Delineating the continuum of marine ecosystem-based management: A US fisheries reference point perspective

Article *in* ICES Journal of Marine Science · December 2015

DOI: 10.1093/icesjms/fsv242

3 authors:

Tara Dolan
Massachusetts Division of Marine Fisheries

Wesley S Patrick
Ministry for the Environment, New Zealand

Jason S Link
National Oceanic and Atmospheric Administration

ICES Journal of Marine Science Advance Access published December 28, 2015

ICES Journal of Marine Science

ICES CIEM International Council for the Exploration of the Sea Conseil International pour l'Exploration de la Mer

ICES Journal of Marine Science; doi:10.1093/icesjms/fsv242

Delineating the continuum of marine ecosystem-based management: a US fisheries reference point perspective

Tara E. Dolan[1], Wesley S. Patrick[2,3]*, and Jason S. Link[4]

[1]*NOAA Fisheries, Office of Science and Technology, 1315 East-West Highway, Silver Spring, MD 20910, USA*
[2]*NOAA Fisheries, Office of Sustainable Fisheries, 1315 East-West Highway, Silver Spring, MD 20910, USA*
[3]*Ministry for the Environment, 23 Kate Sheppard Place, Wellington 6143, New Zealand*
[4]*NOAA Fisheries, Office of the Assistant Administrator, 166 Water St, Woods Hole, MA 02543, USA*

**Corresponding author: tel: +64 04 439 7408; e-mail: wes.patrick@mfe.govt.nz.*

Dolan, T. E., Patrick, W. S., and Link, J. S. Delineating the continuum of marine ecosystem-based management: a US fisheries reference point perspective. – ICES Journal of Marine Science, doi: 10.1093/icesjms/fsv242.

Received 21 July 2015; revised 12 November 2015; accepted 18 November 2015.

Ecosystem management (EM) suffers from linguistic uncertainty surrounding the definition of "EM" and how it can be operationalized. Using fisheries management as an example, we clarify how EM exists in different paradigms along a continuum, starting with a single-species focus and building towards a more systemic and multi-sector perspective. Focusing on the specification of biological and other systemic reference points (SRPs) used in each paradigm and its related regulatory and governance structures, we compare and contrast similarities among these paradigms. We find that although EM is a hierarchical continuum, similar SRPs can be used throughout the continuum, but the scope of these reference points are broader at higher levels of management. This work interprets the current state of the conversation, and may help to clarify the levels of how EM is applied now and how it can be applied in the future, further advancing its implementation.

Keywords: decision criteria, ecosystem approaches, ecosystem-based management, fisheries management, reference points, science communication.

Introduction

There have been copious calls, mandates, and recognized needs for marine ecosystem-based management (EBM; Grumbine, 1994; Larkin, 1996; Pikitch *et al.*, 2004; Arkema *et al.*, 2006). In response, a myriad of governing organizations across multiple ocean-use sectors have promoted some version of this ecosystem management (EM) concept over the past decade (Arkema *et al.*, 2006). This multi-sectoral effort to manage living marine resources in a more holistic fashion has resulted in parallel evolution of overlapping terminology in the management lexicon (Figure 1). The result has been linguistic uncertainty regarding both what EBM means and how it can be operationalized (Yaffee, 1999; Arkema *et al.*, 2006; Link and Browman, 2014). We assert that this linguistic uncertainty is largely due to the term being used in a broad suite of contexts and consequently lacks clear distinctions along a continuum of possible applications.

Many examples of the linguistic uncertainty surrounding EM occur within a fisheries context (Figure 1). In practice, the terms EBM, ecosystem-based fisheries management (EBFM), and ecosystem approach to fisheries management (EAFM) are often poorly distinguished, or they are used interchangeably (Murawski, 2007; Varjopuro *et al.*, 2008; Link and Browman, 2014). Although the focus of this paper is on fisheries, the same framework could be extended to other living marine resources or other ocean-use sectors, such as coastal-zone management (Halpern *et al.*, 2008; Norse, 2010), marine mineral management and aggregates extraction (Atkins *et al.*, 2011), and energy production (Snyder and Kaiser, 2009).

Recognizing that many others have characterized levels of EM, this work views EM as a continuum, starting with a single-species focus and building towards a more systemic and multi-sector perspective (Figure 2). As an organizing device, this work largely focuses on the decision criteria [known formally as biological reference points (BRPs) or systemic reference points (SRPs)] provided across the gradient of EM. In doing so, this work emphasizes the distinctions across the single-species approach to fisheries management

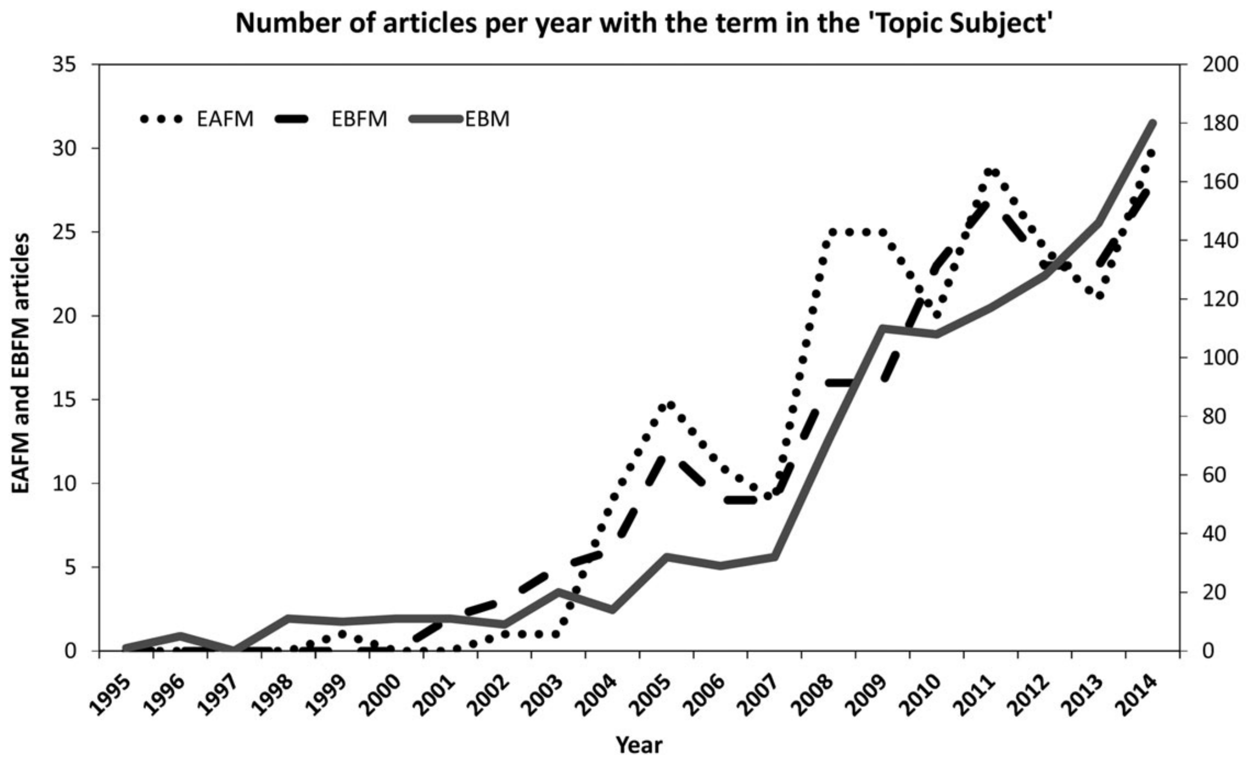

Figure 1. Bibliometric analysis of the Web of Science Database, showing the usage of the terms "EBM", "EBFM", and "EAFM" as topic subjects in peer-reviewed articles over the past two decades. Retrieved 11 November 2015.

