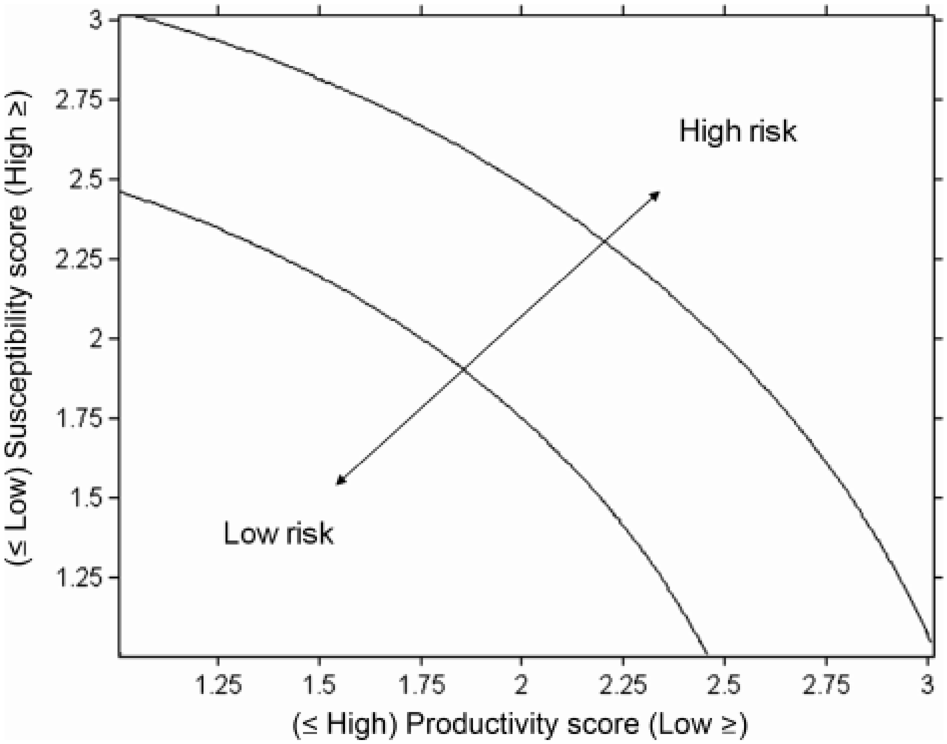

Figure 5. PSA plot shows the calculation of risk based on the combined productivity and susceptibility scores, from Smith et al. (2007).

In practice, PSA can be more or less comprehensive depending on how the scores are obtained. For example, productivity and susceptibility scores can be based on a number of attributes that are then combined to reach the final score for each. As the number of attributes increases, the requirements for data, expert opinion, and potentially resources to complete the assessment also increases. Many examples of differing levels of complexity of PSA can be found in just the aforementioned papers in this section (Hobday et al., 2011; Patrick et al., 2010; Samhouri and Levin, 2012). This flexibility makes PSA a very useful tool for risk assessment that can be adapted to data-rich and data-poor situations.

Uncertainty can be included in PSA by scoring each axis on its relative uncertainty. These uncertainty scores are one way to integrate disparate stakeholder perspectives (or difference in expert judgment) in the analysis. For example, strong disagreement about a susceptibility score for a particular combination of threat and strategic objective may result in a more conservative (higher) score.

<u>Level 3: Fully quantitative risk assessment</u>

Quantitative risk assessments are typically model-based approaches that require more data and technical expertise. In conventional management, quantitative stock assessments are risk assessments, particularly when presented in the context of a decision analysis where the likelihood of multiple outcomes is quantified. Population viability analysis is another type of quantitative risk assessment (typically applied to protected species). Ecosystem models like Ecopath with Ecosim, Atlantis, and others, are typically used for quantitative risk assessment at the scale of the ecosystem.

As we noted at the beginning of this section, Level 3 risk assessments are typically more appropriate after operational objectives have been specified.

Important considerations for risk assessment

The most important consideration in using a risk assessment framework is to choose an approach that can quickly and effectively eliminate low-risk threats from further consideration. This is a key step in reducing the complexity of fishery systems and focusing the effort of carrying out an FEP. We suggest that risk assessment for FEPs should focus on areas that are not already well-covered by conventional management—for example assessing the risk of fishing activities on their targeted stocks is an area where fisheries are already well-managed. Instead, they should focus on issues that cross multiple Fishery Management Plans, such as interacting fisheries, habitats, and human and ecological communities.

There is increasing recognition of the importance of considering cumulative impacts of multiple threats in fishery systems (Crain et al., 2008, p. 200; Kaplan et al., 2012). As recently outlined by Borja et al. (2016), existing risk assessment tools, like ERAEF and PSA, can be adapted to consider the cumulative impacts of multiple threats to strategic objectives in a fishery system.

As with all steps in the "Where are we going" component of FEPs, involving a diverse group of stakeholders will be instrumental to a successful prioritization process. Involving stakeholder input in Level 1 and 2 risk assessments, in particular, can be relatively straightforward through workshops or opportunities for public comment on risk scores.

Examples

Most of the examples we provide for applications of the ERAEF framework to fisheries focus on the threat of fishing activities on the biophysical system. For the scope of FEPs that the Task Force recommends (including human and biophysical systems), the framework will have to be adapted to include economic, social, and cultural endpoints, and the potential of threats may be more broadly defined as well.

- The Aleutian Islands FEP provides an example of a qualitative risk assessment using an approach similar to SICA above. They rated the probability of a potential interaction (or threat) occurring, and the impact of that interaction (or threat) on the biophysical system (ecosystem impact) and human system (economic impact) (NPFMC, 2007). Each threat and impact was scored as high, medium, or low. For example, one type of interaction was a change in water temperature, which they rated as “high” for probability, ecosystem impact, and economic impact. They also rated the time scale and spatial scale of each threat.

- Risk assessments have been conducted for all Australian fisheries using the ERAEF framework. Fletcher et al. (2010) provide an example of a risk assessment focused on the West Coast Bioregion, assessing risk to five high-level values and objectives that include: species sustainability, ecosystem sustainability, economic outcomes, social amenity, and social impacts. Component trees were developed through stakeholder workshops that represented the bioregion in five components: ecological assets, social outcomes, economic outcomes, institutional governance, and external drivers. Each of these components was then subjected to qualitative risk assessment using a method selected based on the data and technical expertise available. Risks were then consolidated across these assessments to create a priority score for each component of the fishery system. These priority scores were then used to inform budget planning and prioritization.
- Samhouri and Levin (2012) apply a risk assessment framework to link populations of seven different indicator species in Puget Sound to coastal activities. They describe the risk of population decline as a combination of exposure and sensitivity to an activity (analogous to susceptibility and productivity in PSA). Exposure and sensitivity were each broken down into multiple components, and the authors included uncertainty by weighting components by their data quality.

