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BUILDING EFFECTIVE FISHERY ECOSYSTEM PLANS

A REPORT FROM THE LENFEST FISHERY ECOSYSTEM TASK FORCE

CONTENTS

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PREFACE

PREFACE

Connections matter. That is the unifying principle of ecosystem-based fisheries management (EBFM). Ecological connections matter because fishing affects target species, predators, prey, competitors, bycatch species, and habitat. Economic connections matter because management affects fishermen, wholesalers, retailers, and recreational fishing guides. And social connections matter because fishing supports families and communities.

U.S. fisheries management has made tremendous strides under the current management framework, which centers on single stocks or stock complexes rather than ecosystems. Since reforms in 1996, the number of overfished stocks has declined dramatically, from 86 to 38, and the number of stocks subject to overfishing has plunged from 72 to 28. In addition, fishermen, managers, and many others have cooperated to reduce bycatch, conserve habitats, and improve the equity and safety of fisheries.

However, conventional management has certain limitations. It generally focuses on one fishing sector at a time, which may unexpectedly lead to worse outcomes in another sector. It often considers a narrow range of issues, potentially overlooking other factors that shape fishery systems, such as loss of habitat and the behavior of people and markets. And fundamentally, the current system is atomized into individual fishery management plans (FMPs), often leaving little opportunity to consider overarching management goals or the trade-offs across fisheries that attend almost every decision.

EBFM provides mechanisms to address these issues and many others. Yet despite this, and despite many other reports and studies that have made the case for EBFM, it has not been widely adopted. We believe a major reason is that there is no clear way to put its principles into practice.

The purpose of this report is to offer a blueprint for Fishery Ecosystem Plans (FEPs) as a means to translate EBFM into action. FEPs have been proposed for this purpose before, and most U.S. Regional Fishery Management Councils have since either started or completed an FEP. But these plans often focus on system description rather than management action.

We are proposing a next generation of FEPs that focus on action. We envision FEPs as a structured planning process that uses adaptive management to operationalize EBFM. This process starts by identifying the key factors that shape a fishery system and considering them simultaneously, as a coherent whole. It then helps managers and stakeholders delineate their overarching goals for the system and refine them into specific, realistic projects. And it charts a course forward with a set of management actions that work in concert to achieve the highest-priority objectives.

This report contains no new science or policy innovations. This is because we have found – through deliberation, document review, and conversations with managers and stakeholders – that EBFM is feasible today using existing science tools, policy instruments, and management structures. Not only that, nearly all of the steps in our process are already being carried out by U.S. fishery managers.

A key element of our approach is the inclusion of humans as part of the ecosystem. This is simply a practical recognition that fisheries management is about managing people for purposes that are defined by people. In our view, EBFM is not about putting nature before humans, any more than conventional management is about putting humans before nature. Rather, EBFM offers a framework for the deliberate, transparent consideration of all relevant scientific evidence and stakeholder goals.

OUR MISSION

The Lenfest Fishery Ecosystem Task Force, convened with support from the Lenfest Ocean Program, consists of 14 researchers pre-eminent in the sciences that support fisheries management. The purpose of the Task Force was to provide a blueprint for FEPs, with the goal of providing guidance to managers on implementing EBFM. The Task Force charge focused on answering three questions: (1) What are the key principles of EBFM that should be included in an FEP, and what is the current status of fisheries ecosystem planning that incorporate these principles? (2) What are the gaps between scientific knowledge and planning? and (3) What are new approaches that can be used to fill these gaps?

TASK FORCE PROCESS

Because the goal of our process was to develop guidance for managers that would be used to influence future decisions about EBFM, it was imperative to the Task Force process that we hear directly from diverse viewpoints on experiences with EBFM. We engaged with stakeholders, managers, and other decision-makers through regional workshops and by convening an advisory panel to help guide our efforts.

Workshops

We convened workshops around the U.S. to hear regional perspectives on EBFM from scientists, managers, and representatives from commercial and industrial fisheries and environmental NGOs. We met in Seattle; New Orleans; Portland, Maine; and Baltimore. At each meeting we invited individuals to share their experiences with EBFM in their region and had candid discussions about EBFM progress, hurdles, and potential next steps. These conversations were invaluable in shaping our perspective of what is possible and in developing our recommendations of what is necessary to move EBFM forward in U.S. fisheries management.

Advisory Panel

The Task Force is advised by a panel of current and former Council members, as well as participants from state agencies and the National Oceanic and Atmospheric Administration's National Marine Fisheries Service (NOAA Fisheries). Because the goal of the Task Force was to provide guidance for managers, we believed that a panel of practitioners would provide grounding to our advice and ensure that our recommendations were realistic. We therefore engaged with the advisory panel throughout our process, and it has been instrumental in developing our findings and recommendations.

HOW THIS REPORT SHOULD BE USED

The first six chapters of this report are intended for an audience with knowledge of and interest in fisheries. We have sought clarity at every juncture, but we also assume some familiarity with basic concepts of fisheries science and management. We hope that novice and non-U.S. readers will still find the general points useful, even if they are unfamiliar with some of the details, especially with regard to the workings of the U.S. Council system and the laws governing fisheries.

Chapter 1 provides our definition and scope of EBFM, reviews progress toward EBFM in the U.S., and describes the key next steps in operationalizing EBFM. Chapter 2 gives reasons to develop next-generation FEPs, describes how we envision FEPs and FMPs can work together to improve management, outlines the nature and purpose of next-generation FEPs, and describes how next-generation FEPs can help overcome many of the perceived barriers to implementing EBFM. Chapter 3 gives the blueprint itself, a structured planning process for FEPs as described above. Chapter 4 provides three key considerations for developing FEPs. Chapter 5 supports the feasibility of the blueprint by providing examples from case studies that illustrate each step of the process. Chapter 6 summarizes our key findings and recommendations that are laid out in Chapters 1-5.

The report also includes an Implementation Volume and three Appendices, which are intended mainly for a narrower audience of managers, Council staff, Council advisers, and other managers and technical professionals. The Implementation Volume provides detailed guidance on a range of scientific tools and policy instruments to carry out this process. It is not our intention to prescribe specific tools or approaches. Instead, we want to provide a menu of options from which Councils could pick and choose what is most appropriate for their system. Appendix A provides an overview of the principles of EBFM and fisheries as systems. Appendix B is a table of challenges to EBFM identified from the scientific literature, with suggestions for how a new generation of FEPs can overcome them. Appendix C provides narratives of the case studies used in Chapter 5. The Implementation Volume and all Appendices can be accessed at www.lenfestocean.org/EBFM.

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CHAPTER 1

EBFM AND FEPS: WHERE ARE WE NOW?

BACKGROUND

Fishing is critical to food security and the well-being of individuals and communities around the world (Cisneros-Montemayor and Sumaila, 2010; FAO, 2014). It is also a globally significant industry, contributing more than US$140 billion to world economies (Food and Agriculture Organization, 2014). The conventional approach to managing people's use of fisheries resources sets regulations by focusing on one species (or group of similar species) and its fisheries at a time to sustain the delivery of food, employment, economies, and social benefits. Where applied, this approach can succeed at avoiding overfishing and rebuilding depleted target stocks (Melnychuk et al., 2012; Melnychuk et al., 2013; Neubauer et al., 2013; NOAA Fisheries, 2015). However, conventional management generally does not focus on the ecological, economic, and social systems that fisheries are part of.

This leads to certain limitations. First, because species and fishing participants do not exist in isolation, regulations focused solely on one fishing sector may unexpectedly lead to worse outcomes in another. Second, because the conventional approach often considers a narrow range of management levers, it may overlook other options. For example, conventional rebuilding plans often focus on reducing fishing mortality of the target species, with less consideration given to other factors slowing recovery, such as loss of habitat. Third, the focus of conventional management makes it difficult to consider the full range of trade-offs that attend many decisions. Management decisions made for one fishery rarely consider broad trade-offs across all fisheries in a region, for instance across jurisdictional boundaries.

The importance of a broader, ecosystem-based approach has been recognized for more than a century (Baird, 1873) and over the past two decades has been increasingly promoted as a more effective framework for fisheries management to meet societal needs (Foley et al., 2013; Francis et al., 2007; Link, 2002; McLeod et al., 2005; Pikitch et al., 2004). For example, several international organizations and agreements have adopted ecosystem-based management frameworks (Bianchi and Skjoldal, 2008; Pikitch et al., 2004) and the U.N. Food and Agriculture Organization (FAO) has provided guidance to implement an ecosystem approach to fisheries (Ecosystem Approach to Fisheries, FAO, 2003). In the European Union, one of the goals of the reformed Common Fisheries Policy is to develop ecosystem-based fisheries management (EBFM), and the broader Marine Strategy Framework Directive (EU COM, 2008) has the goal of "clean, healthy, and productive" oceans ("Good Environmental Status") by 2020. And Australia has a notable track record of implementing ecosystem approaches to fisheries management (Fletcher et al., 2010; Smith et al., 2007), which has contributed to improved sustainability of stocks (Smith et al., 2007).

In the U.S., there has also been progress (which we outline below), but EBFM has not been widely or systematically adopted at the federal level. In this chapter, we further describe the concept of EBFM, review the status of its implementation in the U.S., and introduce what we believe is the critical next step in operationalizing it.

WHAT IS EBFM?

Our definition of EBFM synthesizes multiple existing definitions (Fogarty, 2014; Garcia et al., 2003; Larkin, 1996; Link, 2010; McLeod et al., 2005; Pikitch et al., 2004).

> **EBFM IS A HOLISTIC, PLACE-BASED FRAMEWORK THAT SEEKS TO SUSTAIN FISHERIES AND OTHER SERVICES THAT HUMANS WANT AND NEED BY MAINTAINING HEALTHY, PRODUCTIVE, AND RESILIENT FISHERY SYSTEMS.**

This contrasts with a conventional fisheries management focus, which is more narrowly pointed on the *direct* consequences of management actions on targeted stocks, and protected nontarget species.

Fundamental to EBFM is the conceptualization of fisheries as systems. Fishery systems consist of linked biophysical and human subsystems with interacting ecological, economic, social, and cultural components (Charles, 2014, 2001). A system is made up of its components (e.g., targeted fish stock, interacting species, habitats, people employed by fishing), and the linkages among them (e.g., predator-prey interactions, fishermen who shift from one fishery to another). These linkages can span regulatory units and jurisdictions that are common in conventional management. Management actions that do not account for these linkages can therefore produce unintended indirect effects (Bianchi and Skjoldal, 2008; Ecosystems Principles Advisory Panel, 1999; Garcia et al., 2003). See Appendix A for a fuller description of the Task Force's key principles for understanding fisheries as systems and consequences of these principles for fisheries management.

The goal of EBFM is to improve decision-making by providing a means for managers to transparently consider all components of a fishery system: ecological, social, and economic across all fisheries prosecuted in the system. This triad is also known as the "triple bottom line" (Elkington, 1997; Halpern et al., 2013). Conventional management can take the triple bottom line into account within a single fishery, but EBFM does this more comprehensively by looking across species, fisheries, and jurisdictions. That is, it considers the system as a whole. In an EBFM approach, managers can make decisions that explicitly take into consideration how different components of the fishery system and the linkages among them affect the benefits people receive from fisheries. A holistic view of systems can help managers better identify a fuller suite of threats to fisheries and provide a more coherent framework to account for the dynamics of systems. EBFM can identify elements that confer resilience, helping managers avoid exceeding limits that may lead to rapid and irreversible system change. Finally, EBFM can improve the ability to reach the goals of conventional management by explicitly incorporating environmental and ecological information in science advice used to access stocks.

Several pressing needs in fisheries management can be more effectively addressed with EBFM, including:

- prepare for and respond to rapid environmental change, including by formulating management strategies to sustain fishing-dependent communities;
- assess and respond to cumulative effects from multiple fisheries and from nonfishery stressors, such as land-based pollution and environmental change;
- minimize the risks of system reorganization into new, undesired states;
- modify biological reference points to account for interactions among targeted species, habitats, and environmental conditions.

STATUS OF EBFM IN THE UNITED STATES

Many Regional Fishery Management Councils – the bodies that manage U.S. federal fisheries along with NOAA – have been expanding the scope of conventional management in a stepwise fashion over the past several decades to address such linkages. For example, they have protected important benthic habitats from negative impacts associated with fishing gear by designating Essential Fish Habitat and restricting fishing in certain areas (Murawski et al., 2000). They have also reduced bycatch using several methods, such as catch shares (Little et al., 2014), spatial management (Dunn et al., 2011), and technical management (Melvin et al., 2014). And they have enacted precautionary measures such as biomass buffers to protect forage fish, which serve as important prey to other species (Pikitch et al., 2012, e.g., pp. 41, 47).

Stock assessment models have also advanced to reflect the stepwise expansion of conventional management. For instance, some stock assessments link recruitment to environmental conditions, track changes in mortality due to predators, or use information on habitats to better standardize abundance indices. In fact, our review of 207 quantitative stock assessments found that roughly 45 included explicit habitat or oceanographic conditions and three explicitly included predation (an additional 23 assessments included data on predation in the report for context). This progress demonstrates both the capacity to improve stock assessments by including ecosystem information and the tremendous opportunity to expand the application of EBFM in stock assessments.

Similarly, conventional management has advanced to address social and economic goals of fisheries. For instance, the Alaskan halibut and sablefish individual transferable quota fishery enacted constraints on permit trading and limitations on ownership in 1995 to avoid overconsolidation of quota into a small number of owners, which would lead to few active participants (Kroetz et al., 2015). This has resulted in more fishermen and vessels being active than would have been without these restrictions (Kroetz et al., 2015). Also, groundfish fisheries have implemented Community Quota and Community Development Quota Programs in Alaska (Carothers, 2011; Ginter, 1995) to encourage greater participation by local Alaska communities. Quota leasing through the Community Development Quota program has provided revenue to these communities and produced a nearly fiftyfold increase in asset value (Carothers, 2011; Ginter, 1995). These advances are laudable, but because they have been limited to social and economic goals *within* fisheries (and do not address similar issues that span multiple management jurisdictions or management plans) there are opportunities to expand how fisheries management considers social and cultural outcomes.

Concurrent with Councils' stepwise expansion of the scope of conventional management, an effort to establish a more overarching version of EBFM in the U.S. began two decades ago. In 1999, this Ecosystem Principles Advisory Panel (EPAP) concluded that while conventional fishery planning approaches included provisions to address ecosystem principles, they were not sufficient to implement EBFM because of their inherently narrow focus (Ecosystem Principles Advisory Panel, 1999). **Instead, a new tool was needed: Fishery Ecosystem Plans (FEPs).** The report included recommendations for the development of FEPs, with three objectives in mind:

- provide Council members with a clear description and understanding of the fundamental physical, biological, and human/institutional context of ecosystems within which fisheries are managed;
- direct how that information should be used in the context of Fishery Management Plans (FMPs); and
- set policies by which management options would be developed and implemented.

Over subsequent years, eight FEPs have been developed (others are currently in development), covering four Council regions. The scope of these FEPs varies widely (Table 1.1), but one notable and consistent pattern is that FEPs generally do not include direct links to management actions. This point is also noted in a recent review of FEPs in relation to the recommendations in the EPAP Report (Wilkinson and Abrams, 2015), which found that several of the EPAP recommendations had not been implemented. The review also identified three key elements not included in the original EPAP Report that should be central to the development of future FEPs:

1. establishment of ecosystem goals and objectives;
2. use of ecosystem indicators to monitor progress in achieving goals; and
3. analysis of trade-offs across objectives.

Table 1.1

KEY ASPECTS OF THE FEPS DEVELOPED IN 4 COUNCIL REGIONS

OBJECTIVES AND STRATEGIES	ALEUTIAN ISLANDS (NPFMC)	SOUTH ATLANTIC (SAFMC)	CALIFORNIA CURRENT (PFMC)	MULTIPLE ECOSYSTEMS (PIFMC)
OBJECTIVES				
Integrate and provide information for Council decision-making	✓	✓	✓	✓
Provide indicators to inform health of fishery system	✓			
Build toward ecosystem assessment			✓	
Coordinate conservation and management measures				✓
Set management objectives				✓
Establish structure to provide management advice				
STRATEGIES				
Overview of the fishery system	✓	✓	✓	✓
Indicator development	✓			
Qualitative risk assessment	✓			
Amendments for habitat protection		✓		
Initiatives that can be taken up at the Council's discretion			✓	
Replaces FMPs				✓
Direct links to required action	No	No	No	Yes*

* The FEPs for the Western Pacific Regional Fishery Management Council reorganized existing FMPs but did not revise them.

NEXT STEPS: OPERATIONALIZING EBFM

The Task Force believes that operationalizing EBFM – putting principles into practice - requires a systematic framework. A framework creates a scaffold on which to hang our knowledge of a fishery system. A framework illustrates the pathways through which managers can identify a coherent set of actions to increase and sustain the multiple benefits people derive from fisheries.

The Task Force believes that one reason for the limited application of EBFM is the lack of a structured, deliberate, transparent process for doing so. We further believe that adopting such a process is a necessary next step in operationalizing EBFM. The Task Force therefore proposes that a new generation of FEPs should be used as a tool for operationalizing EBFM.

The rest of this report outlines our vision for these FEPs, how managers can integrate them into existing management (Chapter 2), and our five-step process for creating next-generation FEPs (Chapter 3). Subsequent chapters provide further detail and examples. This process could accomplish critical tasks that are needed to operationalize EBFM such as:

- set and prioritize overarching goals for the fishery system based on a transparent, stakeholder-driven process;
- set performance measures, consider a wide range of alternative actions, and explicitly confront the trade-offs inherent in selecting an alternative;
- specify an internally consistent set of policies that achieve fishery system goals across multiple fisheries; and
- adopt adaptive management, an approach for making decisions under uncertainty and systematically adjusting course based on new information.

Male sea lions in Newport, Oregon, at the Historic Newport Docks (left). A small longline commercial fishing vessel in Kodiak Island, Alaska (right).

REFERENCES

Baird, S. F. 1873. Report on the condition of the sea fisheries of the south coast of New England in 1871 and 1872, Report of the United States Fish Commission. Washington, D.C.

Bianchi, G., Skjoldal, H. R. 2008. The ecosystem approach to fisheries. CABI. Rome, Italy.

Carothers, C. 2011. Equity and access to fishing rights: exploring the community quota program in the Gulf of Alaska. Hum. Organ. 70, 213–223.

Charles, A. 2014. Human dimensions in marine ecosystem-based management, in: Fogarty, M., McCarthy, J. J., eds. The Sea. Harvard University Press, Cambridge, MA, pp. 57–75.

Charles, A. 2001. Sustainable fishery systems, fish and aquatic resources series. Blackwell Science, Oxford.

Cisneros-Montemayor, A. M., Sumaila, U. R. 2010. A global estimate of benefits from ecosystem-based marine recreation: potential impacts and implications for management. J. Bioeconomics 12, 245–268. doi:10.1007/s10818-010-9092-7

Dunn, D. C., Boustany, A. M., Halpin, P. N. 2011. Spatio-temporal management of fisheries to reduce by-catch and increase fishing selectivity. Fish Fish. 12, 110–119. doi:10.1111/j.1467-2979.2010.00388.x

Ecosystem Principles Advisory Panel. 1999. Ecosystem-based fishery management. NOAA Fisheries.

Elkington, J. 1997. Cannibals with forks: the triple bottom line of twenty first century business. Capstone, Mankato.

FAO. 2014. The state of world fisheries and aquaculture: opportunities and challenges. Food and Agriculture Organization of the United Nations. Rome, Italy.

FAO. 2003. Fisheries Management. 2. The ecosystem approach to fisheries. (No. 4 Suppl. 2), FAO Technical Guidelines for Responsible Fisheries. Rome, Italy.

Fletcher, W. J., Shaw, J., Metcalf, S. J., Gaughan, D. J. 2010. An ecosystem based fisheries management framework: the efficient, regional-level planning tool for management agencies. Marine Policy 34, 1226–1238. doi:10.1016/j.marpol.2010.04.007

Fogarty, M. J. 2014. The art of ecosystem-based fishery management. Can. J. Fish. Aquat. Sci. 71, 479–490. doi:10.1139/cjfas-2013-0203

Foley, M. M., Armsby, M. H., Prahler, E. E., Caldwell, M. R., Erickson, A. L., Kittinger, J. N., Crowder, L. B., Levin, P. S. 2013. Improving ocean management through the use of ecological principles and integrated ecosystem assessments. Bioscience 63, 619–631.

Francis, R. C., Hixon, M. A., Clarke, M.E., Murawski, S. A., Ralston, S. 2007. Ten commandments for ecosystem-based fisheries scientists. Fisheries 32, 217–233. doi:10.1577/1548-8446(2007)32[217:TCFBFS]2.0.CO;2

Garcia, S. M., Zerbi, A., Aliaume, C., Do Chi, T., Lasserre, G. 2003. The ecosystem approach to fisheries. Issues, terminology, principles, institutional foundations, implementation and outlook., FAO Fisheries Technical Paper. Food and Agriculture Organization, Rome.

Ginter, J. J. C. 1995. The Alaska community development quota fisheries management program. Ocean Coast. Manag., Property Rights and Fisheries Management 28, 147–163. doi:10.1016/0964-5691(95)00069-0

Halpern, B. S., Klein, C. J., Brown, C. J., Beger, M., Grantham, H. S., Mangubhai, S., Ruckelshaus, M., Tullock, V. J., Watts, M., White, C., Possingham, H. P. 2013. Achieving the triple bottom line in the face of inherent trade-offs among social equity, economic return, and conservation. Proc. Natl. Acad. Sci. U. S. Am. 110, 6229–6234.

Kroetz, K., Sanchirico, J. N., Lew, D. K. 2015. Efficiency costs of social objectives in tradable permit programs. J. Assoc. Environ. Resour. Econ. 2, 339–366.

Larkin, P. A. 1996. Concepts and issues in marine ecosystem management. Rev. Fish Biol. Fish. 6, 139–164.

Link, J. 2010. Ecosystem-based fisheries management: confronting tradeoffs. Cambridge University Press.

Little, A. S., Needle, C. L., Hilborn, R., Holland, D. S., Marshall, C. T. 2014. Real-time spatial management approaches to reduce bycatch and discards: experiences from Europe and the United States. Fish Fish. 16, 576–602. doi:10.1111/faf.12080

McLeod, K. L., Lubchenco, J., Palumbi, S. R., Rosenberg, A. A. 2005. Scientific consensus statement on marine ecosystem-based management. Signed by 221 academic scientists and policy experts with relevant expertise and published by COMPASS.

Melnychuk, M. C., J. A. Banobi, R. Hilborn. 2013. Effects of management tactics on meeting conservation objectives for western North American groundfish fisheries. PLoS ONE 8:e56684.

Melnychuk, M. C., T. E. Essington, T. A. Branch, S. S. Heppell, O. P. Jensen, J. S. Link, S. J. D. Martell, A. M. Parma, J. G. Pope, A. D. M. Smith. 2012. Can catch share fisheries better track management targets? Fish and Fisheries 13:267-290.

Melvin, E. F., Guy, T. J., Read, L. B. 2014. Best practice seabird bycatch mitigation for pelagic longline fisheries targeting tuna and related species. Fish. Res. 149, 5–18. doi:10.1016/j.fishres.2013.07.012

Murawski, S. A., Brown, R., Lai, H. L., Rago, P. J., Hendrickson, L. 2000. Large-scale closed areas as a fishery-management tool in temperate marine systems: the Georges Bank experience. Bull. Mar. Sci. 66, 775–798.

Neubauer, P., O. P. Jensen, J. A. Hutchings, J. K. Baum. 2013. Resilience and recovery of overexploited marine populations. Science 340:347-349.

NOAA Fisheries. 2015. Status of stocks for 2015. NOAA Fisheries, Silver Spring, MD.

Pikitch, E. K., P. D. Boersma, I. L. Boyd, D. O. Conover, P. Cury, T. E. Essington, S. S. Heppell, E. D. Houde, M. Mangel, D. Pauly, E. E. Plaganyi, K. Sainsbury, and R. Steneck. 2012. Little fish, big impact: Managing a crucial link in ocean food webs. Lenfest Ocean Program, Washington D.C.

Pikitch, E. K., C. Santora, E. A. Babcock, A. Bakun, R. Bonfil, D. O. Conover, P. Dayton, P. Doukakis, D. Fluharty, B. Heneman, E. D. Houde, J. Link, P. A. Livingston, M. Mangel, M. K. McAllister, J. Pope, K. J. Sainsbury. 2004. Ecosystem-based fishery management. Science 305, 346–347.

South Atlantic Fishery Management Council. 2009. Fishery Ecosystem Plan of the South Atlantic Region.

Smith, A. D. M., Fulton, E. J., Hobday, A. J., Smith, D. C., Shoulder, P. 2007. Scientific tools to support the practical implementation of ecosystem-based fisheries management. ICES J. Mar. Sci. 64, 633–639.

Wilkinson, E. B., Abrams, K. 2015. Benchmarking the 1999 EPAP recommendations with existing fishery ecosystem plans. NOAA Technical Memorandum NMFS-OSF-5.

CHAPTER 2

THE NATURE AND PURPOSE OF NEXT-GENERATION FISHERY ECOSYSTEM PLANS

INTRODUCTION

Chapter 1 described how ecosystem-based fisheries management (EBFM) can lead to improved decision-making by taking a more holistic view of fishery systems. It argued that one reason EBFM has not been widely adopted in the U.S. is the lack of a structured, deliberate, transparent process for doing so. The Lenfest Fishery Ecosystem Task Force proposes a new generation of Fishery Ecosystem Plans (FEPs) as a tool to carry out that process and translate the principles of EBFM into action.

Here we explain why we believe Regional Fishery Management Councils should develop FEPs and how FEPs can be used in concert with Fishery Management Plans (FMPs) to achieve EBFM, and we describe the overall nature of next-generation FEPs.

WHY DEVELOP AN FEP?

The overall purpose of an FEP is to foster improved decision-making by incorporating the principles of EBFM. By applying a broad suite of considerations and scientific tools, managers can better achieve sustainability goals for fishery systems.

The Task Force recognizes that there are substantial upfront costs to developing and implementing an FEP, while the benefits will follow over the long term. We nevertheless believe that next-generation FEPs warrant Councils' serious consideration because of the following four key benefits.

1. FEPs provide a structured process for translating goals and principles into action.

The main recommendation of this report is that next-generation FEPs be used to create a structured process for establishing goals and translating them into action. This process can help Councils prioritize among the many systemic issues and management goals they face and select which goals and objectives to pursue during the life of the current iteration of the plan. This is important because Councils will not have the resources to pursue all management issues simultaneously. The inability to consider all issues need not prevent them from moving forward on some. While risk and uncertainty will always exist, a triage approach can highlight high risks across the fishery system and thereby identify issues where management action is most urgent and most likely to improve outcomes (Fletcher, 2005; Levin et al., 2014).

2. FEPs provide a coordinated way to simultaneously consider ecological, economical, and social goals.

Our vision for next-generation FEPs to support EBFM includes considerations of food web dynamics, climate forcing, bycatch, and habitat protection (Ecosystem Principles Advisory Panel, 1999). But it equally focuses on human well-being, including equity, and economic considerations in decision-making (see recent review by Long et al., 2015). Therefore, FEPs that focus on fishery systems can demonstrate how fishery managers could assess, and potentially improve, outcomes across these dimensions. This "triple bottom line" offers an opportunity to build a broader, engaged community of stakeholders, scientists, and managers to improve fisheries management (Elkington, 1997).

3. FEPs create a process of identifying and transparently addressing trade-offs.

Next-generation FEPs will explicitly assess trade-offs, particularly across multiple fisheries operating in a Council region. In many cases, decision-makers already weigh multiple objectives implicitly and allocate resources accordingly. However, FEPs could provide a way to reveal and document the full spectrum of expected costs and benefits, monetary and nonmonetary, to all parties of fishery management actions (including but not limited to single-species catch limits). Tools for examining trade-offs within and among economic and ecological objectives are common, and methods to incorporate social and cultural dimensions are emerging. By exploring alternative policy measures in an attempt to root out trade-offs, decision-makers will have a more complete picture of consequences of alternative management actions and so can make better-informed decisions. This can foster an inclusive, transparent process of decision-making, since it makes clear the implications of each decision.

4. **FEPs provide a framework to consider cumulative impacts.**

Fishery systems are increasingly subjected to stressors that are external to fisheries and outside the control of management. Next-generation FEPs can help managers account for these external forces, including land-based pollution, climate forcing, climate change, and shifting global markets. An FEP can also serve as a venue for strategic recommendations on changes in institutional structure to support EBFM—for example, organizing science divisions to promote interaction among various fields (e.g., protected species, habitats, population assessment, social sciences, oceanography).

FISHERY ECOSYSTEM PLANS: A STAGE UPON WHICH FISHERY MANAGEMENT PLANS ACT

As context for the Task Force's vision of next-generation FEPs, this section describes the main ways fisheries regulations are made in the U.S. using FMPs, indicates how FEPs and FMPs can jointly be used to advance EBFM, and highlights the similarities and differences between next-generation FEPs and FMPs.

What are Fishery Management Plans?

In the U.S., fisheries management is operationalized by FMPs. The Magnuson-Stevens Fishery Conservation and Management Act (MSA) encourages integrated management of stocks via FMPs, and thus FMPs often consist of many functionally similar stocks (e.g., groundfish, coastal pelagic species, highly migratory species). The MSA stipulates that FMPs must prevent overfishing; rebuild overfished stocks; and protect, restore, and promote the sustainability of fish stocks. Therefore, FMPs must specify maximum sustainable yield and Optimum Yield[1] (OY), include overfishing definitions, establish a mechanism for specifying Annual Catch Limits, and minimize bycatch. The MSA also requires FMPs to allocate harvest restrictions equitably among sectors, and to describe essential fish habitat (EFH), and minimize to the extent practicable adverse impacts to EFH. In addition to these required components, FMPs also may, at the discretion of a Council, include time/area management requirements, gear requirements, limited access regimes, harvest incentives for reduced bycatch, requirements for fishery observers, and conservation of target and nontarget species and habitats.

FMPs are principally driven by objectives centered on individual species or stocks. The requirement to prevent overfishing and rebuild overfished stocks is the driving policy underlying the MSA and thus FMPs. Therefore, individual FMPs are not designed to lead to a consistent overall framework for the management of interacting species and fishing participants distributed among many FMPs, among species managed by multiple jurisdictions (e.g., federal vs. state), or legal authorities (e.g., MSA and the Endangered Species Act) (Fogarty and Rose, 2013).

1 National Standard 1 of the MSA defines OY as the amount of fish that will provide the greatest overall benefit to the nation based "on maximum sustainable yield from the fishery, as reduced by any relevant economic, social, or ecological factor."

How are FEPs and FMPs used to operationalize EBFM?

The Task Force envisions that next-generation FEPs will be similar to FMPs in certain ways. FEPs, like FMPs, will have the generic elements of a good plan. These include goals and objectives, strategies and actions to achieve objectives, performance evaluation and review, mechanisms for prioritization, and mechanisms for evaluating trade-offs in selecting between alternative strategies and actions.

Next-generation FEPs are distinct from FMPs, however, and the unique features of FEPs might make them preferable for addressing certain issues. FEPs have a different purpose, a different legal mandate, and different scope:

Purpose: The purpose of FMPs is to achieve management goals set for particular species, species groups, or fisheries, while the purpose of FEPs is to achieve the broader goals of EBFM for the fishery system.

Legal mandate: FMPs are statutorily required, legally binding instruments that stem directly from MSA and seek to meet the act's National Standards, whereas FEPs are discretionary and not legally binding. This creates both limitations and opportunities. One potential limitation is difficulty making FEPs "actionable" given that they have no legal basis. However, FEPs can specifically articulate how management plans will be implemented through FMP amendment processes should regulatory changes be needed. One benefit is that the FEP process may be especially helpful for planning and aspirational thinking because an FEP does not trigger mandatory action. This encourages "outside the box" thinking that can inspire novel solutions to complex problems. Management actions that follow from FEPs can be applied on a temporary basis to learn how the system responds and to determine whether expected benefits are produced.