(SSAFM), EAFM, EBFM, and EBM by describing how the quantitative advice for these levels of EM is applied. We also discuss the governance framework where the various levels of EM are implemented.

Levels of EBM

Single-species approach to fisheries management

SSAFM are the natural starting point for elucidating the differences between levels of EM (i.e. EAFM, EBFM, and EBM). SSAFM has been the prevailing paradigm of fisheries management in the United States and elsewhere in the world for decades. A plethora of features that vary in complexity can be applied through SSAFM (Methot *et al.*, 2013), and we acknowledge the fullness of work that goes into producing stock assessment model outputs for informing management measures. From a decision criteria viewpoint, SSAFM produces BRPs that are typically some proxy of maximum sustainable yield (MSY) for individual fish stocks (Figure 2; Restrepo *et al.*, 1998; Methot *et al.*, 2013). These MSY-related BRPs are usually calculated with facets of biomass and fishing rate, from which decisions for suitable management are made.

Surplus production models were one of the founding methods used by fisheries scientists to estimate MSY (Schaefer, 1954; Smith, 1994). This approach has been widely used in fisheries management over the past 70 years to estimate MSY, and variations of these models are still used today in fisheries (e.g. Hoenig *et al.*, 1994; Prager, 1994; McAllister *et al.*, 2001). The calculation of MSY is a data-intensive process requiring a relatively long catch history as well as information on fishing effort, natural mortality, and catchability (Shertzer *et al.*, 2008). In some instances, a broad suite of age-based information is used to estimate stock abundance and removals by catch (Smith, 1994; Quinn and Deriso, 1999). Yet worldwide, many fisheries lack directly estimated MSY-related BRPs (Costello *et al.*, 2012; Ricard *et al.*, 2012). Although MSY cannot be directly estimated for some of these data-poor stocks, a number of indicator-based methods are available to estimate sustainable levels of catch (e.g. Berkson *et al.*, 2011; Carruthers *et al.*, 2014). However, always some form of BRP is produced to determine stock status, which can then be used to inform management decisions.

Within the United States, the federal management governance bodies for SSAFM are the eight Regional Fishery Management Councils [16 USC § 1852(a)]. The regulatory process by which SSAFM is implemented is through fishery management plans (FMPs). These FMPs contain a number of elements such as the goals and objectives of the fishery, BRPs referred to as status determination criteria, specification of catch limits based off of the BRPs, and how yield will be allocated among stakeholders. The BRPs, and setting of annual catch limits, are vetted by a Scientific and Statistical Committee in each Council. NOAA Fisheries is responsible for reviewing these FMPs, on behalf of the US Secretary of Commerce, for consistency with all applicable federal laws and Executive Orders (Methot *et al.*, 2013).

Ecosystem approach to fisheries management

Whether through necessity, innovation, or external pressures to expand the scope of interest, stock assessments have begun to move beyond a purely single-species context (i.e. focus on the biology of the stock and its direct interactions with the fishery). Many assessments now consider other environmental and ecological factors that affect the population dynamics of a stock (Mace, 2001;

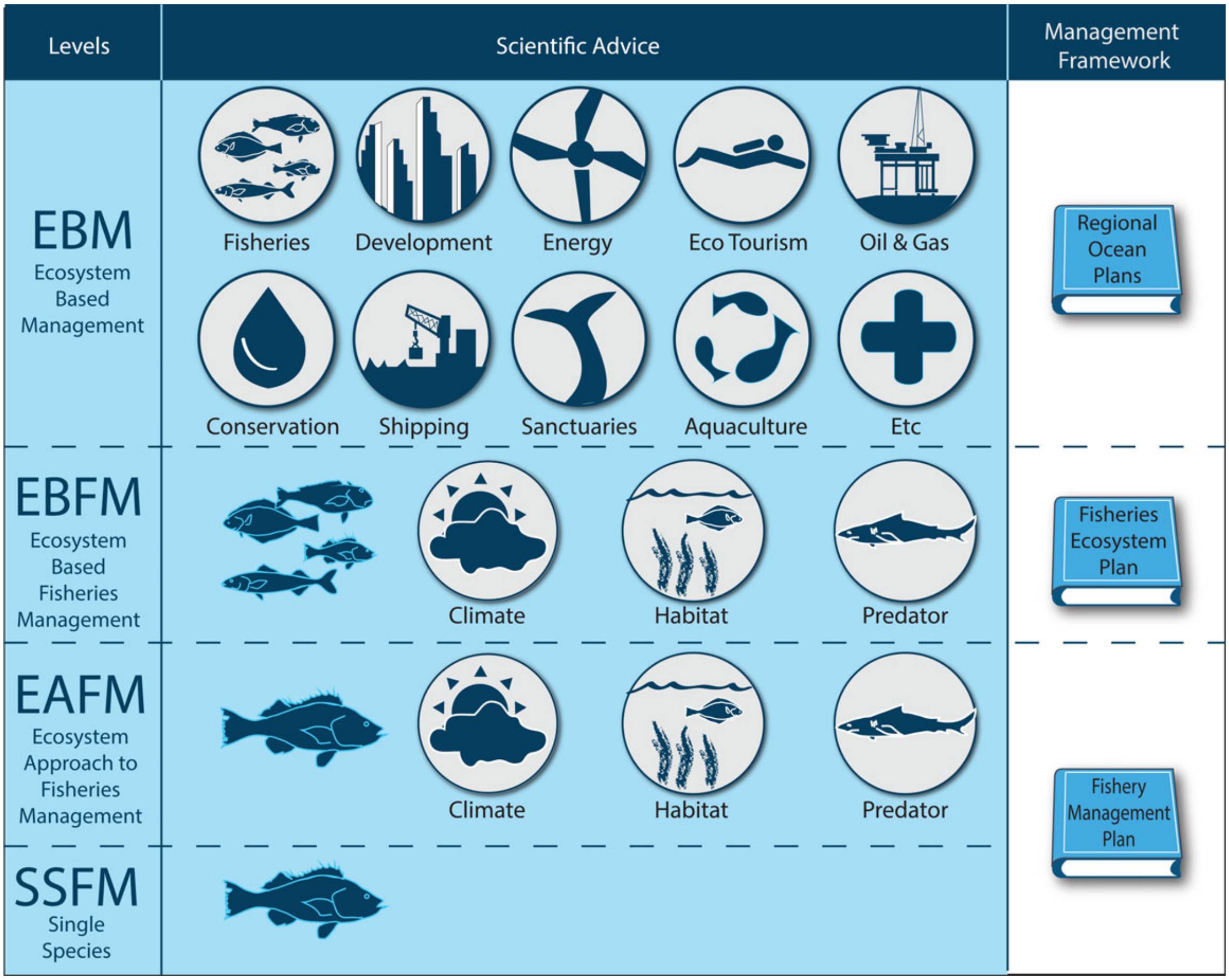

Figure 2. The paradigms of EM, building upwards from single-species management, to EBM. Scientific advice and the sectors of management build with each level, as well as the management framework. Key differences between ecosystem approaches to fisheries management (EAFM) and EBFM is that the later considers the trade-offs of multiple species, as opposed to a stock within a fishery, and EBFM takes a more coordinated approach to management through the use of strategic planning documents like fishery ecosystem plans.