Step 2e, Develop operational objectives

Operational objectives are the translation of high priority strategic objectives into more concrete, measureable objectives (Fletcher et al., 2010; Garcia, 2003; Levin et al., 2014; Sainsbury and Sumaila, 2003). Put simply, they are statements of the specific goal of management action. To be effective, operational objectives clearly articulate the intended endpoints (or directions) or management. Defining them “…involves a relentless assault on ambiguity” (Gregory et al., 2012).

Operational objectives are not unique to EBFM or FEPs. Developing specific objectives is a common practice in fisheries planning in general, but the scope of potential topics for operational objectives is broader for EBFM than for conventional fisheries management.

Best Practices

Operational objectives should be "SMART": specific, measurable, achievable, realistic, and time-bound (Levin et al., 2014; Sainsbury et al., 2000). 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 (O'Boyle and Jamieson, 2006).

We recommend a focus on changes in the state of the fishery system (e.g., increased revenues, equity, fish biomass, ecosystem productivity, area of habitat protected) that generate benefits (e.g., greater well-being, profits, biodiversity, 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 should, to the extent possible, clearly articulate the goal (minimize, maximize, increased, reduce) that is intended for relevant management endpoints (e.g., extinction risk of a vulnerable species, sustaining traditional fisheries communities). They should be as free of value statements as possible e.g., "Improve fleet diversification" would be better written as "Increase diversification" or "Minimize risk of further reductions in fleet diversity".

Operational objectives should have the following main properties (Gregory et al., 2012):

- Complete – They describe fully the intended outcomes relevant to the strategic objective.
- Understandable – They are in plain English and jargon free, and are as unambiguous as possible so that they are understood by all people in the same way.
- Concise – Only objectives relevant to the strategic objective should be considered at this stage.
- Sensitive – They represent desired outcomes of fishery components that can be affected by management actions.

Several texts provide detailed guidance on how to best achieve these traits. Common to these are activities that elicit from stakeholders clear statements of what they want to achieve and why it is important for them (Fletcher and Bianchi, 2014; Gregory et al., 2012). Clearly, this can only be achieved with broad stakeholder participation.

Other Considerations

Operational objectives must eventually include specific targets, that quantify the desired status of the components of the fishery system (Carwardine et al., 2009; Samhouri et al., 2011, 2012). However, these can be challenging to define and do not necessarily need to be included during initial development of the operational objectives. If they are not included at this stage, they will need to be specified as reference points during Step 3a.

Because of the broad overlap between operational objective and performance indicators, these two steps can also be conducted jointly. However, care should be taken to avoid weighting distinct operational objectives at this point, and to minimize specifying a “means” as an objective. An example of specifying a “means” would be “minimize risk of irreversible harm to benthic habitat by placing 10% of habitat in a no-take reserve.” An alternative might be “minimize risk of irreversible harm to benthic habitats such that at least 10% of vulnerable habitat is not at risk from direct harm from bottom-contact fishing gears”. The second does not specify the management measure, although it does still list the specific benchmark value against which the fundamental objective “minimize risk of irreversible harm” is to be judged and achieved. What is most important in this step is to ensure that the decision-making process promotes the exploration of novel solutions to reach the fundamental objectives of stakeholders, and does not inadvertently narrow the scope of potential management strategies.

Examples

Operational objectives are already commonplace in fisheries management. For instance, rebuilding plans for overfished stocks are intended to reach a specific operational objective, of achieving a set population size by a set time frame. Moreover, the operational objective that underlies many single species management strategies is to “maintain the spawning stock at or above the level that minimizes the risk of recruitment overfishing” (Fletcher et al., 2010).

The EAF toolbox provides a number of examples of operational objectives, which in turn are based on experiences in Australia, the South Pacific, and Africa. Fletcher et al. (2010) suggested several possible operational objectives for Australian fisheries. Examples include “maintain or increase regional/local employment in the fishery and related industries” and “maintain the biomass of keystone species at levels that will ensure maintenance of their specific role in ecosystem function.”

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Implementation Volume. Step 2: “Where are we going?”

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Science tools for Step 3: "How will we get there"

The following sections provide guidance on the use of tools for component 3 of the FEP loop, "How will we get there?" We begin by making the following important notes:

- Many of the steps in our framework will require scientific inputs from models of fishery systems. Rose et al. (2015) describe several "best practices" for developing and using models for natural resources. We provide a synthesis of key concepts to improve the communication of scientific guidance for EBFM between modelers, council staff, council members, and other stakeholders (Box 1). While our framework describes distinct steps, in reality these might be conducted as a single integrated activity.
- The use of three terms—performance metrics, operational objective, and reference points—is not consistent across the decision analysis literature. We have attempted to follow the terminology commonly used in fisheries and to clarify important distinctions among terms when necessary.

Step 3a, Develop performance measures

This step of the FEP loop essentially involves describing the desired state of the fishery system, in relation to the operational objective at hand. There are two related tasks. The first is to identify attributes that matter to stakeholders. Examples might include access to fishing opportunities for cultural purposes, population status of bycatch species, economic viability of fisheries, and stock diversity by minimizing impacts to vulnerable stocks. These become performance metrics, attributes of the fishery system that tell us whether the operational objectives have been met. The second task is to set desired levels or directions of change for these performance metrics, known as reference points or reference directions. Together, the performance metrics and reference points (or directions) make up *performance measures.*

Performance measures serve two distinct purposes at this stage in the FEP process. First, they permit evaluation of alternative management action towards meeting the operational objectives. This evaluation will occur both before implementing a management strategy (MSE (see below), where the focus is

Box 1. **10 concepts to enhance the communication and interactions between ecosystem scientists and the receivers of such information, such as fisheries managers, policymakers, stakeholders, and other scientists.**

1: Tools are most useful when asked to address well-defined and specific questions.

Specificity in the question guides the choice of tools, and choosing an appropriate tool is critical to provide useful answers. Specificity in the questions fosters realistic expectations of what the analyses will deliver.

2: The selection of the specific tool used is a rational and logical process that should be part of the documentation.

No tool is ideally suited to address all questions. Decision makers should therefore expect analysts to document why the chosen tool contains the necessarily elements to address the question and what alternative tools might have been used and why were they not selected. Neither prior familiarity nor easy accessibility are valid reasons for selecting a tool.

3. Analyst judgment plays a role in EBFM tools, especially until the protocols become more standardized, and while this creates communication issues, it does not diminish the credibility of the analysis results.

The judgment of the analyst plays a large role in the selection and application details of an analysis. Many EBFM tools involve ecological and socio-economic issues that can be formulated in models in a variety of valid ways. Key decisions should be documented and rationales explained, but such reliance on judgment does not necessarily mean the generated results are automatically less credible.

4. All model-based analyses for EBFM must specify how the model forecasts are evaluated.

Use of a tool should be accompanied by clear documentation of the verification, calibration, and validation that were used. The distinction between these is described below:

Verification: "Did the model do what it was supposed to do?"
Calibration: "Fitting the model to data."
Validation: "Are the predictions robust?"