Scope: The spatial focus of FMPs is often defined by the stock structure of key commercial and recreational species. In contrast, the scale of an FEP is defined by the spatial structure of the fishery system. Because boundaries in fishery systems tend to be porous, FEPs may need to acknowledge known biophysical and socio-economic exchanges. Further, the boundaries of FEPs should recognize the scale of human institutions and governance, including the regional distribution of fishing sectors, fishing effort, stakeholder commitments, and international/tribal treaties.

The scope of possible objectives of an FEP is also broader than a FMP. FEPs specify a Council's vision for economic, ecological, and social sustainability of the whole fishery system. FEPs are the means to consider conflicts or inconsistencies among FMPs, and between fisheries and other ecological and socio-economic objectives. FEPs also provide a platform to examine cumulative impacts of all human activities in the system.

The broad scope of FEPs means that they can also more appropriately address the human dimensions throughout entire fishery systems, such as those highlighted in several places in the MSA. For example, the degree to which allocation of resources to fishermen is fair and equitable (National Standard 4) and the ability for management to take into account the importance of fishery resources to fishing communities[2] (National Standard 8) may be best addressed at the scale of the entire fishery system so that all fisheries (state and federal) can be explicitly considered in their totality.

2 The MSA defines fishery community as a community that is substantially dependent on or substantially engaged in the harvest or processing of fishery resources. Fishing communities include members that reside in a specific location and share a common dependency on fishing or on directly related fisheries-dependent services and industries. (MSA Section 3; and 50 CFR 600.345(b)(3), National Standard 8)

Perhaps more importantly, FEPs can be used to inform OY (Patrick and Link, 2015). While OY is determined for single species, the amount of catch from all fisheries that yields the greatest benefit to the nation is unlikely to be the simple sum of single-species OY, or even sum of OY within an FMP. Rather, systemic OY can only be addressed by looking across all fisheries holistically, considering direct and indirect effects of fisheries on each other, food webs, and coastal communities.

Both FEPs and FMPs will be involved in operationalizing EBFM to some extent. FEPs can integrate across FMPs and address those issues not effectively captured in FMPs. However, if Councils are to achieve their EBFM goals, it is absolutely necessary that the FEP process include explicit steps to modify FMPs with the results of the FEP work projects. Councils can use both FEPs and FMPs in whatever proportion they choose to advance EBFM.

Western Grebe (*Aechmophorus occidentalis*) with fish prey, Monterey Bay, California (top left). Woman deploying a bouy line for commercial halibut longline fishing, Southwest Alaska (top right). Colorful corals deep underwater in Fiji (bottom).

THE NATURE OF NEXT-GENERATION FEPS

This section describes the Task Force's high-level vision of the nature of next-generation FEPs. A more detailed proposal for creating FEPs is provided in the next chapter.

As stated above, our main recommendation is that FEPs be used to create a structured process for translating EBFM principles into action. This means developing *actionable* components for FEPs – ways in which ecosystem considerations lead to management responses. At the same time, FEPs need to be aspirational, to identify the broader system-level goals for the fishery system. This is key to placing system-level thinking at the forefront of fishery management and to placing fisheries firmly in a holistic system context. Without the aspirational component, the FEP can become overly narrow and miss opportunities to make advances from the status quo.

Calls for FEPs to be actionable and aspirational may appear to be at odds. We argue that FEPs can achieve both by *prioritizing* the set of issues that will be considered for management action during the life of a particular plan. The overarching process will involve strategic vision and long-term goals, but the immediate actions will be based on a prioritized list of issues that can be given practical effect over the life of the plan (likely between five and 10 years).

FEPs will be addressing issues for which there is substantial uncertainty – this is a fundamental feature of EBFM. Taking actions under uncertainty requires an adaptive approach to management. This means that managers take action without precisely knowing the outcomes. Instead, they define the risks and benefits of alternative solutions and identify vulnerabilities to key uncertainties, which allows them to identify the actions that are most robust to uncertainty. The adaptive approach to management also means that knowledge of the system is improved by taking action and learning how the system responds (Walters, 1986). Thus, the assessment of outcomes in implementing EBFM must be conducted regularly, and the FEP updated on a schedule so that it evolves in an adaptive fashion. This process is further described in Chapter 3.

Examples of FEP actions and how to implement them

The actionable component of FEPs can take several forms. For instance, it is within the scope of FEPs to:

- identify system-level performance measures and develop management responses to be taken when reference points are approached or exceeded;
- modify or replace harvest control rules to take into account multiple stocks and the relationships among them and the whole system;
- specify the process for updating biological reference points in response to measured ecosystem changes;
- develop a strategy to identify vulnerable nontarget species (either from bycatch or indirect effects of fisheries), monitor changes in risk or population status, and trigger management responses when risk crosses thresholds;
- prioritize vulnerable and valuable habitats for protection and monitoring;
- modify the allocation of fishing opportunities among users to achieve broad social objectives;
- specify the Council's strategy for coordinating with local, regional, and federal authorities regarding ocean uses by multiple sectors; and
- establish standards for information to be formally included in assessment or management decisions. This may include setting forth ways to use local and traditional ecological knowledge; describing what environmental data are suitable and appropriate to enhance assessment; and describing how highly localized information (e.g., much anthropological information) is to be used in regional decision-making.

HOW FEPS CAN ADDRESS THE KEY CHALLENGES TO EBFM

Next-generation FEPs are designed to address many of the perceived challenges to EBFM implementation. These challenges include complexity, uncertainty, unclear objectives, and difficulty reconciling trade-offs. We elaborate on each of these and show how a FEP can overcome them. In addition, Appendix B provides a detailed table of challenges to EBFM identified from the scientific literature, with suggestions for how next-generation FEPs can overcome them (see www.lenfestocean.org/EBFM).

Complexity

Perceived challenge: The complexity of fishery systems is thought to make EBFM costly and time-consuming to implement (Leslie and McLeod, 2007; Tallis et al., 2010; Hilborn, 2011; Cowan et al., 2012; Leslie et al., 2015). This is thought to necessitate new science tools to capture the key feedbacks and responses of systems to fishery regulations and external drivers (Cowan et al., 2012). These science tools are perceived as so complex that decision-makers and stakeholders will not readily understand them. Some claim that complexity in fishery systems defies translation into readily understood and easily tracked indicators, reference points, and simple decision rules (Frid et al., 2006).

FEP solution: FEPs prioritize issues for action, thereby simplifying and focusing decision-making and the science activities that support it. Prioritization also means that actions are taken on a limited number of issues, so that indicators, reference points, and decision rules can be tailored to issues at hand. FEPs provide decision support that can be applied at all levels of information availability.

Uncertainty

Perceived challenge: Our limited ability to predict system behavior means that science is insufficiently precise to guide management (Frid et al., 2006). Even modest extensions to models used to predict fish population status – such as adding environmental information into a stock assessment – can reduce management performance if not done carefully (Punt et al., 2014).

FEP solution: Next-generation FEPs are designed specifically to guide decisions given uncertainty. That is, FEPs are a framework for making decisions under uncertainty by evaluating alternative actions to determine which are robust to key uncertainties and using management actions to reduce uncertainty.

Unclear objectives

Perceived challenge: EBFM has been said to lack clear objectives (Cowan et al., 2012; Hilborn, 2011; Mace, 2001) because EBFM means different things to different people (Christie et al., 2007) and because there is no coherent policy framework to provide them. In contrast, conventional management often has clear, legally mandated objectives.

FEP solution: A central part of next-generation FEPs is development of specific, operational objectives. These objectives reflect the desired states of the fishery system as revealed through engagement with a broad coalition of stakeholders.

REFERENCES

Christie, P., D. L. Fluharty, A. T. White, L. Eisma-Osorio, W. Jatulan. 2007. Assessing the feasibility of ecosystem-based fisheries management in tropical contexts. Marine Policy 31:239-250.

Cowan, J. H., J. C. Rice, C. J. Walters, R. Hilborn, T. E. Essington, J. W. Day, K. M. Boswell. 2012. Challenges for implementing an ecosystem approach to fisheries management. Marine and Coastal Fisheries 4:496-510.

Frid, C., O. Paramor, C. Scott. 2006. Ecosystem-based management of fisheries: is science limiting? ICES Journal of Marine Science 63:1567-1572.

Hilborn, R. 2011. Future directions in ecosystem based fisheries management: a personal perspective. Fisheries Research 108:235-239.

Leslie, H., L. Sievanen, T. G. Crawford, R. Gruby, H.C. Villanueva-Aznar, L. M. Campbell. 2015. Learning from ecosystem-based management in practice. Coastal Management 43:471-497.

Leslie, H. M., K. L. McLeod. 2007. Confronting the challenges of implementing marine ecosystem-based management. Frontiers in Ecology and the Environment 5:540-548.

Levin, P.S., Kelble, C.R., Shuford, R.L., Ainsworth, C., deReynier, Y., Dunsmore, R., Fogarty, M.J., Holsman, K., Howell, E.A., Monaco, M.E., Oakes, S.A. & Werner, F. (2014). Guidance for implementation of integrated ecosystem assessments: a US perspective. ICES J. Mar. Sci. J. Cons., 71, 1198–1204.

Long, R. D., A. Charles, and R. L. Stephenson. 2015. Key principles of marine ecosystem-based management. Marine Policy 57:53-60.

Magnuson-Stevens Fishery Conservation and Management Reauthorization Act of 2006, Pub. L. No. 109-479, 120 Stat. 3575 (2007).

Patrick, W. S., J. S. Link. 2015. Hidden in plain sight: using optimum yield as a policy framework to operationalize ecosystem-based fisheries management. Marine Policy 62:74-81.

Punt, A. E., T. A'Mar, N. A. Bond, D. S. Butterworth, C. L. de Moor, J. A. A. De Oliveira, M. A. Haltuch, A. B. Hollowed, C. Szuwalski. 2014. Fisheries management under climate and environmental uncertainty: control rules and performance simulation. ICES Journal of Marine Science 71:2208-2220.

Tallis, H., P. S. Levin, M. Ruckelshaus, S. E. Lester, K. L. McLeod, D. L. Fluharty, B. S. Halpern. 2010. The many faces of ecosystem-based management: making the process work today in real places. Marine Policy 34:340-348.

Walters, C. J. 1986. Adaptive management of renewable resources. MacMillan Publishing Co., New York.

CHAPTER 3

THE STRUCTURE AND PROCESS OF FISHERY ECOSYSTEM PLANS

INTRODUCTION

Decision-making in an ecosystem-based fisheries management (EBFM) context needs to be structured and deliberate to account for uncertainty and trade-offs among multiple, potentially competing objectives (Walters, 1986; Polasky et al., 2011). By structured, we mean that there is a logical, sequenced process, and by deliberate, we mean the process is conducted with clearly articulated intentions to achieve specific goals.

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

Our approach, summarized in Figure 3.1, is founded on the concept of adaptive management (Holling, 1978; Walters, 1986), a structured approach for improving resource management by systematically learning from management outcomes (Williams et al., 2009; Westgate et al., 2013). This approach shares many features of the Integrated Ecosystem Assessment process already employed by NOAA and others (Levin et al., 2009, 2014) but builds upon that process by focusing on management actions.

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

This "FEP Loop" does not offer a ready-made cookbook for EBFM. The Task Force decided this was not useful to decision-makers because of the diversity of regional conditions, needs, and constraints, and because Councils will undoubtedly need and want to customize their approach to FEP development and implementation. As an adaptive framework, we expect that it will change and that Councils will improve and modify our guidelines. We provide instead a blueprint that outlines key activities, their intended outcomes and purposes, and the sequence with which they should occur to guide the development of next-generation FEPs.

The next section describes the five steps in the development of an FEP. Detailed guidance on the first three steps of the FEP Loop is provided in the Implementation Volume. We do not provide detailed guidance on the last two steps because the Councils are already familiar with these actions (namely, implementing a plan and monitoring results).

Red grouper swimming in a coral reef, Dry Tortugas National Park, Florida (left). Fishing vessel, Florida Keys (right).

Figure 3.1

THE FEP LOOP

The main recommendation of the Task Force report is that FEPs be used to create a structured process for establishing goals and translating them into action. The report proposes the "FEP Loop" process.

Step 1: "Where are we now?"

The purpose of this step is to systemically inventory the status and trends of key components of the fishery system, then assess the risks that the system faces. Key actions associated with this step include:

- **Develop a conceptual model:** Stakeholders, tribes, managers, and scientists co-create a model that provides an inventory of key components of the fishery system and how they interact (EPAP, 1999). This reveals direct and indirect connections within and among social and ecological components of fishery systems.
- **Select and calculate indicators:** Describe the state of the system by documenting status and trends of key fishery system components. This involves a robust process of identifying "vital sign" indicators, measurable properties of the system that reflect system state.
- **Inventory threats**: Work with stakeholders, tribes, managers, and scientists to identify threats to the system and other pressures (see Table 3.1 for examples).

Table 3.1

EXAMPLES OF THREATS AND OTHER PRESSURES POTENTIALLY AFFECTING FISHERY SYSTEMS

Finfish and shellfish aquaculture	Coastal development and engineering
Atmospheric pollution	Dredging
Commercial shipping	Freshwater retention
Fishery removals	Light pollution
Invasive species	Nutrient input/hypoxia/harmful algal blooms
Marine debris	Offshore oil and gas activities
Ocean-based pollution	Power plant operation
Organic pollution	Recreational use
Climate change	Ocean acidification
Global fish markets	Degraded fish habitat
Construction of benthic structures	

Sources: Drawn from Andrews et al., 2015; Halpern et al., 2007

Step 2: "Where are we going?"

The objective of this step is to collaboratively articulate a purpose and direction for the FEP. This includes key actions that embody the aspirational and actionable nature of FEPs. This step identifies broad system level goals, prioritizes issues for action, and identifies tangible, measurable management objectives. Most of these activities involve collaboration with stakeholders, tribes, managers, and scientists.

- **Create a vision statement:** Create a vision statement that declares a management body's core values and purpose. This statement provides the foundation for clear goals for the fishery system. Unlike conventional management vision statements, which are generally focused on individual fishery sectors or species, these encompass goals for the entire fishery system. (See Table 3.2.)
- **Develop strategic objectives:** Strategic objectives are high-level statements of what is to be attained. Unlike vision statements that refer to the fishery system as a whole, strategic objectives are more focused on individual social, ecological, institutional, or economic components of the fishery system. Thus, there will be several strategic objectives underlying the FEP vision. (See Table 3.2 and Example Box 1.)
- **Analyze risks to meeting strategic objectives:** Determine the likelihood that one or more components of the fishery system will reach or remain in an undesirable state.
- **Prioritize strategic objectives:** With information gathered from previous steps, managers and stakeholders identify high-priority strategic objectives based on risk, cost and feasibility, logistics, governance, and stakeholder support. (See Example Box 2.)
- **Develop operational objectives:** Unlike strategic objectives, operational objectives are specific, measureable, achievable, realistic, and time-bound. In other words, they clearly and unambiguously articulate what desired outcomes look like. Operational objectives are therefore the basis for developing actions to achieve EBFM.

Small city of Unalaska, Port of Dutch Harbor, Alaska, part of the Aleutian Islands.

Table 3.2

SAMPLE VISION STATEMENTS, STRATEGIC OBJECTIVES, AND OPERATIONAL OBJECTIVES

VISION STATEMENTS	The Vision for the Eastern Scotian Shelf is of healthy and sustainable ecosystems, economies, and communities supported by collaborative, integrated, and harmonized governance and management. Eastern Scotian Shelf Integrated Management Plan (Fisheries and Oceans Canada, 2007)
	Healthy and productive marine ecosystems supporting thriving, sustainable marine fisheries that provide the greatest overall benefit to stakeholders (MAFMC, 2013)
	Maintain biologically diverse and productive marine ecosystems and foster the long-term sustainable use of marine resources in an ecologically and culturally sensitive manner through the use of a science-based ecosystem approach to resource management (Western Pacific Council FEP)
STRATEGIC OBJECTIVES	Maintain the biomass of keystone species at levels that will ensure maintenance of their specific role in ecosystem function (Fletcher, 2010)
	Diversity of benthic, demersal, and pelagic community types is conserved. (Fisheries and Oceans Canada, 2007)
	"[M]inimize to the extent practicable adverse effects on such habitat caused by fishing, and identify other actions to encourage the conservation and enhancement of such habitat," (Magnuson Stevens Act, 2007)
OPERATIONAL OBJECTIVES	Maintain or increase regional/local employment in the fishery and related industries (Fletcher, 2010)
	Increase the overall abundance of spawning herring to 19,380 tons by 2020 (Puget Sound Partnership website: http://www.psp.wa.gov/)

The boxes in this chapter provide a mix of hypothetical and real examples of how steps of the FEP Loop might be carried out. These are meant as illustrations of the scope of FEPs, the types of issues that might be addressed, and how the FEP Loop leads to EBFM.

EXAMPLE BOX 1: VISIONING AND STRATEGIC OBJECTIVES

The North Pacific Fishery Management Council (NPFMC) report "Ecosystem Based Fishery Management (EBFM) development process and actions, May 2014" illustrates both vision statements and strategic objectives:

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

The first portion of this statement "*The Council envisions sustainable fisheries that provide benefits for harvesters, processors, recreational and subsistence users, and fishing communities*" is the vision statement – the enduring, fundamental, ambitious sense of purpose that is pursued over many years.

The rest of this statement describes the strategic objectives, the high-level statements that indicate what is to be attained. They are *(1) maintain healthy, productive, biodiverse, resilient marine ecosystems that support a range of services; (2) support robust populations of marine species at all trophic levels, including marine mammals and seabirds; and (3) manage using a precautionary, transparent, and inclusive process that allows for analyses of tradeoffs, accounts for changing conditions, and mitigates threats.*

EXAMPLE BOX 2: PRIORITIZATION

Prioritization involves considering all potential issues and threats to the fishery system, and judges the risk each poses to the strategic objectives. This process asks, "What is the extent and likelihood that each of the issues would prevent fishery management goals (these are the strategic objectives) from being met?" and "What is the likely effectiveness of management intervention?"

The Aleutian Islands FEP provides an example of a qualitative risk assessment of potential systemic issues (NPFMC, 2007), which partially illustrates this step. The potential issues were divided into five categories: climate and physical interactions, predator-prey interactions, fishing effects interactions, regulatory interactions, and other socio-economic activity interactions. Each issue was given three scores based on the probability of it occurring, the impact it would have on the biophysical system (ecosystem impact), and the human system (economic impact) (NPFMC, 2007). Scores were assigned as high, medium, low, or unknown.

In Table 3.3, we show the category for potential impacts from fisheries, to illustrate scoring.

Continued on next page

Table 3.3

PROBABILITY AND IMPACT OF FISHING EFFECTS FROM ALEUTIAN ISLANDS FEP

	PROBABILITY	ECOSYSTEM IMPACT	ECONOMIC IMPACT
Total removals from the ecosystem due to fishing impact ecosystem productivity	Medium	High	High
Differences between spatial stock structure and the spatial scale of fishery management may affect managed species	Medium	High	High
Impact of one fishery on another through fishing impacts on habitat	Medium	Medium	Medium
Impact of a fishery on other biota through fishing impacts on habitat	Unknown	Unknown	Low
Impact of bycatch on fisheries	High	Medium	Medium
Commercial fisheries may affect subsistence uses	Medium	Low	Medium

Source: NPFMC (2007)

This assessment did not *score* issues on the potential effectiveness of management response, but it did provide a narrative summary of potential consequences of management for each issue. It also characterized what the Council was already doing to address the issue and what opportunities (strategies) existed to mitigate the risk. This type of information could inform the management response scores that our process calls for. (See Implementation Volume.)

In the FEP Loop, this information will then be used to identify a subset of issues that score high on probability of occurring, severity of impact, and effectiveness of intervention. These high-scoring issues are good candidates for management action.

Step 3: "How will we get there?"

In this step, FEP developers will prepare to operationalize the plan by considering performance measures and potential management actions. Suggested actions include:

- **Develop performance measures:** Performance measures are the metrics describing the fishery system and desired (or avoided) levels for each. They relate directly to the measurable quantities described in the operational objectives as a way to gauge performance and progress towards those objectives.
- **Identify potential management strategies:** Managers and stakeholders should create a thorough list of possible actions and formulate them into alternative management strategies. A management strategy comprises multiple coordinated actions designed to reach the operational objective. It should also specify predetermined management actions that are triggered in response to performance measures. The goal of this stage of the FEP development process is to identify multiple candidate-management strategies, whose likely performance can then be evaluated. The development of management strategies in an EBFM context is enhanced through the explicit consideration of linkages among system components.
- **Evaluate consequences of alternative management actions:** Predict the likely outcomes for each performance measure under each alternative management strategy and judge the sensitivity to key uncertainties. This step screens out poorly performing management strategies, identifies approaches that are robust to various types of uncertainty, and reveals the trade-offs from selecting one strategy over another. A range of tools exists to give effect to this step, including management strategy evaluation and cost benefit analysis. (See Implementation Volume.)
- **Select management strategy:** Managers determine how this step should be carried out, including how to incorporate stakeholder input from across the process.

Strategies should be adaptive, responding to changes in the fishery system. Monitoring and evaluation are therefore critical. (See Example Boxes 3 and 4.)

EXAMPLE BOX 3: BIOLOGICAL REFERENCE POINTS AS PERFORMANCE MEASURES

This box illustrates step 3 of the FEP Loop using the hypothetical example of a fishery system that experts suspect has undergone an environmental regime shift. We posit a fishery that targets several species whose productivity and abundance have been low for several years. It is unclear whether this is due to poor environmental conditions caused by a regime shift or to fishing. Consequently, there is debate over whether the performance measures currently used to judge stock status accurately reflect the health of the stock. These biological reference points are the biomass and fishing mortality rate that produce maximum sustainable yield.

The Council seeks to develop a robust process that uses environmental information to revise/modify biological reference points to account for the possibility of regime shifts. The key concerns

Continued on next page

are failing to detect a regime shift and thereby incorrectly declaring stocks to be in poor status, and erroneously detecting a regime shift and thereby incorrectly declaring stocks to be in good status relative to their reference points.

The Council selects the following performance metrics to judge management success: probability of overfishing, probability of underfishing, precision in estimates of biological reference points, the frequency of stock assessment, cost of management, probability of recruitment impairment, long-term average catch, long-term average landed value, and frequency of fishery closures.

In addition to these conventional fisheries management indicators, systemic indicators consider indirect effects from policies. For instance, low catch quotas that result from incorrectly estimating low stock status (e.g., by triggering a rebuilding plan) might prompt fishermen to switch to different target species and use gears that potentially damage sensitive benthic habitats. Or it may prompt them to fish in areas with higher encounters with threatened, endangered, or protected species to avoid catching stocks erroneously deemed to be overfished. So additional performance metrics might include intensity of fishing on vulnerable habitat and number of interactions with threatened, endangered, or protected species, or other possible outcomes caused by fleet behavior.

These metrics are translated into performance measures by specifying either target levels, levels to be avoided, or desired directions of change for each.

Consultation with stakeholders, scientists, and Council staff produces the following alternatives (ordered from most static to most dynamic):

- Status quo. Biological reference points (including overfished threshold) are static and represent a long-term average.
- Perform expert review of stock assessments whenever a set percentage of stocks are substantially above or below biological reference points, to evaluate whether any biological reference points should be adjusted.
- Adopt a standard-of-evidence approach (as in Klaer et al. [2015]) for identifying regime shifts and adjusting biological reference points.
- Adopt a moving window approach. Biological reference points are based on growth, mortality, and recruitment patterns over most recent time periods (Punt et al., 2014).
- Adopt a dynamic approach. Unfished biomass and other biological reference points are based on very near-term conditions (e.g., what would biomass be this year if there had been no fishing of extant cohorts) (MacCall et al., 1985).
- Apply forward-looking biological reference points that predict changes in stock size by anticipating growth, mortality, and recruitment based on biophysical conditions.

The alternatives could be tested in a number of ways. A qualitative review would identify strengths and vulnerabilities for each approach. Expert opinion could be used to score performance measures (e.g., asking experts whether performance metrics are highly likely, likely, unlikely, or highly unlikely) to reach targets. Simulation models could be used to evaluate performance under a variety of scenarios (e.g., different types of stocks, different data availabilities, different intensities of regime shifts, the degree to which low biomass stocks can be avoided by fishing gear).

EXAMPLE BOX 4: CONSTRAINING STOCKS AND INCIDENTAL TAKE IN A MIXED-SPECIES FISHERY

This box illustrates step 3 of the FEP Loop using the hypothetical example of a fishery that targets several groundfish stocks, some of which are below their biomass limit reference point and therefore need rebuilding. Challenges in rebuilding include bycatch and rapidly increasing abundance of predators of the overfished species. Low quota of overfished species severely constrains fishing opportunities for the fleet. Further, these costs are not spread equally, as overfished species are associated with habitats that are clustered near specific fishing ports. Finally, participants in this fishery are switching to other, state-regulated fisheries and are not catching their quota for groundfish stocks, thereby diminishing economic returns for processors.

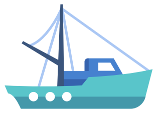
The Council has prioritized this complex issue for attention in an FEP. The problem has multiple dimensions: food web linkages, incidental catch, potential technical and economic solutions, and economic and social consequences that have ripple effects. An operational objective might be to institute a set of management measures as part of a comprehensive strategy that will allow overfished species to recover within Magnuson-Stevens Act-mandated time frames while improving economic performance of the fleet and associated industries.

Through engagement with stakeholders and policymakers, the following alternative policies are proposed:

- status quo; maintain recovery plan through conventional management (low catch quotas for overfished stocks);
- spatial management; establish spatial protections for overfished stocks;
- apply a multiyear quota system, so that annual quota overages do not shut down the fishery;
- develop and encourage gear programs that provide incentives that can selectively harvest predator species and reduce bycatch of overfished species (e.g., risk pools); and
- mitigate effects on affected fishing communities by granting them access to other fisheries (noting that this would result in reduced allocation to existing participants in these other fisheries).

The outcomes of alternative policies, expressed specifically through performance measures, are evaluated through qualitative or quantitative means. Qualitative analysis might involve structured workshops, qualitative modeling, leading to scoring or ranking of outcomes for each performance indicator across each alternative policy. Quantitative analysis would involve statistical modeling, systems modeling, economic modeling to simulate outcomes. All of these would involve close collaboration among policymakers, scientists, and stakeholders.

In some cases, this evaluation might reveal that unique combinations of policy measures are needed. For example, spatial protection might be deemed ineffective because predator abundance would increase in these areas. Thus, a mixture of spatial protections and selective predator harvest is needed. This evaluation might also identify win-win solutions, such as promoting catches in a piscivore fishery to improve economic performance and enhance rebuilding of overfished stocks. At a minimum, the evaluation will identify strategies that generally perform better than others while also identifying trade-offs.



Step 4: "Implement the plan"

Next, Councils will need to implement the FEP. The implementation of the FEP transforms all the work described above into accomplishments through tangible work projects. This includes development of a formal FEP work plan that describes each project, including but not limited to the following details:

- **work plan:** the actual work to be performed, who will perform it, and how regulatory changes in FMPs, if necessary, will be made;
- **resources:** the resources needed, including funding, staff time, and time commitments by stakeholders and partners;
- **outputs:** the outputs, including the form and level of detail needed to inform subsequent decisions; and
- **timeline.**

Step 5: "Did we make it?"

After implementation, it is critical to assess the performance of the FEP. Ongoing monitoring and evaluation of performance measures and management strategies is an integral part of the FEP process. In particular, FEP evaluation will:

- assess the status of the fishery system to determine whether management strategies are meeting their goals (performance measures); and
- determine if unanticipated outcomes or trade-offs have occurred since implementation of the management strategy (vital sign indicators).

Planning for monitoring and evaluation is critical and thereby is a part of all steps of the FEP process. Monitoring and policy evaluation considerations are a key part of indicator selection, selecting performance measures, and designing management strategies that seek to enhance knowledge of the fishery system.

REPEATING THE STEPS: LEARN AND ADJUST

Adaptive management is critical for EBFM. Systematic learning from management experiences is how we gain better understanding of fishery systems. For example, when we implement catch shares, we learn about incentives that drive fleet behavior and how these behaviors feed back to impact ecosystem indicators (Hilborn et al., 2005; Grafton et al., 2006). When we protect habitats from potentially destructive fishing practices, we reveal how fishing practices affect benthic habitats (Lambert et al., 2014). When we create no-take fishery reserves, we learn about productivity of stocks, their levels of depletion, their dispersal, and in some cases the food web connections (Sainsbury, 1993; Russ et al., 2004; Kellner et al., 2010; Wilson et al., 2014). The FEP therefore needs to include a plan for how information gained in monitoring will be used in subsequent iterations to improve policies and lead to better outcomes.

MANAGEMENT STRATEGIES SHOULD SPECIFY PREDETERMINED ACTIONS THAT ARE TRIGGERED IN RESPONSE TO PERFORMANCE MEASURES.

Oil rig in the ocean (left). Silhouette of a fisherman in action (top right). NOAA Fisheries survey ship underway (bottom right).

REFERENCES

Andrews, K. S., G. D. Williams, J. F. Samhouri, K. N. Marshall, V. Gertseva, P. S. Levin. 2015. The legacy of a crowded ocean: indicators, status, and trends of anthropogenic pressures in the California Current ecosystem. Environmental Conservation 42:139-151.

Ecosystems Principles Advisory Panel. 1999. Ecosystem-based fishery management. National Marine Fisheries Service.

Grafton, R. Q., R. Arnason, T. Bjorndal, D. Campbell, H. F. Campbell, C. W. Clark, R. Connor, D. P. Dupont, R. Hannesson, R. Hilborn, J. E. Kirkley, T. Kompas, D. E. Lane, G. R. Munro, S. Pascoe, D. Squires, S. I. Steinshamn, B. R. Turris, Q. Weninger. 2006. Incentive-based approaches to sustainable fisheries. Canadian Journal of Fisheries and Aquatic Sciences 63:699-710.

Halpern, B. S., K. A. Selkoe, F. Micheli, C. V. Kappel. 2007. Evaluating and ranking the vulnerability of global marine ecosystems to anthropogenic threats. Conservation Biology 21:1301-1315.

Hilborn, R., J. M. Orensanz, A. M. Parma. 2005. Institutions, incentives and the future of fisheries. Philosophical Transactions of the Royal Society of London, Series B: Biological Sciences 360:47-57.

Holling, C. S. 1978. Adaptive environmental assessment and management. Wiley-Interscience, Chichester, UK.

Kellner, J. B., S. Y. Litvin, A. Hastings, F. Micheli, P. J. Mumby. 2010. Disentangling trophic interactions inside a Caribbean marine reserve. Ecological Applications 20:1979-1992.

Klaer, N. L., R. N. O'Boyle, J. J. Deroba, S. E. Wayte, L. R. Little, L. A. Alade, P. J. Rago. 2015. How much evidence is required for acceptance of productivity regime shifts in fish stock assessments: are we letting managers off the hook? Fisheries Research 168:49-55.

Levin, P. S., M. J. Fogarty, S. A. Murawski, and D. Fluharty. 2009. Integrated ecosystem assessments: developing the scientific basis for ecosystem-based management of the ocean. Plos Biology 7:23-28.

Levin, P.S., Kelble, C.R., Shuford, R.L., Ainsworth, C., deReynier, Y., Dunsmore, R., Fogarty, M.J., Holsman, K., Howell, E.A., Monaco, M.E., Oakes, S.A. & Werner, F. (2014). Guidance for implementation of integrated ecosystem assessments: a US perspective. ICES J. Mar. Sci. J. Cons., 71, 1198–1204.