Keyl and Wolff, 2008; Link, 2010). This extension of single-species management is frequently termed an EAFM (Link, 2002; Fogarty *et al.*, 2012). From a BRP perspective, most fishery EM work performed in the United States and in other countries is often considered EAFM (Pitcher *et al.*, 2009; Skern-Mauritzen *et al.*, 2015). However, other actions (e.g., designation of marine protected areas, forage fish harvest strategies, etc.) taken by fishery managers and scientists could also be considered EAFM. By incorporating ecosystem considerations into stock assessments, EAFM aims to enhance the understanding of fishery dynamics and provide better-informed management decisions (Figure 2). The BRPs produced by this approach are similar to those produced and used in SSAFM; they just include or consider ecosystem considerations more directly.

Ecosystem information can be incorporated directly into stock assessment models. These ecosystem-linked assessments or extended stock assessment models account for ecological and environmental processes that are thought to influence population dynamics through predation (e.g. Tyrrell *et al.*, 2011; Rossberg *et al.*, 2013), habitat-mediated or physiochemically mediated changes to carrying capacity (e.g. Hobday and Tegner, 2002; Keyl and Wolff, 2008), growth (e.g. Lorenzen, 2008), structural changes in the stock–recruitment function (e.g. Clark *et al.*, 2003; Schirripa *et al.*, 2009), or a combination of these (e.g. Hollowed *et al.*, 2009). In some instances, there are multispecies models (Daan and Sissenwine, 1991; Hollowed *et al.*, 2000; Link, 2010; Link *et al.*, 2010a) that attempt to capture the dynamics and interactions of several (but not all) stocks within the ecosystem. In other instances, ecosystem considerations are not directly incorporated into stock assessment models, but are used to provide context regarding the uncertainty surrounding a BRP or future management actions (e.g. Witherell *et al.*, 2000; Stram and Evans, 2009; Levin and Wells, 2011; Zador, 2012).

The venue for management in EAFM is the same as with SSAFM (i.e. through FMPs implemented by Regional Fishery Management Councils). Within the management implementation phase, EAFM is operationally very similar to SSAFM. The only difference between these two paradigms is that BRPs used to inform management decisions under EAFM, more directly capture a broader range of dynamics that can impact fish stocks (Table 1).

Table 1. Levels of marine EM, with a description of how each level focuses on different sections, biological components, objectives, scientific advice, implementation framework, and ideal implementation body (adapted from Link and Browman, 2014).

Feature	SSAFM	EAFM	EBFM	EBM
Sector of focus	Fisheries	Fisheries	Fisheries	All
Focus of biological hierarchy	Stock/population	Stock/population	Community	Whole system and connected systems
Primary analysis objective	Determine the status of stocks	Determine the status of stocks	Address fisheries sector LMR trade-offs	Address cross-sector trade-offs
	Ascertain stock productivity	Ascertain stock productivity	Ascertain ecosystem productivity	Identify best mix of goods and services across systems
			Identify best mix of goods and services across fisheries	
Scientific advice produced	Biological reference points (BRPs)	BRPs	Systemic reference points (SRPs), which include BRPs	SRPs
Implementation framework	Fishery management plan (FMP)	FMP	Fishery ecosystem plan	Regional Ocean Action Plans, NEPA
Implementation body	Fishery Management Council (FMC)	FMC	FMC	Regional Ocean Council

Ecosystem-based fisheries management

EBFM takes a system-level perspective on fisheries in an ecosystem. Previous works on EBFM have included an exhaustive list of broader goals (e.g. Hall and Mainprize, 2004; Pikitch *et al.*, 2004, 2009; Fletcher, 2005), but a primary take-away from these studies is that managing trade-offs to optimize the overall fisheries yield of an ecosystem over time is the crux of EBFM (Figure 2; Link, 2010). Thus, EBFM differs from EAFM in that it focuses on multiple or all fisheries within an ecosystem and takes a coordinated and strategic approach to providing the greatest benefit to the nation (Patrick and Link, 2015a). Whereas EAFM focuses on a single stock within a fishery and takes a more piecemeal or opportunistic approach to incorporating ecosystem considerations into management decisions.

To address trade-offs within the fisheries sector, some level of overall constraint for the system is typically needed (Link, 2010). For example, the use of aggregate production models to estimate aggregate group or system-level BRPs is increasingly common (Polovina, 1984; Mueter and Megrey, 2006; Gamble and Link, 2009; Fogarty *et al.*, 2012). Once assembled, these functional groups can be modelled in a similar fashion to extended stock assessment models to explore the effects of climate and habitat (Gaichas *et al.*, 2012a, b; Gamble and Link, 2012). A broader range of foodweb and end-to-end models can also be used to simulate and estimate system-level BRPs (Townsend *et al.*, 2008; Link *et al.*, 2010a; Fulton *et al.*, 2011). This example shows that MSY-related BRPs can still be calculated, but they are done so for aggregate groups or for all fisheries within an ecosystem.

An important point regarding EBFM is that there are more decision criteria beyond those related to biological yield. SRPs include BRPs, but also acknowledge other ecosystem-level goals, such as conservation, resilience, or socio-economic considerations (Kellner *et al.*, 2011). Several studies have demonstrated the integrative nature of work needed for these SRPs (Coll *et al.*, 2008; Libralato *et al.*, 2008; Pranovi *et al.*, 2012), the range of empirical and modelling sources able to provide these SRPs (Murawski, 2000; Link, 2005; Link *et al.*, 2010b; Shin *et al.*, 2010), and the development of critical thresholds of a wide range of multivariate ecosystem indicators to delineate such SRPs (Samhouri *et al.*, 2009; Fay *et al.*, 2013; Large *et al.*, 2013). Although SRPs are being developed in several ecosystems, their use is not yet widespread. Work to establish more formal decision criteria for multiple objectives is ongoing, but is used informally in most regions. For example, the North Pacific Regional Management Council specifies system-level BRPs (Witherell *et al.*, 2000; Hollowed *et al.*, 2011) as an overall constraint when setting groundfish quotas, and uses ecosystem information (not formal SRPs) as indicators to inform management decisions (Stram and Evans, 2009; Zador, 2012).