5. Careful evaluation of EBFM analyses includes understanding the hidden assumptions and the tool's domain of applicability

Modeling tools often have many hidden assumptions. Decision-makers should ask modelers whether the predictions are robust to such assumptions.

6. Distinguishing how uncertainty is considered in EBFM analyses enables proper interpretation of results for management decisions.

Uncertainty in modeling tools comes from a number of sources, from chance events, to uncertainty in model parameters, or from uncertainty in the structure of the system.

7. The terms associated with the use of EBFM tools need to be carefully defined.

As with most fields, the language of EBFM includes great deal of jargon, and the meaning of a number of common terms may vary within and among the sub-disciplines of EBFM. While some attempts at standardizing these terms continue, carefully and clearly defining terms and how they are used is a best practice.

8. Whether a tool addresses an issue and what questions can be asked of a tool is not simply determined by lists of variables and parameters.

Explicit representation (as a variable or parameter) doesn't mean that the model fully captures all of the effects of that issue. Further, a model can be used to represent an issue in an indirect way.

9. Use of multiple tools to address the same question can be a powerful way to increase confidence in results but does require careful interpretation in order for the multiple model results to be used correctly.

Clear explanation of multiple models and how independent they truly are is crucial to determine if agreement among models could be equivalent to independent pieces of evidence. Seemingly distinct models may share many key assumptions, leading to erroneous interpretation (over or under confidence) when multiple models agree or disagree. Inferences derived from multiple models can be quite powerful, but users of information derived from such efforts should take care to understand their construction, linkages and feedbacks.

10. Effective communication of EBFM tool implementation and use is time consuming but is critical for results to be properly incorporated into the management process.

As with all management efforts, many issues in EBFM arise by the challenges in communicating the methods and results to an audience with a wide range of technical knowledge. Furthermore, many of the tools are new and unfamiliar to the audience, and may be complicated. Consequently, documentation should be mostly self-sufficient, and should describe exactly the tool and the methods used in the specific application. There is no simple solution to the communication issue; but the investment in comprehensive explanation of what exactly a specific model application is computing pays off in increased transparency and focusing discussion on relevant scientific aspects of the analysis.

on choosing a strategy) and also after implementation of a strategy to judge its effectiveness and adapt management. Second, they reveal the trade-offs that managers need to confront. Because a management action might have multiple effects on the fishery system, performance metrics will span components of the fishery system directly relevant to the operational objectives, as well as additional components that are likely to be affected by the action. That is, the collection of performance metrics should generally be broader than those directly relevant to meeting the operational objectives.

Reference points are specific benchmark levels of performance metrics that are used to judge whether an operational objective was met and whether other components of the fishery system have been adversely affected (Sainsbury and Sumaila 2003). There are two main types of reference points. The first is a target reference point, which is the level of the performance metric that would indicate that the operational objective is being satisfactorily achieved. The second is a limit reference point, which is the level to be strictly avoided because crossing it greatly increases the risk of serious or irreversible harm to the fishery system.

A key point is that while performance metrics and reference points foster objective evaluation of management decisions, the process of selecting them involves both technical inputs and value judgments (Gregory et al., 2012).

Best practices for selecting performance metrics

This section gives several best practices from the literature, along with illustrative hypothetical examples.

Many practitioners of decision science and fisheries science have identified properties of good performance metrics (Jennings, 2005, Keeney and Gregory, 2005, Rice and Rochet, 2005, Gregory et al., 2012). Generally speaking, good performance metrics have the same properties as good status and trend indicators (Step 1b). That is, they should be sensitive, specific, easily understood, and measureable. However, because they are tied specifically to objectives, good performance metrics also have additional properties (from (Gregory et al., 2012)):

- Complete and concise, such that the indicators include main consequences of management that are relevant to the fisheries objectives, but are also not redundant and unnecessarily complex.
- Unambiguous, such that anyone would interpret a change in the performance metric in the same way

- Direct, such that the performance metric speaks as directly as possible to the objective, without need for inference via indirect proxies.

Performance metrics might reflect the state of one or more components of fishery system, or might reflect rate of change in these components. For example, a performance metric might be the biomass of bycatch of vulnerable species, or could be the trend in annual bycatch measured over a specified time period.

For fishery system components that are difficult to measure directly, pressure-based indicators might be appropriate as proxies. For example, if the management objective is to maintain ecological functioning of sensitive habitats from bottom-contact fishing gear, a consequence-impact assessment of bottom-contact fishing to benthic habitats (Williams et al., 2011) might be conducted regularly based on information on where the fleet is fishing, the gear that is used, and the spatial distribution of habitat types. More complex models to judge seabed impacts have also been developed and could be used to generate performance metrics (New England Fishery Management Council, 2011).

Selecting performance metrics begins with identifying candidate performance metrics. This usually requires broad input from stakeholders (Prigent et al., 2008), and requires a process so that all relevant affected components of the fishery system are adequately represented in the set of performance metrics. This step is critical to ensure that the set of performance metrics reveals trade-offs that decision-makers need to balance.

Returning to our example above—where an operational objective is to maintain ecological functioning of sensitive habitats—performance metrics would likely include exposure of vulnerable habitats to damaging gear, and managers might also consider economic and social metrics related to coastal communities dependent on fishing. If regulations are likely to lead to a change in fishing practices (e.g. locations or gear), then anticipated social, economic, and ecological consequences associated with those changes might be reflected in choice of metrics. Generally, simple conceptual models or related qualitative models of fishery systems (see above) can reveal those components that should be selected as candidate performance metrics (Prigent et al., 2008, Dambacher et al., 2009), but quantitative models can also be used (Fulton et al., 2005, Samhouri et al., 2009).

Once candidate metrics have been identified, they must be evaluated and compiled into a portfolio. This process has two components. One is technical: do the performance metrics meet the technical standards needed to be useful (Rice and Rochet, 2005)? The other component is non-technical: do they span all considerations necessary to make an informed choice (Gregory et al., 2012)?

Given the many criteria for effective performance metrics, selecting performance metrics usually involves compromises among criteria; rarely will there be a single portfolio that ideally satisfies all criteria.

Best practices for setting reference points

Once a suite of performance metrics is selected, target and/or limit reference points need to be established. Setting target and limit reference points for performance metrics in an EBFM context is a relatively new area of resource management, and few precedents have been established. In a small number of cases, targets and limits are prescribed based on legal mandates, e.g. Magnuson-Stevens Fishery Conservation and Management Act (MSA), Marine Mammal Protection Act, Endangered Species Act (ESA). For many others, there is no such technical interpretation of legal mandates to guide target or limit reference points.

This creates a difficult situation. Policymakers understandably want to use the "best available science," which in this case would mean technically based estimates of reference points. Yet, science tools will often only provide a broad range of possible targets and limits. This is partly because the high uncertainty in fishery systems limits our ability to precisely estimate reference points for fishery systems. It is also because setting reference points necessarily requires value judgments.