Lambert, G. I., S. Jennings, M. J. Kaiser, T. W. Davies, J. G. Hiddink. 2014. Quantifying recovery rates and resilience of seabed habitats impacted by bottom fishing. Journal of Applied Ecology 51:1326-1336.

MacCall, A. D., R. A. Klingbeil, R. D. Method. 1985. Recent increased abundance and potential productivity of Pacific mackerel (*Scomber japonicus*). CalCOFI.

Magnuson-Stevens Fishery Conservation and Management Reauthorization Act of 2006, Pub. L. No. 109-479, 120 Stat. 3575 (2007).

NPFMC. 2007. Aleutian Islands Fishery Ecosystem Plan. North Pacific Fisheries Management Council.

NPFMC 2014. Status of Ecosystem Based Fishery Management (EBFM) development process and actions, May 2014.

Polasky, S., S. R. Carpenter, C. Folke, and B. Keeler. 2011. Decision-making under great uncertainty: environmental management in an era of global change. Trends Ecol Evol 26:398-404.

Puget Sound Partnership. 2011. Puget Sound Vital Signs. Accessed Sept. 29, 2016. http://www.psp.wa.gov/vitalsigns/pacific_herring_indicator1.php

Punt, A. E., T. A'Mar, N. A. Bond, D. S. Butterworth, C. L. de Moor, J. A. A. De Oliveira, M. A. Haltuch, A. B. Hollowed, C. Szuwalski. 2014. Fisheries management under climate and environmental uncertainty: control rules and performance simulation. ICES Journal of Marine Science 71:2208-2220.

Russ, G. R., A. C. Alcala, A. P. Maypa, H. P. Calumpong, A. T. White. 2004. Marine reserve benefits local fisheries. Ecological Applications 14:597-606.

Sainsbury, K. J. 1993. Application of an experimental approach to management of a tropical multispecies fishery with highly uncertain dynamics. ICES Marine Science Symposium 193:301-320.

Walters, C. J. 1986. Adaptive management of renewable resources. MacMillan Publishing Co., New York.

Westgate, M. J., G. E. Likens, D. B. Lindenmayer. 2013. Adaptive management of biological systems: a review. Biological Conservation 158:128-139.

Williams, B. K., R. C. Szaro, C. D. Shapiro. 2009. Adaptive management: the US Department of the Interior technical guide. Washington, DC: Adaptive Management Working Group, US Department of the Interior.

Wilson, J. R., S. R. Valencia, M. C. Kay, H. S. Lenihan. 2014. Integration of no-take marine reserves in the assessment of data-limited Fisheries. Conservation Letters 7:451-458.

CHAPTER 4

KEY CONSIDERATIONS FOR THE FEP LOOP

Chapter 3 proposes an adaptive planning cycle for ecosystem-based fisheries management (EBFM). This "FEP Loop" is purposefully not prescriptive so that implementation can be customized to regional needs and constraints. The process will undoubtedly be conducted in different ways by different Regional Fishery Management Councils, and the Implementation Volume provides detailed guidance on technical tools available to implement the loop. (available at www.lenfestocean.org/EBFM)

This chapter focuses on three broad observations the Task Force believes should guide the creation and implementation of Fishery Ecosystem Plans (FEPs): (1) existing tools and processes are sufficient to develop FEPs and implement EBFM, (2) stakeholder input is critical and should be central to fishery system planning, and (3) managers must rely on both science and societal value judgments in setting explicit, measurable goals, identifying alternative strategies, and choosing among them.

A pelican dries its feathers while a shrimp boat trawls in the background (left). A school of herring, a forage fish (center). People fishing in the surf (right).

EXISTING TOOLS AND PROCESSES ARE SUFFICIENT TO DEVELOP NEXT-GENERATION FEPS AND IMPLEMENT EBFM

Achieving EBFM through FEPs will involve using and adapting existing scientific tools and policy instruments. This section reviews these two categories.

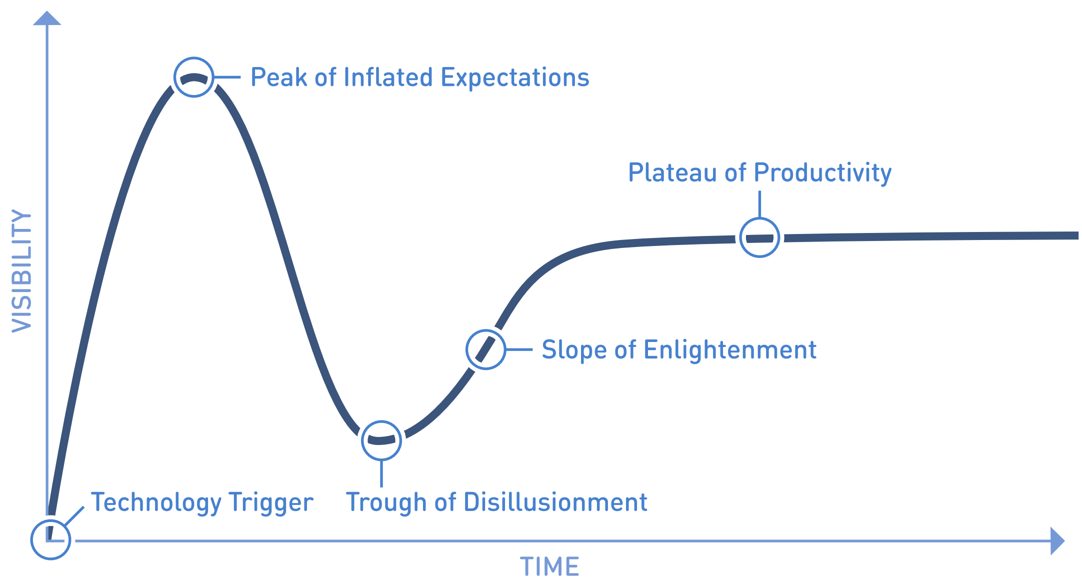
Science Tools

Our review of EBFM activity in selected case studies (Chapter 5) and in our in-depth overview of tools for FEP steps (Implementation Volume) reveal that existing scientific tools are already being used and applied for all parts of the FEP process. These tools cover a broad range of qualitative, semi-quantitative, and quantitative methods and span socio-cultural, economic, and ecological dimensions of fisheries. We therefore conclude, as have others, that scientific tools exist to support the FEP process at many levels of information availability and technical capacity (Smith et al., 2007; FAO, 2009; Lester et al., 2010; Patrick and Link, 2015). This finding opposes the common objection that we lack the ability to provide a technical basis for EBFM. Available science tools span a range of information needs and scientific capacity, meaning that Councils can choose the tools that are the most appropriate given their access to technical experts and data availability. FEPs do not necessarily require large, complex systems models.

This view that science is limiting arises partly from a tendency to hold EBFM science tools to the same technical standards as those used today in conventional fisheries management. These technical standards are unrealistic and inappropriate, in part because EBFM tools are new in comparison to conventional fisheries tools such as stock assessments. In the case of single-species tools, years of experience and development of stock assessment methods have led to a highly standardized process of application, evaluation, and interpretation. Prior to arriving at this point, these tools followed the "hype cycle" (Figure 4.1). With many EBFM tools, we are only somewhere near the peak in the first cycle of technology adoption. Thus, as these tools are used, disappointment and tension should not be viewed as failure of EBFM but as normal, healthy development and adoption, just as single-species tools developed and were adopted. Moreover, it is important to note that single-species tools were used for many years before the performance of the models was fully understood, and managers did not wait to use them until they reached present-day capabilities.

Figure 4.1

THE HYPE CYCLE



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

Source: Gartner's Research Hype Cycle: https://commons.wikimedia.org/wiki/File:Gartner_Hype_Cycle.svg by Jeremy Kemp, used with permission under Creative Commons license BY-SA 3.0: https://creativecommons.org/licenses/by-sa/3.0/deed.en

In addition, EBFM tools should be applied early in any process of assessment or analysis and not delayed until all of the data and information deemed necessary are available. There is a misconception about EBFM tools, and modeling tools in general, that they should be the last step in analyses and should not be attempted with incomplete or imperfect information (Starfield, 1997). EBFM tool development, like most analyses, is best done iteratively, with the initial attempts made early on to identify critical unknowns so that subsequent applications become increasingly robust and relevant to management. Often the model will identify a different set of critical information needs than conventional wisdom or intuition would suggest (Walters, 1986).

Because tools to support EBFM are diverse, the translation of best practices into standards will be different for each type of tool. Clearly articulating best practices that apply to all tools is therefore critical. For instance, it is reasonable to expect that the properties and behaviors of each type of tool are well-understood and vetted in some capacity by decision-makers (Kaplan and Marshall, 2016). In addition, the broad nature of EBFM tools often means that scientists, stakeholders, managers, and decision-makers need to work collaboratively to ensure that science considers key system feedbacks and appropriately addresses the policy issue at hand (Fulton et al., 2013).

Policy Instruments

We expect FEPs to use novel mixtures of existing policy instruments. Councils have already been testing these policy instruments in conventional management settings, and we contend that thoughtfully designed portfolios of these policies can also achieve FEP goals. That is not to say that the current applications of these instruments are always consistent with an EBFM approach or that there is nothing new in the implementation of EBFM. Rather, these instruments have mostly been designed under current objectives, and a new design might be more appropriate under EBFM. These instruments include harvest control rules, community development quotas, catch shares, time and space management, bycatch quotas, risk pools, and quota baskets.

We describe two real-world examples to illustrate the following points regarding the modification of existing policy instruments for EBFM:

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

In the first example, from the Barents Sea, capelin is an important commercially fished species, as well as a key prey species for cod, seabirds, and pinnipeds. Capelin undergo wide fluctuations in population productivity based on environmental conditions and predator abundances (Hjermann et al., 2004; Hjermann et al., 2010). The Joint Norwegian-Russian Fishery Commission, which overseas fisheries management in this region, has dual objectives of sustaining capelin fisheries while conserving adequate prey for predators. To meet the objectives, a strategy was chosen using the conventional idea of a harvest control rule, but modified based on the idea that management should minimize the risk of capelin recruitment failure. To this end, a harvest control rule was modified, wherein annual catches are set such that there is a 95 percent probability of maintaining the capelin spawning stock biomass above a limit reference point of 200,000 metric tons (mt), after accounting for estimated predation removals by the cod population. The limit reference point was selected by identifying the smallest spawning biomass in the capelin data set that had produced a strong recruitment event (100,000 mt), which was then doubled to account for assessment uncertainty (ICES, 2014).

THOUGHTFULLY DESIGNED PORTFOLIOS OF EXISTING POLICY INSTRUMENTS CAN ACHIEVE FEP GOALS.

In the second example, from the Bering Sea-Aleutian Islands ecosystem of Alaska, fisheries catch numerous groundfish species, principally highly valued walleye pollock, Pacific cod, sablefish, and several flatfish species. The North Pacific Fisheries Management Council (NPFMC) set an ecosystem strategic objective to "assure the continued health of the target species themselves and to mitigate the impact of commercial groundfish operations on other elements of the natural environment." An operational objective was to avoid significant and adverse changes to the productivity of the Bering Sea and Aleutian Islands fisheries (NPFMC, 2015). To achieve this objective, the NPFMC modified a conventional single-species catch cap to instead limit combined landings of all groundfish at 2 million mt annually. This reference point was based on the notion that productivity levels of the groundfish species are interdependent. However, quantifying those dependencies is challenging, and existing science tools were not capable of reliably estimating multispecies maximum sustainable yield (MSY). The Council therefore took a simple approach of setting a cap on yields that was within the range of MSY levels summed over all stocks, reduced to account for uncertainty and to make MSY levels closer to optimum yield. The 2 million mt cap has been triggered multiple times since the policy was implemented. Consequently, exploitation rates are commonly less than MSY.

STAKEHOLDER INPUT IS CENTRAL TO FISHERY SYSTEM PLANNING

We envision that stakeholders will contribute to next-generation FEPs in a number of ways (Gray and Hatchard, 2008). They provide important knowledge of biophysical systems, socio-cultural systems, and technical (gear) aspects of fisheries. This information is critical for describing a system and identifying alternative management strategies. Further, stakeholder participation is necessary to understand and account for their values, needs, and desires for the fishery system. This information is critical for setting objectives, performance indicators, and reference levels. Finally, stakeholder participation can help build a sense of ownership and trust in the FEP process.

The Task Force recognizes that effective stakeholder participation can be challenging to achieve. One main challenge is ensuring appropriate representation. Generally, if the cost of participation is high, groups with greater financial resources will be disproportionately represented (Osborn et al., 2000; Berinsky, 2004). Participation costs can be substantial – travel costs and time commitment can dissuade many stakeholders. While such costs cannot be eliminated, they can be reduced by careful planning, selection of appropriate participation tools, and efficient conduct of meetings. The rotation of meeting locations by Councils already is an important step. An additional challenge is that effective participation requires a degree of trust among stakeholders. Well-trained facilitators are generally needed, particularly for the more contentious steps (Gregory et al., 2012). Shared construction of qualitative fishery system models can be an effective way of building trust and shared understanding among diverse stakeholders.

MANAGERS MUST RELY ON BOTH SCIENCE AND SOCIETAL VALUE JUDGMENTS IN SETTING EXPLICIT, MEASURABLE GOALS, IDENTIFYING ALTERNATIVE STRATEGIES, AND CHOOSING AMONG THEM

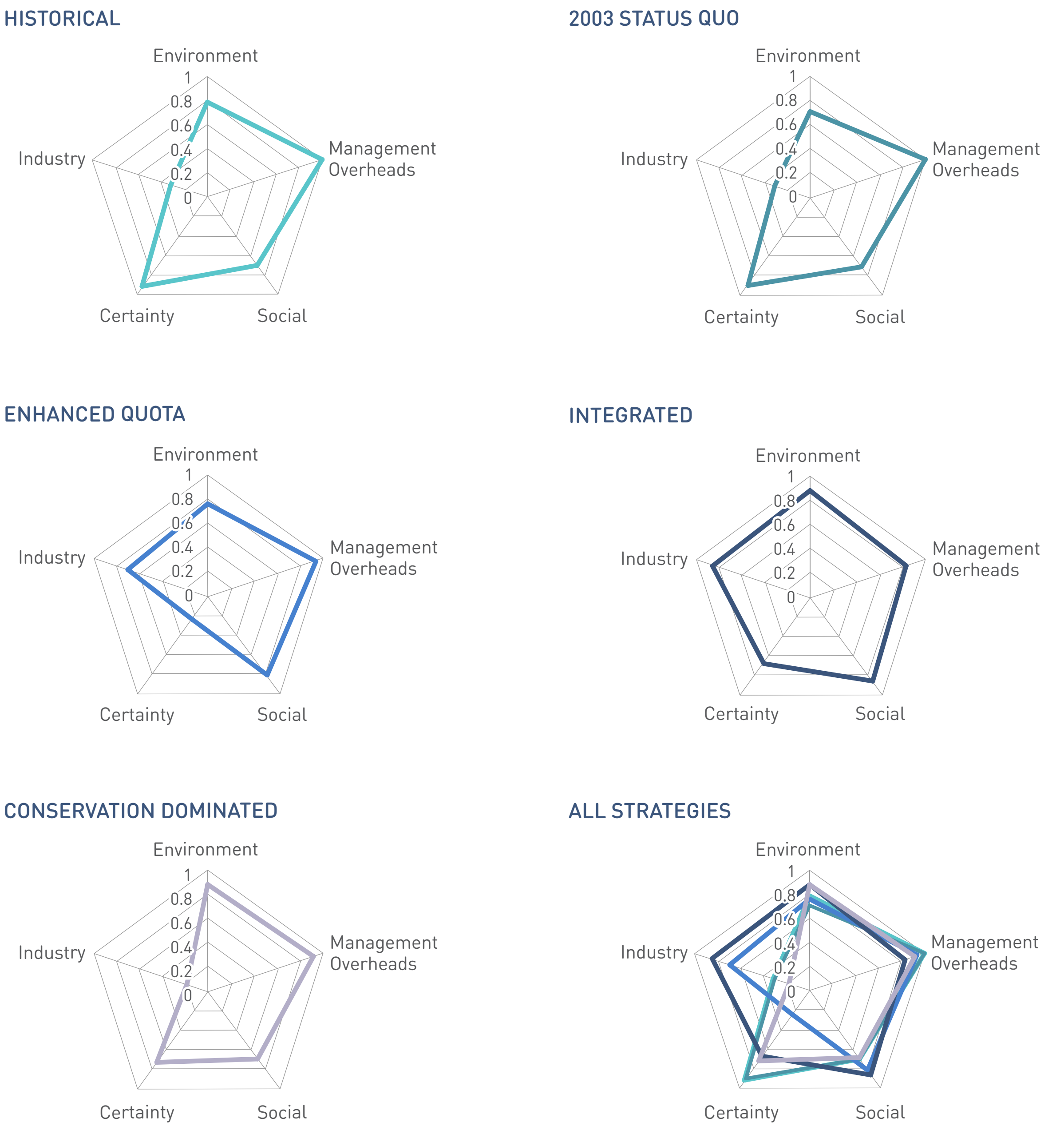
Both scientific analysis and societal values contribute to the FEP process. Science can inform decisions, but answering questions such as "what is important to us," "what are desired states of fishery systems," and "what is the best choice given trade-offs" requires value judgments. We emphasize this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

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

We illustrate the interplay between science and values to inform EBFM decisions using a recent example from southeastern Australia (Fulton et al., 2014). Like most fishery systems, the southern and eastern scalefish and shark fishery in Australia is complex, with many distinct stakeholders, legal mandates, and objectives. Beginning in the early 2000s, poor economic performance and deteriorating ecological status prompted managers to engage stakeholders and scientists to identify management objectives, select performance measures, and identify alterative management strategies. Technical science staff used this information to establish modeling experiments to predict how performance measures would likely respond to each strategy and then summarized the findings to reveal the trade-offs among strategies tested (Figure 4.2). A key finding was that no single strategy outperformed all others on each performance measure. Rather, there were trade-offs that could not be completely eliminated via additional scientific study or strategy evaluation. Thus, decision-making required the judgment of policymakers, who selected the "integrated" strategy because it demonstrated the best balance across management objectives.

Figure 4.2

PREDICTED OUTCOMES FOR 5 ALTERNATIVE STRATEGY SCENARIOS IN AUSTRALIA



A score of 1 indicates good performance, 0 indicates poor performance. No strategy outperformed others across every management dimension, and no strategy can clearly be removed from consideration.

Source: From Fulton et al., 2014

CLOSING COMMENTS

This chapter highlighted important concepts for operationalizing EBFM through next-generation FEPs. These concepts are key because they each span nearly all of the steps of the FEP Loop. Application of FEPs will require attention to many additional considerations that apply to individual steps in the planning process. Detailed guidance on individual steps is provided in the Implementation Volume. (Access at www.lenfestocean.org/EBFM)

Trawlers in a harbor, Perth, Australia.

REFERENCES

Berinsky, A. J. 2004. Silent voices: public opinion and political participation in America. Princeton University Press, Princeton, NJ.

FAO. 2009. Report of the workshop on toolbox for applying ecosystem approach to fisheries. Rome 26-29 February 2008. FAO, Rome.

Fulton, E. A., T. Jones, F. Boschetti, K. L. Chapman, R. L. Little, G. Syme, P. Dzidic, R. Gorton, M. Sporic, W. de la Mare. 2013. Assessing the impact of stakeholder engagement in management strategy evaluation. International Journal of Economics and Management Engineering 3:83-99.

Fulton, E. A., A. D. Smith, D. C. Smith, P. Johnson. 2014. An integrated approach is needed for ecosystem based fisheries management: insights from ecosystem-level management strategy evaluation. PLoS ONE 9:e84242.

Gray, T., J. Hatchard. 2008. A complicated relationship: stakeholder participation and the ecosystem-based approach to fisheries management. Marine Policy 32:158-168.

Gregory, R. S., L. Failing, M. Harstone, G. Long, T. McDaniels, and D. Ohlson. 2012. Structured decision making. John Wiley & Sons, Oxford.

Hjermann, D. Ø., B. Bogstad, G. E. Dingsør, H. Gjøsæter, G. Ottersen, A. M. Eikeset, N. C. Stenseth. 2010. Trophic interactions affecting a key ecosystem component: a multistage analysis of the recruitment of the Barents Sea capelin (*Mallotus villosus*). Canadian Journal of Fisheries and Aquatic Sciences 67:1363-1375.

Hjermann, D. Ø., G. Ottersen, N. C. Stenseth.2004. Competition among fishermen and fish causes the collapse of Barents Sea capelin. Proceedings of the National Academy of Sciences of the United States of America 101:11679-11684.

ICES. 2014. Capelin in subareas I and II, excluding division IIa west of 5°W (Barents Sea capelin). ICES, Denmark.

Kaplan, I. C., K. N. Marshall. 2016. A guinea pig's tale: learning to review end-to-end marine ecosystem models for management applications. ICES Journal of Marine Science: doi:10.1093/icesjms/fsw047

Lester, S. E., K. L. McLeod, H. Tallis, M. Ruckelshaus, B. S. Halpern, P. S. Levin, F. P. Chavez, C. Pomeroy, B. J. McCay, C. Costello, S. D. Gaines, A. J. Mace, J. A. Barth, D. L. Fluharty, J. K. Parrish. 2010. Science in support of ecosystem-based management for the US West Coast and beyond. Biological Conservation 143:576-587.

North Pacific Fisheries Management Council. 2015. Fishery management plan for groundfish of the Bering Sea and Aleutian Islands management area. Anchorage, AK.

Osborn, M. J., J. S. Rosenthal, M. A. Turner. 2000. Meetings with costly participation. The American Economic Review 90:927-943.

Patrick, W. S., J. S. Link. 2015. Myths that continue to impede progress in ecosystem-based fisheries management. Fisheries 40:155-160.

Smith, A. D. M., E. J. Fulton, A. J. Hobday, D. C. Smith, P. Shoulder. 2007. Scientific tools to support the practical implementation of ecosystem-based fisheries management. ICES Journal of Marine Science 64:633-639.

Starfield, A. M. 1997. A pragmatic approach to modeling for wildlife management. Journal of Wildlife Management 61:261-270.

Walters, C. J. 1986. Adaptive management of renewable resources. MacMillan Publishing Co., New York.

CHAPTER 5

CAPACITY TO DEVELOP NEXT-GENERATION FEPS: AN EVALUATION OF CASE STUDIES

Chapter 3 provides a structured process for translating the principles of ecosystem-based fisheries management (EBFM) into action. This chapter examines case studies in the U.S. and abroad to highlight where the steps in this process have been implemented. These case studies suggest that U.S. Regional Fishery Management Councils and similar bodies already have the tools and capacity to develop next-generation Fishery Ecosystem Plans (FEPs) using current management structures and resources.

CASE STUDIES AND APPROACHES

We compiled case studies based on the extensive expertise, knowledge, and geographic scope of the Lenfest Fishery Ecosystem Task Force members. The U.S. case studies span a wide geographic range, with examples from Canada, Europe, and Australia providing additional coverage (Figure 5.1). This was not intended to be a comprehensive review but to provide examples of activities already occurring that fit with our proposed "FEP Loop" process to illustrate the capacity to develop next-generation FEPs.

Figure 5.1

MAP OF CASE STUDIES AND THE MAIN TOPICS COVERED

To compile the case studies, the Task Force gathered information to answer two questions: "what is the major fishery system issue relevant to management?" and "what actions have occurred to address that issue (if any)?" Table 5.1 summarizes the actions in our next-generation FEP framework that have been taken for each case study. Table 5.2 gives details on the management activity that fits each step. For the U.S., we focused on steps taken by the Councils and by one other authority, the Atlantic States Marine Fisheries Commission (ASMFC). We also considered NOAA work presented to or intended for Council use, such as integrated ecosystem assessments (IEAs) and the Chesapeake Bay FEP. For international case studies, we focused on actions taken by Canada's Department of Fisheries and Oceans (DFO); the European Commission and the International Council for the Exploration of the Sea (ICES), which provides scientific advice to the Commission; and the Australian Fisheries Management Authority (AFMA). Every region described has additional EBFM actions underway, but we did not include these, either because they are not complete or are not as illustrative of our FEP framework. Appendix C provides full descriptions of each case study (see www.lenfestocean.org/EBFM). The remainder of this chapter presents the overall findings and key lessons from the case studies.


John Wollwerth/shutterstock

Danita Delimon/Getty Images


Thomas De Craene/EyeEm

Man and child going fishing on a dock with crab trap (top). Popular local fish market in Ketchikan, Alaska (bottom left). Close-up of a lobster swimming underwater (bottom right).

Table 5.1

RESULTS OF THE 10 CASE STUDIES

This table shows 10 case studies of management bodies that have undertaken EBFM (see report for full details). A checkmark indicates that parts of the FEP Loop have been developed for one or more species. This illustrates that the process is feasible using existing tools. However, most of these actions did not take place within the systematic framework of an FEP and therefore did not realize the main advantages of EBFM.

STEPS	NEW ENGLAND GROUNDFISH	MID-ATLANTIC BUTTERFISH	ATLANTIC MENHADEN	GULF OF MEXICO GAG GROUPER
1. WHERE ARE WE NOW?				
System inventory and conceptual model	✓	✓	✓	✓
Select indicators		✓		✓
Inventory threats				
2. WHERE ARE WE GOING?				
Vision statement		✓	✓	
Strategic objectives	✓	✓	✓	
Assess risk to objectives				
Prioritize objectives				
Operational objectives	✓			
3. HOW WILL WE GET THERE?				
Performance measures	✓			
Management strategies	✓			
Evaluate strategies	✓			
Select strategy	*	✓	✓	✓
4. IMPLEMENTATION		✓	✓	✓
5. DID WE MAKE IT?				

* Management alternatives have been voted on by the Council but not adopted.

	PACIFIC SARDINES	PACIFIC WHALES AND SALMON	ALASKA GROUNDFISH	WESTERN SCOTIAN SHELF FISH AND INVERTEBRATES	BALTIC COD, HERRING, AND SPRAT	AUSTRALIAN SMALL PELAGICS
	✓	✓	✓	✓	✓	
	✓	✓	✓	✓	✓	
			✓			
			✓	✓	✓	
	✓	✓	✓	✓	✓	
		✓	✓			✓
			✓			✓
	✓		✓			✓
	✓	✓	✓			✓
	✓	✓	✓			✓
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Table 5.2

CASE STUDY SUMMARIES

CASE STUDY	SUMMARY OF ACTIONS THAT MATCH THE NEXT-GENERATION FEP PROCESS
NEW ENGLAND GROUNDFISH HABITAT	**Step 1.1 & 1.2, system inventory/conceptual model, select indicators:** The NOAA Northeast Fisheries Science Center reviewed the status and trends of the Northeast region (including New England) in the Ecosystem Status Report of the Northeast Shelf Large Marine Ecosystem (Ecosystem Assessment Program, 2012). This report covers a broad range of topics (as with most step 1 actions) and includes indicators such as zooplankton size index, ratio of pelagic to demersal fish biomass, coral distributions, and fisheries revenue. **Step 2.2, strategic objectives:** The New England Fishery Management Council adopted an objective from the essential fish habitat (EFH) mandate in the Magnuson-Stevens Act: "minimize to the extent practicable adverse effects on such habitat caused by fishing, and identify other actions to encourage the conservation and enhancement of such habitat" (Grabowski et al., 2014; Magnuson-Stevens Fishery Conservation and Management Act, 2007). **Step 2.5, operational objectives:** The Fishery Management Plan (FMP) for this fishery includes objectives related to groundfish habitat, such as identifying seasonal closed areas to reduce impacts on spawning. **Step 3.1, 3.2, 3.3, performance measures, identify and evaluate management strategies:** A Closed Area Technical Team (appointed by the Council) identified alternative spatial management strategies. The team then evaluated the strategies based on performance indicators, such as overlap with existing EFH, unique habitat features, and species diversity indices within the areas proposed for protection. **Step 3.4, select strategy:** In June 2015, the Council adopted multiple new and revised closed areas. As of August 2016, the amendment document and accompanying environmental impact statement are undergoing final review by NOAA Fisheries.
MID-ATLANTIC BUTTERFISH	**Step 1.1 & 1.2, system inventory/conceptual model, select indicators:** The Council initiated an EAFM Guidance Document in 2011 (Mid-Atlantic Fishery Management Council [MAFMC], 2015). The first draft (April 2016) has an inventory that includes forage fish, climate, and trends in indicators such as temperature and landings. The draft also has a conceptual model of habitat interactions in the mid-Atlantic. **Step 2.1 & 2.2, vision and strategic objectives:** The MAFMC Strategic Plan (MAFMC, 2013) vision statement is: "Healthy and productive marine ecosystems supporting thriving, sustainable marine fisheries that provide the greatest overall benefit to stakeholders." One strategic objective from the plan is: "Develop management approaches that minimize adverse ecosystem impacts." **Step 3.4, select strategy:** The Council adopted a strategy to improve the stock assessment for butterfish using an ecosystem approach. It involved using a thermal niche model to determine annual estimates of availability of butterfish to the trawl survey. In the end, a constant availability (from the model) was used and directly incorporated into the 2014 assessment (Adams et al., 2015). This improved the assessment and led to updating butterfish reference points.

CASE STUDY	SUMMARY OF ACTIONS THAT MATCH THE NEXT-GENERATION FEP PROCESS
ATLANTIC MENHADEN	**Step 1.1 & 1.2, system inventory/conceptual model, select indicators:** The Chesapeake Bay FEP includes information on Atlantic menhaden, food web interactions, habitat, patterns of total removal, externalities, and economic and social dimensions (Chesapeake Bay Fisheries Ecosystems Advisory Panel, 2006). The FEP also includes a section on indicators of ecosystem health and biological reference points, including an index of ecosystem integrity and multispecies habitat suitability indices. Finally, the FEP includes conceptual models of food webs and habitat webs (diagrams linking fisheries, the ecosystem, and habitat management). **Step 2.1 & 2.2, vision and strategic objectives:** From ASMFC (2012): "The goal of Amendment 2 is to manage the Atlantic menhaden fishery in a manner that is biologically, economically, socially and ecologically sound, while protecting the resource and those who benefit from it." In addition, a "fundamental" objective from the recent ASMFC memorandum is to "Sustain menhaden to provide for predators." To that end, ASMFC is developing ecosystem-based reference points for Atlantic menhaden that will serve to ensure adequate menhaden numbers as forage while allowing a sustainable fishery. **Step 3.4, select strategy:** The ASMFC selected strategies to both improve Atlantic menhaden assessment and protect feeding opportunities of predators within the Chesapeake Bay. Menhaden stock assessments use information on predator consumption of menhaden to better estimate mortality rates and update reference points for menhaden. In the Chesapeake Bay, menhaden catch was capped at 87,200 (mt) (SouthEast Data, Assessment, and Review [SEDAR], 2015) to reduce the probability of localized depletion.
GULF OF MEXICO GAG GROUPER AND RED TIDE	**Step 1.1 & 1.2, system inventory/conceptual model, select indicators:** The Ecosystem Status Report for the Gulf of Mexico (Karnauska et al., 2013) inventories and presents status and trends for individual species, fisheries, and environmental components, such as red tides. A "driver, pressure, state, impact, and response" conceptual model was used to select indicators (Kelble et al., 2013). **Step 3.4, select strategy:** The Gulf of Mexico Fishery Management Council selected a strategy to improve the gag grouper stock assessment by including the large mortality caused by a red tide in 2005 (SEDAR, 2014). This resulted in updated reference points used in existing harvest management strategies.