EBFM, like the other levels of fisheries EM, is implemented by Regional Fishery Management Councils. However, EBFM would ideally use fishery ecosystem plans (FEPs) for strategically managing fisheries, which several Regional Fishery Management Councils have implemented (Tromble, 2008). An idealized version of these integrated management plans would include facets of both strategic (long-term) and tactical (short-term) decisions, fisheries sector-level targets, and goals with enforceable management consequences if goals are not met (EPAP, 1999; Tromble, 2008). The objectives of FEPs would be implemented through FMPs, which have the regulatory authority under existing US mandates [16 USC §1853(a)]. The system would be evaluated relative to these goals through the use of SRPs, as previously described. This adaptive process can help determine whether management effectively incorporates the broader principles, goals, and policies of the Regional Fishery Management Councils.

Ecosystem-based management

EBM is the broadest scope of the management continuum described herein, spanning multiple sectors within an ecosystem (Figure 2; McLeod and Leslie, 2009; Norse, 2010). EBM of coastal and ocean resources has gained considerable momentum in the policy arena, being recommended by several ocean commissions (POC, 2004; NOP, 2010) and intergovernmental agencies (FAO, 2003; Foley *et al.*, 2013). Given its widespread acceptance as the management paradigm of the idealized future, many attempts have been made to establish a working definition. Most notably, McLeod *et al.* (2005) provide a scientific consensus statement on marine EBM, consistent with a review by Arkema *et al.* (2006), which identified three general criteria with most definitions considering: sustainability, ecological status, and inclusion of human dimensions. Further attempts to find an operational definition for EBM in the marine context have come from a variety of perspectives, emphasizing coastal marine spatial planning (White *et al.*, 2012), resilience theory (Hughes *et al.*, 2005; Levin and Lubchenco, 2008), fisheries science (Ruckelshaus *et al*., 2008; Link and Browman, 2014), socio-economics (Kellner *et al*., 2011; Menzel *et al*., 2013; Sanchirico *et al*., 2013), conservation (Grumbine, 1994; Slocombe, 1998), engineering (de la Mare, 2005), and operational management and governance (Tallis *et al*., 2010; Berkes, 2012), among others. EBM is the management paradigm that addresses cumulative impacts; seeks to ascertain the best mix of ecosystem goods and services produced by different ecosystem sectors and processes, or through emergent properties; provides systemic reference points; and quantifies risks across sectors with the ultimate purpose of maintaining core functionality (Norse, 2010). To implement these facets of EBM, both production-based BRPs (i.e. yield) and a broader range of SRPs are needed.

Integrative, cumulative, and quantitative SRPs (e.g. Libralato *et al*., 2008; Pranovi *et al*., 2012) represent an important advance in how systemic properties can be understood and detected to respond to a wide range of uses and pressures. Just as MSY-related BRPs can be estimated at either the stock or aggregate level, many of these cumulative indicators can be estimated for solely the fishery or multi-sector uses. A range of approaches can be used to specify multi-sector SRPs. Qualitative or semi-quantitative contextual and leading indicators are often overlooked but can provide ecosystem-level advice in terms of highlighting major ecosystem features and processes that are likely to impact all ocean-uses. Regionally applied risk-assessment frameworks are one example of a type of qualitative or semi-quantitative method for rapidly assessing ecosystem status to provide management advice (Fletcher, 2005; Hobday *et al*., 2011). In these cases and others, ecosystem status can be measured by an array of cross-sectoral metrics of the socio-ecological system, with suitable reference points identified (Crain *et al*., 2008; Samhouri *et al*., 2010; Fay *et al*., 2013). A range of ecosystem models can also identify these ecosystem-level decision criteria (Fulton and Link, 2014).

From a practical perspective, ecosystems that straddle geopolitical and jurisdictional boundaries will likely pose increased management challenges across ocean-use sectors when compared with just the fishery sector (Folke *et al*., 2005; Berkes, 2010). Marine EBM has been more successfully implemented at the local scale; for instance, several National Marine Sanctuaries have multi-sector management plans (Airame *et al*., 2003; Young *et al*., 2007; Ruckelshaus *et al*., 2008; Tissot *et al*., 2009).

In the United States, few institutions have the authority necessary to make decisions involving cross-sector trade-offs. The White House's National Ocean Policy's Regional Ocean Councils (NOP, 2010) are the closest approximation to management institutions for EBM at the large marine ecosystem scale. However, the NOP implementation plan is not yet in effect and Regional Ocean Councils have limited oversight over their member agencies. An example of the types of broad-scale trade-offs and the cross-sectoral coordination they require is the evaluation of the relative costs and benefits of using a portion of the Northeast continental shelf for offshore windfarms vs. its use for shipping channels (Samoteskul *et al*., 2014), conserving migratory routes for endangered right whales (e.g. Pendoley *et al*., 2014), or maintaining productive scallop beds (M. Fogarty, pers. comm.) in the same locale. These evaluations were achieved under existing governance structures, though in a relatively inefficient manner given the absence of an overarching regulatory authority. As the NOP becomes more fully implemented and Regional Ocean Councils gain authority, there may be marine ecosystem management plans, analogous to FMPs or FEPs, that improve the transparency, coordination, and planning of multi-sectored management decisions.

Perhaps one underutilized means for implementing marine EBM in the United States is the National Environmental Policy Act (NEPA; 42 USC 4321 et seq). The Act invokes trade-off analysis by requiring applicants to provide alternatives to a proposed action. However, some argue that impact analysis is usually done from a strong sectoral perspective by agencies responsible only for a given sector, without much reference to other agencies or issues (Rosenberg and McLeod, 2005). Furthermore, it is unclear whether the primary documents that come from a NEPA framework (environmental impact statements or environmental assessments) are the most appropriate delivery tool for EBM. Yet if viewed from an EBM perspective, the general NEPA governance framework could provide a means for enhanced coordination across multiple sector decisions.

Discussion

By emphasizing reference points (i.e. BRPs and SRPs), the present work delineates the different levels of marine EM. It also notes the similarities among these decision criteria, distinguishing how such reference points can be applied to different levels of organization. Although each EM level is unique, including SSAFM, each paradigm actually represents a continuum of management (Link, 2002). This implies that management approaches can and should adopt some of the best aspects of all approaches along this gradient, depending on the issue being addressed. However, all levels remain viable, given the particular issues being addressed, and, as demonstrated here, all have suitable capacity for establishing and using reference points to inform decision-making.

Incorporating ecosystem information at a level appropriate to analytical efforts and management needs is increasingly being recognized as the norm, not the exception. Doing so will likely carry long-term gains in the form of increased resource and management stability, upon which stronger business plans could be built (Edwards *et al*., 2004; Gaichas *et al*., 2012b; Gamble and Link, 2012; Fogarty *et al*., 2012; Kasperski, 2014). Decision-makers will need to embrace all levels of EM to fully address the range of objectives they face. The salient point is that a systemic approach will afford gains in efficiencies and address ever-present trade-offs.