Here we describe several tools or approaches that can be used to set reference points. While we recognize that target and limit reference points might require distinct information, we treat them both together here to highlight the range of general approaches. Any one of these approaches may be sufficient in a given setting, and the approaches vary widely in terms of data requirements, technical capacity, and costs.

Reference points from other systems or general knowledge

Reference points can be set by borrowing on past experiences in other systems. For example, Sainsbury and Sumaila (2003) list target and limit reference levels based on "best practices" for several ecological objectives, drawing on general experience in fishery systems. Broadly applicable reference points can also come from detailed investigations of common EBFM issues. Smith et al. (2011) and Pikitch et al. (2012) reached broadly similar conclusions on ecosystem-based management of forage fish fisheries by using simulation models of food webs to forecast ecological consequences from different levels of forage fish depletion. These two studies are notable because (1) the properties and tendencies of the models used were well understood (2) multiple model types were included (3) two distinct teams used different collections of models but made similar recommendations. In other cases, investigations may be data-based. For example, McClanahan et al. (2011) used a large empirical data set to relate fish biomass density to multiple metrics of coral reef status and identified threshold levels of fish biomass density below which coral ecosystem status becomes degraded.

We recognize that all fishery systems are unique. There is a natural tendency for stakeholders to believe that these "best practice" reference points do not apply to their system. In some cases this belief is warranted. However, default recommendations that are based on a transparent process provide a starting point to guide the process of setting reference points. While highlighting unique features of fishery systems is important in this process, there also needs to be a clear standard of proof to judge whether generalized reference points do not apply or need to be seriously altered to meet objectives.

Baselines

Most commonly, baselines are used to reflect the levels that an indicator might be expected to reach in an unexploited system. Because of this framing, baselines are most commonly applied to ecological performance metrics. Importantly, the baseline is not presumed to be the target (Sainsbury and Sumaila, 2003, Samhouri et al., 2011). Rather, estimates of baseline conditions provide two things to help policy makers set targets and limits. First they reveal the full range of levels that are possible for performance metrics. Clearly, targets can't exceed baseline levels, so knowing the baseline help sharpen the decision on a range of values that is plausible. Additionally, knowing what levels are possible also reveals opportunities for improvement that might not otherwise be apparent. By the same token, they can also reveal how human activities have shaped biophysical systems and vice versa.

A common way to reveal baselines is through historical data. In some cases there are long-term records of monitoring, catch, trade records, etc. to reveal the state of system components during periods of less intense resource extraction. Alternative sources of data, such as stakeholder interviews (Beaudreau et al., 2011), restaurant menus (Levin and Dufault, 2010, Thurstan et al., 2015), and archeological records (Jackson et al., 2001) have also been used to reveal long-term change. Historical records must be interpreted cautiously, since historical levels may not be representative of current baseline levels due to changes in climate or other broad-scale drivers.

Cross-site comparisons also can inform baselines. A typical approach is to identify portions of the fishery system that are thought to reflect "baseline" conditions, such as areas with some sort of historical protection from human activities.

Reference Directions

In many cases, it may not be possible to reach any reasonable degree of agreement on a preferred value that a performance metric should reach. In these same cases, there could be broad agreement on the direction of change that is preferred. In these cases, reference directions can be used instead of reference points (Link et al., 2002, Trenkel and Rochet, 2003, Jennings, 2005, Samhouri et al., 2011). For example, a reference direction might be "to stop or reduce the rate at which quota is consolidated in a fishing fleet" without specifying the level of quota allocation that one seeks to achieve. Reference directions should generally specify some minimum or maximum rate of change in a performance metric that would be deemed acceptable. Moreover, reference directions should have a clearly specified time horizon for when the preferred change occur. A natural choice is to define the time period as the life cycle of the FEP, so that the next iteration of the FEP can revisit the reference point with the benefit of improved understanding. In some cases, this new understanding might lead stakeholders to conclude that the performance metric has reached the desired level.

Stakeholder consultation

Because target reference points reveal the preferred state of the fishery system, one natural way to judge stakeholder preferences is to ask them in a structured way. One common approach that is used in several fields is social norm mapping (Manning, 2013). A norm is a group's belief of what is acceptable. Norms are distinct from attitudes and stated preferences, because they derive from cultural rules that drive behavior and imply a sense of obligation. Social norm maps show the levels of performance metrics that are deemed desirable and acceptable by a group (Manning, 2013), where the "group" is the collection of stakeholders in a fishery. These maps are typically derived via surveys that pose alternative states of performance metrics, and ask stakeholders to rate the degree of acceptability of each state. For example, Smyth et al. (2007) used normative theory to judge acceptable levels for several performance indicators for Lake Champlain. This exercise revealed that stakeholders had much stronger views on some performance metrics than others, and identified ranges of values that stakeholders deemed acceptable. Clearly, target reference points should be within the range of levels deemed acceptable.

Quantitative Analysis

Data and model results from the fishery system can directly inform reference points. Because limit reference points deal with risk of serious or irreversible harm, they involve somewhat less subjective input than target reference points (the preferred level of a performance metric). For that reason, we focus on quantitative tools to inform setting of limit reference points, with an eye towards characterizing risk and avoiding crossing thresholds (tipping points) beyond which recovery is difficult.

Thresholds are often defined as non-linear response of a performance metric to some pressure. Well-known examples derive from toxicology, where the effect of a chemical on an organism is related to the exposure concentration, usually showing a sharp threshold values below which there is little effect and above which effects increase markedly. Similar threshold type behavior can be present for other pressure-state linkages. Time series analysis (Sugihara et al., 2012) and non-linear model fitting to cross-site comparison or time series (e.g. Daskalov et al., 2007, Oguz and Gilbert, 2007) can test for these thresholds. In a single-species context, there is a rich literature on population viability analyses that seeks to define threshold population sizes below which extinction risk is greatly elevated due to chance events or due to Allee effects (Morris and Doak, 2002). This approach is already commonly used for protected species that are incidentally captured in fishing gear. Finally, simulation models of fishery systems can reveal possible thresholds that result from interactions among system components (Walters and Kitchell, 2001).

Examples

Performance metrics are already widely used in conventional fisheries management. For example, fishery Councils indicate their performance in part by reporting on the proportion of stocks that are overfished or currently experiencing overfishing. This performance metric is based on attributes of the fishery system (population size and fishing rate) relative to limit reference points.

More recently, broad fishery system performance metrics have been developed that span the "triple bottom line" of ecological, economic and social sustainability (Anderson et al. 2015). However, these were not necessarily tied to specific operational objectives of the regional fishery management body, but rather broader visions for fisheries management as defined by international organizations. That said, the performance metrics themselves imply some operational objectives, and many of the components of the "triple bottom line" indicators could be applied to evaluate progress towards a specific operational objective. Recently, the Northeast Fishery Science Center developed a suite of social and economic performance metrics, in this case to judge the consequence of implementing catch share (sector) programs in the groundfish fishery (Clay et al., 2014). This example is notable in that the performance metrics were based directly on the management objectives (stated in Amendment 16 of the Multispecies Groundfish Fishery Management Plan), and selection of performance metrics involved broad stakeholder participation, including regional NOAA staff and scientists, industry leaders, members of fishery management councils, and academic scientists.