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CASE STUDY	SUMMARY OF ACTIONS THAT MATCH THE NEXT-GENERATION FEP PROCESS
PACIFIC SARDINES AND TEMPERATURE	**Step 1.1 & 1.2, system inventory/conceptual model, select indicators:** The Pacific Fishery Management Council's (PFMC) Pacific Coast FEP summarizes information on the ecosystem and includes information on Pacific sardines and the relationship with sea surface temperature (PFMC, 2013a). The IEA for the California Current includes a conceptual model of the integrated socio-ecological system, as well as status and trends indicators of forage availability, sea lion pup counts, and seabird at-sea densities (Levin et al., 2013; NOAA's California Current region website). **Step 2.2, strategic objectives:** One objective for the coastal pelagic species FMP (which includes sardines) is to "Provide adequate forage for dependent predators" (PFMC, 2013a). **Step 3, "How will we get there":** The Council convened a workshop to determine new potential management strategies (PFMC, 2013b). Hurtado-Ferro and Punt (2014) performed a management strategy evaluation using an age-structured population model and evaluated strategies based on performance criteria such as variance of catch, mean catch, and spawning stock biomass. The resulting harvest control rule included the use of a new temperature index and a fishery closure when biomass is below 150,000 metric tons (mt). **Step 5:** The sardine stock assessment calls for continued monitoring of the relationship between temperature and sardine productivity.
INTERACTING PROTECTED SPECIES – PACIFIC KILLER WHALES AND CHINOOK SALMON	**Step 1.1 & 1.2, system inventory/conceptual model, select indicators:** The Pacific Coast FEP summarizes information on the entire California Current ecosystem, including salmon in the diet of killer whales (PFMC, 2013a). The IEA for the California Current has a conceptual model (see sardine case study) and includes status and trend indicators of salmon abundance and condition, climate drivers such as El Niño-Southern Oscillation, and sea lion pup counts (Levin et al., 2013). **Step 2.2, strategic objectives:** Objectives stemming from the killer whale recovery plan (mandated by the Endangered Species Act) include: "Ensure adequate habitat to support a recovered population of Southern Resident killer whales. Habitat needs include sufficient quantity, quality, and accessibility of prey species" (NOAA Fisheries, 2008). **Step 2.3, risk assessment:** One study assessed risks to killer whales from salmon fisheries (in Hilborn et al., 2012) but did not link them to an explicit objective. **Step 3.3 & 3.4:** Hilborn et al. (2012) conducted an evaluation of the management strategy to close ocean chinook salmon fisheries. They concluded that complete cessation of fishing would increase chinook abundance by a maximum of 25% and that the effects would be difficult to predict but unlikely to translate to increased prey for killer whales, so the Council chose the status quo strategy.

CASE STUDY	SUMMARY OF ACTIONS THAT MATCH THE NEXT-GENERATION FEP PROCESS
ALASKA GROUNDFISH AND AVOIDING ECOSYSTEM OVERFISHING	**Steps 1a & 1b, system inventory/conceptual model, select indicators:** The Ecosystem Considerations Report for the Alaska Regions (North Pacific Fisheries Management Council [NPFMC], 2015a) and Aleutian Islands FEP (NPFMC, 2007) contain thorough inventories with status and trends of indicators such as the Pacific Decadal Oscillation, sea ice extent, catch per unit effort of structural epifauna, diatom abundance anomalies, and groundfish mortality rate. **Step 1.3, inventory threats:** The Aleutian Islands FEP provides a qualitative inventory of threats or risks for the whole ecosystem, including risks of ocean acidification, coastal development, and impacts of fisheries on other biota (see Chapter 3, Example Box 2). **Steps 2.1 & 2.2, vision and strategic objectives:** The Council's vision statement is: "The Council envisions sustainable fisheries that provide benefits for harvesters, processors, recreational and subsistence users, and fishing communities, which (1) are maintained by healthy, productive, biodiverse, resilient marine ecosystems that support a range of services; (2) support robust populations of marine species at all trophic levels, including marine mammals and seabirds; and (3) are managed using a precautionary, transparent, and inclusive process that allows for analyses of tradeoffs, accounts for changing conditions, and mitigates threats" (NPFMC, 2014). The groundfish FMP (NPFMC, 2015b) for the Bering Sea/Aleutian Islands has multiple ecosystem strategic objectives, including "Preserve food web." **Step 2.3 & 2.5, assess risk to strategic objectives and develop operational objectives:** The Alaska Groundfish Programmatic Supplemental Environmental Impact Statement (PSEIS) (NOAA Fisheries, 2004) assesses risk for all objectives. Within the PSEIS and groundfish FMP are specific operational objectives, including "Maintain or adjust current protection measures as appropriate to avoid jeopardy of extinction or adverse modification of critical habitat for ESA-listed Steller sea lions." **Step 3, "How will we get there":** In 2004, the PSEIS reanalyzed management alternatives. Based on performance measures in the PSEIS for various ecosystem metrics (and implied desired directions for metrics), the Council selected the strategy of a systemwide cap of 2 million mt on groundfish catch (NPFMC, 2015b). This cap has been triggered in multiple years, leading to reductions in catch limits, and exploitation rates are thereby commonly less than single-species maximum sustainable yield for most species.
WESTERN SCOTIAN SHELF FISH AND INVERTEBRATE FISHERIES	**Step 1.1 & 1.2, system inventory/conceptual model, select indicators:** The State of the Ocean Report for the Scotian Shelf, as well as the Ecosystem Status and Trends Report for the Gulf of Maine and Scotian Shelf (Worcester and Parker, 2010) presents a system inventory, as well as time series data on multiple indicators in this system, such as North Atlantic Oscillation index, pH trends, and Bray–Curtis Index of similarity of species. **Step 2.1 & 2.2, vision and strategic objectives:** The vision statement from the DFO Regional Oceans Plan for the Maritimes Region is "Healthy marine and coastal ecosystems, sustainable communities and responsible use supported by effective management processes" (DFO, 2014). Overarching all fisheries in the region are conservation and social objectives (see DFO [2013] as an example) such as: "Biodiversity: Do not cause unacceptable reduction in biodiversity in order to preserve the structure and natural resilience of the ecosystem."

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CASE STUDY	SUMMARY OF ACTIONS THAT MATCH THE NEXT-GENERATION FEP PROCESS
BALTIC COD, HERRING, AND SPRAT	**Step 1.1 & 1.2, system inventory/conceptual model, select indicators:** A Working Group on Integrated Assessments of the Baltic Sea (WGIAB) produced assessments of the various subsystems of the Baltic Sea (ICES, 2015). These assessments include multivariate analyses of time-series for ecosystem indicators encompassing abiotic (nutrients, hydrography) as well as plankton and fish time-series. **Step 2.1 & 2.2, vision and strategic objectives:** The Common Fisheries Policy of the European Union (EU) gives the following goal: "Fish stocks should be brought up to healthy levels and be maintained in healthy conditions." A strategic objective for herring, cod, and sprat specifically is to "ensure that the Baltic stocks of cod, herring and sprat are exploited in a sustainable way according to the principles of maximum sustainable yield and of the ecosystem approach to fisheries management" (COM, 2013). **Step 3.4, select strategy:** The EU adopted a strategy to improve stock assessments by updating sprat and herring reference points using single-species stock assessments with mortality parameters determined by multispecies models (ICES, 2015). These updated reference points are used in the harvest strategy.
AUSTRALIAN SMALL PELAGIC FISHERY AND ECOSYSTEM IMPACTS	**Step 2.3, risk assessment:** Daley et al., (2007) carried out an ecological risk assessment for the fishery that examines the risks to five ecological components: target species; byproduct and bycatch species; threatened, endangered, and protected species; habitats; and ecological communities. **Step 2.5, operational objectives:** Management endorsed the use of the Marine Stewardship Council's (MSC) criteria for evaluating the impacts of fishing low trophic-level species on the ecosystem that were suggested by the group of fishery scientists reviewing the fishery. The criteria are: (1) no more than 15% of other species or groups are impacted by more than 40% and (2) no species is impacted by more than 70% (MSC, 2014). **Step 3 "How will we get there":** The objectives included a specific performance measure – change in biomass of species – and stated the need to avoid a change of more than 40%. Management strategies were identified by a group of fishery scientists with considerable interaction with AFMA and stakeholders in the fishery. Researchers used an ecosystem model (Smith et al., 2015) to evaluate management strategies. They concluded that the status quo target stock size (50% of unexploited biomass) met the performance measure, and AFMA selected it as the management strategy.

Note: Step 4 is not shown in the table. In general, when step 3 has been carried out, so has step 4.

OVERVIEW OF FINDINGS

Across the case studies, managers have already undertaken activities (actions corresponding to individual steps or substeps) that correspond to the majority of the steps of the Task Force's FEP process (Table 5.2). Moreover, within most case studies, managers have usually undertaken a majority of the substeps. Looking across steps, some activities were fairly common (e.g., step 1, "Where are we?"), whereas activities for step 5 ("Did we make it?") were less common. We note that additional relevant activities may be occurring in the regions covered by our case studies but not documented in a way that we could identify.

Within the first two steps, earlier substeps were more likely to be implemented than later ones, suggesting that continued development of existing EBFM projects would provide benefits. For example, in "Where are we?" there were many examples of system inventories or conceptual models, developing system indicators, and evaluating status and trends, but fewer examples of an explicit process evaluating and listing potential threats to the fishery system. For step 2, "Where are we going?" many case studies had examples of strategic visions and objectives, but none had an explicit prioritization process of those objectives and only three developed more specific operational objectives (to our knowledge). Additionally, there were few examples of risk assessment pertaining to objectives. However, we did find examples of risk assessment without explicit objectives.

For step 3, "How will we get there?" the later activities in our FEP process were more common. There were many cases in which managers identified alternative management strategies and evaluated them against one or more criteria or performance measures (sometimes within FMPs), but fewer cases where the performance measures were explicitly linked to specific operational objectives. It is possible that operational objectives were identified but not explicitly documented; it is also possible that the evaluation of management strategies was conducted without context related to objectives. Additionally, in most cases performance measures did not have specific targets (e.g., desired levels). However, it is possible that in these cases reference directions (preferred directions for change without numerical targets) were used to choose management strategies, although we did not find explicit documentation of this.

There were several examples of management strategies that modified conventional reference points using ecosystem information (steps 3.4 and 4). For example, the harvest strategy for gag grouper used a stock assessment model that explicitly considers mortality due to red tide effects.

KEY LESSONS

The capacity for management to develop next-generation FEPs already exists

Looking across all case studies, nearly all FEP steps have been conducted in some manner, usually in multiple regions. If we also consider scientific research not initiated by management, even more examples emerge that fit within our vision for next-generation FEPs. This includes economic risk assessment for cod, herring, and lobster fisheries in the Gulf of Maine (Ryan et al., 2010), and impacts of climate-driven range shifts of summer flounder (Pinsky and Fogarty, 2012). Still more examples come from work by management that is in progress or completed but not in use. This includes work in the Baltic Sea to calculate multispecies maximum sustainable yield from multispecies models for herring, cod, and sprat (European Commission, 2014; ICES, 2013) and research to develop ecosystem reference points for menhaden by the Atlantic menhaden technical team and the Biological-Ecological Reference Points work group (SEDAR, 2015). Thus, managers have many jumping off points to develop next-generation FEPs using existing science tools, policy instruments, and management structures.

The Australian small pelagic fishery (SPF) was one of a handful of case studies in which managers used an explicit operational objective and corresponding performance measures to evaluate alternative management strategies (see also the New England groundfish and Alaska groundfish case studies). Public concern about the impact of the SPF on predators, protected species, and other fisheries arose in 2012 when a large factory trawler (later dubbed a supertrawler) was brought into the country for use in the SPF (Tracey et al., 2013). This led to a number of government inquiries and to intense scrutiny of the management of the fishery and a call for a review of the SPF harvest strategy. This review was undertaken in collaboration with fishery scientists, AFMA, and stakeholders in the fishery. Operational objectives were: the abundance levels of no more than 15 percent of other species or groups are affected by more than 40 percent, and no species is affected by more than 70 percent (a threshold derived from MSC [2014] recommendations). Management endorsed these criteria and reference points, and researchers then tested management strategies using an ecosystem model (Smith et al., 2015) to determine which met the operational objectives. They found that a target harvest strategy of B50 (50 percent of unexploited biomass) for the target SPF species met the criteria.

Next-generation FEPs can streamline management by placing existing activities in a structured framework

Despite the many steps that have already been undertaken, these activities are rarely conducted as part of a structured decision-making process such as the one described in Chapter 3. The Task Force believes that ongoing activities could have greater impacts on decision-making and improve efficiency if they were integrated using an FEP. In particular, none of these case studies had an explicit prioritization process that we could identify based on expert knowledge or documentation. It is possible that prioritization occurred implicitly or by a process that was not clear to us. Regardless, prioritization is a critical step to reduce a potentially overwhelming situation into a tractable one.

The case study of Atlantic menhaden illustrates how a structured process might have streamlined a management process. In 2015, the ASMFC'S Atlantic Menhaden Technical Team had identified potential performance measures (such as environmental indicators, indices of forage abundance, and prey-predator biomass ratios) and alternative strategies (e.g., cap on annual menhaden catch within the Chesapeake Bay). However, it noted that without clear statements of system goals by the Commission, it could not make recommendations on which potential performance measures were most appropriate (SEDAR, 2015, Appendix E). The Commission has since identified strategic objectives (but not operational), and the Biological-Ecological Reference Points Workgroup is working to select one or more models to develop reference points (analogous to performance measures) based on the objectives (ASMFC, 2015). This example is by no means unique; multiple other case studies had metrics, but few had a formal process for selecting metrics and few related metrics to targets or limits.

FEP-like activities were accomplished in a variety of ways

Commonly conducted activities such as "taking inventory" appear in several forums. Some inventories appear as part of an existing FEP, such as the Pacific FEP (PFMC, 2013a) and the Chesapeake Bay FEP (Chesapeake Bay Fisheries Ecosystem Advisory Panel, 2006). Others exist outside of FEPs, including the Ecosystem Status Report for the Gulf of Mexico (Karnauskas et al., 2013), Ecosystem Status Report for the Northeast Shelf Large Marine Ecosystem (Ecosystem Assessment Program, 2012), Alaska Marine Ecosystem Considerations Report (NPFMC, 2015a), the State of the Ocean Report for the Scotian Shelf, and the Integrated Assessments of the Baltic Sea (ICES, 2015).

Another example of diverse approaches comes from step 3.3, "Evaluating management strategies." In some cases, large ecosystem models are used (e.g., Australia small pelagics) whereas others used single-species models with environmental information (e.g., Pacific sardine). In still other cases, multiple tools are used, including in the Alaska groundfish example, where alternatives were evaluated using a multispecies model, a habitat impact model, and a socio-economic extension of the multispecies model (NOAA Fisheries, 2004).

REFERENCES

Adams, C. F., Miller, T. J., Manderson, J. P., Richardson, D. E., Smith, B. E. 2015. Butterfish 2014 stock assessment. US Dept Commer, Northeast Fish Sci Cent Ref Doc. 15-06; 110 p. Available from NOAA Fisheries, 166 Water St., Woods Hole, MA 02543-1026, or online at http://www.nefsc.noaa.gov/publications.

ASMFC. 2015. Memorandum. http://www.asmfc.org/uploads/file/56426d04BERP_Am3Development_Oct2015.pdf.

ASMFC. 2012. Amendment 2 to the Interstate Fishery Management Plan for Atlantic Menhaden. Atlantic Menhaden Plan Development Team, ASMFC.

Chesapeake Bay Fisheries Ecosystem Advisory Panel (NOAA Chesapeake Bay Office). 2006. Fisheries ecosystem planning for Chesapeake Bay. American Fisheries Society, Trends in Fisheries Science and Management 3, Bethesda, MD.

COM. 2013. Regulation (EU) No. 1380/2013 of the European Parliament and of the Council of 11 December 2013 on the Common Fisheries Policy, amending Council Regulations (EC) No. 1954/2003 and (EC) No. 1224/2009 and repealing Council Regulations (EC) No. 2371/2002 and (EC) No. 639/2004 and Council Decision 2004/585/EC.

Daley, R., Dowdney, J., Bulman, C., Sporcic, M., Fuller, M., Ling, S., Hobday, A. 2007. Ecological risk assessment for the effects of fishing. Report for the midwater trawl sub-fishery of the Small Pelagic Fishery. Report for the Australian Fisheries Management Authority. Canberra, Australia.

DFO. 2013. Canadian Atlantic herring (*Clupea harengus*) – SWNS Rebuilding Plan – Atlantic Canada. 2013. Fisheries and Oceans Canada.

DFO. 2014. Regional Oceans Plan – Maritimes region: background and program description. Fisheries and Oceans Canada. 45 p.

DFO. 2012. State of the ocean report for the Scotian Shelf and the Gulf of Maine [webpage]. http://www.dfo-mpo.gc.ca/oceans/publications/soto-rceo/2012/scotian-ecossais-eng.html. Accessed on 15 April 2016.

Ecosystem Assessment Program. 2012. Ecosystem status report for the Northeast Shelf Large Marine Ecosystem – 2011. US Dept Commer, Northeast Fish Sci Cent Ref Doc. 12-07; 32 p. Available from: NOAA Fisheries, 166 Water St., Woods Hole, MA 02543-1026.

European Commission. 2014. Proposal for a regulation of the European Parliament and of the Council establishing a multiannual plan for the stocks of cod, herring, and sprat in the Baltic Sea and the fisheries exploiting those stocks, amending Council Regulation (EC) No. 2187/2005 and repealing Council Regulation (EC) No. 1098/2007. COM (2014) 614 final. 2014/0285 (COD).

Grabowski, J. H., M. Bachman, C. Demarest, S. Eayrs, B. P. Harris, V. Malkoski, D. Packer, D. Stevenson. 2014. "Assessing the vulnerability of marine benthos to fishing gear impacts." Reviews in Fisheries Science & Aquaculture 22, no. 2: 142-155.

Hilborn, R., S. P. Cox, F. M. D. Gulland, D. G. Hankin, N. T. Hobbs, D. E. Schindler, A. W. Trites. 2012. The effects of salmon fisheries on southern resident killer whales: final report of the independent science panel. Prepared with the assistance of D. R. Marmorek and A. W. Hall, ESSA Technologies Ltd. (Vancouver, B.C.) for NOAA Fisheries (Seattle, WA) and Fisheries and Oceans Canada (Vancouver, B.C.). xv + 61 pp. + Appendices.

Hurtado-Ferro, F., Punt, A. E. 2014. Revised analyses related to Pacific sardine harvest parameters. Pacific Fishery Management Council, Portland, OR.

ICES. 2015. Report of the ICES/HELCOM working group on integrated assessments of the Baltic Sea (WGIAB), 9–13 March 2015, Cádiz, Spain. ICES CM 2015/SSGIEA:08. 30 pp.

ICES. 2013. Report of the benchmark workshop on Baltic multispecies assessments (WKBALT), 4–8 February 2013, Copenhagen, Denmark. ICES CM 2013/ACOM:43

Karnauskas, M., Schirripa, M. J., Kelble, C. R., Cook, G. S., Craig, J. K., eds. 2013. Ecosystem status report for the Gulf of Mexico. NOAA Technical Memorandum NMFS-SEFSC-653. 52 pp.

Kelble, C. R., Loomis, D. K., Lovelace, S., Nuttle, W. K., Ortner, P. B., Fletcher, P., Cook, G. S., Lorenz, J. J., Boyer, J. N. 2013. The EBM-DPSER conceptual model: integrating ecosystem services into the DPSIR framework. PloS ONE, 8:p.e70766.

Levin, P. S., B. K. Wells, M. B. Sheer, eds. 2013. California Current integrated ecosystem assessment: phase II report. Available from http://www.noaa.gov/iea/CCIEA-Report/index.

MAFMC. 2015. Ecosystem approach to fisheries management [webpage]. http://www.mafmc.org/eafm. Accessed 15 April 2016.

MAFMC. 2013. 2014-2018 strategic plan. Mid-Atlantic Fishery Management Council, 800 N. State St., Suite 201, Dover, DE 19901.

Magnuson-Stevens Fishery Conservation and Management Act. 2007. Public Law 94-265. As amended by the Magnuson-Stevens Fishery Conservation and Management Reauthorization Act (P.L. 109-479).

MSC. 2014. MSC fisheries standard and guidance v2.0. Marine Stewardship Council, Marine House, 1 Snow Hill, London EC1A2DH, United Kingdom.

New England Fishery Management Council. 2016. Omnibus essential fish habitat Amendment 2 (in review). New England Fishery Management Council, 50 Water St., Mill 2, Newburyport, MA 01950.

NOAA Fisheries. 2008. Recovery plan for southern resident killer whales (*Orcinus orca*). NOAA Fisheries, Northwest Region, Seattle, WA.

NOAA Fisheries. 2004. Final programmatic supplemental environmental impact statement for the Alaska groundfish fisheries. NOAA Fisheries Alaska Region, P.O. Box 21668, Juneau, AK 99802-1668. pp.

NPFMC. 2015a. Ecosystem considerations 2015: status of Alaska's marine ecosystems. Edited by Stephani Zador. North Pacific Fishery Management Council, 605 W. 4th Ave., Suite 306, Anchorage, AK 99301.

NPFMC. 2015b. Fishery Management Plan for groundfish of the Bering Sea and Aleutian Islands management area. North Pacific Fishery Management Council, 605 W. 4th Ave., Suite 306, Anchorage, AK 99301.

NPFMC. 2014. North Pacific Fishery Management Council Ecosystem based fishery management (EBFM) development process and actions, May 2014. North Pacific Fishery Management Council, 605 W. 4th Ave., Suite 306, Anchorage, AK 99301.

NPFMC. 2007. Aleutian Islands Fishery Ecosystem Plan. North Pacific Fishery Management Council, 605 W. 4th Ave., Suite 306, Anchorage, AK 99301.

PFMC. 2013a. Pacific Coast Fishery Ecosystem Plan for the U.S. portion of the California Current Large Marine Ecosystem – public review draft, February 2013. (Document prepared for the Council and its advisory entities.) Pacific Fishery Management Council, 7700 N.E. Ambassador Place, Suite 101, Portland, OR 97220-1384.

PFMC. 2013b. Report of the Pacific sardine harvest parameters workshop. Pacific Fishery Management Council, Portland, OR.

Pinsky, M. L., Fogarty, M. 2012. Lagged social-ecological responses to climate and range shifts in fisheries. Climatic Change, 115(3-4): 883-891

Ryan, R. W., Holland, D. S. and Herrera, G. E. 2010. Bioeconomic equilibrium in a bait-constrained fishery. Marine Resource Economics, 25(3), pp. 281-293.

SEDAR. 2015. SEDAR 40 – Atlantic menhaden stock assessment report. SEDAR, North Charleston, SC. 643 pp.

SEDAR. 2014. SEDAR 33 – Gulf of Mexico gag stock assessment report. SEDAR, North Charleston, SC. 609 pp.

Smith, A. D. M., CSIRO. 2015. Review and update of harvest strategy settings for the Commonwealth small pelagic fishery –single species and ecosystem considerations. Hobart. Final Report of FRDC Project No. 2013/028.

Tracey, S., Buxton, C., Gardner, C., Green, B., Hartmann, K., Haward, M., Jabour, J., Lyle, J., McDonald, J. 2013. Super trawler scuppered in Australian fisheries management reform. Fisheries, 38(8), pp. 345-350.

Worcester, T., M. Parker. 2010. Ecosystem status and trends report for the Gulf of Maine and Scotian Shelf. DFO Can. Sci. Advis. Sec. Res. Doc. 2010/070. vi + 59 p.

CHAPTER 6

MAIN FINDINGS AND RECOMMENDATIONS

1. OPERATIONALIZING EBFM REQUIRES A STRUCTURED PLANNING PROCESS THAT LEADS TO ACTION

Finding: Existing Fishery Ecosystem Plans (FEPs) are strong on descriptive information, particularly for the biophysical component of fishery systems. However, they generally do not fulfill the Ecosystem Principles Advisory Panel's 1999 recommendations to (1) direct how that information should be used in the context of Fishery Management Plans (FMPs) and (2) set policies by which management options would be developed and implemented. Instead, ecosystem-based fisheries management (EBFM) in the U.S. has proceeded in a piecemeal fashion and without a structured planning process whose goal is to inform management action. Consequently, action has been delayed because there is no process to prioritize among objectives or to make decisions in the face of uncertainty and trade-offs.

Recommendation: The highest priority for next-generation FEPs should be moving from description to actions that operationalize EBFM in the face of multiple objectives, trade-offs, and uncertainty. This should begin with a structured planning process such as the one described in this report. Specifically, FEPs should:

- specify how the FEP leads to changes in FMPs that initiate or modify management actions;
- clearly define goals for the fishery system, recognizing that the goals of different stakeholders may be diverse or conflicting;
- create a process of prioritization that leads to operational objectives, performance measures, and reference points for the fishery system;
- create a process for identifying alternative management actions and evaluating trade-offs among them;
- specify predetermined management actions that are triggered in response to performance measures;
- create a process to monitor management effectiveness; and
- be adaptive, so that lessons learned from implementation are used to iteratively improve management.

2. FEPS CAN BE DEVELOPED USING EXISTING TOOLS AND PROCESSES

Finding: The challenges to implementing EBFM are surmountable using present science tools, policy instruments, and management structures. Although EBFM is often assumed to require complex, sophisticated technical inputs, science tools are available to support the FEP process at all levels of data availability and technical capacity. Policy instruments already used in conventional fisheries management can be used to support FEP goals, and the existing statutory requirements and management structures can accommodate EBFM.

A key challenge to EBFM is understanding and coping with uncertainty. There will always be uncertainty about the fishery system's response to management actions, regardless of management approach. FEPs do not banish uncertainty; they help managers identify it and incorporate it into their decision-making. FEPs are a framework for adaptive management, which reduces uncertainty over time by generating new data from the outcomes of management actions.

Recommendation: The Lenfest Fishery Ecosystem Task Force recommends that U.S. Regional Fishery Management Councils create actionable FEPs using existing tools and processes.

For example, Integrated Ecosystem Assessment (IEA) teams have developed conceptual models, biophysical and socio-cultural indicators, and tools to define and evaluate reference points for several fishery systems. In addition, Councils already have policy instruments from conventional management that can be modified and combined into portfolios to support FEP goals and objectives. Examples include harvest control rules, catch shares, bycatch quotas, and spatial and seasonal management.

3. FEPS CAN INTEGRATE SOCIAL, ECONOMIC, AND ECOLOGICAL GOALS

Finding: Fundamental to EBFM is the conceptualization of fisheries as systems that consist of linked biophysical and human subsystems with interacting ecological, economic, socio-cultural, and institutional components. However, existing FEPs tend to focus on biophysical subsystems and not on human subsystems or linkages between the subsystems.

Recommendation: FEPs should include ecological, economic, and social goals and set forth a process by which decision-makers and stakeholders can address issues and anticipate likely outcomes that span all of these dimensions.

4. FEPS CAN PROMOTE TRANSPARENCY IN DECISION-MAKING AND TRADE-OFFS

Finding: Council decision-making would be improved by using a transparent process to evaluate trade-offs. Confronting trade-offs—i.e., making decisions with full awareness of the attendant costs and benefits – is arguably the single most important function of EBFM.

Recommendation: FEPs should enhance transparency by engaging stakeholders to help define and prioritize objectives, performance measures, and alternative management strategies. These steps are particularly important to implement EBFM because of the large number of potential systemic issues that could be addressed, the large number of performance measures that management will seek to attain, and the diversity of management actions that might be implemented. Selecting among policy alternatives usually involves subjective weighting and trade-offs among performance measures by decision-makers. Transparency and engagement are helpful in making this process responsive to stakeholders and society.

In addition to these findings, the Task Force recognizes that regional experimentation with FEP development presents an opportunity for learning and for sharing lessons across regions. The Task Force therefore also recommends that NOAA and the Councils establish a timetable for a national review of FEPs to compare their structures and outcomes, and to identify what worked and what failed.

The Lenfest Ocean Program is a grantmaking program that funds scientific research on policy-relevant topics concerning the world's oceans and communicates the results. Supported research projects are motivated by policy questions for which additional scientific information could help inform decision-makers of relevant marine science. The Program was established in 2004 by the Lenfest Foundation and is managed by The Pew Charitable Trusts (www.lenfestocean.org, Twitter handle: @LenfestOcean).

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APPENDIX A: Concepts and principles for marine ecosystem based fisheries management

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

Appendix A

CONCEPTS AND PRINCIPLES FOR MARINE ECOSYSTEM BASED FISHERIES MANAGEMENT

Here we articulate the Task Force vision of ecosystem-based fisheries management (EBFM) that underlies and guides our recommendations for fishery ecosystem plans. Many distinct definitions of ecosystem-based managemetn – and EBFM – exist (Grumbine 1994, Larkin 1996, Pikitch et al. 2004, McLeod et al. 2005), so we offer a synthetic definition that encapsulates several common themes among them. That is, we define EBFM as a holistic, place-based framework that seeks to sustain fisheries and other services that humans want and need by maintaining healthy, productive, and resilient fishery systems. (Larkin 1996, Garcia et al. 2003, Pikitch et al. 2004, McLeod et al. 2005, Link 2010, Fogarty 2014). This contrasts with the single-species management framework that is more narrowly focused on the direct consequences of management actions on targeted stocks while largely ignoring the systems (both natural and human) within which those stocks are imbedded.

A more specific vision of EBFM emerges by summarizing commonly-stated principles and concepts. When reviewing the abundant literature on this topic, we found a strong focus on the dynamics, structure, and sustainability of natural systems, with less consideration of the structure and dynamics of human systems, linkages between ecological and human systems and the need for management to meet ecological, economic and social objectives (Urquhart et al. 2011, Halpern et al. 2013, Klain et al. 2014, Anderson et al. 2015, Hilborn et al. 2015) – the triple bottom line (Anderson et al. 2015). We therefore reviewed common principles for EBFM, and updated some as needed to produce a list that includes both ecological and human attributes. Our intent was to identify the principles that have received the most attention (e.g., Long et al. 2015) and are most relevant for fisheries management rather than to form a comprehensive list of EBFM topics.

Fisheries are Systems

Fundamental to ecosystem-based management is the conceptualization of fisheries as systems that consist of linked biophysical and human subsystems with interacting ecological, economic, social, and cultural components (Charles 2001, 2014). Within this context, we synthesize the principles relevant to fisheries as systems.

A system is comprised of its components (e.g. targeted fish stock, people employed by fishing), and the linkages among them. A linkage simply refers to the case when the status or action of one component influences another component. Because fishery systems typically contain many linked components, management actions can produce unintended indirect effects if these linkages are not accounted for (Ecosystems Principles Advisory Panel 1999, Garcia et al. 2003, Bianchi et al. 2008). We describe some of the key types of linkages in natural, human, and cross-system linkages here.

Within the ecological systems, there are important linkages between biophysical processes (e.g. oceanography and geology) with biological processes affecting organisms such as reproduction, growth, and mortality. Fishery systems are also affected by ecological linkages among these organisms – species interactions that range from predation and competition to parasitism and cooperative hunting – that influence individual survival and biological diversity (Ecosystems Principles Advisory Panel 1999, Garcia et al. 2003, Bianchi et al. 2008).

Human systems consist of diverse linkages among individuals directly engaged in fishing (harvesters), the post-harvest system (processors, distribution, and markets), and the larger communities in which these individuals belong. Critically, harvesters are often diverse, consisting of subsistence, recreational and commercial sectors, and actions of one group can indirectly affect another, and these sectors may have distinct objectives for management.

Human systems are strongly and directly linked to natural systems through targeted species – those sought for food or for livelihood – and indirectly to non-targeted species with which targeted species interact. Human systems can also alter the habitats that species depend upon. Critically, economic, cultural and ethical aspects of human systems govern the demand for seafood or livelihoods and thereby dictate the intensity and nature of fishing activities (Long et al. 2015). The status of natural systems directly affects livelihoods of fishery dependent communities and is sometimes critical for maintaining cultural traditions and the meanings the individuals derive from them.

Distinct sectors within human systems also interact whereby activities by one sector affects other sectors – for example, fisheries compete with transportation, energy, and recreational use of water bodies (Halpern et al. 2008). This complexity, especially in coastal and estuarine systems creates significant challenges for management and governance.