The BRPs noted here for the fisheries sector revolve around MSY or proxies thereof. Moving forward, this is unlikely to change. Yet what merits further consideration is how the estimation of MSY is done, either inclusive of ecosystem factors or for aggregate groups. That MSY is appropriate for all levels of EM, but is just applied differently, is not a trivial observation. Ultimately, the basis of managing removals of living marine resources is knowledge of their productivity. The production of living marine resources is particularly amenable to the ecosystem approaches discussed here, which measure the flow and transfer of energy among organisms. This underlying production basis is scalable and transferable across levels of the biological hierarchy, such that MSY and related BRPs can actually be estimated using multiple approaches and then placed in the same context (Fogarty *et al*., 2012; Gaichas *et al*., 2012a, b). This use of MSY can capitalize on long-standing familiarity with this class of BRPs in the fishery sector, making the uptake of its novel applications more palatable (Fogarty, 2014). Moreover, the limits of production in an ecosystem provide the ultimate constraint on what is harvestable, thus either facilitating or forcing discussions regarding trade-offs within those bounds.

Beyond MSY or production-based reference points, there are also SRPs that warrant consideration for various levels of EM. This is especially true for EBFM and EBM, where other facets of marine ecosystem dynamics warrant examination (Folke *et al.*, 2005; Berkes, 2010; Kellner *et al.*, 2011). There are always competing objectives and goals across different fishing fleets, and certainly across ocean-use sectors. Thus, the need to measure, develop, and consider a broader set of reference points for conservation, resilience, or socio-economics emerges. Fortunately, there are several SRPs (e.g. Coll *et al.*, 2008; Libralato *et al.*, 2008; Pranovi *et al.*, 2012) and methods to compare and contrast among competing SRPs (Fay *et al.*, 2013; Large *et al.*, 2013) to address EBFM and EBM requirements. This multi-criteria optimization problem is obvious for EBFM and EBM (Linkov and Moberg, 2012). What is less obvious is that it is also true for EAFM and SSAFM. Perhaps the need to more formally add some of these broader SRPs, and the considerations they bring, into lower levels of EM should be revisited. The objections to doing so usually centre on the lack of data or limited understanding of functional relationships among processes and features of an ecosystem (Link, 2002; Link *et al.*, 2010a, 2012). In contrast, proponents argue that much of these data are readily available, simulations have typically shown systemic responses are robust to the dynamic fluctuations of fish stocks in the ecosystem (Fogarty *et al.*, 2012; Gaichas *et al.*, 2012a, b; Link *et al.*, 2012), and the benefits of more and thoughtfully selected information outweigh the alternative of continuing to ignore such considerations. A key suggestion is that additional ecosystem considerations, to the point of multiple reference points, ought to be incorporated into the marine resource management process regardless of the level of EM (e.g. Fay *et al.*, 2013).

The question remains, however, are there adequate governance structures to utilize these SRPs? Many authors have called attention to the fact that there are several impediments to fully implementing EM. For example, there is a perception that the role of governance structures in EM has not yet been articulated sufficiently to comprise an operational model for management (Leslie *et al.*, 2008; Pitcher and Lam, 2010; Berkes, 2012). Others have noted that higher levels of EM can only be achieved in data-rich regions, that it results in too conservative and restrictive advice, or that it requires to many resources to be operationally feasible (reviewed in Patrick and Link, 2015b). The present work and others (cf. Pikitch *et al.*, 2004; Murawski, 2007; Hobday *et al.*, 2011; Fogarty, 2014; Patrick and Link, 2015b) challenge these perceptions, noting that there is in fact wide latitude for inclusion of such factors into the management process.

It is to be hoped, this study has clarified that SSAFM, EAFM, and EBFM can all readily be implemented in the current context of fishery management council governance. Doing so would entail rethinking how FMPs are used and the development of FEPs, but the basis for doing so exists. The technical underpinnings, in terms of being able to calculate and provide suitable SRPs, are not a limiting factor (Link, 2010; Patrick and Link, 2015b). The authors acknowledge that challenges remain to fully emplace governance structures to execute full marine EBM. Smaller-scale examples (Airame *et al.*, 2003; Young *et al.*, 2007; Ruckelshaus *et al.*, 2008; Tissot *et al.*, 2009) as noted above are already doing some form of marine EBM. It is also noteworthy that several larger-scale institutions such as regional Integrated Assessment groups already exist (e.g. DeReynier *et al.*, 2009; DeReynier, 2012; Walther and Möllmann, 2014) and that, perhaps with the more coordinated use of NEPA authorities, implementing broad-scale marine EBM is more feasible than it is typically understood to be (Leslie *et al.*, 2008; Link, 2010; Patrick and Link, 2015b).

Lastly, does linguistic uncertainty truly matter? For those involved in the practice of resource management, reflecting on semantics may seem irrelevant to the real business of getting things done. It may be as Pauly (2008) stated: "the difference between EBM and EBFM is not relevant to anything real. What is important is what happens on the ground". Although the authors here concur with Pauly's sentiment of implementing the best actionable management, semantics can matter. Disintegration of useful paradigms into meaningless buzzwords contributes to the continuing confusion and actually hampers people from working together to define appropriate objectives (Palmer *et al.*, 1997; Arkema *et al.*, 2006). Thus, it is an argument for, not against, why semantics matter. If the end goal is occluded by linguistic uncertainty, so too will be any clear performance metrics to actually implement EM (Arkema *et al.*, 2006). The present work does not claim to solve these problems, but proposes an interpretation of the current state of the conversation. In doing so, the hope is that this work clarifies the levels of how EM is and can be applied, further advancing its implementation.

Acknowledgements

We are very grateful to K. Abrams, D. Detlor, M. Karnauskas, K. Osgood, F. Pflieger, G.Tromble, and J. Samhouri for providing helpful comments and edits, as well as our anonymous journal peer reviewers.

References

Airame, S., Dugan, J. E., Lafferty, K. D., Leslie, H., McArdle, D. A., and Warner, R. R. 2003. Applying ecological criteria to marine reserve design: a case study from the California Channel Islands. Ecological Applications, 13: S170–S184.

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

Atkins, J. P., Burdon, D., Elliot, M., and Gregory, A. J. 2011. Management of the marine environment: integrating ecosystem services and societal benefits with the DPSIR framework in a system approach. Marine Pollution Bulletin, 62: 215–226.

Berkes, F. 2010. Linkages and multilevel systems for matching governance and ecology: lessons from roving bandits. Bulletin of Marine Science, 86: 235–250.

Berkes, F. 2012. Implementing ecosystem-based management: evolution or revolution? Fish and Fisheries, 13: 465–476.

Berkson, J., Barbieri, J. L., Cadrin, S., Cass-Calay, S., Crone, P., Dorn, M., Friess, C., *et al.* 2011. Calculating acceptable biological catch for stocks that have reliable catch data only. US Department of Commerce, NOAA Technical Memorandum, NMFS-SEFSC 616, Miami, FL. 56 pp.