Fulton et al. (2014) describe a comprehensive comparison of several management frameworks relative to a lengthy set of management objectives that span ecological, economic, and social dimensions in the southeast Australian shark and scalefish fishery. Many of these were conceptual rather than operational objectives, but nevertheless these were operationalized through the selection of 33 performance metrics against which the costs and benefits of the alternative management frameworks could be identified. These performance metrics were identified based on an iterative consultation process with a broad range of stakeholders.

In the above examples, there were few attempts to identify reference points, but implied reference directions were clear. In the New England groundfish example, preferred directions of change of social indicators are obvious. For instance, metrics such as "costs to participate in management", and "number of fishery-related injuries" have a clear reference direction (to be as low as possible), and evaluating alternative policies does not require comparison to a specific target level.

Step 3b, Identify Potential Management Strategies

In this step, managers and stakeholders identify possible management actions and formulate them into management strategies. A management strategy is a pathway to reach target reference points and avoid limit reference points, thereby achieving operational objectives. A management strategy consists of a comprehensive set of actions (regulatory or scientific, see Chapter 3) that are taken in response to the changing state of the fishery system. Management actions may be either regulatory (e.g. to change allowable gears, target species, seasons, or closed areas) or scientific (e.g. to resolve a key question or improve the assessment of important system components).

A strength of single-species management in the U.S. is that when system moves past reference points, pre-determined management actions are triggered (NRC 2014). We recommend extending this to FEPs by identifying and evaluating potential management strategies in advance of crossing an FEP reference point.

The goal of this stage of the FEP development process is to identify multiple candidate management strategies, whose likely performance can then be evaluated. Devising multiple distinct alternative strategies is important for a number of reasons (Gregory et al., 2012):

1. Exploration of many possible alternatives is more likely to identify novel, creative strategies.

2. Decision-making is easier and more accurately reflects preferences when posed as a selection among alternatives (Hsee 1996).

3. Thorough exploration of alternatives dispels the notion of a "silver bullet" solution that will avoid hard choices.

Research and past experience have revealed several ways to facilitate management strategy development, but all involve engagement with stakeholders, policy makers and scientists.

The evaluation of alternative management strategies is the key step (see below) that reveals trade-offs, making them tangible and explicit.

Best practices for devising alternative management strategies

Involving a diversity of stakeholders in the FEP process can help identify a wider range of possible alternatives, allowing for a more thorough exploration of possible management strategies. At the same time, diversity of stakeholders can also constrain the set of candidate alternatives to those that are actually plausible and feasible (Fulton et al., 2014).

Because the goal is to find a wide range of distinct strategies, it is important to overcome the tendency to make minor adjustments to existing strategies. One way to foster this exploration is by taking each performance metric and asking stakeholders to imagine strategies that would be most effective at reaching the performance metric target (Gregory et al., 2012). These "bookend" strategies will not likely be adopted, or even evaluated, but they encourage stakeholders to think more broadly beyond current management.

The process needs to maintain focus on the different ways to reach the objectives, as explicitly codified by the performance metrics and reference points.

It is advisable to include in the set of alternatives a reference strategy, such as the status quo. This allows the MSE process to assess improvements from current conditions that the alternative strategies can provide, and also to identify where things may get worse.

To the extent possible, proposed management strategies should be adaptive (i.e., the decisions taken will change as the perceived state of the system changes). Adaptive strategies are common in conventional fisheries management, where harvest control rules are used to set annual catch limits based on estimated population abundance. In an FEP context, one needs to identify fishery system metrics (possibly performance metrics, but not necessarily) upon which management response will be based, the levels of these metrics that trigger the response, and the management response that is to be taken. The trigger reference points – levels of the fishery system metrics that trigger some change in management action – should be chosen to ensure that the performance metrics reach targets and avoid limits.

Other Considerations

The development and evaluation of alternative strategies is often an iterative process where the initial evaluation of alternate strategies leads to suggestions for adjustments to them (Gregory et al., 2012, Fulton et al., 2013, Fulton et al., 2014). This requires sustained engagement, so it is important that there are sufficient resources available to support this engagement (Fulton et al., 2013).

Fishery indicators that trigger management response should ideally be leading, not lagging indicators of system status. They should also be readily measurable on time frames relevant to management decisions. For these reasons, the indicators used in the adaptive management strategy may not be among the performance metrics.

Examples: Policy instruments for management strategies

The process of identifying alternative management strategies occurs commonly but is rarely documented in a formal way. This makes it difficult to gather examples of this process in action. We focus instead on policy instruments that might be used as part of management strategies. Specifically, we find that there are a suite of fishery management instruments that are currently being utilized in conventional fishery management, which are also potential tools in the EBFM regulatory toolkit (Table 1).

Table 1. Examples of policy instruments organized by EBFM management issue.

	Examples of instruments	Fishery example
Climate & Environmental Variability		
	Harvest control rule based on climate conditions	Sardines in the California Current, West Coast of U.S.
Community well-being		
	Community development quota (CDQ)	Bering Sea pollock, groundfish, halibut
	Community Equity Program	Alaska halibut and sablefish fishery
	Restrictions on trading in catch shares systems	Alaska halibut and sablefish fishery
	Disaster relief	New England cod fishery
Conservation of forage fish		
	Retention limits	ALL FMP forage fish - Bering Sea Aleutian Islands
	Restrictions on end use (product types)	ALL FMP forage fish - Bering Sea Aleutian Islands
	Harvest Control Rules	Southern Ocean krill; Barents Sea capelin
Habitat Protection and Restoration		
	Essential Fish Habitat designations	New England, Deep-water corals off of Mid-Atlantic
	Time/area closures	Alaska Coral Gardens
Optimizing Returns from system		
	Mesh size restrictions	Australia: Southern and Eastern Scalefish and Shark Fishery, targeting a wide range of demersal species
	Quota baskets in catch share programs	New Zealand
	Species quota	Iceland

	exchanges	
	Deemed values	New Zealand
	Mixed species exemption	U.S. Fishery policy
	Cap on all catch in ecosystem	Bering Sea cap
	Territorial use rights (TURFs)	Chile: Loco fisheries, Japan
	Cooperatives/Sector-based	New England groundfish fishery
Protected Species bycatch (includes marine mammals and shorebirds plus prohibited species)		
	Vessel bycatch quotas	New Zealand; Eastern Pacific tuna fishery
	Risk pools	US West Coast sablefish fishery
	Fleet-wide mortality quota	US Alaska groundfish and short-tailed albatross
	Move on rules	Southeast Australia: Small Pelagic Fishery targeting sardine, jack mackerel, etc.; Northeast U.S.: mackerel fishery (river herring bycatch)

We elaborate on specific examples below.