Below we review properties of fisheries systems that are relevant for EBFM.

Principles of EBFM: Key attributes of fishery systems

Systems are dynamic

Systems are constantly changing in response to internal and external drivers (Ecosystems Principles Advisory Panel 1999, Garcia et al. 2003, Bianchi et al. 2008, Long et al. 2015). An internal driver might be the recovery of a large, apex predator which results in reductions of lower trophic level species. An external driver might be distant markets that dictate prices for landed fish. These changes can happen over short time scales (seasonal or annual) or over longer time scales (decades). Changes can occur quickly, for instance when climatological conditions shift into distinct regimes.

Diversity provides benefits

Diversity is considered a hedge against uncertainty and a means of enhancing ability of systems to withstand external shocks (Ecosystems Principles Advisory Panel 1999, Garcia et al. 2003, Francis et al. 2007, Bianchi et al. 2008, Long et al. 2015). There are many dimensions of diversity relevant for EBFM. Biological diversity incorporates genetic, taxonomic, functional, and ecosystem characteristics of populations and communities. Human diversity incorporates cultural, ethnic, geographic, and technological characteristics of communities engaged in fisheries. For example, diversity in fishing opportunities can, in some cases, foster the maintenance of livelihoods in the face of environmental and economic variability (Kasperski and Holland 2013).

Resources are limited

There are limits to the rate at which natural systems can provide benefits to humans (Ecosystems Principles Advisory Panel 1999, Garcia et al. 2003). This is already appreciated in single species management, where the maximum long-term sustainable catch is often explicitly estimated for those stocks of particular economic importance. At a systems level, there is a limit on the total rate of removals from an ecosystem that is sustainable. This rate will depend on the inherent productivity of the system, the trophic level of targeted species, and the diversity of species harvested. In most cases, the system-level maximum sustainable yield is less than the sum of individual species maximum sustainable yields largely because the methods used to estimate species maximum yields do not consider the interactions among species (Link 2010).

Systems are scaled in time and space

System dynamics are governed by multiple processes that operate at vastly different scales in time and space (Ecosystems Principles Advisory Panel 1999, Long et al. 2015). The scaling of social, ecological, and institutional processes is critical for effective management of fishery systems. In particular, cross-scale interactions (linkages between processes that operate at small spatial or short temporal scales with those that operate on broader spatial or time scales) are common and can confound prediction and management if not explicitly identified (Ecosystems Principles Advisory Panel 1999). This is because forecasting response of systems with cross-scale dynamics is generally not possible when the system is viewed at only a single scale (Peters et al. 2004). Moreover, lack of formal consideration of cross-scale interactions – particularly between social and ecological systems – often lead to ineffective management decisions (Cash et al. 2006, Peters et al. 2007)

System boundaries are open

Marine ecosystems are porous and boundaries are poorly defined; yet, exchanges across system boundaries can be important drivers of change (Ecosystems Principles Advisory Panel 1999, Long et al. 2015). Open boundaries can contribute to or threaten the stability of an ecosystem. Variable boundary conditions can promote or limit connectivity and thus impact dispersal and migrations of marine organisms and fisheries dependent on them.

Ecological and human system boundaries can be different

Natural, human, and governance subsystems often have different boundaries and geographic scope, which can have management implications. The spatial scope of management needs to be clearly defined (Arkema et al. 2006), as does the extent to which the natural and human systems are influenced by external factors, and the spatial scope of these factors (e.g., markets in one part of the world driving demand for fish products from another part of the world).

Systems have tipping points

System change can be rapid and irreversible, so it is important to know what components of systems confer resilience and maintain those elements (Ecosystems Principles Advisory Panel 1999, Francis et al. 2007, Long et al. 2015). Once a tipping point has been crossed, it must be recognized and appropriate actions must be taken to avoid collapse of fisheries and biological communities that support them. Failure to recognize tipping points makes restoration difficult. Large-scale climatic change is one cause of rapid change that may be followed by sustained conditions for decades. Inertia in the social components of fishery systems can cause lags in the response to ecological or social tipping points.

Principles of EBFM: Key attributes for EBFM implementation

Now that we have a clear idea of the concept and principles of fisheries as systems, we briefly list below a series of guiding principles for implementing EBFM, with specific focus for how scientific information should be used in an EBFM framework. We note here that many of these are not unique to EBFM; that is, they are important components of any successful management system. But rather, these elements are a necessary part of EBFM.

Integrated management is needed

Regional fisheries organizations generally have authority to regulate activities in one ocean use sector (fishing), yet regulatory decisions need to be made in the context of other ocean use sectors (energy, tourism and recreation, shipping, etc.) and in some cases terrestrial land use sectors (e.g. coastal zone development, agriculture). Management plans that presume status quo conditions may not meet their objectives if changes in other sectors alter fishing opportunities or alter population or ecosystem productivity. The cumulative effects of multiple ocean uses on fisheries may be additive, synergistic (the cumulative effect is greater than the sum of individual effects), or antagonistic (the cumulative effect is less than the sum of individual effects) (Thia-Eng 1993, McLeod et al. 2005, Long et al. 2015)

Scientific advice for EBFM is interdisciplinary

EBFM requires integration of several scientific disciplines, such as oceanography, geology, population biology, community food web ecology, economics, anthropology, sociology, and political science (Bianchi et al. 2008, Long et al. 2015).

EBFM requires broad stakeholder involvement

It is important for all stakeholders, including marginalized groups, to be engaged in the decision making process. In an EBFM context, the stakeholder base is typically much broader than in single species management. This engagement is particularly important for mapping trade-offs and for understanding system structure. Broad stakeholder engagement often leads to expanded sets of management alternatives (Bianchi et al. 2008, Daw et al. 2015, Long et al. 2015), and is critical for devising decision rules (Fogarty 2014).

Management decisions must be made under uncertainty

Our ability to predict the behaviour of complex systems is limited, so decisions need to be made in a structured way that acknowledges this uncertainty (Garcia 1994, Ecosystems Principles Advisory Panel 1999, Long et al. 2015, Hall and Mainprice 2004). There are three related concepts that apply to management under uncertainty

Risk-Based Frameworks: Risk-based frameworks identify outcomes that management seeks to avoid, and then judges both the likelihood that management objectives will be met and the effect of uncertainty on objectives (Fletcher 2014).

Precautionary Management: The precautionary approach to management means avoiding actions that have a high risk of causing serious or irreversible harm. Often, the precautionary approach has been associated with placing the burden of proof on individuals that seek to engage in fishing activities to demonstrate that doing so will not cause unacceptable ecological harm (Dayton 1998, Gerrodette et al. 2002). A broad view of the precautionary approach is needed that balances risk across management objectives.

Adaptive management

By evaluating the response of systems to management actions, one can gain understanding about how the system works, thereby reducing uncertainty (Ecosystems Principles Advisory Panel 1999, Garcia et al. 2003, Hall and Mainprize 2004, Long et al. 2015). Consequences of management actions can reveal system linkages that were not previously understood, or their importance under-estimated (Dayton et al. 2002). Although "active" adaptive management that usually requires experimentation is often not feasible (Walters 1997), responsible "passive" adaptive management can be undertaken for most management actions.

EBFM requires ecosystem monitoring, indicators, and reference points

Effective monitoring of fisheries systems is essential to gauge the success of management actions, to identify unintended indirect effects of decisions, to identify changes in the ecosystem that will affect the performance of management systems, and to enable adaptive management. Monitoring under EBFM will likely involve system level indicators and establishing system reference points (Link 2002, Garcia et al. 2003, Hall and Mainprize 2004, Arkema et al. 2006, Bianchi et al. 2008, Tallis et al. 2010). Indicators may track the status of individual components of fishery systems, either because they are directly related to management objectives or because they are a useful proxy of valued components of fishery systems. Indicators may also track the status of the system-level properties relevant for its structure and functioning. System-level reference points indicate target or limits and guide the application of management interventions

Ecosystem decision rules are needed

Just as in single-species management (e.g., where harvest control rules are used to set quota based on estimated stock abundance), EBFM will likely require decision rules that guide tactical decisions based on system state. The adoption of these decision rules will require stakeholder participation to identify system goals, and an analysis of alternative decision rules to identify those that are most likely to meet EBFM management objectives (Hall and Mainprize 2004, Bianchi et al. 2008). Decision rules should be as simple, transparent, and easily understood as is possible (Fogarty 2014).

Trade-offs need to be identified

Because of the connections among and within biophysical and social systems, decisions made to favor some activities (e.g. particular fishing sectors) may cause harm in other sectors. Traditional management often makes decisions without consideration of these trade-offs (Link 2010). Lack of attention doesn't render a fundamental trade-off non-existent. Science can provide information about trade-offs, but usually there is no single win-win management alternative that will maximize benefits across all management objectives (Halpern et al. 2013). Broad stakeholder involvement is needed to identify trade-offs because some trade-offs are hidden from policy makers and scientists tasked with giving advise (Fogarty 2014, Daw et al. 2015). Broader trade-offs with other marine sectors of commerce and use also are implied in comprehensive EBFM, particularly in estuarine and coastal fisheries. Conflicts with transportation, ports, energy industries, and agriculture, for example, will arise, and trade-offs may need to be negotiated.

Protect and restore key components

In many ecological and social systems, a handful of components are responsible for providing benefits from fisheries and thereby support management objectives. Identifying these key components, and then ensuring that actions do not pose risk of irreversible harm to these components, will be an important component of EBFM (Francis et al. 2007). These key components might be ecological keystone species, cultural keystone species, diversity in fishing opportunities, or critical habitats for valued stocks.

References

Anderson, J. L., C. M. Anderson, J. Chu, J. Meredith, F. Asche, G. Sylvia, M. D. Smith, D. Anggraeni, R. Arthur, A. Guttormsen, et al. 2015. The fishery performance indicators: a management tool for triple bottom line outcomes. PLoS ONE 10:e0122809.

Arkema, K. K., S. C. Abramson, and B. M. Dewsbury. 2006. Marine ecosystem-based management: from characterization to implementation. Frontiers in Ecology and the Environment 4:525-532.

Bianchi, G., P. Sandberg, H. R. Skjoldal, and K. Thorarinsson. 2008. The Bergen conference on implementing the ecosystem approach to fisheries (Bergen

Norway, 26-28, September 2006): Summary and main conclusions. Pages 1-19 in G. Bianchi and H. R. Skjoldal, editors. The Ecosystem Approach to Fisheries. FAO, Rome.
Cash, D. W., W. N. Adger, F. Berkes, P. Garden, L. L., P. Olsson, L. Pritchard, and O. Young. 2006. Scale and cross-scale dynamics: governance and information in a multi-level world. Ecology and Society 11:8.
Charles, A. 2001. Sustainable Fishery Systems. Blackwell Science, Oxford.
Charles, A. 2014. Human dimensions in mrine ecosystem-based management. Pages 57-75 in M. Fogarty and J. J. McCarthy, editors. The Sea. Harvard University Press, Cambridge, MA.
Daw, T. M., S. Coulthard, W. W. Cheung, K. Brown, C. Abunge, D. Galafassi, G. D. Peterson, T. R. McClanahan, J. O. Omukoto, and L. Munyi. 2015. Evaluating taboo trade-offs in ecosystems services and human well-being. Proc Natl Acad Sci U S A 112:6949-6954.
Dayton, P. K. 1998. Reversal of the burden of proof in fisheries managment. Science 279:821-822.
Dayton, P. K., S. Thrush, and F. C. Coleman. 2002. The Ecological Effects of Fishing in Marine Ecosystems of the United States,. The Pew Oceans Commission, Arlington, VA.
Ecosystems Principles Advisory Panel. 1999. Ecosystem-based fishery management. National Marine Fisheries Service.
Fletcher, W. J. 2014. Review and refinement of an existing qualitative risk assessment method for application within an ecosystem-based management framework. ICES Journal of Marine Science 72:1043-1056.
Fogarty, M. J. 2014. The art of ecosystem-based fishery management. Canadian Journal of Fisheries and Aquatic Sciences 71:479-490.
Francis, R. C., M. A. Hixon, M. E. Clarke, S. A. Murawski, and S. Ralston. 2007. Ten Commandments for Ecosystem-Based Fisheries Scientists. Fisheries 32:217-233.
Garcia, S. M., A. Zerbi, C. Aliaume, T. Do Chi, and G. Lasserre. 2003. The ecosystem approach to fisheries. Issues, terminology, principles, institutional foundations, implementation and outlook., Food and Agriculture Organization, Rome.
Garcia, S. M. 1994. The precautionary principle: Its implications in capture fisheries management. Ocean & Coastal Management 22:99-125.
Gerrodette, T., P. K. Dayton, S. Macinko, and M. J. Fogarty. 2002. Precautionary management of marine fishereis: moving beyond burden of proof. Bulletin of Marine Science 70:657-668.
Grumbine, R. E. 1994. What is ecosystem management? Conservation Biology 8:27-38.
Hall, S. J. and B. Mainprize. 2004. Towards Ecosytem-based fisheries management. Fish and Fisheries 5:1-20.
Halpern, B. S., C. Klein, J., C. J. Brown, M. Beger, H. S. Grantham, S. Mangubhai, M. Ruckelshaus, V. J. Tullock, M. Watts, C. White, et al. 2013. Achieving the triple

bottom line in the face of inherent trade-offs among social equity, economic return, and conservation. Proceedings of the National Academy of Science of the United States of America 110:6229-6234.

Halpern, B. S., S. Walbridge, K. A. Selkoe, C. V. Kappel, F. Micheli, C. D'Agrosa, J. F. Bruno, K. S. Casey, C. Ebert, H. E. Fox, et al. 2008. A global map of human impact on marine ecosystems. Science 319:948-952.

Hilborn, R., E. A. Fulton, B. S. Green, K. Hartmann, S. R. Tracey, and R. A. Watson. 2015. When is a fishery sustainable? Canadian Journal of Fisheries and Aquatic Sciences:1-9.

Kasperski, S. and D. S. Holland. 2013. Income diversification and risk for fishermen. Proceedings of the National Academy of Science of the United States of America 110:2076-2081.

Klain, S. C., R. Beveridge, and N. J. Bennett. 2014. Ecologically sustainable but unjust? Negotiating equity and authority in common-pool marine resource management. Ecology and Society 19.

Larkin, P. A. 1996. Concepts and issues in marine ecosystem management. Reviews in Fish Biology and Fisheries 6:139-164.

Link, J. 2002. Ecological considerations in fisheries management: When does it matter? Fisheries 27:10-17.

Link, J. S. 2010. Ecosystem-based fisheries management: confronting tradeoffs. Cambridge University Press, Cambridge.

Long, R. D., A. Charles, and R. L. Stephenson. 2015. Key principles of marine ecosystem-based management. Marine Policy 57:53-60.

McLeod, K. L., J. Lubchenco, S. R. Palumbi, and A. A. Rosenberg. 2005. Scientific Concensus Statement on Marine Ecosystem-Based Management,.

Peters, D. P., R. A. Pielke, Sr., B. T. Bestelmeyer, C. D. Allen, S. Munson-McGee, and K. M. Havstad. 2004. Cross-scale interactions, nonlinearities, and forecasting catastrophic events. Proc Natl Acad Sci U S A 101:15130-15135.

Peters, D. P. C., B. T. Bestelmeyer, and M. G. Turner. 2007. Cross-scale interactions and changing pattern-process relationships: Consequences for system dynamics. Ecosystems 10:790-796.

Pikitch, E. K., C. Santora, E. A. Babcock, A. Bakun, R. Bonfil, D. O. Conover, P. Dayton, P. Doukakis, D. Fluharty, B. Heneman, et al. 2004. Ecosystem-based fishery management. Science 305:346-347.

Tallis, H., P. S. Levin, M. Ruckelshaus, S. E. Lester, K. L. McLeod, D. L. Fluharty, and B. S. Halpern. 2010. The many faces of ecosystem-based management: Making the process work today in real places. Marine Policy 34:340-348.

Thia-Eng, C. 1993. Essential elements of integrated coastal zone management. Ocean & Coastal Management 21:81-108.

Urquhart, J., T. Acott, M. Reed, and P. Courtney. 2011. Setting an agenda for social science research in fisheries policy in Northern Europe. Fisheries Research 108:240-247.

Walters, c. 1997. Challenges in adaptive management of riparian and coastal ecosystems. Conservation Ecology 1:[online] URL: http://www.consecol.org/vol1/iss2/art1/.

APPENDIX B: Challenges to EBFM

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

Appendix B
Challenges to EBFM

The following page presents a table of challenges to EBFM identified from the scientific literature, with the Task Force's suggestions for how a new generation of FEPs can overcome them.

Theme	EBFM Challenge	FEP Solution
System boundaries and jurisdictions	Scale issue: mismatch between ecological, social, and legal jurisdictional scales[1–4]	FEPs explicitly state the scope of the issues they are trying to address in the "Where are we?" step of the FEP loop; these will be prioritized in the "Where are we going?" step
Integrated management/ Interdisciplinarity	Mismatch of spatial and temporal scale of social science and natural science data	FEPS can identify where there are data gaps and mismatches in the "Where are we?" step of the FEP loop and the prioritization process "where are we going?" will identify where they matter. This can lead to identification of strategies to match the data scales
Stakeholder involvement	Many issues with stakeholder participation that are present with single-species management are amplified with EBFM, especially with respect to trade-off decisions[5]	FEPS involve stakeholders at every step of the FEP loop. Concept diagrams identified in the "Where are we going?" step identify relevant stakeholders, and trade-offs analysis in the "How do we get there?" step explicitly recognize stakeholder values.
Uncertainty	Adding drivers to stock assessment increases estimation and measurement uncertainty[6]	FEPS can incorporate model uncertainties and identify robust management strategies in the "How do we get there?" step of the FEP loop
	Ecosystems are complex adaptive systems that require an adjustment in our modeling and thinking[7]	
	Prediction of effects of climate change on fisheries production and distribution is uncertain[8]	
	Reduced predictability about future stock sizes of key specoes[9]	
	There is high uncertainty in ecosystem models because of knowledge gaps in basic ecology[10]	
Indicators and Reference Points	Defining thresholds and limits for ecological functioning is difficult[11]	FEPs loop can define process to assess risk, and allowable activities based on risk, using well-established science tools
	If diversity (stock, genetic, taxonomic, etc.) is important, what tools are available to ensure that diversity is maintained?[11]	FEPs can use the "How do we get there?" step to explore common sense rules to minimize intense selectivity on a limited set of ecosystem components
Trade-offs	Difficulty reconciling tradeoffs among competing interests and values[2,4]	An explicit strength of FEPS is that they can explore trade-offs, with stakeholders, in the "How do we get there?" step of the FEP loop
Objectives	Objectives of EBFM are not as clear as they are for single species management[7,9]	FEPs explicitly state the scope of the issues they are trying to address in the "Where are we?" step of the FEP loop; these will be prioritized in "Where are we going?" step
	Should EBFM attempt to protect every species or only those deemed necessary to maintain ecosystem health[5]	
	It is unrealistic to protect or restore to a natural state[3]	
	EBFM means different things to different people[3,10]	FEPS involve stakeholders at every step of the FEP loop. Concept diagrams identified in the "Where are we going?" step identify relevant stakeholders, and trade-offs analysis in the "How do we get there?" step explicitly recognize stakeholder values.
	Sustainability can be operationally defined in single species assessments (MSY-related) but becomes much more complicated in EBFM.[7]	The "How will we get there?" step of the FEP loop employs Management Strategy Evaluation, which could address questions of multispecies objectives and trade-offs
Costs and Resources	Costs of monitoring and implementation[1,12,13]	The prioritization process in the "Where are we going?" step of the FEP loop will identify and triage where to focus limited resources
	Mismatch between expectations and resources for EBFM[2]	The stakeholder-inclusive prioritization process in the "Where are we going?" step of the FEP loop will identify and triage where to focus limited resources
	Incorporating stakeholders into an entire process is expensive[2,4,14]	
Data and knowledge limitations	Perception that EBFM is too data-hungry, and we have insufficient knowledge and too much uncertainty to move forward[2,3,9]	FEPS can incorporate model and data uncertainties and identify robust management strategies in the "How do we get there?" step of the FEP loop. Qualitative approaches are possible for data poor situations
Complexity	Science is overly complex and difficult[1,9,15–17]	FEPs prioritize explicitly stated objectives in the "Where are we going?" step of the FEP loop, which defines a range of tools that can inform the "How do we get there?" step
	Some practitioners (including scientists) think that doing EBFM means you have to model everything[4]	FEP includes ecosystem status assessment and prioritization of threats in the "Where are we?" step of the FEP loop
	Many hypotheses about ecosystem structure and function[9]	FEPS can incorporate of model and process uncertainties and identify robust management strategies in the "How do we get there?" step of the FEP loop
Perceptions	EBFM proponents perceive any failure of management is due to the lack of EBFM approach, rather than a failure for other reasons.[3]	FEPS involve stakeholders at every step of the FEP loop. Concept diagrams identified in the "Where are we going?" step of the FEP loop will identify pressures and threats, and the different perception of why management may have failed.
	EBFM analyses tend to treat humans as a disturbance rather than a member of the ecosystem.[3]	FEPS involve stakeholders at every step of the FEP loop. Concept diagrams identified in the "Where are we going?" step of the FEP loop will identify pressures and threats, and the different perception of why management may have failed.

References:

1. Jr, J. H. C. et al. Challenges for Implementing an Ecosystem Approach to Fisheries Management. Mar. Coast. Fish. 4, 496–510 (2012).
2. FAO. *Fisheries Management. 2. The ecosystem approach to fisheries.* (2003).
3. Christie, P., Fluharty, D. L., White, A. T., Eisma-Osorio, L. & Jatulan, W. Assessing the feasibility of ecosystem-based fisheries management in tropical contexts. *Mar. Policy* **31,** 239–250 (2007).
4. Leslie, H. M. *et al.* Operationalizing the social-ecological systems framework to assess sustainability. *Proc. Natl. Acad. Sci.* **112,** 5979–5984 (2015).
5. Gray, T. & Hatchard, J. A complicated relationship: stakeholder participation and the ecosystem-based approach to fisheries management. *Mar. Policy* **32,** 158–168 (2008).
6. Skern-Mauritzen, M. *et al.* Ecosystem processes are rarely included in tactical fisheries management. *Fish Fish.* n/a–n/a (2015). doi:10.1111/faf.12111
7. Gaichas, S. K. & Francis, R. C. Network models for ecosystem-based fishery analysis: a review of concepts and application to the Gulf of Alaska marine food web. *Can. J. Fish. Aquat. Sci.* **65,** 1965–1982 (2008).
8. Szuwalski, C. S. & Hollowed, A. B. Climate change and non-stationary population processes in fisheries management. *ICES J. Mar. Sci. J. Cons.* fsv229 (2016).
9. Mace, P. M. A new role for MSY in single-species and ecosystem approaches to fisheries stock assessment and management. *Fish Fish.* **2,** 2–32 (2001).
10. Field, J. C. & Francis, R. C. Considering ecosystem-based fisheries management in the California Current. *Mar. Policy* **30,** 552–569 (2006).
11. Frid, C. L., Paramor, O. A. & Scott, C. L. Ecosystem-based management of fisheries: is science limiting? *ICES J. Mar. Sci. J. Cons.* **63,** 1567–1572 (2006).
12. Walters, C. J. Is adaptive management helping to solve fisheries problems? *AMBIO J. Hum. Environ.* **36,** 304–307 (2007).
13. Hilborn, R. Future directions in ecosystem based fisheries management: A personal perspective. *Fish. Res.* **108,** 235–239 (2011).
14. Tallis, H. *et al.* The many faces of ecosystem-based management: making the process work today in real places. *Mar. Policy* **34,** 340–348 (2010).
15. Murawski, S. A., Brown, R., Lai, H.-L., Rago, P. J. & Hendrickson, L. Large-scale closed areas as a fishery-management tool in temperate marine systems: the Georges Bank experience. *Bull. Mar. Sci.* **66,** 775–798 (2000).
16. Link, J. S. What does ecosystem-based fisheries management mean. *Fisheries* **27,** 18–21 (2002).
17. Rice, J. Managing fisheries well: delivering the promises of an ecosystem approach. *Fish Fish.* **12,** 209–231 (2011).

APPENDIX C: Case Study Narratives and Examples of the FEP Process

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

Appendix C
CASE STUDY NARRATIVES AND EXAMPLES OF THE FEP PROCESS

Groundfish and Habitat in New England

This case study focuses on the Gulf of Maine region in New England, in the Northwest Atlantic larger marine ecosystem, governed by the Northeast Fisheries Management Council (NEFMC).

Background of Fisheries System Topic

One ecologically and economically important finfish fishery in the Gulf of Maine is the multispecies groundfish fishery, with iconic species like cod (*Gadus morhua*) and haddock (*Melanogrammus aeglefinus*). Other important fisheries include the herring (*Clupea harengus*) fishery and the American lobster (*Homarus americanus*) fishery. Groundfish consume both lobsters and herring, and have strong effects on lobster behavior (i.e., reduce their movement and restrict them to shelter habitat; McMahan et al. 2013). Meanwhile, herring is used as bait in the lobster fishery (Grabowski et al. 2010), connecting these two fisheries through this anthropogenic linkage.

There has long been tension among these three fisheries. The groundfish fishery is convinced that the herring fishery both catches groundfish as bycatch and causes groundfish schools to disperse when they catch herring near groundfish schools. Both the lobster and groundfish fisheries supported the federal management efforts to limit the herring fishery through gear restrictions (banned mid-water trawls in favor of purse seining), limits to harvest in specific sections, and seasonal spawning closures in the nearshore waters of the Gulf of Maine that coincide with the peak of the lobster fishing season in summer. The lobster fishery supported these measures in spite of the fact that it made it more challenging for the herring fishery to land the fish that the lobster fishery needs for bait, and it potentially increased the proportion of herring that was landed for human consumption instead of bait. There are also issues around groundfish fishermen landing lobsters (allowed in Massachusetts, but not in Maine) and the limited ability of fishermen to move among fisheries to match the ebbs and flows of different species. The groundfish fishery is extremely stressed, and wants greater access to and certainty in catch levels looking out into the near to midterm (3-5 years). Emergency actions shutting down the groundfish fishery and the annual assessments are causing the industry both severe economic hardship and inducing high levels of stress.

Summary of Management Activity Related to Steps in the FEP Process Loop

The Ecosystem Status Report of the Northeast Shelf Large Marine Ecosystem (Ecosystem Assessment Program 2012) was completed in 2012 and contains descriptions of components of the fishery system, including climate, physical pressures, primary and secondary production, invertebrates, fish, protected species, and anthropogenic factors. This report also includes time-series data on components of the system and indicators (integrative ecosystem measures).

There is EBFM activity related to the groundfish fishery (including cod) and habitat. A strategic objective adopted by the New England Fishery Management Council from the Essential Fish Habitat mandate was – "describe and identify essential fish habitat for the fishery based on the guidelines established by the Secretary under section 305(b)(1)(A), minimize to the extent practicable adverse effects on such habitat caused by fishing, and identify other actions to encourage the conservation and enhancement of such habitat," (NEFMC 2016; Grabowski et al. 2014; Magnuson-Stevens Fishery Conservation and Management Act 2007). Based on this objective, more specific objectives were identified related to EFH and on-going work on groundfish habitat in the NEFMC's Omnibus Habitat Amendment 2. Specifically: "The first groundfish-specific purpose of this amendment is to improve protection for juvenile groundfish and their habitats (Purpose D). Success at younger ages can have positive productivity benefits for managed resources, and therefore action is needed to protect the habitats important for juvenile groundfish, particularly for commercially valuable species. A second groundfish-specific purpose of this amendment is to identify seasonal closed areas in the Northeast Multispecies FMP that would reduce impacts on spawning groundfish and on the spawning activity of key groundfish species, because the protection of spawning fish is needed to sustainably manage stocks (Purpose E)" (NEFMC 2016).

A management strategy evaluation process was used to evaluate various fisheries closures that may impact groundfish habitat based on the objectives above. Specifically, a Swept area seabed impacts model (SASI) was developed to evaluate different gear-types in terms of adverse effects on fish habitat (Omnibus Habitat Amendment 2 Appendix D; Grabowski et al. 2014). The SASI model highlighted areas vulnerable to fishing gear and this information was paired with analyses on juvenile habitat and adult spawning habitat of cod and other groundfish. Based on this information, a Closed Area Technical Team identified potential management strategies in the form of possible alternative closed areas. Information on all the spatial management alternatives (including the preferred strategies) are detailed in the Habitat Omnibus Amendment II Volume 3 (under review at the time this report). The alternative spatial management strategies were then evaluated through impact analysis to determine the potential impacts of each strategy on habitat, human community, protected resources (protected species), managed resources, fisheries, and cumulative impacts (Omnibus volumes IV and V). Alternative spatial management strategies were then voted on by the council (Grabowski per. comm.). There was also additional public comment and public hearings on the Omnibus amendment. As of July 2016, the amendment document and accompanying EIS is undergoing final review. Final NMFS approval and rulemaking will occur later this year.

Butterfish, habitat, and Fisheries Interactions in the Mid-Atlantic

This case study focuses on Butterfish and longfin inshore squid fisheries and habitat of butterfish, in the Mid-Atlantic region of the Northeast United States, governed by the Mid-Atlantic Fisheries Management Council.

Background of Fisheries System Topic

Butterfish (*Peprilus triacanthus*) in the mid-Atlantic is primarily a bycatch species and butterfish bycatch caps have constrained the fishery for longfin inshore squid (*Doryteuthis pealeii*). There is a high degree of habitat overlap between butterfish and squid and technical measures, e.g., minimum mesh size, have been only partly successful in reducing bycatch. The butterfish stock was determined to be overfished in the 2003 stock assessment, but the trends in the 2003 assessment conflicted with trends observed in the following assessment in 2009. One problem with the stock assessment of butterfish is that the degree of overlap between the stock and the trawl surveys is variable depending on environmental conditions – leading to attempts to quantify this in the most recent stock assessment (see below). The 2009 stock assessment resulted in a determination that fishing mortality rates had been extremely low in recent years and could not account for the apparent decline in butterfish biomass. However, the biological reference points estimated from this assessment were rejected by the assessment review panel as a basis for management (Northeast Fisheries Science Center 2010). As a result, the industry was faced with a situation in which it was widely acknowledged that fishing mortality rates on butterfish were extremely low, yet the rebuilding plan continued to call for tight caps on butterfish bycatch in the squid fishery. This situation led to reduced economic benefits to squid fishermen and distrust of the assessment by the industry.

Summary of FEP Process Activity and Tools

There is ongoing work by the Mid-Atlantic Fisheries Management Council (MAFMC) to inventory the fishery system and system-level ecosystem approaches, including information related to forage fish (such as butterfish) and climate. This work is part of the councils EAFM Guidance Document development that was initiated in 2011

(MAFMC 2015). As of April 2016, there was a first draft of the full guidance document that includes trends in indicators such as temperature and landings and a conceptual model of habitat interactions in the Mid-Atlantic.

Work to develop a strategic vision and strategic objectives that broadly relate to the case study topics was completed in 2013 and presented in the MAFMC Strategic Plan (MAFMC 2013). The vision statement decided on is: "*Healthy and productive marine ecosystems supporting thriving, sustainable marine fisheries that provide the greatest overall benefit to stakeholders*," (MAFMC 2013). This vision, other goals, and a comprehensive strategic plan were developed through the "Visioning and Strategic Planning Project". This project was initiated at a time when all MAFMC managed fisheries were rebuilt and no longer overfished, leading to some flexibility to cultivate the council's management strategies (MAFMC 2012). This planning strategy included a "large-scale stakeholder outreach effort" (MAFMC 2012) and input was collected from stakeholders through surveys, port meetings (roundtable sessions), and position letters, with more than 1,500 participants (MAFMC 2012). This effort was initiated in order to gain a full understanding of the system from stakeholder information and to broaden stakeholder involvement (only a small percent of stakeholders participated in the management process previously; MAFMC 2012). Stakeholder involvement included members from commercial and recreational fisheries, environmental organizations, seafood users, scientists and researchers, and more. The vision statement itself was developed based on questions to stakeholders about how they envision "successful" fisheries in the Mid-Atlantic.