Carruthers, T. R., Punt, A. E., Walters, C. J., MacCall, A., McAllister, M. K., Dick, E. J., and Cope, J. 2014. Evaluating methods for setting catch limits in data-limited fisheries. Fisheries Research, 153: 48–68.

Clark, R. A., Fox, C. J., Viner, D., and Livermore, M. 2003. North sea cod and climate change—modelling the effects of temperature on population dynamics. Global Change Biology, 9: 1669–1680.

Coll, M., Libralato, S., Tudela, S., Palomera, I., and Pranovi, F. 2008. Ecosystem overfishing in the ocean. PLoS One, 3: e3881.

Costello, C., Ovando, D., Hilborn, R., Gaines, S. D., Deschenes, O., and Lester, S. E. 2012. Status and solutions for the world's unassessed fisheries. Science, 338: 517–520.

Crain, C. M., Kroeker, K., and Halpern, B. S. 2008. Interactive and cumulative effects of multiple human stressors in marine systems. Ecology Letters, 11: 1304–1315.

Daan, N., and Sissenwine, M. P. (Eds). 1991. Multispecies models relevant to management of living resources. ICES Marine Science Symposia, 193, Copenhagen, Denmark. 358 pp.

de la Mare, W. K. 2005. Marine ecosystem-based management as a hierarchical control system. Marine Policy, 29: 57–68.

DeReynier, Y. 2012. Making ecosystem-based management a reality: the Pacific Fishery Management Council and the California Current integrated ecosystem assessment. California Cooperative Oceanic Fisheries Investigations Reports, 53: 81–88.

DeReynier, Y., Levin, P., and Shoji, N. 2009. Bringing stakeholders, scientists, and managers together through an integrated ecosystem assessment process. Marine Policy, 34: 534–540.

Edwards, S. F., Link, J. S., and Rountree, B. P. 2004. Portfolio management of wild fish stocks. Ecological Economics, 49: 317–329.

EPAP (Ecosystem Principles Advisory Panel). 1999. Ecosystem Based Fishery Management. National Marine Fisheries Service, Silver Spring, MD. 62 pp.

FAO (Food and Agriculture Organization). 2003. The Ecosystem Approach to Fisheries. FAO Technical Guidelines for Responsible Fisheries 4, Suppl. 2, Rome, Italy. 112 pp.

Fay, G., Large, S. I., Link, J. S., and Gamble, R. J. 2013. Testing systemic fishing responses with ecosystem indicators. Ecological Modelling, 265: 45–55.

Fletcher, W. J. 2005. The application of qualitative risk assessment methodology to prioritize issues for fisheries management. ICES Journal of Marine Science, 62: 1576–1587.

Fogarty, M. J. 2014. The art of ecosystem-based fishery management. Canadian Journal of Fisheries and Aquatic Sciences, 71: 479–490.

Fogarty, M. J., Overholtz, W. J., and Link, J. S. 2012. Aggregate surplus production models for demersal fishery resources of the Gulf of Maine. Marine Ecology Progress Series, 459: 247–258.

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

Folke, C., Hahn, T., Olsson, P., and Norberg, J. 2005. Adaptive governance of social–ecological systems. Annual Reviews of Environmental Resources, 30: 441–473.

Fulton, E. A., and Link, J. S. 2014. Modeling approaches for marine ecosystem-based management. *In* The Sea, Vol 16 Marine Ecosystem-based Management, pp. 121–170. Ed. by M. J. Fogarty, and J. J. McCarthy. Harvard University Press, Cambridge, USA.

Fulton, E. A., Link, J. S., Kaplan, I. C., Savina-Roll, M., Johnson, P., Ainsworth, C., Horne, P., *et al.* 2011. Lessons in modeling and management of marine ecosystems: the Atlantis experience. Fish and Fisheries, 12: 171–188.

Gaichas, S. K., Bundy, A., Miller, T. J., Moksness, E., and Stergiou, K. I. 2012a. What drives marine fisheries production? Marine Ecology Progress Series, 459: 159–163.

Gaichas, S., Gamble, R., Fogarty, M., Benoît, H., Essington, T., Fu, C., Koen-Alonso, M., *et al.* 2012b. Assembly rules for aggregate-species production models: simulations in support of management strategy evaluation. Marine Ecology Progress Series, 459: 275–292.

Gamble, R. J., and Link, J. S. 2009. Analyzing the tradeoffs among ecological and fishing effects on an example fish community: a multispecies (fisheries) production model. Ecological Modelling, 220: 2570–2582.

Gamble, R. J., and Link, J. S. 2012. Using an aggregate production simulation model with ecological interactions to explore effects of fishing and climate on a fish community. Marine Ecology Progress Series, 459: 259–274.

Grumbine, R. E. 1994. What is ecosystem management? Conservation Biology, 8: 27–38.

Hall, S. J., and Mainprize, B. 2004. Towards ecosystem-based fisheries management. Fish and Fisheries, 5: 1–20.

Halpern, B. S., McLeod, K. L., Rosenberg, A. A., and Crowder, L. B. 2008. Managing for cumulative impacts in ecosystem-based management through ocean zoning. Ocean and Coastal Management, 51: 203–211.

Hobday, A. J., Smith, A. D. M., Stobutzki, I. C., Bulman, C., Daley, R., Dambacher, J. M., Deng, R. A., *et al.* 2011. Ecological risk assessment for the effects of fishing. Fisheries Research, 108: 372–384.

Hobday, A. J., and Tegner, M. J. 2002. The warm and the cold: influence of temperature and fishing on local population dynamics of red abalone. California Cooperative Oceanic Fisheries Investigations Reports, 43: 74–96.

Hoenig, J. M., Warren, W. G., and Stocker, M. 1994. Bayesian and related approaches to fitting surplus production models. Canadian Journal of Fisheries and Aquatic Sciences, 51: 1823–1831.

Hollowed, A. B., Aydin, K. Y., Essington, T. E., Ianelli, J. N., Megrey, B. A., Punt, A. E., and Smith, A. D. M. 2011. Experience with quantitative ecosystem assessment tools in the northeast Pacific. Fish and Fisheries, 12: 189–208.

Hollowed, A. B., Bax, N., Beamish, R., Collie, J., Fogarty, M., Livington, P., and Pope, J. 2000. Are multispecies models an improvement on single-species models for measuring fishing impacts on marine ecosystems? ICES Journal of Marine Science, 57: 707–719.

Hollowed, A. B., Bond, N. A., Wilderbuer, T. K., Stockhausen, W. T., A'mar, Z. T., Beamish, R. J., Overland, J. E., *et al.* 2009. A framework for modelling fish and shellfish responses to future climate change. ICES Journal of Marine Science, 66: 1584–1594.

Hughes, T. P., Bellwood, D. R., Folke, C., Steneck, R. S., and Wilson, J. 2005. New paradigms for supporting the resilience of marine ecosystems. Trends in Ecology and Evolution, 20: 380–386.