Harvest control rule based on climate conditions. The biological productivity of many fish stocks depends on environmental and climatic conditions. Management of the Pacific Sardine fishery in the California Current incorporated environmental/climate factors directly into a harvest control rule. In particular, the Council utilized sea surface temperature (SST) to determine the fishing mortality in the harvest control rule and in setting biological reference points (Pacific Fishery Management Council, 2011).

Conservation of forage fish. A key component in implementing EBFM is addressing forage fish management (Smith et al., 2011; Pikitch et al., 2012). Councils manage forage fish stocks to protect prey of multiple upper trophic predators including predatory fish, seabirds, and mammals. The NPFMC, for example, prohibits the targeting of forage fish (50+ species, including eulachon, capelin, sand lance, sandfish, krill) and discourages their retention by limiting the end-product types (and therefore economic return) of the fish in the Bering Sea, Aleutian Islands, and Gulf of Alaska. Specifically, retained bycatch of forage fish can only be processed into fishmeal. In other jurisdictions, modifications to single-species control rules have also been used for Southern Ocean krill and Barents Sea capelin to adjust annual harvests levels such that sufficient prey are available for predators (Sainsbury et al., 2000, ICES 2014)

Mixed-stock exemption. A significant motivation for EBFM is the notion that overall productivity of the ecosystem both from a conservation and exploitation perspective can be increased by adjusting the relative catch rates of species to better balance fishing pressure with the productivity of stocks. The requirement under MSA that no fish stock can experience overfishing does include an exemption for mixed-stock fisheries. While in general the overfishing limit is an important benchmark, it does constrain the set of feasible EBFM actions that a Council can undertake. This is especially true in mixed-species fisheries, where it might be beneficial for the recovery of stock X if the council permitted overfishing to occur on fish stock Y for a number of years. Under the mixed-stock exemption, this type of overfishing can be permitted if the council can demonstrate the benefits and that the overfishing will not result in an overfished status that triggers protection under ESA (NRC, 2014). According to the a 2014 National Research Council report (NRC, 2014) on rebuilding, “the Mixed-Stock Exemption has not been invoked, in part due to the narrow range of situations to which it applies under the [MSA]."

Species quota exchanges. The selectivity of fishing gear and the difficulty of matching catches with catch limits, both at the vessel and sector level and to limit targeting on certain age/size classes, are long-standing challenges in fishery management. This is especially true with EBFM, where these cross-sector and fishery issues come to the fore. One instrument that helps fishermen match catches with quota is species quota exchanges, which have been used in fisheries in New Zealand, Canada, and Iceland (Sanchirico et al., 2006). Under Iceland’s catch share program, quota shares are put into “cod equivalents” that allows quota owners to convert cod quota to other demersal species and make conversions among those other species. The program also puts restrictions on these exchanges. For example, demersal species other than cod cannot be converted into cod, owners cannot convert more than five percent of their total quota in any given year into ‘‘cod equivalent’’ units, and no more than two percent of their quota can be converted into any one species. These restrictions attempt to reduce the possibility for large overruns of total allowable catch in any given year. Nova Scotia used a similar exchange in the mobile gear groundfish catch share program but discontinued it after only a couple of years due to the management costs and concerns on overruns (Sanchirico et al., 2006). The management costs for these types of real-time management systems have gone down over time with technological advances (e.g., computer log books, online accounting of catches, quota balances, etc.).

Addressing bycatch of protected species: technology and location restrictions. Commercial fishing has both indirect effects on protected species, via food webs, and direct interactions through bycatch and gear entanglement. The indirect interactions are addressed to some extent with forage fish conservation measures and habitat protections. In terms of the direct interactions, there are many examples of restrictions on fishing technology and location. For example, in the northeast Atlantic, regulations require the connections between lobster traps and buoys to snap under pressure to reduce the entanglements of the ESA-listed right whales. In the Puget Sound, there are depth restrictions (120 feet) for salmon recreational fishing to reduce the bycatch on ESA-listed (threatened) Yelloweye rockfish. Fishery managers also employ move on rules, where areas are closed to a fishery when reports of catches with significant shares of protected species (e.g., river herring bycatch in the mackerel fishery) and or to avoid localized depletion of prey fields (e.g., southeast Australia sardine and jack mackerel fisheries). Similar management is also used in the conservation of the endangered right whales in the northeast Atlantic.

Risk pools. While regulators can impose dynamic area restrictions, there are also cases where fishermen have developed their own collaborative programs to manage bycatch with protected and prohibited species. For example, in the West Coast groundfish catch share, fishermen developed risk pools where they pool their quota on "weak" stocks in mixed fisheries to better able them to address the risk associated with one bad trawl that could shut the season down for them and potential others (Holland, 2010, Holland and Jannot, 2012). In Alaska, organizations such as Sea State have formed to provide real-time information to fishermen to avoid areas where fishermen are catching higher than expected levels of prohibited species (Abbott and Wilen, 2009).

Community development quotas. Achieving the triple bottom line of EBFM requires the use of socioeconomic policy instruments as part of the toolkit. Considering these tools as essential parts of EBFM has for the most part been superseded by the focus on setting allowable catch limits and meeting National Standard 1. The next generation FEPs, however, will bring the social and economic issues to the fore. Therefore the use of instruments to minimize adverse community impacts or consider the role of efficiency has an important role to play in implementing EBFM. One instrument used to address community access to resources is *community development quotas* (CDQs). In remote portions of western Alaska, 65 communities were granted the rights to a portion of the total allowable catches for halibut, sablefish, and pollock. CDQs have been shown to sustain fisheries investment in rural communities, increase local participation, lead to poverty alleviation, and, for remote and isolated communities, can be a significant driver of economic growth.

Restrictions on trading in catch shares systems. Another instrument utilized to address community access to fishery resources is participation *restrictions in catch share programs* (vessels, sectors) and in *trading restrictions* in programs that permit trading of quota. For example, the rationale for including restrictions in the Alaskan Halibut and Sablefish individual quota program in 1995 was to preserve the small-scale, owner-operated character of the fishery and to further engineer the potential distributional outcomes associated with capacity reduction in individual transferable quota (ITQ) systems. Specific restrictions in Halibut and Sablefish include quota linked to vessel size classes and areas, limits exist on corporate ownership and consolidation and divisibility, and there are provisions requiring quota owners to be on board the vessel during fishing operations. While there are potential social benefits from these restrictions, there is also a potential cost to society in terms of the reduction in the economic gains from the fishery. A recent study, for example, estimated the long-run costs of the restrictions in the Halibut and Sablefish program at 25 percent and 9 percent, respectively (Kroetz et al. 2015).