One activity related to EBFM is the use of environmental data in the butterfish stock assessment (Adams et al. 2015), leading to a single species harvest control rule with an ecosystem consideration. There was a specific Term of Reference for the stock assessment that required the assessment scientists to consider oceanographic factors and include them in the assessment model if possible. Through an academic-industry-NOAA collaborative process, key environmental drivers of butterfish spatial distribution were identified and used to estimate the annual overlap between the stock and the trawl survey. Specifically, bottom temperature was used to define the availability of butterfish to the NEFSC trawl survey by measuring overlap between their thermal habitat and the trawl survey footprint. This thermal niche model determined annual estimates of availability of butterfish to the trawl survey, but in the end, a constant availability (from the model) was used because there was relatively little interannual variability in availability (62-75%). This information was directly incorporated into the 2014 assessment, which concluded that the stock is not overfished (and never was) and that overfishing is not occurring. While this difference in estimated stock status cannot be attributed to the use of environmental data, the inclusive process by which the environmental data was brought into the assessment resulted in greater confidence in the assessment by industry.

One tactical tool not currently in use is habitat modeling to identify areas of high butterfish bycatch that squid fishermen can avoid. Preliminary investigation suggests that the habitat preferences of the two species are too similar to reliably separate them by habitat.

Atlantic Menhaden

This case study focuses on the forage fish Atlantic menhaden. The present-day fishery is concentrated in the Mid-Atlantic, specifically in coastal, nearshore, and estuarine regions. Management of Atlantic menhaden is governed by the Atlantic States Marine Fisheries Commission (ASMFC).

Background of Fisheries System Topic

Atlantic menhaden (*Brevoortia tyrannus*) constitutes the biggest fishery in the Mid-Atlantic large marine ecosystem. This species has historically contributed from 100,000 to above 700,000 tons annually. Menhaden is a key forage for other managed species in regional fisheries and are important prey for seabirds and marine mammals. Products from the menhaden reduction fisheries supply feeds to livestock and aquaculture industries on a global scale and products from the bait fisheries on menhaden supply bait to other managed fisheries (e.g., crabs, lobster). Menhaden spawn offshore but juvenile production is dependent on estuarine nurseries.

The Atlantic menhaden has been referred to as "the most important fish in the sea," highlighting its role in supporting predators in the ecosystem and potentially having an important role in improving or affecting water quality through its filtering activities. So-called "localized depletion" of menhaden concerns recreational fishermen who believe predator availability is controlled by local abundance of menhaden, and this led to a cap on menhaden catch in the Chesapeake Bay. A single company catches and processes most menhaden. Additionally, a single, large facility processes the Atlantic menhaden catch from the Atlantic reduction fishery. Human health supplements (omega-3 products) are a relatively new product of the menhaden industry.

Menhaden in the Chesapeake Bay are managed as a part of the coastwide menhaden stock- the assessment of menhaden and its coastwide reference points and management include the Chesapeake component of the fishery. However, special regulations on fishing are imposed in Chesapeake Bay, including a cap on total catch. Local regulations abound in the Bay—e.g., purse seines are not allowed in Maryland waters, but are the major fishing gear used in Virginia to catch menhaden. The ASMFC has allocated menhaden among the states that have historically fished them and the biggest allocation is to Virginia, with a large part of that state’s allocation coming from catches in Chesapeake Bay (>50,000 tons annually in recent years).

Summary of Management Activity Related to Steps in the FEP Process Loop

The Chesapeake Bay FEP is one system inventory that includes information on Atlantic menhaden (Chesapeake Bay Fisheries Advisory Panel 2006) (alternatively The Ecosystem Status Report for the Northeast Shelf Large Marine Ecosystem also is a relevant system inventory for this case study).

The strategic vision for the menhaden fishery involves maintaining a valuable and sustainable menhaden fishery while avoiding damage to the ecosystem and menhaden-dependent predators. Specifically, from ASMFC (2012): "*The goal of Amendment 2 is to manage the Atlantic menhaden fishery in a manner that is biologically, economically, socially and ecologically sound, while protecting the resource and those who benefit from it."* This strategic vision was developed over multiple years and the original statement was very focused on the menhaden fishery and its yield. Through pressure from multiple stakeholders, mainly recreational fisheries and environmentalists, the strategic vision was broadened and the ASFMC gradually accepted and included ecosystem-level objectives that currently make up the vision statement (see ASMFC 2004). In addition to this vision statement, broad level objectives for the fishery can be found in the most recent stock assessment (SEDAR 2015).

Two relevant ecosystem-related management strategies exist for menhaden. Within the stock assessment for menhaden, a predation mortality value derived from a Multispecies Virtual Population Analysis provides a measure of age-specific natural mortality, leading to a single-species harvest control rule/strategy with an ecosystem consideration. Alternatively, in the Chesapeake Bay, there is a management strategy that caps the catch at 87,200 metric tons (mt) (SEDAR 2015), a measure enacted by ASMFC to reduce the probability of localized depletion of menhaden (ASMFC 2005).

An Atlantic Menhaden Technical Team and the Biological-Ecological Reference Points subgroup identified performance indicators for menhaden including environmental indicators, indices of forage abundance, and prey: predator ratios (SEDAR 2015). This team also worked on developing ecosystem reference points (ERPs) but stated that without explicit goals from the board, they could not recommend a ERP to adopt (SEDAR 2015 Appendix E). However, an inclusive set of performance indicators was identified and the BERP subgroup is proceeding with development of model and MSE-like analysis to test different harvest control rules. The BERP indicator and reference point work and recommendations in SEDAR 40 led the ASMFC to develop ecosystem objectives (ASMFC memorandum - 2015). Fundamental objectives such as "sustain menhaden to provide for predators" were identified. This work is on-going and not currently used in management.

In addition, there is ongoing research outside of ASMFC to develop ecosystem indicators and ecosystem reference points for Atlantic menhaden through a Lenfest-funded project, based on a coastwide Ecopath with Ecosim modeling approach. Additionally, the ASFMC recently launched a socio-economic study for Atlantic menhaden (ASMFC 2016).

Red Tide Impacts on Gag Grouper in the Gulf of Mexico

This case study focuses on the Gag grouper (*Mycteroperca microlepis*) fishery in the Gulf of Mexico, specifically from the coast to the continental shelf edge of the marine ecosystem, primarily in the eastern half of the Gulf. This region is governed by the Gulf of Mexico Fishery Management Council and the Florida Fish and Wildlife Conservation Commission.

Background of Fisheries System Topic

Gag grouper is a 2nd-level priority species (the stock(s) are designated as overfished OR stock(s) are undergoing overfishing or in need of an assessment) in the Gulf of Mexico and one of the more important reef fish species exploited in the eastern Gulf (second only to red grouper). There are three types of fisheries for Gag grouper: a commercial fishery, a recreational fishery, and a for-hire fishery (charter- and headboat), with the recreational fishery having overwhelmingly large catch. Because Gag is part of a multi-species reef fish complex, the targeted species in this group (e.g., gag) results in significant bycatch of other economically important reef fishes (e.g., red snapper *Lutjanus campechanus*, scamp *Mycteroperca phenax*, red grouper *Epinephelus morio*). Bycatch mortality (e.g., due to size limits, season) exceeds the landed catch because fish often occur at depths that preclude recovery from baro-trauma. Prey of Gag grouper includes some economically important species as well (e.g., vermilion snapper). Gag are piscivorous top-level predators as adults on offshore reefs, but primarily crustacivores as juveniles in seagrass habitat. There is continued research focused on offshore spawning sites of gag grouper, but no attention paid to two other essential habitats: open water (important for larval stages) and seagrass beds occupied by juvenile Gag.

Finally, harmful algal blooms or red tide events in the West Florida Shelf likely cause increased mortality for gag grouper. Particularly, a severe event in 2005 coincided with a sharp decline in gag grouper abundance indices. However, the mechanism behind how red tide causes mortality in gag is not known (direct toxicity or indirect impact) (SEDAR 2014).

Summary of Management Activity Related to Steps in the FEP Process Loop

The Ecosystem Status Report for the Gulf of Mexico (Karnauska et al. 2013) summarizes components of the fishery system. This report also presents status and trends for individual species, fisheries and environmental components/indicators such as data on trends of red tide events. This report is part of the Integrated Ecosystem Assessment work for the Gulf of Mexico and a DPSER conceptual model was used to select indicators that "reflect the status of key drivers, pressures, states, ecosystem services, and responses in the ecosystem" (Kelble et al. 2013).

Management is still single-species management, with little of no direct consideration of ecosystem-level concerns except for those relevant to red tide, which led to a single species management strategy with an ecosystem consideration. An additional source of mortality was added to the Gag grouper stock assessment in the Gulf of Mexico because of the large mortality caused by a red tide event in 2005 (SEDAR 2014). Red tide was modeled as a fishing fleet removing Gag and picked up as "discard" rather than "directed fishing mortality", doubling mortality predicted in the previous SEDAR (10). There is also ongoing work by the Integrated Ecosystem Assessment working group (presented in the gag stock assessment) on red tide severity indices (from remote sensing data and FWRI's Harmful Algal Bloom database), that could be used as environmental covariates in the stock assessment model (SEDAR 2014). However, these indices are not currently used. Additionally, there is continued monitoring of red tide events with the goal to be able to forecast potential problems from red tide and determine how it actually affects fish.

Pacific Sardine and Temperature

This case study focuses on the Pacific Sardine fishery in the California Current ecosystem in the Northeast Pacific, managed by the Pacific Fishery Management Council.

Background of Fisheries System Topic

The Pacific sardine (*Sardinops sagax*) fishery was the largest in terms of catch for any of the species included in the PFMC CPS (Coastal Pelagic Species) FMP in the California Current system, till the closure of the fishery in 2015. Sardine are prey for predatory fish in the west coast groundfish, salmon, halibut, and migratory species (including albacore) fisheries, leading to potential trade-offs between fisheries. Sardine are also prey for other marine species, including protected marine mammals and seabirds.

Sardine recruitment is related to ocean conditions, with specifically higher recruitment in warm ocean conditions (related to PDO). The current sardine harvest control rule addresses these issues. General pelagic harvest control is set to be:

Harvest Target Level = (BIOMASS-CUTOFF) x FRACTION x DISTRIBUTION (Hill et al. 2014). The CUTOFF term is the lowest estimated value of biomass, below which no fishing is allowed (to protect the stock when biomass is low). Recently in 2015 the fishery was shutdown because it's believed to have dropped below this level. The FRACTION term is set at anywhere between 5-20% based on temperature for the previous 3 years since sardine productivity is higher in warmer ocean conditions (higher FRACTION with higher temperatures). There is also a maximum allowable catch that is set at 200,000 mt so that there is never extremely high catch levels in case there is an error in biomass estimation. Max catch and cap on catch help to allow for (or buffer for) continued prey for sardine predators. This harvest control rule also assumes 87% of the stock is in US waters (to deal with management across countries).

Summary of Management Activity Related to Steps in the FEP Process Loop

The Pacific Coast Fishery Ecosystem Plan summaries information on the entire California Current ecosystem and includes information on Pacific sardine and the relationship with sea surface temperature (PFMC 2013a). Within this FEP, there is a summary of ecosystem goals across Fishery Management Plans (FMPs). One broad goal or objective for Coastal Pelagic species (including sardine), is to "Provide adequate forage for dependent predators" (PFMC 2013). Additionally, there is an Integrated Ecosystem Assessment (IEA) for the California Current that includes status and trends of specific components (Levin et al. 2013).

The harvest control rule stated above that includes the temperature related term, was decided on based on a recent management strategy evaluation. The strong relationship between sea surface temperature (originally at Scripps pier) and recruitment was established in a management context by Jacobsen and MacCall (1995) during work on the sardine assessment (later approved by the SSC). In later assessments, it became apparent that the pattern between Scripps sea surface temperature and sardine productivity no longer held (Kevin Hill pers. Comm., McClatchie et al. 2010, Lindegren et al. 2012). Work by McClatchie et al. 2010 also showed a relationship between California Cooperative Oceanic Fisheries Investigations (CalCOFI) sea surface temperature and sardine productivity. After the deficiency of Scripps pier temperature as a predictor was identified by stock assessment scientists and the SSC, the Pacific Fishery Management Council convened a workshop to determine a new initial set of management strategies (PFMC 2013b). This workshop included members of the SSC, the PFMC CPS Advisory subpanel, the PFMC CPS management team, and other scientists. Hurtado-Ferro and Punt (2014) took the management strategies identified in the 2013 workshop and performed a management strategy evaluation using an age-structured population model of Pacific Sardine as the operating model and evaluating the performance of the strategies based on different performance criteria or indicators, such as variance of catch, mean catch, SSB, and more (see Hurtado-Ferro and Punt 2014 for all criteria and strategies). Strategies tested included using the previous temperature indicator, the new temperature indicator (CalCOFI temperature), and various levels of the cut-off value. After the MSE was reviewed, the control rule that included the use of CalCOFI temperature was selected (see PFMC 2014b). The continued use of the 150,000 mt cut-off management strategy was included in the selected strategy.

There was/is continued monitoring of the relationship between temperature and sardine productivity in the stock assessment and through this monitoring it was originally discovered that the relationship between Scripps pier temperature and sardine productivity no longer held. Moving forward, there is no formal re-evaluation of the temperature-recruitment relationship from year to year, but monitoring of these factors in the stock assessments can show when there is deviation from the pattern.

Interacting Protected Species in the Pacific (Killer whale and Chinook Salmon)

This case study focuses on protected salmon species (particularly Chinook, *Oncorhynchus tshawytscha*) in the Northeast Pacific (California Current to S.E. Alaska, including Puget Sound) and protected marine mammal predators that prey on salmon. Salmon fisheries on the West Coast are managed by the Pacific Fisheries Management Council, in cooperation with the Pacific Salmon Commission, which provides guidance on the international Pacific Salmon Treaty between the U.S. and Canada. Marine mammal populations are managed by NOAA Fisheries.

Background of Fisheries System Topic

Pacific salmon fisheries on the US West Coast primarily target Chinook, Coho (*Oncorhynchus kisutch*), and Pink Salmon (*Oncorhynchus gorbuscha*) and 17 species are listed as threatened or endangered under ESA. Fisheries sectors include ocean commercial fisheries, recreational fisheries, and tribal (commercial, subsistence, and ceremonial) fisheries. Salmon management over the past several decades has focused on controlling and mitigating the 4 H's: harvest, hatcheries, hydropower dams, and habitat.

Potential conflicts between fisheries and marine mammals center on Chinook salmon, southern resident killer whales (*Orcinus orca*), and pinnipeds (primarily harbor seals (*Phoca vitulina*) and California sea lions (*Zalophus californianus*)). Southern resident killer whales are listed as endangered under the U.S. Endangered Species Act, and pinnipeds are protected by the Marine Mammal Protection Act (MMPA). Since its inception in 1972, many MMPA-protected pinnipeds on the West Coast have been increasing rapidly. The effects of pinniped and killer whale predation on Pacific salmon are not currently addressed by fisheries management. Additionally transboundary/trans-country salmon migration complicates management because an individual salmon can travel through the ocean waters of two countries and four U.S. states during its life-time, and may be subject to fishing or predation in any of those areas.

Salmon and killer whales are iconic organisms in the Pacific Northwest and both have high non-monetary value in the region. Killer whales also support a lucrative whale watching industry in the San Juan Islands of Washington. Predation interactions create the potential for salmon fisheries to conflict with social goals. While a waiver of the moratorium on take of California sea lions has been granted to haze and remove individuals predating on returning salmon near Bonneville Dam on the Columbia River, whether more general culling of pinnipeds would be socially acceptable is an open question.

A considerable amount of ecosystem management already occurs to benefit Pacific Salmon recovery (freshwater and habitat restoration, and modifications to dam operations and hatchery practices). However, salmon management could benefit from an investigation of changing natural mortality rates from increasing predators. Currently, the assessment model for salmon has assumed a fixed natural mortality rate through time, despite the significant increases in pinniped populations.

Summary of Management Activity Related to Steps in the FEP Process Loop

The Pacific Council's Fishery Ecosystem Plan provides general information on direct and indirect interactions between fisheries and marine mammals on the West Coast. The FEP also mentions the importance of salmon in the diets of endangered killer whale (PFMC 2013a). NOAA's Integrated Ecosystem Assessment (IEA) for the California Current includes salmon and marine mammals as key ecosystem components, with multiple indicators for each (Levin et al. 2013. The marine mammal indicators currently focus on pinniped species and have not yet been expanded to cetaceans.

The Pacific Council's Salmon Fishery Management Plan does not have specific objectives for managing salmon fisheries in light of their importance as prey to marine mammals. However, protected species in marine waters are managed by NOAA Fisheries, and objectives/goals stemming from the killer whale recovery plan (mandated by the Endangered Species Act) include: "Ensure adequate habitat to support a recovered population of Southern Resident killer whales. Habitat needs include sufficient quantity, quality, and accessibility of prey species," (NMFS 2008).

NOAA Fisheries and the Department of Fisheries and Oceans (DFO) Canada convened an independent scientific review panel to evaluate the effects of salmon fisheries on southern resident killer whales (Hilborn et al. 2012). The panel reviewed science that suggested that Southern Resident Killer whale survival and fecundity rates were correlated with indices of Chinook abundance (Hilborn et al. 2012, Ward et al. 2009). The panel also evaluated simulations of a salmon population model that closed all ocean fishing on Chinook, and concluded that even complete cessation of fishing would increase Chinook abundance by a maximum of 25 percent. The panel concluded that the effects of this small change in Chinook abundance would be difficult to predict, but would be unlikely to translate to increased prey (or survival or fecundity) for killer whales. Instead, Chinook abundance is more strongly influenced by freshwater habitat and ocean conditions than by fishing mortality.

Alaska groundfish and avoiding ecosystem overfishing

This case study focuses on the Alaska Groundfish fishery in the Bering Sea and Aleutian Islands, managed by the North Pacific Fishery Management Council.

Background of Fisheries System Topic

Main Bering Sea fisheries consist of high-volume walleye pollock (*Gadus chalcogrammus*) fisheries, and other groundfish fisheries, including Pacific halibut (*Hippoglossus stenolepis*), sablefish (*Anoplopoma fimbria*) and Pacific cod (*Gadus macrocephalus*). Many of these fisheries are rationalized as ITQs or cooperatives and the fleet is socially heterogeneous consisting of non-Alaska residents, non-indigenous Alaska residents, and indigenous Alaska residents. Most groundfish fisheries also are conducted by multiple commercial sectors defined by gears or vessel characteristics. Climate is a widely known driver of population and community dynamics particularly at decadal scales. Walleye Pollock recruitment is related to annual-scale climate variation that affects timing of sea ice melt and water temperatures. Food web interactions are also considered important in this ecosystem and have implications for fisheries. A recent outburst of arrowtooth flounder (*Atheresthes stomias*) populations is thought to have reduced Walleye Pollock recruitment over the past 15 years (see Ianelli et al. *in press*). Previous declines of ESA listed western Aleutian stocks of Steller sea lion (*Eumetopias jubatus*) were thought by some to stem partly from competition with

Pollock fisheries (though also atka mackerel [*Pleurogrammus monopterygius*] and pacific cod), leading to fishery closures in feeding grounds surrounding Steller sea lion rookeries in the western Aleutians. However, this hypothesis for sea lion declines is controversial, and other hypotheses include: 1) environmental change, 2) predation by killer whales, 3) disease, 4) contaminants, 5) anthropogenic effects including direct and incidental mortality, and 6) combinations of all of the above. Available data do not point to any single hypothesis as being the most likely.

Species use across sectors has generated recent controversy. For instance, the bycatch of Chinook salmon (*Oncorhynchus tshawytscha*) and halibut in the trawl sector might reduce returns and opportunities for subsistence, recreational and directed commercial fisheries for these species. Because of the total cap on groundfish removals at 2 million metric tons per year, high quotas for pollock will reduce opportunities for fisheries in other groundfish sectors. In the Bering Sea, many fishermen express concerns about the high costs of entry into many commercial groundfish fisheries. The cod jig fishery is an entry-level fishery that has become increasingly popular because it is open to entering fishermen in this region.

Summary of Management Activity Related to Steps in the FEP Process Loop

The Ecosystem Considerations Report for the Alaska Regions (Bering Sea/Aleutian Islands, Gulf of Alaska, and Arctic) stemmed from the groundfish FMPs (Arctic, BSAI, and Gulf) (NPFMC 2015a) and contains ecosystem assessment and ecosystem status and trends and indicators for each region in Alaska. The goal of this annual report is to compile results from multiple research efforts and provide an ecosystem context for fishery management decisions. The Ecosystem Considerations Report began in 1995 when the NPFMC Groundfish Plan Team provided a separate document to the SAFE report on ecosystem considerations for the Groundfish fishery. In following years, additional elements were added to the report including bycatch effects, information on seabirds and mammals, essential fish habitat, oceanographic changes, and trends in ecosystem-based management. In 1999 a proposal was put forward to begin to include information on ecosystem status and trends and indicators.

The Aleutian Islands FEP is also a system inventory for this region, but also contains a system-wide risk assessment (NPFMC 2007). This FEP has a non-quantitative risk assessment (following classic risk assessment defined in NRC 1983 and EPA 1992 but qualitative) that looks at the ecological and economic impacts (low, medium, high, or unknown) of different activities (vessel traffic, change in fishery habitat, oil and gas activities, and more) based on the professional judgment of the Aleutian Islands Ecosystem Team and consensus judgment of the Ecosystem Team members.

For Alaska fisheries (and our Alaska groundfish case study), there is a broad ecosystem vision statement that states: "*Vision Statement – The Council envisions sustainable fisheries that provide benefits for harvesters, processors, recreational and* *subsistence users, and fishing communities, which (1) are maintained by healthy, productive, biodiverse, resilient marine ecosystems that support a range of services; (2) support robust populations of marine species at all trophic levels, including marine mammals and seabirds; and (3) are managed using a precautionary, transparent, and inclusive process that allows for analyses of tradeoffs, accounts for changing conditions, and mitigates threats*," (NPFMC 2014). This statement was developed by the Ecosystem Committee for the North Pacific Fishery Management Council, brought on partly by input from stakeholders that the council did not previously have a vision statement or ecosystem objectives (pers. Comm. Bill Tweit).

The Groundfish FMPs have multiple high level ecosystem related objectives including: "*Preserve food web*" and "*Incorporate ecosystem-based considerations into fishery management decisions, as appropriate*." Also more specific objectives about avoiding impacts to seabirds and mammals: "*Maintain or adjust current protection measures as appropriate to avoid jeopardy of extinction or adverse modification of critical habitat for ESA-listed Steller sea lions*," (NPFMC 2015b). The full list of 45 objectives (some ecosystem focused and others more single species focused) come from the 2004 council review of the BSAI/GOA groundfish fisheries (the Alaska Groundfish Programmatic Supplemental Environmental Impact Statement - PSEIS) and the groundfish management policy described in that report. Various components related to the objectives were analyzed based on the impacts of fishery management alternatives on those components. For example, one major objective is "Avoid impacts to Seabirds and Marine Mammals," and as part of the PSEIS (NMFS 2004), different fisheries management alternatives were analyzed for direct/indirect impacts on seabirds and marine mammals.

For Alaska's Bering Sea/Aleutian Islands groundfish fisheries, total catch of groundfish in the region can't exceed a 2 million mt catch cap. Acceptable Biological Catch (ABCs) are set for each stock separately, and then Annual Catch Limits (ACLs) are set so that they all total ACLs don't sum to above 2 million (only partially based on the ecosystem state). This cap was put into place in order to limit fleet capacity and avoid ecosystem overfishing (NPFMC 2015b). The OY (optimum yield) of 2 million mt value was chosen based on 85% of historical annual summed MSY estimates (1.4 to 2 million mt) (NPFMC 2015b). In the programmatic supplemental environmental impact statement, multiple alternative harvest management policies for groundfish were considered and the preferred strategy chosen was the 2 million mt. cap.

Contrasting fish and invertebrate fisheries and species interactions in the Western Scotian Shelf, Canada

This case study focuses on the Scotian Shelf, specifically the Western Scotian Shelf (North Atlantic Fisheries Organisation Division 4X), managed by Fisheries and Oceans Canada (DFO) in the Maritimes Region.

Background of Fisheries System Topic

There are several considerations for the Western Scotian Shelf fisheries, which include fisheries for groundfish, pelagic fish and invertebrates. Groundfish are harvested with trawl, gillnet or longline gear as part of a multi-species groundfish fishery, mostly targeting pollock (*Pollachius virens*), haddock (*Melanogrammus aeglefinus*) and cod (*Gadus morhua*), which is primarily caught as bycatch now, due to its low abundance. There are technical interactions, with by-catch species such as American plaice (*Hippoglossoides platessoides*), white hake (*Urophycis tenuis*), yellowtail flounder (*Pleuronectes ferruginea*), witch flounder (*Glyptocephalus cynoglossus*), winter flounder (*Pseudopleuronectes americanus*), halibut (*Hippoglossus hippoglossus*), and redfish (Sebastes spp.). Herring (*Clupea harengus*), the main forage fish species in the area, are over-fished, and prey for many of the groundfish, as well as seabirds and mammals. There is also concern about the unrecorded landings of herring used for bait in lobster (*Homarus americanus*) fishery. The main invertebrate fisheries are for scallop (*Placopecten magellanicus)* and lobster, some by-catch of groundfish, especially flatfish, in the former. Finally, there is an offshore lobster fishery and a large pelagic fishery, including bluefin tuna (*Thunnus thynnus*) and swordfish (*Xiphias gladius*). Currently groundfish and herring stocks are depressed, but invertebrate stocks (scallop and lobster) are doing well.

Herring are prey for many groundfish, as well as marine mammals, seabirds and large pelagic predators such as tunas. They also are dependent on zooplankton for food, and are likely predators of ichthyoplankton and cod and other groundfish eggs, although this has not been quantified in this area. Groundfish biomass is generally low, due to excess fishing, but may also be related to predation and environmental change.

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

Summary of Management Activity Related to Steps in the FEP Process Loop

Fisheries and Oceans Canada produce State of the Ocean Reports for the different regions in Canada (FEPs are not used by DFO). The State of the Ocean Report for the Scotian Shelf, including the Western Scotian Shelf, covers a range of topics including ocean acidification, climate change and its effects on ecosystems, habitats and biota, Scotian Shelf in context, at-risk species, marine habitats and communities, trophic structure, ocean noise, waste and debris, invasive species, and water and sediment quality (http://www.dfo-mpo.gc.ca/science/coe-cde/soto/scotian-eng.asp). The State of the Ocean reports as well as the Ecosystem Status and Trends Report for the Gulf of Maine and Scotian Shelf (Worcester and Parker 2010) have time series data on many components/indicators in this system. There is ongoing work to assess risk to ecologically and biologically significant areas in the Western Scotian Shelf and other regions, but these assessments are not complete (see DFO 2014).

Within the DFO Regional Oceans Plan for the Maritimes Region (that includes the Scotian Shelf) there is the following broad vision statement for the region: "*Healthy marine and coastal ecosystems, sustainable communities and responsible use supported by effective management processes,"* (DFO 2014b). For individual species or fisheries in this case study (herring, groundfish, lobster, and scallop), each has an IFMP with specific goals or objectives. Within the lobster management plan for example, there are goals related to broader ecosystem impacts including: "Control unintended incidental mortality of North Atlantic right whales," and "Manage area disturbed of bottom habitat," (DFO 2011). Overarching all fisheries in the region are the following conservation and social objectives (see DFO 2013 as an example):

1. Productivity: Do not cause unacceptable reduction in productivity so that components can play their role in the functioning of the ecosystem.
2. Biodiversity: Do not cause unacceptable reduction in biodiversity in order to preserve the structure and natural resilience of the ecosystem.
3. Habitat: Do not cause unacceptable modification to habitat in order to safeguard both physical and chemical properties of the ecosystem.

Social, cultural and economic objectives

4. Culture and Sustenance: Respect Aboriginal and treaty rights to fish.
5. Prosperity: Create the circumstances for economically prosperous fisheries.

Finally, a Multispecies Virtual Population Analysis model (MSVPA) was developed to explore mortality of herring by predators (Guenette and Stephenson 2012), but this information and the model are not in use by management.

Interacting Fisheries in the Baltic Sea

This case study focuses on the Eastern Baltic Sea (ICES SD 25-32) for which Total Allowable Catches are scientifically advised by the International Council for the Exploration of the Sea (ICES) and management decisions are made by the European Union.

Summary of Fisheries System Topic

Eastern Baltic Sea fisheries are mainly focused on demersal cod (*Gadus morhua*) (bottom/pelagic trawling, gillnets) and pelagic forage fish, herring (*Clupea harengus*) and sprat (*Sprattus sprattus*). Cod and forage fishes strongly interact ecologically through (1) cod top-down predation and (2) sprat and herring predation on cod eggs. Furthermore, there is competition for zooplankton food between sprat and herring. Cod overfishing has hence in recent history caused a strong sprat increase. The large sprat stock depressed cod recruitment through egg predation and top-down control of zooplankton. Additionally, sprat density-dependent growth reductions have been observed in herring and sprat. Reduced herring growth and condition may negatively influence herring recruitment. All species, but especially cod, are strongly dependent (mainly species recruitment) on the physical oceanographic environment. Recent environmental conditions have resulted in distribution changes leading to a spatial mismatch on species interactions.

The social dimension of this case study includes the balance between economic optimization and equity aspects between sectors (demersal vs. pelagic) and regions. Socio-cultural preferences that may affect management decisions are local preference for resource species (cod in the south vs. sprat in the north). There are furthermore cultural differences in management goals reflected by a restoration/protection focus in Sweden versus an economic/exploitation focus in countries such as Poland.

Summary of Management Activity Related to Steps in the FEP Process Loop

System inventories for the Baltic Sea have been conducted within different ICES initiatives. The ICES/HELCOM Working Group on Integrated Assessments of the Baltic Sea (WGIAB) conducted what they called Integrated Trends Assessments (ITAs) of the various sub-systems of the Baltic Sea. These include multivariate analyses of time-series encompassing abiotic (nutrients, hydrography, fishing pressure) as well as plankton (phyto- and zooplankton) and fish (pelagic and demersal) time-series. Results for the Central Baltic are published in Möllmann et al. (2009) and analyses for multiple sub-systems in Diekmann & Möllmann (2010), and are irregularly updated within WGIAB. Furthermore, within ICES groups, there is development of ecosystem overviews for all European marine regions. The ecosystem overview for the Baltic Sea is in progress but will be published on the ICES website (http://www.ices.dk/community/advisory-process/Pages/Ecosystem-overviews.aspx).

Broad ecosystem goals for the region can be found in the Common Fisheries Policy (CFP) and the Marine Strategy Framework Directive (MSFD). The Common Fishery Policy of the EU was reformed in 2014 and now has the goal that, "Fish stocks should be brought up to healthy levels and be maintained in healthy conditions"(COM 2013). The CFP strives to develop ecosystem-based fisheries management by applying an MSY approach: "Fish stocks should be exploited at maximum sustainable yield levels. These levels can be defined as the highest catch that can be safely taken year after year and which maintains the fish population size at maximum productivity." Further elements of the CFP reform towards an ecosystem approach are (i) the stepwise implementation of a discard ban ("landing obligation") and (ii) efforts towards a stronger regional stakeholder involvement ("regionalization") to enhance compliance with management decisions. Overall, management of Baltic fish stocks is still single-species. However, presently a multi-annual ("long-term") management plan for multiple Baltic fish stocks is promoted within the legislative process of the EU. While not including a real multi-species MSY approach, F_{MSY} values are intended to be set within ranges that implicitly account for multi-species management goals. In addition minimum levels of the spawning stock biomass are set for conservation purposes.