Kasperski, S. 2014. Optimal multi-species harvesting in ecologically and economically interdependent fisheries. Environmental Resource Economics, doi:10.1007/s10640-014-9805-9

Kellner, J. B., Sanchirico, J. N., Hastings, A., and Mumby, P. J. 2011. Optimizing for multiple species and multiple values: tradeoffs inherent in ecosystem-based fisheries management. Conservation Letters, 4: 21–30.

Keyl, F., and Wolff, M. 2008. Environmental variability and fisheries: what can models do? Reviews in Fish Biology and Fisheries, 18: 273–299.

Large, S. I., Fay, G., Friedland, K. D., and Link, J. S. 2013. Defining trends and thresholds in responses of ecological indicators to fishing and environmental pressures. ICES Journal of Marine Science, 70: 755–767.

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

Leslie, H. M., Rosenberg, A. A., and Eagle, J. 2008. Is a new mandate needed for marine ecosystem-based management? Frontiers in Ecology and the Environment, 6: 43–48.

Levin, S. A., and Lubchenco, J. 2008. Resilience, robustness, and marine ecosystem-based management. Bioscience, 5: 27–32.

Levin, S. A., and Wells, B. 2011. Development of an annual report on conditions in the California Current Ecosystem. Pacific Fisheries Management Council, Discussion Document, Portland, OR. 319 pp. http://www.pcouncil.org/wp-content/uploads/H1b_ATT1_DD_CA_ECO_NOV2011BB.pdf (last accessed 15 July 2015).

Libralato, S., Coll, M., Tudela, S., Palomera, I., and Pranovi, F. 2008. Novel index for quantification of ecosystem effects of fishing as removal of secondary production. Marine Ecology Progress Series, 355: 107–129.

Link, J. S. 2002. What does ecosystem-based fisheries management mean? Fisheries, 27: 18–21.

Link, J. S. 2005. Translating ecosystem indicators into decision criteria. ICES Journal of Marine Science, 62: 569–576.

Link, J. S. 2010. Ecosystem-Based Fisheries Management: Confronting Tradeoffs. Cambridge University Press, Cambridge, UK.

Link, J. S., and Browman, H. I. 2014. Integrating what? Levels of marine ecosystem-based assessment and management. ICES Journal of Marine Science, 71: 1170–1173.

Link, J. S., Ihde, T. F., Harvey, C. J., Gaichas, S. K., Field, J. C., Brodziak, J. K. T., Townsend, H. M., *et al.* 2012. Dealing with uncertainty in ecosystem models: the paradox of use for living marine resource management. Progress in Oceanography, 102: 102–114.

Link, J. S., Ihde, T. F., Townsend, H. M., Osgood, K. E., Schirripa, M. J., Kobayashi, D. R., Gaichas, S. (Eds) *et al.* 2010a. Report of the 2nd National Ecosystem Modeling Workshop (NEMoW II): bridging the credibility gap—dealing with uncertainty in ecosystem models. US Department of Commerce, NOAA Technical Memorandum NMFS-F/SPO-102, Silver Spring, MD. 72 pp.

Link, J. S., Yeman, D., Shannon, L. J., Coll, M., Shin, Y. J., Hill, L., and de Fatima Borges, M. 2010b. Relating marine ecosystem indicators to fishing and environmental drivers: an elucidation of contrasting responses. ICES Journal of Marine Science, 67: 787–795.

Linkov, I., and Moberg, E. 2012. Multi-Criteria Decision Analysis: Environmental Applications and Case Studies. CRC Press, Boca Raton, USA.

Lorenzen, K. 2008. Fish population regulation beyond "stock and recruitment": the role of density-dependent growth in the recruited stock. Bulletin of Marine Science, 83: 181–196.

Mace, P. M. 2001. A new role for MSY in single-species and ecosystem approaches to fisheries stock assessment and management. Fish and Fisheries, 2: 2–32.

McAllister, M. K., Pikitch, E. K., and Babcock, E. A. 2001. Using demographic methods to construct Bayesian priors for the intrinsic rate of increase in the Schaefer model and implications for stock rebuilding. Canadian Journal of Fisheries and Aquatic Sciences, 58: 1871–1890.

McLeod, K., and Leslie, H. (Eds). 2009. Ecosystem-Based Management for the Oceans. Island Press, Washington, DC, USA.

McLeod, K. L., Lubchenco, S. R., Palumbi, S. R., and Rosenberg, A. A. 2005. Scientific consensus statement on marine ecosystem-based management. Communication Partnership for Science and the Sea (COMPASS). http://www.compassonline.org/sites/all/files/document_files/EBM_Consensus_Statement_v12.pdf (last accessed 15 July 2015).

Menzel, S., Kappel, C. V., Broitman, B. R., Micheli, F., and Rosenberg, A. A. 2013. Linking human activity and ecosystem condition to inform marine ecosystem based management. Aquatic Conservation: Marine and Freshwater Ecosystems, 23: 506–514.

Methot, R. D., Jr, Tromble, G. R., Lambert, D. M., and Greene, K. E. 2013. Implementing a science-based system for preventing overfishing and guiding sustainable fisheries in the United States. ICES Journal of Marine Science, 71: 183–194.

Mueter, F. J., and Megrey, B. A. 2006. Using multi-species surplus production models to estimate ecosystem-level maximum sustainable yields. Fisheries Research, 81: 189–201.

Murawski, S. A. 2000. Definitions of overfishing from an ecosystem perspective. ICES Journal of Marine Science, 57: 649–658.

Murawski, S. A. 2007. Ten myths concerning ecosystem approaches to marine resource management. Marine Policy, 31: 681–690.

NOP (National Ocean Policy). 2010. Stewardship of the Ocean, Our Coasts, and the Great Lakes. Executive Order 13546, The White House, Washington, DC. http://www.whitehouse.gov/the-press-office/executive-order-stewardship-ocean-our-coasts-and-great-lakes (last accessed 15 July 2015).

Norse, E. A. 2010. Ecosystem-based spatial planning and management of marine fisheries: why and how? Bulletin of Marine Science, 86: 179–195.

Palmer, M. A., Ambrose, R. F., and Poff, N. L. 1997. Ecological theory and community restoration ecology. Restoration Ecology, 5: 291–300.

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

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

Pauly, D. 2008. EBM opinion: on marine ecosystems, fisheries management, and semantics. Marine Ecosystems and Management, 2: 5.

Pendoley, K. L., Schofiled, G., Whittock, P. A., Ierodiaconou, D., and Hays, G. C. 2014. Protected species use of a coastal marine migratory corridor connecting marine protected areas. Marine Biology, 161: 1455–1466.

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

Pitcher, T. J., Kalikoski, D., Short, K., Varkey, D., and Pramod, G. 2009. An evaluation of progress in implementing ecosystem-based management of fisheries in 33 countries. Marine Policy, 33: 223–232.

Pitcher, T. J., and Lam, M. E. 2010. Fishful thinking: rhetoric, reality, and the sea before us. Ecology and Society, 15: 12.

POC (Pew Oceans Commission). 2004. America's Living Oceans: Charting a course for sea change. PEW Oceans Commission, A Report to the Nation Recommendations for a New Ocean Policy, Arlington, VA. 143 pp.