Important considerations

Here we highlighted that there are many examples of single-species management employing instruments that have or can have beneficial ecosystem impacts. At the same time, there are also instances where current conventional management approaches impact negatively on the ability to achieve the optimized returns from ecosystems. In some cases, conventional management has resulted in the "institutionalization" of specialization in fishing operations. The specialization results from the unit of management for most fishery allocation decisions in the United States being a fishing sector defined by gear and fish stock in a specific region (Kasperski and Holland, 2013, NRC, 2014). The allocation to sectors, such as the fixed gear or the hook and line, often prohibit fishermen to switch between gear types. For example, a trawler might decide that it would be more profitable to fish its allocation with fixed gear but is not permitted to switch even though there might be positive ecological benefits beyond their own economic returns. Such a restriction was in place before the west coast Sablefish fishery moved to a catch share program that permitted fishermen to use trawl allocated catch in the fixed gear fishery if they found it profitable to do so (Kroetz and

Sanchirico, 2010). Since the mid-1980s, New Zealand fishery management has also permitted fishermen to determine the most profitable method of fishing subject of course to restrictions that guarantee that the habitats are conserved (Newell et al., 2005)

Step 3c, Evaluate consequences of alternative management actions

With management alternatives in hand, a formal analysis of policy options can occur. Management Strategy Evaluation (MSE) (Smith, 1994) is a commonly used policy analysis approach in fisheries and can be used to assess the strengths and weaknesses of different management options. Punt et al. (2014) provide a review of best practices for MSE and Plagányi (2007) and Rose et al. (2015) give best practices for using ecological models for MSE and EBFM generally. Many Councils are familiar with the process in the single-species context in terms of testing harvest control rules and stock assessment methods against single species management objectives.

MSE tests the utility of management strategies and decision rules by evaluating a range of management scenarios using multiple indicators to assess their performance (and potentially multiple operating models). Importantly, the objective of formal MSE is not optimality. Rather, it screens out poorly performing management strategies and identifies approaches that are robust to various types of uncertainty. There is unlikely to be a 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. It also incorporates a number of important features that make it an ideal supporting process for FEPs (Sainsbury et al., 2000), including:

1) Performance metrics can be evaluated quantitatively 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.

What is management strategy evaluation and what tools are used?

Tools to evaluate alternative management strategies and actions fall into the broad class of decision support tools. The tool most widely used for this purpose in fisheries management is MSE. Other related approaches include cost benefit analysis (CBA) and multi-criteria decision analysis (MCDA).

MSE has been succinctly summarised as "assessing the consequences of a range of management strategies or options and presenting the results in a way that lays bare the trade-offs in performance across a range of management objectives" (Smith, 1994). Initial steps include identifying objectives, performance measures, and alternative strategies or management actions, all of which will have been completed given the process outlined in Chapter 3 using the tools previously described in this chapter. The next step is to predict the consequences of applying each alternative strategy under consideration, where the consequences are quantified using the performance metrics. Methods to make such predictions are described further below. The final step is to communicate the results as a "decision table," where the rows constitute the set of alternative management strategies and the columns represent the performance metrics (relating to the various objectives). An important additional element in MSE is to consider the uncertainty in making the predictions, and to represent that uncertainty either directly in the performance metrics, or as a third dimension in the decision table.

The most technically difficult step in the process is to be able to predict the future consequences of adopting each alternative management strategy. This is particularly difficult where the strategy being considered is itself adaptive (the decisions taken will change as the perceived state of the system changes). Adaptive management strategies involve the three elements of monitoring, periodic assessment of changing system status using information from the monitoring, and the application of decision rules based on the estimated status. MSE to evaluate adaptive management strategies then requires the ability to predict not only future states of the fishery system as a consequence of management actions, but also how those future states will be estimated based on future monitoring and assessments.

Use of MSE is widespread in single species fisheries management (Punt et al., 2014) and has been proposed to support EBFM (Sainsbury et al., 2000). Most MSE is highly quantitative and involves use of simulation models to make the predictions. Such methods are highly technical and, for many applications in EBFM, require the use of ecosystem models of various levels of complexity. While there have been rapid developments in the use of such models recently, whether they are fit for purpose needs to be decided case by case (Plagányi, 2007). Simpler models have also been used (Plagányi et al., 2014) and can be more readily verified. Very simple qualitative models are also seeing increasing use (Hosack et al., 2008, Dambacher et al., 2009)), while predictions based on expert judgement have also been used in some instances to good effect (Smith et al., 2004).

It is important to recognize that MSE does not define “optimal” strategies as this choice would depend on weightings across all objectives, which in any case will differ widely among different stakeholders. However MSE can help identify clearly sub-optimal strategies, that is, ones for which better strategies exist no matter which objective or performance measure is considered.

In addition to MSE, there are a variety of approaches used to integrate social and economic insights into management evaluation, such as cost-benefit analysis, cost-effectiveness, economic impact, and multi-attribute utility theory (for more discussion see, Holland et al. (2010). Cost benefit analysis (CBA) involves either comprehensive or partial assessments of the economic benefits and costs of projects or policies. CBA can both incorporate information on economic values expressed in markets, such as fishing revenues and costs, but can also include values associated with goods and services not traded in markets, such as values associated with marine mammal populations (Lew, 2015). While CBA is used to help identify management outcomes that offer the greatest net social benefit to society, a regional council fishery management council might be interested in elucidating trade-offs in cases where desired outcomes have already been determined. Such approaches, called cost-effectiveness analysis (CEA), can help determine the most efficient means of achieving specified management goals in cases where these goals are predetermined by legislation, prior consensus, or other means. CEA can also provide insight on the costs of obtaining various management outcomes in cases where the information necessary to determine all of the economics benefits of these outcomes is unavailable. Regional economic modelling, or economic impact analysis, measures changes in economic activity or indicators (e.g., regional income, gross value of landings, workers employed, gross expenditures, multipliers) related to monetary flows between economic sectors. These flows, while providing insight into the raw quantity of economic activity within a given region, are not necessarily related to changes in economic benefits or costs. As such, care should be taken in how to interpret the signals provided by metrics. Another approach is multi-attribute utility theory, which is a cousin of CBA and MSE, in that it is designed to allow assessment policies such as EBFM in which multiple attributes are affected. It is more similar to CBA than MSE, however, because it attempts to estimate a single cardinal “value” whereby policies may be ranked. However, unlike CBA, the “weights” or relative importance given to each policy attribute are not determined by economic value. Instead, the weights are generally defined by decision makers, policy experts, or analysts.

Best practices

Plagányi (2007) identified best practice approaches to use of ecosystem models to address issues in EBFM. A broad range of model types was considered, including whole of ecosystem models, minimum realistic models, individual-based models, and bioenergetics models. The analysis included their strengths and weaknesses, and the types of uses to which they are best suited, including for evaluating management strategies (MSE). No one modelling approach was found to be superior across all types of applications, and specific guidance is provided for model selection to address various issues in EBFM.

Punt et al. (2014) provide a recent review of best practice approaches for MSE. This includes advice on selecting performance measures, dealing with uncertainty, identifying candidate management strategies, simulating the application of management strategies, presenting results, and selecting a management strategy.