There are multiple ongoing, not completed, projects within ICES and the Baltic related to EBFM. For the Baltic Sea a new ICES initiative (Workshop on developing integrated advice for Baltic Sea ecosystem-based fisheries management - WKDEICE) has been tasked to show how to integrate environmental and socio-economic information into advice. The group works on developing ecosystem indicators (abiotic/biotic) and how these can be included in short-term stock projections. Furthermore, socio-economic model simulation will be conducted. The overall goal of this process is to develop single and multi-species F_{MSY} options for the interacting species of cod, herring and sprat.

Previous efforts within ICES evaluated multi-species F_{MSY} but they are presently not considered due to uncertainties inherent in the multispecies model and cod input data (ICES 2013). Finally, there are a number of papers that have done MSEs for the Baltic Sea with respect to management plans, expected climate change effects, eutrophication, or economic considerations, but these have not been conducted within the operational management setting, only sometimes in relation to an ICES group (e.g. Bastardie et al. 2010, Gårdmark et al. 2013, Niiranen et al. 2013, Voss et al. 2014). On the other hand, management strategies from sprat and herring stock assessments include predation mortality parameters from MSVPA models, leading to single-species ecosystem consideration management strategies (ICES 2015).

Small Pelagic Fishery and Ecosystem Impacts in Australia

This case study focuses on the Small Pelagic Fishery (SPF) covering much of Eastern and Southern Australia and managed by the Australian Fisheries Management Authority (AFMA) (federally managed, not state managed).

Summary of Fisheries System Topic

The small pelagic fishery comprises commercial mid-water and bottom trawl fisheries targeting four low- to mid-trophic level species (Australian sardine *Sardinop sagax*, blue mackerel *Scomber australasicus*, jack mackerel *Trachurus declivis*, and redbait *Emmelichthys nitidus*). Product from this fishery is mainly used for fish feed (aquaculture), with only a limited amount used for direct human consumption (high volume low value product). There are multiple conservation concerns surrounding this fishery. Specifically, there is concern about the fishery impact on predators of SPF species including seabirds and marine mammals (trophic-mediated impact including through localized depletion of prey) and concern about the accidental catch of protected species by the commercial fishery (direct mortality from fishing).

Additionally, there is a recreational fishery for Southern Bluefin Tuna (*Thunnus maccoyii*) (SBT) off the East Coast of Tasmania, within the area of the SPF. The recreational and charter fishery mostly targets Tuna but also some other large pelagic species such as swordfish (*Xiphias gladius*). A commercial SBT fishery is managed by AFMA but the recreational fisheries are generally controlled by the states. There are social concerns related to the interactions between the recreational SBT fisheries and the small pelagic fisheries. One concern is the impact of SPF fishery on prey of SBT and therefore potential impacts on the abundance and distribution of Tuna that would adversely affect recreational fishing opportunities and experience.

Summary of Management Activity Related to Steps in the FEP Process Loop

Ecological risk assessment (ERA) is used to inform management of all federally-managed (and many state-managed) fisheries in Australia and a comprehensive ERA was done for the SPF fishery in 2007 (Daley et al. 2007). This ERA used a hierarchical approach with three levels: 1) remove activities that are determined to have low impact (Scale Intensity Consequence Analysis), 2) semi-quantitative prioritization process for species and habitats impacted by fishing (Productivity Susceptibility Analysis), 3) quantitative modeling based analysis (further prioritization and cumulative impact analysis).

The Australian public raised further concerns about risks posed by the SPF fishery. Particular concerns about the impact of the SPF on predators, protected species, other parts of the ecosystem, and other fisheries arose during 2012 when one of the license holders (quota owners) brought in from overseas a very large factory trawler (later dubbed a "super trawler") to fish its quota. Environmental and recreational fishing groups launched a media campaign against the use of this vessel and this led to widespread public disquiet. The federal government intervened and eventually banned the vessel all together. A description of these events can be found in Tracey et al (2013).

These events also coincided with a heightened public awareness about the trophic impacts of fishing "forage fish" including several of the species targeted in the SPF (sardine, Jack mackerel) due to publications such as the Lenfest report (Pikitch et al. 2012) and the publication of the Marine Stewardship Council criteria for assessing the sustainability of low trophic level species to take account of trophic impacts (MSC 2014).

It was this constellation of factors that led AFMA to review the SPF harvest strategy in 2013, with a particular focus on determining target and limit reference points that took account of impacts on predators of the target species in the SPF, as well as more general impacts on the food web. This review was undertaken and the results reported in Smith et al (2015) and led to a new harvest strategy for the fishery, adopted in 2015 (AFMA 2015).

The review of the SPF harvest strategy was undertaken by a group of fishery scientists and involved considerable interaction with AFMA and with stakeholders in the fishery, both in the initial design phase of the review, and during its course. The scientific group initially suggested using the MSC criteria for assessing low trophic level fisheries as objectives/performance indicators for management strategy evaluation for the review and this suggestion was endorsed by the Resource Assessment Group for the fishery, and by AFMA management. Adopting MSC criteria was seen as adopting a credible international standard.

The MSC criteria and guidelines allow the use of credible ecosystem models to evaluate impacts of fishing LTL species on other parts of the food web. The criteria for determining acceptable impact are that:

1. No other species is impacted by more than 70%
2. No more than 15% of other species or groups are impacted by more than 40%

The SPF review used an existing Atlantis ecosystem model tuned to the particular circumstances of the SPF (Smith et al 2015) to evaluate management strategies that would meet these operational objectives and performance indicators. The analysis concluded that harvest rates that achieved a target stock size of B50 (50% of unexploited biomass) met this performance criterion (no species or group was impacted by more than 40%) (Smith et al. 2015). Note that B50 was the status quo target stock size for the fishery before this analysis (corresponding to the maximum economic yield (MEY) target for all AFMA managed fisheries). Note that in the absence of availability of an ecosystem model for this specific ecosystem, the "safe" target stock size would likely have been set at a more conservative 75% of unfished biomass, in line with guidance from MSC and the Lenfest Forage fish report and similar to the reference point used for krill fishing by CCAMLR.

References

Adams CF, Miller TJ, Manderson JP, Richardson DE, Smith BE. 2015. Butterfish 2014 Stock Assessment. US Dept Commer, Northeast Fish Sci Cent Ref Doc. 15-06; 110 p. Available from: National Marine Fisheries Service, 166 Water Street, Woods Hole, MA 02543-1026, or online at http://www.nefsc.noaa.gov/publications/

AFMA (2015) Small Pelagic Fishery Harvest Strategy (last revised April 2015)

[ASMFC] Atlantic States Marine Fisheries Commission. 2016. Fisheries Focus, Volume 25, Issue 1, February/March 2016.

[ASMFC] Atlantic States Marine Fisheries Commission. 2015. MEMORANDUM - http://www.asmfc.org/uploads/file/56426d04BERP_Am3Development_Oct2015.pdf

[ASMFC] Atlantic States Marine Fisheries Commission. 2012. Amendment 2 to the Interstate Fishery Management Plan for Atlantic Menhaden. Atlantic Menhaden Plan Development Team, ASFMC.

[ASMFC] Atlantic States Marine Fisheries Commission. 2005. Addendum II to amendment 1 to the state fishery management plan for Atlantic menhaden. Atlantic States Marine Fisheries Commission, Washington, DC. http://www.asmfc.org/uploads/file//546b96ecAtlMenhadenAddendumII_05.pdf

[ASMFC] Atlantic States Marine Fisheries Commission. 2004. Atlantic Menhaden Workshop Report & Proceedings, A report of a workshop conducted by the Atlantic States Marine Fisheries Commission, October 12 – 14, 2004, Alexandria, VA. Special Report No. 83 of the Atlantic States Marine Fisheries Commission.

Bastardie, F., Nielsen, JR, and Kraus, G. 2010. The eastern Baltic cod fishery: a fleet-based management strategy evaluation framework to assess the cod recovery plan of 2008. ICES Journal of Marine Science, 67: 71–86.

Chesapeake Bay Fisheries Ecosystem Advisory Panel (National Oceanic and Atmospheric Administration Chesapeake Bay Office). 2006. Fisheries ecosystem planning for Chesapeake Bay. American Fisheries Society, Trends in Fisheries Science and Management 3, Bethesda, Maryland.

COM 2013. REGULATION (EU) No 1380/2013 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 11 December 2013 on the Common Fisheries Policy, amending Council Regulations (EC) No 1954/2003 and (EC) No 1224/2009 and repealing Council Regulations (EC) No 2371/2002 and (EC) No 639/2004 and Council Decision 2004/585/EC.

DFO. State of the Ocean Report for the Scotian Shelf and Gulf of Maine. http://www.dfo-mpo.gc.ca/science/coe-cde/soto/scotian-eng.asp

DFO. 2011. INSHORE LOBSTER (*Homarus americanus*) INTEGRATED FISHERIES MANAGEMENT PLAN (SUMMARY) MARITIMES REGION. Fisheries and Oceans Canada

DFO. 2013. Canadian Atlantic Herring (*Clupea harengus*) - SWNS Rebuilding Plan - Atlantic Canada – 2013. Fisheries and Oceans Canada.

DFO. 2014. Regional Oceans Plan – Maritimes Region: Background and Program Description. Fisheries and Oceans Canada. 45 p.

Diekmann, R., and C. Möllmann (Eds.). 2010. Integrated ecosystem assessments of seven Baltic sea areas covering the last three decades. ICES Cooperative Research Report No. 302.

Ecosystem Assessment Program. 2012. Ecosystem status report for the Northeast Shelf Large Marine Ecosystem– 2011. US Dept Commer, Northeast Fish Sci Cent Ref Doc. 12-07; 32 p. Available from: NOAA Fisheries, 166 Water St., Woods Hole, MA 02543-1026.

[EPA] Environmental Protection Agency. 1992. Framework for Ecological Risk Assessment. Risk Assessment Forum, U.S. Environmental Protection Agency. Washington, DC 20460. February 1992.

Gardmark, A., Lindegren, M., Neuenfeldt, S., Blenckner, T., Heikinheimo, O., Müller-Karulis B., Niiranen, S., Tomczak, M.T., Aro, E., Wikstrom, A. and Möllmann, C. (2013) Biological ensemble modeling to evaluate potential futures of living marine resources. Ecological Applications 23:742-754

Grabowski, J. H., Bachman, M., Demarest, C., Eayrs, S., Harris, B. P., Malkoski, V., Packer, D., & Stevenson, D. (2014). Assessing the vulnerability of marine benthos to fishing gear impacts. *Reviews in Fisheries Science & Aquaculture*, *22*(2), 142-155.

Grabowski, J. H., E. J. Clesceri, J. Gaudette, A. Baukus, M. Weber, and P. O. Yund. 2010. Use of herring bait to farm lobsters in the Gulf of Maine. PLoS One 5(4): e10188.

Guénette S., and R. L. Stephenson. 2012. Accounting for predators in ecosystem-based management of herring fisheries of the Western Scotian Shelf. In: Kruse GH, Browman HI, Cochrane KL, Evans D and others (eds) Global progress in ecosystem-based fisheries management. Alaska Sea Grant, University of Alaska, Fairbanks, AK, p 105–128

Hill, K.T., Crone, P.R., Demer, D.A., Zwolinski, J., Dorval, E., Macewicz, B.J., 2014. Assessment of the Pacific Sardine resource in 2014 for U.S. management in 2014-15. NOAA Technical Memorandum NMFS.

Hurtado-Ferro, F. and Punt, A.E. (2014*)* Revised Analyses Related to Pacific Sardine Harvest Parameters*.* Pacific Fishery Managmenet Council*,* Portland, OR*.*

Ianelli, J., Holsman, K.K., Punt, A.E. and Aydin, K., 2015. Multi-model inference for incorporating trophic and climate uncertainty into stock assessments. Deep Sea Research Part II: Topical Studies in Oceanography. *In press.*

ICES. 2015. Report of the Baltic Fisheries Assessment Working Group (WGBFAS). ICES Advisory Committee. ICES CM 2015/ACOM:10

ICES. 2013. Report of the Benchmark Workshop on Baltic Multispecies Assessments (WKBALT). ICES Advisory Committee. ICES CM 2013/ACON:43

Jacobson, L.D. and MacCall, A.D., 1995. Stock-recruitment models for Pacific sardine (Sardinops sagax). Canadian Journal of Fisheries and Aquatic Sciences, 52:566-577.

Karnauskas, M., Schirripa, M. J., Kelble, C. R., Cook, G. S., Craig, J. K. (eds.) 2013. Ecosystem status report for the Gulf of Mexico. NOAA Technical Memorandum NMFS-SEFSC-653, 52 pp.

Kelble, C.R., Loomis, D.K., Lovelace, S., Nuttle, W.K., Ortner, P.B., Fletcher, P., Cook, G.S., Lorenz, J.J. and Boyer, J.N., 2013. The EBM-DPSER conceptual model: integrating ecosystem services into the DPSIR framework. PloS one, 8:p.e70766.

Levin, P.S., B.K. Wells, M.B. Sheer (Eds). 2013. California Current Integrated Ecosystem Assessment: Phase II Report. Available from http://www.noaa.gov/iea/CCIEA-Report/index.

Lindegren, M. and Checkley Jr, D.M., 2012. Temperature dependence of Pacific sardine (Sardinops sagax) recruitment in the California Current Ecosystem revisited and revised. Canadian Journal of Fisheries and Aquatic Sciences, 70:245-252.

[MAFMC] Mid-Atlantic Fishery Management Council. 2013. 2014-2018 Strategic Plan. Mid-Atlantic Fishery Management Council, 800 North State St., Suite 201, Dover, DE 19901.

[MAFMC] Mid-Atlantic Fishery Management Council. 2012. Stakeholder Input Report. Mid-Atlantic Fishery Management Council, 800 North State St., Suite 201, Dover, DE 19901.

Magnuson-Stevens Fishery Conservation and Management Act. 2006. Public Law 94-265. As amended by the Magnuson-Stevens Fishery Conservation and Management Reauthorization Act (P.L. 109-479)

McClatchie, S., Goericke, R., Auad, G. and Hill, K., 2010. Re-assessment of the stock-recruit and temperature-recruit relationships for Pacific sardine (Sardinops sagax). Canadian Journal of Fisheries and Aquatic Sciences, 67:1782-1790.

McMahan, M. D., D. C. Brady, D. Cowan, J. H. Grabowski, and G. D. Sherwood. 2013. Using fine-scale acoustic telemetry to observe the effects of a groundfish predator (Atlantic cod, Gadus morhua) on the movement behavior of the American lobster (Homarus americanus). Canadian Journal of Fisheries and Aquatic Sciences 70:1625:1634.

Möllmann, C., Diekmann, R., Müller-Karulis, B., Kornilovs, G., Plikshs, M. and Axe, P. 2009. Reorganization of a large marine ecosystem due to atmospheric and anthropogenic pressure: a discontinuous regime shift in the Central Baltic Sea. Global Change Biology, 15: 1377-1393.

MSC (2014) Fisheries Standard and Guidance v2.0

[NEFMC] New England Fishery Management Council. 2016. Omnibus Habitat Amendment 2. *In Review*. New England Fishery Management Council. http://www.nefmc.org/library/omnibus-habitat-amendment-2

Niiranen, N., Yletyinen, J., Tomczak, M.T., Blenckner, T., Hjerne, O., MacKenzie, B.R., Müller-Karulis, B., Neumann, T. and Meier, H.E.M, 2013. Combined effects of global climate change and regional ecosystem drivers on an exploited marine food web. Global Change Biology, 19: 3327-3342.

[NMFS] National Marine Fisheries Service. 2008. Recovery Plan for Southern Resident Killer Whales (Orcinus orca). National Marine Fisheries Service, Northwest Region, Seattle, Washington.

NMFS. 2004. Final Programmatic Supplemental Environmental Impact Statement for the Alaska Groundfish Fisheries. NMFS Alaska Region, P.O.Box 21668, Juneau, Alaska 99802-1668. pp.7000.

Northeast Fisheries Science Center. 2010. 49th Northeast Regional Stock Assessment Workshop (49th SAW) Assessment Summary Report. US Dept Commer, Northeast Fish Sci Cent Ref Doc. 10-01; 41 p. Available from: National Marine Fisheries Service, 166 Water Street, Woods Hole, MA 02543-1026, or online at http://www.nefsc.noaa.gov/nefsc/publications/

[NPFMC] North Pacific Fishery Management Council. 2015a. Ecosystem considerations 2015: Status of Alaska's Marine Ecosystems. Edited by Stephani Zador. North Pacific Fishery Management Council, 605 W. 4th Avenue, Suite 306, Anchorage, AK 99301.

[NPFMC] North Pacific Fishery Management Council. 2015b. Fishery Management Plan for Groundfish of the Bering Sea and Aleutian Islands Management Area. North Pacific Fishery Management Council, 605 W. 4th Avenue, Suite 306, Anchorage, AK 99301.

[NPFMC] North Pacific Fishery Management Council. 2014. North Pacific Fishery Management Council Ecosystem Based Fishery Management (EBFM) development process and actions, May 2014. North Pacific Fishery Management Council, 605 W. 4th Avenue, Suite 306, Anchorage, AK 99301.

NPFMC. Aleutian Islands Fishery Ecosystem Plan. 2007. North Pacific Fishery Management Council, 605 W. 4th Avenue, Suite 306, Anchorage, AK 99301.

[NRC] National Research Council. 1983. Risk Assessment in the Federal Government: Managing the Process. National Academy Press, Washington, DC, 191 p.

[PFMC] Pacific Fishery Management Council. 2014a. Status of the Pacific Coast Coastal Pelagic Species Fishery and Recommended Acceptable Biological Catches; Stock Assessment and Fishery Evaluation 2014. Pacific Fishery Management Council, 7700 NE Ambassador Place, Suite 101, Portland, Oregon 97220-1384.

PFMC. 2014b. Small Pelagic Species Management Team Report on Sardine Harvest Parameters Changes. Pacific Fishery Management Council, Portland, OR. March 2014.

PFMC. 2013a. Pacific Coast Fishery Ecosystem Plan for the U.S. Portion of the California Current Large Marine Ecosystem – Public Review Draft, February 2013. (Document prepared for the Council and its advisory entities.) Pacific Fishery Management Council, 7700 NE Ambassador Place, Suite 101, Portland, Oregon 97220-1384.

PFMC. 2013b. Report of the Pacific Sardine Harvest Parameters Workshop. Pacific Fishery Management Council, Portland, OR

Pikitch, E., Boersma, P.D., Boyd, I.L., Conover, D.O., Cury, P., Essington, T., Heppell, S.S., Houde, E.D., Mangel, M., Pauly, D., Plagányi, É., Sainsbury, K., and Steneck, R.S. 2012. Little Fish, Big Impact: Managing a Crucial Link in Ocean Food Webs. Lenfest Ocean Program. Washington, DC. 108 pp.

SEDAR. 2014. SEDAR 33 – Gulf of Mexico Gag Stock Assessment Report. SEDAR, North Charleston SC. 609 pp [MAFMC] Mid-Atlantic Fishery Management Council. 2015. Ecosystem Approach to Fisheries Management [webpage]. http://www.mafmc.org/eafm/ Accessed on April 15, 2016.

SEDAR. 2015. SEDAR 40 – Atlantic Menhaden Stock Assessment Report. SEDAR, North Charleston SC. 643 pp.Daley, R., Dowdney, J., Bulman, C, Sporcic, M., Fuller, M., Ling, S. and Hobday, A (2007). Ecological Risk Assessment for the Effects of Fishing. Report for the midwater trawl sub-fishery of the Small Pelagic Fishery. Report for the Australian Fisheries Management Authority. Canberra, Australia.

Smith, A.D.M., T.M. Ward, F. Hurtado, N. Klaer, E. Fulton and A.E. Punt (2015) Review and update of harvest strategy setting for the commonwealth Small Pelagic Fishery: single species and ecosystem considerations. Final Report of FRDC Project No. 2013/028

Tracey, S., C. Buxton, C. Gardner, B. Green, K. Hartmann, M. Haward, J. Jabour, J. Lyle, J. McDonald (2013) Super trawler scuppered in Australian fisheries management reform. *Fisheries*, 38(8): 345-350

Voss, R., Quaas, M.F., Schmidt, J.O., Tahvonen, O., Lindegren, M. and Möllmann, C. (2014) Assessing social-ecological trade-offs to advance ecosystem-based fisheries management. PloS one 9:e107811

Ward, E. J., Holmes, E. E., & Balcomb, K. C., 2009. Quantifying the effects of prey abundance on killer whale reproduction. Journal of Applied Ecology, 46(3), 632-640.

Worcester, T., and M. Parker. 2010. Ecosystem Status and Trends Report for the Gulf of Maine and Scotian Shelf. DFO Can. Sci. Advis. Sec. Res. Doc. 2010/070. vi + 59 p. Hilborn, R., S. P. Cox, F. M.D. Gulland, D.G. Hankin, N.T. Hobbs, D.E. Schindler, and A.W. Trites. 2012. The Effects of Salmon Fisheries on Southern Resident Killer Whales: Final Report of the Independent Science Panel. Prepared with the assistance of D.R. Marmorek and A.W. Hall, ESSA Technologies Ltd., Vancouver, B.C. for National Marine Fisheries Service (Seattle. WA) and Fisheries and Oceans Canada (Vancouver, BC). xv + 61 pp. + Appendices

IMPLEMENTATION VOLUME

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

CONTENTS

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

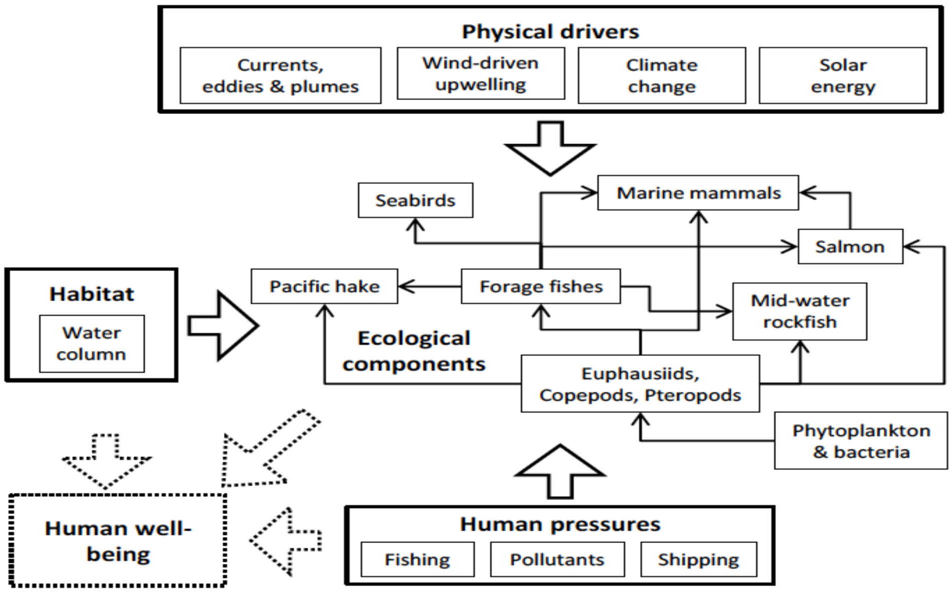

Figure 1. An example of a basic conceptual model of the coastal pelagic system in the Northern California Current. Model from Andrews et al., 2015

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?").

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).

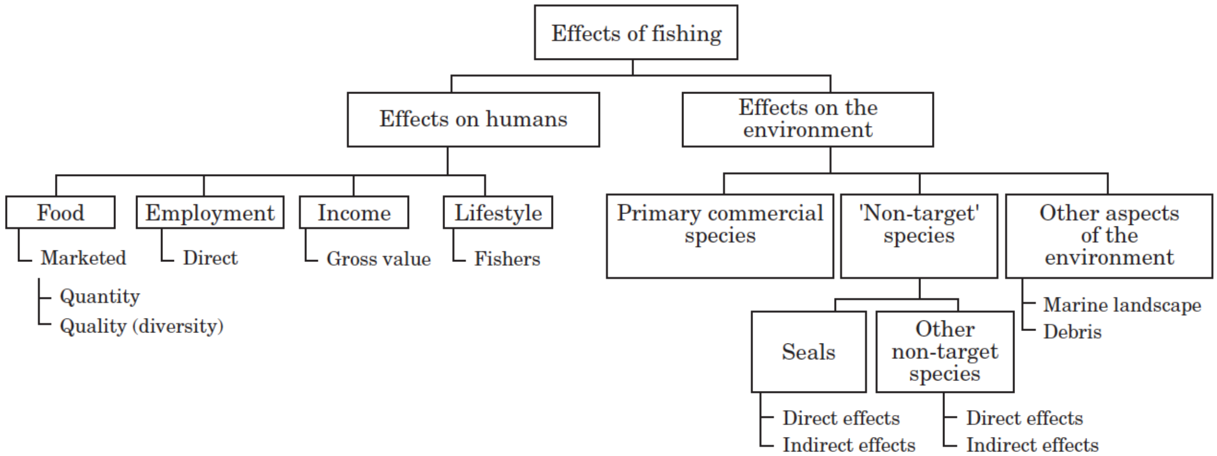

Figure 2. An example of a component tree for an Australian trawl fishery (Chesson et al., 1999).

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.

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References

Abel, N., H. Ross, and P. Walker. 1998. Mental models in rangeland research, communication and management. Rangeland Journal 20: 77-91.

Andrews, K.S., Williams, G.D., Samhouri, J.F., Marshall, K.N., Gertseva, V., Levin, P.S., 2015. The legacy of a crowded ocean: indicators, status, and trends of anthropogenic pressures in the California Current ecosystem. Environmental Conservation 42: 139–151.

Chesson, J., Clayton, H., Whitworth, B., 1999. Evaluation of fisheries-management systems with respect to sustainable development. ICES Journal of Marine Science: Journal du Conseil 56: 980–984.

deYoung, B., Barange, M., Beaugrand, G., Harris, R., Perry, R.I., Scheffer, M., Werner, F., 2008. Regime shifts in marine ecosystems: detection, prediction and management. Trends Ecol. Evol. 23: 402–9. doi:10.1016/j.tree.2008.03.008

Doren, R.F., Trexler, J.C., Gottlieb, A.D., Harwell, M.C., 2009. Ecological indicators for system-wide assessment of the greater everglades ecosystem restoration program. Ecological indicators 9: S2–S16.

Dray, A., Perez, P., Jones, N., Le Page, C., D'Aquino, P., White, I., Auatabu, T., 2006. The AtollGame experience: from knowledge engineering to a computer-assisted role playing game. Journal of Artificial Societies and Social Simulation 9.

Ecosystems Principles Advisory Panel. 1999. Ecosystem-based fishery management. National Marine Fisheries Service.

Elliott, M. (2002). The role of the DPSIR approach and conceptual models in marine environmental management: an example for offshore wind power. Marine pollution bulletin, 44(6): iii-vii.

Fay, G., Large, S.I., Link, J.S., Gamble, R.J., 2013. Testing systemic fishing responses with ecosystem indicators. Ecological Modelling 265: 45–55. doi:10.1016/j.ecolmodel.2013.05.016

Fay, G., Link, J.S., Large, S.I., Gamble, R.J., 2015. Management performance of ecological indicators in the Georges Bank finfish fishery. ICES Journal of Marine Science: Journal du Conseil 72: 1285–1296.

Fletcher, W.J., Bianchi, G., 2014. The FAO–EAF toolbox: making the ecosystem approach accessible to all fisheries. Ocean & Coastal Management 90: 20–26.

Fletcher, W.J., Chesson, J., Sainsbury, K.J., Hundloe, T.J., Fisher, M., 2005. A flexible and practical framework for reporting on ecologically sustainable development for wild capture fisheries. Fisheries Research 71: 175–183.

Halpern, B.S., Longo, C., Hardy, D., McLeod, K.L., Samhouri, J.F., Katona, S.K., Kleisner, K., Lester, S.E., O'Leary, J., Ranelletti, M., others, 2012. An index to assess the health and benefits of the global ocean. Nature 488: 615–620.

Harwell, C. C., C. W. Deren, G. H. Snyder, W. D. Solecki, J. Wilson, and M. A. Harwell. 1999. Use of a conceptual model of societal drivers of ecological change in South

Florida: implications of an ecosystem management scenario. Urban Ecosystems 3: 345-368.

Harwell, M. A., J. H. Gentile, K. W. Cummins, R. C. Highsmith, R. Hilborn, C. P. McRoy, J. Parrish, and T. Weingartner. 2010. A conceptual model of natural and anthropogenic drivers and their influence on the Prince William Sound, Alaska, ecosystem. Human and Ecological Risk Assessment 16: 672-726.

Jahan, S. (2015). Human Development Report 2015. Work for Human Development. New York: United Nations Development Programme.

Jennings, S., 2005. Indicators to support an ecosystem approach to fisheries. Fish and Fisheries 6: 212–232.

Jones, N. A., H. Ross, T. Lynam, P. Perez, and A. Leitch. 2011. Mental Models: An Interdisciplinary Synthesis of Theory and Methods. Ecology and Society 16: 13.

Karnauskas, M., Schirripa, M. J., Kelble, C. R., Cook, G. S., & Craig, J. K. (2013). Ecosystem status report for the Gulf of Mexico. NOAA Technical Memorandum NMFS-SEFSC, 653: 52.

Kelble, C. R., Loomis, D. K., Lovelace, S., Nuttle, W. K., Ortner, P. B., Fletcher, P., ... & Boyer, J. N. (2013). The EBM-DPSER conceptual model: integrating ecosystem services into the DPSIR framework. PloS one, 8(8): e70766.

Kershner, J., Samhouri, J.F., James, C.A., Levin, P.S., 2011. Selecting indicator portfolios for marine species and food webs: a Puget Sound case study. PLoS one 6: e25248.

Kleisner, K.M., Coll, M., Lynam, C.P., Bundy, A., Shannon, L., Shin, Y.-J., Boldt, J.L., Diallo, I., Fox, C., Gascuel, D., others, 2015. Evaluating changes in marine communities that provide ecosystem services through comparative assessments of community indicators. Ecosystem Services 16: 413–429.

Levin, P.S., Breslow, S., Harvey, C., Norman, K.C., Poe, M.R., WIlliams, G.D., 2016. Conceptualization of Social-Ecological Systems of the California Current: an examination of interdisciplinary science supporting Ecosystem-based Management. Coastal Management. 44: 397-408

Levin, P.S., B.K. Wells, and M.B. Sheer (eds.). 2013. California Current Integrated Ecosystem Assessment: Phase II Report. http://www.noaa.gov/iea/regions/california-current-region/index.html

Levin, P.S., Damon, M., Samhouri, J.F., 2010. Developing meaningful marine ecosystem indicators in the face of a changing climate. Stanford Journal of Law, Science and Policy 2: 37–48.

Levin, P.S., Schwing, F., 2011. Technical background for an IEA of the California Current: Ecosystem Health, Salmon, Groundfish, and Green Sturgeon. NOAA Technical Memorandum, NMFS-NWFSC 109: 330.

Longo, C., Halpern, B.S., Lindenmayer, D., Barton, P., Pierson, J., 2015. Building indicators for coupled marine socio-ecological systems. Indicators and Surrogates of Biodiversity and Environmental Change 137.