Polovina, J. J. 1984. Model of a coral reef ecosystem. I. The ECOPATH model and its application to French Frigate Shoals. Coral Reefs, 3: 1–11.

Prager, M. H. 1994. A suite of extensions to a nonequilibrium surplus-production model. Fishery Bulletin, 92: 374–389.

Pranovi, F., Link, J., Fu, C. H., Cook, A. M., Liu, H., Gaichas, S., Friedland, K., *et al.* 2012. Trophic-level determinants of biomass accumulation in marine ecosystems. Marine Ecology Progress Series, 459: 185–201.

Quinn, T. J., and Deriso, R. B. 1999. Quantitative Fish Dynamics. Oxford University Press, Oxford, UK.

Restrepo, V. R., Thompson, G. G., Mace, P. M., Gabriel, W. L., Low, L. L., MacCall, A. D., Methot, R. D., *et al.* 1998. Technical guidance on the use of precautionary approaches to implementing National Standard 1 of the Magnuson–Stevens Fishery Conservation and Management Act. Department of Commerce, NOAA Technical Memorandum NMFS-F/SPO-31, Silver Spring, MD. 54 pp.

Ricard, D., Minto, C., Jensen, O. P., and Baum, J. K. 2012. Examining the knowledge base and status of commercially exploited marine species with the RAM Legacy Stock Assessment Database. Fish and Fisheries, 13: 380–398.

Rosenberg, A. A., and McLeod, K. L. 2005. Implementing ecosystem-based approaches to management for the conservation of ecosystem services. Marine Ecology Progress Series, 300: 270–274.

Rossberg, A. G., Houle, J. E., and Hyder, K. 2013. Stock–recruitment relations controlled by feeding interactions alone. Canadian Journal of Fisheries and Aquatic Sciences, 70: 1447–1455.

Ruckelshaus, M., Klinger, T., Knowlton, N., and DeMaster, D. P. 2008. Marine ecosystem-based management in practice: scientific and governance challenges. BioScience, 58: 53–63.

Samhouri, J. F., Levin, P. S., and Ainsworth, C. H. 2010. Identifying thresholds for ecosystem-based management. PLoS One, 5: e8907.

Samhouri, J. F., Levin, P. S., and Harvey, C. J. 2009. Quantitative evaluation of marine ecosystem indicator performance using food web models. Ecosystems, 12: 1283–1298.

Samoteskul, K., Firestone, J., Corbett, J., and Callahan, J. 2014. Changing vessel routes could significantly reduce the cost of future offshore wind projects. Journal of Environmental Management, 141: 146–154.

Sanchirico, J. N., Lew, D., Kling, D., Haynie, A., and Layton, D. 2013. Conservation values in marine ecosystem-based management. Marine Policy, 38: 523–530.

Schaefer, M. B. 1954. Some aspects of the dynamics of populations important to the management of commercial marine fisheries. Bulletin of the Inter-American Tropical Tuna Commission, 1: 27–56.

Schirripa, M. J., Goodyear, C. P., and Methot, R. M. 2009. Testing different methods of incorporating climate data into the assessment of US West Coast sablefish. ICES Journal of Marine Science, 66: 1605–1613.

Shertzer, K. W., Prager, M. H., and Williams, E. H. 2008. A probability-based approach to setting annual catch levels. Fishery Bulletin, 106: 225–232.

Shin, Y. J., Bundy, A., Shannon, L. J., Coll, M., Fulton, E. A., Link, J. S., Jouffre, D., *et al.* 2010. Can simple be useful and reliable? Using ecological indicators for representing and comparing the states of marine ecosystems. ICES Journal of Marine Science, 67: 717–731.

Skern-Mauritzen, M., Ottersen, G, Handegard, N. O., Huse, G., Dingsør, G. E., Stenseth, N. C., and Kjesbu, O. S. 2015. Ecosystem processes are rarely included in tactical fisheries management. Fish and Fisheries, doi: 10.1111/faf.12111.

Slocombe, D. S. 1998. Defining goals and criteria for ecosystem-based management. Environmental Management, 22: 483–493.

Smith, R. D. 1994. Scaling Fisheries. Cambridge University Press, Cambridge, UK.

Snyder, B., and Kaiser, M. J. 2009. Offshore wind power in the US: regulatory issues and models for regulation. Energy Policy, 37: 4442–4453.

Stram, D. L., and Evans, D. C. K. 2009. Fishery management responses to climate change in the North Pacific. ICES Journal of Marine Science, 66: 1633–1639.

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

Tissot, B. N., Walsh, W. J., and Hixon, M. A. 2009. Hawaiian Islands marine ecosystem case study: ecosystem- and community-based management in Hawaii. Coastal Management, 37: 255–273.

Townsend, H. M., Link, J. S., Osgood, K. E., Gedamke, T., Watters, G. M., Polovina, J. J., and Levin, P. S. (Eds) *et al.* 2008. Report of the National Ecosystem Modeling Workshop (NEMoW). US Department of Commerce, NOAA Technical Memorandum, NMFS-F/SPO-87, Silver Spring, MD. 93 pp.

Tromble, G. R. 2008. The ecosystem approach to fisheries management in the USA. *In* The Ecosystem Approach to Fisheries, pp. 301–308. Ed. by G. Bianchi, and H. R. Skjoldal. CAB International and FAO, Rome, Italy.

Tyrrell, M. C., Link, J. S., and Moustahfid, H. 2011. The importance of including predation in some fish population models: implications for biological reference points. Fisheries Research, 108: 1–8.

Varjopuro, R., Gray, T., Hatchard, J., Rauschmayer, F., and Wittmer, H. 2008. Introduction: interaction between environment and fisheries—the role of stakeholder participation. Marine Policy, 32: 147–157.

Walther, Y., and Möllmann, C. 2014. Bringing integrated ecosystem assessments to real life—a scientific framework for ICES. ICES Journal of Marine Science, 71: 1183–1186.

White, C., Halpern, B. S., and Kappel, C. V. 2012. Ecosystem service tradeoff analysis reveals the value of marine spatial planning for multiple ocean uses. Proceedings of the National Academy of Sciences of the United States of America, 109: 4696–4701.

Witherell, D., Pautzke, C., and Fluharty, D. 2000. An ecosystem-based approach for Alaska groundfish fisheries. ICES Journal of Marine Science, 57: 771–777.

Yaffee, S. L. 1999. Three faces of ecosystem management. Conservation Biology, 13: 713–725.

Young, O. R., Osherenko, G., Ekstrom, J., Crowder, L. B., Ogden, J., Wilson, J. A., Day, J. C., *et al.* 2007. Solving the crisis in ocean governance: place-based management of marine ecosystems. Environment, 49: 20–32.

Zador, S. (Ed.). 2012. Ecosystem considerations. National Marine Fisheries Service, Alaska Fisheries Science Center, Seattle, WA. 254 pp. http://www.afsc.noaa.gov/REFM/docs/2011/ecosystem.pdf (last accessed 15 July 2015).

Handling editor: Mary Hunsicker