Important considerations

An important consideration in MSE analysis is the adequate representation of uncertainty. This is important when evaluating single species harvest strategies (Butterworth and Punt, 1999) and is just as important but more challenging for applications in EBFM. In using models to predict the consequences of management actions, various sources of uncertainty need to be considered, including structural uncertainty (model selection and key assumptions), parameter uncertainty (ecosystem models typically have a large number of parameters, many of them difficult to estimate), and management implementation uncertainty (responses to management interventions or regulations do not always go according to plan). Given that EBFM focuses on coupled biophysical and socio-economic systems, sources of uncertainty about both ecosystem dynamics and human behaviour are important to capture. In particular, uncertainty about human behaviour and responses has been highlighted as an important and somewhat neglected issue (Fulton et al., 2011).

Examples

There is increasing use of MSE, particularly involving use of ecosystem models to predict the consequences of management actions, in evaluating options for implementing EBFM. Some analyses have been used to identify generic classes of management strategies for particular types of problem, for example for management of forage fish while avoiding undue impacts on predators (Smith et al., 2011, Pikitch et al., 2012). In other cases, the tools have been used to address problems specific to a particular fishery (Plagányi et al., 2013, Fulton et al., 2014).

MSE has been used to evaluate and help design the harvest strategy for the Pacific sardine fishery for the Pacific Fishery Management Council (Hurtado-Ferro and Punt, 2014). This harvest strategy uses environmental data directly in the harvest control rule to modify harvest rates from 5 percent to 15 percent as stock productivity changes under varying environmental conditions (changes in water temperature). The strategy also involves the selection of a cut-off level of biomass below which no fishing takes place. This is implemented to achieve EBFM goals related to impacts on dependent species.

MSE has seen fairly wide use in Australia to address EBFM issues. Three of these have been at “whole of fishery” level, helping to identify broad strategies to deliver EBFM outcomes across a range of ecological, economic and social objectives. The first of these occurred in a complex multi-species, multi-fleet fishery in south eastern Australia, and involved the use of both expert opinion and ecosystem modelling (using the Atlantis modelling framework) to predict the consequences of broad combinations of management tools including quotas, effort controls, gear controls and spatial management (Fulton et al., 2014). This resulted in substantial changes to the way this fishery was managed, although FEPs are not used in Australian fisheries so that the changes were adopted within existing management arrangements.

The second Australian example involved a tropical rock lobster fishery in the Torres Strait in northern Australia, involving both commercial and indigenous fishing (Plagányi et al., 2013). Predicting the consequences of alternative approaches to managing this fishery involved combining a spatial biological model with a bio-economic model and a semi-quantitative Bayesian Network model. Management strategies included various combinations of fleet-wide quotas, individual transferable quotas, and community quotas. Performance was evaluated against a broad set of ecological, economic and social performance measures, with the social objectives varying greatly between indigenous and commercial fishers. The analysis highlighted the trade-offs and conflicts in satisfying the needs of both sectors.

The third Australian example focused on a tropical prawn fishery, in the Gulf of Carpentaria (Dichmont et al., 2013). In this case, a hybrid model was used for the simulations, making use of pre-existing models developed for the prawn fishery itself (including simulating the dynamics of the fishing fleet), an ecosystem model (Ecosim), and a habitat impact model, all feeding into an ecological risk assessment model. The strategies evaluated included the use of marine spatial closures to help meet conservation as well as fishery management objectives.

Step 3d, Select management strategy

Based on these analyses, managers can select a management strategy for implementation. In the context of the FEP, a management strategy will consist of both the management actions to be implemented (e.g., a 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. The latter is a simple extension of single-species approaches, whereby crossing a reference limit triggers an action to avoid risk to the long-term sustainability of the stock.

This step involves a policy choice rather than a scientific or evaluation process, and so we provide no technical guidance.

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Science tools for Step 4: "Implement the Plan" and Step 5: "Did we make it?"

Step 4. Implement the Plan.

The implementation of the FEP transforms all the work described above into accomplishments through tangible work projects. Here, we consider FEP *projects* as an interrelated group of activities needed to achieve an operational objective (Meffe et al., 2002). Projects in an FEP are explicit and ideally answer the following questions:

- 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 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?
- What are the project outputs?
- How will outputs of FEPs link to Fishery Management Plans (FMPs)?

The answers to these questions allow managers to prioritize based on the value of each activity to the mission and its cost.

Types of projects that would be appropriate to an FEP include:

- Modeling exercises intended to examine trade-offs among ecological, social, and economic endpoints
- Indicator development activities to ensure indicators are sensitive to management actions
- Surveys to illuminate the impact of alternative management strategies on coastal communities
- Ecosystem monitoring to evaluate how management strategies influence ecosystem properties and dynamics

For each project, and for the FEP as a whole, we recommend a formal work plan that describes the project, the resources needed, the outputs and the timeline.

Step 5. Did we make it?

Monitoring and evaluation of chosen indicators and management strategies is an integral part of the FEP process. Monitoring and evaluation is necessary to assess the status of the fishery system, to determine whether management strategies are meeting their goals, and to reveal the trade-offs that have occurred since implementation of the management strategy.

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 reliably answer clearly articulated management questions (Katz, 2013). In the case of FEPs, monitoring of the general system status and performance indicators must be sufficient to (a) determine fishery system status and (b) assess whether the operational objectives developed as part of the FEP process have been achieved. While apparently 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.

Two types of monitoring are particularly important to FEPs:

Effectiveness monitoring is used to evaluate whether specific management actions had the desired effect on the system component that is directly targeted by the management action. It links threat reduction to changes in the status of the fishery system components that are specified in the operational objectives.

Trend monitoring is a systematic series of observations over time for the purpose of detecting change in the state of the fishery system (Metcalf et al., 2008). It is directly tied to the initial "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 Chapter 3, Figure 3.1 as a return from step 5 to step 3.) Typically, trend monitoring is not used to evaluate management actions, although some indicators may prove useful for this.

A final and related issue that informs effectiveness and trend monitoring is attribution – to what extent was the change in fishery system attributable to the management action. It is important that this question be asked in advance of developing monitoring programs so that attribution can be evaluated.

For example, in order to achieve an increase in recruitment, managers might attempt to restore nursery habitat via spatial restriction of trawling. Effectiveness monitoring would then focus on the changes in habitat targeted by the management action. In trend monitoring, one might monitor the biomass or recruitment of a fish species or fishing revenues. Attribution measures the extent to which the change in habitat was due to the management action, and the extent to which changes in biomass or recruitment is due to the change in habitat. This attribution will require thoughtful design of monitoring (what to monitor, how frequently, at what scale) by anticipating the challenges in attributing cause-effect caused by confounding variables.

Importantly, monitoring not only includes measurements of the biophysical environment, but also includes social and economic systems. McLeod and Leslie (2009) suggest that socioeconomic monitoring can enhance the ability of managers to:

- Estimate how coastal management is contributing to community development
- Value marine resources from ecosystem services and cultural and economic significance
- Measure people's support for various management actions including conservation
- Facilitate stakeholder involvement by gaining greater understanding of perceptions
- Tailor management to local conditions by developing education programs based on community understanding of resource conditions and threats

We recommend that FEPs include a project on monitoring and evaluation.

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