Martins, J.H., Camanho, A.S., Gaspar, M.B., 2012. A review of the application of driving forces–Pressure–State–Impact–Response framework to fisheries management. Ocean & coastal management 69: 273–281.
Methratta, E.T., Link, J.S., 2006. Evaluation of quantitative indicators for marine fish communities. Ecological Indicators 6: 575–588.
NPFMC, 2007. Aleutian Islands Fishery Ecosystem Plan. Anchorage, Alaska: NPFMC. http://www.npfmc.org/aleutian-islands-fishery-ecosystem-plan/
NPFMC, 2015. Ecosystem Considerations 2015: Status of Alaska's Marine Ecosystems. Anchorage, Alaska: NPFMC. https://www.afsc.noaa.gov/REFM/Docs/2015/ecosystem.pdf
O'Boyle, R., Jamieson, G., 2006. Observations on the implementation of ecosystem-based management: experiences on Canada's east and west coasts. Fisheries research 79: 1–12.
Özesmi, U., Özesmi, S.L., 2004. Ecological models based on people's knowledge: a multi-step fuzzy cognitive mapping approach. Ecological Modelling 176: 43–64.
Prigent, M., Fontenelle, G., Rochet, M.-J., Trenkel, V.M., 2008. Using cognitive maps to investigate fishers' ecosystem objectives and knowledge. Ocean & Coastal Management 51: 450–462. doi:10.1016/j.ocecoaman.2008.04.005
Rice, J.C., Rochet, M.-J., 2005. A framework for selecting a suite of indicators for fisheries management. ICES Journal of Marine Science: Journal du Conseil 62: 516–527.
SAFMC, 2009. Fishery Ecosystem Plan of the South Atlantic Region.
Shepherd, K.D., Shepherd, G., Walsh, M.G., 2015. Land health surveillance and response: A framework for evidence-informed land management. Agricultural Systems 132: 93–106.
Shin, Y.-J., Bundy, A., Shannon, L.J., Blanchard, J.L., Chuenpagdee, R., Coll, M., Knight, B., Lynam, C., Piet, G., Richardson, A.J., others, 2012. Global in scope and regionally rich: an IndiSeas workshop helps shape the future of marine ecosystem indicators. Reviews in Fish Biology and Fisheries 22: 835–845.
Shin, Y.-J., Shannon, L.J., Bundy, A., Coll, M., Aydin, K., Bez, N., Blanchard, J.L., de Fatima Borges, M., Diallo, I., Diaz, E., others, 2010. Using indicators for evaluating, comparing, and communicating the ecological status of exploited marine ecosystems. 2. Setting the scene. ICES Journal of Marine Science: Journal du Conseil 67: 692–716.
Stier, A. C., J. F. Samhouri, S. Gray, R. G. Martone, M. E. Mach, B. S. Halpern, C. V. Kappel, C. Scarborough, and P. S. Levin. 2016. Integrating expert percpetions into food web conservation and management. Conservation Letters. In press.

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).

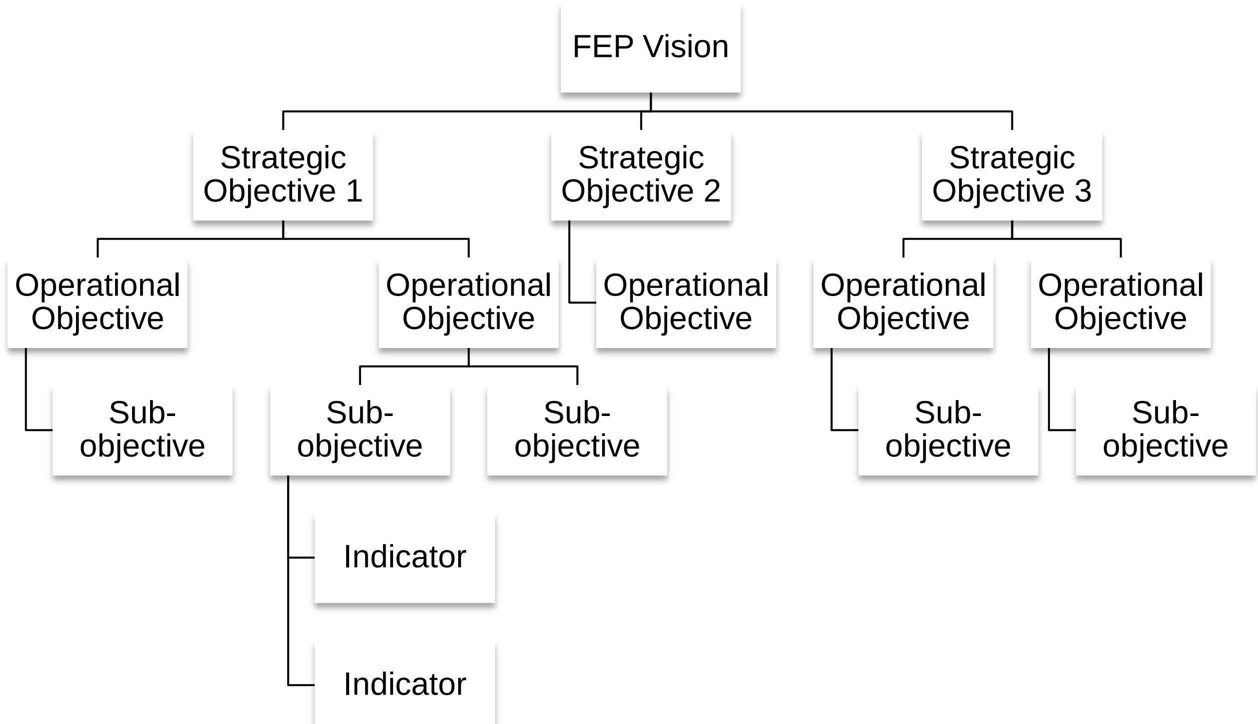

Figure 3. The hierarchical structure of FEP Visions, Strategic Objectives, and Operational Objectives

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).

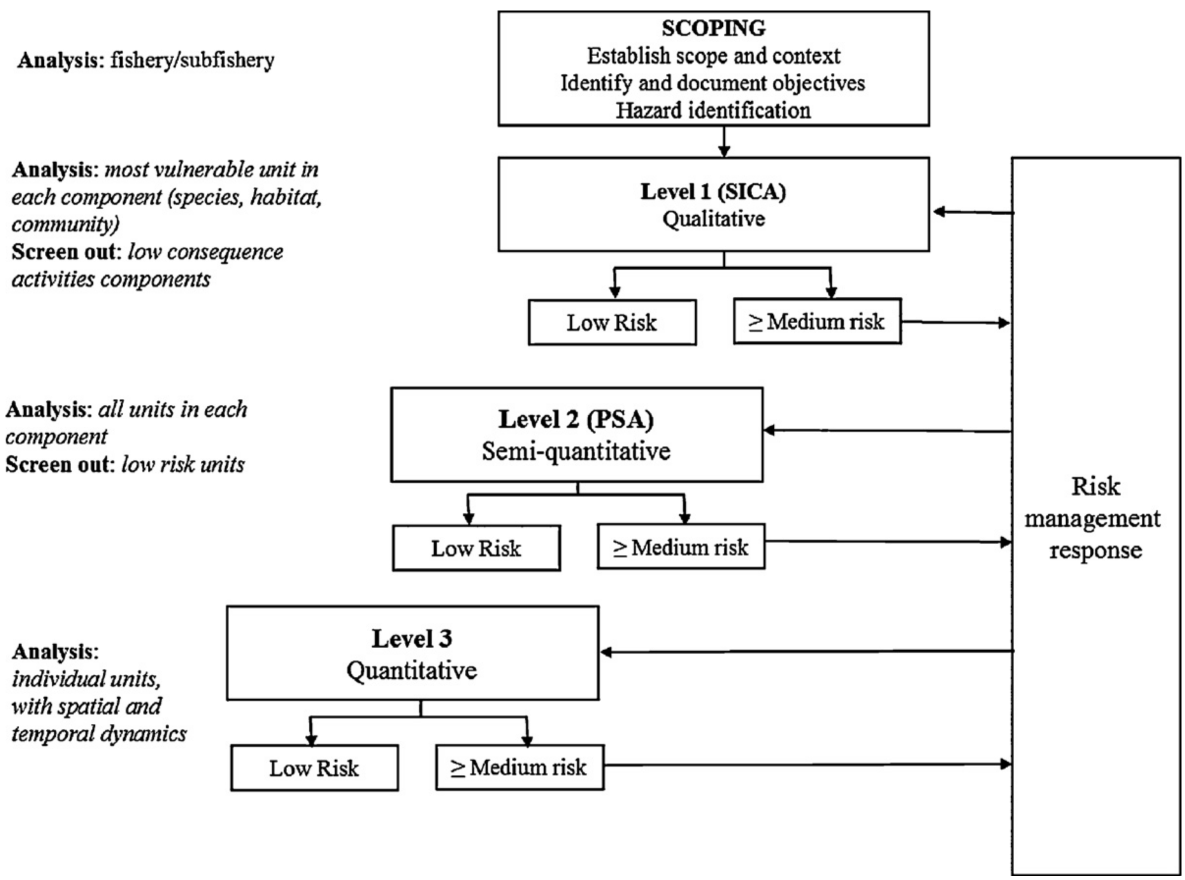

Figure 4. Ecological Risk Assessment Framework for an Australian fishery, from Hobday et al. (2011).

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.

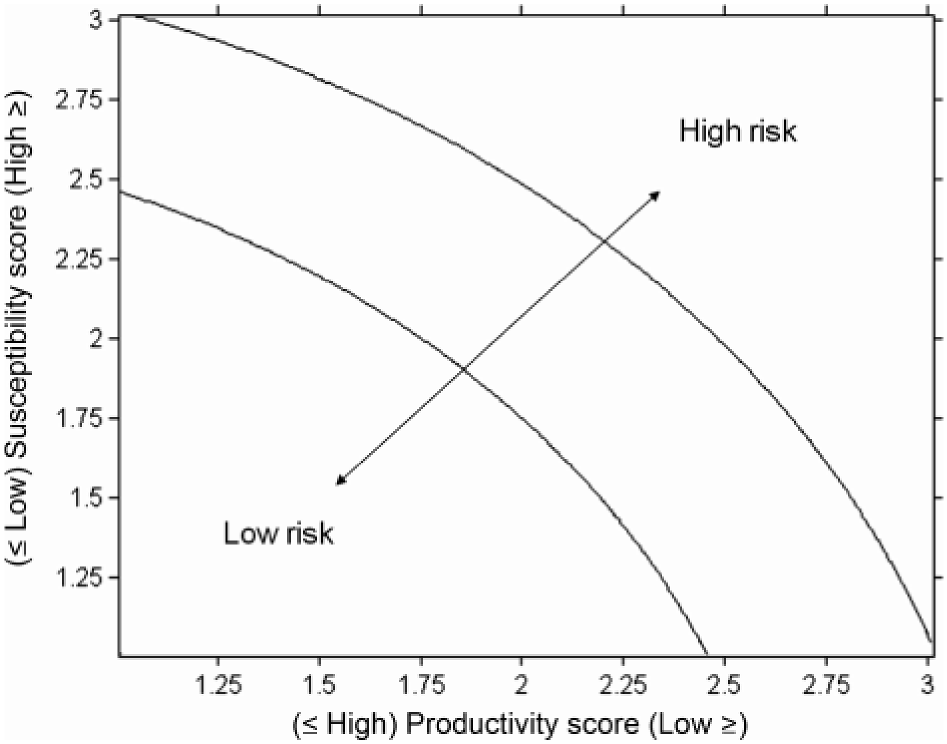

Figure 5. PSA plot shows the calculation of risk based on the combined productivity and susceptibility scores, from Smith et al. (2007).

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."

References

Ban, N.C., Alidina, H.M., Ardron, J.A., 2010. Cumulative impact mapping: Advances, relevance and limitations to marine management and conservation, using Canada's Pacific waters as a case study. Mar. Policy 34: 876–886. doi:10.1016/j.marpol.2010.01.010

Baum, J.R., Locke, E.A., Kirkpatrick, S.A., 1998. A longitudinal study of the relation of vision and vision communication to venture growth in entrepreneurial firms. J. Appl. Psychol. 83: 43.

Borja, A., Elliott, M., Andersen, J.H., Berg, T., Carstensen, J., Halpern, B.S., Heiskanen, A.-S., Korpinen, S., Lowndes, J.S.S., Martin, G., Rodriguez-Ezpeleta, N., 2016.

Overview of Integrative Assessment of Marine Systems: The Ecosystem Approach in Practice. Mar. Ecosyst. Ecol. 20. doi:10.3389/fmars.2016.00020
Carwardine, J., Klein, C.J., Wilson, K.A., Pressey, R.L., Possingham, H.P., 2009. Hitting the target and missing the point: target-based conservation planning in context. Conserv. Lett. 2: 4–11. doi:10.1111/j.1755-263X.2008.00042.x
Collins, J.C., Porras, J.I., 1996. Building your company's vision. Harv. Bus. Rev. 74: 65.
Cooperrider, D., Whitney, D.D., Stavros, J.M., 2008. The appreciative inquiry handbook: For leaders of change. Berrett-Koehler Publishers.
Crain, C.M., Kroeker, K., Halpern, B.S., 2008. Interactive and cumulative effects of multiple human stressors in marine systems. Ecol. Lett. 11: 1304–1315.
Fletcher, W.J., 2005. The application of qualitative risk assessment methodology to prioritize issues for fisheries management. ICES J. Mar. Sci. J. Cons. 62: 1576–1587. doi:10.1016/j.icesjms.2005.06.005
Fletcher, W.J., Bianchi, G., 2014. The FAO–EAF toolbox: making the ecosystem approach accessible to all fisheries. Ocean Coast. Manag. 90: 20–26.
Fletcher, W.J., Shaw, J., Metcalf, S.J., Gaughan, D.J., 2010. An ecosystem based fisheries management framework: the efficient, regional-level planning tool for management agencies. Mar. Policy 34: 1226–1238.
Garcia, S.M., 2003. The ecosystem approach to fisheries: issues, terminology, principles, institutional foundations, implementation and outlook. Food & Agriculture Org.
Gregory, R.S., Failing, L., Harstone, M., Long, G., McDaniels, T., Ohlson, D., 2012. Structured Decision Making. John Wiley & Sons, Oxford.
Halpern, B.S., Kappel, C.V., Selkoe, K.A., Micheli, F., Ebert, C.M., Kontgis, C., Crain, C.M., Martone, R.G., Shearer, C., Teck, S.J., 2009. Mapping cumulative human impacts to California Current marine ecosystems. Conserv. Lett. 2: 138–148. doi:10.1111/j.1755-263X.2009.00058.x
Hobday, A.J., Smith, A.D.M., Stobutzki, I.C., Bulman, C., Daley, R., Dambacher, J.M., Deng, R.A., Dowdney, J., Fuller, M., Furlani, D., others, 2011. Ecological risk assessment for the effects of fishing. Fish. Res. 108: 372–384.
Jennings, S., 2005. Indicators to support an ecosystem approach to fisheries. Fish Fish. 6: 212–232.
Kantabutra, S., 2009. Toward a behavioral theory of vision in organizational settings. Leadersh. Organ. Dev. J. 30: 319–337.
Kantabutra, S., Avery, G.C., 2010. The power of vision: statements that resonate. J. Bus. Strategy 31: 37–45.
Kaplan, I.C., Gray, I.A., Levin, P.S., 2012. Cumulative impacts of fisheries in the California Current. Fish Fish. 14: 515–527. doi:10.1111/j.1467-2979.2012.00484.x
Larwood, L., Falbe, C.M., Kriger, M.P., Miesing, P., 1995. Structure and meaning of organizational vision. Acad. Manage. J. 38: 740–769.
Levin, P.S., Kelble, C.R., Shuford, R.L., Ainsworth, C., deReynier, Y., Dunsmore, R., Fogarty, M.J., Holsman, K., Howell, E.A., Monaco, M.E., Oakes, S.A., Werner, F.,

2014. Guidance for implementation of integrated ecosystem assessments: a US perspective. ICES J. Mar. Sci. J. Cons. 71: 1198–1204. doi:10.1093/icesjms/fst112
Mace, G.M., Possingham, H.P., Leader-Williams, N., 2007. Prioritizing choices in conservation, in: Macdonald, D.W., Service, K. (Eds.), Key Topics in Conservation Biology. pp. 17–34.
Meffe, G., Nielsen, L., Knight, R.L., Schenborn, D., 2012. Ecosystem management: adaptive, community-based conservation. Island Press.
NPFMC, 2007. Aleutian Islands Fishery Ecosystem Plan. Anchorage, Alaska: NPFMC. http://www.npfmc.org/aleutian-islands-fishery-ecosystem-plan/
O'Boyle, R., Jamieson, G., 2006. Observations on the implementation of ecosystem-based management: experiences on Canada's east and west coasts. Fish. Res. 79: 1–12.
Patrick, W.S., Spencer, P., Link, J., Cope, J., Field, J., Kobayashi, D., Lawson, P., Gedamke, T., Cortes, E., Ormseth, O., others, 2010. Using productivity and susceptibility indices to assess the vulnerability of United States fish stocks to overfishing. Fish. Bull. 108: 305–322.
Rice, J., Trujillo, V., Jennings, S., Hylland, K., Hagstrom, O., Astudillo, A., Jensen, J.N., others, 2005. Guidance on the application of the ecosystem approach to management of human activities in the European marine environment. Coop. Res. Rep.-Int. Counc. Explor. SEA 273.
Rogers, K., Biggs, H., 1999. Integrating indicators, endpoints and value systems in strategic management of the rivers of the Kruger National Park. Freshw. Biol. 41: 439–451.
Sainsbury, K., Punt, A.E., Smith, A.D.M., 2000. Design of operational management strategies for achieving fishery ecosystem objectives. ICES J. Mar. Sci. 57: 731–741. doi:10.1006/jmsc.2000.0737
Sainsbury, K., Sumaila, U.R., 2003. Incorporating ecosystem objectives into management of sustainable marine fisheries, including "best practice" reference points and use of Marine Protected Areas, in: Sinclair, M., Valdimarsson, G. (Eds.), Responsible Fisheries in the Marine Ecosystem. FAO, Rome, pp. 343–361.
Samhouri, J.F., Lester, S.E., Selig, E.R., Halpern, B.S., Fogarty, M.J., Longo, C., McLeod, K.L., 2012. Sea sick? Setting targets to assess ocean health and ecosystem services. Ecosphere 3: 1–18. doi:10.1890/ES11-00366.1
Samhouri, J.F., Levin, P.S., 2012. Linking land- and sea-based activities to risk in coastal ecosystems. Biol. Conserv. 145: 118–129. doi:10.1016/j.biocon.2011.10.021
Samhouri, J.F., Levin, P.S., Andrew James, C., Kershner, J., Williams, G., 2011. Using existing scientific capacity to set targets for ecosystem-based management: A Puget Sound case study. Mar. Policy 35: 508–518. doi:10.1016/j.marpol.2010.12.002

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

Smith, A.D.M., Fulton, E.J., Hobday, A.J., Smith, D.C., Shoulder, P., 2007. Scientific tools to support the practical implementation of ecosystem-based fisheries management. ICES J. Mar. Sci. J. Cons. 64: 633–639.

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.

References

Abbott, J. K. and J. E. Wilen. 2009. Regulation of fisheries bycatch with common-pool output quotas. Journal Of Environmental Economics And Management 57:195-204.

Anderson, J. L., C. M. Anderson, J. Chu, J. Meredith, F. Asche, G. Sylvia, M. D. Smith, D. Anggraeni, R. Arthur, A. Guttormsen, et al. 2015. The fishery performance indicators: a management tool for triple bottom line outcomes. PLoS ONE 10:e0122809.

Beaudreau, A. H., P. S. Levin, and K. C. Norman. 2011. Using folk taxonomies to understand stakeholder perceptions for species conservation. Conservation Letters 4:451-463.

Butterworth, D. S. and A. E. Punt. 1999. Experiences in the evaluation and implementation of management procedures. ICES Journal of Marine Science 56:985-998.

Clay, P. M., A. Kitts, and P. Pinto da Silva. 2014. Measuring the social and economic performance of catch share programs: Definition of metrics and application to the U.S. Northeast Region groundfish fishery. Marine Policy 44:27-36.

Dambacher, J. M., D. J. Gaughan, M. J. Rochet, P. A. Rossignol, and V. M. Trenkel. 2009. Qualitative modelling and indicators of exploited ecosystems. Fish and Fisheries 10:305-322.

Daskalov, G. M., A. N. Grishin, S. Rodionov, and V. Mihneva. 2007. Trophic cascades triggered by overfishing reveal possible mechanisms of ecosystem regime shifts. Proceedings of the National Academy of Sciences 104:10518-10523.

Dichmont, C. M., N. Ellis, R. H. Bustamante, R. Deng, S. Tickell, R. Pascual, H. Lozano-Montes, and S. Griffiths. 2013. Evaluating marine spatial closures with conflicting fisheries and conservation objectives. Journal of Applied Ecology 50:1060-1070.

Fulton, E. A., T. Jones, F. Boschetti, K. L. Chapman, R. L. Little, G. Syme, P. Dzidic, R. Gorton, M. Sporic, and W. de la Mare. 2013. Assing the impact of stakeholder engagement in management strategy evaluation. International Journal of Economics and Management Engineering 3:83-99.

Fulton, E. A., A. D. Smith, D. C. Smith, and P. Johnson. 2014. An integrated approach is needed for ecosystem based fisheries management: insights from ecosystem-level management strategy evaluation. PLoS ONE 9:e84242.

Fulton, E. A., A. D. M. Smith, and A. E. Punt. 2005. Which ecological indicators can robustly detect effects of fishing. ICES Journal of Marine Science 62:540-551.

Fulton, E. A., A. D. M. Smith, D. C. Smith, and I. E. van Putten. 2011. Human behaviour: the key source of uncertainty in fisheries management. Fish and Fisheries 12:2-17.

Gregory, R. S., L. Failing, M. Harstone, G. Long, T. McDaniels, and D. Ohlson. 2012. Structured Decision Making. John Wiley & Sons, Oxford.

Holland, D., J. N. Sanchirico, R. Johnston, and D. Joglekar. 2010. Economic Analysis for Ecosystem Based Management: Applications to Marine and Coastal Environments. RFF PRess.

Holland, D. S. 2010. Markets, pooling and insurance for managing bycatch in fisheries. Ecological Economics 70:121-133.

Holland, D. S. and J. E. Jannot. 2012. Bycatch risk pools for the US West Coast Groundfish Fishery. Ecological Economics 78:132-147.

Hosack, G. R., K. R. Hayes, and J. M. Dambacher. 2008. Assessing model structure uncertainty through an analysis of system feedback and Bayesian networks. Ecological Applications 18:1070-1082.

Hsee, C. K. 1996. The evaluability hypothesis: An explanation for preference reversals between joint and separate evaluation of alternatives. Organizational Behavior and Human Decision Processes 67:247-267.

Hurtado-Ferro, F. and A. E. Punt. 2014. Revised analyses related to Pacific sardine harvest parameters. Pacific Fisheries Management Council, March 2014.

ICES. 2014. Capelin in Subareas I and II, excluding Dvision IIa west of 5°W (Barents Sea Capelin). ICES, Denmark, CO.

Jackson, B. C., M. X. Kirby, W. H. Berger, K. A. Bjorndal, L. W. Botsford, B. B.J., B. R.H., R. Cooke, J. Erlandson, J. A. Estes, et al. 2001. Historical overfishing and the recent collapse of coastal ecosystems. Science 293:629-638.

Jennings, S. 2005. Indicators to support an ecosystem approach to fisheries. Fish and Fisheries 6:212-232.

Kasperski, S. and D. S. Holland. 2013. Income diversification and risk for fishermen. Proceedings of the National Academy of Science of the United States of America 110:2076-2081.

Keeney, R. L. and R. S. Gregory. 2005. Selecting Attributes to Measure the Achievement of Objectives. Operations Research 53:1-11.

Kroetz, K. and J. N. Sanchirico. 2010. Economic insights into the costs of design restrictions in ITQ programs. Resources for the Future www rff.org.

Kroetz, K., J. N. Sanchirico, and D. K. Lew. 2015. Efficiency Costs of Social Objectives in Tradable Permit Programs. Journal of the Association of Environmental and Resource Economists 2:339-366.

Levin, P. S. and A. Dufault. 2010. Eating up the food web. Fish and Fisheries 11:307-312.

Lew, D. K. 2015. Willingness to pay for threatened and endangered marine species: A review of the literature and prospects for policy use. Frontiers in Marine Science 2.

Link, J. S., J. K. T. Brodziak, S. F. Edwards, W. J. Overholtz, D. Mountain, J. W. Jossi, T. D. Smith, and M. J. Fogarty. 2002. Marine ecosystem assessment in a fisheries management context. Canadian Journal of Fisheries and Aquatic Sciences 59:1429-1440.

Manning, R. E. 2013. Social norms and reference points: integrating sociology and ecology. Environmental Conservation 40:310-317.

McClanahan, T. R., A. J. Graham, M. A. MacNeil, N. A. Muthiga, J. E. Cinner, J. H. Bruggemann, and S. K. Wilson. 2011. Critical thresholds and tangible targets for ecosystem-based management of coral reef fisheries. Proceedings of the National Academy of Science of the United States of America 108:17230-17233.

Morris, W. F. and D. F. Doak. 2002. Quantitative conservation biology. Sinauer Associates, Inc., Sunderland, MA.

National Research Council. 2014. Evaluating the Effectiveness of Fish Stock Rebuilding Plans in the United States. The National Acadmies Press, Washington D.C.

New England Fishery Management Council. 2011. Essential Fish Habiat (EFH) Omnibus Amendment: The swept area seabead impact (SASI) model-A tool for analysing the effects of fishing on essential habitat. New England Fishery Management Council.

Newell, R. G., J. N. Sanchirico, and J. N. Kerr. 2005. Fishing quota markets. Journal Of Environmental Economics And Management 49:437-462.

Implementation Volume. Step 3: "How will we get there?"

NRC. 2014. Evaluating the Effectiveness of Fish Stock Rebuilding Plans in the United States. National Academies Press.

Oguz, T. and D. Gilbert. 2007. Abrupt transitions of the top-down controlled Black Sea pelagic ecosystem during 1960-2000: Evidence for regime-shifts under strong fishery exploitation and nutrient enrichment modulated by climate-induced variations. Deep-Sea Research Part 1-Oceanographic Research Papers 54:220-242.

Pacific Fisheries Management Council. 2011. Coastal pelagic species fishery management plan. Page 48, Portland, OR.

Pikitch, E. K., P. D. Boersma, I. L. Boyd, D. O. Conover, P. Cury, T. E. Essington, S. S. Heppell, E. D. Houde, M. Mangel, D. Pauly, et al. 2012. Little fish, big impact: Managing a crucial link in ocean food webs. Lenfest Ocean Program, Washington D.C.

Plagányi, E. E. 2007. Models for an ecosystem approach to fisheries. FAO, Rome.

Plagányi, É. E., A. E. Punt, R. Hillary, E. B. Morello, O. Thébaud, T. Hutton, R. D. Pillans, J. T. Thorson, E. A. Fulton, A. D. M. Smith, et al. 2014. Multispecies fisheries management and conservation: tactical applications using models of intermediate complexity. Fish and Fisheries 15:1-22.

Plagányi, E. E., I. van Putten, T. Hutton, R. A. Deng, D. Dennis, S. Pascoe, T. Skewes, and R. A. Campbell. 2013. Integrating indigenous livelihood and lifestyle objectives in managing a natural resource. Proceedings of the National Academy of Sciences of the United States of America.

Prigent, M., G. Fontenelle, M.-J. Rochet, and V. M. Trenkel. 2008. Using cognitive maps to investigate fishers' ecosystem objectives and knowledge. Ocean & Coastal Management 51:450-462.

Punt, A. E., D. S. Butterworth, C. L. de Moor, J. A. A. De Oliveira, and M. Haddon. 2014. Management strategy evaluation: best practices. Fish and Fisheries.

Rice, J. and M. Rochet. 2005. A framework for selecting a suite of indicators for fisheries management. ICES Journal of Marine Science 62:516-527.

Rose, K. A., S. Sable, D. L. DeAngelis, S. Yurek, J. C. Trexler, W. Graf, and D. J. Reed. 2015. Proposed best modeling practices for assessing the effects of ecosystem restoration on fish. Ecological Modelling 300:12-29.

Sainsbury, K., A. E. Punt, and A. D. M. Smith. 2000. Design of operational management strategies for achieving fishery ecosystem objectives. ICES Journal of Marine Science 57:731-741.

Sainsbury, K. and U. R. Sumaila. 2003. Incorporating ecosystem objectives into management of sustainable marine fisheries, including 'best practice' reference points and use of Marine Protected Areas. Pages 343-361 *in* M. Sinclair and G. Valdimarsson, editors. Responsible Fisheries in the Marine Ecosystem. FAO, Rome.

Samhouri, J. F., P. S. Levin, C. Andrew James, J. Kershner, and G. Williams. 2011. Using existing scientific capacity to set targets for ecosystem-based management: A Puget Sound case study. Marine Policy 35:508-518.

Samhouri, J. F., P. S. Levin, and C. J. Harvey. 2009. Quantitative Evaluation of Marine Ecosystem Indicator Performance Using Food Web Models. Ecosystems 12:1283-1298.

Sanchirico, J., D. Holland, K. Quigley, and M. Fina. 2006. Catch-quota balancing in multispecies individual fishing quotas. Marine Policy 30:767-785.

Smith, A. D., C. J. Brown, C. M. Bulman, E. A. Fulton, P. Johnson, I. C. Kaplan, H. Lozano-Montes, S. Mackinson, M. Marzloff, L. J. Shannon, et al. 2011. Impacts of fishing low-trophic level species on marine ecosystems. Science 333:1147-1150.

Smith, A. D. M. 1994. Management strategy evaluation - the light on the hill. Pages 249-253 *in* D. A. Hancock, editor. Australian Society for Fish Biology Workshop Proceedings, Perth, 24-25 August 1993. Australian Society for Fish Biology, Perth.

Smith, A. D. M., M. Sachse, D. C. Smith, J. D. Prince, I. A. Knuckley, P. Baelde, T. J. Walker, and S. Talman. 2004. Alternative management strategies for the Southern and Eastern Scalefish and Shark Fishery Qualitative Assessment, Stage 1.

Smyth, R. L., M. C. Watzin, and R. E. Manning. 2007. Defining acceptable levels for ecological indicators: an approach for considering social values. Environ Manage 39:301-315.

Sugihara, G., R. May, H. Ye, C. H. Hsieh, E. Deyle, M. Fogarty, and S. Munch. 2012. Detecting causality in complex ecosystems. Science 338:496-500.

Thurstan, R. H., L. McClenachan, L. B. Crowder, J. A. Drew, J. N. Kittinger, P. S. Levin, C. M. Roberts, and J. M. Pandolfi. 2015. Filling historical data gaps to foster solutions in marine conservation. Ocean & Coastal Management 115:31-40.

Trenkel, V. M. and M.-J. Rochet. 2003. Performance of indicators derived from abundance estimates for detecting the impact of fishing on a fish community. Canadian Journal of Fisheries and Aquatic Sciences 60:67-85.

Walters, C. and J. F. Kitchell. 2001. Cultivation/depensation effects on juvenile survival and recruitment: implications for the theory of fishing. Canadian Journal of Fisheries and Aquatic Sciences 58:39-50.

Williams, A., J. Dowdney, A. D. M. Smith, A. J. Hobday, and M. Fuller. 2011. Evaluating impacts of fishing on benthic habitats: A risk assessment framework applied to Australian fisheries. Fisheries Research 112:154-167.

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.

References

Katz, S. L. 2013. Monitoring endangered species. Page in press *in* N. MacLeod, Archibald, D. Levin, P.S., editor. Extinction. Gale Publishing, Farmington Hills, MI

McLeod, K. and H. Leslie. 2009. Ecosystem-based management for the oceans. Cambridge Univ Press.

Meffe, G., J. L. Nielsen, R. L. Knight, and D. A. Schenborn. 2002. Ecosystem management: adaptive, community-based conservation. Island Press.

Metcalf, S. J., J. M. Dambacher, A. J. Hobday, and J. M. Lyle. 2008. Importance of trophic information, simplification and aggregation error in ecosystem models. Marine Ecology Progress Series 360:25-36.